CONJUNCTIVE USE PLANNING OF WATER RESOURCES IN A CANAL COMMAND

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that this dissertation entitled **"CONJUNCTIVE USE PLANNING OF WATER RESOURCES IN A CANAL COMMAND"** being submitted in partial fulfillment of the requirements for the award of the degree of Master of Technology in WATER RESOURCE DEVELOPMENT (CIVIL), at Water Resource Development & Management Department, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from 16th July, 2005 to 30th June, 2006 under the guidance of **Dr. Deepak Khare**, Associate Professor, Water Resource Development & Management Department, Indian Institute of Technology, Roorkee.

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

(YAW MIREKU)

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

Agriculture is one of the single largest sectors of most countries economy. It contributes about 35 percent of GDP to some countries, directly accounts for 40 percent of export earnings and employs more than 50 percent of some countries civilian force. The resource of most countries depends on agricultural output.

Population explosion has necessitated the need for expansion of agricultural production. Water is evidently the most vital element in the life of plants. However, in recent years, changes in weather pattern have resulted in rainfall being ill-timed and inadequate in some places. Because in some places, the water requirements of crops can not be met by rainfall alone, irrigation schemes incorporating a network of canals and distributaries have been put in place to meet the water requirement of crops. These networks of canals and distributaries also contribute to an increase in groundwater recharge. This recharged groundwater can be used to meet the water needs of crops when rainfall and surface run-off is low.

Conjunctive use of surface and ground water is the management of surface- and ground-water resources in a coordinated operation to the end that the total yield of such a system over a period of years exceeds the sum of the yields of the separate components of the system resulting from an uncoordinated operation. Commonly, conjunctive use involves using surface water supplies in periods of ample rainfall and runoff and groundwater supplies when surface water is limited or unavailable.

The objective of conjunctive use is to increase the yield, reliability of supply, and general efficiency of a water supply system by diverting water from streams and surface reservoirs for conveyance to and storage in ground-water basins for later use when surface water is not available.

Conjunctive use model consists of an optimization model and groundwater model. An optimization model is required for conjunctive use planning to obtain optimal cropping pattern and optimal allocation of surface and ground water resources satisfying a series of constraints. A groundwater simulation model is required to know the aquifer response to excitations.

The main objective of the present work is to develop a conjunctive use model for optimal planning of surface and ground water resources in the Omkareshwar Canal Command of Khandwa district in Madhya Pradesh, India. A linear programming optimization model is formulated to obtain optimal cropping pattern and the optimal allocation of surface and ground water resources. Different Scenarios of availability of surface and ground water resources are analysed to determine the net benefits and the allocation of water resources.

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

Agriculture has been and continues to be one of the main occupations of billions of people living on Earth. The resources of most countries depend on agricultural output. Water is evidently the most vital element in the life of plants.

However, in recent years due to changes in weather pattern, the total rainfall in a particular area may be either insufficient, or ill-timed. And this can result in poor harvest and reduced yield of crops. In order to get the maximum yield from crop production, it is essential to supply the optimum quantity of water, and to maintain correct timings of water delivery. Additionally, rapid population growth needs to be matched by a corresponding expansion of agricultural production.

Because in some places the total rainfall needed by crops is less, it has necessitated the provision of irrigation works to make available more water to crops as and when it is needed. These irrigation projects increase the groundwater recharge that, in the absence of proper drainage measures, results in waterlogging and salt accumulation. The maximum permissible level of water table in such areas is governed by the requirement of maintaining a minimum depth of water table from the ground surface, which primarily depends upon the depth of the root zone of the crops grown in the area.

In areas where canal irrigation has not been introduced, irrigation requirements in general are met by groundwater withdrawals. However, large groundwater withdrawals can lower the groundwater table excessively. This lowering of the water table can render many shallow wells dry, reduce base flow in hydraulically connected rivers and induce salt water intrusion in coastal aquifers. The reduction of base flow can adversely affect the ecology of the surrounding regions, operation of downstream surface water projects and quality of surface water.

It is therefore, important that all the water resources in a region are considered in unison so as to maximize the benefits that could accrue from the combined use of surface water and groundwater. The advantages of both resources have to be taken into consideration for effective and optimum management.

