EVALUATION OF CROP WATER REQUIREMENT AND CROPPING PATTERN OF MAHAKALI IRRIGATION PROJECT

A DISSERTATION

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By

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CANDIDATE'S DECLARATION

I, hereby, certify that the work which is being presented in this dissertation entitled **"EVALUATION OF CROP WATER REQUIREMENT AND CROPPING PATTERN OF MAHAKALI IRRIGATION PROJECT"** in partial fulfillment of the requirement for the award of Degree of Master of Technology, submitted in the Department of Hydrology, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from 16th July 2007 to 30th June 2008 under the supervision and guidance of Dr. Ranvir Singh, Professor, Department of Hydrology, I.I.T., Roorkee.

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

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Date: June, 2008

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

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SYNOPSIS

Mahakali Irrigation Project (MIP) is a large irrigation project in Kanchanpur district of Nepal. Its development plan consists of three stages namely Stage-I with Net Command Area (NCA) of 4800 hectare (ha), Stage-II with NCA of 6800 ha and Stage-III with NCA of 33520 ha. Stage-I and Stage-II are at operation and Maintenance stage while Stage-III is under construction. Stage-I is considered in the present study. Joint Irrigation Management (PJM) has been successfully implemented in Stage- I of this project. MIP Stage-I is divided into four blocks with each block having a Water Users' Associations (WUA). There is an apex committee which is called Water Users' Association Co-ordination Committee (WUACC).

As per Memorandum of Understandings (MOUs) the WUAs will look after the tertiary canals in their jurisdiction. Irrigation Department will look after the main canal, branch canals, distributaries, minors and sub-minors. In addition to the operation and maintenance of tertiary canals Water Users' Association Co-ordination Committee will collect water tax from WUAs. The collected amount will be deposited to Irrigation Department and WUACC will receive its part according to the prevailing Irrigation Rules and Regulations as management grant.

Now the farmers are organized through WUAs, they are interested to optimize the cropping pattern to maximize their return by using their land and water resources optimally.

In this dissertation an attempt has been made to evaluate the water requirement of crops grown in the study area and to find out optimal cropping pattern to maximize net returns, satisfying the energy (calorie) and nutrients requirement of the inhabitants of the study area. The study has been done on both full irrigation and variable irrigation basis for various crops.

FAO Penman-Monteith method has been used to determine the reference crop evapotranspiration (ET_0), Quadratic function has been utilized as the production function in variable irrigation model and Linear programming technique has been utilized for optimization in the present study.

NOTATIONS/ ABBREVIATIONS

NOTATIONS/ ABBREVIATION	DESCRIPTION
ALT, Alt, alt	Altitude
amsl	Above mean sea level
Cm, cm	Centimeter
e_a	actual vapor pressure [kpa]
Epan	Pan evaporation [mm/day]
e_s	Saturated vapour pressure [kpa]
$e_s - e_a$	Saturated vapour deficit [kpa]
ETo	Reference evapotranspiration [mm/day]
F.I.R., FIR	Field irrigation requirement
G	Soil heat flux density [$MJm^{-2}day^{-1}$]
G.C.A., GCA	Gross command area
Gm, gm	Gram
G.W., GW	Ground water
Ha, ha, ha.	Hectares
Ham, ham, ha-m	Hectare meter
Km, km	Kilometer
Kg, kg	Kilogram
L.P., LP	Linear programming
M, m	Meter
Mbar, mbar	Millibar
MM, mm	Millimeter
N.C.A., NCA	Net command area
N.I.R., NIR	Net irrigation requirement
REQ., Req., req.	Requirement
RH, Rh	Relative humidity
S.W., SW	Surface water
u_2	Wind velocity at 2 meter height
Δ	Slope vapour pressure curve [kpa/^{o}c]
γ	Psychromertic constant [kpa/^{o}c]

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CHAPTER– I

INTRODUCTION

1.1 GENERAL

Through the achievements made in crop science and production technology over the last decades agriculture is now able to feed the majority of world's population better than in past. However, there is an increasing concern that the present knowledge, resources and technologies will not be adequate to meet the demands, once there are 8 billion people on this planet by about 2020.

About 60% of the world land surface is suitable for grazing, half of which (i.e. $3.4\text{x}10^9$ ha) can also be used for arable cropping in a sustainable manner. Nations are endowed with good land to very different degrees. The area of land suitable for cropping, but still unused, is very significant in southern Africa and America, but suitable unused land is already scarce in Asia and East Africa. Yet, the growing population, particularly in Asia, and the changing diets will lead to a much higher food demand. Thus a great challenge for the coming decades will be the task of enhancing food production to ensure food security for the steadily growing world population. Most of that increase will have to come from intensified agriculture, supported by irrigation. Where irrigated agriculture is developed, water used for irrigation can represent more than 90% of water consumption. In an increasing number of countries existing resources are fully exploited (Smith, 2000; FAO, 2002). An answer therefore lies in improving agricultural productivity and water use efficiency (FAO, 2002).

In many countries, efforts to raise levels of agricultural production through increase in cultivated land, cropping intensity and yields have led to a greater dependence on irrigation. This pressure has been most severe in developing nations, where water resources are often scarce and many irrigation systems are primitive. The importance of irrigation in increasing food supplies is well recognized; consequently, 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. However, emphasis is now being placed on the need to improve the performance of existing systems.

Several factors have to be considered in irrigation management, particularly for a mixed cropping pattern. One of the key decisions to be made is how much water should be allocated to different cropped areas. The decision should be based on the availability of land and water resources, reliability of the water supply and benefit from crop production. There are two possible strategies for the application of water to the crops. The first is to apply irrigation water at a level which gives maximum net income. The approach may be used when there is no constraint on irrigation supplies. However, when a constraint exists, it is useful to provide alternative levels of irrigation water and thus cover a larger area, which may result in higher returns. This calls for optimum allocation and distribution of water along with scientific planning of cropping patterns. Field research by agricultural scientists has shown that high crop yields are attainable even when water supplies are limited, if irrigation scheduling is based on an understanding of crop water needs and responses in a given environment [CBIP, 1991].

In Nepal, agriculture is the major contributor to the national economy with a 41 per cent share in the GDP. About 81 per cent of the country's population is employed in the agricultural sector as a labour force for farming. Nepalese agriculture is heavily dependent on the monsoon rains because of the limited infrastructural development for irrigation. Hence, the weather plays a great role in the country's agricultural production and national economy. About 93 per cent of the cultivated area is under the cereal crops of paddy rice, maize, wheat, millet and barley. However, paddy alone accounts for 53 per cent of that area. Nepal is facing food deficit problem. In 1996/97, Nepal produced 3.98 million metric tonnes of food-grains against the estimated requirement of 4.08 million metric tonnes, thus registering an overall food deficit situation. This deficit balance started to appear in 1991.Out of cultivated land (2.6 million hectares) about 60 % is dependent on vagaries of weather and only about 40 % area is getting irrigation facility, out of which only about 17 % area is receiving reliable year round irrigation. Even after full exploitation of all surface and ground water resources it would only be possible to irrigated about 2/3rd of the cultivated area. Since the dependency on rainfall is high, there is a substantial annual variation in the production levels of food-grains and other agricultural outputs, depending upon the pattern of rainfall. Therefore, efforts are necessary for proper management and utilization of scarce resources and to get maximum possible yield from the irrigated agriculture.

To get maximum net production from an area proper crop planning is essential. Though the crop planning depends upon type of crops, water resources, climatic factors, crop water requirement, method of irrigation and drainage, soil characteristics, topography and social-economy, etc; it mainly depends on availability of land and water resources and proper estimation of water requirement of crops that can be grown under given agro-climatic condition.

For efficient management of water resources, proper policies for optimal use of land and water resources are needed in the catchment area. The objective of the irrigation management may be to derive the maximum agricultural production per unit of water supplied by the system and spread the irrigation facilities to as large section of cultivators as possible in the command area. Though production is a function of amount of irrigation, over irrigation under any circumstances may cause to reverse result.

A production function is a quantitative relationship between the maximum physical product obtainable and the dose of water used when all other factors of production is kept at desired level. The production function could be utilized to achieve the economic goal.

In a given agro-climatic region, cropping pattern is to be decided in such a manner that it optimizes the available resources. Planned conjunctive use of surface and ground water is one management technique which is being developed to obtain maximum utilization of the water resources available to an area. Full utilization of the water resources of an area means the utilization of both surface and ground water. Because of the hydraulic interactions between the two supplies, the extent to which efficiency is attained is proportional to the degree of integrated planning. Planning for conjunctive use should therefore be stressed upon for the development of water resources in any region.

Linear optimization technique is best suited for planning and resources allocation problems. It can be defined as a set of mathematical methods for allocating scarce resources to achieve clearly stated organizational objectives. The term linear implies that the model has fixed and definable linear relationship among the decision variables of the problem. The term optimal clearly refers to an orderly process by which the decision variables are solved in such a way as to maximize the degree of achievement of the given objective. The technique of linear optimization is also known as Linear Programming. It has been successfully applied to a wide spectrum of problems across many fields like business, industry, agriculture and military sectors, etc.

The study area Mahakali Irrigation Project (MIP) Stage-I is located in the Far Western Terai of Nepal, on the left bank of the Mahakali River. The nearest town is Mahendranagar, which is the government centre for both the Kanchanpur District and Mahakali Zone. Stage-I and Stage-II of the Project area is, at present, supplied with water from the Sarda Barrage (constructed in 1928) in accordance with the water sharing agreement made in 1920 between Government of Nepal (GON) and the Government of India (GOI).

The implementation of Stage-I was commenced in 1971 with a main canal capacity of 13 m^3/sec to irrigate a net command area of 5,000 ha. These works were completed in 1975. However, due to water management problems, it was only possible to irrigate 3,400 ha. To overcome these problems and complete the Project, Government of Nepal requested assistance from the World Bank in 1979. The International Development Agency (IDA) appraised the Project and a credit agreement was signed in September 1980. Implementation of the civil works down to tertiary level (both canals and drains) was completed in mid 1987 and a net command area of 4,800 ha was brought under irrigation.

Since completion in 1987, the Stage-I area has been functioning reasonably well. With the implementation of Stage-I, the Mahakali Irrigation Development Board (MIDB) had updated the feasibility study report of Stage-II in 1988. Stage-II has a net command area of 6,800 ha, comprising two parts, a small area of about 400 ha adjoining Stage-I, and a larger area of about 6,400 ha lying some 15 km to the south of Stage-I, adjacent to the Indian border. The IDA appraised the Stage-II for implementation in May 1988 and the construction work was completed in June 1998.

A new Indo-Nepal bilateral treaty was signed on 12 February 1996, which is called the "Treaty for Integrated Development of Mahakali River including Sarda, Tanakpur, and Pancheswor Multi-purpose Project." The new treaty super shades the old 1920 agreement. According to this treaty an article applied to Stage–I and Stage–II is 'Nepal shall have the right to a supply of 28.35 m^3/sec (1,000 cusecs) of water from the Sarda Barrage in the wet season (i.e. from 15th May to 15th October) and 4.25 m^3/sec (150 cusecs) in the dry season (i.e. from 16th October to 14th May)'.

Initially, the main canal capacity was 13 m^3/sec in order to convey water to the Stage-I and Stage-II area. This capacity was increased to 28.35 m^3/sec, in 1998. During the dry season a supply of 4.25 m^3/sec will be supplied on a continuous basis or at a rate of 8.5 m^3/sec during alternate 10-days periods.

With the new treaty, the water supply to Nepal from the Mahakali River will be considerably increased. The enhanced entitlement of water from the new treaty has made it possible to study the feasibility of extending irrigation into the Stage-III area with a net command area of 33520 ha.

Till 1979, the existing irrigation system was operated and maintained by the Department of Irrigation. With the commencement of Stage-I in 1980, the operation of the existing irrigation system came under the control of the Project Manager of Mahakali Irrigation Project. After restructuring the organizational structure of the Department of

Irrigation into divisions and sub divisions in 2002, Stage-I and Stage-II has been managed by Mahakali Irrigation Management Division No. 8. Up to 1998, Mahakali Irrigation Project had been receiving sufficient funds from the World Bank. However, since the completion of the Stage-II, it has experienced some financial hardship. The limited financial resources have adversely affected the organization in its post-construction services such as desilting of the main canals, and handing over of the tertiary canals to the farmers.

The institutional development history of MIP shows that the farmers' organizations in Stage-I have experience of more than a decade. The area has been divided into four Blocks (Nos.1-4), with each Block having a Water Users' Association (WUA). The blocks are sub-divided into Tertiary Units of about 28-30 ha each. A Tertiary Unit has a Tertiary level farmers' organization called a Tertiary Committee (TC). A Tertiary Unit is divided into about 7 Outlet Units (of about 4 ha each), which is fed by a field channel that gets its water from the tertiary canal through a Field Outlet. The outlet level is a bottom level farmers' organization called a Water Users' Group (WUG). It is assumed that there are, on average 7 farmers per WUG. There is a Project level water users' organization, called a Water Users' Association Co-ordination Committee (WUACC). There are already established rules, regulations, electoral procedures and a practice of organizing the farmers at MIP.

The study area is fully connected with the network of roads with the major cities of Nepal. Mahendra Rajmarg, the major national highway of Nepal, passes through the study area. The study area is one of the fast developing areas of the country. The data required for estimation of input coefficients and resource requirements of constraints in the system modeling are available for this study area.

In the present study an attempt has been made to develop a plan involving optimized cropping pattern from the point of view of optimum net returns from the study area. Crop water requirement has been estimated by Penman-Monteith method for the existing crops. Quadratic production function has been adopted in this study to evaluate the irrigation-yield relationships. Linear programming has been used as an optimization technique. The results obtained under different conditions and constraints have been compared in order to arrive at the optimal cropping pattern.

1.2 OBJECTIVES OF THE STUDY

The aim of the study is to find out an optimal crop water plan resulting in maximum crop yield, high crop intensity, and increased food production thereby, obtaining maximum net benefits to farmers.

The specific objectives are

- To compute the crop water requirement and irrigation water requirement of various crops grown in the study area.
- To select and compute the crop water production function of various crops for different depths of water application and utilize them for developing a variable irrigation model.
- To find out the optimal cropping pattern.

1.3 METHODOLOGY

The present study utilizes the data collected from various sources such as Mahakali Irrigation Management Division No. 8 Mahendranagar, District Agriculture Development Office Kanchanpur, District Livestock Office Kanchanpur, Office of District Development Committee Kanchanpur, Feasibility Study Report of Mahakali Irrigation Project Stage-III, publications National Agricultural Research Center (NARC), etc. FAO- CROPWAT window version 4.3 is used for determining the Reference Crop Evapotranspiration (ET_o). Linear Programming is used as the tool for optimization of cropping pattern for the study area. Microsoft Office is also used as and when it was necessary.

CHAPTER– II

REVIEW OF LITERATURE

2.1 GENERAL

Irrigation is defined as the application of water to the soil for the purpose to supplement the water to the available rainfall for give better yield. During recent past because of the introduction of high yielding varieties of seeds, improved methods of cultivation, invention and use of improved and sophisticated agricultural equipments, improved irrigation application, efficient use of manure and fertilizer, adoption of watershed and land management practices; the age old cropping pattern that has been sustained by various situation of rainfall and types has undergone vast changes.

Irrigation planning is an essential component of water management in irrigated agriculture. At the start of each irrigation season, one must develop irrigation programs for a combination of crops, which will maximize the net return along with efficient water use in limited land to achieve the self-sufficiency in food production, nutritional requirement and calorie requirement. Therefore optimal use of land and water resources is essential for optimal crop planning which gives maximum net return under some given limitations.

Crop planning aims to evolve a cropping pattern, which maximizes the socioeconomic benefits of irrigation. Cropping pattern means the proportion of area under different crops at a particular period of time. Irrigation water allocation is based on information about the irrigated area, crop types, and near-surface meteorological conditions that determine the crop water demands. Any change in cropping pattern means a change in the portion of area under different crops.

The aim of this study is to find out an optimal cropping pattern resulting in maximum crop yield, high crop intensity, and increased food production thereby, obtaining maximum net benefits to farmers. For this purpose, linear programming technique has been sought out. Optimal use of water in crop production requires a proper understanding of crop water requirement and knowledge of production function applicable to the model. The review of literature is presented in the following paragraphs mainly dealing with the above aspects.

2.2 CROP WATER REQUIREMENT

The assessment of water requirement for various crops is an important factor in choice of crops and it is one of the necessities in planning of any irrigation project. Studies of irrigation water requirements have been carried out since irrigation was practiced. Irrigation provides supplemental water to meet the crop water requirements besides natural rainfall. Hydraulic designs for canals are based on the peak flow rate required to meet the crop water requirement. For the design of a water conveyance system, it is necessary to assess the water requirement of the crops intended to be grown in the command area. In irrigation system, water allocations are based on assumptions about the irrigated area, crop types, and the near surface meteorological conditions that determine crop water requirements.

Crop water requirement also called crop evapotranspiration (ETcrop), has been defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1977). Crop evapotranspiration is the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

A large number of empirical methods have been developed over last 60 years by numerous scientists and specialists' world wide to estimate evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly, and yet evaporation data are frequently needed at short notice for project planning or irrigation scheduling design. To meet these needs, guidelines were developed and published in the FAO Irrigation and Drainage Paper No. 24 - Crop Water Requirements. To accommodate users with different data availability, four methods were presented to calculate the reference crop evapotranspiration (ET_o) namely the Blaney-Criddle, Radiation, Modified Penmen and Pan Evaporation methods. The Modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop. It was expected that the pan evaporation method would give acceptable estimates, depending on the location of the pan. The radiation method was suggested for areas where available climate data include measured air temperature and sunshine hours, cloudiness or radiation, but not measured wind speed and air humidity. And the publication proposed the use of Bliney-Criddle method for areas where available climate data cover air temperature data only.

These climatic methods to calculate ETo were all calibrated for ten-day or monthly calculations, not for daily or hourly calculations. The Blaney-Criddle method was recommended for periods of one month or longer. For pan evaporation method it was suggested that calculations should be done for periods of ten days or longer. Users have not always respected these conditions and calculations have often been done on daily time steps.

Advances in research and the more accurate assessment of crop water use have revealed weaknesses in the methodologies. Numerous researches analyzed the performances of the four methods for different locations. Although the results of such analyses could have been influenced by site or measurement conditions or by bias in weather data collection, it became evident that the proposed methods do not behave the same way in different locations around the world. Deviations from computed to observed values were often found to exceed ranges indicated by FAO. The modified Penman was frequently found to overestimate ETo, even by up to 20% for low evaporative conditions. The other FAO recommended equations showed variable adherence to the reference crop evapotranspiration of standard grass.

In May 1990, FAO organized a consultation of experts and researchers in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, to review the FAO methodologies on crop water requirements, and advice on the revision and update of procedures. The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculating the various parameters. The FAO Penman-Monteith method was developed by defining the reference crop as a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered. The method overcomes the shortcomings of the previous FAO Penman method and provides values that are more consistent with actual crop water use data worldwide. Furthermore, recommendations have been developed using the FAO Penman-Monteith method with limited climatic data, thereby largely eliminating the need for any other reference evapotranspiration methods and creating a consistent and transparent basis for a globally valid standard for crop water requirement calculations.

The FAO Penman-Monteith method uses standard climatic data that can be easily measured or derived from commonly measured data. All calculation procedures have been standardized according to the available weather data and the time scale of computation. The calculation methods, as well as the procedures for estimating missing climatic data, are presented in FAO Irrigation and Drainage Paper No. 56.

To evaluate the performance of these and other estimation procedures under different climatological conditions, a major study was undertaken under the auspices of the committee on irrigation water requirement of American Society of Civil Engineers (ASCE).The ASCE study analyzed the performance of 20 different methods, using 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. In 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 study conform the over estimation of the modified Penman method introduced in FAO Irrigation and Drainage Paper No. 24, and the variable performance of the different methods depending on their adaptation to local conditions. The comparative study may be summarized as follows:

(i) The Penman methods may require local calibration of the wind function to achieve satisfactory results.

(ii) The radiation methods show good results in humid climates where the aerodynamics term is relatively small, but performance in arid conditions is erratic and tends to underestimate evapotranspiration.

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

(iv) Pan Evapotranspiration methods clearly reflect the shortcomings of predicting crop evapotranspiration from open water evaporation. The methods are susceptible to the microclimatic conditions under which the pans are operating and the rigour of station maintenance. Their performance proves erratic.

(v) The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climate has been indicated in both ASCE and European studies..

The FAO Penman-Monteith method is recommended as standard method. It is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climatic conditions, and also has provision for application in data short situations.

FAO Penman-Monteith method has been used to calculate the crop water requirement in this study.

2.3 CROP WATER PRODUCTION FUNCTION

Production function is an industrial engineering approach that was used initially by the manufacturing industries (Head et al, 1978). Thereafter the concepts were being used by agricultural economists for providing the benchmark of how efficiently resources are being used in farms.

A production function represents a schedule or mathematical formulation expressing the relationships between inputs and outputs. Production function is the locus of points of feasible (attainable) production set as a result of variations in the input quantity. To put it differently for a given technology, the production function is a quantitative relationship showing the maximum physical product obtainable from a given set of inputs (Maji and Heady, 1975).

Irrigation scientists have attempted to establish production as a relationship between the maximum possible agricultural yields per unit area to depth of water applied to achieve it. The crop-water production function (CWPF), which expresses the relationship between crop yield and total seasonal irrigation, is a very useful tool for irrigation planning purposes. With this function decision makers can assess irrigation water needs to meet production targets or, conversely, estimate likely crop production for fixed volumes of water. Hexemand Heady (1978) provide a classic discussion of CWPF derivation and use. In spite of the utility of CWPFs, determination of yield–irrigation relationships can be quite expensive in terms of resources and time, as it has traditionally relied upon extensive experimentation (Russo and Bakker, 1987; Zhang and Oweis, 1999). Hence a variable irrigation model has been formulated in this dissertation to test the model accurately.

Some important production functions are

- (i) Cobb-Douglas function
- (ii) Mitscherlich-Spillman function
- (iii) Polynomial functions

2.3.1 COBB-DOUGLAS FUNCTION

Cobb-Douglass function was initially fitted to data for U.S. manufacturing industries during1899-1922 but has also been used to estimate biological relationships. A two-variable Cobb-Douglas function is given as $Y = a\ W^b N^c$, where Y is yield per unit area, W = water applied per unit area, and N =fertilizer applied per unit area. Despite the computational ease of estimating parameters for this function, it has properties generally not representative of plant-water-fertilizer relationship. Both W and N are limited in the sense that if either equals zero, Y also equals zero. The undefined maximum product, the impossibility of negative marginal products tend to make the Cobb-Douglas function generally less desirable for estimating plant-water-fertilizer relationships.

2.3.2 MITSCHERLICH-SPILLMAN FUNCTION

Mitscherlich and Spillman functions for two variable are given as $Y = A\ [1- B_1.e^{-c1.w}]\ [1- B_2.e^{-c2.N}]$ and $Y = A\ (1-R_w^{W})\ (1- R_n^{N})$.The response surface for one variable Mitscherlich or Spillman model is asymptotic to the maximum yield. In case of two variable functions, the isoquants are asymptotic to the W and N axes, indicating that W can never substitute completely for N and vice versa. The isoclines begin at the origin, are curved, and approach linearity. The principal limitations of these functions are the isoclines do not converge because the response surface is asymptotic to a plane rather than reaching a definite maximum point. There is little evidence that it is applicable to plant-water-fertilizer relationship.

2.3.3 POLYNOMIAL FUNCTIONS

Polynomial functions of varying degrees are often used to estimate input-output relationship. These forms are especially appropriate when the input-out relationship be such that the marginal product becomes negative and yield declined. The basic polynomial form is derived from a concept known as Taylor's expansion series. The concept behind this is that the limit of a sequence can thus be written as the sum to infinity of a convergent series. Any member of the sequence and the sum of any number of terms of the series can then serve as an approximate value of the limit. Commonly used polynomials are as follows:

a) Quadratic function
b) Square root function
c) Three-halves or 1.5 polynomial function.

2.3.3.1 QUADRATIC FUNCTION

A quadratic function is a second degree polynomial function which is obtained by neglecting the higher terms from a Taylor's expansion series and represented as in the form $Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2$. The terms X_1^2 and X_2^2 would permit the response surface to curve downward and exhibit negative marginal product at high use-level for X_1 and X_2. With the quadratic function, the marginal product curve is linear. This latter property does not appear to be consistent with most agronomic relationships, but it may not be a serious limitation.

2.3.3.2 SQUARE ROOT FUNCTION

A square root function is obtained by transformation made on X_1 and X_2 as by replacing the square power of X_1 and X_2 to half power in the quadratic function which can be written as $Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^{0.5} + b_4X_2^{0.5} + b_5X_1X_2$. This function has properties similar to those described for the quadratic function but the marginal product curve for either X_1 or X_2 declines at a decreasing rate while those for quadratic are linear.

2.3.3.3 THREE-HALVES OR 1.5 POLYNOMIAL FUNCTION

A three-halves (1.5 polynomial) function is an additional transformation of X_1 and X_2 as by replacing the square power of X_1 and X_2 to 1.5 power in the quadratic function which can be written as $Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^{1.5} + b_4X_2^{1.5} + b_5X_1X_2$. Several properties of this model are similar to the square root function however the marginal product of either X_1 or X_2 declines at an increasing rate. This formulation is extremely difficult for estimating isoquants and isoclines.

Horst Mendershausen, Frisch, Haavelmo and Reirsol (1928) threw comments on Cobb-Douglas production arguing that data used by Douglas were too multi-collinear to allow for a reliable determination of the production function coefficients. They pointed out towards improvement of the implicit coefficient from other side.

Marschak and Andrews (1944), Hoch (1962), Mundlak and Hoch (1963), and Mundlak (1994) commented on Cobb-Douglas production function as it cannot represent the real world of input-output relationship because inputs (like lobour, capital and fertilizer etc) are determined by firms not by the economist.

K.Palanisami and T.Ramesh (2005) used Cobb-Douglas production function to determine water productivity at farm level in bhavani basin, tamilnadu, India.

Pratap Singh et al. (1987) carried out a comparative study of different types of crop water production functions on wheat with controlled irrigation at Berlin (FRG) and in field plots at Hisar (India) under different climatic conditions with and without water deficit conditions. Testing the results over lysimeter, it was observed that quadraric production function was performing better in water deficit condition.

M.S. Al-Jamal et al. (2000) computed the crop water production function for onion in New Mexico and noticed that under sprinkler irrigation method with zero drainage linear function was fitting well, while applying drip irrigation method the quadratic function was fitting better.

David C. Nielsen (2001) conducted studies with chickpea, field pea, and lentil during the 1996–1999 growing seasons at the USDA Central Great Plains Research Station to explore the crop water production functions and it was observed that all three crops showed linear increases in seed yield with increases in water use.

Quadratic function has been utilized in this study due to its several advantages over other methods.

2.4 OPTIMIZATION TECHNIQUE

Due to increasing water scarcity, greater attention is being given to water management in irrigated as well as in rain fed agriculture. A farmer at the start of each irrigation season needs to have optimum cropping pattern and irrigation programs, which will maximize the economic return. Under these circumstances there is an urgent need to introduce efficient techniques in land and water resources management for optimal utilization of the available land and water resources. The term optimal refers to an orderly process by which the decision variables are solved in such a way as to maximize the degree of achievement of the objective.

Conventional irrigation practices in most of the world are designed to avoid crop stress in order to maximize yields. 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. The objective of maximizing benefits is fundamentally different from maximization of yields and requires an altogether different approach to irrigation management. Maximizing yields implies full irrigation of the crop while maximizing benefits will generally mean deficit irrigation.

Research has shown that there is more to be gained when irrigation decisions are based instead on an economic objective, the maximization of specific benefits. Following consequences would be observed while optimizing net benefits:

(a) Maximizing net income when water is not limited

If our objective is to maximize yield per unit of land, the conventional approach to irrigation, we can determine the amount of water to apply by setting the derivative of the yield function to zero and solving for water.

(b) Maximizing net income when water is the limiting resource

When irrigation is constrained by limited water availability or limited irrigation system capacity, the water saved by reducing the depth of irrigation might be used to irrigate additional land. The problem then is to determine the optimum trade off between the depth of applied water and the area to be irrigated.

(c) Optimization for multiple fields and crops

The problem becomes more complex when multiple fields and crops are involved and water is limited. Since limited water implies an opportunity cost for water, the decision-maker must consider all fields and any alternative uses of water simultaneously, allocating more water to more profitable crops, or perhaps marketing water to off-farm users. Such whole-farm analyses typically rely on mathematical programming techniques (e.g. Linear Programming or Dynamic Programming) to optimize for the entire farm as a single planning unit. The added complexity of whole-farm analysis is illustrated in a paper by Martin and VanBrocklin (1989) who used dynamic programming to determine optimal planting and water use strategies for a mix of un-irrigated and irrigated crops.

While discussing the potential benefits of economic optimization in irrigation management, there are several critical and in some cases controversial issues; these include the question of whether reduced irrigation will actually save water, how salinity might be managed when irrigation depth is reduced and what additional risk is faced by farmers employing an optimization strategy.

If less water is applied a larger fraction of the field will be under irrigation. Deep percolation (leaching) losses will be reduced; as a result the leaching of soluble chemicals reduces, while application efficiency will increase (Hart and Reynolds, 1965). Yields will be reduced as well, but the profitability and productivity of the water will increase. An analysis by Stewart, et al. (1974) provides some perspective on changes in deep percolation that might be expected as irrigation depth is reduced. Using experimental data relating corn yield to applied water in Davis, they estimated that a 5.8% reduction in total applied water would be accompanied by a 40% reduction in percolation. They also estimated that yields would be reduced by 1.1%, though there would be no reduction in profits. The general remarks of these studies were as follows:

(i) Optimization implies reduced irrigation, and results in increased application efficiency;
(ii) At the optimum point, yield reductions per unit of land will be small, while reductions in water use will be relatively large;
(iii) Total crop production from a limited water supply will be increased;
(iv) Net farm income will increase up to a point; and
(v) Leaching and non-point source pollution will be reduced.

An optimal planning and management model involves identification of the decision variables, the constraints and the objective functions which are to be maximized or minimized. The optimization techniques generally used for optimal allocation of land and water to various crops are as follows:

2.4.1 BENEFIT-COST APPROACH

Benefit cost approach serves only as screening technique to identify the potential alternatives under given planning conditions. However Dorfman (1965) considered these approaches as complementary to each other and not mutually exclusive. This approach has been used to test economic feasibility of project by allocating scarce resources among different alternatives and select the best one. But often they are limited to a very few alternatives due to its time and fund constraints. It is very tedious and complex job to select the best alternative with the help of benefit cost approach if the numbers of alternatives are large, especially in case of multipurpose projects. The computation of benefit cost ratio becomes extremely complex due to inter relations and feedbacks between different alternatives.

The inadequacy of benefit-cost approach is pointed out by Tolly and Riggs (1961), Smith et.al. (1961), Smith and Castle (1964), Prest and Turvey (1965) and, Hall and Dracup (1970).

2.4.2 FUNCTIONAL APPROACH

The functional approach aims to solve a set of mathematical equations generally related to obtain as a function of amount and timing of water use in presence of various technical and other inputs in the production processes. The main difficulty in this approach is the need to have knowledge on numerous production functions for variety of crops, seasons, regions and resources. However the inequality of resource limitations can not be handled by conventional formulation of this approach. All the available resources must be consumed fully.

For these limitations, Hall and Dracup (1970) found this approach unsuitable as principal method to choose the best alternative; Yaron (1970) combined production function analysis approach with the linear programming model to estimate water demand of crops. Thus the functional approach has a limited but quite significant role in water resources system analysis estimating product response to a number of inputs.

2.4.3 PROGRAMMING APPROACH

Programming approach is essentially an efficient way of determining optimal production plan when a large number of alternatives are associated with equally large number of resources restrictions of different kinds and magnitude. Such programming models have the distinct advantage of solving optimization problems of complex nature precisely and quickly using digital computer. The programming approach can be classified as Linear programming, Dynamic programming, Non- Linear programming, Geometric programming, Multi-objective programming, Integer programming, Network method, game theory, Stochastic programming etc. These programming techniques are useful in finding the optima of a function of several variables under a prescribed set of constraints. In broad sense programming can be classified as Non-linear and Linear programming models.

The non-linear programming models are suitable for treating non-convex, non-linear and discontinuous objectives and constraint functions with ease. Therefore these models have certain important advantages for the analysis of water resources system. The necessary and sufficient conditions for the optimal solution of programming problems laid the foundations for a great deal of later research in non-linear programming.

Charnes and Cooper (1961) developed stochastic programming techniques and solved problems by assuming design parameters to be independent and normally distributed. In some circumstances, optimization analysis may be complicated by uncertainty, and uncertainty implies risk. A variety of algorithms have been proposed for choosing between alternative strategies where risk is a concern. Stochastic dominance techniques have been used to derive quasi-optimal strategies that account for risk in a general way, narrowing the range of alternatives to those most likely to conform to the manager's attitudes about risk (Mjelde, et al., 1990).

Dynamic programming has also been used frequently in research on irrigation optimization (Martin and Van Brocklin, 1989). Though not as computationally efficient as linear programming, this more flexible technique allows greater freedom in the use of discrete and stochastic variables and non linear functional relationships.

Dantzig (1963) extended simplex method for linear programming problems. Integer programming is one of the most exciting and rapidly developing areas of optimization. The desire to optimize more than one objective or goal while satisfying the physical limitations led to the development of multi-objective programming methods. Network analysis methods are essentially management control techniques. The game theory has been applied to solve several mathematical, economical and military problems.

Simulation modeling, allows the greatest flexibility in accommodating the complexities of the real world (*e.g.* English, et al., 1992), but simulation is more computationally intensive, and must be linked to a research algorithm to reduce the number of simulations needed to arrive at an optimum solution. A promising technique employed by Canpolat (1997) and Alvarez, et al. (2002) used genetic algorithms to substantially increase the efficiency of the search procedure for evaluating complex sets of alternative seasonal irrigation strategies.

A number of simulation and optimization models have been applied in the past to decide planning and operating strategies for irrigation reservoir systems (Kumar and Pathak 1989; Vedula and Mujumdar, 1992). Rao et al., (1990) developed a model for optimal weekly irrigation scheduling policy for two crops by considering both seasonal as well as intra seasonal competition for water. Vedula and Nagesh Kumar (1996) developed a mathematical programming model to determine the steady state optimal operating policy and the associated optimal crop-water allocations to all the crops for a single purpose irrigation reservoir, combining linear programming in the intra-seasonal period and stochastic dynamic programming in inter seasonal period.

To determine an optimal irrigation strategy the analyst will need to employ crop yield models and operations research, and will need to plan for some degree of crop stress. Rather than regarding application efficiency as a pre-determined constant for a given irrigation system, the efficiency will become a decision variable, determined in large part by the management strategy chosen (English, 1999).

Most farming situations are concerned with several crops grown in the same season. Both allocations of land and water resources under a multi-crop situation in a season should be considered (Paul et al., 2000). When a large number of enterprises are to be considered under an equally large number of constraints, linear programming approach is preferred.

2.4.3.1 LINEAR PROGRAMMING

Economists while developing methods for optimal allocation of resources first recognized the linear programming type optimization problem in 1930's.During world war II, the United States Air Force sought more effective procedures of allocating resources and turned to linear programming. So linear programming problem was formulated and the simplex method of solution was devised.

Linear programming is a mathematical method of allocating scarce resources to achieve an objective within the bounds of environmental constraints. Linear programming involves formulation and solution of a certain type of managerial problem by optimizing a linear objective function subject to constraints. The technique of linear optimization is known as Linear Programming. It can be defined as a set of mathematical methods for allocating scarce resources to achieve clearly stated organizational objectives. The term linear implies that the model has fixed and definable relationship among the decision variables of the problem. It has been successfully applied to a wide spectrum of problems across many fields like business, industry, agriculture and military sectors etc. Linear Programming becomes more readily available for practical use, primarily because of continuing development of computer technology. Linear optimization is best suited for planning and resources allocation.

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

The development of mathematical models to generate irrigation programs has received the attention of many investigators.

Castle (1964) used linear programming technique to allocate water optimally between two agricultural regions.

Dorfman (1965) designed three simple linear programming models to evolve optimum production plans for Khairpur feeder, west region in Indus valley, under three selected situations.

Heady et. al. (1973, 1975) employed linear programming models for USA. Heady model (1973) was applied to obtain optimal water and land allocation and agricultural needs for USA in 2000 AD. The model includes 223 production areas, 1891 land resources areas and 51 water supply regions.

Hiremath (1973) used multi-period linear programming for temporal and spatial allocation of irrigation water in Krishnarajsagar Project of the Mysore State. The water allocation was done among 12 time period, 6 canal areas, and 1126 crop activities under 259 resources constraints pertaining to land, net flow in the reservoir and the available supply of fertilizers.

Singh, I (1974) worked out the optimal pattern of distribution of water, using available ground water as a supplement to canal water, in Upper Ganga canal in western Utter Pradesh to maximize the return.

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.

Lakshi Narayan and Raj Gopalan (1977) applied linear programming technique to determine the optimal cropping pattern and optimal release policy from canals and tube wells during various months in a year for net return maximization.

Sinha and Charyulu (1980) formulated linear programming model, considering the existing irrigation system of Gomti Kalyani Doab. Optimal cropping pattern was determined by allocating cultivated areas to various alternative crops with a view to maximize net benefit.

Ranvir Singh (1981) worked out a plan involving land and water resources (Surface and Ground water) and their future development for individual river basins and also for India as a whole. Multilevel and multi period analysis were done using linear programming technique to optimize land, water and fertilizer resources for each of the 20 river basins individually and also for the Indian sub-continent.

Agrawal and Agrawal (1982) applied linear programming technique in combination with water budgeting to optimize agriculture production, based on an area under major irrigation winter crops, their yields per unit area and the total irrigation water actually applied by canals in Hissar, Harayana, India.

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 and based on water production functions were compared.

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

Mrs. Anita Singh (1990) employed modified simplex method of linear programming to optimize land, water and fertilizer resources of Narmada Basin for four phases of development.

Paudyal and 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.

H. Mishra (1991) formulated linear programming model for study area of Mahanadi and Chitrotpala Island, Orissa to find out a policy for optimal use of land and water resources.

Onta et. al. (1991) 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.

D. Panda (1993) used linear programming model and goal programming for optimal crop planning in Kansbahal Irrigation Project in Sundergarh district of Orissa, India.

K. Sinha (1997) used linear programming technique and formulated linear programming model to optimally allocate multi resources like land and water resources along with human labour, seeds, manure, fertilizer, etc. to maximize net benefit for the Badanala Irrigation Project, Rayagada, district of Orissa, India.

S. Gupta (1999) used linear programming model and goal programming for optimal crop planning in Barna irrigation Project in Madhya Pradesh, India.

Hesham M. Ali and Mohamed R. Mahmoud (1999) formulated a program to determine optimal allocation and crop pattern in Egypt by the use of linear programming. The objective function of the crop area allocation model is to minimize the amount of irrigation water used.

Mohamed Haouari, Mohamed N. Azaiez (1999) proposed a mathematical linear programming model for optimal cropping patterns under water deficits in dry regions. In this model crops may be deliberately under-irrigated in order to increase the total irrigated area and possibly the profit.

Singh et. al. (2001) used linear programming model to suggest the optimal cropping pattern at different water availability levels in the command of Shahi distributory in Uttar Pradesh, India. The constraints used in the model are total available water, land during different seasons, the minimum area under wheat and rice for local food requirements, farmer's socio economic conditions and preference to grow a particular crop in a specific area.

Ishtiaq Hassan (2004) used linear programming model to determine the optimum cropping pattern for the irrigated area of Punjab, Pakistan using national and WTO price options.

Bhabagrahi Sahoo, Anil K. Lohani and Rohit K. Sahu (2006) developed linear programming and fuzzy optimization models for planning and management of available land-water-crop system of Mahanadi-Kathajodi delta in eastern India. The models are used to optimize the economic return, production and labour utilization, and to search the related cropping patterns and intensities with specified land, water, fertilizer and labour availability, and water use pattern constraints.

The development of optimization models for improved water management expanded rapidly in the last decade. Linear programming is used for multiple crop models and dynamic programming for a single crop model. In irrigated agriculture, where various crops are competing for a limited quantity of land and water resources, many researcher and scientists have pointed out that linear programming is one of the best tools for optimal allocation of land and water resources.

The optimal cropping pattern and area allocation with respect to availability of water resources were obtained for different seasons by developing an optimization model. In addition to the rational water use, there is need for selecting economically viable cropping pattern for a given area with available resources. Such cropping pattern can be obtained through the use of optimization models. The optimal cropping pattern was obtained for different soil types (saline and non-saline), type of agriculture (rain fed and irrigated) and seasons (monsoon and winter) using Linear Programming (LP) model. The objective of the LP model is to find the maximum annual net return from different cropping patterns and areas for all types of agriculture (rain fed and irrigated) under different soil types. This optimization is subject to various constraints such as surface and groundwater availability and their mass balance, cropping pattern restrictions.

In practice, the principles of irrigation optimization have been the subject of extensive research for several decades, but to date those principles have not been put to use in production agriculture. Broad guidelines that approximate optimum irrigation management strategies have been proposed, for example, Keller and Bleisner (1990) suggest under-irrigating by 20% when water supplies are limited. But such rules of thumb may sometimes miss the optimum by a wide margin. English and Raja (1996) found that optimum water use may be on the order of 30% to 50% less than full irrigation for three crops in three very different settings (wheat in the Columbia Basin, cotton in California and maize in sub-Saharan Africa) under water limiting conditions.

Conventional irrigation practices are based on two key specifications, the crop water requirement and the nominal application efficiency. The crop water requirement has long been defined as that which will prevent crop water stress in order to avoid loss of yield or quality (Haise and Hagan, 1967). Nominal application efficiency derives from a stipulation noted earlier that irrigation adequacy should be 90% for high or medium valued crops, or 75% for low valued crops. Conventional irrigation is therefore defined in terms of the amount of applied water required to prevent stress in 90% of the field. Though somewhat dated, these stipulations are still the foundation of standard irrigation practice worldwide The 1992 revision of FAO defines crop water requirements in terms of full production potential (Doorenbos and Pruitt, 1992). A recent revision to the National Engineering Handbook assumes 90% adequacy in deriving nominal application efficiencies for various irrigation systems (NRCS, 1996).

Linear programming approach has been used in this study.

CHAPTER- III

DESRIPTION OF THE STUDY AREA

3.1 GENERAL

The Mahakali Irrigation Project (MIP) is a run-off the river type irrigation project. The source river is Mahakali river, which is also known as Sarda river downstream in Indian territory. The MIP area is divided into three stages. Stage-I, covering 4,800 ha, was completed in 1988. Stage-II, covering 6,800 ha has been completed in 1998 and the Net Command Area (NCA) by surface water of Stage-III is estimated at about 28,255 ha.

At present, the Stage-I and Stage-II command areas of the MIP are supplied with water from the Sarda Barrage in the Mahakali River, which was completed in 1928, in accordance with the water sharing agreement made in 1920 between the Government of Nepal (GON) and the Government of India (GOI). The Mahakali River is a snow-fed river with part of its catchments area in Tibet (China), and part in India and Nepal. The river forms the international boundary between Nepal and India. During the monsoon period it has a peak discharge up to 14,000 m^3/sec and a mean low flow of about 130 m^3/sec in the dry season. In accordance with the agreement, an 11.5 m wide Head-Regulator was constructed at the Sarda Barrage to convey water to Nepal, via the main canal section M-1-C. Stage-III area will be supplied water from the Tanakpur Barrage and of the Sarda canal (India) according to a new Indo-Nepal bilateral treaty, signed in 1996, which super shades the old 1920 agreement. According to the new treaty, Nepal is entitled to draw 66.6 m^3/sec of water from the Mahakali River (via the Sarda and Tanakpur Barrages) during the Kharif season and 22.75 m^3/sec during the Rabi season, while a minimum of 10 m^3/sec will be released throughout the year into the Mahakali River, downstream of the Sarda Barrage in order to guarantee a stable environment. The enhanced entitlement of water from the new treaty has made it possible to study the feasibility of extending irrigation into the Stage-III area.

The total length of Stage-I main canal (M-1-C) is 13.74 km. The initial canal capacity of M-1-C was for 13.0 m^3/sec in order to convey water to the Stage-I and Stage-II area during the monsoon season (15th May-15th October). This capacity was increased at the head works to 28.35 m^3/sec, in 1998, in accordance with the new treaty. During the dry season (16th October-14th May) 4.25 m^3/sec will be supplied on a continuous basis or at a rate of 8.5 m^3/sec during alternate 10-days periods.

3.2 PROJECT AREA

The study area, Mahakali Irrigation Project (MIP) Stage-I is located in the Far Western Terai of Nepal, on the left bank of the Mahakali River. The nearest town is Mahendranagar, which is the government centre for both the Kanchanpur District and Mahakali Zone. The MIP Stage-1 commands the area of Mahendranagar Municipality's Ward No. 2,4,11 to 19 and the area of Suda Village Development Committee's Ward No. 1 to 5.

The command area consists of recent alluvial plain. The area is clearly defined by the MIP Stage-I Main Canal (M-1-C) in the north, the Shuklaphant Wild Life Reserve in the south, the Mahakali River in the west, and the Chaudhar River in the east. The area is almost level with gentle north to south slope. The elevation of area ranges from 170 to 220 m above mean sea level. The latitude and longitude of Mahendranagar is 29°02' N and 80°13' E respectively. Figure No. 3.1 shows location and command area map of the Mahakali Irrigation project Stage–I.

3.3 CLIMATE OF THE AREA

The project area is located in the Far-Western part of the Terai plains, at the foothills of the Siwalik range. There are distinct wet and dry seasons with wide variation in rainfall from year to year. The foothills cause strong orographic rainfall during the monsoon season from around 15th June to 15th September. Winter precipitation occurs around December and January from the Western Disturbances, while isolated showers occur during the hot season, between March to May.

The area experiences a tropical to sub-tropical climate. The climate is characterized by the monsoon with a mean rainfall of 1,780 mm/year for Kanchanpur district. Of this, about 88 per cent falls during the period June to September. The mean daily temperature ranges from 14 °C in January to 31 °C in June, with a mean maximum temperature of 37.5 °C in May, and a mean minimum temperature of 6.9 °C in January. The winter season is warm in the daytime and cold during the night and morning. The mean annual evaporation rate is 1,222 mm in the Kanchanpur District. The mean relative humidity for April and August are 45 percent and 83 percent, respectively. The wind speed varies from 5.5 km/sec in April to 1.9 km/sec in October, indicating that hot months are also windy, while slight wind erosion could occur in the dry season..

3.4 SOIL AND LAND USE OF THE AREA

The command area exhibits three dominant soils: loam, sandy loam and loamy sand. The soils consist of alluvial fan, recent alluvial plain and some active alluvial plain. Soils at the northern side, including the central southern part of the study area, are deep and well to moderately well drained. Whereas soils in the southern part of the study area are poorly drained, soils from the southern and western sides are excessively drained and lighter in texture. The dominant soils of the study area are Ustochrepts, Haplaquepts, Haplustolls and some kinds of Entisol, such as Ustiflavends and Flavequents (Source: MIP Stage-III Feasibility Study Report).

Land use of the area, according to land use map of LRMP, topographic maps of 1998 on a scale of 1:25,000, and information obtained from the District Forest Office, Kanchanpur is classified as below:

- Agriculture land which is further subdivided into irrigated/partially irrigated land and rain-fed land,
- Forest, and
- Others, including urban, village, rivers, grazing land etc.

The types of land can be classified as Parceo, Tenant, Wetland and Dry land (Source: District Profiles).

3.5 AGRICULTURAL CONDITION

Agriculture is the main occupation in the district, with paddy, wheat and maize as the main cereal crops. Other crops include oilseeds, pulses, vegetables, sugarcane and sunflower. There is very good market for the production from the study area nearby. Presently, in summer (Kharif) season Paddy, Maize and Vegetables are grown, in winter (Rabi) season Wheat, Pulses, Oil crops, Potato and Vegetables are grown, and in Spring season Paddy, Maize and Vegetables are practiced to be grown in some areas. Sugarcane is also grown in a small part of the area as year round crop. In the study area, the average yield of paddy and wheat was 2.7 and 1.8 t/ha, respectively, which is higher than the yield rate of the Far Western Development Region and the nation as a whole. However, the yield rate is still low when compared with that of properly managed irrigated areas with improved agriculture farming practices.

Besides agriculture, local people also rear livestock. About 450,000 livestock have been reported in the Kanchanpur District (District Livestock Office, Kanchanpur, 2006), but few people are involved in trade and business. A limited number of off-farm and income-generating activities are available in the command area.

3.6 POPULATION

According to 2001 census data the total population of the study area (Mahakali Irrigation Project Stage-I area) is 27053. Table 3.1 shows population figures of different areas of Mahakali Irrigation Project Stage-I as per 2001 census.

Table 3.1: Population by 2001 of different areas of MIP Stage-I

Name of the area	No. of households	Female population	Male population	Total population
Mahendranagar Municipality Ward No. 2,4,11 - 19	2892	8338	8680	17019
Suda Village Development Committee Ward No 1,2,3,4,5	1616	4918	5116	10034
Total		13256	13796	27053

Projected population by 2017 AD is given in Table 3.2. The population growth rate is estimated about 3.47 % for the period from 2001 to 2011 and 3.04 % for the period from 2011 to 2021.

Table 3.2: Projected population by 2017 of MIP Stage-I area

Name of the area	No. of households	Female population	Male population	Total population
Mahendranagar Municipality Ward No. 2,4,11 - 19	4790	13808	14375	28185
Suda Village Development Committee Ward No 1,2,3,4,5	2676	8145	8473	16617
Total		21953	22848	44802

(Source: Office of District Development Committee, Kanchanpur.)

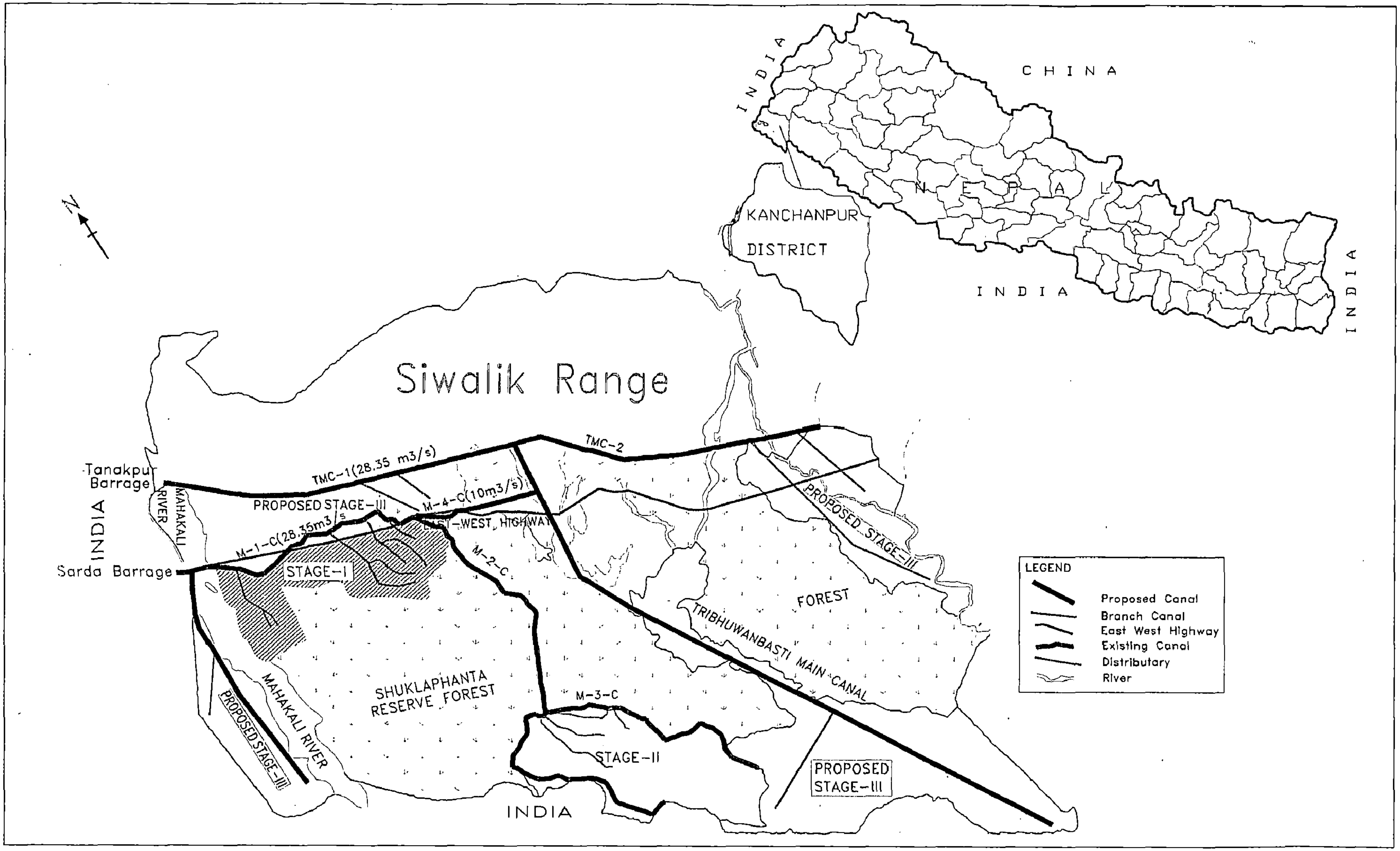

Fig 3.1: Location and command area map of Mahakali Irrigation Project Stage–I

3.7 DATA USED IN THE PRESENT STUDY

The data used in the present study have been collected from various offices such as Mahakali Irrigation Management division No. 8, Mahendranagar, Office of District development Committee, Kanchanpur, District Agricultural Office, Kanchanpur, Far Western Regional Irrigation Directorate, Dhangadhi and from various reports such as Feasibility Study Report of Mahakali Irrigation Project, Report of National Agricultural Research Centre (NARC), Feasibility Study Report of Ground Water Potential of Nepal by Ground Water Development Board, etc. Some data have been collected from different books, manuals, journals and papers such Planning and Design Strengthen Project (PDSP)-Manual No. M3, FAO Irrigation and Drainage Manual No. 3, 4 and 6 and Paper No. 24, 49 and 56, USDA National Nutrient Database for Standard Reference–Release 18 (2005) etc.

3.7.1 RAINFALL AND EVAPORATION DATA

Table 3.3 shows mean monthly rainfall and pan evaporation in mm of Mahakali Irrigation Project Stage-I area (Hydro meteorological station - Mahendranagar).

Table 3.3: Mean monthly rainfall and pan evaporation

Month	Average Rainfall in mm	Pan Evaporation Loss in mm
January	24.90	40.30
February	38.70	62.70
March	18.10	102.30
April	18.80	144.00
May	44.30	164.30
June	255.90	147.00
July	531.90	124.00
August	499.00	117.80
September	292.40	108.00
October	34.60	96.10
November	5.20	66.00
December	16.50	49.60
Total	1780.30	1222.10

(Source: PDSP - Hydrology and Meteorology manual M3)

3.7.2 HYDROMETEOROLOGICAL DATA

Table No. 3.4 shows the hydro-meteorological and solar data considered for the present study.

3.7.3 PRESENT CROPPING PATTERN

Table No. 3.5 shows the present cropping pattern of Mahakali Irrigation Project Stage–I.

Table 3.4: Hydro-meteorological data of Mahendranagar station (MIP Stage–I)

Latitude: - 29^0 02' N Longitude: - 80^0 13' E Altitude:-176 m. amsl

Month	Tmax in °C	Tmin in °C	Tmean in °C	RHmax in %	RHmin in %	RHmean in %	Wind velocity in		n in hrs	N in hrs	n/ N
							Km/ day	m/ s			
Jan	21.8	7.0	7.0	97	75	86	38.4	0.44	8.2	10.46	0.78
Feb	24.0	8.6	8.6	94	64	79	52.8	0.61	8.9	11.14	0.80
Mar	29.2	12.4	12.4	86	56	71	64.8	0.75	9.5	12.00	0.79
Apr	35.3	16.9	16.9	63	39	51	81.6	0.94	9.7	12.86	0.75
May	37.6	22.2	22.2	61	45	53	79.2	0.92	9.2	13.54	0.68
June	36.3	24.9	24.9	76	60	68	76.8	0.89	6.7	13.94	0.48
July	32.8	25.4	25.4	87	77	82	69.6	0.81	5.6	13.82	0.41
Aug	32.5	25.5	25.5	88	80	84	57.6	0.67	5.9	13.16	0.45
Sep	32.1	23.9	23.9	89	79	84	43.2	0.50	6.7	12.38	0.54
Oct	30.7	18.5	18.5	87	73	80	36.0	0.42	7.7	11.52	0.67
Nov	27.9	12.1	12.1	90	70	80	31.2	0.36	8.5	10.66	0.80
Dec	23.7	7.9	7.9	95	74	85	36.0	0.42	8.2	10.28	0.80

(Source:

1. Climatological Record of Nepal – Department of Hydrology and Meteorology.
2. FAO – CLIMWAT database.
3. PDSP, Hydrology and Meteorology Manual - M3.
4. Feasibility Study Report of MIP Stage – III.)

3.7.4 CROP YIELD AND RETURN PER HECTARE

Table No. 3.6 shows the crop yield and net benefits from crops at rain fed stage. Table No. 3.7 shows the crop yield and net benefits from crops at full irrigation stage.

3.7.5 ENERGY AND NUTRIENTS CONTENT OF DIFFERENT CROPS

Table No. 3.8 shows the calorie, Protein, Calcium, Iron, Vitamin A, Vitamin C and Vitamin E content of different crops.

3.7.6 ENERGY AND NUTRIENTS REQUIREMENT

The over all average Energy (Calorie) and Nutrients (Protein, Calcium, Iron, Vitamin A, Vitamin C and Vitamin E) requirement per person of the study area has been estimated according to FAO/WHO recommendations. Table 3.9 shows the energy and nutrients requirement of the study area by 2017 A.D.

Table 3.5: Present cropping pattern of MIP Stage–I

Sl. No.	Name of Crops	Planting Date	Harvesting Date	Crop Area in ha.	Crop Coverage in %
	Summer Crops				
1	Paddy Rice (Local)	Aug 1	15-Nov	267.31	5.57
2	Paddy Rice (Improved)	July 1	30-Oct	4128.00	86.00
3	Maize (Local)	June1	30-Aug	96.00	2.00
4	Maize (Improved)	June1	30-Aug	144.00	3.00
5	Vegetable (Summer)	June1	30-Aug	14.40	0.30
6	Sugercane	Mar 1	20-Jan	1.24	0.03
	Sub Total			4650.95	96.89
	Winter Crops				
1	Wheat	Nov 15	Mar 15	3993.60	83.2
2	Oilseed	Oct 22	Feb 22	136.97	2.85
3	Lentil	Nov 7	Mar 7	290.90	6.06
4	Other Pulses (Grams, Peas, Beans,etc.)	Nov 7	Feb 17	2.90	0.06
5	Potato	Nov 7	Mar 7	113.38	2.36
6	Winter Vegetable (Cabbage, Cauliflower, Carrot, Raddish, Tomato etc.)	Oct 22	Feb 22	76.14	1.59
	Sub Total			4613.88	96.12
	Spring Crops				
1	Maize (Spring)	Mar 1	May 30	2.90	0.06
2	Paddy Rice (Spring)	Mar 22	July 7	43.20	0.9
3	Sunflower	Feb 22	May 27	8.28	0.17
4	Vegetable (Spring)	Mar1	May 30	51.84	1.08
	Sub Total			106.21	2.21
	Total			9371.04	195.23

3.7.7 SURFACE WATER AVAILABILITY

Stage-I and Stage-II of the Project area is, at present, supplied with water from the Sarda Barrage, constructed in 1928, in accordance with the water sharing agreement made in 1920 between Government of Nepal (GON) and the Government of India (GOI). Mahakali (Sarda) river is the western bordering river between Nepal and India. A new Indo-Nepal bilateral treaty was signed on 12 February 1996, which is called the "Treaty for Integrated Development of Mahakali River including Sarda, Tanakpur, and Pancheswor Multi-purpose Project." The new treaty super shades the old 1920 agreement. The water distribution, according to this treaty, is as follows:

a) Nepal shall have the right to a supply of 28.35 m^3/sec (1,000 cusecs) of water from the Sarda Barrage in the wet season (i.e. from 15th May to 15th October) and 4.25 m^3/sec (150 cusecs) in the dry season (i.e. from 16th October to 14th May).

Table 3.6: Crop yield and net benefits from crops at Rain Fed stage

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	1011	915	400	9900	7000	45	19271	2.110	26586	1519	28105	8834	5521
2	Paddy Rice (Improved)	980	1283	500	9900	7000	45	19708	2.730	34398	1638	36036	16328	10205
3	Maize (Local)	532	543	400	9000	4200	45	14720	1.620	16362	0	16362	1642	1026
4	Maize (Improved)	532	543	400	9000	4200	45	14720	1.720	17372	0	17372	2652	1657
5	Vegetable (Summer)	313	1915	1000	13700	5800	45	22773	8.850	99209	0	99209	76436	47772
6	Sugercane	7720	1904	500	16500	6800	45	33469	35.300	58245	0	58245	24776	15485
	Winter Crops													
1	Wheat	1932	1240	200	7500	7000	45	17917	1.570	14758	377	15135	-2782	-1739
2	Oilseed	824	858	200	4300	3400	45	9627	5.700	25023	0	25023	15397	9623
3	Lentil	2098	384	400	3700	2400	45	9028	5.900	23010	0	23010	13982	8739
4	Other Pulses	2098	384	400	3700	2400	45	9028	0.800	31200	0	31200	22172	13858
5	Potato	21905	1998	500	12300	5000	45	41748	9.110	80624	0	80624	38876	24297
6	Winter Vegetable	313	1915	1000	13700	5800	45	22773	9.500	144495	0	144495	121722	76076
	Spring Crops													
1	Maize (Spring)	532	543	400	9000	4200	45	14720	1.720	17372	0	17372	2652	1657
2	Paddy Rice (Spring)	980	1283	500	4714	2009	45	9531	2.730	34398	1112	35510	25979	16237
3	Sunflower	800	726	300	4300	3400	45	9571	0.660	26400	0	26400	16829	10518
4	Vegetable (Spring)	313	1915	1000	13700	5800	45	22773	8.850	84872	0	84872	62099	38812

(Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.)

Table 3.7: Crop yield and net benefits from crops at Full Irrigation stage

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in Irs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	798	3145	404	11700	7200	45	23292	2.896	36493	2835	39328	16036	10023
2	Paddy Rice (Improved)	798	3908	505	11700	7200	45	24156	4.481	56458	2043	58501	34345	21466
3	Maize (Local)	384	2959	404	9700	4600	45	18091	2.110	21311	318	21629	3537	2211
4	Maize (Improved)	384	2959	404	9700	4600	45	18091	3.764	38016	318	38334	20243	12652
5	Vegetable (Summer)	379	5241	1010	13500	6400	45	26575	19.117	214307	0	214307	187732	117332
6	Sugercane	9545	5539	505	17600	7800	45	41034	66.332	109448	773	110220	69186	43242
	Winter Crops													
1	Wheat	1709	4510	202	9100	7600	45	23166	3.718	34947	803	35749	12584	7865
2	Oilseed	444	2969	202	5700	4000	45	13359	1.054	46272	12038	58309	44950	28094
3	Lentil	1972	2190	404	5500	4200	45	14311	1.181	46061	193	46254	31943	19964
4	Other Pulses	1972	2190	404	5500	4200	45	14311	1.100	42899	193	43092	28781	17988
5	Potato	20150	5636	505	14200	6800	45	47336	19.110	169122	0	169122	121787	76117
6	Winter Vegetable	379	5241	1010	13500	6400	45	26575	19.118	290781	0	290781	264206	165129
	Spring Crops													
1	Maize (Spring)	384	2959	404	9700	4600	45	18091	3.764	38016	318	38334	20243	12652
2	Paddy Rice (Spring)	798	3908	404	11700	7200	45	24055	4.460	56201	1112	57313	33257	20786
3	Sunflower	606	2518	303	5700	4000	45	13172	1.621	64846	583	65429	52257	32661
4	Vegetable (Spring)	379	5241	1010	13500	6400	45	26575	19.110	183265	0	183265	156689	97931

(Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.)

Table 3.8: Calorie and nutrients content per kg of different crops

Sl. No.	Name of crop	Energy in Kcal	Protien Content in gm	Calcium in mg	Iron in mg	Vitamin A in mcg RAE	Vitamin C in mg	Vitamin E in mg
	Summer crops							
1	Paddy rice (Local)	3160	133.5	570.0	185.4	0.0	0.0	49.2
2	Paddy rice (Improved)	3160	133.5	570.0	185.4	0.0	0.0	49.2
3	Maize (local)	3650	94.2	70.0	27.1	0.0	0.0	0.0
4	Maize (Improved)	3650	94.2	70.0	27.1	110.0	0.0	4.9
5	Vegetables	250	19.8	430.0	4.4	2188.0	283.0	5.3
6	Sugarcane	3870	0.0	10.0	0.1	0.0	0.0	0.0
	Winter crops							
7	Wheat	3310	103.5	270.0	32.1	0.0	0.0	10.1
8	Oilseed	5730	177.3	9750.0	145.5	0.0	0.0	2.5
9	Lentil	3530	258.0	560.0	75.4	20.0	44.0	4.9
10	Other pulses	3430	217.0	1300.0	52.3	10.0	0.0	0.0
11	potato	790	20.7	70.0	7.8	0.0	197.0	0.1
12	Vegetables	250	19.8	430.0	4.4	2188.0	283.0	5.3
	Spring Crops							
13	Maize (Spring)	3650	94.2	70.0	27.1	110.0	0.0	4.9
14	Paddy Rice (Spring)	3160	133.5	570.0	185.4	0.0	0.0	49.2
15	Sunflower	5700	227.8	1160.0	67.7	30.0	14.0	345.0
16	Vegetables (Spring)	250	19.8	430.0	4.4	2188.0	283.0	5.3

(Source:
1. Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002).
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).)

b) India shall maintain a flow of not less than 10m^3/sec (350 cusecs) downstream of the Sarda Barrage in the Mahakali River to maintain and preserve the river eco-system.

c) A supply of 28.35 m^3/sec (1,000 cusecs) of water in the wet season (i.e. from 15th May to 15th October) and 8.50 m^3/sec (300 cusecs) in the dry season (i.e. from 16th October to 14th May). For this purpose, and for the purposes of Article 1, India shall construct the head regulator(s) near the left under sluice of the Tanakpur Barrage and also the waterways of the required capacity up to the Nepal-India border. Such head regulator(s) and waterways shall be operated jointly.

d) India shall supply 10m^3/sec (350 cusecs) of water to irrigate the Dodhara-Chandani area of Nepalese Territory, throughout the year.

With the new treaty, the water supply to Nepal from the Mahakali River will be considerably increased. The enhanced entitlement of water from the new treaty has made it possible to study the feasibility of extending irrigation into the Stage-III area with a net command area of 33520 ha (both by surface water and ground water). Stage–III is planed to receive excess water in monsoon season after meeting irrigation requirement of Stage–I and Stage–II through M-4-C, an extension of M-1-C in addition to water supply from Tanakpur barrage. In dry (non-monsoon) season Nepal is supplied with 4.25 m^3/sec, which distributed in command area of Stage–I and Stage–II, no excess water is available for Stage-III area because it is even not sufficient for existing Stage–I and Stage–II areas. Distributing the available water according command area basis of Stage–I and Stage-II, Stage-I will have right for water supply of 1.76 m^3/sec in dry season (i.e. from 16th October to 14th May).

Table 3.9: Energy and nutrients requirement of MIP Stage–I area

Sl. No.	Name of Energy/ Nutrition	Unit	Requirement per capita per day per 1000 Kcal		Requirement per capita per day		Average Req. per capita per day	Total Annual Requirement
			Male	Female	Male	Female		
1	Energy	Kcal			2533	2093	2317	37889275410
2	Protien	g	22.5	25	57	52.3	54.7	894494331
3	Calcium	mg	350	500	886.6	1046.5	965	15780384450
4	Iron	mg	4	12	10.1	25.1	17.5	286172775
5	Vitamin-A	µg_REA	210	250	531.9	523.3	527.7	8629335621
6	Vitamin-C	mg	16	23	40.5	48.1	44.2	722790666
7	Vitamin-E	mg	3.6	3.6	9.1	7.5	8.3	135727659

(Note:-

1. Population by 2017 will be as Male = 22848 (51%) and Female = 21953 (49%).
2. Estimated average energy requirement for Male = 2533 Kcal and for Female = 2093 Kcal.

Source:

1. The State of Food Insecurity in the World, FAO (2000).
2. FAO/WHO Expert Consultation on Human Vitation and Mineral Requirements (2000).)

Figure 3.2 shows water distribution plan among the different stages of Mahakali Irrigation Project. Table 3.10 shows the monthly surface water availability.

3.7.8 GROUND WATER AVAILABILITY

Ground water potential in the study area (MIP Stage–I) is very good. Conjunctive use of ground water and surface water will be beneficial for irrigation. The principal source of groundwater in the terai (plain) area of Nepal is rainfall and the infiltration of surface water (rivers) through the permeable beds. Various studies have been undertaken for recharge estimations, based on rainfall only. Ground water survey and investigation were carried out by different agencies at different time. Duba, D. in 1982 under Water and Energy Commission Secretariat (WECS) first undertook the study to estimate the Ground Water

Resources in Terai of Nepal, followed by Ground Water Development Consultant (U.K.) under Department of Irrigation Hydrology and Meteorology in 1987 and then Ground Water Resource Development Board carried out a comprehensive reassessment study to set ground water resource development strategies for irrigation in the Terai through the Ground Water Resource Development Project in 1994. All studies were conducted on the district basis. These studies provide a great deal of information about groundwater resources and development concepts in Terai belt of Nepal.

Based on these studies ground water recharge in the Kanchanpur district has been calculated with three methods. The first method utilizes the data from Duba. The second method assumes that 10 percent of the rainfall will recharge the groundwater, while the third method assumes a specific yield and considers water level fluctuations. All the three methods use an area of 1,480 km^2 for the Kanchanpur Terai. These three methods give the estimates of recharge as 577, 235 and 544 MCM per year, respectively. These estimates do not consider rejected recharge due to soil saturation, nor the increase of recharge possible if the water level would fall by pumping irrigation water. Potential evapotranspiration was estimated using the water table fluctuation between pre and post monsoon periods over the district. The loss of groundwater due to water table fluctuations was considered to be due to evapotranspiration.

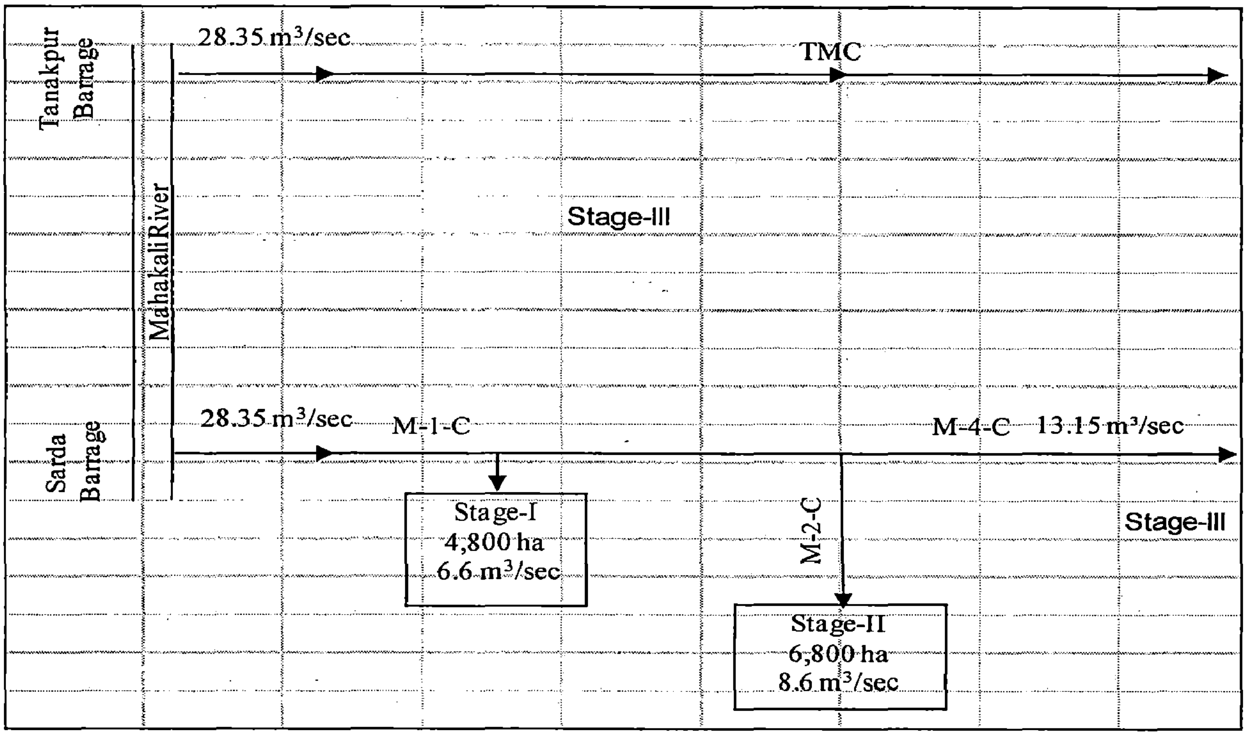

Fig. 3.2: Schematic diagram of the water distribution of MIP (all stages)

Table 3.10: Maximum monthly available surface water supply

Month	Available flow at H/R in m^3/s	Monthly availble supply at H/R in Ha-m
January	1.76	471.40
February	1.76	425.78
March	1.76	471.40
April	1.76	456.19
May	1.76/ 6.60	1182.30
June	6.60	1710.72
July	6.60	1767.74
August	6.60	1767.74
September	6.60	1710.72
October	6.60/ 1.76	1098.66
November	1.76	456.19
December	1.76	471.40

(Note:- Availabe flow is
- in monsoon season (15th May to 15th October) = 6.60 m3/s and
- in non-monsoon (dry) season (16th October to 14th May) = 1.76 m3/s.)

The average fluctuation over the district is estimated as 2.5 m, out of which 2 m of the fluctuation is assumed to be attributed to evapotranspiration. With specific yields of saturated sediments estimated as 15 percent, and an area of Terai in the district as 1,480 km^2, the potential evapotranspiration was estimated to be 447 MCM per year. A rough estimate of subsurface outflow to India was also attempted with the assumptions that the average aquifer saturated thickness is 44 percent of 32 m, i.e. 14 m, with an assumed porosity of 15 percent. The aquifer width is considered to be 50 km along the border with India. The hydraulic conductivity is taken as 75 m/day along the border with a hydraulic gradient of 1m per km, i.e. 0.001. The subsurface flow to India is estimated as 19 MCM per year at the rate of 0.5 m/day.

There are around 5000 existing Shallow Tube Wells in the district yielding a supply of 10 liter/sec for 6 hours per day on an average outside the study area (Stage-I). But there is no ground water utilization of any form for irrigation in the study area. Calculations for available ground in the study area has been done by taking the recharge as 544 MCM as estimated by considering specific yield and water fluctuation method for district having a gross recharge area of 1,480 km^2. Utilizable ground water has been calculated by deducting the sub surface out flows (19 MCM to India). Available flow is then obtained by deducting the present utilizations if any. Available ground water in the study area has been computed assuming that ground water is proportionally distributed over the recharge area; the gross command area of Stage-I is taken as 6000 ha and no ground water utilization at present. Monthly ground water availability has been estimated taking the capacity of pumping plant into consideration on the basis of 6 hours of working per day to pump out 1/12th of the total annual utilizable ground water resources. Maximum monthly ground water that can be pumped out is obtained if the pumps are operated for all the 24 hours of the day. Table 3.11 shows the utilizable ground water resources in the study area.

Table 3.11: Utilizable ground water resources in the study area

Name of the bolck	Area of the recharge block (Gross) in ha	Annual utilizable GW in MCM	Present Annual Withdrawal in MCM	Available Annual GW for Irrigation in MCM	Available Annual GW for Irrigation in Ha-m	Monthly maximum available GW (operating pumps for 24 hrs instead of 6hrs per day) in Ha-m
Plain Area of Kanchanpur District	148000	525	394.20	130.80	13080	4360
Mahakali Irrigation Project Stage - I	6000	21.2838	0	21.2838	2128.38	709.46

3.7.9 UNIT COST OF SURFACE WATER

The cost of surface water may be classified into two heads namely operation and maintenance cost and overhead cost (fixed cost) of surface water. Total cost of surface water can be obtained by adding these two costs. The per hectare development cost of project is to be converted to per unit cost of water. The annual fixed cost can again have two parts annual recovery cost and annual interest on investment cost. The investment cost of Mahakali Irrigation Project stage-I was 370.45 Million NRs in 1987. According to the financial assistance agreement held between Government of Nepal (GON) and International Development Association (IDA) the capital recovery factor and interest rate (service charge) was set at 4% and 0.75% for the 30 years period of the project life. Using these factors fixed cost (annual capital recovery cost and annual interest) has been computed. Annual operation and maintenance cost has been estimated on the actual basis, taking an average of last three years actual expenditure invested in canal operation and maintenance by the Mahakali Irrigation Management Division including office expenses. The operation cost was work out on the basis of irrigated command area and then has been converted to the basis of per hectare meter of water delivered (Ranvir Singh, 1981). Unit cost of surface water is thus obtained as IRs 1669.94 per hectare-meter.

3.7.10 UNIT COST OF GROUND WATER

This cost may be classified into two heads namely, installation cost and operation cost. The operation cost should include the cost of fuel/ electricity, lubricants, repair and operator charges. These costs should be worked out per unit of water (Ranvir Singh, 1981). Dhruba pant and Madhav Belbase have studied about 'Socio-ecological Implications of Ground water in Nepal' and found that average installation cost of a shallow tube well is about NRs 42,000 and per hour operation cost is about NRs 45. Assuming the life of a shallow tube well as 20 years, capital recovery rate and interest rate as 6%, the fixed cost of a shallow tube well has been worked out which comes to be NRs 0.23 per hour. Then the total cost per hour of a shallow tube well is NRs 45.29. When average yield of a shallow tube well is taken as 10 liter/sec (as mentioned in the feasibility study report of MIP Stage-III) the cost of ground water comes to be IRs 7862.44 per hectare-meter.

3.8 MINIMUM AGRICULTURAL PRODUCTION REQUIREMENT

Depending on the food habits and balance diet requirement of the population by 2017 A.D. of the Mahakali Irrigation Project command area, minimum requirement of various crop yields and like wise minimum area required for these crops, has been worked out and presented in Table No. 3.12.

Table 3.12: Minimum area requirement of different crops in MIP Stage-I

Sl. No.	Name of crop	Crop yield required per capita per day in gms	Average Crop Yield in t/ha	Minimum Area Required per Person per Year in ha	Minimum Area Required for population by 2017 in ha	Requirement period
1	Paddy Rice (Local, Improved & Spring paddy)	300	3.412	0.0321	1438	Yearly
2	Maize (Local, Improved & Spring Maize)	25	2.640	0.0035	155	Yearly
3	Summer Vegetables	250	15.266	0.0060	268	4 months
5	Wheat	175	2.912	0.0219	983	Yearly
6	Oilcrops (Mustard, Linseed & Sunflower)	70	1.067	0.0240	1073	Yearly
7	Pulses (Lentil & Other Pulses)	60	0.973	0.0225	1008	Yearly
8	potato	50	15.360	0.0012	53	Yearly
9	Winter Vegetables	250	15.510	0.0059	264	4 months
10	Spring Vegetables	250	15.262	0.0060	268	4 months

(Source:
1. FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Note:
1. Crop products are in full grains.
2. The eatable proportion from the raw food grains is assumed as
(i) Eatable (white/ brown) rice - 2/3rd of raw paddy grains.
(ii) Eatable wheat/maize flour - 100 % of raw wheat/maize grains.
(iii) Refined oil - 1/3rd of oil seeds.
(iv) Eatable pulse (fractured) - 9/10th of pulse grains.)

CHAPTER– IV

CROP WATER REQUIREMENT

4.1 GENERAL

Crop water requirement also called crop evapotranspiration (ET_{crop}), has been defined as "the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including soil, water and fertility and achieving full production potential under the given growing environment" (Doorenbos and Pruitt, 1977). This is a combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration, is referred to as evapotranspiration (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period when the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

4.2 REFERENCE CROP EVAPOTRANSPIRATION

The crop evapotranspiration (ET_c) can be written as

$$ET_c = K_c * ET_o \qquad \text{--------------------------------} \qquad (4.1)$$

Where, K_c = crop coefficient,

ET_o = reference crop evapotranspiration in mm/day.

The reference crop evapotranspiration (also called as reference evapotranspiration) is the rate of evapotranspiration from an extensive surface of clipped grass or alfalfa that is well-watered, and fully shades the ground. The clipped grass reference is considered to be a "cool-season" grass variety such as perennial rye grass. The FAO-24 publication by Doorenbos and Pruitt (1977) suggested that the clipped grass surface be maintained at 8 to 15 cm in height. The FAO Penman-Monteith method was developed by defining the reference crop as a hypothetical crop with an assumed height of 0.12 m, with a fixed surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered. There are several methods to estimate ET_0 depending upon availability of data, location of the area (Latitude, Longitude and Altitude) and climate of the area but most widely used methods are Modified Penman method and Penman-Monteith method.

4.2.1 MODIFIED PENMAN METHOD

This uses the method of Doorenbos and Pruitt (1977). The equations used are those presented by Smith (1988) for a grass reference crop. In this method the equation for reference evapotranspiration is given as below:

$$ET_0 = C\,[W.R_n + (1-W).f(u).(e_a-e_d)] \qquad \text{----------------} \qquad (4.2)$$

Where,

ET_0 = Reference evapotranspiration in mm/day

C = Adjustment factor to compensate for effect of day and night weather conditions,

W = Temperature and elevation related weighing factor,

R_n = Net radiation in mm/day = $R_{ns}-R_{nl}$

R_{ns} = Net incoming shortwave radiation in mm/day $=R_a\,(1-\alpha)\,(0.25+0.50n/N)$

R_a = Extraterrestrial radiation in mm/day

α = Reflection coefficient (0.25 for most of the crops)

n/N = Ratio of actual sunshine hours to maximum possible sunshine hours

R_{nl} = Net long wave radiation in mm/day

(e_a-e_d) = Saturation vapor pressure deficit in mili bar

f (u) = Wind related function = $0.27\,(1+u/100)$

u = Wind velocity in Km/day at 2 meter height from ground level

The calculation methods along with relevant tables and figures are described in FAO Irrigation and Drainage Paper No. 24 and 33. The equation has been widely used world wide but it is difficult to use this method in data short situations and this method has a tendency to overestimate ET_0 in temperate climates.

Reference Evapotranspiration (ET_0) for Stage-I and Stage-II area of Mahakali Irrigation Project was computed using Modified Penman method. Monthly ET_0 values computed by Modified Penmen method are presented in Table No. 4.1.