1.2 CONJUNCTIVE USE

Conjunctive use of surface and ground waters is the management of surface and ground water resources in a coordinated operation to the end that the total yield of such a system over a period of years exceeds the sum of the yields of the separate components of the system resulting from an uncoordinated operation. Commonly, conjunctive use involves using surface water supplies in periods of ample rainfall and runoff and groundwater supplies when surface water is limited or unavailable.

Both surface water and groundwater storage are used to redistribute water in time to match supply and demand. However, surface and groundwater storage differ in storage capacity, recharge and depletion rates, capital and operation costs and constraints.

Compared with surface storage, groundwater storage offers vast storage reserves, usually orders of magnitude larger than the available surface storage in most watersheds. These reserves can be used as a reliable source to reduce or eliminate surface water shortages. Moreover, the great natural storage capacity of the aquifer can be utilized to store excess surface water in wet periods, increasing groundwater levels for use in subsequent dry periods. Traditionally, groundwater has been used only as a backup supply for times of shortage. Most large water supply systems continue to depend exclusively on surface water.

Planning and managing a complex water system with groundwater and surface water components entails considering many aspects – hydrological, operational, economic, legal, social, etc.-

The primary aim in any water resource project based on conjunctive use concept is to optimize the combined utilization of available and proposed surface and ground water facilities. The objective of conjunctive use is to increase the yield, reliability of supply, and general efficiency of a water system by diverting water from streams and surface reservoirs for conveyance to and storage in ground-water basins for later use when surface water is not available.

A conjunctive use model consists of an optimization model and groundwater model. An optimization model is required for conjunctive use planning to obtain optimal allocation of surface and ground water resources satisfying a series of constraints. A groundwater simulation model is required to know the aquifer response to excitations. In a conjunctive use setting, the groundwater aquifer is actively managed to recharge surplus surface water during wet years; this stored water is extracted in dry years to supplement or replace surface water supplies.

Conjunctive use planning requires an integrated evaluation of the surface water and groundwater resources in a basin. Several key issues need to be carefully studied before adopting a conjunctive use strategy. These issues include:

- Availability of storage in the aquifer(s)
- Transmissive characteristics and retention capacities of the aquifer(s)
- Production capacity of the aquifer(s)
- Natural recharge of the aquifer(s)
- Potential for induced natural recharge of the aquifer(s)
- Potential for artificial recharge of the aquifer(s)
- Stream - aquifer interactions
- Quality of groundwater
- Quality of the recharge water
- Safe yield of the aquifer
- Response characteristics of the groundwater system
- Economic and Environmental benefits of conjunctive use

Planning process also involves working with local stakeholders to identify issues, constraints, goals and objectives. This information is used with the available data to establish basin management objectives appropriate to local conditions. Planning also involves conducting technically rigorous and defensible analysis and produce project plans that are accessible and understandable to non-technical persons. The planning process should support decisions on feasible projects and implementation of facilities and policies that meet current and future water supply needs.

Conjunctive use management allows surface water and groundwater to be managed in an efficient and effective manner by taking advantage of the ability of surface storage to capture and temporarily store storm water and the ability of aquifer to serve as long-term storage.

There are three components to a conjunctive use management project. The **first** is to recharge groundwater when surface water and runoff is available to increase groundwater storage. In some areas this is accomplished by reducing groundwater use and substituting it with surface water, allowing natural recharge to increase groundwater storage (also called in-lieu recharge). The **second** component is to switch to groundwater use in dry periods when surface water is scarce. The **third** component is to have an ongoing monitoring program to evaluate and allow water managers to respond to changes in groundwater, surface water, or environmental conditions that could violate management objectives or impact other water users. Together these components make up a conjunctive use management project.