4.2.2 FAO PENMAN-MONTEITH EQUATION

The Penman-Monteith equation used for 24 hour calculations of reference evapotranspiration (ET_o) is given as

$$ET_o = \frac{[0.408 * \Delta * (R_n - G) + \gamma * \frac{900}{(T+273)} * u_2 * (e_s - e_a)]}{\Delta + \gamma * (1 + 0.34 * u_2)} \quad \text{-------} \quad (4.3)$$

Where,

ET_o = Reference evapotranspiration in mm/day,

R_n = Net radiation at the crop surface in $MJ/m^2/day$,

G = Soil heat flux density in MJ/m2/day,

T = Mean daily air temperature at 2 m height in °C,

u_2 = Wind speed at 2 m height in m/sec,

e_s = Saturation vapor pressure in kPa,

e_a = Actual vapor pressure in kPa,

(e_s-e_a) = Saturation vapor pressure deficit in kPa,

Δ = Slope vapor pressure curve in kPa/°C,

γ = Psychrometric constant in kPa/°C.

The method overcomes the shortcomings of the previous FAO Penman method and provides values that are more consistent with actual crop water use data worldwide. Furthermore, recommendations have been developed using the FAO Penman-Monteith method with limited climatic data, thereby largely eliminating the need for any other reference evapotranspiration methods and creating a consistent and transparent basis for a globally valid standard for crop water requirement calculations. The FAO Penman-Monteith method uses standard climatic data that can be easily measured or derived from commonly measured data. All calculation procedures have been standardized according to the available weather data and the time scale of computation. The calculation methods, as well as the procedures for estimating missing climatic data, are presented in FAO Irrigation and Drainage Paper No. 56.

ET_o by FAO Penman-Monteith method can be computed using computer software packages. A software CROPWAT window version 4.3 uses the FAO Penman-Monteith equations to assess ET_o. In the present study CROPWAT 4.3 window version has been used to compute ET_o. The computed ET_o values are presented in the Table No. 4.2.

Table 4.1: ETo by Modified Penmen method as used in MIP Stage-I

Month	Eto data Computed by Modified Penman method in mm/day
January	1.84
February	2.82
March	4.29
April	6.45
May	7.12
June	5.59
July	5.34
August	4.36
September	3.7
October	3.44
November	2.66
December	1.89
Average	4.13

Table 4.2: Climate and ET_0 data by CROPWAT 4.3 windows version

Country: NEPAL Station: MAHENDRANAGAR

Altitude: 176 meter(s) above M.S.L.

Latitude: 29.03 Deg. (North) Longitude: 80.22 Deg. (East)

Month	T_{max}	T_{min}	Humidity	Wind Speed	SunShine	Solar Radiation	ET_o
	(°C)	(°C)	(%)	(Km/day)	(Hours)	(MJ/m^2/day)	(mm/day)
January	21.8	7.0	86.0	38.4	8.2	14.0	1.68
February	24.0	8.6	79.0	52.8	8.9	17.1	2.46
March	29.2	12.4	71.0	64.8	9.5	20.7	3.70
April	35.3	16.9	51.0	81.6	9.7	23.4	5.16
May	37.6	22.2	53.0	79.2	9.2	23.7	5.66
June	36.3	24.9	68.0	76.8	6.7	20.2	4.97
July	32.8	25.4	82.0	69.6	5.6	18.4	4.21
August	32.5	25.5	84.0	57.6	5.9	18.1	4.03
September	32.1	23.9	84.0	43.2	6.7	17.7	3.71
October	30.7	18.5	80.0	36.0	7.7	16.5	3.00
November	27.9	12.1	80.0	31.2	8.5	14.9	2.12
December	23.7	7.9	85.0	36.0	8.2	13.3	1.58
Average	30.3	17.1	75.3	55.6	7.9	18.2	3.52

4.2.3 COMPARISON BETWEEN ET_o VALUES COMPUTED BY MODIFIED PENMAN MEYHOD AND PANMAN-MONTEITH METHOD

Table No. 4.3 shows a comparative study of ET_o values as computed by using Modified Penman method and Penman-Monteith method. It shows that ET_o values computed by Modified Penman method are higher than the ET_o values computed by Penman-Monteith method in all months except in September. ET_o values computed by Modified Penman method are ranging from -0.27 % in September to 26.84 % in July over the ET_o values computed by Penman-Monteith method. On average Modified Penman method exhibits overestimate in ET_o values by 17.08 %. This study is compatible to the various researches discussed in Chapter-II.

Table 4.3: Comparison between ETo values

Month	ETo Computed by Modified Penman method in mm/day	ETo Computed by Penman-Monteith method in mm/day	High (+) or low (-) than ETo values by Penman-Monteith method in %
January	1.84	1.68	9.52
February	2.82	2.46	14.63
March	4.29	3.70	15.95
April	6.45	5.16	25.00
May	7:12	5.66	25.80
June	5.59	4.97	12.47
July	5.34	4.21	26.84
August	4.36	4.03	8.19
September	3.7	3.71	-0.27
October	3.44	3.00	14.67
November	2.66	2.12	25.47
December	1.89	1.58	19.62
Average	4.13	3.52	17.08

The FAO Penman-Monteith equation is adopted to compute ET_o in the present study.

4.3 CROP COEFFICIENT

The crop coefficient (K_c) is basically the ratio of the crop evapotranspiration (ET_{crop}) to the reference evapotranspiration (ET_o) and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, albedo (reflectance) of the crop-soil surface, canopy resistance and evaporation from soil, especial from exposed soil. Factors determining the crop coefficient are crop type, climate, soil evaporation and crop growth stages. Crop growth stage is divided into four stages such as initial stage, crop development stage, mid season stage and late season stage. Figure 4.1 illustrates the variation in K_c for crops as influenced by weather factors.

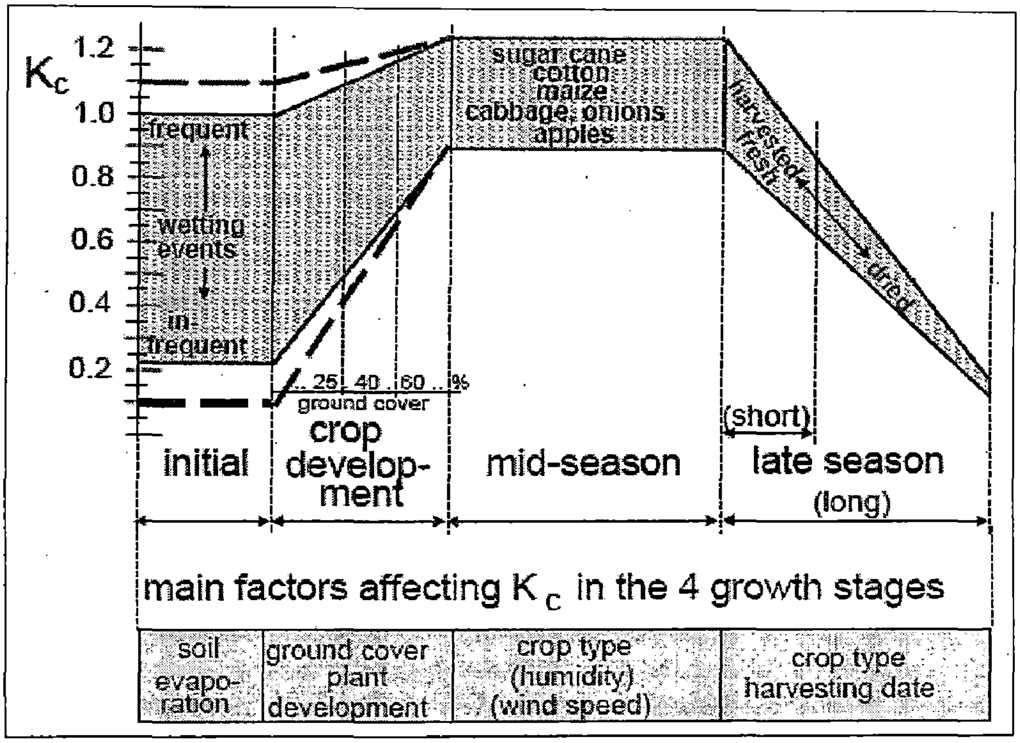

Fig. 4.1: Typical ranges expected in K_c for the four growth stages

The crop coefficient K_c for any period of the growing season is derived, by considering, during the initial and mid-season stages K_c is constant and that during crop development and late season stages K_c varies linearly between the K_c at the end of the previous stage ($K_{c\,prev}$) and the K_c at the beginning of the next stage ($K_{c\,next}$), which is $K_{c\,end}$ in the case of the late season stage. This is represented by the following relation:

$$K_{ci} = K_{c\,prev} + [\{i - \sum (L_{prev})\}/L_{stage}]\,(K_{c\,next} - K_{c\,prev}) \text{ ------------- } \qquad (4.4)$$

Where,

i = day number within the growing season

K_{ci} = crop coefficient on day i,

L_{stage} = length of the stage under consideration [days],

$\sum (L_{prev})$ = sum of the lengths of all previous stages [days].

A typical crop coefficient curve showing position of $K_{c\,ini}$, $K_{c\,mid}$ and $K_{c\,end}$ is illustrated by Figure 4.2.

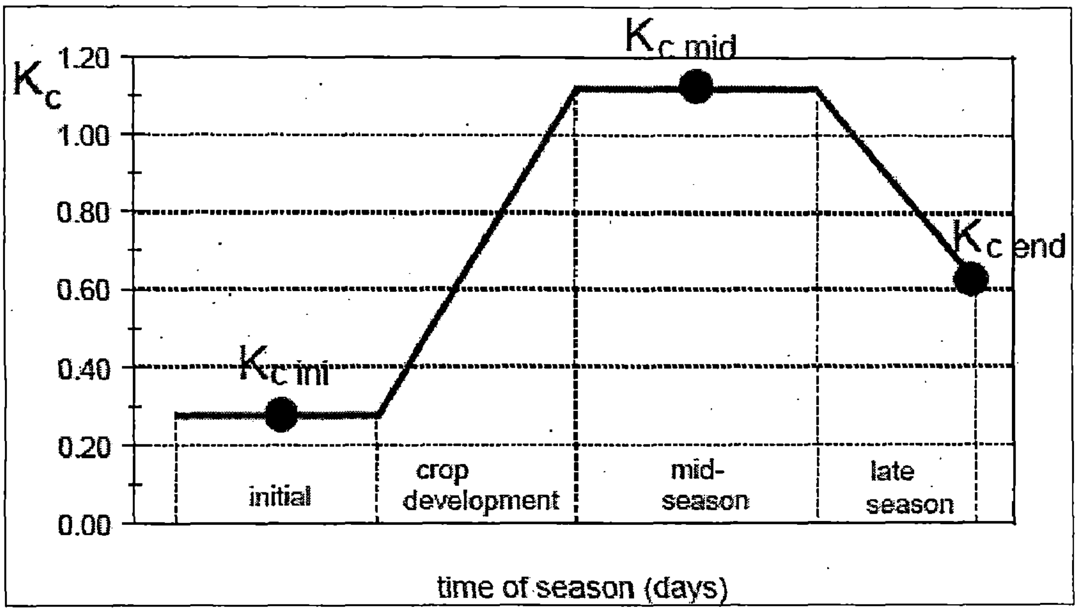

Fig. 4.2: Crop coefficient curve

Length of crop development stages for various planting periods and climatic regions are elaborated in Table–11 of FAO Irrigation and Drainage Paper 56. Lengths of crop development stages provided in this table are indicative of general conditions, but may vary substantially from region to region, with climate, cropping conditions, and with crop variety. Therefore, appropriate local information is essential before setting the length of crop development stages. In this study crop development period (planting – harvesting date) has been taken from project report and length of each growing stages has been set with the help of Table–11 of FAO-56. K_c values and plant height of different crops in different stages are recommended by FAO-56 in Table-12. This shows single (time-averaged) crop coefficients, K_c, and mean maximum plant heights for non stressed, well-managed crops in sub humid climates (with average day time minimum relative humidity (RH_{min}) 45 % and calm to moderate wind speeds averaging 2 m/s) for use with the FAO Penman-Monteith ET_o. In the real crop field exactly these conditions seldom exists. Where the crop field conditions differ from that, these K_c values are required to adjust. Procedure for specific adjustment to K_c values for all three stages are suggested in FAO-56. The K_c values selected from Table-12 can be adjusted as follows:

For climates where RH_{min} differs from 45% or where u_2 is larger or smaller than 2.0 m/s, specific adjustment to K_c values derived from Table 12, may be applied as follows:

(i) **$K_{c\ ini}$**: - Initial crop water requirement is mainly for evaporation, which depends upon the magnitude and frequency of wetting events (either by irrigation or by rainfall) and evaporation power of the atmosphere. The procedure for adjustment to $K_{c\ ini}$ for different types of wetting events and atmospheric conditions are described in FAO-56 with relevant tables and figures. In this study, due to the lack of such information, $K_{c\ ini}$ could not be adjusted.

(ii) **$K_{c\ mid}$**: - When RH_{min} differs from 45 % or u_2 differs from 2 m/s, the $K_{c\ mid}$ value is adjusted as follow:

$K_{c\ mid} = K_{c\ mid}\ (\text{Table}) + [0.04\ (u_2 - 2) - 0.004\ (RH_{min} - 45)]\ (h/3)^{0.3}$ ------ (4.5)

(iii) **$K_{c\ end}$** - When RH_{min} differs from 45 % or u_2 differs from 2 m/s, the $K_{c\ end}$ value is adjusted as follow:

$K_{c\ end} = K_{c\ end}\ (\text{Table}) + [0.04\ (u_2 - 2) - 0.004\ (RH_{min} - 45)]\ (h/3)^{0.3}$ ------- (4.6)

The adjustment to $K_{c\ end}$ is applicable only when $K_{c\ end}$ (Table) ≥ 0.45, no adjustment is required if $K_{c\ end} < 0.45$.

Table No. 4.4 shows adjusted K_c values of different crops along with the days of growth stages of the crops grown in the study area.

4.4 IRRIGATION WATER REQUIREMENT

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

4.4.1 NET IRRIGATION REQUIREMENT (NIR)

Net irrigation requirement is the soil holding capacity at root zone depth to store available moisture for plants growth.

So, NIR = ET_c + percolation losses – Effective rainfall ------------------------ (4.7)

Effective rainfall is that portion of rainfall which can be effectively used by a crop, i.e. rain which is stored in the crop root zone. Therefore, effective rainfall is less than total rainfall due to interception, runoff, percolation and other losses. In the present study, effective rainfall has been computed using USDA method by CROPWAT 4.3 software. In USDA method following formula is used for calculating effective rainfall.

$P_{eff} = (P_{mon} * (125 - 0.2 * P_{mon})) / 125$ for $P_{mon} \leq 250$ mm ------- (4.8)

$P_{eff} = 125 + 0.1 * P_{mon}$ for $P_{mon} > 250$ mm -------- (4.9)

Where, P_{eff} = Effective rainfall in mm,

P_{mon} = Total monthly rainfall in mm

Table 4.4: K_c values of different crops of Mahakali Irrigation Project Stage–I

Sl. No.	Name of the crop	Planting date	Harvesting date	Total days	Days of different crop development stages				Kc values for different stages (adjusted)			
					Initial	Development	Mid season	Late season	Kc ini	Kc dev	Kc mid	Kc end
	summer crops											
1	Paddy Rice (Local)	Aug 1	Nov15	120	20	25	40	20	1.05	1.05-1.07	1.07	0.78
2	Paddy Rice (Improved)	July 1	Oct30	105	20	25	50	25	1.05	1.05-1.06	1.06	0.77
3	Maize (Local)	June1	Aug30	90	20	25	25	20	0.30	0.30-1.04	1.04	0.43
4	Maize (Improved)	June1	Aug30	90	20	25	25	20	0.30	0.30-1.04	1.04	0.43
5	Vegetable (Summer)	June1	Aug30	90	20	30	25	15	0.50	0.50-0.90	0.90	0.70
6	Sugercane	Mar 1	Jan20	320	30	50	180	60	0.40	0.40-1.09	1.09	0.57
	Winter crops											
1	Wheat	Nov 15	Mar15	120	15	25	50	30	0.40	0.40-1.03	1.03	0.40
2	Oilseed	Oct 22	Feb22	120	20	35	45	20	0.35	0.35-1.03	1.03	0.35
3	Lentil	Nov 7	Mar7	120	20	25	50	25	0.40	0.40-1.00	1.00	0.30
4	Other Pulses (Grams, Peas, Beans,etc.)	Nov 7	Feb17	100	20	30	30	20	0.40	0.40-1.05	1.05	0.47
5	Potato	Nov 7	Mar7	120	25	30	35	30	0.50	0.50-1.04	1.04	0.67
6	Winter Vegetable	Oct 22	Feb22	120	25	35	40	20	0.70	0.70-0.95	0.95	0.88
	Spring crops											
1	Maize (Spring)	Mar 1	May30	90	20	25	25	20	0.30	0.30-1.17	1.17	0.56
2	Paddy Rice (Spring)	Mar 22	Jul7	105	20	25	40	20	1.05	1.05-1.15	1.15	0.81
3	Sunflower	Feb 22	May27	95	20	25	35	15	0.35	0.35-1.13	1.13	0.35
4	Vegetable (Spring)	Mar1	May30	90	20	30	25	15	0.50	0.50-0.98	0.98	0.78

References:
1. FAO - Irrigation and Drainage Paper No. 24
2. FAO - Irrigation and Drainage Paper No. 56

Table No. 4.5 shows the total rainfall and effective rainfall of Mahakali Irrigation Project Stage–I area.

Table 4.5: Total rainfall and effective rainfall of MIP Stage-I by CROPWAT 4.3

Month	ETo (mm/day)	Total Rainfall (mm/month)	Effective Rainfall (mm/month)
January	1.68	24.9	23.9
February	2.46	38.7	36.3
March	3.70	18.1	17.6
April	5.16	18.8	18.2
May	5.66	44.3	41.2
June	4.97	255.9	150.6
July	4.21	531.9	178.2
August	4.03	499.0	174.9
September	3.71	292.0	154.2
October	3.00	34.6	32.7
November	2.12	5.2	5.2
December	1.58	16.5	16.1
Total (mm/Year)	1287.34	1779.9	849.1

4.4.2 FIELD IRRIGATION REQUIREMENT (FIR)

It is the irrigation requirement, which includes the losses in the field watercourses and in the field. Field irrigation requirement is given as follows:

$$FIR = NIR / \eta_f \quad \text{---} \quad (4.10)$$

Where,

η_f = Field application efficiency

4.4.3 GROSS IRRIGATION REQUIREMENT (GIR)

It is the irrigation requirement, which includes the conveyance losses in canals and distributaries up to the field in addition to the field application losses, i.e. field irrigation requirement plus conveyance losses. Gross irrigation requirement is given as follows:

$$GIR = FIR / \eta_c = NIR / (\eta_f * \eta_c) = NIR / \eta_i \quad \text{---------------------------} \quad (4.11)$$

Where,

η_c = Conveyance efficiency,

η_i = Irrigation efficiency

In the present study field application efficiency has been taken as 0.60 for non-paddy crops and 0.85 for paddy crops (Ref. PDSP- M3 Manual). Conveyance efficiency has been taken as 0.70 in case of surface water utilization but in case of ground water utilization conveyance losses have been neglected (i.e. conveyance efficiency is considered as 1.00).

The sample calculation of net irrigation requirement for a paddy crop (rice) and a non-paddy crop (wheat) is given in Table No. 4.6 and Table No. 4.7 respectively. Table No. 4.8 shows the gross irrigation requirement of all the crops grown in the study area.

Table 4.6: Sample calculation of irrigation requirement for Paddy crop (Rice-improved)

Project: Mahakali Irrigation Project | Hydro-Meteorological Station: Mahendranagar

Crop: Paddy Rice (Improved) | Planting Date: July 1

Description	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Remarks
ETo (mm/day)	1.68	2.46	3.70	5.16	5.66	4.97	4.21	4.03	3.71	3.00	2.12	1.58		CROPWAT Calculations
Growth stages						Land Prep.	Initial Stg	Crop.Dev .Stg	Mid.Seas Stg	Late.S.Stg				
Growth stage length						June1-Jun30	Jul1-Jul20	Jul21-Aug15	Aug16-Oct5	Oct6-Oct30				
Kc per growth stages							1.05	>>	1.06	0.77				FAO-56 (Adjusted)
Kc per month							1.05	1.06	1.06	0.94				
ETcrop (mm/day)							4.42	4.25	3.93	2.82				Kc*ETo
ETcrop (mm/month)							137.17	131.81	118.0	84.53				
Water for land Preparation, soil saturation- SAT (mm)						200								FAO-IWM_Training Manual No. 3 (SAT = 200mm)
Deep Percolation losses - PERC (mm)							155	155	150	75				PDSP:M3-Table 4.4 (Perecolation @ 5mm/day)
Water Layer (WL) for transplanting/ sowing (mm)							100							FAO-IWM_Training Manual No. 3 (100mm)
Total Water Req., ETc+SAT+PERC+WL (mm)						200	392.17	286.81	268.0	159.53			1306.51	
Effective Rainfall, Pe (mm)	23.91	36.30	17.58	18.23	41.16	150.59	178.19	174.90	154.24	32.68	5.16	16.06		USDA method
NIR (mm)						49.41	213.98	111.91	113.76	126.85			615.91	
Field Irrigation Efficiency						0.85	0.85	0.85	0.85	0.85				PDSP:M3-page 38
FIR (mm)						58.13	251.74	131.66	133.83	149.24			724.60	
Conveyance Efficiency						0.70	0.70	0.70	0.70	0.70				FAO-IWM_Training Manual No. 4
GIR (mm)						83.04	359.63	188.09	191.19	213.19			1035.14	

Table 4.7: Sample calculation of irrigation requirement for Non-paddy crop (Wheat)

Project: Mahakali Irrigation Project		Hydro-Meteorological Station:	Mahendranagar
Crop: Wheat		Planting Date:	November 15

Description	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		Total	Remarks
ETo (mm/day)	1.68	2.46	3.70	5.16	5.66	4.97	4.21	4.03	3.71	3.00	2.12	1.58			CROPWAT Calculations
Growth stages	Mid.S.Stg	Late.S.Stg									Initial Stage	Crop.Dev.Stg	M.S.S		
Growth stage length	Dec26-Feb15	Feb16-Mar15									Nov15-Nov30	Dec1-Dec25	D26-F15		
Kc per growth stages	1.03	0.40									0.4	> >	1.03		FAO-56 (Adjusted)
Kc per month	1.03	0.95	0.56								0.40	0.77			
ETcrop (mm/day)	1.73	2.34	2.06								0.85	1.21			Kc*ETo
ETcrop (mm/month)	53.64	65.52	30.94								12.72	37.59			
Water for land Preparation (mm)											60				PDSP:M3-page 27
Total Water Req., ETc+LP (mm)	53.64	65.52	30.94								72.72	37.59		260.42	
Effective Rainfall, Pe (mm)	23.91	36.30	17.58	18.23	41.16	150.59	178.19	174.90	154.24	32.68	5.16	16.06			USDA method
NIR (mm)	29.73	29.22	13.37								67.56	21.53		161.41	
Field Irrigation Efficiency	0.60	0.60	0.60								0.60	0.60			PDSP:M3-page 38
FIR (mm)	49.56	48.70	22.28								112.61	35.88		269.02	
Conveyance Efficiency	0.70	0.70	0.70								0.70	0.70			FAO-IWM_Training Manual No. 4
GIR (mm)	70.80	69.57	31.82								160.86	51.26		384.31	

Table 4.8: Gross irrigation requirements in mm

Project:	Mahakali Irrigation Project Stage - I	Hydrometeorological Station:	Mahendranagar
Water Availability:	6.6 m3/s - 15th May to 15th Oct 1.76 m3/s - 16th Oct to 14th May	Command Area:	4800 ha

Sl No.	Name of Crops	Crop Duration	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	Summer Crops														
1	Paddy Rice (Local)	Aug1-Nov30							36.66	355.37	192.47	371.86	38.71		995.06
2	Main Paddy Rice (improved)	Jun15-Sep30						83.04	359.63	188.09	191.19	213.19			1035.14
3	Summer Maize (Local)	Jun1-Aug30						0.00	0.00	0.00					0.00
4	Summer Maize (improved)	Jun1-Aug30						0.00	0.00	0.00					0.00
5	Summer Vegetable	Jun1-Aug30						0.00	0.00	0.00					0.00
6	Sugercane	Mar1-Jan20	0.00		67.39	180.14	318.37	27.86	0.00	0.00	0.00	163.20	150.37	71.96	979.29
	Winter Crops														
1	Wheat	Nov15-Mar15	70.80	69.57	31.82								160.86	51.26	384.31
2	Oil crops	Oct22-Feb22	70.73	5.36								0.00	56.60	70.90	203.58
3	Lentil	Nov7-Mar7	67.02	52.88	0.00								28.47	55.86	204.22
4	Pulses	Nov7-Feb17	72.36	0.00									28.43	53.29	154.08
5	Potato	Nov7-Mar7	72.35	66.92	2.39								45.77	47.68	235.11
6	Winter Vegetables	Oct22-Feb22	61.13	31.78								0.00	96.77	65.82	255.50
	Spring Crops														
1	Maize (Spring)	Mar1-May30			56.01	354.08	307.21								717.30
2	Paddy Rice (Spring)	Mar22-Jul7		23.02	409.25	601.09	529.49	216.36	0.00						1779.21
3	Sunflower	Feb22-May27		0.00	94.58	362.32	233.32								690.21
4	Spring Vegetable	Mar1-May30			101.98	257.58	277.72								637.28

CHAPTER– V

PRODUCTION FUNCTION

5.1 GENERAL

In chapter–II the importance of the production function has been discussed. As we know, if we provide irrigation facilities to the crop its productivity increases, but this increasing trend of productivity has limitation up to the net irrigation requirement of the crop. That means the production reaches its peak at the stage when the crop is provided with the required NIR. On over irrigation it will give an adverse result. It clearly shows that production function in this case has both rising and falling limbs. On the other hand the function has got a diminishing return.

Some of the important Production Functions are

- (i) Cobb-Douglas production function
- (ii) Mitscherlich-Spillman production function
- (iii) Polynomial production functions

Each of these production functions is described briefly in the following sections.

5.2 COBB-DOUGLAS PRODUCTION FUNCTION

The Cobb-Douglas Production Function is a linear homogeneous production function. It shows either constant increasing or decreasing trend. The shortcomings of Cobb-Douglas Production Function are:

- (i) It has constant elasticity.
- (ii) Function starts from the origin, but in actual field practice some product comes out as a result of fixed factors.
- (iii) The function can not describe any two relationships simultaneously.
- (iv) It does not show the definite maximum product.
- (v) The function can not show the negative marginal product.

Therefore the Cobb-Douglas production function is generally less desirable for estimating plant-water-fertilizer relationships because in agriculture we expect a diminishing return with a definite peak.

5.3 MITSCHERLICH-SPILLMAN PRODUCTION FUNCTION

Mitscherlich and Spillman functions are exponential type of functions. Mitscherlich function for two variables is given as

$Y = A\ [1 - B_1.e^{-c1.W}]\ [1 - B_2.e^{-c2.N]}$ ---------------------- (5.1)

And Spillman developed an exponential function with some features similar to the Mitscherlich formulations. The general form for the two variable Spillman function is as follows:

$Y = A\ (1 - R_w^{\ W})\ (1 - R_n^{\ N})$ ----------------------------- (5.2)

Where, Y = Total output

W, N = Variable inputs (say, Water and Fertilizer)

B_1, B_2 = Residual inputs (i.e. soil moisture or preplant fertilizer)

c_1, c_2 = Constants representing the 'effect factor' of W and N

A = Maximum total output that can be attained

R_w, R_n = Constants - ratio of successive increments of product to total product

The response surface for one variable Mitscherlich or Spillman model is asymptotic to the maximum yield. In case of two variable functions, the isoquants are asymptotic to the W and N axes, indicating that W can never substitute completely for N and vice versa. The isoclines begin at the origin, are curved, and approach linearity. The principal limitations of these functions are that the isoclines do not converge because the response surface is asymptotic to a plane rather than reaching a definite maximum point and the marginal product curve never become negative, as might be in the case of fertilizer used in excess. For these reasons, these functions are not applicable for samples drawn from experiments or surveys where input magnitudes are great enough to cause a decline in total product.

5.4 POLYNOMIAL PRODUCTION FUNCTION

Polynomial functions of varying degrees are often used to estimate input-output relationship. These forms are especially appropriate when the input-out relationship is such that the marginal product becomes negative and yield declined. The basic polynomial form is derived from a concept known as Taylor's expansion series. The concept behind this is that the limit of a sequence can thus be written as the sum to infinity of a convergent series. Any member of the sequence and the sum of any number of terms of the series can then serve as an approximate value of the limit. Commonly used polynomials are as follows:

a) Quadratic function

b) Square root function

c) Three-halves or 1.5 polynomial function.

5.4.1 QUADRATIC FUNCTION

A quadratic function is a second degree polynomial function which is obtained by neglecting the higher terms from a Taylor's expansion series. Quadratic production for two variables can be represented by

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2 \quad \text{----------------------} \quad (5.3)$$

Where, Y = Output

X_1, X_2 = Inputs

b_o = Residual output when there is no input applied

b_1, b_2, b_3, b_4, b_5 = Constants (effect factors for different level of inputs)

The terms X_1^2 and X_2^2 would permit the response surface to curve downward and exhibit negative marginal product at high use-level for X_1 and X_2. With the quadratic function, the marginal product curve is linear.

5.4.2 SQUARE ROOT FUNCTION

A square root function is the transformation of quadratic production function, obtained by replacing the square power of X_1 and X_2 to half power in the quadratic function which can be written as

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^{0.5} + b_4X_2^{0.5} + b_5X_1X_2 \quad \text{--------------------} \quad (5.4)$$

This function has properties similar to those described for the quadratic function but the marginal product curve for either X_1 or X_2 declines at a decreasing rate while those for quadratic function are linear.

5.4.3 THREE-HALVES OR 1.5 POLYNOMIAL FUNCTION

A three-halves (1.5 polynomial) function is an additional transformation of X_1 and X_2 obtained by replacing the square power of X_1 and X_2 to 1.5 power in the quadratic function which can be written as

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_1^{1.5} + b_4X_2^{1.5} + b_5X_1X_2 \quad \text{----------------------} \quad (5.5)$$

Several properties of this model are similar to the square root function however the marginal product of either X_1 or X_2 declines at an increasing rate.

Quadratic function has been used in this study due to its several advantages over other methods.

5.5 SINGLE VARIABLE QUADRATIC EQUATION

The general form of single variable quadratic production function equation used in this study is as follow:

$$Y = a + bX - cX^2 \quad \text{--} \quad (5.6)$$

Where,

Y = Yield in tones per hectare (output)
X = Irrigation in meter (input)
a = Yield from rain fed condition in tones per hectare
b, c = Coefficients to determined for each crop

The negative sign of c indicates that the curve is sloping downwards, which means it shows diminishing rate of return.

5.5.1 PROPERTIES OF QUADRATIC PRODUCTION FUNCTION

The properties of quadratic production function are

(i) Marginal productivity is at a constant rate (i.e. slope is constant)
(ii) Maximum product is defined.
(iii) One resource can be completely substituted for another.
(iv) It shows a distinct peak.

Figure No. 5.1 shows a typical Crop Water Production Function curve.

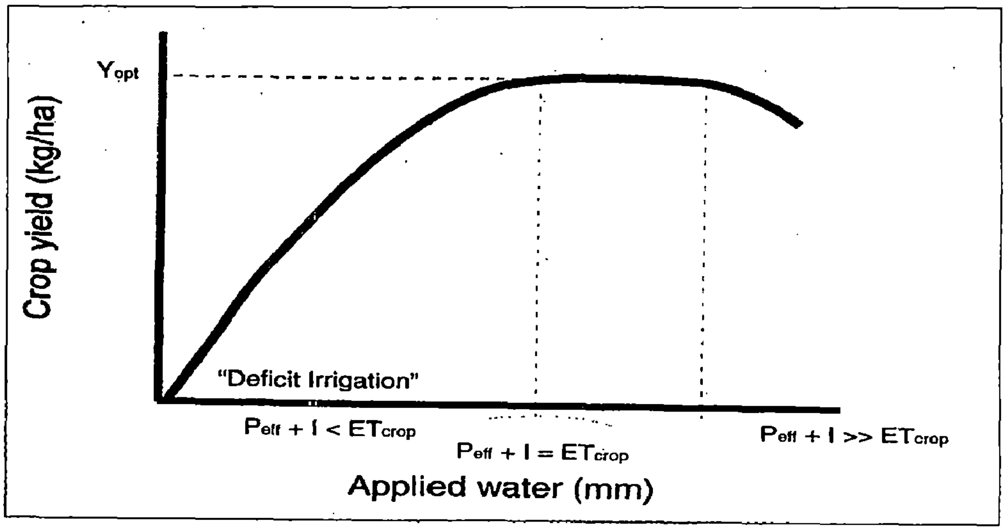

Fig. 5.1: Typical crop water production function curve

5.5.2 APPLICATION

The production function is applied in the variable irrigation model of this dissertation. For each crop different levels of irrigation is applied and the corresponding yield is calculated using production function.

The equation used in the calculations is equation no. (5.6) as described in section 5.5 and is given by

$$Y = a + bX - cX^2$$

Five different levels of irrigation have been given to each crop and its corresponding yields were calculated.

For maximum yield condition,

$$dY/dX = 0$$

$$\text{Or} \quad b - 2cX = 0$$

$$\text{Or} \quad b - 2cX_{max} = 0$$

$$\text{Or} \quad b = 2cX_{max} \quad \text{----------------------------} \quad (5.7)$$

Putting value of b in equation (5.6), we get

$$Ymax = a + 2cX^2_{max} - cX^2_{max} = a + cX^2_{max}$$

$$\text{Or} \quad Y_{max} - a = cX^2_{max}$$

$$\text{Or} \quad c = (Y_{max} - a)/ X^2_{max} \quad \text{----------} \quad (5.8)$$

for maximum yield condition.

From equation (5.7) and (5.8) the values of the constants b and c can be found out and separate production function can be formulated for each crop.

5.6 PRODUCTION FUNCTION FOR INDIVIDUAL CROPS

In the present study five different levels of irrigation have been given to each crop as given below in Table No. 5.1.

Table 5.1: Different Levels of Irrigation

Level of irrigation	% of depth of irrigation supplied
1	100
2	75
3	50
4	25
5	0

Production function of different crops is given in Table No. 5.2.

5.7 CALCULATIONS

The yield per ha at different levels of irrigation for all crops under the present study has been calculated using the production function as obtained above and presented in Table No. 5.3.

Table No. 5.4.1 to Table No. 5.4.5 show net benefits per ha for all crops at different levels of irrigation.

The energy and nutrient values per ha at different levels of irrigation for all crops have been calculated and provided in Table No. 5.5.1 to 5.5.5.

Table No. 5.6 shows the net irrigation requirement of all crops for different levels of irrigation.

Table 5.2: Production function for different crops

Sl. No.	Name of crop	a in tonnes	Ymax in tonnes	Xmax in mm	Xmax in m	c = (Ymax - a)/ Xmax^2	b = 2c.Xmax	Y = a + b.X - c.X^2
	Summer Crops							
1	Paddy rice (local)	2.110	2.896	1068.57	1.0686	0.688	1.471	Y = 2.11+1.471*X-0.688*x^2
2	Paddy rice (Improved)	2.730	4.481	891.76	0.8918	2.202	3.927	Y = 2.73+3.927*X-2.202*x^2
3	Maize (local)	1.620	2.110	49.12	0.0491	203.108	19.952	Y = 1.62+19.952*X-203.108*x^2
4	Maize (Improved)	1.720	3.764	49.12	0.0491	847.251	83.229	Y = 1.72+83.229*X-847.251*x^2
5	Vegetables	8.850	19.110	120.69	0.1207	704.340	170.018	Y = 8.85+170.18*X-704.34*x^2
6	Sugarcane	35.300	66.332	979.29	0.9793	32.359	63.377	Y = 35.3+63.377*X-32.359*x^2
	Winter crops							
7	Wheat	1.570	3.718	384.31	0.3843	14.544	11.178	Y = 1.57+11.178*X-14.544*x^2
8	Oilseed	0.570	1.054	203.58	0.2036	11.678	4.755	Y = 0.57+4.755*X-11.678*x^2
9	Lentil	0.590	1.181	204.22	0.2042	14.170	5.788	Y = 0.59+5.788*X-14.170*x^2
10	Other pulses	0.800	1.100	154.08	0.1541	12.637	3.894	Y = 0.8+3.894*X-12.637*x^2
11	potato	9.110	19.110	235.11	0.2351	180.912	85.067	Y = 9.11+85.067*X-180.912*x^2
12	Vegetables	9.500	19.110	255.50	0.2555	147.210	75.225	Y = 9.5+75.255*X-147.210*x^2
	Spring Crops							
13	Maize (Spring)	1.720	3.764	413.43	0.4134	11.958	9.888	Y = 1.72+9.888*X-11.958*x^2
14	Paddy Rice (Spring)	2.730	4.459	1779.21	1.7792	0.546	1.944	Y = 2.73+1.944*X-0.546*x^2
15	Sunflower	0.660	1.621	303.85	0.3038	10.409	6.326	Y = 0.66+6.326*X-10.409*x^2
16	Vegetables (Spring)	8.850	19.110	223.94	0.2239	204.583	91.630	Y = 8.85+91.630*X-204.583*x^2

Table 5.3: Crop yields at different levels of irrigation

Name of Crop	Production Function	Irrigation Levels (X) in m					Yield (Y) at different irrigation levels in t/ha				
		100% (1)	75% (2)	50% (3)	25% (4)	0% (5)	1	2	3	4	5
Summer Crops											
Paddy rice (local)	Y = 2.11+1.471*X-0.688*x^2	1.069	0.801	0.534	0.267	0.000	2.896	2.847	2.700	2.454	2.110
Paddy rice (Improved)	Y = 2.73+3.927*X-2.202*x^2	0.892	0.669	0.446	0.223	0.000	4.481	4.371	4.043	3.496	2.730
Maize (local)	Y = 1.62+19.952*X-203.108*x^2	0.049	0.037	0.025	0.012	0.000	2.110	2.079	1.987	1.834	1.620
Maize (Improved)	Y = 1.72+83.229*X-847.251*x^2	0.049	0.037	0.025	0.012	0.000	3.764	3.636	3.253	2.614	1.720
Vegetables	Y = 8.85+170.18*X-704.34*x^2	0.121	0.091	0.060	0.030	0.000	19.117	18.474	16.549	13.341	8.850
Sugarcane	Y = 35.3+63.377*X-32.359*x^2	0.979	0.734	0.490	0.245	0.000	66.332	64.392	58.574	48.877	35.300
Winter crops											
Wheat	Y = 1.57+11.178*X-14.544*x^2	0.384	0.288	0.192	0.096	0.000	3.718	3.584	3.181	2.510	1.570
Oilseed	Y = 0.57+4.755*X-11.678*x^2	0.204	0.153	0.102	0.051	0.000	1.054	1.024	0.933	0.782	0.570
Lentil	Y = 0.59+5.788*X-14.170*x^2	0.204	0.153	0.102	0.051	0.000	1.181	1.144	1.033	0.849	0.590
Other pulses	Y = 0.8+3.894*X-12.637*x^2	0.154	0.116	0.077	0.039	0.000	1.100	1.081	1.025	0.931	0.800
potato	Y = 9.11+85.067*X-180.912*x^2	0.235	0.176	0.118	0.059	0.000	19.110	18.485	16.610	13.485	9.110
Vegetables	Y = 9.5+75.255*X-147.210*x^2	0.256	0.192	0.128	0.064	0.000	19.118	18.515	16.711	13.706	9.500
Spring Crops											
Maize (Spring)	Y = 1.72+9.888*X-11.958*x^2	0.413	0.310	0.207	0.103	0.000	3.764	3.636	3.253	2.614	1.720
Paddy Rice (Spring)	Y = 2.73+1.944*X-0.546*x^2	1.779	1.334	0.890	0.445	0.000	4.460	4.352	4.027	3.487	2.730
Sunflower	Y = 0.66+6.326*X-10.409*x^2	0.304	0.228	0.152	0.076	0.000	1.621	1.561	1.381	1.080	0.660
Vegetables (Spring)	Y = 8.85+91.630*X-204.583*x^2	0.224	0.168	0.112	0.056	0.000	19.110	18.469	16.545	13.339	8.850

Table 5.4.1: Net benefits at 100 % (full) irrigation (level: 1)

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By Product	Total		
	Summer Crops													
1	Paddy Rice (Local)	798	3145	404	11700	7200	45	23292	2.896	36493	2835	39328	16036	10023
2	Paddy Rice (Improved)	798	3908	505	11700	7200	45	24156	4.481	56458	2043	58501	34345	21466
3	Maize (Local)	384	2959	404	9700	4600	45	18091	2.110	21311	318	21629	3537	2211
4	Maize (Improved)	384	2959	404	9700	4600	45	18091	3.764	38016	318	38334	20243	12652
5	Vegetable (Summer)	379	5241	1010	13500	6400	45	26575	19.117	214307	0	214307	187732	117332
6	Sugercane	9545	5539	505	17600	7800	45	41034	66.332	109448	773	110220	69186	43242
	Winter Crops													
7	Wheat	1709	4510	202	9100	7600	45	23166	3.718	34947	803	35749	12584	7865
8	Oilseed	444	2969	202	5700	4000	45	13359	1.054	46272	12038	58309	44950	28094
9	Lentil	1972	2190	404	5500	4200	45	14311	1.181	46061	193	46254	31943	19964
10	Other Pulses	1972	2190	404	5500	4200	45	14311	1.100	42899	193	43092	28781	17988
11	Potato	20150	5636	505	14200	6800	45	47336	19.110	169122	0	169122	121787	76117
12	Winter Vegetable	379	5241	1010	13500	6400	45	26575	19.118	290781	0	290781	264206	165129
	Spring Crops													
13	Maize (Spring)	384	2959	404	9700	4600	45	18091	3.764	38016	318	38334	20243	12652
14	Paddy Rice (Spring)	798	3908	404	11700	7200	45	24055	4.460	56201	1112	57313	33257	20786
15	Sunflower	606	2518	303	5700	4000	45	13172	1.621	64846	583	65429	52257	32661
16	Vegetable (Spring)	379	5241	1010	13500	6400	45	26575	19.110	183265	0	183265	156689	97931

Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.

Table 5.4.2: Net benefits at 75 % irrigation (level: 2)

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	798	3145	404	11700	7200	45	23292	2.847	35872	2787	38659	15367	9604
2	Paddy Rice (Improved)	798	3908	505	11700	7200	45	24156	4.371	55080	1993	57074	32917	20573
3	Maize (Local)	384	2959	404	9700	4600	45	18091	2.079	21002	313	21315	3224	2015
4	Maize (Improved)	384	2959	404	9700	4600	45	18091	3.636	36726	307	37033	18942	11839
5	Vegetable (Summer)	379	5241	1010	13500	6400	45	26575	18.474	207098	0	207098	180522	112827
6	Sugercane	9545	5539	505	17600	7800	45	41034	64.392	106248	750	106998	65964	41227
	Winter Crops													
7	Wheat	1709	4510	202	9100	7600	45	23166	3.584	33686	774	34459	11294	7058
8	Oilseed	444	2969	202	5700	4000	45	13359	1.024	44944	11692	56636	43276	27048
9	Lentil	1972	2190	404	5500	4200	45	14311	1.144	44620	187	44807	30496	19060
10	Other Pulses	1972	2190	404	5500	4200	45	14311	1.081	42168	189	42357	28047	17529
11	Potato	20150	5636	505	14200	6800	45	47336	18.485	163591	0	163591	116256	72660
12	Winter Vegetable	379	5241	1010	13500	6400	45	26575	18.515	281616	0	281616	255041	159401
	Spring Crops													
13	Maize (Spring)	384	2959	404	9700	4600	45	18091	3.636	36726	307	37033	18942	11839
14	Paddy Rice (Spring)	798	3908	404	11700	7200	45	24055	4.352	54833	1085	55918	31863	19914
15	Sunflower	606	2518	303	5700	4000	45	13172	1.561	62442	562	63004	49832	31145
16	Vegetable (Spring)	379	5241	1010	13500	6400	45	26575	18.469	177115	0	177115	150540	94087

Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.

Table 5.4.3: Net benefits at 50 % irrigation (level: 3)

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	798	3145	404	11700	7200	45	23292	2.700	34014	2642	36657	13365	8353
2	Paddy Rice (Improved)	798	3908	505	11700	7200	45	24156	4.043	50944	1843	52788	28632	17895
3	Maize (Local)	384	2959	404	9700	4600	45	18091	1.987	20074	300	20373	2282	1426
4	Maize (Improved)	384	2959	404	9700	4600	45	18091	3.253	32855	275	33130	15039	9399
5	Vegetable (Summer)	379	5241	1010	13500	6400	45	26575	16.549	185511	0	185511	158936	99335
6	Sugercane	9545	5539	505	17600	7800	45	41034	58.574	96647	682	97329	56296	35185
	Winter Crops													
7	Wheat	1709	4510	202	9100	7600	45	23166	3.181	29900	687	30587	7421	4638
8	Oilseed	444	2969	202	5700	4000	45	13359	0.933	40959	10655	51615	38256	23910
9	Lentil	1972	2190	404	5500	4200	45	14311	1.033	40298	169	40466	26156	16347
10	Other Pulses	1972	2190	404	5500	4200	45	14311	1.025	39975	179	40154	25844	16152
11	Potato	20150	5636	505	14200	6800	45	47336	16.610	146998	0	146998	99662	62289
12	Winter Vegetable	379	5241	1010	13500	6400	45	26575	16.711	254180	0	254180	227605	142253
	Spring Crops													
13	Maize (Spring)	384	2959	404	9700	4600	45	18091	3.253	32855	275	33130	15039	9399
14	Paddy Rice (Spring)	798	3908	404	11700	7200	45	24055	4.027	50744	1004	51748	27693	17308
15	Sunflower	606	2518	303	5700	4000	45	13172	1.381	55233	497	55730	42558	26599
16	Vegetable (Spring)	379	5241	1010	13500	6400	45	26575	16.545	158666	0	158666	132091	82557

Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.

Table 5.4.4: Net benefits at 25 % irrigation (level: 4)

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	798	3145	404	11700	7200	45	23292	2.454	30919	2402	33321	10029	6268
2	Paddy Rice (Improved)	798	3908	505	11700	7200	45	24156	3.496	44050	1594	45644	21488	13430
3	Maize (Local)	384	2959	404	9700	4600	45	18091	1.834	18527	276	18804	712	445
4	Maize (Improved)	384	2959	404	9700	4600	45	18091	2.614	26404	221	26625	8533	5333
5	Vegetable (Summer)	379	5241	1010	13500	6400	45	26575	13.341	149548	0	149548	122973	76858
6	Sugercane	9545	5539	505	17600	7800	45	41034	48.877	80646	569	81216	40182	25114
	Winter Crops													
7	Wheat	1709	4510	202	9100	7600	45	23166	2.510	23591	542	24133	967	605
8	Oilseed	444	2969	202	5700	4000	45	13359	0.782	34319	8928	43247	29888	18680
9	Lentil	1972	2190	404	5500	4200	45	14311	0.849	33094	138	33233	18922	11826
10	Other Pulses	1972	2190	404	5500	4200	45	14311	0.931	36319	163	36482	22171	13857
11	Potato	20150	5636	505	14200	6800	45	47336	13.485	119342	0	119342	72006	45004
12	Winter Vegetable	379	5241	1010	13500	6400	45	26575	13.706	208473	0	208473	181898	113686
	Spring Crops													
13	Maize (Spring)	384	2959	404	9700	4600	45	18091	2.614	26404	221	26625	8533	5333
14	Paddy Rice (Spring)	798	3908	404	11700	7200	45	24055	3.487	43932	869	44801	20746	12966
15	Sunflower	606	2518	303	5700	4000	45	13172	1.080	43219	389	43608	30436	19022
16	Vegetable (Spring)	379	5241	1010	13500	6400	45	26575	13.339	127919	0	127919	101343	63340

Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.

Table 5.4.5: Net benefits at rain fed condition (level: 5)

Sl. No.	Name of crops	Production cost of inputs excluding water in NRs/ha							Crop Yield in t/ha	Gross Return in NRs/ha			Net Return in NRs/ha	Net Return in IRs/ha
		Seed	Fertilizer	Pesticides	Human Labour	Animal Labour	Land Tax	Total		Main Product	By product	Total		
	Summer Crops													
1	Paddy Rice (Local)	1011	915	400	9900	7000	45	19271	2.110	26586	1519	28105	8834	5521
2	Paddy Rice (Improved)	980	1283	500	9900	7000	45	19708	2.730	34398	1638	36036	16328	10205
3	Maize (Local)	532	543	400	9000	4200	45	14720	1.620	16362	0	16362	1642	1026
4	Maize (Improved)	532	543	400	9000	4200	45	14720	1.720	17372	0	17372	2652	1657
5	Vegetable (Summer)	313	1915	1000	13700	5800	45	22773	8.850	99209	0	99209	76436	47772
6	Sugercane	7720	1904	500	16500	6800	45	33469	35.300	58245	0	58245	24776	15485
	Winter Crops													
1	Wheat	1932	1240	200	7500	7000	45	17917	1.570	14758	377	15135	-2782	-1739
2	Oilseed	824	858	200	4300	3400	45	9627	5.700	25023	0	25023	15397	9623
3	Lentil	2098	384	400	3700	2400	45	9028	5.900	23010	0	23010	13982	8739
4	Other Pulses	2098	384	400	3700	2400	45	9028	0.800	31200	0	31200	22172	13858
5	Potato	21905	1998	500	12300	5000	45	41748	9.110	80624	0	80624	38876	24297
6	Winter Vegetable	313	1915	1000	13700	5800	45	22773	9.500	144495	0	144495	121722	76076
	Spring Crops													
1	Maize (Spring)	532	543	400	9000	4200	45	14720	1.720	17372	0	17372	2652	1657
2	Paddy Rice (Spring)	980	1283	500	4714	2009	45	9531	2.730	34398	1112	35510	25979	16237
3	Sunflower	800	726	300	4300	3400	45	9571	0.660	26400	0	26400	16829	10518
4	Vegetable (Spring)	313	1915	1000	13700	5800	45	22773	8.850	84872	0	84872	62099	38812

Source:-

1. Feasibility Study Report of Mahakali Irrigation Project Stage - III.
2. Annual Report (Fiscal Year 2006/07) of District Agriculture Development Office, Kanchanpur.

Table 5.5.1: Energy and nutrients content of different crops per hectare at 100 % (full) irrigation (level: 1)

Sl. No.	Name of crop	Crop Yield per ha in kg	Energy and Nutrients content per kg							Energy and Nutrients content per ha						
			Energy Kcal	Protien gm	Calcium mg	Iron mg	Vitamin A mcg_RAE	Vitamin C mg	Vitamin E mg	Energy Million Kcal	Protien tonnes	Cal. kg	Iron kg	Vit. A g_RAE	Vit. C kg	Vit. E kg
	Summer crops															
1	Paddy rice (Local)	2896	3160	133.5	570.0	185.4	0.0	0.0	49.20	9.152	0.387	1.651	0.537	0.000	0.000	0.142
2	Paddy rice (Improved)	4481	3160	133.5	570.0	185.4	0.0	0.0	49.20	14.159	0.598	2.554	0.831	0.000	0.000	0.220
3	Maize (local)	2110	3650	94.2	70.0	27.1	0.0	0.0	0.00	7.701	0.199	0.148	0.057	0.000	0.000	0.000
4	Maize (Improved)	3764	3650	94.2	70.0	27.1	110.0	0.0	4.90	13.739	0.355	0.263	0.102	0.414	0.000	0.018
5	Vegetables	19117	250	19.8	430.0	4.4	2188.0	283.0	5.30	4.779	0.379	8.221	0.084	41.829	5.410	0.101
6	Sugarcane	66332	3870	0.0	10.0	0.1	0.0	0.0	0.00	256.704	0.000	0.663	0.007	0.000	0.000	0.000
	Winter crops															
7	Wheat	3718	3310	103.5	270.0	32.1	0.0	0.0	10.10	12.306	0.385	1.004	0.119	0.000	0.000	0.038
8	Oilseed	1054	5730	177.3	9750.0	145.5	0.0	0.0	2.50	6.040	0.187	10.277	0.153	0.000	0.000	0.003
9	Lentil	1181	3530	258.0	560.0	75.4	20.0	44.0	4.90	4.169	0.305	0.661	0.089	0.024	0.052	0.006
10	Other pulses	1100	3430	217.0	1300.0	52.3	10.0	0.0	0.00	3.773	0.239	1.430	0.058	0.011	0.000	0.000
11	potato	19110	790	20.7	70.0	7.8	0.0	197.0	0.10	15.097	0.396	1.338	0.149	0.000	3.765	0.002
12	Vegetables	19118	250	19.8	430.0	4.4	2188.0	283.0	5.30	4.779	0.379	8.221	0.084	41.830	5.410	0.101
	Spring Crops															
13	Maize (Spring)	3764	3650	94.2	70.0	27.1	110.0	0.0	4.90	13.739	0.355	0.263	0.102	0.414	0.000	0.018
14	Paddy Rice (Spring)	4460	3160	133.5	570.0	185.4	0.0	0.0	49.20	14.095	0.595	2.542	0.827	0.000	0.000	0.219
15	Sunflower	1621	5700	227.8	1160.0	67.7	30.0	14.0	345.00	9.241	0.369	1.881	0.110	0.049	0.023	0.559
16	Vegetables (Spring)	19110	250	19.8	430.0	4.4	2188.0	283.0	5.30	4.777	0.378	8.217	0.084	41.813	5.408	0.101

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table 5.5.2: Energy and nutrients content of different crops per hectare at 75 % irrigation (level: 2)

Sl. No.	Name of crop	Crop Yield per ha in kg	Energy and Nutrients content per kg							Energy and Nutrients content per ha						
			Energy Kcal	Protien gm	Calcium mg	Iron mg	Vitamin A mcg_RAE	Vitamin C mg	Vitamin E mg	Energy Million Kcal	Protien tonnes	Cal. kg	Iron kg	Vit. A g_RAE	Vit. C kg	Vit. E kg
	Summer crops															
1	Paddy rice (Local)	2847	3160	133.5	570.0	185.4	0.0	0.0	49.2	8.997	0.380	1.623	0.528	0.000	0.000	0.140
2	Paddy rice (Improved)	4371	3160	133.5	570.0	185.4	0.0	0.0	49.2	13.814	0.584	2.492	0.810	0.000	0.000	0.215
3	Maize (local)	2079	3650	94.2	70.0	27.1	0.0	0.0	0.0	7.590	0.196	0.146	0.056	0.000	0.000	0.000
4	Maize (Improved)	3636	3650	94.2	70.0	27.1	110.0	0.0	4.9	13.272	0.343	0.255	0.099	0.400	0.000	0.018
5	Vegetables	18474	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.619	0.366	7.944	0.081	40.422	5.228	0.098
6	Sugarcane	64392	3870	0.0	10.0	0.1	0.0	0.0	0.0	249.199	0.000	0.644	0.006	0.000	0.000	0.000
	Winter crops															
7	Wheat	3584	3310	103.5	270.0	32.1	0.0	0.0	10.1	11.862	0.371	0.968	0.115	0.000	0.000	0.036
8	Oilseed	1024	5730	177.3	9750.0	145.5	0.0	0.0	2.5	5.866	0.182	9.982	0.149	0.000	0.000	0.003
9	Lentil	1144	3530	258.0	560.0	75.4	20.0	44.0	4.9	4.039	0.295	0.641	0.086	0.023	0.050	0.006
10	Other pulses	1081	3430	217.0	1300.0	52.3	10.0	0.0	0.0	3.709	0.235	1.406	0.057	0.011	0.000	0.000
11	potato	18485	790	20.7	70.0	7.8	0.0	197.0	0.1	14.603	0.383	1.294	0.144	0.000	3.642	0.002
12	Vegetables	18515	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.629	0.367	7.962	0.081	40.511	5.240	0.098
	Spring Crops															
13	Maize (Spring)	3636	3650	94.2	70.0	27.1	110.0	0.0	4.9	13.273	0.343	0.255	0.099	0.400	0.000	0.018
14	Paddy Rice (Spring)	4352	3160	133.5	570.0	185.4	0.0	0.0	49.2	13.752	0.581	2.481	0.807	0.000	0.000	0.214
15	Sunflower	1561	5700	227.8	1160.0	67.7	30.0	14.0	345.0	8.898	0.356	1.811	0.106	0.047	0.022	0.539
16	Vegetables (Spring)	18469	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.617	0.366	7.942	0.081	40.410	5.227	0.098

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table 5.5.3: Energy and nutrients content of different crops per hectare at 50 % irrigation (level: 3)

Sl. No.	Name of crop	Crop Yield per ha in kg	Energy and Nutrients content per kg							Energy and Nutrients content per ha						
			Energy	Protien	Calcium	Iron	Vitamin A	Vitamin C	Vitamin E	Energy	Protien	Cal.	Iron	Vit. A	Vit. C	Vit. E
			Kcal	gm	mg	mg	mcg_RAE	mg	mg	Million Kcal	tonnes	kg	kg	g_RAE	kg	kg
	Summer crops															
1	Paddy rice (Local)	2700	3160	133.5	570.0	185.4	0.0	0.0	49.2	8.531	0.360	1.539	0.500	0.000	0.000	0.133
2	Paddy rice (Improved)	4043	3160	133.5	570.0	185.4	0.0	0.0	49.2	12.777	0.540	2.305	0.750	0.000	0.000	0.199
3	Maize (local)	1987	3650	94.2	70.0	27.1	0.0	0.0	0.0	7.254	0.187	0.139	0.054	0.000	0.000	0.000
4	Maize (Improved)	3253	3650	94.2	70.0	27.1	110.0	0.0	4.9	11.873	0.306	0.228	0.088	0.358	0.000	0.016
5	Vegetables	16549	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.137	0.328	7.116	0.073	36.209	4.683	0.088
6	Sugarcane	58574	3870	0.0	10.0	0.1	0.0	0.0	0.0	226.682	0.000	0.586	0.006	0.000	0.000	0.000
	Winter crops															
7	Wheat	3181	3310	103.5	270.0	32.1	0.0	0.0	10.1	10.529	0.329	0.859	0.102	0.000	0.000	0.032
8	Oilseed	933	5730	177.3	9750.0	145.5	0.0	0.0	2.5	5.346	0.165	9.097	0.136	0.000	0.000	0.002
9	Lentil	1033	3530	258.0	560.0	75.4	20.0	44.0	4.9	3.647	0.267	0.579	0.078	0.021	0.045	0.005
10	Other pulses	1025	3430	217.0	1300.0	52.3	10.0	0.0	0.0	3.516	0.222	1.332	0.054	0.010	0.000	0.000
11	potato	16610	790	20.7	70.0	7.8	0.0	197.0	0.1	13.122	0.344	1.163	0.130	0.000	3.272	0.002
12	Vegetables	16711	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.178	0.331	7.186	0.074	36.564	4.729	0.089
	Spring Crops															
13	Maize (Spring)	3253	3650	94.2	70.0	27.1	110.0	0.0	4.9	11.874	0.306	0.228	0.088	0.358	0.000	0.016
14	Paddy Rice (Spring)	4027	3160	133.5	570.0	185.4	0.0	0.0	49.2	12.726	0.538	2.296	0.747	0.000	0.000	0.198
15	Sunflower	1381	5700	227.8	1160.0	67.7	30.0	14.0	345.0	7.871	0.315	1.602	0.093	0.041	0.019	0.476
16	Vegetables (Spring)	16545	250	19.8	430.0	4.4	2188.0	283.0	5.3	4.136	0.328	7.114	0.073	36.200	4.682	0.088

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table 5.5.4: Energy and nutrients content of different crops per hectare at 25 % irrigation (level: 4)

Sl. No.	Name of crop	Crop Yield per ha in kg	Energy and Nutrients content per kg							Energy and Nutrients content per ha						
			Energy	Protien	Calcium	Iron	Vitamin A	Vitamin C	Vitamin E	Energy	Protien	Cal.	Iron	Vit. A	Vit. C	Vit. E
			Kcal	gm	mg	mg	mcg_RAE	mg	mg	Million Kcal	tonnes	kg	kg	g_RAE	kg	kg
	Summer crops															
1	Paddy rice (Local)	2454	3160	133.5	570.0	185.4	0.0	0.0	49.2	7.754	0.328	1.399	0.455	0.000	0.000	0.121
2	Paddy rice (Improved)	3496	3160	133.5	570.0	185.4	0.0	0.0	49.2	11.047	0.467	1.993	0.648	0.000	0.000	0.172
3	Maize (local)	1834	3650	94.2	70.0	27.1	0.0	0.0	0.0	6.695	0.173	0.128	0.050	0.000	0.000	0.000
4	Maize (Improved)	2614	3650	94.2	70.0	27.1	110.0	0.0	4.9	9.542	0.246	0.183	0.071	0.288	0.000	0.013
5	Vegetables	13341	250	19.8	430.0	4.4	2188.0	283.0	5.3	3.335	0.264	5.736	0.059	29.189	3.775	0.071
6	Sugarcane	48877	3870	0.0	10.0	0.1	0.0	0.0	0.0	189.152	0.000	0.489	0.005	0.000	0.000	0.000
	Winter crops															
7	Wheat	2510	3310	103.5	270.0	32.1	0.0	0.0	10.1	8.307	0.260	0.678	0.081	0.000	0.000	0.025
8	Oilseed	782	5730	177.3	9750.0	145.5	0.0	0.0	2.5	4.479	0.139	7.622	0.114	0.000	0.000	0.002
9	Lentil	849	3530	258.0	560.0	75.4	20.0	44.0	4.9	2.995	0.219	0.475	0.064	0.017	0.037	0.004
10	Other pulses	931	3430	217.0	1300.0	52.3	10.0	0.0	0.0	3.194	0.202	1.211	0.049	0.009	0.000	0.000
11	potato	13485	790	20.7	70.0	7.8	0.0	197.0	0.1	10.653	0.279	0.944	0.105	0.000	2.657	0.001
12	Vegetables	13706	250	19.8	430.0	4.4	2188.0	283.0	5.3	3.427	0.271	5.894	0.060	29.989	3.879	0.073
	Spring Crops															
13	Maize (Spring)	2614	3650	94.2	70.0	27.1	110.0	0.0	4.9	9.542	0.246	0.183	0.071	0.288	0.000	0.013
14	Paddy Rice (Spring)	3487	3160	133.5	570.0	185.4	0.0	0.0	49.2	11.018	0.465	1.987	0.646	0.000	0.000	0.172
15	Sunflower	1080	5700	227.8	1160.0	67.7	30.0	14.0	345.0	6.159	0.246	1.253	0.073	0.032	0.015	0.373
16	Vegetables (Spring)	13339	250	19.8	430.0	4.4	2188.0	283.0	5.3	3.335	0.264	5.736	0.059	29.185	3.775	0.071

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)

2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table 5.5.5: Energy and nutrients content of different crops per hectare at rain fed condition (level: 5)

Sl. No.	Name of crop	Crop Yield per ha in kg	Energy and Nutrients content per kg							Energy and Nutrients content per ha						
			Energy	Protien	Calcium	Iron	Vitamin A	Vitamin C	Vitamin E	Energy	Protien	Cal.	Iron	Vit. A	Vit. C	Vit. E
			Kcal	gm	mg	mg	mcg_RAE	mg	mg	Million Kcal	tonnes	kg	kg	g_RAE	kg	kg
	Summer crops															
1	Paddy rice (Local)	2110	3160	133.5	570.0	185.4	0.0	0.0	49.2	6.668	0.282	1.203	0.391	0.000	0.000	0.104
2	Paddy rice (Improved)	2730	3160	133.5	570.0	185.4	0.0	0.0	49.2	8.627	0.364	1.556	0.506	0.000	0.000	0.134
3	Maize (local)	1620	3650	94.2	70.0	27.1	0.0	0.0	0.0	5.913	0.153	0.113	0.044	0.000	0.000	0.000
4	Maize (Improved)	1720	3650	94.2	70.0	27.1	110.0	0.0	4.9	6.278	0.162	0.120	0.047	0.189	0.000	0.008
5	Vegetables	8850	250	19.8	430.0	4.4	2188.0	283.0	5.3	2.213	0.175	3.806	0.039	19.364	2.505	0.047
6	Sugarcane	35300	3870	0.0	10.0	0.1	0.0	0.0	0.0	136.611	0.000	0.353	0.004	0.000	0.000	0.000
	Winter crops															
7	Wheat	1570	3310	103.5	270.0	32.1	0.0	0.0	10.1	5.197	0.162	0.424	0.050	0.000	0.000	0.016
8	Oilseed	570	5730	177.3	9750.0	145.5	0.0	0.0	2.5	3.266	0.101	5.558	0.083	0.000	0.000	0.001
9	Lentil	590	3530	258.0	560.0	75.4	20.0	44.0	4.9	2.083	0.152	0.330	0.044	0.012	0.026	0.003
10	Other pulses	800	3430	217.0	1300.0	52.3	10.0	0.0	0.0	2.744	0.174	1.040	0.042	0.008	0.000	0.000
11	potato	9110	790	20.7	70.0	7.8	0.0	197.0	0.1	7.197	0.189	0.638	0.071	0.000	1.795	0.001
12	Vegetables	9500	250	19.8	430.0	4.4	2188.0	283.0	5.3	2.375	0.188	4.085	0.042	20.786	2.689	0.050
	Spring Crops															
13	Maize (Spring)	1720	3650	94.2	70.0	27.1	110.0	0.0	4.9	6.278	0.162	0.120	0.047	0.189	0.000	0.008
14	Paddy Rice (Spring)	2730	3160	133.5	570.0	185.4	0.0	0.0	49.2	8.627	0.364	1.556	0.506	0.000	0.000	0.134
15	Sunflower	660	5700	227.8	1160.0	67.7	30.0	14.0	345.0	3.762	0.150	0.766	0.045	0.020	0.009	0.228
16	Vegetables (Spring)	8850	250	19.8	430.0	4.4	2188.0	283.0	5.3	2.213	0.175	3.806	0.039	19.364	2.505	0.047

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table 5.6: Gross irrigation requirement (in mm) for different levels of irrigation

Sl No.	Name of Crops	Level of Irrigation	% of Irrigation Depth	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	Summer Crops															
1	Paddy Rice (Local)	1	100							36.66	355.37	192.47	371.86	38.71		995.06
		2	75							27.49	266.52	144.35	278.89	29.03		746.29
		3	50							18.33	177.68	96.23	185.93	19.35		497.53
		4	25							9.16	88.84	48.12	92.96	9.68		248.76
2	Main Paddy Rice (improved)	1	100						83.04	359.63	188.09	191.19	213.19			1035.14
		2	75						62.28	269.72	141.07	143.39	159.90			776.36
		3	50						41.52	179.81	94.04	95.60	106.60			517.57
		4	25						20.76	89.91	47.02	47.80	53.30			258.79
3	Summer Maize (Local)	1	100						0	0	0					0
		2	75						0	0	0					0
		3	50						0	0	0					0
		4	25						0	0	0					0
4	Summer Maize (improved)	1	100						0	0	0					0
		2	75						0	0	0					0
		3	50						0	0	0					0
		4	25						0	0	0					0
5	Summer Vegetable	1	100						0	0	0					0
		2	75						0	0	0					0
		3	50						0	0	0					0
		4	25						0	0	0					0
6	Sugercane	1	100	0		67.39	180.14	318.37	27.86	0.00	0.00	0.00	163.20	150.37	71.96	979.29
		2	75	0		50.5432	135.1	238.778	20.8935	0	0	0	122.4	112.78	53.968	734.47
		3	50	0		33.6954	90.069	159.186	13.929	0	0	0	81.599	75.187	35.978	489.64
		4	25	0		16.8477	45.034	79.5928	6.96451	0	0	0	40.799	37.594	17.989	244.82

Sl No.	Name of Crops	Level of Irrigation	% of Irrigation Depth	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	Winter Crops															
7	Wheat	1	100	70.80	69.57	31.82								160.86	51.26	384.31
		2	75	53.10	52.18	23.87								120.65	38.44	288.23
		3	50	35.40	34.78	15.91								80.43	25.63	192.15
		4	25	17.70	17.39	7.96								40.22	12.81	96.08
8	Oil crops	1	100	70.73	5.36								0	56.60	70.90	203.58
		2	75	53.05	4.02								0	42.45	53.18	152.69
		3	50	35.36	2.68								0	28.30	35.45	101.79
		4	25	17.68	1.34								0	14.15	17.73	50.90
9	Lentil	1	100	67.02	52.88	0								28.47	55.86	204.22
		2	75	50.26	39.66	0								21.35	41.90	153.17
		3	50	33.51	26.44	0								14.23	27.93	102.11
		4	25	16.75	13.22	0								7.12	13.97	51.06
10	Pulses	1	100	72.36	0									28.43	53.29	154.08
		2	75	54.27	0									21.32	39.97	115.56
		3	50	36.18	0									14.21	26.64	77.04
		4	25	18.09	0									7.11	13.32	38.52
11	Potato	1	100	72.35	66.92	2.39								45.77	47.68	235.11
		2	75	54.26	50.19	1.79								34.33	35.76	176.33
		3	50	36.17	33.46	1.19								22.88	23.84	117.55
		4	25	18.09	16.73	0.60								11.44	11.92	58.78
12	Winter Vegetables	1	100	61.13	31.78								0	96.77	65.82	255.50
		2	75	45.85	23.83								0	72.58	49.37	191.63
		3	50	30.57	15.89								0	48.38	32.91	127.75
		4	25	15.28	7.94								0	24.19	16.46	63.88

Sl No.	Name of Crops	Level of Irrigation	% of Irrigation Depth	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
	Spring Crops															
13	Maize (Spring)	1	100			56.01	354.08	307.21								717.30
		2	75			42.01	265.56	230.41								537.97
		3	50			28.01	177.04	153.60								358.65
		4	25			14.00	88.52	76.80								179.32
14	Paddy Rice (Spring)	1	100		23.02	409.25	601.09	529.49	216.36	0						1779.21
		2	75		17.26	306.94	450.82	397.12	162.27	0						1334.41
		3	50		11.51	204.63	300.55	264.74	108.18	0						889.61
		4	25		5.75	102.31	150.27	132.37	54.09	0						444.80
15	Sunflower	1	100		0	94.58	362.32	233.32								690.21
		2	75		0	70.93	271.74	174.99								517.66
		3	50		0	47.29	181.16	116.66								345.11
		4	25		0	23.64	90.58	58.33								172.55
16	Spring Vegetable	1	100			101.98	257.58	277.72								637.28
		2	75			76.49	193.19	208.29								477.96
		3	50			50.99	128.79	138.86								318.64
		4	25			25.50	64.40	69.43								159.32

CHAPTER– VI

MODEL FORMULATION

6.1 GENERAL

A model is a true representation of reality. It helps to get the optimal solution out of several alternatives. In a model, the mental image is reflected correctly. A model can be used to improve understanding of the ways in which a system behaves in circumstances, where it is not possible to construct with a real world situation. This involves a representation of the situation in which we are interested, and of what might happen next. The study of models has been increased manifold by the use of computers now. The study and use of model though is of very old origin, but in the application of system analysis for planning and management of water resources system is of recent origin.

6.2 LINEAR PROGRAMMING (LP)

Linear Programming is one of the most widely used techniques of management science. It is a mathematical method of allocating scarce resources to achieve an objective within the bounds of given constraints. Linear programming involves the formulation and solution of certain type of managerial problem by optimizing a linear objective function subject to linear constraints. The desired outcome may be measured in terms of profits, cost, effectiveness, time, space, distance or welfare of the public, expressed in a linear relationship among the system variables, thus becomes the objective function of a linear programming model. The amount of available resources, also expressed as linear function (equations or inequalities), represent constraints, which define the feasibility area for optimization. Linear programming is used to identify the best combination of limited resources so as to optimize the objective.

6.2.1 ADVANTAGES OF LINEAR PROGRAMMING

The main advantages of linear programming are as follows:

(i) 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.

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

(iii) Solving simultaneous equations is very time consuming even if number of unknowns is equal to the number of equations. But linear programming saves a lot of time.

(iv) Linear programming can be used to solve the problem giving optimal solution, which algebraic and mathematical methods do not provide.

6.2.2 BASIC REQUIREMENTS OF LINEAR PROGRAMMING

A linear programming problem must meet the following requirements.

(i) Objective Function: - A linear programming problem must have an explicit objective criterion to optimize. The objective function may be either maximization or minimization of the criterion, but never both. However a maximization problem can be converted to a minimization and vice versa.

(ii) Limited Resources: - If there were unlimited resources, efficient resource allocation would present no managerial problem. In order to apply linear programming a decision problem must involve activities that require consumption of limited resources. These limited resources may be production capacity, manpower, time, money, space or technology. The amount of limited resources is usually expressed as constraints for the problem.

(iii) Decision Variables and Their Relationships: - Linear programming is most effective for those problems that involve a large number of decision (or activity) variables. These variables are usually interrelated in terms of utilization of resources and require simultaneous solutions.

(iv) Linearity and Additivity: - The primary requirement of linear programming is the linearity in the objective function and in the constraints. The word linear implies that relationship among decision variables (products, activities, etc) must be directly proportional. The proportionality requires that the measure of outcome and resource usage must be proportional to the level of each component activity.

(v) Divisibility: - Linear programming requires a complete divisibility of fractional values of the decision variables. In other words, fractional values of the decision variables and resources must be permissible in obtaining an optimal solution.

(vi) Deterministic: - In linear programming all model coefficients (e.g. unit profit contribution to each product, the amount of resources required per unit of product and the amount of available resources) are assumed to be known with certainty. In real world situations, however model coefficients are never deterministic. A number of techniques have been developed to handle linear programming with uncertain coefficients, such as sensitivity analysis, parametric linear programming and chance constrained programming.

6.3 OBJECTIVES OF THE PRESENT LP MODELLING

The present study aims to find out a policy for optimal use of land and water resources resulting in maximum net benefits from the crops in the study area. For this purpose two models namely full irrigation model and variable irrigation model have been formulated in this study. In the full irrigation model the yield of a crop has been considered as the yield when irrigation is applied as per requirements. But in the variable irrigation model multilevel yields at different levels of irrigation have been utilized. The multilevel yields at different levels of irrigation have been found out by the use of quadratic production function as already discussed in the previous chapter. But the objective function and constraints are same for both the models. A comparative study has been made on the results obtained from these two models. It determines a profitable level of irrigation to the crops.

6.4 MAIN FEATURES OF THE PRESENT LP MODELLING

The main features of the model are

(i) Multi period analysis: - The water use has been considered in twelve different periods in a year. Each calendar month is used as a separate period. The number of periods varies from crop to crop.

(ii) Multi level analysis: - In the variable irrigation model, five levels of irrigation have been suggested for each crop and corresponding yields have been utilized as alternative crop process.

(iii) Crop area constraint: - Minimum areas for paddy, Maize, Wheat, Oilseed, Pulse, Potato, Vegetables have been considered in this model to make the study area self sufficient in food to a great extent.

(iv) Balance diet constraint: - The minimum Energy (calorie), Protein, Calcium, Iron, Vitamin A, Vitamin C and Vitamin E (required for the inhabitants of this study area by 2017 A.D.) constraints have also been tried in both the models to test whether the cropping pattern is able to fulfill the above requirements or not.

6.5 ASSUMPTION IN THE PRESENT LP MODELLING

All characteristic assumptions of linear programming, namely additivity and linearity, divisibility and single value expectations are fully applicable in the present study. In addition the following assumptions were also made:

(i) The high yielding varieties of crops already in use in the study area would continue to be used in near future.

(ii) The relative structure of prices of various products and inputs would not change significantly in near future to affect the optimal plans.

(iii) The estimated potential of surface water and ground water utilization would not change significantly in near future.

(iv) The technology for utilization of surface water and ground water for irrigation purpose would not change significantly in near future.

(v) All constraints in the model have equal importance in solving the problem.

6.6 MODEL FORMULATION

6.6.1 THE DECISION VARIABLES:

The decision variables in the linear programming model are A_j, S_k and G_k. where,

A_j Optimal crop area, j = 1, 2, 3, --------------------N

S_k Optimal surface water release, k = 1, 2, 3, ------M

G_k Optimal ground water release, k = 1, 2, 3, ------M

6.6.2 OBJECTIVE FUNCTION:

Objective function is to maximize the net benefits from an optimal cropping pattern, surface water and ground water utilization in the study area, is written as:

$$\text{Max}Z=\sum_{j=1}^{N}(B_jY_j-C_j)A_j-\sum_{k=1}^{M}C_sS_k-\sum_{k=1}^{M}C_gG_k \qquad \text{---------------} \qquad (6.1)$$

Where,

B_j = Unit price of j^{th} crop yield in Rs /tonne

Y_j = Yield of j^{th} crop in tonnes/ha

A_j = Area under j^{th} crop in ha, $j = 1, 2, 3 \ldots\ldots\ldots N$

C_j = cost of agricultural inputs in Rs/ha

N = Total number of feasible crops

M = Total number of periods (12 months)

S_k = Surface water release in k^{th} period, $k = 1, 2, 3 \ldots\ldots\ldots M$

G_k = Ground water release in k^{th} period, $k = 1, 2, 3 \ldots\ldots\ldots M$

C_s, C_g = Cost of unit volume of surface and ground water.

Therefore, $(B_jY_j-C_j)$ is the net return excluding the cost of irrigation from the j^{th} crop.

6.6.3 CONSTRAINTS

1. Irrigation Requirement: -

The water requirement for various crops in each month can not exceed surface and ground water resources. If δ_{jk} is the net irrigation requirement of j^{th} crop during k^{th} period, the irrigation requirement constraint can be written as:

$$\sum_{J=1}^{N} A_j\delta_{jk} \leq [\eta_s S_k + \eta_g G_k] \qquad \text{-----------------------------} \quad (6.2)$$

Where, η_s and η_k are the efficiencies of irrigation for surface and ground water respectively, which are used to find the gross water requirement.

2. Land Availability: -

Area under various crops during any period can not exceed the culturable command area of the study area.

$$A_{jk} \leq A \qquad \text{--} \quad (6.3)$$

$$A_{jk}=\lambda_{jk}.A \qquad \text{--} \quad (6.4)$$

$$\sum_{j=1}^{N} \lambda_{jk} \leq 1, k=1,2,3,\ldots\ldots\ldots M$$

Where, ------------------------ (6.5)

A_{jk} = Area under j^{th} crop in k^{th} period

A = Culturable command area

λ_{jk} = Fraction of area under jth crop in kth period

3. **Surface Water Availability: -**

Optimal surface water release at any time can not exceed the allocated surface water flow (as per Indo-Nepal treaty) of that period.

$$S_k \leq \text{Net available monthly surface water}, \; k = 1, 2 \ldots M \quad \text{-----} \quad (6.6)$$

The maximum surface water utilization during any period can not exceed the conveyance capacity of the canal system during that period.

$$S_k \leq \text{Conveyance capacity of the canal}, \; k = 1, 2 \ldots M \quad \text{-------} \quad (6.7)$$

4. **Ground Water Withdrawals: -**

The total optimal ground water release can not exceed the net annual available ground water.

$$\sum G_k \leq \text{Net available annual ground water}, \; k = 1, 2 \ldots M \quad \text{-------} \quad (6.8)$$

5. **Minimum Area: -**

In order to satisfy the basic food needs of the population of the study area a minimum area constraint for some crops is imposed as:

$$A_j \geq A_{\min j} \quad \text{---} \quad (6.9)$$

Where,

$A_{\min j}$ = Minimum area for jth crop, j = 1, 2 ....N

6. **Energy Requirement: -**

In order to satisfy the calorie requirement of the population of the study area this constraint is also imposed as:

$$\sum_{J=1}^{N} A_j Y_j E_j \geq ER \quad \text{-----------------------------------} \quad (6.10)$$

Where,

E_j = Calorie value of jth crop (kcal/kg), j = 1, 2 ....N

ER = Total calorie requirement of the study area (kcal)

7. **Protein Requirement: -**

In order to satisfy the protein requirement of the population of the study area this constraint is also imposed as:

Where, $\sum_{J=1}^{N} A_jY_jP_j \geq PR$ -- (6.11)

P_j = Protein value of j^{th} crop (gm/kg), j = 1, 2 ...N

PR =Total protein requirement of the study area (gms)

8. Calcium Requirement:-

In order to satisfy the calcium requirement of the population of the study area this constraint is also imposed as:

Where, $\sum_{J=1}^{N} A_jY_jC_j \geq CR$ -- (6.12)

C_j = Calcium value of jth crop (gm/kg), j = 1, 2 ...N

CR = Total calcium requirement of the study area

9. Iron Requirement: -

In order to satisfy the iron requirement of the population of the study area, this constraint is also imposed as:

Where, $\sum_{J=1}^{N} A_jY_jI_j \geq IR$ -- (6.13)

I_j = Calcium value of j^{th} crop (gm/kg), j = 1, 2 ...N

IR = Total calcium requirement of the study area (gms)

10. Vitamin-A Requirement: -

In order to satisfy the vitamin A requirement of the population of the study area this constraint is also imposed as:

Where, $\sum_{J=1}^{N} A_jY_jVA_j \geq VAR$ ---------------------------------- (6.14)

VA_j = Vitamin-A value of j^{th} crop (gm/kg), j = 1, 2 ....N

VAR = Total Vitamin-A requirement of the study area (gms)

11. Vitamin-C Requirement: -

In order to satisfy the vitamin A requirement of the population of the study area this constraint is also imposed as:

Where, $\sum_{J=1}^{N} A_jY_jVC_j \geq VCR$ ---------------------------------- (6.15)

VC_j = Vitamin-C value of j^{th} crop (gm/kg), j = 1, 2 ....N

VCR = Total Vitamin-C requirement of the study area (gms)

12. Vitamin-E Requirement: -

In order to satisfy the vitamin A requirement of the population of the study area this constraint is also imposed as:

$$\sum_{J=1}^{N} A_j Y_j VE_j \geq VER \qquad \text{---------------------------------------} \qquad (6.16)$$

Where,

VE_j = Vitamin-E value of jth crop (gm/kg), j = 1, 2 ....N

VER = Total Vitamin-E requirement of the study area (gms)

6.7 FULL IRRIGATION MODEL

In full irrigation model the decision variables are A_j, S_k and G_k. For A_j (i.e. area under jth crop in ha.) the following notations are used for 16 crops in the model.

A11	Area under Paddy Rice (local)
A12	Area under Main Paddy Rice (improved)
A13	Area under Summer Maize (local)
A14	Area under Summer Maize (improved)
A15	Area under Summer Vegetables
A16	Area under Sugarcane
A21	Area under Wheat
A22	Area under Oil crops
A23	Area under Lentil
A24	Area under Pulses
A25	Area under Potato
A26	Area under Winter Vegetables
A31	Area under Spring Maize
A32	Area under Spring Paddy Rice
A33	Area under Sunflower
A34	Area under Spring Vegetables

Where,

A11, A12 ... A16	represent to summer season crops
A21, A22... A26	represent to winter season crops
A31, A32, A33, A34	represent to spring season crops

For Sk (optimal surface water release for irrigation in ha-m) the following notations are used for 12 months (from January to December respectively) in the model:

S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12.

For Gk (optimal ground water withdrawal for irrigation in ha-m) the following notations are used for 12 months (from January to December respectively) in the model:

G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12.

6.7.1 OBJECTIVE FUNCTION

Net benefit values (B_jY_j-C_j) for each crop have been calculated and presented in Table No. 3.7. C_s and C_g are taken as IRs.1669.94 and IRs. 7862.44 as mentioned in Section 3.7.9 and Section 3.7.10 respectively in Chapter-III.

Hence the objective function for use of both surface water and ground water is

Max Z = 10023 A11+21466 A12+2211 A13+12652 A14+117332 A15+43242 A16 +7865 A21+28094 A22+19964 A23+17988 A24+76117 A25+165129 A26+12652 A31+20786 A32+32661 A33+97931 A34-1669.94 S1-1669.94 S2-1669.94 S3-1669.94 S4-1669.94 S5-1669.94 S6-1669.94 S7-1669.94 S8-1669.94 S9-1669.94 S10-1669.94 S11-1669.94 S12-7862.44 G1-7862.44 G2-7862.44 G3-7862.44 G4-7862.44 G5-7862.44 G6-7862.44 G7-7862.44 G8-7862.44 G9-7862.44 G10-7862.44 G11-7862.44 G12; -------------- (6.17)

6.7.2 CONSTRAINTS

1. Irrigation Requirement Constraints:

The gross irrigation requirement of crops has been presented in the Table No 4.8 in Chapter -IV. The conveyance efficiency of canals is assumed 70 % and it has been used in calculating the gross water requirements. The conveyance efficiency is applicable in case of surface water release as the main canal and distributaries are considerably long but in the case of ground water releases it may be neglected as most of the tube wells would be installed on the crop fields.

The constraints for each of the twelve months for use of both surface water and ground water releases to meet the gross water requirements are as follows:

0.07080 A21+0.07073 A22+0.06702 A23+0.07236 A24+0.07235 A25+0.06113 A26 ≤ S11+G11/0.7; -- (6.18)

0.06957 A21+ 0.00536 A22+0.05288 A23+0.06692 A25+0.03178 A26+0.02302 A32 ≤ S12+G12/0.7; -- (6.19)

$$0.06739\,A16+0.03182\,A21+0.00239\,A25+0.05601\,A31+0.40925\,A32+0.09458\,A33+0.10198\,A34 \le S13+G13/0.7; \tag{6.20}$$

$$0.18014\,A16+0.35408\,A31+0.60109\,A32+0.36232\,A33+0.25758\,A34 \le S14+G14/0.7; \tag{6.21}$$

$$0.31837\,A16+0.30721\,A31+0.52949\,A32+0.23332\,A33+0.27772\,A34 \le S15+G15/0.7; \tag{6.22}$$

$$0.08304\,A12+0.02786\,A16+0.21636\,A32 \le S16+G16/0.7; \tag{6.23}$$

$$0.03666\,A11+0.35963\,A12 \le S17+G17/0.7; \tag{6.24}$$

$$0.35537\,A11+0.18809\,A12 \le S18+G18/0.7; \tag{6.25}$$

$$0.19247\,A11+0.19119\,A12 \le S19+G19/0.7; \tag{6.26}$$

$$0.37186\,A11+0.21319\,A12+0.16320\,A16 \le S20+G20/0.7; \tag{6.27}$$

$$0.03871\,A11+0.15037\,A16+0.16086\,A21+0.05660\,A22+0.02847\,A23+0.02843\,A24+0.04577\,A25+0.09677\,A26 \le S21+G21/0.7; \tag{6.28}$$

$$0.07196\,A16+0.05126\,A21+0.07090\,A22+0.05586\,A23+0.05329\,A24+0.04768\,A25+0.06582\,A26 \le S22+G22/0.7; \tag{6.29}$$

The constraints for each of the twelve months for use of surface water only can be obtained by removing the terms containing ‘G’ from the above equations.

2. Land Availability Constraints:

The total CCA in the study area is 4800 ha. So at any time period of the year the total cropping area should not exceed 4800 ha. Therefore, as per Table No. 3.5 and Table No. 4.8 the land availability constraints are

$$A16+A21+A22+A23+A24+A25+A26 \le 4800; \tag{6.30}$$

$$A21+A22+A23+A24+A25+A26 \le 4800; \tag{6.31}$$

$$A21+A23+A25+A32+A33 \le 4800; \tag{6.32}$$

$$A16+A21+A23+A25+A31+A32+A33+A34 \le 4800; \tag{6.33}$$

$$A16+A31+A32+A33+A34 \le 4800; \tag{6.34}$$

$$A12+A13+A14+A15+A16+A31+A32 \le 4800; \tag{6.35}$$

$$A11+A12+A13+A14+A15+A16 \le 4800; \tag{6.36}$$

$$A11+A12+A16 \le 4800; \tag{6.37}$$

$$A11+A12+A16+A22+A26 \le 4800; \tag{6.38}$$

$$A11+A16+A22+A23+A24+A25+A26 \le 4800; \tag{6.39}$$

3. Surface Water Availability Constraints:

The surface water availability for Mahakali Irrigation Project Stage- I is 6.60 cumecs from 15th May to 15th October and 1.76 cumecs from 16th October to 14th May. Table No. 3.10 shows the maximum monthly surface water (in ha-m) that can be available for irrigation. So the surface water availability constraints are

$S1 \leq 471.40$; -- (6.40)
$S2 \leq 425.78$; -- (6.41)
$S3 \leq 471.40$; -- (6.42)
$S4 \leq 456.19$; -- (6.43)
$S5 \leq 1182.30$; -- (6.44)
$S6 \leq 1710.72$; -- (6.45)
$S7 \leq 1767.74$; -- (6.46)
$S8 \leq 1767.74$; -- (6.47)
$S9 \leq 1710.72$; -- (6.48)
$S10 \leq 1098.66$; -- (6.49)
$S11 \leq 456.19$; -- (6.50)
$S12 \leq 471.40$; -- (6.51)

4. Ground Water Availability Constraints:

As discussed in Section 3.7.8 and shown in Table No.3.11, maximum ground water available in the present study area is 2128.38 ha-m per year and the maximum ground water that can be pumped in a month is limited to 709.46 ha-m. So the ground water availability constraints are

$G1 \leq 709.46$; -- (6.52)
$G2 \leq 709.46$; -- (6.53)
$G3 \leq 709.46$; -- (6.54)
$G4 \leq 709.46$; -- (6.55)
$G5 \leq 709.46$; -- (6.56)
$G6 \leq 709.46$; -- (6.57)
$G7 \leq 709.46$; -- (6.56)
$G8 \leq 709.46$; -- (6.59)
$G9 \leq 709.46$; -- (6.60)
$G10 \leq 709.46$; -- (6.61)
$G11 \leq 709.46$; -- (6.62)

$G12 \leq 709.46$; -- (6.63)

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G11+G12 \leq 2128.38$;-------------- (6.64)

5. Minimum Area Constraints:

Table No. 3.12 shows the minimum area for different crops in the study area. So the minimum area constraints are

$A11+A12+A32 \geq 1438$; -- (6.65)

$A13+A14+A31 \geq 155$; -- (6.66)

$A15 \geq 268$; -- (6.67)

$A21 \geq 983$; -- (6.68)

$A22+A33 \geq 1073$; -- (6.69)

$A23+A24 \geq 1008$; -- (6.70)

$A25 \geq 53$; -- (6.71)

$A26 \geq 264$; -- (6.72)

$A34 \geq 268$; -- (6.73)

6. Energy Requirement Constraints:

The energy (calorie) content of various crops per hectare has been shown in the Table No. 3.8 in Chapter-III. The total annual energy requirement of the study area is estimated to be 37889 Million kcal as shown in Table No. 3.9 in Chapter-III. So the energy requirement constraint is

$9.152\ A11+14.159\ A12+7.701\ A13+13.739\ A14+4.779\ A15+256.704\ A16+12.306\ A21+6.040\ A22+4.169\ A23+3.773\ A24+15.097\ A25+4.779\ A26+13.739\ A31+14.095\ A32+9.241\ A33+4.777\ A34 \geq 37889$; -------------------------------------- (6.74)

7. Protein Requirement Constraints:

The protein content of various crops per hectare has been shown in the Table No. 3.8 in Chapter-III. The total annual protein requirement of the study area is estimated to be 894.494 tonnes as shown in Table No. 3.9 in Chapter-III. So the protein requirement constraint is

$0.387\ A11+0.598\ A12+0.199\ A13+0.355\ A14+0.379\ A15+0.385\ A21+0.187\ A22+0.305\ A23+0.239\ A24+0.396\ A25+0.379A26+0.355\ A31+0.595\ A32+0.369\ A33+0.378\ A34 \geq 894.494$; -- (6.75)

8. Calcium Requirement Constraints:

The calcium content of various crops per hectare has been shown in the Table no. 3.8 in Chapter-III. The total annual calcium requirement of the study area is estimated to be 15780 kg as shown in Table no. 3.9 in Chapter-III. So the calcium requirement constraint is

$$1.651\ A11+2.554\ A12+0.148\ A13+0.263\ A14+8.221\ A15+0.663\ A16+1.004\ A21+10.277\ A22+0.661\ A23+1.430\ A24+1.338\ A25+8.221\ A26+0.263\ A31+2.542\ A32+1.881\ A33+8.217\ A34 \geq 15780; \tag{6.76}$$

9. Iron Requirement Constraints:

The iron content of various crops per hectare has been shown in the Table no. 3.8 in Chapter-III. The total annual iron requirement of the study area is estimated to be 286.173 kg as shown in Table no. 3.9 in Chapter-III. So the iron requirement constraint is

$$0.537\ A11+0.831\ A12+0.057\ A13+0.102\ A14+0.084\ A15+0.007\ A16+0.119\ A21+0.153\ A22+0.089\ A23+0.058\ A24+0.149\ A25+0.084\ A26+0.102\ A31+0.827\ A32+0.110\ A33+0.084\ A34 \geq 286.173; \tag{6.77}$$

10. Vitamin-A Requirement Constraints:

The vitamin-A content of various crops per hectare has been shown in the Table no. 3.8 in Chapter-III. The total annual vitamin-A requirement of the study area is estimated to be 8629 g_RAE as shown in Table no. 3.9 in Chapter-III. So the vitamin-A requirement constraint is

$$0.414\ A14+41.829\ A15+0.024\ A23+0.011\ A24+41.830\ A26+0.414\ A31+0.049\ A33+41.813\ A34 \geq 8629; \tag{6.78}$$

11. Vitamin-C Requirement Constraints:

The vitamin-C content of various crops per hectare has been shown in the Table no. 3.8 in Chapter-III. The total annual vitamin-C requirement of the study area is estimated to be 722.79 kg as shown in Table no. 3.9 in Chapter-III. So the vitamin-C requirement constraint is

$$5.410\ A15+0.052\ A23+3.765\ A25+5.410\ A26+0.023\ A33+5.408\ A34 \geq 722.79; \tag{6.79}$$

12. Vitamin-E Requirement Constraints:

The Vitamin-E content of various crops per hectare has been shown in the Table no. 3.8 in Chapter-III. The total annual Vitamin-E requirement of the study area is estimated to be 135.728 kg as shown in Table no. 3.9 in Chapter-III. So the Vitamin-E requirement constraint is

$$0.142\ A11+0.220\ A12+0.018\ A14+0.101\ A15+0.038\ A21+0.003\ A22+0.006\ A23+0.002\ A25+0.101\ A26+0.018\ A31+0.219\ A32+0.559\ A33+0.101\ A34 \geq 135.728; \text{----} \quad (6.80)$$

6.8 VARIABLE IRRIGATION MODEL

In variable irrigation the area under each crop has been divided into five categories as discussed in Chapter-V. It is represented by suffixing 1, 2, 3, 4, and 5 to the notations as used in the full irrigation model. For example A111 represents the area under Paddy Rice (Local) in hectare with level of irrigation 1 (i.e. 100 % or full irrigation) where as A115 represents the area under Paddy Rice (Local) in hectare with level of irrigation 5 (i.e. 0 % or rain fed condition). The notations for S_k and G_k are same as in full irrigation model.

6.8.1 OBJECTIVE FUNCTION

Net benefit values (B_jY_j-C_j) for each crop have been calculated for different levels of irrigation and are shown in Table No. 5.4.1 to Table No. 5.4.5 in Chapter-V. Cs and Cg are IRs.1669.94 and IRs.7862.44 as mentioned in Section 3.7.9 and Section 3.7.10 respectively in Chapter-III.

Hence the objective function for use of both surface water and ground water is

Max Z = 10023 A111+9604 A112+8353 A113+6268 A114+5521 A115+21466 A121+20573 A122+17895 A123+13430 A124+10205 A125+2211 A131+2015 A132+1426 A133+445 A134+1026 A135+12652 A141+11839 A142+9399 A143+5333 A144+1657 A145+117332 A151+112827 A152+99335 A153+76858 A154+47772 A155+43242 A161+41227 A162+35185 A163+25114 A164+15485 A165 +7865 A211+7058 A212+4638 A213+605 A214-1739 A215+28094 A221+27048 A222+23910 A223+18680 A224+9623 A225+19964 A231+19060 A232+16347 A233+11826 A234+8739 A235+17988 A241+17529 A242+16152 A243+13857 A244+13858 A245+76117 A251+72660 A252+62289 A253+45004 A254+24297 A255+165129 A261+159401 A262+142253 A263+113686 A264+76076 A265+12652 A311+11839 A312+9399 A313+5333 A314+1657 A315+20786 A321+19914 A322+17308 A323+12966 A324+9876 A325+32661 A331+31145 A332+26599 A333+19022 A334+10518 A335+97931 A341+94087 A342+82557 A343+63340 A344+38812 A345-1669.94 S1-1669.94 S2-1669.94 S3-1669.94 S4-1669.94 S5-1669.94 S6-1669.94 S7-1669.94 S8-1669.94 S9-1669.94 S10-1669.94 S11-

1669.94 S12-7862.44 G1-7862.44 G2-7862.44 G3-7862.44 G4-7862.44 G5-7862.44 G6-7862.44 G7-7862.44 G8-7862.44 G9-7862.44 G10-7862.44 G11-7862.44 G12; -------- (6.81)

6.8.2 CONSTRAINTS

1. Irrigation Requirement Constraints:

The gross irrigation requirement of crops has been presented in the Table No 5.6 in Chapter-V. The conveyance efficiency of canals is assumed 70 % and it has been used in calculating the gross water requirements. The conveyance efficiency is applicable in case of surface water release as the main canal and distributaries are considerably long but in the case of ground water releases it may be neglected as most of the tube wells would be installed on the crop fields.

The constraints for each of twelve months for use of both surface water and ground water releases to meet the gross water requirements are as follows:

0.07080 A211+0.05310 A212+0.03540 A213+0.01770 A214+0.07073 A221+.05305 A222+0.03536 A223+0.01768 A224+0.06702 A231+0.5026 A232+0.03351 A233+0.01675 A234+0.07236 A241+0.05427 A242+0.03618 A243+0.01809 A244+0.07235 A251+0.05426 A252+0.03617 A253+0.01806 A254+0.06113 A261+0.04585 A262+0.03057 A263+0.01528 A264 ≤ S1+G1/0.70; --- (6.82)

0.06957 A211+0.05218 A212+0.03478 A213+0.01739 A214+ 0.00536 A221+0.00402 A222+0.00268 A223+0.00134 A224+0.05288 A231+0.03966 A232+0.02644 A233+0.01322 A234+0.06692 A251+0.05019 A252+0.03346 A253+0.01673 A254+0.03178 A261+0.02383 A262+0.01589 A263+0.00794 A264+0.02302 A321+0.01726 A322+0.01151 A323+0.00575 A324 ≤ S2+G2/0.70; --- (6.83)

0.06739 A161+0.05054 A162+0.03370 A163+0.01685 A164+ 0.03182 A211+0.02387 A212+0.01591 A213+0.00796 A214+0.00239 A251+0.00179 A252+0.00119 A253+0.00060 A254+0.05601 A311+0.04201 A312+0.02801 A313+0.01400 A314+0.40925 A321+0.30694 A322+0.20463 A323+0.10231 A324+0.09458 A331+0.07093 A332+0.04729 A333+0.02364 A334+0.10198 A341+0.07649 A342+0.05099 A343+0.02550 A344 ≤ S3+G3/0.70; ----(6.84)

0.18014 A161+0.13510 A162+0.09007 A163+0.04503 A164+0.35408 A311+0.26556 A312+0.17704 A313+0.08852 A314+0.60109 A321+0.45082 A322+0.30055 A323+0.15027 A324+0.36232 A331+0.27174 A332+0.18116 A333+0.09058 A334+0.25758 A341+0.19319 A342+0.12879 A343+0.06440 A344 ≤ S4+G4/0.70; ---------------------- (6.85)

0.31837 A161+0.23878 A162+0.15919 A163+0.07959 A164+0.30721 A311+0.23041 A312+0.15360 A313+0.07680 A314+0.52949 A321+0.39712 A322+0.26474 A323+0.13237

A324+0.23332 A331+0.17499 A332+0.11666 A333+0.05833 A334+0.27772 A341+0.20829
A342+0.13886 A343+0.06943 A344 ≤ S5+G5/0.70; ---------------------- (6.86)

0.08304 A121+0.06228 A122+0.04152 A123+0.02076 A124+0.02786 A161+0.02089
A162+0.01393 A163+0.00696 A164+0.21636 A321+0.16227 A322+0.10818 A323+0.05240
A324 ≤ S6+G6/0.70; -- (6.87)

0.03666 A111+0.02749 A112+0.01833 A113+0.00916 A114+0.35963 A121+0.26972
A122+0.17981 A123+0.08991 A124 ≤ S7+G7/0.70; ---------------------- (6.88)

0.35537 A111+0.26652 A112+0.17768 A113+0.08884 A114+0.18809 A121+0.14107
A122+0.09404 A123+0.04702 A124 ≤ S8+G8/0.70; ---------------------- (6.89)

0.19247 A111+0.14435 A112+0.09623 A113+0.04812 A114+0.19119 A121+0.14339
A122+0.09560 A123+0.04780 A124 ≤ S9+G9/0.70; ---------------------- (6.90)

0.37186 A111+0.27889 A112+0.18593 A113+0.09296 A114+0.21319 A121+0.15990
A122+0.10660 A123+0.05330 A124+0.16320 A161+0.12240 A162+0.08160 A163+0.04080
A164 ≤ S10+G10/0.70; -- (9.91)

0.03871 A111+0.02903 A112+0.01935 A113+0.00968 A114+0.15037 A161+0.11278
A162+0.07519 A163+0.03759 A164+0.16086 A211+0.12065 A212+0.08043 A213+0.04022
A214+0.05660 A221+0.04245 A222+0.02830 A223+0.01415 A224+0.02847 A231+0.02135
A232+0.01423 A233+0.00712 A234+0.02843 A241+0.02132 A242+0.01421 A243+0.00711
A244+0.04577 A251+0.03433 A252+0.02288 A253+0.01144 A254+0.09677 A261+0.07258
A262+0.04838 A263+0.02419 A264 ≤ S11+G11/0.70; ---------------------- (6.92)

0.07196 A161+0.05397 A162+0.03598 A163+0.01799 A164+0.05126 A211+0.03844
A212+0.02563 A213+0.01281 A214+0.07090 A221+0.05318 A222+0.03545 A223+0.01773
A224+0.05586 A231+0.04190 A232+0.02793 A233+0.01397 A234+0.05329 A241+0.03997
A242+0.02664 A243+0.01332 A244+0.04768 A251+0.03576 A252+0.02384 A253+0.01192
A254+0.06582 A261+0.04937 A262+0.03291 A263+0.01646 A264 ≤ S12+G12/0.70;
-- (6.93)

The constraints for each of the twelve months for use of surface water only can be obtained by removing the terms containing 'G' in above equations.

2. Land Availability Constraints:

The total CCA in the study area is 4800 ha. So at any time of the year the total cropping area should not exceed 4800 ha. Therefore, as per Table No 3.5 and Table No 5.6 the land availability constraints are

$A161+A162+A163+A164+A165+A211+A212+A213+A214+A215+A221+A222+A223+A224+A225+A231+A232+A233+A234+A235+A241+A242+A243+A244+A245+A251+A252+A253+A254+A255+A261+A262+A263+A264+A265 \leq 4800;$ ---- (6.94)

$A211+A212+A213+A214+A215+A221+A222+A223+A224+A245+A231+A232+A233+A234+A235+A241+A242+A243+A244+A245+A251+A252+A253+A254+A255+A261+A262+A263+A264+A265 \leq 4800;$ ---------------------------------- (6.95)

$A211+A212+A213+A214+A215+A231+A232+A233+A234+A235+A251+A252+A253+A254+A255+A321+A322+A323+A324+A325+A331+A332+A333+A334+A335 \leq 4800$ ---------------------------------- (6.96)

$A161+A162+A163+A164+A165+A211+A212+A213+A214+A215+A231+A232+A233+A234+A235+A251+A252+A253+A254+A255+A311+A312+A313+A314+A315+A321+A322+A323+A324+A325+A331+A332+A333+A334+A335+A341+A342+A343+A344+A345 \leq 4800;$ -- (6.97)

$A161+A162+A163+A164+A165+A311+A312+A313+A314+A315+A321+A322+A323+A324+A325+A331+A332+A333+A334+A335+A341+A342+A343+A344+A345 \leq 4800;$ ---------------------------------- (6.98)

$A121+A122+A123+A124+A125+A131+A132+A133+A134+A135+A141+A142+A143+A144+A145+A151+A152+A153+A154+A155+A161+A162+A163+A164+A165+A321+A322+A323+A324+A325 \leq 4800;;$ ---------------------------------- (6.99)

$A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A131+A132+A133+A134+A135+A141+A142+A143+A144+A145+A151+A152+A153+A154+A155+A161+A162+A163+A164+A165 \leq 4800;$ ---------------------------------- (6.100)

$A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A161+A162+A163+A164+A165 \leq 4800;$ -- (6.101)

$A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A161+A162+A163+A164+A165+A221+A222+A223+A224+A225+A261+A262+A263+A264+A265 \leq 4800;$ ---------------------------------- (6.102)

$A111+A112+A113+A114+A115+A161+A162+A163+A164+A165+A211+A212+A213+A214+A215+A221+A222+A223+A224+A225+A231+A232+A233+A234+A235+A241+A242+A243+A244+A245+A251+A252+A253+A254+A255+A261+A262+A263+A264+A265 \leq 4800;$ -- (6.103)

3. Surface Water Availability Constraints:

The surface water availability for Mahakali Irrigation Project Stage- I is 6.60 cumecs from 15th May to 15th October and 1.76 cumecs from 16th October to 14th May. Table No. 3.10 shows the maximum monthly surface water (in ha-m) that can be available for irrigation. So the surface water availability constraints are

$$S1 \leq 471.40; \tag{6.104}$$
$$S2 \leq 425.78; \tag{6.105}$$
$$S3 \leq 471.40; \tag{6.106}$$
$$S4 \leq 456.19; \tag{6.107}$$
$$S5 \leq 1182.30; \tag{6.108}$$
$$S6 \leq 1710.72; \tag{6.109}$$
$$S7 \leq 1767.74; \tag{6.110}$$
$$S8 \leq 1767.74; \tag{6.111}$$
$$S9 \leq 1710.72; \tag{6.112}$$
$$S10 \leq 1098.66; \tag{6.113}$$
$$S11 \leq 456.19; \tag{6.114}$$
$$S12 \leq 471.40; \tag{6.115}$$

4. Ground Water availability Constraints:

As discussed in Section 3.7.8 and shown in Table No.3.11, maximum ground water available in the present study area is 2128.38 ha-m per year and the maximum ground water that can be pumped in a month is limited to 709.46 ha-m. So the ground water availability constraints are

$$G1 \leq 709.46; \tag{6.116}$$
$$G2 \leq 709.46; \tag{6.117}$$
$$G3 \leq 709.46; \tag{6.118}$$
$$G4 \leq 709.46; \tag{6.119}$$
$$G5 \leq 709.46; \tag{6.120}$$
$$G6 \leq 709.46; \tag{6.121}$$
$$G7 \leq 709.46; \tag{6.122}$$
$$G8 \leq 709.46; \tag{6.123}$$
$$G9 \leq 709.46; \tag{6.124}$$
$$G10 \leq 709.46; \tag{6.125}$$
$$G11 \leq 709.46; \tag{6.126}$$

$G12 \leq 709.46;$ -- (6.127)

$G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G11+G12 \leq 2128.38;$ ------------- (6.128)

5. Minimum Area Constraints:

Table No. 3.12 shows the minimum area for different crops in the study area. So the minimum area constraints are

$A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A321+A322+A323+A324+A325 \geq 1438;$ --- (6.129)

$A131+A132+A133+A134+A135+A141+A142+A143+A144+A145+A311+A312+A313+A314+A315 \geq 155;$ --- (6.130)

$A151+A152+A153+A154+A155 \geq 268;$ --------------------------------------- (6.131)

$A211+A212+A213+A214+A215 \geq 983;$ --------------------------------------- (6.132))

$A221+A222+A223+A224+A225+A331+A332+A333+A334+A335 \geq 1073;$ ----- (6.133)

$A231+A232+A233+A234+A235+A241+A242+A243+A244+A245 \geq 1008;$ ----- (6.134)

$A251+A252+A253+A254+A255 \geq 53;$ --------------------------------------- (6.135)

$A261+A262+A263+A264+A265 \geq 264;$ --------------------------------------- (6.136)

$A341+A342+A343+A344+A345 \geq 268;$ --------------------------------------- (6.137)

6. Energy Requirement Constraints:

The energy (calorie) content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual energy requirement of the study area is estimated to be 37889.3 Million kcal as shown in Table No. 3.9 in Chapter-III. So the energy requirement constraint is

9.152 A111+8.997 A112+8.531 A113+7.754 A114+6.668 A115+14.159 A121+13.814 A122+12.777 A123+11.047 A124+8.627 A125+7.701 A131+7.590 A132+7.254 A133+6.695 A134+5.913 A135+13.739 A141+13.272 A142+11.873 A143+9.542 A144+6.278 A145+4.779 A151+4.619 A152+4.137 A153+3.335 A154+2.213 A155+256.704 A161+249.199 A162+226.682 A163+189.152 A164+136.611 A165+12.306 A211+11.862 A212+10.529 A213+8.307 A214+5.197 A215+6.040 A221+5.866 A222+5.346 A223+4.479 A224+3.266 A225+4.169 A231+4.039 A232+3.647 A233+2.995 A234+2.083 A235+3.773 A241+3.709 A242+3.516 A243+3.194 A244+2.744 A245+15.097 A251+14.603 A252+13.122 A253+10.653 A254+7.197 A255+4.779 A261+4.629 A262+4.178 A263+3.427 A264+2.375 A265+13.739 A311+13.273 A312+11.874 A313+9.542 A314+6.278 A315+14.095 A321+13.752 A322+12.726 A323+11.018

A324+8.627 A325+9.241 A331+8.898 A332+7.871 A333+6.159 A334+3.762 A335+4.777 A341+4.617 A342+4.136 A343+3.335 A344+2.213 A345 ≥ 37889.3; ------------ (6.138)

7. Protein Requirement Constraint:

The protein content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual protein requirement of the study area is estimated to be 894.49 tonnes as shown in Table No. 3.9 in Chapter-III. So the protein requirement constraint is

0.387 A111+0.380 A112+0.360 A113+0.328 A114+0.282 A115+0.598 A121+0.584 A122+0.540 A123+1.467 A124+0.364 A125+0.199 A131+0.196 A132+0.187 A133+0.173 A134+0.153 A135+0.355 A141+0.343 A142+0.306 A143+0.246 A144+0.162 A145+0.379 A151+0.366 A152+0.328 A153+0.264 A154+0.175 A155+0.385 A211+0.371 A212+0.329 A213+0.260 A214+0.424 A215+0.187 A221+0.182 A222+0.165 A223+0.139 A224+0.101 A225+0.305 A231+0.295 A232+0.267 A233+0.219 A234+0.152 A235+0.239 A241+0.235 A242+0.222 A243+0.202 A244+0.174 A245+0.396 A251+0.383 A252+0.344 A253+0.279 A254+0.189 A255+0.379 A261+0.367 A262+0.331 A263+0.271 A264+0.188 A265+0.355 A311+0.343 A312+0.306 A313+0.246 A314+0.162 A315+0.595 A321+0.581 A322+0.538 A323+0.465 A324+0.364 A325+0.369 A331+0.356 A332+0.315 A333+0.246 A334+0.150 A335+0.378 A341+0.366 A342+0.328 A343+0.264 A344+0.175 A345 ≥ 894.49;

---------------- (6.139)

8. Calcium Requirement Constraint:

The calcium content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual calcium requirement of the study area is estimated to be 15780 kg as shown in Table No. 3.9 in Chapter-III. So the calcium requirement constraint is

1.651 A111+1.623 A112+1.539 A113+1.399 A114+1.203 A115+2.554 A121+2.492 A122+2.305 A123+1.993 A124+1.556 A125+0.148 A131+0.146 A132+0.139 A133+0.128 A134+0.113 A135+0.263 A141+0.255 A142+0.228 A143+0.183 A144+0.120 A145+8.221 A151+7.944 A152+7.116 A153+5.736 A154+3.806 A155+0.663 A161+0.644 A162+0.586 A163+0.489 A164+0.353 A165+1.004 A211+0.968 A212+0.859 A213+0.678 A214+0.424 A215+10.277 A221+9.982 A222+9.097 A223+7.622 A224+5.558 A225+0.661 A231+0.641 A232+0.579 A233+0.475 A234+0.330 A235+1.430 A241+1.406 A242+1.332 A243+1.211 A244+1.040 A245+1.338 A251+1.294 A252+1.163 A253+0.944 A254+0.638 A255+8.221 A261+7.962 A262+7.186 A263+5.894 A264+4.085 A265+0.263 A311+0.255 A312+0.228

A313+0.183 A314+0.120 A315+2.542 A321+2.481 A322+2.296 A323+1.987 A324+1.556
A325+1.881 A331+1.811 A332+1.602 A333+1.253 A334+0.766 A335+8.217 A341+7.942
A342+7.144 A343+5.736 A344+3.806 A345 ≥ 15780; -------------------- (6.140)

9. Iron Requirement Constraint:

The iron content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual iron requirement of the study area is estimated to be 286.17 kg as shown in Table No. 3.9 in Chapter-III. So the iron requirement constraint is

0.537 A111+0.528 A112+0.500 A113+0.455 A114+0.391 A115+0.831 A121+0.810
A122+0.750 A123+0.648 A124+0.506 A125+0.057 A131+0.056 A132+0.054 A133+0.050
A134+0.044 A135+0.102 A141+0.099 A142+0.088 A143+0.071 A144+0.047 A145+0.084
A151+0.081 A152+0.073 A153+0.059 A154+0.039 A155+0.007 A161+0.006 A162+0.006
A163+0.005 A164+0.004 A165+0.119 A211+0.115 A212+0.102 A213+0.081 A214+0.050
A215+0.153 A221+0.149 A222+0.136 A223+0.114 A224+0.083 A225+0.089 A231+0.086
A232+0.078 A233+0.064 A234+0.044 A235+0.058 A241+0.057 A242+0.054 A243+0.049
A244+0.042 A245+0.149 A251+0.144 A252+0.130 A253+0.105 A254+0.071 A255+0.084
A261+0.081 A262+0.074 A263+0.060 A264+0.042 A265+0.102 A311+0.099 A312+0.088
A313+0.071 A314+0.047 A315+0.827 A321+0.807 A322+0.747 A323+0.646 A324+0.506
A325+0.110 A331+0.106 A332+0.093 A333+0.073 A334+0.045 A335+0.084 A341+0.081
A342+0.073 A343+0.059 A344+0.039 A345 ≥ 286.17; -------------------- (6.141)

10. Vitamin-A requirement Constraint:

The vitamin-A content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual vitamin-A requirement of the study area is estimated to be 8629.34 g_RAE as shown in Table No. 3.9 in Chapter-III. So the vitamin-A requirement constraint is

0.414 A141+0.400 A142+0.358 A143+0.288 A144+0.189 A145+41.829 A151+40.422
A152+36.209 A153+29.189 A154+19.364 A155+0.024 A231+0.023 A232+0.021
A233+0.017 A234+0.012 A235+0.011 A241+0.011 A242+0.10 A243+0.009 A244+0.008
A245+41.830 A261+40.511 A262+36.564 A263+29.989 A264+20.786 A265+0.414
A311+0.400 A312+0.358 A313+0.288 A314+0.189 A315+0.049 A331+0.047 A332+0.041
A333+0.032 A334+0.020 A335+41.813 A341+40.410 A342+36.200 A343+29.185
A344+19.364 A345 ≥ 8629.34; -- (6.142)

11. Vitamin-C Requirement Constraint:

The vitamin-C content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual vitamin-C requirement of the study area is estimated to be 722.79 kg as shown in Table No. 3.9 in Chapter-III. So the vitamin-C requirement constraint is

5.410 A151+5.228 A152+4.683 A153+3.775 A154+2.505 A155+0.052 A231+0.50
A232+0.045 A233+0.037 A234+0.026 A235+3.765 A251+3.642 A252+3.272 A253+2.657
A254+1.795 A255+5.410 A261+5.240 A262+4.729 A263+3.879 A264+2.689 A265+0.023
A331+0.022 A332+0.019 A333+0.015 A334+0.009 A335+5.408 A341+5.227 A342+4.682
A343+3.775 A344+2.505 A345 $\geq$ 722.79; -- (6.143)

12. Vitamin-E Requirement Constraint:

The Vitamin-E content of various crops per hectare has been shown in the Table No. 5.5.1 to Table No. 5.5.5 in Chapter-V. The total annual Vitamin-E requirement of the study area is estimated to be 135.73 kg as shown in Table No. 3.9 in Chapter-III. So the Vitamin-E requirement constraint is

0.142 A111+0.140 A112+0.133 A113+0.121 A114+0.104 A115+0.831 A121+0.215
A122+0.199 A123+0.172 A124+0.134 A125 +0.018 A141+0.018 A142+0.016 A143+0.013
A144+0.008 A145+0.101 A151+0.098 A152+0.088 A153+0.071 A154+0.047 A155+0.038
A211+0.036 A212+0.032 A213+0.025 A214+0.016 A215+0.003 A221+0.003 A222+0.002
A223+0.002 A224+0.001 A225+0.006 A231+0.006 A232+0.005 A233+0.004 A234+0.003
A235+0.002 A251+0.002 A252+0.002 A253+0.001 A254+0.001 A255+0.101 A261+0.098
A262+0.089 A263+0.073 A264+0.050 A265+0.018 A311+0.018 A312+0.016 A313+0.013
A314+0.008 A315+0.219 A321+0.214 A322+0.198 A323+0.172 A324+0.134 A325+0.559
A331+0.539 A332+0.476 A333+0.373 A334+0.228 A335+0.101 A341+0.098 A342+0.088
A343+0.071 A344+0.047 A345 $\geq$ 135.73; -- (6.144)

CHAPTER- VII

RESULTS AND DISCUSSION

7.1 GENERAL

To arrive at an optimal cropping pattern two models namely full irrigation model and variable irrigation model have been tried in the present study. The full irrigation model is formulated to fulfill the total water requirement of all crops to be planted in each season. The variable irrigation model is formulated for five levels of irrigation, in which the crops receive irrigation at different levels. Some crops would be irrigated to fulfill the crop water requirement while others crops may get deficit irrigation. In both the model twelve constraints namely irrigation requirement, land availability, surface water availability, ground water availability, minimum area requirement, minimum energy (calorie) requirement, minimum protein requirement, minimum calcium requirement, minimum iron requirement, minimum vitamin-A requirement, minimum vitamin-C requirement and minimum vitamin-E requirement, with three decision variables namely optimal crop area (A_j), optimal surface water release (S_k) and optimal ground water release (G_k) have been considered. Total twelve plans, six each under full irrigation model and variable irrigation model with different arrangement of constraints have been worked out as follows.

1. **Full Irrigation Model:** In the full irrigation model following six plans has been considered.

Plan 11- Full irrigation model with the use of both surface water and ground water, and with minimum area, minimum energy (calorie), minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 12- Full irrigation model with the use of both surface water and ground water, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraint.

Plan 13- Full irrigation model with the use of both surface water and ground water, but without minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 14- Full irrigation model with the use of surface water only, and with minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 15- Full irrigation model with use of surface water only, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraints.

Plan 16- Full irrigation model with the use of surface water only, but without minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

2. **Variable Irrigation Model:** In the variable irrigation model following six plans has been considered in the similar way as discussed in full irrigation model above.

Plan 21- Variable irrigation model with the use of both surface water and ground water, and with minimum area, minimum energy (calorie), minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 22- Variable irrigation model with the use of both surface water and ground water, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraint.

Plan 23- Variable irrigation model with the use of both surface water and ground water, but without minimum area and minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 24- Variable irrigation model with the use of surface water only, and with minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

Plan 25- Variable irrigation model with the use of surface water only, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraints.

Plan 26- Variable irrigation model with the use of surface water only, but without minimum area and minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints.

A computer software based on linear programming technique named 'LINGO' developed by Lindo system, USA is used to solve linear programming model formulated under various plans as enlisted above. Sample input files for linear programming solved with 'LINGO' package of Plan 11 and Plan 21 and their output files are enclosed in Appendix-3.

7.2 RESULTS

7.2.1 RESULT OF PLAN 11

Plan 11 is a full irrigation model with the use of both surface water and ground water, and with minimum area, minimum energy (calorie), minimum protein, minimum minerals and minimum vitamins requirement constraints. The objective function as shown in Equation No. 6.17 in section 6.7.1 has been solved with the following linear constraints.

(i) Irrigation requirement constraints
(ii) Land availability constraints
(iii) Surface water availability constraints
(iv) Ground water availability constraints
(v) Minimum area constraints
(vi) Minimum energy requirement constraint
(vii) Minimum protein requirement constraint
(viii) Minimum calcium requirement constraint
(ix) Minimum iron requirement constraint
(x) Minimum vitamin-A requirement constraint
(xi) Minimum vitamin-C requirement constraint
(xii) Minimum vitamin-E requirement constraint

The results obtained are analyzed and presented in Table no. 7.1.

7.2.2 RESULT OF PLAN 12

Plan 12 is a full irrigation model with the use of both surface water and ground water, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraint. In this plan the objective function is same as used in Plan 11. All the constraints as used in Plan 11 except minimum area constraint have been imposed. The results obtained are analyzed and presented in Table no. 7.2.

7.2.3 RESULT OF PLAN 13

Plan 13 is a full irrigation model with the use of both surface water and ground water, but without minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. In this plan the objective function is same as used in Plan 11. All the constraints as used in Plan 11 except minimum area, minimum calorie, minimum protein, minimum minerals and minimum vitamins requirement constraints have been imposed. The results obtained are analyzed and presented in Table no. 7.3.

Table 7.1: Analysis of result of Plan 11

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	1438
A13	Maize (local)	
A14	Maize (Improved)	
A15	Vegetables	3362
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	983
A22	Oilseed	
A23	Lentil	
A24	Other pulses	1008
A25	potato	53
A26	Vegetables	2756
	Subtotal	4800
	Spring Crops	
A31	Maize (Spring)	155
A32	Paddy Rice (Spring)	
A33	Sunflower	1073
A34	Vegetables (Spring)	2536
	Subtotal	3764

Water Consumption:

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	315		315
February	160		160
March	400		400
April	456	448	905
May	1002		1002
June	119		119
July	517		517
August	270		270
September	275		275
October	307		307
November	456		456
December	288		288
Total	4565	448	5014

Area under Summer Crops =	4800	ha
Area under Winter Crops=	4800	ha
Area under Spring Crops =	3764	ha
Total Area =	13364	ha
Cropping Intensity =	278	%
Net Benefits in Rs. =	1.18E+09	
Net Benefits in Rs./ ha. =	88636.64	
Surface Water Utilized =	4565	ha-m
Ground Water Utilized =	448	ha-m
Total Water Utilized =	5014	ha-m
Average Water Utilized/ha =	0.3752	ha-m
Average Surface Water Utilized/ha =	0.3416	ha-m
Average Ground Water Utilized/ha =	0.0336	ha-m
Net Benefits in Rs./ ha-m of Water Utilized =	236248.22	

Table 7.2: Analysis of result of Plan 12

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	
A13	Maize (local)	
A14	Maize (Improved)	
A15	Vegetables	4800
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	
A22	Oilseed	
A23	Lentil	
A24	Other pulses	
A25	potato	
A26	Vegetables	4800
	Subtotal	4800
	Spring Crops	
A31	Maize (Spring)	
A32	Paddy Rice (Spring)	
A33	Sunflower	
A34	Vegetables (Spring)	4800
	Subtotal	4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	293		293
February	153		153
March	471	13	484
April	456	546	1002
May	1182	106	1288
June			0
July			0
August			0
September			0
October			0
November	456	6	462
December	316		316
Total	3328	670	3998

Area under Summer Crops =	4800	ha
Area under Winter Crops=	4800	ha
Area under Spring Crops =	4800	ha
Total Area =	14400	ha
Cropping Intensity =	300	%
Net Benefits in Rs. =	1.82E+09	
Net Benefits in Rs./ ha. =	126045.49	
Surface Water Utilized =	3328	ha-m
Ground Water Utilized =	670	ha-m
Total Water Utilized =	3998	ha-m
Average Water Utilized/ha =	0.2776	ha-m
Average Surface Water Utilized/ha =	0.2311	ha-m
Average Ground Water Utilized/ha =	0.0465	ha-m
Net Benefits in Rs./ ha-m of Water Utilized =	453975.30	

Table 7.3: Analysis of result of Plan 13

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	
A13	Maize (local)	
A14	Maize (Improved)	
A15	Vegetables	4800
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	
A22	Oilseed	
A23	Lentil	
A24	Other pulses	
A25	potato	
A26	Vegetables	4800
	Subtotal	4800
	Spring Crops	
A31	Maize (Spring)	
A32	Paddy Rice (Spring)	
A33	Sunflower	
A34	Vegetables (Spring)	4800
	Subtotal	4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	293		293
February	153		153
March	471	13	484
April	456	546	1002
May	1182	106	1288
June			0
July			0
August			0
September			0
October			0
November	456	6	462
December	316		316
Total	3328	670	3998

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 4800 ha
Total Area = 14400 ha
Cropping Intensity = 300 %
Net Benefits in Rs. = 1.82E+09
Net Benefits in Rs./ ha. = 126045.49
Surface Water Utilized = 3328 ha-m
Ground Water Utilized = 670 ha-m
Total Water Utilized = 3998 ha-m
Average Water Utilized/ha = 0.2776 ha-m
Average Surface Water Utilized/ha = 0.2311 ha-m
Average Ground Water Utilized/ha = 0.0465 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 453975.30

7.2.4 RESULT OF PLAN 14

Plan 14 is a full irrigation model with the use of surface water only, and with minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. In this plan all other terms of the objective function and constraints are similar to Plan 11 except the terms having ground water (G_k). Linear constraints that have been solved in this plan are listed below.

(i) Irrigation requirement constraints
(ii) Land availability constraints
(iii) Surface water availability constraints
(iv) Minimum area constraints
(v) Minimum energy requirement constraint
(vi) Minimum protein requirement constraint
(vii) Minimum calcium requirement constraint
(viii) Minimum iron requirement constraint
(ix) Minimum vitamin-A requirement constraint
(x) Minimum vitamin-C requirement constraint
(xi) Minimum vitamin-E requirement constraint

The results obtained are analyzed and presented in Table no. 7.4.

7.2.5 RESULT OF PLAN 15

Plan 15 is a full irrigation model with use of surface water only, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraints. In this plan the objective function is same as used in Plan 14. All the constraints as used in Plan 14 except minimum area constraint have been imposed. The results obtained are analyzed and presented in Table no. 7.5.

7.2.6 RESULT OF PLAN 16

Plan 16 is a full irrigation model with the use of surface water only, without minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. All the constraints as used in Plan 14 except minimum area, minimum calorie, minimum protein, minimum minerals and minimum vitamins requirement constraints have been imposed. The results obtained are analyzed and presented in Table no. 7.6.

Table 7.4: Analysis of result of Plan 14

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	1438
A13	Maize (local)	
A14	Maize (Improved)	155
A15	Vegetables	3207
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	983
A22	Oilseed	4
A23	Lentil	1008
A24	Other pulses	
A25	potato	53
A26	Vegetables	2752
	Subtotal	4800
	Spring Crops	
A31	Maize (Spring)	
A32	Paddy Rice (Spring)	
A33	Sunflower	1069
A34	Vegetables (Spring)	268
	Subtotal	1337

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	310		310
February	213		213
March	160		160
April	456		456
May	324		324
June	119		119
July	517		517
August	270		270
September	275		275
October	307		307
November	456		456
December	291		291
Total	3697	0	3697

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 1337 ha
Total Area = 10937 ha
Cropping Intensity = 228 %
Net Benefits in Rs. = 9.50E+08
Net Benefits in Rs./ ha. = 86906.75
Surface Water Utilized = 3697 ha-m
Ground Water Utilized = 0 ha-m
Total Water Utilized = 3697 ha-m
Average Water Utilized/ha = 0.3380 ha-m
Average Surface Water Utilized/ha = 0.3380 ha-m
Average Ground Water Utilized/ha = 0.0000 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 257097.408

Table 7.5: Analusis of result of Plan 15

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	
A13	Maize (local)	
A14	Maize (Improved)	
A15	Vegetables	4800
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	
A22	Oilseed	
A23	Lentil	
A24	Other pulses	
A25	potato	
A26	Vegetables	4714
	Subtotal	4714
	Spring Crops	
A31	Maize (Spring)	
A32	Paddy Rice (Spring)	
A33	Sunflower	
A34	Vegetables (Spring)	1771
	Subtotal	1771

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	288		288
February	150		150
March	181		181
April	456		456
May	492		492
June			0
July			0
August			0
September			0
October			0
November	456		456
December	310		310
Total	2333	0	2333

Area under Summer Crops =	4800	ha
Area under Winter Crops=	4714	ha
Area under Spring Crops =	1771	ha
Total Area =	11285	ha
Cropping Intensity =	235	%
Net Benefits in Rs. =	1.51E+09	
Net Benefits in Rs./ ha. =	133908.23	
Surface Water Utilized =	2333	ha-m
Ground Water Utilized =	0	ha-m
Total Water Utilized =	2333	ha-m
Average Water Utilized/ha =	0.2067	ha-m
Average Surface Water Utilized/ha =	0.2067	ha-m
Average Ground Water Utilized/ha =	0	ha-m
Net Benefits in Rs./ ha-m of Water Utilized =	647706.658	

Table 7.6: Analysis of result of Plan 16

Crop Area

Crop No.	Name of Crop	Area in ha
	Summer Crops	
A11	Paddy rice (local)	
A12	Paddy rice (Improved)	
A13	Maize (local)	
A14	Maize (Improved)	
A15	Vegetables	4800
A16	Sugarcane	
	Subtotal	4800
	Winter crops	
A21	Wheat	
A22	Oilseed	
A23	Lentil	
A24	Other pulses	
A25	potato	
A26	Vegetables	4714
	Subtotal	4714
	Spring Crops	
A31	Maize (Spring)	
A32	Paddy Rice (Spring)	
A33	Sunflower	
A34	Vegetables (Spring)	1771
	Subtotal	1771

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	288		288
February	150		150
March	181		181
April	456		456
May	492		492
June			0
July			0
August			0
September			0
October			0
November	456		456
December	310		310
Total	2333	0	2333

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4714 ha
Area under Spring Crops = 1771 ha
Total Area = 11285 ha
Cropping Intensity = 235 %
Net Benefits in Rs. = 1.51E+09
Net Benefits in Rs./ ha. = 133908.23
Surface Water Utilized = 2333 ha-m
Ground Water Utilized = 0 ha-m
Total Water Utilized = 2333 ha-m
Average Water Utilized/ha = 0.2067 ha-m
Average Surface Water Utilized/ha = 0.2067 ha-m
Average Ground Water Utilized/ha = 0 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 647706.66

7.2.7 RESULT OF PLAN 21

Plan 21 is a variable irrigation model with the use of both surface water and ground water, and with minimum area, minimum energy (calorie), minimum protein, minimum minerals and minimum vitamins requirement constraints. The objective function as shown in equation no. 6.81 in section 6.8.1 has been solved with the following linear constraints.

(i) Irrigation requirement constraints
(ii) Land availability constraints
(iii) Surface water availability constraints
(iv) Ground water availability constraints
(v) Minimum area constraints
(vi) Minimum energy requirement constraint
(vii) Minimum protein requirement constraint
(viii) Minimum calcium requirement constraint
(ix) Minimum iron requirement constraint
(x) Minimum vitamin-A requirement constraint
(xi) Minimum vitamin-C requirement constraint
(xii) Minimum vitamin-E requirement constraint

The results obtained are analyzed and presented in Table no. 7.7.

7.2.8 RESULT OF PLAN 22

Plan 22 is a variable irrigation model with the use of both surface water and ground water, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraint. In this plan the objective function is same as used in Plan 21. All the constraints as used in Plan 21 except minimum area constraint have been imposed. The results obtained are analyzed and presented in Table no. 7.8.

7.2.9 RESULT OF PLAN 23

Plan 23 is a variable irrigation model with the use of both surface water and ground water, but without minimum area and minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. In this plan the objective function is same as used in Plan 21. All the constraints as used in Plan 21 except minimum area, minimum calorie, minimum protein, minimum minerals and minimum vitamins requirement constraints have been imposed. The results obtained are analyzed and presented in Table no. 7.9.

Table 7.7: Analysis of result of Plan 21

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100% (1)	75% (2)	50% (3)	25% (4)	0% (5)	
	Summer Crops						
A11	Paddy rice (local)						
A12	Paddy rice (Improved)	1438					1438
A13	Maize (local)						
A14	Maize (Improved)						
A15	Vegetables	3362					3362
A16	Sugarcane						
	Subtotal	4800					4800
	Winter crops						
A21	Wheat	983					983
A22	Oilseed						
A23	Lentil						
A24	Other pulses	1008					1008
A25	potato	53					53
A26	Vegetables	2756					2756
	Subtotal	4800					4800
	Spring Crops						
A31	Maize (Spring)	155					155
A32	Paddy Rice (Spring)						
A33	Sunflower	1073					1073
A34	Vegetables (Spring)	2536					2536
	Subtotal	3764					3764

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	315		315
February	160		160
March	400		400
April	456	448	905
May	1002		1002
June	119		119
July	517		517
August	270		270
September	275		275
October	307		307
November	456		456
December	288		288
Total	4565	448	5014

Area under Summer Crops =	4800	ha
Area under Winter Crops=	4800	ha
Area under Spring Crops =	3764	ha
Total Area =	13364	ha
Cropping Intensity =	278	%
Net Benefits in Rs. =	1.18E+09	
Net Benefits in Rs./ ha. =	88636.64	
Surface Water Utilized =	4565	ha-m
Ground Water Utilized =	448	ha-m
Total Water Utilized =	5014	ha-m
Average Water Utilized/ha =	0.3752	ha-m
Average Surface Water Utilized/ha =	0.3416	ha-m
Average Ground Water Utilized/ha =	0.0336	ha-m
Net Benefits in Rs./ ha-m of Water Utilized =	236248.22	

Table 7.8: Analysis of result of Plan 22

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100%	75%	50%	25%	0%	
	Summer Crops						
A11	Paddy rice (local)						0
A12	Paddy rice (Improved)						0
A13	Maize (local)						0
A14	Maize (Improved)						0
A15	Vegetables	4800					4800
A16	Sugarcane						0
	Subtotal	4800					4800
	Winter crops						
A21	Wheat						0
A22	Oilseed						0
A23	Lentil						0
A24	Other pulses						0
A25	potato						0
A26	Vegetables	4800					4800
	Subtotal	4800					4800
	Spring Crops						
A31	Maize (Spring)						0
A32	Paddy Rice (Spring)						0
A33	Sunflower						0
A34	Vegetables (Spring)	4800					4800
	Subtotal	4800					4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	293		293
February	153		153
March	471	13	484
April	456	546	1002
May	1182	106	1288
June			0
July			0
August			0
September			0
October			0
November	456	6	462
December	316		316
Total	3328	670	3998

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 4800 ha
Total Area = 14400 ha
Cropping Intensity = 300 %
Net Benefits in Rs. = 1.82E+09
Net Benefits in Rs./ ha. = 126045.49
Surface Water Utilized = 3328 ha-m
Ground Water Utilized = 670 ha-m
Total Water Utilized = 3998 ha-m
Average Water Utilized/ha = 0.2776 ha-m
Average Surface Water Utilized/ha = 0.2311 ha-m
Average Ground Water Utilized/ha = 0.0465 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 453975.30

Table 7.9: Analysis of result of Plan 23

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100%	75%	50%	25%	0%	
	Summer Crops						
A11	Paddy rice (local)						
A12	Paddy rice (Improved)						
A13	Maize (local)						
A14	Maize (Improved)						
A15	Vegetables	4800					4800
A16	Sugarcane						
	Subtotal	4800					4800
	Winter crops						
A21	Wheat						
A22	Oilseed						
A23	Lentil						
A24	Other pulses						
A25	potato						
A26	Vegetables	4800					4800
	Subtotal	4800					4800
	Spring Crops						
A31	Maize (Spring)						
A32	Paddy Rice (Spring)						
A33	Sunflower						
A34	Vegetables (Spring)	4800					4800
	Subtotal	4800					4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	293		293
February	153		153
March	471	13	484
April	456	546	1002
May	1182	106	1288
June			
July			
August			
September			
October			
November	456	6	462
December	316		316
Total	3328	670	3998

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 4800 ha
Total Area = 14400 ha
Cropping Intensity = 300 %
Net Benefits in Rs. = 1.82E+09
Net Benefits in Rs./ ha. = 126045.49
Surface Water Utilized = 3328 ha-m
Ground Water Utilized = 670 ha-m
Total Water Utilized = 3998 ha-m
Average Water Utilized/ha = 0.2776 ha-m
Average Surface Water Utilized/ha = 0.2311 ha-m
Average Ground Water Utilized/ha = 0.0465 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 453975.30

7.2.10 RESULT OF PLAN 24

Plan 24 is a variable irrigation model with the use of surface water only, and with minimum area, minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. In this plan all other terms of the objective function and constraints are similar to Plan 21 except the terms having ground water (G_k). Linear constraints that have been solved in this plan are listed below.

(i) Irrigation requirement constraints
(ii) Land availability constraints
(iii) Surface water availability constraints
(iv) Minimum area constraints
(v) Minimum energy requirement constraint
(vi) Minimum protein requirement constraint
(vii) Minimum calcium requirement constraint
(viii) Minimum iron requirement constraint
(ix) Minimum vitamin-A requirement constraint
(x) Minimum vitamin-C requirement constraint
(xi) Minimum vitamin-E requirement constraint

The results obtained are analyzed and presented in Table no. 7.10.

7.2.11 RESULT OF PLAN 25

Plan 25 is a variable irrigation model with the use of surface water only, and with minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints but without minimum area constraints. In this plan the objective function is same as used in Plan 24. All the constraints as used in Plan 24 except minimum area constraint have been imposed. The results obtained are analyzed and presented in Table no. 7.11.

7.2.12 RESULT OF PLAN 26

Plan 26 is a variable irrigation model with the use of surface water only, but without minimum area and minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints. All the constraints as used in Plan 24 except minimum area, minimum calorie, minimum protein, minimum minerals and minimum vitamins requirement constraints have been imposed. The results obtained are analyzed and presented in Table no. 7.12.

Table 7.10: Analysis of result of Plan 24

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100%	75%	50%	25%	0%	
	Summer Crops						
A11	Paddy rice (local)						0
A12	Paddy rice (Improved)	1438					1438
A13	Maize (local)						0
A14	Maize (Improved)						0
A15	Vegetables	3362					3362
A16	Sugarcane						0
	Subtotal	4800					4800
	Winter crops						
A21	Wheat	983					983
A22	Oilseed						0
A23	Lentil						0
A24	Other pulses	1008					1008
A25	potato	53					53
A26	Vegetables	2756					2756
	Subtotal	4800					4800
	Spring Crops						
A31	Maize (Spring)					155	155
A32	Paddy Rice (Spring)						0
A33	Sunflower					1073	1073
A34	Vegetables (Spring)		2012	524			2536
	Subtotal		2012	524		1228	3764

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	315		315
February	160		160
March	212		212
April	456		456
May	492		492
June	119		119
July	517		517
August	270		270
September	275		275
October	307		307
November	456		456
December	288		288
Total	3867	0	3867

Area under Summer Crops =	4800 ha
Area under Winter Crops=	4800 ha
Area under Spring Crops =	3764 ha
Total Area =	13364 ha
Cropping Intensity =	278 %
Net Benefits in Rs. =	1.15E+09
Net Benefits in Rs./ ha. =	85900.93
Surface Water Utilized =	3867 ha-m
Ground Water Utilized =	0 ha-m
Total Water Utilized =	3867 ha-m
Average Water Utilized/ha =	0.2894 ha-m
Average Surface Water Utilized/ha =	0.2894 ha-m
Average Ground Water Utilized/ha =	0 ha-m
Net Benefits in Rs./ ha-m of Water Utilized =	296873.72

Table 7.11: Analysis of result of Plan 25

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100%	75%	50%	25%	0%	
	Summer Crops						
A11	Paddy rice (local)						0
A12	Paddy rice (Improved)						0
A13	Maize (local)						0
A14	Maize (Improved)						0
A15	Vegetables	4800					4800
A16	Sugarcane						0
	Subtotal	4800					4800
	Winter crops						
A21	Wheat						0
A22	Oilseed						0
A23	Lentil						0
A24	Other pulses						0
A25	potato						0
A26	Vegetables	4457	343				4800
	Subtotal	4457	343				4800
	Spring Crops						
A31	Maize (Spring)						0
A32	Paddy Rice (Spring)						0
A33	Sunflower						0
A34	Vegetables (Spring)			2284	2516		4800
	Subtotal	0	0	2284	2516	0	4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	288		288
February	150		150
March	181		181
April	456		456
May	492		492
June			0
July			0
August			0
September			0
October			0
November	456		456
December	310		310
Total	2333	0	2333

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 4800 ha
Total Area = 14400 ha
Cropping Intensity = 300 %
Net Benefits in Rs. = 1.70E+09
Net Benefits in Rs./ ha. = 117907.92
Surface Water Utilized = 2333 ha-m
Ground Water Utilized = 0 ha-m
Total Water Utilized = 2333 ha-m
Average Water Utilized/ha = 0.1620 ha-m
Average Surface Water Utilized/ha = 0.1620 ha-m
Average Surface Water Utilized/ha = 0 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 727725.20

Table 7.12: Analysis of result of Plan 26

Crop Area

Crop No.	Name of Crop	Crop Area in ha with the irrigation levels of					Total crop area in ha
		100%	75%	50%	25%	0%	
	Summer Crops						
A11	Paddy rice (local)						0
A12	Paddy rice (Improved)						0
A13	Maize (local)						0
A14	Maize (Improved)						0
A15	Vegetables	4800					4800
A16	Sugarcane						0
	Subtotal	4800					4800
	Winter crops						
A21	Wheat						0
A22	Oilseed						0
A23	Lentil						0
A24	Other pulses						0
A25	potato						0
A26	Vegetables	4457	343				4800
	Subtotal	4457	343				4800
	Spring Crops						
A31	Maize (Spring)						0
A32	Paddy Rice (Spring)						0
A33	Sunflower						0
A34	Vegetables (Spring)			2284	2516		4800
	Subtotal	0	0	2284	2516	0	4800

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	288		288
February	150		150
March	181		181
April	456		456
May	492		492
June			0
July			0
August			0
September			0
October			0
November	456		456
December	310		310
Total	2333	0	2333

Area under Summer Crops = 4800 ha
Area under Winter Crops= 4800 ha
Area under Spring Crops = 4800 ha
Total Area = 14400 ha
Cropping Intensity = 300 %
Net Benefits in Rs. = 1.70E+09
Net Benefits in Rs./ ha. = 117907.92
Surface Water Utilized = 2333 ha-m
Ground Water Utilized = 0 ha-m
Total Water Utilized = 2333 ha-m
Average Water Utilized/ha = 0.1620 ha-m
Average Surface Water Utilized/ha = 0.1620 ha-m
Average Ground Water Utilized/ha = 0 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 727725.20

7.3 DISCUSSION OF RESULTS

The existing cropping pattern has been taken into account while suggesting the optimal cropping pattern for the command area. Table no. 7.13 shows the results of existing cropping pattern. For comparison between the existing plan and the proposed twelve plans a table of abstract of analysis of results is prepared and presented in Table no. 7.14.

Table 7.13: Analysis of existing cropping pattern

Crop Area

Crop No.	Name of Crops	Crop Area in ha with the irrigation		Total crop area in ha
		100% (1)	0% (5)	
	Summer Crops			
A11	Paddy rice (local)	267.3		267.3
A12	Paddy rice (Improved)	3845.0	232.1	4077.1
A13	Maize (local)	158.1		158.1
A14	Maize (Improved)	10.8	71.6	82.3
A15	Vegetables		66.2	66.2
A16	Sugarcane		1.2	1.2
	Subtotal	4281.1	371.2	4652.3
	Winter crops			
A21	Wheat	3842.5	150.6	3993.1
A22	Oilseed	69.1	67.9	137.0
A23	Lentil	280.1	10.8	290.9
A24	Other pulses	2.9		2.9
A25	potato	89.4	24.0	113.4
A26	Vegetables	51.7	24.4	76.1
	Subtotal	4335.7	277.7	4613.4
	Spring Crops			
A31	Maize (Spring)	2.9		2.9
A32	Paddy Rice (Spring)	43.0		43.0
A33	Sunflower	8.3		8.3
A34	Vegetables (Spring)	51.0		51.0
	Subtotal	105.2		105.2

Water Consumption

Month	Water Utilized in ha-m		
	Surface Water	Ground Water	Total Water
January	306		306
February	291		291
March	147		147
April	45		45
May	41		41
June	329		329
July	1393		1393
August	819		819
September	787		787
October	100		100
November	456		456
December	226		226
Total	4940	0	4940

Area under Summer Crops = 4652 ha
Area under Winter Crops= 4613 ha
Area under Spring Crops = 105 ha
Total Area = 9371 ha
Cropping Intensity = 195 %
Net Benefits in Rs. = 1.54E+08
Net Benefits in Rs./ ha. = 16396.38
Surface Water Utilized = 4940 ha-m
Ground Water Utilized = 0 ha-m
Total Water Utilized = 4940 ha-m
Average Water Utilized/ha = 0.5272 ha-m
Average Surface Water Utilized/ha = 0.5272 ha-m
Average Ground Water Utilized/ha = 0 ha-m
Net Benefits in Rs./ ha-m of Water Utilized = 31103.18

Table 7.14: Abstract of analysis of results

Sl. No.	Name of the item	Unit	Existing	Plan 11	Plan 12	Plan 13	Plan 14	Plan 15	Plan 16	Plan 21	Plan22	Plan 23	Plan 24	Plan 25	Plan 26
1	Net benefit	Rs	1.54E+08	1.18E+09	1.82E+09	1.82E+09	9.50E+08	1.51E+09	1.51E+09	1.18E+09	1.82E+09	1.82E+09	1.15E+09	1.70E+09	1.70E+09
2	Net benefit / Ha	Rs	16396	88637	126045	126045	86907	133908	133908	88637	126045	126045	85901	117908	117908
3	Net benefit / ha-m of water utilized	Rs	31103	236248	453975	453975	257097	647707	647707	236248	453975	453975	296874	727725	727725
4	Area under summer crops	ha	4652	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800
5	Area under winter crops	ha	4613	4800	4800	4800	4800	4714	4714	4800	4800	4800	4800	4800	4800
6	Area under spring crops	ha	105	3764	4800	4800	1337	1771	1771	3764	4800	4800	3764	4800	4800
7	Total crop area	ha	9371	13364	14400	14400	10937	11285	11285	13364	14400	14400	13364	14400	14400
8	Cropping intensity	%	195	278	300	300	228	235	235	278	300	300	278	300	300
9	Surface water utilized	Ha-m	4940	4565	3328	3328	3697	2333	2333	4565	3328	3328	3867	2333	2333
10	Ground water utilized	Ha-m	0	448	670	670	0	0	0	448	670	670	0	0	0
11	Total water utilized	Ha-m	4940	5014	3998	3998	3697	2333	2333	5014	3998	3998	3867	2333	2333
12	Average water utilized / ha	m	0.527	0.375	0.278	0.278	0.338	0.207	0.207	0.375	0.278	0.278	0.289	0.162	0.162
13	Average surface water utilized / ha	m	0.527	0.342	0.231	0.231	0.338	0.207	0.207	0.342	0.231	0.231	0.289	0.162	0.162
14	Average ground water utilized / ha	m	0.000	0.034	0.047	0.047	0.000	0.000	0.000	0.034	0.047	0.047	0.000	0.000	0.000

The results obtained under different plans are discussed below on the following aspects.

7.3.1 COMPARISON OF RESULTS BETWEEN PAIR OF PLANS SUBJECTED TO SAME CONSTRAINTS

The following pairs of plans have subjected to the same constraints:

(i) Plan 11 and Plan 21
(ii) Plan 12 and Plan 22
(iii) Plan 13 and Plan 23
(iv) Plan 14 and Plan 24
(v) Plan 15 and Plan 25
(vi) Plan 16 and Plan 26

Comparison between these pair of plans is given below.

(i) Comparison between Plan 11 and Plan 21:-

Plan 11 is a full irrigation model and Plan 21 is a variable irrigation model with the use of both surface water and ground water. Both the plans are subjected to the same constraints. The cropping area intensity in both plans is same which is equal to 278 %. Both the plans give identical results. All parameters including average water utilization, surface water utilization, ground water utilization, net benefit, net benefit per ha, net benefit per Ha-m of water utilized are same in both Plan 11 and Plan 21. As there is enough water, the areas under all the crops come under the 1st level (i.e. 100 %) of irrigation in the variable irrigation model (Plan 21). The crop areas under all crops except vegetables are at its minimum requirement levels.

(ii) Comparison between Plan 12 and Plan 22:-

Plan 12 is a full irrigation model and Plan 22 is a variable irrigation model with the use of both surface water and ground water. Both the plans are subjected to the same constraints. The other constraints in these two models are same as in Plan 11 and Plan 21 except the minimum area constraints. There is no minimum area constraint in Plan 12 and Plan 22. The cropping area intensity in both plans is 300 %. Since there is enough water available as in Plan 11 and Plan 21, both the plans give identical results and in the variable irrigation model (Plan 22) the areas under all the crops come under the 1st level of irrigation. As there is no minimum area constraints, vegetables are the only crops in all three summer, winter and spring seasons in both the plans.

(iii) Comparison between Plan 13 and Plan 23:-

Plan 13 is a full irrigation model and Plan 23 is a variable irrigation model with the use of both surface water and ground water. Both the plans are subjected to the same constraints. The other constraints in these two models are same as in Plan 12 and Plan 22 except the minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints; these are absent in both the plans. The cropping area intensity in both plans is 300 %. Since there is also enough water available as in Plan 11 and Plan 21, both the plans give identical results and in the variable irrigation model (Plan 23) the areas under all the crops come under the 1st level of irrigation. As there is no minimum area constraints, vegetables are the only crops in all three summer, winter and spring seasons in both the plans.

(iv) Comparison between Plan 14 and Plan 24:-

Plan 14 is a full irrigation model and Plan 24 is a variable irrigation model with the use of surface water only. Both the plans are subjected to the same constraints. The other constraints in these two models are same as in Plan 11 and Plan 21 except the ground water availability constraints. The cropping area intensity is 228 % and 278 % of Plan 14 and plan 24 respectively. Net benefit, net benefit per Ha-m of water utilized are found more in case of Plan 24 than Plan 14, while net benefit per ha is more in Plan 14 than in Plan 24. In Plan 24 the average water utilization is less than Plan 14. In Plan 24 the areas of summer and winter crops come under 1st level of irrigation but the area of spring maize and spring sunflower come under 5th level of irrigation and the area of spring vegetables come under 2nd and 3rd level of irrigation.

(v) Comparison between Plan 15 and Plan 25:-

Plan 15 is a full irrigation model and Plan 25 is a variable irrigation model with the use of surface water only. Both the plans are subjected to the same constraints. The other constraints in these two models are same as in Plan 14 and Plan 24 but without minimum area constraints which is absent in both the plans. The cropping area intensity is 235 % and 300 % of Plan 15 and plan 25 respectively. Net benefit, net benefit per Ha-m of water utilized are found more in case of Plan 25 than Plan 15, while net benefit per ha is more in Plan 15 than in Plan 25. In Plan 25 the average water utilization is less than Plan 15. Because both the plans are subjected to without minimum area constraints, it is found that vegetables are the only crops in all three summer, winter and spring seasons. In variable irrigation model (Plan 25) the area of all summer vegetables come under the 1st level of irrigation but due to the insufficient water availability, the area of winter vegetables come under 1st and 2nd level of irrigation and the area of spring vegetables come under 3rd and 4th level of irrigation.

(vi) Comparison between Plan 16 and Plan 26:-

Plan 16 is a full irrigation model and Plan 26 is a variable irrigation model with the use of surface water only. Both the plans are subjected to the same constraints. The other constraints in these two models are same as in Plan 15 and Plan 25 but without minimum energy, minimum protein, minimum minerals and minimum vitamins requirement constraints, which are absent in both the plans. The cropping area intensity is 235 % and 300 % of Plan 16 and Plan 26 respectively as in Plan 15 and Plan 25. Other results are also same as in the Plan 15 and Plan 25.

7.3.2 COMPARISON OF RESULTS BETWEEN FULL IRRIGATION MODEL AND VARIABLE IRRIGATION MODEL

It has been observed that under same set of constraints the full irrigation model and variable irrigation model with the use of surface water and ground water, when enough water is available, give the identical results. The plans having identical results are Plan 11 and Plan 21, Plan 12 and Plan 22 and Plan 13 and Plan 23. But in case of the use of surface water only, when the available water is not enough, it has been observed that under same set of constraints variable irrigation model gives more net benefit and net benefit per ha-m of water utilization, while net benefit per ha and average water utilization per ha are less than those of full irrigation model. The pair of plans having such results is Plan 14 and Plan 24, Plan 15 and Plan 25, Plan 16 and Plan 26. Since the net benefit in case of variable irrigation model is more than the full irrigation model, the importance of protective irrigation in the variable irrigation is significant while considering the economic aspects of agriculture. The optimum use of water (quantity of water utilization per ha) in case of variable irrigation model is less than that of full irrigation model. The rest of water therefore can be utilized to irrigate more area instead of providing irrigation as per its requirement. The variable irrigation model gives more return because the water utilization per crop is less. It selects the profitable level of irrigation for crops. Therefore the variable irrigation model is more efficient than the full irrigation model. It is clear from the above discussion that extensive irrigation is more profitable than intensive irrigation. In case of the areas, where water availability is not restricted, intensive irrigation may be preferable.

7.3.3 COMPARISON OF RESULTS BETWEEN PLANS WITH MINIMUM AREA CONSTRAINTS AND WITHOUT MINIMUM AREA CONSTRAINTS

Plans subjected to without minimum area constraints have only vegetable crops in all three summer, winter and spring seasons. Plans subjected to without minimum area constraints have more net benefit, net benefit per ha, net benefit per ha-m of water utilization and less average water utilization per ha than those of the corresponding plans with minimum area constraints. That means Plan 12, Plan 13, Plan 15, Plan 16, Plan 22, Plan 23, Plan 25 and Plan 26 have more net benefit, net benefit per ha, net benefit per ha-m of water utilized and less average water utilization than those Plan 11, Plan 14, Plan 21 and Plan 24 respectively.

7.3.4 COMPARISON OF RESULTS BETWEEN PLANS WITH MINIMUM ENERGY AND NUTRIENTS REQUIREMENT CONSTRAINTS AND WITHOUT MINIMUM ENERGY AND NUTRIENTS REQUIREMENT CONSTRAINTS

Plans subjected to with and without minimum energy, minimum protein, minimum calcium, minimum iron, minimum vitamin-A, minimum vitamin-C and minimum vitamin-E requirement constraints have the results similar to that are discussed in section 7.3.3 above for plans without minimum area constraints. The results shows the maximum net benefits, net benefit per ha and net benefit per ha-m of water utilized through vegetable crops in all three seasons. There is no effect of minimum energy, minimum protein, minimum calcium, minimum iron, minimum vitamin-A, minimum vitamin-C and minimum vitamin-E requirement constraints in the optimum result of the without minimum area plans. That means minimum energy, minimum protein, minimum calcium, minimum iron, minimum vitamin-A, minimum vitamin-C and minimum vitamin-E requirements are satisfied by vegetable crops alone but it neither fulfills the balance diet requirements nor is the food habit of the people of the study area. Therefore, to meet the balance diet requirements and self sufficiency in food, minimum areas may be maintained.

7.3.5 COMPARISON OF RESULTS BETWEEN PLANS WITH THE USE OF BOTH SURFACE WATER AND GROUND WATER AND PLANS WITH THE USE OF SURFACE WATER ONLY

Plans with use of both surface water and ground water have more net benefits, net benefits per ha and less net benefit per ha-m of water utilized than those of plans with the use of surface water only when subjected to the same constraints except Plan 15 and Plan16 which have more benefit per ha than the corresponding Plan 12 and Plan 13 respectively. The average water utilization per ha is less in the plans with the use of surface water only than those of plans with the use of both surface water and ground water. That means plans 11,12,13, 21, 22 and 23 have more net benefit, more average water utilization per ha and less net benefit per ha-m of water utilized than those of plans 14,15,16, 24, 25 and 26 respectively.

7.3.6 COMPARISON OF RESULTS BETWEEN THE EXISTING CROPPING PATTERN AND THE PROPOSED PLANS

Table No. 7.14 shows the abstract of results of existing plan and the plans 11, 12, 13, 14, 15, 16, 21, 22, 23, 24, 25 and 26. Comparison has been made as below:

(i) Self Sufficiency in Food Grains of the Study Area:-

The existing cropping pattern does not satisfy the minimum food requirement of the study area. Among proposed plans 12, 13, 15, 16, 22, 23, 25 and 26 also do not satisfy the minimum food requirement of the study area where as plans 11, 14, 21 and 24 satisfy the minimum food requirement.

(ii) Energy (calorie), Protein, Minerals and Vitamin requirement of the study area:-

It is found that the existing pattern and all the proposed plans are satisfying the energy (calorie), protein, minerals and vitamin requirement of the study area.

(iii) Cropping Area Intensity:-

Figure 7.1 shows the comparison of cropping area intensity among the all plans. It is found that plans 12, 13, 22, 23 ,25 and 26 have 300 % cropping area intensity where as the existing pattern has 195 %, plans 11, 21 and 24 have 278 %, plan 14 has 228 % and plans 15 and 16 have 235 % cropping area intensities respectively.

Figure 7.2 shows the comparison of net benefits among all plans and it is found that plans 12, 13, 22 and 23 show maximum net benefit followed by 25, 26, 15, 16, 11, 21, 24, 14 and the existing pattern at last.

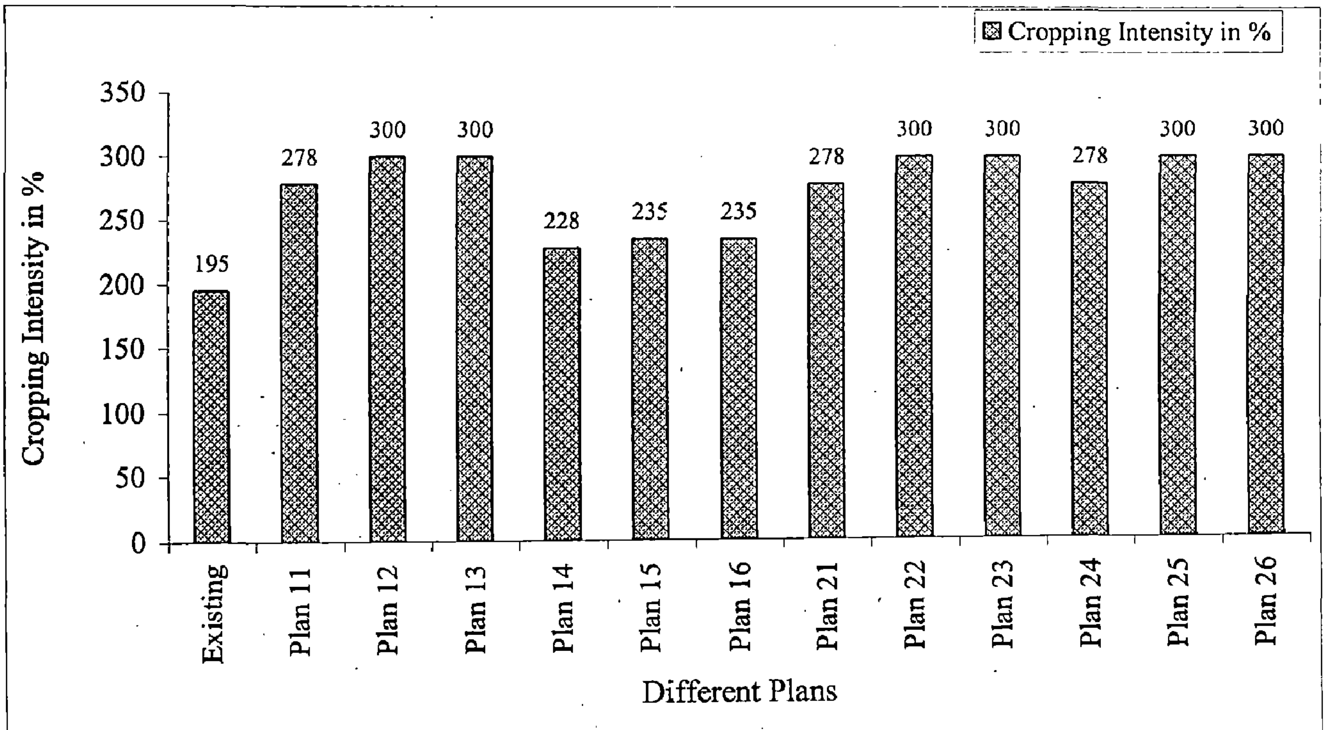

Fig. 7.1: Comparison of cropping intensity

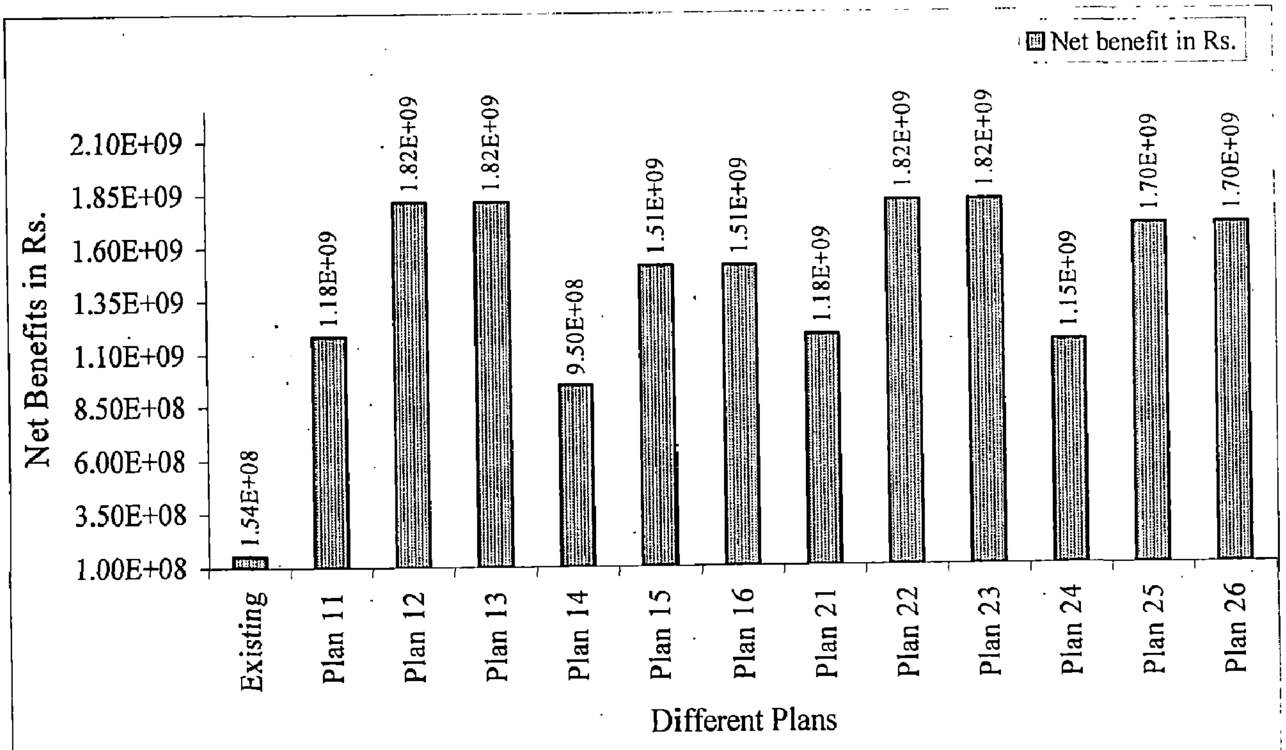

Fig. 7.2: Comparison of net benefits

(v) Average Water Utilization per Hectare:-

Figure 7.3, 7.4 and 7.5 show the comparison of average water utilization per hectare, comparison of surface water utilization per ha and comparison of average ground water utilization per ha among all the plans including existing pattern respectively; and it is found that the existing pattern has the highest average water utilization per ha whereas plans 25 and 26 have the lowest average water utilization per ha.

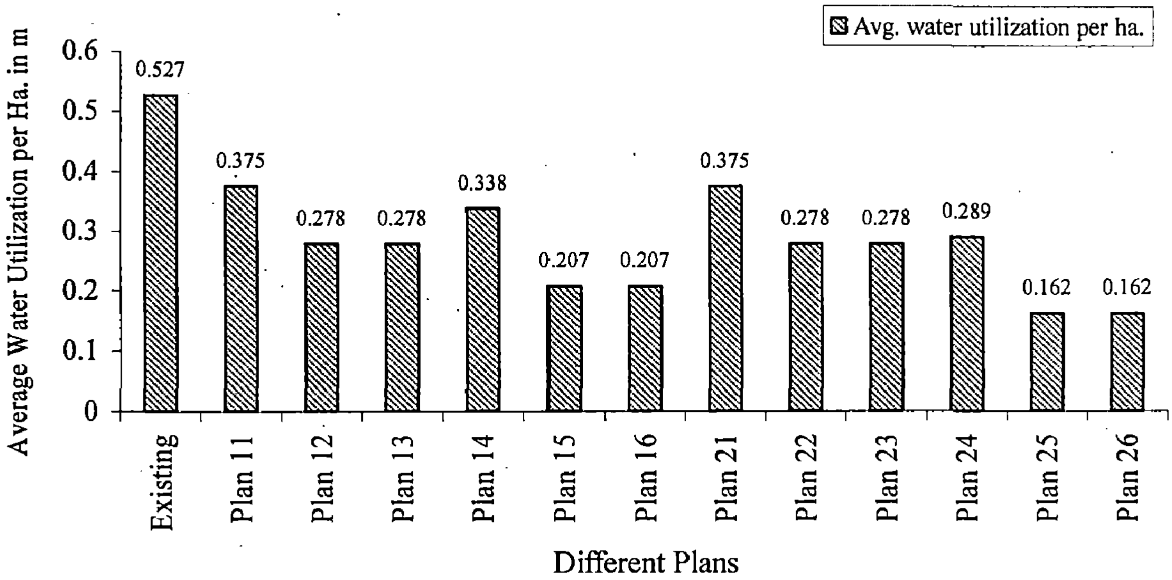

Fig. 7.3: Comparison of avg. water utilization per ha.

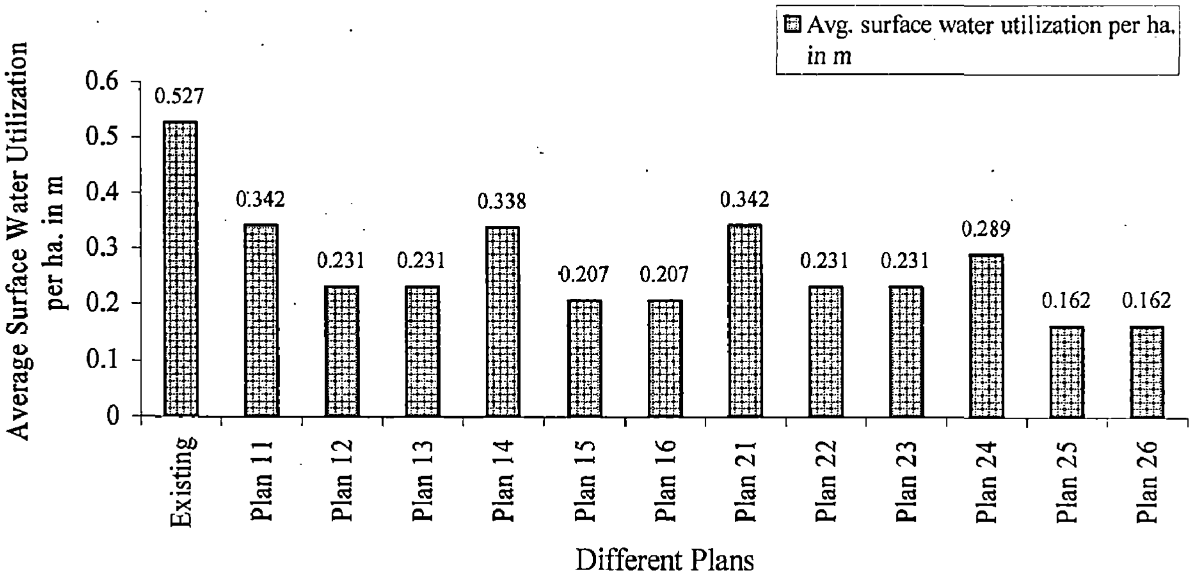

Fig. 7.4: Comparison of avg. surface water utilization per hectare in meter

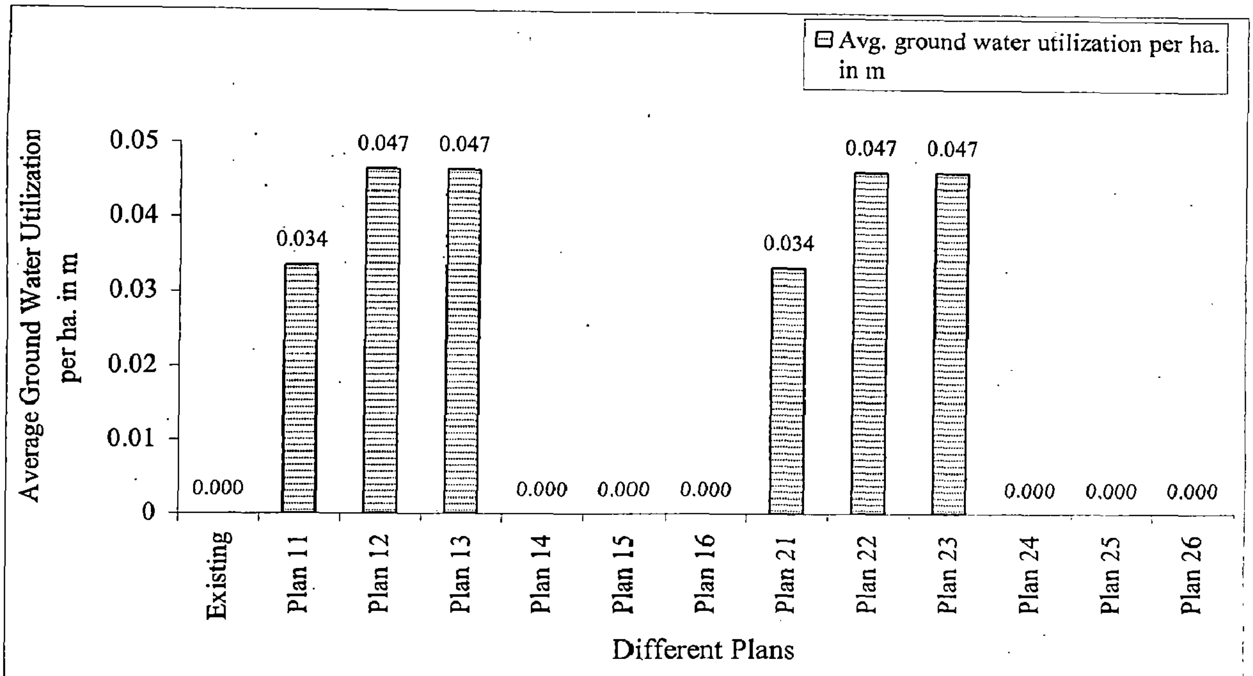

Fig. 7.5: Comparison of avg. ground water utilization per ha.

(vi) Net Benefit per Hectare:-

Figure 7.6 shows the net benefit per hectare for existing pattern and all proposed plans and it is found that plan 15 and 16 have the highest net benefit per ha followed by plans 12, 13, 22, 23, 25, 26, 11, 21, 14, 24 and at last the existing pattern.

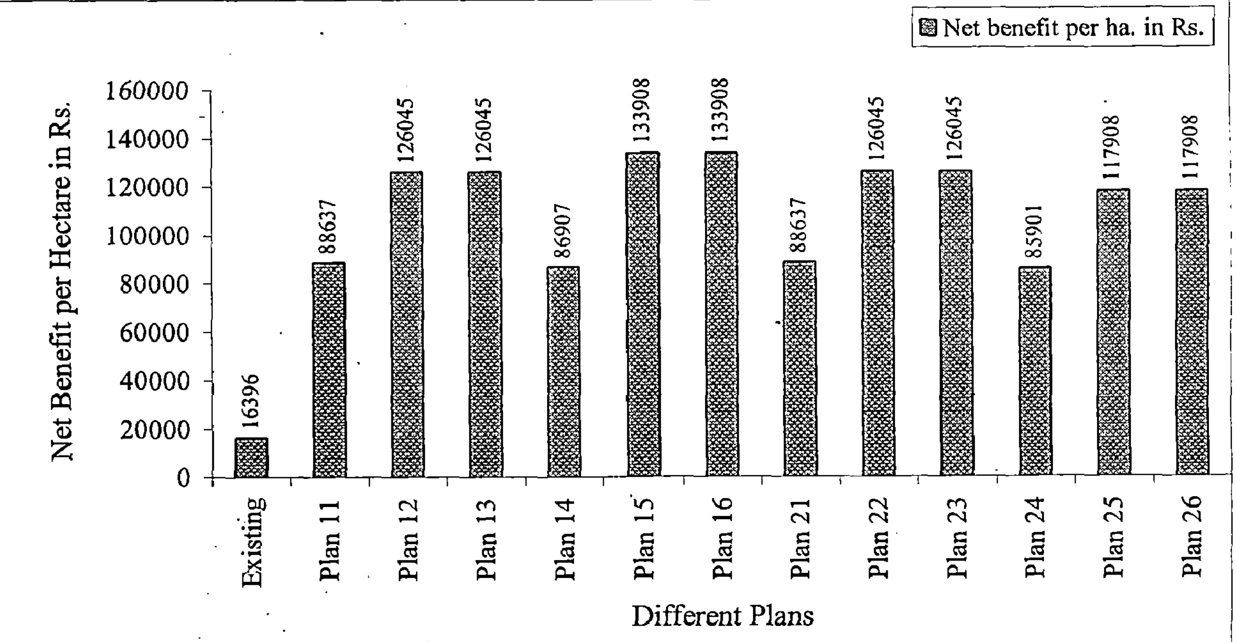

Fig. 7.6: Comparison of net benefit per hectare

(vii) Net Benefit per Ha-m of Water Utilized:-

Figure 7.7 shows the net benefit per hectare-meter of water utilized for existing pattern and all proposed plans and it is found that plans 25 and 26 have the highest net benefit per ha-m of water utilized followed by plans 15 and 16, 12, 13, 22, 23, 24, 14, 11, 21 and at last the existing pattern.

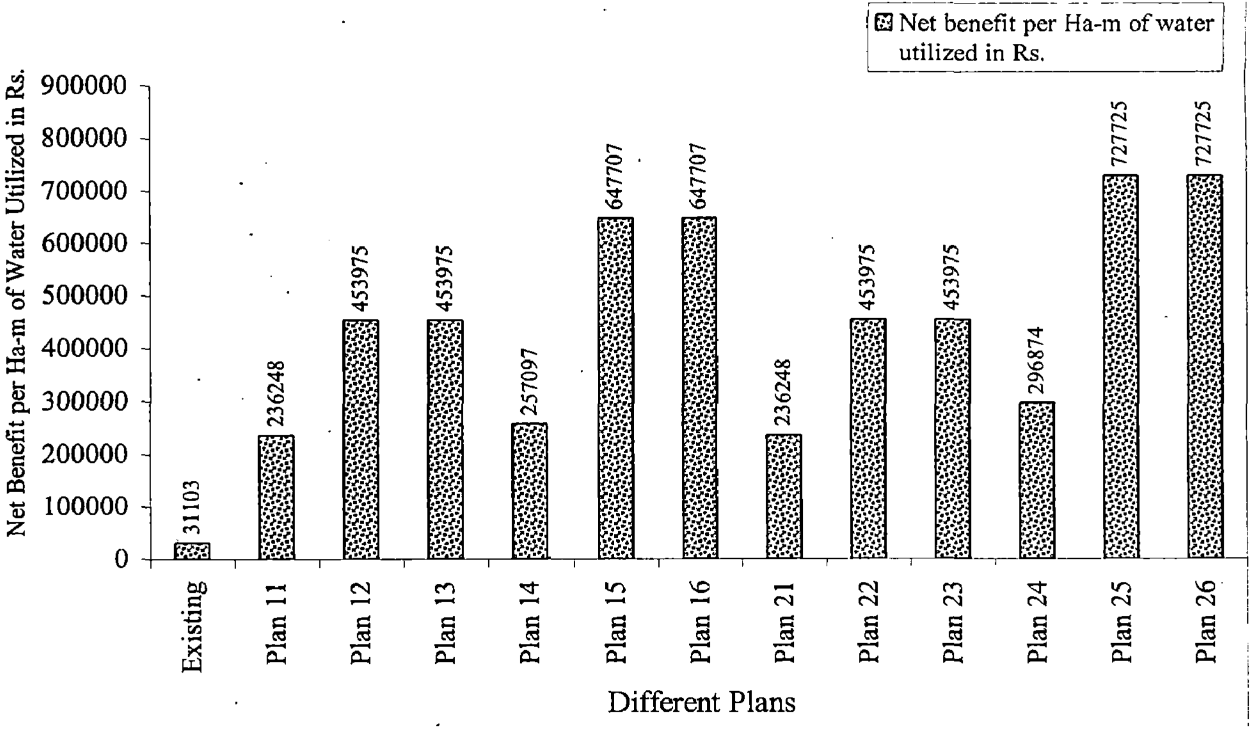

Fig. 7.7: Comparison of net benefit per Ha-m of water utilized

7.3.7 COMPARISON OF OPTIMUM WATER UTILIZED AMONG ALL PLANS

It is noticed that the available surface water is critical in the month of April and November that is 456.19 ha-m (1.76 m^3/sec). Available surface water of these two months is totally utilized in all the plans except the existing plan, where the total available surface water in the month of November was only utilized fully. In other months there is surplus surface water in all the plans. Ground water is utilized for the months of March to May (spring season) and November in plans 11, 12, 13, 21, 22 and 23 but not to full availability level. Therefore there is surplus ground water around the whole year. Plan 14, 15, 16, 24, 25, 26 and the existing pattern utilizes only surface water; there is no ground water utilization.

CHAPTER– VIII

SUMMARY AND CONCLUSIONS

8.1 SUMMARY

In the present study an attempt has been made to develop a plan for optimal cropping pattern to get maximum return from the study area.

8.1.1 OBJECTIVES

The aim of the study is to find out an optimal crop water plan resulting in maximum crop yield, high crop intensity, and increased food production thereby, obtaining maximum net benefits to farmers.

The specific objectives are

a) To compute the crop water requirement and irrigation water requirement of various crops grown in the study area.

b) To select and compute the crop water production function of various crops for different depths of water application and utilize them for developing a variable irrigation model.

c) To find out the optimal cropping pattern.

8.1.2 STUDY AREA

The study area Mahakali Irrigation Project (MIP) Stage-I is located in the Far Western Terai of Nepal, on the left bank of the Mahakali River. The nearest town is Mahendranagar, which is the government centre for both the Kanchanpur District and Mahakali Zone. Stage-I and Stage-II of the Project area is, at present, supplied with water from the Sarda Barrage, constructed in 1928, in accordance with the water sharing agreement made in 1920 between Government of Nepal (GON) and the Government of India (GOI).

Project implementation was commenced in 1971 with design and construction, by the Department of Irrigation (DOI), of the main canal with a capacity of 13 m^3/sec and distribution systems to irrigate a net command area of 5,000 ha. These works were completed in 1975. However, due to water management problems, it was only possible to irrigate 3,400 ha only. To overcome these problems and complete the Project, GON requested assistance from the International Bank for Reconstruction and Development (IBRD). The International

Development Agency (IDA) appraised Stage-I of the Project and a credit agreement was signed by GON in September 1980. Implementation of the main civil works down to tertiary level (both canals and drains) was completed in mid 1987 and a CCA of 4,800 ha were brought under irrigation. All civil works are now being maintained by the Project with the in-field systems being the responsibility of the farmers.

Since completion in 1988, the Stage-I area has been functioning reasonably well. With the implementation of Stage-I, the Mahakali Irrigation Development Board (MIDB) decided that the feasibility of Stage-II should be updated. The update was completed in 1988. Together with the reassessment, the IDA appraised the Stage-II for implementation in May 1988. The implementation met with many problems, but the work was substantially completed in June 1998.

A new Indo-Nepal bilateral treaty was signed on 12 February 1996, which is called the "Treaty for Integrated Development of Mahakali River including Sarda, Tanakpur, and Pancheswor Multi-purpose Project." The new treaty super shades the old 1920 agreement. According to this treaty, the article related to supply of water for Stage–I and Stage–II is 'Nepal shall have the right to a supply of 28.35 m^3/sec (1,000 cusecs) of water from the Sarda Barrage in the wet season (i.e. from 15th May to 15th October) and 4.25 m^3/sec (150 cusecs) in the dry season (i.e. from 16th October to 14th May)'. During the dry season 4.25 m^3/sec will be supplied on a continuous basis or at a rate of 8.5 m^3/sec during alternate 10-days periods.

Prior to the Mahakali Irrigation Project (MIP), the existing irrigation system was operated and maintained by the Department of Irrigation (DOI) till 1979. With the commencement of Stage-I in 1980, the operation of the existing irrigation system came under the control of the Project Manager (PM) who was responsible for managing the system under the governance of the Mahakali Irrigation Development Board (MIDB) up to 1999. In consideration with the changing perspective of time and vision, Government of Nepal dissolved the MIDB in early 2000. At present, the MIP is managed by the Mahakali Irrigation Management Division No. 8.

Up to 1998, MIP received sufficient funds from the World Bank for construction purposes. However, since the completion of development work of the Stage-II, it has experienced some financial hardship. The limited financial resources have adversely affected the organization in its post-construction services such as desilting of the main canals, and handing over of the tertiary canals to the farmers.

The study area is fully connected with the network of roads with the major cities of Nepal. Mahendra Rajmarg, the major national highway of Nepal, passes through the study area. The study area is one of the fast developing areas of the country. The data required for estimation of input coefficients and resource requirements of constraints in the system modeling are available for this study area.

8.1.3 CROP WATER REQUIREMENT

To compute the reference crop evapotranspiration (ET_o), the FAO Penman–Monteith equation has been used as explained in Section 4.2.2 by equation No. 4.3 of Chapter-IV.

The crop coefficient K_c is taken from Table No. 12 of FAO- 56 and modified as discussed in 4.2 of Chapter-IV. Crop Evapotranspiration (ET_{crop}) is computed by multiplying ET_0 with K_c. Net irrigation requirement is determined by taking effective rainfall, ET_{crop} and other requirement such as presowing requirement, transplanting requirement, losses etc. into account as discussed in Section 4.4 of Chapter-IV.

8.1.4 PRODUCTION FUNCTION

Three types of production functions such as Cobb-Douglas, mitscherlich-spillman, function and polynomial production functions were studied.

Out of these production functions, the quadratic production function under the family of polynomial production function was found to be more suitable to get a relationship between quantity of irrigation applied in depth and yield of crops.

Five levels of irrigation have been used for each crop. The first level of irrigation refers to 100 % irrigation, i.e. full irrigation. The fifth level stands for 0 % irrigation, i.e. rainfed. Three intermediate levels are 75 %, 50 % and 25 %. For each level of irrigation the yield has been obtained using production function.

8.1.5 MODEL

Two models namely full irrigation model and variable irrigation model were formulated for the purpose of optimization of cropping pattern. In the full irrigation model the crop gets irrigation up to net irrigation requirement. No choice was given for under irrigation. But in the variable irrigation model five choices of quantity of irrigation were given to each crop. Five types of areas depending on irrigation facilities were suggested for each crop thereby providing a choice for selection of economic use of water resources.

Total twelve plans have been formulated out of which six plans have been taken into account for both surface water and ground water, where as another six plans have been taken into account for surface water only. Different constraints were imposed on these plans to find out the possible result. Figure No. 8.1, 8.2 and 8.3 shows net benefits of different plans.

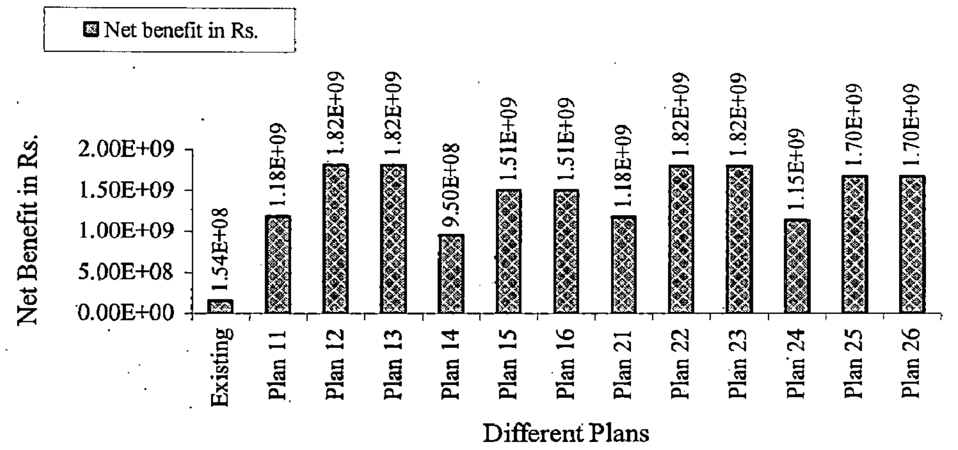

Fig. 8.1: Net benefits of different plans

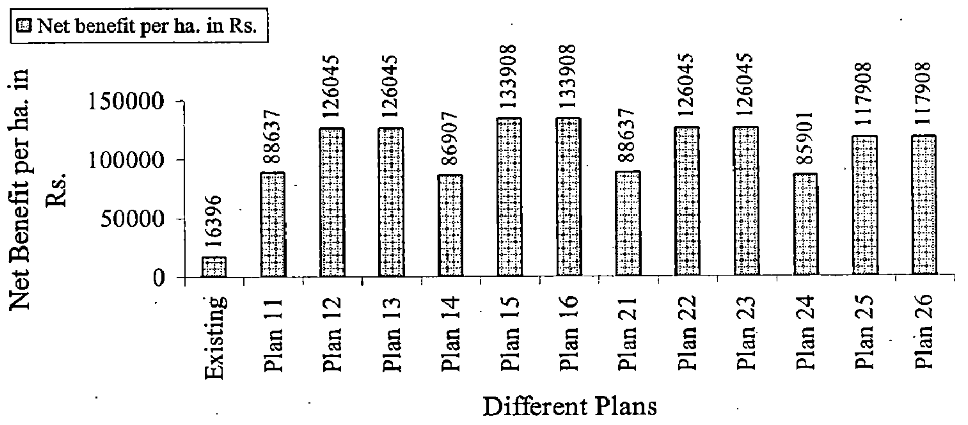

Fig. 8.2: Net benefits per ha. of different plans

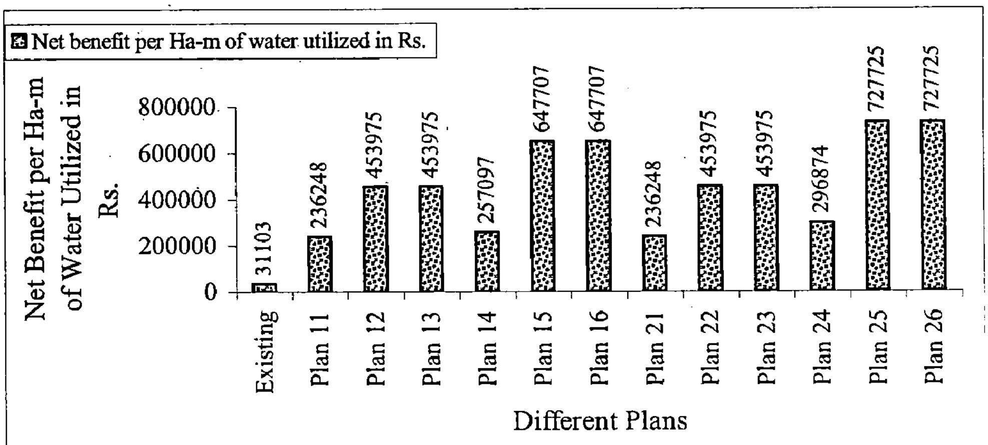

Fig. 8.3:Net benefit per Ha-m of water utilized of different plans

8.1.6 RESULTS AND DISCUSSION

The results obtained under different plans and the existing cropping pattern were analyzed and given in Tables 7.1 to 7.14.

The linear model for optimal cropping pattern has been formulated and solved on the basis of self-sufficiency in food grains of the study area, energy-protein-nutritional requirement, net benefit, net benefit per hectare and net benefit per ha-m of water utilized. The preference to plans to satisfy self-sufficiency in food grains of the study area, energy, protein and nutritional requirement and net benefit, is Plan 11 (or 21), Plan 24 and Plan 14 in descending order. If net benefit is the only criteria then the preference to plans is Plan 12 (or 13 or 22 or 23), Plan 25 (or 26), Plan 15 (or 16), Plan 11 (or 21), Plan 24 and Plan 14 in descending order. If net benefit per hectare is the only criteria then the preference to plans is Plan 15 (or 16), Plan 12 (or 13 or 22 or 23), Plan 25 (or 26), Plan 11 (or 21), Plan 14 and Plan 24 in descending order. If net benefit per hectare per ha-m of water utilization is only the criteria then the preference is Plan 25 (or 26), Plan 15 (or 16), Plan 12 (or 13 or 22 or 23), Plan 24, Plan 14 and Plan 11 (or 21) in descending order. If only surface water use is considered and self sufficiency in food grains of the study area, energy, protein and nutritional requirement and net benefit are the criterions to be satisfied, the preference to plans is Plan 24 and Plan 14 in descending order. If only surface water use is considered, and net benefit is only the criteria, the preference to plans is Plan 25 (or 26), Plan 15 (or 16), Plan 24 and Plan 14 in descending order.

8.2 LIMITATIONS OF THE STUDY

In the present study, the limitations encountered were:

i. Stochastic component is not considered.

ii. Current population was not available, so census data of 2001 has been used for forecasting the population of the study area.

iii. Due to non availability of soil data (area wise) suitable for different crops, this constraint could not be imposed.

8.3 CONCLUSIONS

The following conclusions were drawn for the study area:

(i) The variable irrigation model is more suitable and efficient than full irrigation model while deciding the optimal water use.

(ii) The production function has got a lot of significance to decide the quantity of irrigation water to a crop.

(iii) In the present study use of both surface water and ground water gives maximum net benefit, but in actual practice the ground water of the study area is not explored. So exploration of ground water should be done in the study area.

(iv) At present Plan 24 may be suggested for the study area to satisfy the maximum net benefit and self sufficiency in food. Plan 25 (or 26) may be suggested for maximum net benefits only. Plan 11 (or 21) is suggested for the study area in future when ground water will be explored to satisfy the maximum net benefit and self sufficiency in food. Plan 12 (or 13 or 22 or 23) is suggested for future when ground water will be explored for maximum net benefit only.

(v) Finally, it is suggested in general to provide extensive irrigation facilities instead of intensive irrigation facilities to get more returns from agriculture. Intensive irrigation may be suggested where plenty of water is available at low cost.

8.4 SUGGESTIONS

In order to achieve more precise and realistic results to enhance the present study, and for the future work a few suggestions are enlisted below:

(i) Sensitivity analysis is to be made to how the net return changes when the problem parameters change.

(ii) In the present study only objective is to maximize the net return, but multi objective analysis can be done and the best one can be selected from it.

(iii) Actual measurement by field experiments may be considered to arrive at more precise crop water requirement.

(iv) Models may be devised to determine the optimal timing and level of irrigation.

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APPENDIX– 1

Table E.1: Calculation of potential evapotranspiration by Modified Penman method

Station: Mahendranagar (0105) Latitude : 29° 02' N Elevation : 176 m. amsl Longitude : 80° 13' E

Sl.No.	Descriptions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A.	Given Conditions												
1	Mean Max. Temp., Tmax (0C)	21.80	24.00	29.20	35.30	37.60	36.30	32.80	32.50	32.10	30.70	27.90	23.70
2	Mean Min. Temp., Tmin (0C)	7.00	8.60	12.40	16.90	22.20	24.90	25.40	25.50	23.90	18.50	12.10	7.90
3	Mean Temp. Tmean (0C)	14.40	16.30	20.80	26.10	29.90	30.60	29.10	29.00	28.00	24.60	20.00	15.80
4	Mean Max. Relative Humidity, RHmax (%)	97.00	94.00	86.00	63.00	61.00	76.00	87.00	88.00	89.00	87.00	90.00	95.00
5	Mean Min. Relative Humidity, RH min (%)	75.00	64.00	56.00	39.00	45.00	60.00	77.00	80.00	79.00	73.00	70.00	74.00
6	Mean Relative Humidity, RH mean (%)	86.00	79.00	71.00	51.00	53.00	68.00	82.00	84.00	84.00	80.00	80.00	84.50
7	Mean Rainfall (mm)	24.90	38.70	18.10	18.80	44.30	255.90	531.90	499.00	292.40	34.60	5.20	16.50
8	Mean speed (km/hr)	1.60	2.20	2.70	3.40	3.30	3.20	2.90	2.40	1.80	1.50	1.30	1.50
B.	Calculations												
1	Vapour Pressure (Ea-Ed)												
(i)	Ea at Tmean (Table 5) (mbar)	16.46	18.56	24.60	33.81	42.17	43.90	40.33	40.10	37.80	30.94	23.40	17.96
(ii)	Ed = Ea * RHmean/100 (mbar)	14.16	14.66	17.47	17.24	22.35	29.85	33.07	33.68	31.75	24.75	18.72	15.18
(iii)	Ea - Ed (mbar)	2.30	3.90	7.13	16.57	19.82	14.05	7.26	6.42	6.05	6.19	4.68	2.78
2	Wind function f(u)												
(i)	Wind speed , (U) at 2m height km/day	38.40	52.80	64.80	81.60	79.20	76.80	69.60	57.60	43.20	36.00	31.20	36.00
(ii)	fu = 0.27 (1+U/100) (Table 7)	0.37	0.41	0.44	0.49	0.48	0.48	0.46	0.43	0.39	0.37	0.35	0.37
3	Weighing factor (W)												
(i)	W at Tmean (Table 9)	0.62	0.65	0.70	0.75	0.78	0.79	0.78	0.78	0.77	0.74	0.69	0.64
(ii)	(1-W) (Table 8)	0.38	0.35	0.30	0.25	0.22	0.21	0.22	0.22	0.23	0.26	0.31	0.36
4	Net Radiation Rn												
(i)	Extra Terrestrial radiation Ra (mm/day)-(Table 10)	9.04	10.89	13.25	15.25	16.50	16.90	16.75	15.70	14.00	11.79	9.69	8.54
(ii)	Estimated Sunshine Ratio (n/N)-(Proforma C.1)	0.78	0.79	0.79	0.81	0.75	0.47	0.62	0.47	0.45	0.66	0.84	0.84
(iii)	Rs = (0.25+0.5*n/N) *Ra (mm/day)	5.81	7.03	8.55	9.98	10.34	8.17	9.40	7.62	6.66	6.84	6.47	5.71
(iv)	Rns = 0.75*Rs (mm/day)	4.36	5.27	6.41	7.49	7.76	6.13	7.05	5.72	5.00	5.13	4.85	4.28
	f(t) (Table 12)	13.56	13.86	14.76	15.93	16.68	16.85	16.52	16.50	16.30	15.55	14.60	13.77
	f(Ed) (Table 13)	0.176	0.159	0.136	0.120	0.101	0.097	0.105	0.105	0.110	0.120	0.140	0.162
(v)	Rnl = f(t)*f(Ed)*(0.1+0.9*n/N) (mm/day)	1.92	1.78	1.63	1.58	1.30	0.85	1.14	0.91	0.91	1.29	1.74	1.90
(vi)	Rn = Rns-Rnl (mm/day)	2.44	3.49	4.78	5.91	6.46	5.28	5.91	4.81	4.09	3.84	3.11	2.38
5	Adjustment Factor C	1	1	1	1	1	1	1	1	1	1	1	1
6	Potential Evapotranspiration mm/day ETo = C[W*Rn+(1-W)*f(u)*(Ea-Ed)]	1.84	2.82	4.29	6.45	7.12	5.59	5.34	4.36	3.7	3.44	2.66	1.89

Note: Table No. refer to FAO Irrigation and Drainage paper no. 24

APPENDIX- 2

Table E.2.1: Energy and nutrition requirement computations

Project: Mahakali Irrigation Project

Stage: I

1. Population Distribution

Year of Estimation	Total Population	Male out of Total Population	Female out of Total Population	Age Group 0 - 14 Years				Age Group 15 - 60 Years				Age Group Over 60 Years			
				Male		Female		Male		Female		Male		Female	
				%	Population	%	Population	%	Population	%	Population	%	Population	%	Population
2001	27053	13796	13256	33.3	4594	33.5	4441	60.1	8291	60.8	8060	6.6	911	5.7	756
2007	33195	16929	16266	33.3	5637	33.5	5449	60.1	10174	60.8	9890	6.6	1117	5.7	927
2017	44802	22848	21953	33.3	7608	33.5	7354	60.1	13732	60.8	13347	6.6	1508	5.7	1251
2037	75746	38627	37118	33.3	12863	33.5	12435	60.1	23215	60.8	22568	6.6	2549	5.7	2116

2. Energy and Protien Requirement computions

a) Average Energy Requirement for Age Group 0 - 14 Years:

Averge Energy Req. for Male (Kcal/ day)	Averge Energy Req. for Female (Kcal/ day)	Averge Protien Req. for Male (gm/ day)	Averge Protien Req. for Female (Kcal/ day)	Age Group 0 - 1 Years				Age Group 1 - 5 Years				Age Group 5 - 10 Years				Age Group 10 - 14 Years			
				Male		Female		Male		Female		Male		Female		Male		Female	
				E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)
1807	1657	22.92	23.29	820	13.67	820	13.67	1350	15.5	1350	15.5	1975	24	1775	24	2300	38.5	2025	40

b) Average Energy Requirement for Age Group 15 - 60 Years:

Averge Energy Req. for Male (Kcal/ day)	Averge Energy Req. for Female (Kcal/ day)	Averge Protien Req. for Male (gm/ day)	Averge Protien Req. for Female (Kcal/ day)	Age Group 15 - 18 Years				Age Group 18 - 30 Years				Age Group 30 - 60 Years			
				Male		Female		Male		Female		Male		Female	
				E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)
2944	2332	49.44	41.27	2750	54.00	2150	44.00	3000	49	2350	41	2950	49	2350	41

c) Average Energy Requirement for Age Group Over 60 Years:

Averge Energy Requirement for Male (Kcal/ day)	Averge Energy Requirement for Female (Kcal/ day)	Averge Protien Requirement for Male (gm/ day)	Averge Protien Requirement for Female (Kcal/ day)	Age Group Over 60 Years			
				Male		Female	
				E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)
2450	2100	49.00	41.00	2450	49.00	2100	41.00

d) Average Energy Requirement by Gender:

Averge Energy Requirement for Male (Kcal/ day)	Averge Energy Requirement for Female (Kcal/ day)	Averge Protien Requirement for Male (gm/ day)	Averge Protien Requirement for Female (Kcal/ day)	Age Group 0 - 14 Years				Age Group 15 - 60 Years				Age Group Over 60 Years			
				Male		Female		Male		Female		Male		Female	
				E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)	E (Kcal/ day)	P (gm/ day)
2533	2093	40.58	35.23	601.731	7.63	555.095	7.80	1769.34	29.72	1417.86	25.09	161.7	3.23	119.7	2.34

e) Average Energy Requirement for Overall Population:

Averge Energy Requirement for Male (Kcal/ day)	Averge Energy Requirement for Female (Kcal/ day)	Averge Protien Requirement for Male (gm/ day)	Averge Protien Requirement for Female (Kcal/ day)	Energy Requirement (Kcal/day)				Protien Requirement (gm/ day)				Average total requirements	
				Male		Female		Male		Female		Energy (Kcal/day)	Protien (gm/ day)
				%	Value	%	Value	%	Value	%	Value		
2533	2093	40.58	35.23	51.01	1292	48.99	1025	51.01	21.00	48.99	17.00	2317	38.00

Source:

1. FAO Nutrition Meeting Report Series, No. 52;
2. WHO Technical Reort Series No. 522, 1973 (Energy and Protien Requirements: report of a Joint FAO/WHO Ad Hoc Expert Committee)

Table E.2.2: Energy content of different crops per 100 gm

Sl. No.	Name of crop	Quantity & Unit	Protien Content		Fat content		Carbohydrate		Fibre, diteiry		Total Energy	Energy, USDA	Calcium	Iron	Vitamin A	Vitamin C	Vitamin E
			gm	Kcal/gm	gm	Kcal/gm	gm	Kcal/gm	gm	Kcal/gm	Kcal	Kcal	mg	mg	mcg_RAE	mg	mg
	Summer Crops																
1	Paddy rice (local)	100 gm	13.35	3.41	20.85	8.37	49.69	4.12	21	2.00	467	316	57.000	18.540	0.000	0.000	4.920
2	Paddy rice (Improved)	100 gm	13.35	3.41	20.85	8.37	49.69	4.12	21	2.00	467	316	57.000	18.540	0.000	0.000	4.920
3	Maize (local)	100 gm	9.42	2.73	4.74	8.37	74.26	4.03	0	2.00	365	365	7.000	2.710	0.000	0.000	0.000
4	Maize (Improved)	100 gm	9.42	2.73	4.74	8.37	74.26	4.03	13.4	2.00	391	365	7.000	2.710	11.000	0.000	0.490
5	Vegetables	100 gm	1.98	2.44	0.21	8.37	5.2	3.57	2.5	2.00	30	25	43.000	0.440	218.800	28.300	0.530
6	Sugarcane	100 gm	0.00	4.00	0	9.00	99.6	4.00	0	2.00	398	387	1.000	0.010	0.000	0.000	0.000
	Winter crops																
1	Wheat	100 gm	10.35	3.59	1.56	8.37	74.24	3.78	12.5	2.00	356	331	27.000	3.210	0.000	0.000	1.010
2	Oilseed	100 gm	17.73	4.00	49.67	8.84	23.45	4.00	11.8	2.00	627	573	975.000	14.550	0.000	0.000	0.250
3	Lentil	100 gm	25.80	3.47	1.06	8.37	60.28	4.07	30.5	2.00	405	353	56.000	7.540	2.000	4.400	0.490
4	Other pulses	100 gm	21.70	3.47	1.49	8.37	62.78	4.07	15	2.00	373	343	130.000	5.230	1.000	0.000	0.000
5	potato	100 gm	2.07	2.78	0.1	8.37	17.98	4.03	2.2	2.00	83	79	7.000	0.780	0.000	19.700	0.010
6	Vegetables	100 gm	1.98	2.44	0.21	8.37	5.2	3.57	2.5	2.00	30	25	43.000	0.440	218.800	28.300	0.530
	Spring Crops																
1	Maize (Spring)	100 gm	9.42	2.73	4.74	8.37	74.26	4.03	13.4	2.00	391	365	7.000	2.710	11.000	0.000	0.490
2	Paddy Rice (Spring)	100 gm	13.35	3.41	20.85	8.37	49.69	4.12	21	2.00	467	316	57.000	18.540	0.000	0.000	4.920
3	Sunflower	100 gm	22.78	4.00	49.57	8.84	18.76	4.00	10.5	2.00	625	570	116.000	6.770	3.000	1.400	34.500
4	Vegetables (Spring)	100 gm	1.98	2.44	0.21	8.37	5.2	3.57	2.5	2.00	30	25	43.000	0.440	218.800	28.300	0.530

Source:

1. Food Energy - Methods of Analysis and Conversion Factors, FAO Food and Nutrition Paper - 77 (2002)
2. USDA National Nutrient Database for Standard Reference, Release 18 (2005).

Table E.2.3: FAO recommendations for nutrient requirements

Nutrient requirements for women* and men

Nutrient	Adult female per day	Adult male per day	Adult male per 1 000 kcal[1]	Adult female per 1 000 kcal[2]
Calcium (mg)	1000	1000	500	350
Iron (mg)[3]	24	11	12	4
Vitamin A (µg RE)	500	600	250	210
Vitamin C (mg)	45	45	23	16
Vitamin E (mg)	7.5	10	3.6	3.6
Niacin (mg)	14	16	7	6
Protein (g)	50	63	25	22.5

[1] Based on total dietary energy intake of 2 000 kcal per day.
[2] Based on total dietary energy intake of 2 800 kcal per day.
[3] Based on 12 percent bioavailability.
* These figures do not reflect the greater needs of pregnant and lactating women.

Source: For vitamins and minerals; Joint FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements, Report on Recommended Nutrient Intakes. FAO Bangkok, September 1998.

Table E.2.4: Computation of unit cost of Ground Water

(i) Capital Recovery and Interest		
Installation Cost of a Shallow Tube Well (STW), C =	42000	NRs
Life of STW (n) =	20	years
Capital Recovery and Interest Rate (i) =	6	%
Annual Capital Recovery = C[i*(1+i)^n/{(1+i)^n-1}] =	1.01288E-13	NRs
Annual Interest = C*I =	2520	NRs
Annual Capital Recovery and Interest =	2520	NRs
Per Hour Capital Recovery and Interest =	0.29	NRs
(ii) Operation and Maintence Cost		
Per Hour O & M Cost of a STW =	45.00	NRs
(iii) Total Per Hour Cost of a STW		
Cost per hour = Capital Recovery + Interest + O & M Cost =	45.29	NRs
Discharge per hr of a STW (@10 l/s) =	36.00	Cu. M
Cost of Ground Water per Cu. M =	1.26	NRs
Cost of GW per MCM = 1257990.87 NRs =	**786244.29**	**IRs**
Cost of GW per Ha-m = 12579.91 NRs =	**7862.44**	**IRs**

Source:
1. Socio-Ecological Implications of Groundwater in Nepal by Dhruba Pant & Madhav Belbase.

Table E.2.5: Computation of unit cost of Surface Water

Name of Project: Mahakali Irrigation Project (MIP) Stage: I CCA: 4,800 ha

Project Completion Date: 1987 Useful Life of the Project(n): 30 Years

Annual Cost of a project is given as

Annual Cost = Annual Capital Recovery + Annual Interest + Annual O & M Cost

Ca = Ci [i1*(1+i1)^n/{(1+i1)^n-1}] + i2*Ci + O & M Cost

Where, K = Investment Cost in NRs
i1 = Capital Recovery Rate in %
i2 = Interest Rate in %

(i) Annual Capital Recovery and Annual Interest
Total Investment Cost: NRs. 370.45 M NRs Capital Recovery Rate (i1): 4 %

Interest Rate/ Service Charge (i2): 0.75 %
Therefore,
Annual Capital Recovery = 370.45 [0.04*(1+0.04)^30/{(1+0.04)^30-1}] = 21.42 M NRs.

Annual Interst = 370.45*(0.75/100) = 2.778375 M NRs.

(ii) Annual Operation and Maintenance (O & M) Cost

CCA (MIP Stage I): 4,800 ha CCA (MIP Stage II): 6,800

CCA (MIP Stage I & II): 11,600 ha

Annual O & M Cost for Stage I & II was observed as follows:

Sl. No.	Year	Operation Cost (NRs)	Maintenance Cost (NRs)	Total O & M Cost (NRs)	Remarks
1	2003/4	1691000	13968000	15659000	
2	2005/6	3856000	10245000	14101000	
3	2006/7	5216000	21019000	26235000	
			Average	18665000	NRs

Annual Cost of Stage I & II = 18665000 NRs = 18.665 M NRs

Annual Cost of Stage I = 7.72344828 M NRs

Total Annual Cost of Stage I = 31.9249835 M NRs = 31924983.5 NRs

Annual Surface Water Release for Stage I = 119.902464 MCM
Or 11990.25 Ha-m

Unit Cost of Surface Water Per M m3
= 266257.94 NRs = 166411.21 IRs
Unit Cost of Surface Water Per Ha-m = 1664.11 IRs

Table E.2.6: Sample calculation for net benefits from crops at Full Irrigation condition

Production Parameters	Crop budget of major crops														
	Paddy (Local)	Paddy (Imp.)	Maize (Local)	Maize (Imp.)	Summer Veg.	Sugar cane	Wheat	Oil crops	Lentil	Other Pulses	Potato	Winter Veg.	Spring paddy	Sun-flower	Spring Veg.
1. Gross Return (i+ii) (NRs/ha)	39,328	58,501	21,629	38,334	214,307	110,220	35,749	58,309	46,254	43,092	169,122	290,781	57,313	65,429	183,265
i.. Main Product (kg/ha)	2,896	4,481	2,110	3,764	19,117	66,332	3,718	1,054	1,181	1,100	19,110	19,118	4,460	1,621	19,110
Price (NRs/kg)	12.60	12.60	10.10	10.10	11.21	1.65	9.40	43.90	39.00	39.00	8.85	15.21	12.60	40.00	9.59
Value (Rs/ha)	36,493	56,458	21,311	38,016	214,307	109,448	34,947	46,272	46,061	42,899	169,122	290,781	56,201	64,846	183,265
ii. By-Product (kg/ha)	4,725	3,405	4,240	4,240	1,605	10,300	2,675	1,605	21	21	4,240	1,605	1,853	45	1,605
Price (NRs/kg)	0.60	0.60	0.08	0.08	0.00	0.08	0.30	7.50	9.00	9.00	0.00	0.00	0.60	13.05	0.00
Value (NRs/ha)	2,835	2,043	318	318	0	773	803	12,038	193	193	0	0	1,112	583	0
2. Production Cost (A+B+C) (NRs/ha)	23,292	24,156	18,091	18,091	26,575	41,034	23,166	13,359	14,311	14,311	47,336	26,575	24,055	13,172	26,575
A. Input Cost (i+ii+iii) (Nrs/ha)	4,347	5,211	3,746	3,746	6,630	15,589	6,421	3,614	4,566	4,566	26,291	6,630	5,110	3,427	6,630
i. Seed (NRs/ha)	798	798	384	384	379	9,545	1,709	444	1,972	1,972	20,150	379	798	606	379
a. Seed Rate (kg/ha)	50.5	50.5	25.25	25.25	0.606	4545	121.2	8.08	40.4	40.4	1515	0.606	50.5	12.12	0.606
Price (NRs/kg)	15.80	15.80	15.20	15.20	625.00	2.10	14.10	54.90	48.80	48.80	13.30	625.00	15.80	50.00	625.00
Value (NRs/ha)	798	798	384	384	379	9,545	1,709	444	1,972	1,972	20,150	379	798	606	379
ii. Fertiliser Cost (a+b+c+d) (Nrs/ha)	3,145	3,908	2,959	2,959	5,241	5,539	4,510	2,969	2,190	2,190	5,636	5,241	3,908	2,518	5,241
a. Urea (kg/ha)	99	196	107	107	169	212	179	82	10	10	108	169	196	40	169
Price (NRs/kg)	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70	10.70
Value (NRs/ha)	1058	2095	1146	1146	1812	2269	1910	882	103	103	1157	1812	2095	431	1812
b. DAP (kg/ha)	89	66	66	66	131	131	110	89	89	89	176	131	66	89	131
Price (NRs/kg)	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80
Value (NRs/ha)	1757	1313	1313	1313	2600	2600	2180	1757	1757	1757	3480	2600	1313	1757	2600
c. Potash (kg/ha)	33	51	51	51	84	68	42	33	33	33	101	84	51	33	84
Price (NRs/kg)	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.90
Value (NRs/ha)	330	500	500	500	830	670	420	330	330	330	1,000	830	500	330	830
d. Manure (kg/ha)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Price (NRs/kg)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Value (NRs/ha)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
iii. Pesticides (NRs/ha)	404	505	404	404	1,010	505	202	202	404	404	505	1,010	404	303	1,010

B. Total Labour + Animal Cost (i+ii)	18,900	18,900	14,300	14,300	19,900	25,400	16,700	9,700	9,700	9,700	21,000	19,900	18,900	9,700	19,900
i. Human Labour (Rs/ha)	11,700	11,700	9,700	9,700	13,500	17,600	9,100	5,700	5,500	5,500	14,200	13,500	11,700	5,700	13,500
a. Family Labour (Man-days)	83	83	74	74	99	113	68	48	44	44	96	99	83	48	99
Value (NRs/ha)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Price (NRs/Day)	8300	8300	7400	7400	9900	11300	6800	4800	4400	4400	9600	9900	8300	4800	9900
b. Hired Labour (Man-days)	34	34	23	23	36	63	23	9	11	11	46	36	34	9	36
Price (NRs/Day)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Value (NRs/ha)	3,400	3,400	2,300	2,300	3,600	6,300	2,300	900	1,100	1,100	4,600	3,600	3,400	900	3,600
ii. Draft Animal (NRs/ha)	7,200	7,200	4,600	4,600	6,400	7,800	7,600	4,000	4,200	4,200	6,800	6,400	7,200	4,000	6,400
a. Family Owned animal (Pair-days)	27	27	17	17	24	28	27	15	17	17	25	24	27	15	24
Price (NRs/Day)	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Value (NRs/ha)	5400	5400	3400	3400	4800	5600	5400	3000	3400	3400	5000	4800	5400	3000	4800
b. Hired Animal (Pair-days)	9	9	6	6	8	11	11	5	4	4	9	8	9	5	8
Price (NRs/Day)	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Value (NRs/ha)	1,800	1,800	1,200	1,200	1,600	2,200	2,200	1,000	800	800	1,800	1,600	1,800	1,000	1,600
C. Land tax per season (NRs/ha)	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
NET RETURN (NRs/ha) (1-2)	16,036	34,345	3,537	-20,243	187,732	69,186	12,584	44,950	31,943	28,781	121,787	264,206	33,257	52,257	156,689
Financial Return (Net Return + Family Labour Cost), NRs/ha	29,736	48,045	14,337	31,043	202,432	86,086	24,784	52,750	39,743	36,581	136,387	278,906	46,957	60,057	171,389
NET RETURN (IRs/ha)	10,023	21,466	2,211	12,652	117,332	43,242	7,865	28,094	19,964	17,988	76,117	165,129	20,786	32,661	97,931

Note: 1.Most of the farmers are using their own seed source, so price of seed at sowing time in village is taken as seed price for calculation.

2.Financial Net Return is the sum of net return and cost of family human labour and animal labours

3.Land tax is NRs 45/Season (NRs 60/Bigha = NRs 90/ha)

5.Transportation Cost is added in fertiliser Cost (NRs 15/Bag = NRs 0.30/kg)

Source :

1. Feasibility Report Mahakali Irrigation Project Stage - III (2002)

2. Annual Programme and Statistical Report (2006), published by District Agricultural Development Office of Kanchanpur District, Nepal

3. Household survey and Participatory Rural Appraisal (PRA) ; November 2000

APPENDIX – 3

SAMPLES OF LINGO MODELS AND THEIR SOLUTIONS

MODEL FOR PLAN 11: FULL IRRIGATION MODEL WITH MINIMUM AREA REQUIREMENT AND MINIMUM ENERGY & NUTRITIONAL REQUIREMENT CONSTRAINTS (Both Surface Water & Ground Water)

! OBJECTIVE FUNCTION (To MAXIMIZE NET BENEFITS IN RS);

MAX = 10023* A11+21466* A12+2211* A13+11845* A14+117332* A15+43242* A16 +7865* A21+28094* A22+19964* A23+17988* A24+76117* A25+165129* A26+11845* A31+20786* A32+32661* A33+97931* A34-1669.94* S1-1669.94* S2-1669.94* S3-1669.94* S4-1669.94* S5-1669.94* S6-1669.94* S7-1669.94* S8-1669.94* S9-1669.94* S10-1669.94* S11-1669.94* S12-7862.44* G1-7862.44* G2-7862.44* G3-7862.44* G4-7862.44* G5-7862.44* G6-7862.44* G7-7862.44* G8-7862.44* G9-7862.44* G10-7862.44* G11-7862.44* G12;

! SUBJECT TO;

! Irrigation Requirement Constraints (in ha-m);

0.07080*A21+0.07073*A22+0.06702*A23+0.07236*A24+0.07235*A25+0.06113*A26 <= S1+G1/0.70;

0.06957*A21+ 0.00536* A22+0.05288* A23+0.06692* A25+0.03178* A26+0.02302* A32 <= S2+G2/0.70;

0.06739* A16+ 0.03182* A21+0.00239* A25+0.05601* A31+0.40925 *A32+0.09458* A33+0.10198* A34 <= S3+G3/0.70;

0.18014* A16+0.35408* A31+0.60109* A32+0.36232* A33+0.25758* A34 <= S4+G4/0.70;

0.31837* A16+0.30721* A31+0.52949* A32+0.23332* A33+0.27772* A34 <= S5+G5/0.70;

0.08304* A12+0.02786* A16+0.21636* A32<= S6+G6/0.70;

0.03666* A11+0.35963* A12 <= S7+G7/0.70;

0.35537* A11+0.18809* A12 <= S8+G8/0.70;

0.19247* A11+0.19119* A12 <= S9+G9/0.70;

0.37186* A11+0.21319* A12+0.16320* A16 <= S10+G10/0.70;

0.03871* A11+0.15037* A16+0.16086* A21+0.05660* A22+0.02847* A23+0.02843* A24+0.04577* A25+0.09677* A26 <= S11+G11/0.70;

```
0.07196* A16+0.05126* A21+0.07090* A22+0.05586* A23+0.05329* A24+0.04768*
A25+0.06582* A26 <= S12+G12/0.70;

! Land Availability Constraints (in ha);

A16+A21+A22+A23+A24+A25+A26 <= 4800;

A21+A22+A23+A24+A25+A26 <= 4800;

A21+A23+A25+A32+A33 <= 4800;

A16+A21+A23+A25+A31+A32+A33+A34 <= 4800;

A16+A31+A32+A33+A34 <= 4800;

A12+A13+A14+A15+A16+A32<= 4800;

A11+A12+A13+A14+A15+A16 <= 4800;

A11+A12+A16 <= 4800;

A11+A12+A16+A22+A26 <= 4800;

A11+A16+A21+A22+A23+A24+A25+A26 <= 4800;

! Surface Water Availability Constraints (in ha-m);

S1 <= 471.40;

S2 <= 425.78;

S3 <= 471.40;

S4 <= 456.19;

S5 <=1182.30;

S6 <= 1710.72;

S7 <= 1767.74;

S8 <= 1767.74;

S9 <= 1710.72;

S10 <= 1098.66;

S11 <= 456.19;
```

S12 <= 471.40;

! Ground Water Availability Constraints (in ha-m);

G1 <= 709.46;

G2 <= 709.46;

G3 <= 709.46;

G4 <= 709.46;

G5 <= 709.46;

G6 <= 709.46;

G7 <= 709.46;

G7 <= 709.46;

G8 <= 709.46;

G9 <= 709.46;

G10 <= 709.46;

G11 <= 709.46;

G12 <= 709.46;

G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G11+G12 <= 2128.38;

! Minimum Area Constraints (in ha);

A11+A12+A32 >= 1438;

A13+A14+A31 >= 155;

A15 >= 268;

A21 >= 983;

A22+A33 >= 1073;

A23+A24 >= 1008;

A25 >= 53;

A26 >= 264;

```
A34 >= 268;

! Energy Requirement Constraints (in Mkcal);

9.152* A11+14.159* A12+7.701* A13+13.739* A14+4.779* A15+256.704* A16+12.306*
A21+6.040* A22+4.169* A23+3.773* A24+15.097* A25+4.779* A26+13.739*
A31+14.095* A32+9.241* A33+4.777* A34 >= 37889;

! Protein Requirement Constraints (in tone);

0.387* A11+0.598* A12+0.199* A13+0.355* A14+0.379* A15+0.385* A21+0.187*
A22+0.305* A23+0.239* A24+0.396* A25+0.379*A26+0.355* A31+0.595* A32+0.369*
A33+0.378* A34 >= 894.494;

! Calcium Requirement Constraints (in kg);

1.651* A11+2.554* A12+0.148* A13+0.263* A14+8.221* A15+0.663* A16+1.004*
A21+10.277* A22+0.661* A23+1.430* A24+1.338* A25+8.221* A26+0.263* A31+2.542*
A32+1.881* A33+8.217* A34 >= 15780;

! Iron Requirement Constraints (in kg);

0.537* A11+0.831* A12+0.057* A13+0.102* A14+0.084* A15+0.007* A16+0.119*
A21+0.153* A22+0.089* A23+0.058* A24+0.149* A25+0.084* A26+0.102* A31+0.827*
A32+0.110* A33+0.084* A34 >= 286.173;

! Vitamin A Requirement Constraints (in gm_RAE);

0.414* A14+41.829* A15+0.024* A23+0.011* A24+41.830* A26+0.414* A31+0.049*
A33+41.813* A34 >= 8629;

! Vitamin C Requirement Constraints (in kg);

5.410* A15+0.052* A23+3.765* A25+5.410* A26+0.023* A33+5.408* A34 >= 722.79;

! Vitamin E Requirement Constraints (in kg);

0.142* A11+0.220* A12+0.018* A14+0.101* A15+0.038* A21+0.003* A22+0.006*
A23+0.002* A25+0.101* A26+0.018* A31+0.219* A32+0.559* A33+0.101* A34 >=
135.728;

END
```

RESULT OF PLAN 11: FULL IRRIGATION MODEL WITH MINIMUM AREA REQUIREMENT AND MINIMUM ENERGY & NUTRITIONAL REQUIREMENT CONSTRAINTS (Both Surface Water & Ground Water)

```
Global optimal solution found.
Objective value:                              0.1184540E+10
Total solver iterations:                                 20


                     Variable           Value        Reduced Cost
                          A11        0.000000            58746.42
                          A12        1438.000            0.000000
                          A13        0.000000            29338.41
                          A14        0.000000            18897.41
                          A15        3362.000            0.000000
                          A16        0.000000            336997.6
                          A21        983.0000            0.000000
                          A22        0.000000            71188.36
                          A23        0.000000            93987.03
                          A24        1008.000            0.000000
                          A25        53.00000            0.000000
                          A26        2756.000            0.000000
                          A31        155.0000            0.000000
                          A32        0.000000            100106.3
                          A33        1073.000            0.000000
                          A34        2536.000            0.000000
                           S1        314.8441            0.000000
                           S2        159.5198            0.000000
                           S3        400.1929            0.000000
                           S4        456.1900            0.000000
                           S5        1002.268            0.000000
                           S6        119.4115            0.000000
                           S7        517.1479            0.000000
                           S8        270.4734            0.000000
                           S9        274.9312            0.000000
                          S10        306.5672            0.000000
                          S11        455.9067            0.000000
                          S12        288.0319            0.000000
                           G1        0.000000            5476.811
                           G2        0.000000            5476.811
                           G3        0.000000            5476.811
                           G4        448.4792            0.000000
                           G5        0.000000            5476.811
                           G6        0.000000            5476.811
                           G7        0.000000            5476.811
                           G8        0.000000            5476.811
                           G9        0.000000            5476.811
                          G10        0.000000            5476.811
                          G11        0.000000            5476.811
                          G12        0.000000            5476.811

                          Row    Slack or Surplus      Dual Price
                            1       0.1184540E+10        1.000000
                            2        0.000000            1669.940
                            3        0.000000            1669.940
                            4        0.000000            1669.940
                            5        0.000000            5503.708
                            6        0.000000            1669.940
                            7        0.000000            1669.940
                            8        0.000000            1669.940
```

```
     9        0.000000          1669.940
    10        0.000000          1669.940
    11        0.000000          1669.940
    12        0.000000          1669.940
    13        0.000000          1669.940
    14        0.000000          0.000000
    15        0.000000          0.000000
    16        2691.000          0.000000
    17        0.000000          95879.28
    18        1036.000          0.000000
    19        0.000000          117332.0
    20        0.000000          0.000000
    21        3362.000          0.000000
    22        606.0000          0.000000
    23        0.000000          164702.3
    24        156.5559          0.000000
    25        266.2602          0.000000
    26        71.20710          0.000000
    27        0.000000          3833.768
    28        180.0322          0.000000
    29        1591.308          0.000000
    30        1250.592          0.000000
    31        1497.267          0.000000
    32        1435.789          0.000000
    33        792.0928          0.000000
    34       0.2832500          0.000000
    35        183.3681          0.000000
    36        709.4600          0.000000
    37        709.4600          0.000000
    38        709.4600          0.000000
    39        260.9808          0.000000
    40        709.4600          0.000000
    41        709.4600          0.000000
    42        709.4600          0.000000
    43        709.4600          0.000000
    44        709.4600          0.000000
    45        709.4600          0.000000
    46        709.4600          0.000000
    47        709.4600          0.000000
    48        709.4600          0.000000
    49        1679.901          0.000000
    50        0.000000         -97594.62
    51        0.000000         -85782.59
    52        3094.000          0.000000
    53        0.000000         -253358.4
    54        0.000000         -65759.96
    55        0.000000         -146971.6
    56        0.000000         -184857.2
    57        2492.000          0.000000
    58        2268.000          0.000000
    59        52569.30          0.000000
    60        4334.077          0.000000
    61        63585.41          0.000000
    62        1952.919          0.000000
    63        353449.2          0.000000
    64        46314.50          0.000000
    65        1694.743          0.000000
```

MODEL FOR PLAN 21: VARIABLE IRRIGATION MODEL WITH MINIMUM AREA, MINIMUM ENERGY AND NUTRITIONAL REQUIREMENT CONSTRAINTS (With Both Surface Water and Ground Water)

! OBJECTIVE FUNCTION (MAXIMIZATION OF NET BENEFITS IN RS);

Max = 10023* A111+9604* A112+8353* A113+6268* A114+5521* A115+21466* A121+20573* A122+17895* A123+13430* A124+10205* A125+2211* A131+2015* A132+1426* A133+445* A134+1026* A135+12652* A141+11839* A142+9399* A143+5333* A144+1657* A145+117332* A151+112827* A152+99335* A153+76858* A154+47772* A155+43242* A161+41227* A162+35185* A163+25114* A164+15485* A165 +7865* A211+7058* A212+4638* A213+605* A214-1739* A215+28094* A221+27048* A222+23910* A223+18680* A224+9623* A225+19964* A231+19060* A232+16347* A233+11826* A234+8739* A235+17988* A241+17529* A242+16152* A243+13857* A244+13858* A245+76117* A251+72660* A252+62289* A253+45004* A254+24297* A255+165129* A261+159401* A262+142253* A263+113686* A264+76076* A265+12652* A311+11839* A312+9399* A313+5333* A314+1657* A315+20786* A321+19914* A322+17308* A323+12966* A324+9876* A325+32661* A331+31145* A332+26599* A333+19022* A334+10518* A335+97931* A341+94087* A342+82557* A343+63340* A344+38812* A345-1669.94* S1-1669.94* S2-1669.94* S3-1669.94* S4-1669.94* S5-1669.94* S6-1669.94* S7-1669.94* S8-1669.94* S9-1669.94* S10-1669.94* S11-1669.94* S12-7862.44* G1-7862.44* G2-7862.44* G3-7862.44* G4-7862.44* G5-7862.44* G6-7862.44* G7-7862.44* G8-7862.44* G9-7862.44* G10-7862.44* G11-7862.44* G12;

! SUBJECT TO;

! **Irrigation Requirement Constraints (in ha-m);**

0.07080* A211+0.05310* A212+0.03540* A213+0.01770* A214+0.07073* A221+.05305* A222+0.03536* A223+0.01768* A224+0.06702* A231+0.5026* A232+0.03351* A233+0.01675* A234+0.07236* A241+0.05427* A242+0.03618* A243+0.01809* A244+0.07235* A251+0.05426* A252+0.03617* A253+0.01806* A254+0.06113* A261+0.04585* A262+0.03057* A263+0.01528* A264 <= S1+G1/0.70;

0.06957* A211+0.05218* A212+0.03478* A213+0.01739* A214+ 0.00536* A221+0.00402* A222+0.00268* A223+0.00134* A224+0.05288* A231+0.03966* A232+0.02644* A233+0.01322* A234+0.06692* A251+0.05019* A252+0.03346* A253+0.01673* A254+0.03178* A261+0.02383* A262+0.01589* A263+0.00794* A264+0.02302* A321+0.01726* A322+0.01151* A323+0.00575* A324 <= S2+G2/0.70;

0.06739* A161+0.05054* A162+0.03370* A163+0.01685* A164+ 0.03182* A211+0.02387* A212+0.01591* A213+0.00796* A214+0.00239* A251+0.00179* A252+0.00119* A253+0.00060* A254+0.05601* A311+0.04201* A312+0.02801* A313+0.01400* A314+0.40925* A321+0.30694* A322+0.20463* A323+0.10231* A324+0.09458* A331+0.07093* A332+0.04729* A333+0.02364* A334+0.10198* A341+0.07649* A342+0.05099* A343+0.02550* A344 <= S3+G3/0.70;

0.18014* A161+0.13510* A162+0.09007* A163+0.04503* A164+0.35408* A311+0.26556* A312+0.17704* A313+0.08852* A314+0.60109* A321+0.45082*

A322+0.30055* A323+0.15027* A324+0.36232* A331+0.27174* A332+0.18116* A333+0.09058* A334+0.25758* A341+0.19319* A342+0.12879* A343+0.06440* A344 <= S4+G4/0.70;

0.31837* A161+0.23878* A162+0.15919* A163+0.07959* A164+0.30721* A311+0.23041* A312+0.15360* A313+0.07680* A314+0.52949* A321+0.39712* A322+0.26474* A323+0.13237* A324+0.23332* A331+0.17499* A332+0.11666* A333+0.05833* A334+0.27772* A341+0.20829* A342+0.13886* A343+0.06943* A344 <= S5+G5/0.70;

0.08304* A121+0.06228* A122+0.04152* A123+0.02076* A124+0.02786* A161+0.02089* A162+0.01393* A163+0.00696* A164+0.21636* A321+0.16227* A322+0.10818* A323+0.05240* A324 <= S6+G6/0.70;

0.03666* A111+0.02749* A112+0.01833* A113+0.00916* A114+0.35963* A121+0.26972* A122+0.17981* A123+0.08991* A124 <= S7+G7/0.70;

0.35537* A111+0.26652* A112+0.17768* A113+0.08884* A114+0.18809* A121+0.14107* A122+0.09404* A123+0.04702* A124 <= S8+G8/0.70;

0.19247* A111+0.14435* A112+0.09623* A113+0.04812* A114+0.19119* A121+0.14339* A122+0.09560* A123+0.04780* A124 <= S9+G9/0.70;

0.37186* A111+0.27889* A112+0.18593* A113+0.09296* A114+0.21319* A121+0.15990* A122+0.10660* A123+0.05330* A124+0.16320* A161+0.12240* A162+0.08160* A163+0.04080* A164 <= S10+G10/0.70;

0.03871* A111+0.02903* A112+0.01935* A113+0.00968* A114+0.15037* A161+0.11278* A162+0.07519* A163+0.03759* A164+0.16086* A211+0.12065* A212+0.08043* A213+0.04022* A214+0.05660* A221+0.04245* A222+0.02830* A223+0.01415* A224+0.02847* A231+0.02135* A232+0.01423* A233+0.00712* A234+0.02843* A241+0.02132* A242+0.01421* A243+0.00711* A244+0.04577* A251+0.03433* A252+0.02288* A253+0.01144* A254+0.09677* A261+0.07258* A262+0.04838* A263+0.02419* A264 <= S11+G11/0.70;

0.07196* A161+0.05397* A162+0.03598* A163+0.01799* A164+0.05126* A211+0.03844* A212+0.02563* A213+0.01281* A214+0.07090* A221+0.05318* A222+0.03545* A223+0.01773* A224+0.05586* A231+0.04190* A232+0.02793* A233+0.01397* A234+0.05329* A241+0.03997* A242+0.02664* A243+0.01332* A244+0.04768* A251+0.03576* A252+0.02384* A253+0.01192* A254+0.06582* A261+0.04937* A262+0.03291* A263+0.01646* A264 <= S12+G12/0.70;

! Land Availability Constraints (in ha);

A161+A162+A163+A164+A165+A211+A212+A213+A214+A215+A221+A222+A223+A224+A225+A231+A232+A233+A234+A235+A241+A242+A243+A244+A245+A251+A252+A253+A254+A255+A261+A262+A263+A264+A265 <= 4800;

```
A211+A212+A213+A214+A215+A221+A222+A223+A224+A245+A231+A232+A233+A2
34+A235+A241+A242+A243+A244+A245+A251+A252+A253+A254+A255+A261+A262
+A263+A264+A265 <= 4800;

A211+A212+A213+A214+A215+A231+A232+A233+A234+A235+A251+A252+A253+A2
54+A255+A321+A322+A323+A324+A325+A331+A332+A333+A334+A335 <= 4800;

A161+A162+A163+A164+A165+A211+A212+A213+A214+A215+A231+A232+A233+A2
34+A235+A251+A252+A253+A254+A255+A311+A312+A313+A314+A315+A321+A322
+A323+A324+A325+A331+A332+A333+A334+A335+A341+A342+A343+A344+A345 <=
4800;

A161+A162+A163+A164+A165+A311+A312+A313+A314+A315+A321+A322+A323+A3
24+A325+A331+A332+A333+A334+A335+A341+A342+A343+A344+A345 <= 4800;

A121+A122+A123+A124+A125+A131+A132+A133+A134+A135+A141+A142+A143+A1
44+A145+A151+A152+A153+A154+A155+A161+A162+A163+A164+A165+
A321+A322+A323+A324+A325 <= 4800;

A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A131+A132+A133+A1
34+A135+A141+A142+A143+A144+A145+A151+A152+A153+A154+A155+A161+A162
+A163+A164+A165 <= 4800;

A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A161+A162+A163+A1
64+A165 <= 4800;

A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A161+A162+A163+A1
64+A165+A221+A222+A223+A224+A225+A261+A262+A263+A264+A265 <= 4800;

A111+A112+A113+A114+A115+A161+A162+A163+A164+A165+A211+A212+A213+A2
14+A215+A221+A222+A223+A224+A225+A231+A232+A233+A234+A235+A241+A242
+A243+A244+A245 +A251+A252+A253+A254+A255+A261+ A262+A263+A264+A265
<= 4800;

! Surface Water Availability Constraints (in ha-m);

S1 <= 471.40;

S2 <= 425.78;

S3 <= 471.40;

S4 <= 456.19;

S5 <=1182.30;

S6 <= 1710.72;

S7 <= 1767.74;
```

S8 <= 1767.74;

S9 <= 1710.72;

S10 <= 1098.66;

S11 <= 456.19;

S12 <= 471.40;

! Ground Water Availability Constraints (in ha-m);

G1 <= 709.46;

G2 <= 709.46;

G3 <= 709.46;

G4 <= 709.46;

G5 <= 709.46;

G6 <= 709.46;

G7 <= 709.46;

G7 <= 709.46;

G8 <= 709.46;

G9 <= 709.46;

G10 <= 709.46;

G11 <= 709.46;

G12 <= 709.46;

G1+G2+G3+G4+G5+G6+G7+G8+G9+G10+G11+G12 <= 2128.38;

! Minimum Area Constraints (in ha);

A111+A112+A113+A114+A115+A121+A122+A123+A124+A125+A321+A322+A323+A324+A325 >= 1438;

A131+A132+A133+A134+A135+A141+A142+A143+A144+A145+A311+A312+A313+A314+A315 >= 155;

A151+A152+A153+A154+A155 >= 268;

```
A211+A212+A213+A214+A215 >= 983;

A221+A222+A223+A224+A225+A331+A332+A333+A334+A335 >= 1073;

A231+A232+A233+A234+A235+A241+A242+A243+A244+A245 >= 1008;

A251+A252+A253+A254+A255 >= 53;

A261+A262+A263+A264+A265 >= 264;

A341+A342+A343+A344+A345 >= 268;

! Energy Requirement Constraints (in Mkcal);

9.152* A111+8.997* A112+8.531* A113+7.754* A114+6.668* A115+14.159*
A121+13.814* A122+12.777* A123+11.047* A124+8.627* A125+7.701* A131+7.590*
A132+7.254* A133+6.695* A134+5.913* A135+13.739* A141+13.272* A142+11.873*
A143+9.542* A144+6.278* A145+4.779* A151+4.619* A152+4.137* A153+3.335*
A154+2.213* A155+256.704* A161+249.199* A162+226.682* A163+189.152*
A164+136.611* A165+12.306* A211+11.862* A212+10.529* A213+8.307* A214+5.197*
A215+6.040* A221+5.866* A222+5.346* A223+4.479* A224+3.266* A225+4.169*
A231+4.039* A232+3.647* A233+2.995* A234+2.083* A235+3.773* A241+3.709*
A242+3.516* A243+3.194* A244+2.744* A245+15.097* A251+14.603* A252+13.122*
A253+10.653* A254+7.197* A255+4.779* A261+4.629* A262+4.178* A263+3.427*
A264+2.375* A265+13.739* A311+13.273* A312+11.874* A313+9.542* A314+6.278*
A315+14.095* A321+13.752* A322+12.726* A323+11.018* A324+8.627* A325+9.241*
A331+8.898* A332+7.871* A333+6.159* A334+3.762* A335+4.777* A341+4.617*
A342+4.136* A343+3.335* A344+2.213* A345 >= 37889.3;

! Protein Requirement Constraints (in tone);

0.387* A111+0.380* A112+0.360* A113+0.328* A114+0.282* A115+0.598* A121+0.584*
A122+0.540* A123+1.467* A124+0.364* A125+0.199* A131+0.196* A132+0.187*
A133+0.173* A134+0.153* A135+0.355* A141+0.343* A142+0.306* A143+0.246*
A144+0.162* A145+0.379* A151+0.366* A152+0.328* A153+0.264* A154+0.175*
A155+0.385* A211+0.371* A212+0.329* A213+0.260* A214+0.424* A215+0.187*
A221+0.182* A222+0.165* A223+0.139* A224+0.101* A225+0.305* A231+0.295*
A232+0.267* A233+0.219* A234+0.152* A235+0.239* A241+0.235* A242+0.222*
A243+0.202* A244+0.174* A245+0.396* A251+0.383* A252+0.344* A253+0.279*
A254+0.189* A255+0.379* A261+0.367* A262+0.331* A263+0.271* A264+0.188*
A265+0.355* A311+0.343* A312+0.306* A313+0.246* A314+0.162* A315+0.595*
A321+0.581* A322+0.538* A323+0.465* A324+0.364* A325+0.369* A331+0.356*
A332+0.315* A333+0.246* A334+0.150* A335+0.378* A341+0.366* A342+0.328*
A343+0.264* A344+0.175* A345 >= 894.49;

! Calcium Requirement Constraints (in kg);

1.651* A111+1.623* A112+1.539* A113+1.399* A114+1.203* A115+2.554* A121+2.492*
A122+2.305* A123+1.993* A124+1.556* A125+0.148* A131+0.146* A132+0.139*
A133+0.128* A134+0.113* A135+0.263* A141+0.255* A142+0.228* A143+0.183*
```

A144+0.120* A145+8.221* A151+7.944* A152+7.116* A153+5.736* A154+3.806* A155+0.663* A161+0.644* A162+0.586* A163+0.489* A164+0.353* A165+1.004* A211+0.968* A212+0.859* A213+0.678* A214+0.424* A215+10.277* A221+9.982* A222+9.097* A223+7.622* A224+5.558* A225+0.661* A231+0.641* A232+0.579* A233+0.475* A234+0.330* A235+1.430* A241+1.406* A242+1.332* A243+1.211* A244+1.040* A245+1.338* A251+1.294* A252+1.163* A253+0.944* A254+0.638* A255+8.221* A261+7.962* A262+7.186* A263+5.894* A264+4.085* A265+0.263* A311+0.255* A312+0.228* A313+0.183* A314+0.120* A315+2.542* A321+2.481* A322+2.296* A323+1.987* A324+1.556* A325+1.881* A331+1.811* A332+1.602* A333+1.253* A334+0.766* A335+8.217* A341+7.942* A342+7.144* A343+5.736* A344+3.806* A345 >= 15780;

! Iron Requirement Constraints (in kg);

0.537* A111+0.528* A112+0.500* A113+0.455* A114+0.391* A115+0.831* A121+0.810* A122+0.750* A123+0.648* A124+0.506* A125+0.057* A131+0.056* A132+0.054* A133+0.050* A134+0.044* A135+0.102* A141+0.099* A142+0.088* A143+0.071* A144+0.047* A145+0.084* A151+0.081* A152+0.073* A153+0.059* A154+0.039* A155+0.007* A161+0.006* A162+0.006* A163+0.005* A164+0.004* A165+0.119* A211+0.115* A212+0.102* A213+0.081* A214+0.050* A215+0.153* A221+0.149* A222+0.136* A223+0.114* A224+0.083* A225+0.089* A231+0.086* A232+0.078* A233+0.064* A234+0.044* A235+0.058* A241+0.057* A242+0.054* A243+0.049* A244+0.042* A245+0.149* A251+0.144* A252+0.130* A253+0.105* A254+0.071* A255+0.084* A261+0.081* A262+0.074* A263+0.060* A264+0.042* A265+0.102* A311+0.099* A312+0.088* A313+0.071* A314+0.047* A315+0.827* A321+0.807* A322+0.747* A323+0.646* A324+0.506* A325+0.110* A331+0.106* A332+0.093* A333+0.073* A334+0.045* A335+0.084* A341+0.081* A342+0.073* A343+0.059* A344+0.039* A345 >= 286.17;

! Vitamin A Requirement Constraints (in gm_RAE);

0.414* A141+0.400* A142+0.358* A143+0.288* A144+0.189* A145+41.829* A151+40.422* A152+36.209* A153+29.189* A154+19.364* A155+0.024* A231+0.023* A232+0.021* A233+0.017* A234+0.012* A235+0.011* A241+0.011* A242+0.10* A243+0.009* A244+0.008* A245+41.830* A261+40.511* A262+36.564* A263+29.989* A264+20.786* A265+0.414* A311+0.400* A312+0.358* A313+0.288* A314+0.189* A315+0.049* A331+0.047* A332+0.041* A333+0.032* A334+0.020* A335+41.813* A341+40.410* A342+36.200* A343+29.185* A344+19.364* A345 >= 8629.34;

! Vitamin C Requirement Constraints (in kg);

5.410* A151+5.228* A152+4.683* A153+3.775* A154+2.505* A155+0.052* A231+0.50* A232+0.045* A233+0.037* A234+0.026* A235+3.765* A251+3.642* A252+3.272* A253+2.657* A254+1.795* A255+5.410* A261+5.240* A262+4.729* A263+3.879* A264+2.689* A265+0.023* A331+0.022* A332+0.019* A333+0.015* A334+0.009* A335+5.408* A341+5.227* A342+4.682* A343+3.775* A344+2.505* A345 >= 722.79;

```
! Vitamin E Requirement Constraints (in kg);

0.142* A111+0.140* A112+0.133* A113+0.121* A114+0.104* A115+0.831* A121+0.215*
A122+0.199* A123+0.172* A124+0.134* A125 +0.018* A141+0.018* A142+0.016*
A143+0.013* A144+0.008* A145+0.101* A151+0.098* A152+0.088* A153+0.071*
A154+0.047* A155+0.038* A211+0.036* A212+0.032* A213+0.025* A214+0.016*
A215+0.003* A221+0.003* A222+0.002* A223+0.002* A224+0.001* A225+0.006*
A231+0.006* A232+0.005* A233+0.004* A234+0.003* A235+0.002* A251+0.002*
A252+0.002* A253+0.001* A254+0.001* A255+0.101* A261+0.098* A262+0.089*
A263+0.073* A264+0.050* A265+0.018* A311+0.018* A312+0.016* A313+0.013*
A314+0.008* A315+0.219* A321+0.214* A322+0.198* A323+0.172* A324+0.134*
A325+0.559* A331+0.539* A332+0.476* A333+0.373* A334+0.228* A335+0.101*
A341+0.098* A342+0.088* A343+0.071* A344+0.047* A345 >= 135.73;

END
```

RESULT OF PLAN 21: VARIABLE IRRIGATION MODEL WITH MINIMUM AREA, MINIMUM ENERGY AND NUTRITIONAL REQUIREMENT CONSTRAINTS (With Both Surface Water and Ground Water)

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 Global optimal solution found.
 Objective value:                              0.1184540E+10
 Total solver iterations:                                 26


                       Variable           Value        Reduced Cost
                           A111        0.000000            58746.42
                           A112        0.000000            58749.95
                           A113        0.000000            59585.54
                           A114        0.000000            61255.12
                           A115        0.000000            61586.71
                           A121        1438.000            0.000000
                           A122        0.000000            460.8529
                           A123        0.000000            2706.689
                           A124        0.000000            6739.542
                           A125        0.000000            9532.378
                           A131        0.000000            29338.41
                           A132        0.000000            29534.41
                           A133        0.000000            30123.41
                           A134        0.000000            31104.41
                           A135        0.000000            30523.41
                           A141        0.000000            18897.41
                           A142        0.000000            19710.41
                           A143        0.000000            22150.41
                           A144        0.000000            26216.41
                           A145        0.000000            29892.41
                           A151        3362.000            0.000000
                           A152        0.000000            4505.000
                           A153        0.000000            17997.00
                           A154        0.000000            40474.00
                           A155        0.000000            69560.00
                           A161        0.000000            336997.6
                           A162        0.000000            338431.1
                           A163        0.000000            343891.6
                           A164        0.000000            353381.1
                           A165        0.000000            362428.6
                           A211        983.0000            0.000000
                           A212        0.000000            646.5689
                           A213        0.000000            2906.104
                           A214        0.000000            6778.673
                           A215        0.000000            8962.225
                           A221        0.000000            71188.36
                           A222        0.000000            72149.37
                           A223        0.000000            75202.36
                           A224        0.000000            80347.37
                           A225        0.000000            89319.37
                           A231        0.000000            93987.03
                           A232        0.000000            95561.14
                           A233        0.000000            97433.49
                           A234        0.000000            101869.2
                           A235        0.000000            104871.0
                           A241        1008.000            0.000000
                           A242        0.000000            394.6739
                           A243        0.000000            1707.331
                           A244        0.000000            3938.022
                           A245        0.000000            3872.696
```

```
A251        53.00000         0.000000
A252        0.000000         3358.841
A253        0.000000         13631.67
A254        0.000000         30818.49
A255        0.000000         51427.38
A261        2756.000         0.000000
A262        0.000000         5621.341
A263        0.000000         22662.67
A264        0.000000         51122.99
A265        0.000000         88626.33
A311        155.0000         0.000000
A312        0.000000         174.1812
A313        0.000000         1975.346
A314        0.000000         5402.510
A315        0.000000         8439.691
A321        0.000000         100106.3
A322        0.000000         99659.38
A323        0.000000         100946.5
A324        0.000000         103966.7
A325        0.000000         105740.7
A331        1073.000         0.000000
A332        0.000000         880.5724
A333        0.000000         4791.162
A334        0.000000         11732.73
A335        0.000000         19601.32
A341        2536.000         0.000000
A342        0.000000         3331.106
A343        0.000000         14348.14
A344        0.000000         33052.24
A345        0.000000         57067.28
  S1        314.8441         0.000000
  S2        159.5198         0.000000
  S3        400.1929         0.000000
  S4        456.1900         0.000000
  S5        1002.268         0.000000
  S6        119.4115         0.000000
  S7        517.1479         0.000000
  S8        270.4734         0.000000
  S9        274.9312         0.000000
 S10        306.5672         0.000000
 S11        455.9067         0.000000
 S12        288.0319         0.000000
  G1        0.000000         5476.811
  G2        0.000000         5476.811
  G3        0.000000         5476.811
  G4        448.4792         0.000000
  G5        0.000000         5476.811
  G6        0.000000         5476.811
  G7        0.000000         5476.811
  G8        0.000000         5476.811
  G9        0.000000         5476.811
 G10        0.000000         5476.811
 G11        0.000000         5476.811
 G12        0.000000         5476.811

 Row    Slack or Surplus      Dual Price
   1      0.1184540E+10         1.000000
   2        0.000000            1669.940
   3        0.000000            1669.940
   4        0.000000            1669.940
   5        0.000000            5503.708
```

```
   6        0.000000           1669.940
   7        0.000000           1669.940
   8        0.000000           1669.940
   9        0.000000           1669.940
  10        0.000000           1669.940
  11        0.000000           1669.940
  12        0.000000           1669.940
  13        0.000000           1669.940
  14        0.000000           0.000000
  15        0.000000           0.000000
  16        2691.000           0.000000
  17        0.000000           95879.28
  18        1036.000           0.000000
  19        0.000000           117332.0
  20        0.000000           0.000000
  21        3362.000           0.000000
  22        606.0000           0.000000
  23        0.000000           164702.3
  24        156.5559           0.000000
  25        266.2602           0.000000
  26        71.20710           0.000000
  27        0.000000           3833.768
  28        180.0322           0.000000
  29        1591.308           0.000000
  30        1250.592           0.000000
  31        1497.267           0.000000
  32        1435.789           0.000000
  33        792.0928           0.000000
  34       0.2832500           0.000000
  35        183.3681           0.000000
  36        709.4600           0.000000
  37        709.4600           0.000000
  38        709.4600           0.000000
  39        260.9808           0.000000
  40        709.4600           0.000000
  41        709.4600           0.000000
  42        709.4600           0.000000
  43        709.4600           0.000000
  44        709.4600           0.000000
  45        709.4600           0.000000
  46        709.4600           0.000000
  47        709.4600           0.000000
  48        709.4600           0.000000
  49        1679.901           0.000000
  50        0.000000          -97594.62
  51        0.000000          -85782.59
  52        3094.000           0.000000
  53        0.000000          -253358.4
  54        0.000000          -65759.96
  55        0.000000          -146971.6
  56        0.000000          -184857.2
  57        2492.000           0.000000
  58        2268.000           0.000000
  59        52569.00           0.000000
  60        4334.081           0.000000
  61        63585.41           0.000000
  62        1952.922           0.000000
  63        353448.8           0.000000
  64        46314.50           0.000000
  65        2573.359           0.000000
```