Groundwater recharge is the movement of surface water from the land surface, through the topsoil and subsurface, and into de-watered aquifer space. Recharge occurs naturally from precipitation falling on the land surface, from water stored in lakes, and from creeks and rivers carrying storm runoff. Recharge also occurs when water is placed into constructed recharge ponds (also called spreading basins), when water is injected into the subsurface by wells, and when water is released into creeks and rivers beyond what occurs from the natural hydrology (for example, by releases of imported water). These later examples of recharge are often called artificial, intentional, managed or induced recharge. Significant amounts of recharge can also occur either intentionally or incidentally from applied irrigation water and from water placed into unlined conveyance facilities. Groundwater banking is the recharge (often of imported surface water or local flood water) into de-watered aquifer space for later recovery and use or exchange with others.

1.3 POTENTIAL BENEFITS FROM CONJUNCTIVE USE PLANNING & MANAGEMENT

Conjunctive use management is used to improve water supply reliability, to reduce groundwater overdraft and land subsidence, to protect water quality, and to improve environmental conditions. The potential benefits from additional conjunctive management are highly dependent on adequate water quality and the ability to capture, convey, and recharge surface water.

In addition to water supply benefits, conjunctive use management can provide environmental benefits when recharge basins are designed to be compatible with wildlife habitat, such as using natural flood plains and wetlands as recharge areas. Re-operation of surface water storage and using the water conjunctively with groundwater can avoid impacts to aquatic species by allowing better management of in stream flow and water quality conditions. Additional benefits of conjunctive use may include

- Better management capabilities with less waste
- Greater flood control capabilities
- Greater control over surface reservoir releases; and
- More efficient operation of pump plants and other facilities

The aquifer is also a natural distribution system, reducing need for artificial conveyance facilities. It is possible to recharge in a place above the aquifer and to use water from the aquifer in a well far from the recharge point.

Groundwater recharge can be used for treatment, because of the chemical and biological purification afforded by the passage of stream water through the unsaturated and saturated zones (Freeze and Cherry 1979). Another possible use of conjunctive use operation is to improve final water quality by blending surface water and groundwater of different qualities. Groundwater maintains relatively constant temperature and chemical quality, but contamination would be difficult to control and correct.

1.4 CONSTRAINTS IN IMPLEMENTING CONJUNCTIVE USE PROGRAM

Some constraints in implementing conjunctive use programs are as follows:

1.4.1 Physical and Operational Constraints

Physical constraints relate to water quality, aquifer yield and the variability of surface water supply. Supply of water for recharge of groundwater basin in a watershed may be inadequate. Underground storage space may be insufficient. Land may not be available at affordable costs for recharge facilities. Change in land use upstream could alter amount, regimen, and quality of water available. For example, urban development could increase water diversion and use in an area, decrease natural percolation, and increase runoff peaks.

Water rights and uses downstream from point of diversion from a stream used to recharge a ground water basin must be protected. Also, natural stream recharge to downstream ground water basins must be maintained.

Groundwater levels in basins where surface water is to be stored as part of conjunctive-use program should not be lowered to a point that would cause seawater intrusion in coastal areas, invasion of connate brines and other poorer quality water, and land subsidence in basins with clay and silt formations. Impact of lowering ground water levels below bottoms of existing wells must be mitigated.

1.4.2 Financial and Institutional Constraints

Conjunctive use program requires users to switch between surface and ground water supplies. A large disparity in prices of water from these two sources would discourage the use of the more expensive water. Project funds may come from different sources. Public funds are usually used for surface facilities, especially in rural areas.

Use of groundwater basins to implement a conjunctive use program may not receive favourable consideration from public officials who suffer from the "edifice mentality" favouring "bigger and better" dams.

Lack of agreement on respective roles and the resulting inadequate coordination and cooperation among governmental agencies may seriously hamper the implementation of conjunctive use projects. In most countries, the surface water infrastructure, groundwater, and agriculture (large user of water) are under the jurisdiction of different departments/ministries. Also, funding, design and construction, and operation may be the responsibility of different agencies.

1.4.3 Legal Constraints

Legal constraints on water use include existing water rights and associated regional and inter-regional water law, desired flows for endangered species. Legal constraints can hinder implementation of conjunctive use management. Law governing groundwater is less advanced than law for surface water because of the complexity and lack of understanding of the mechanics of groundwater flow, and the private nature of groundwater development and ownership in many countries (Hall and Dracup 1970, Frederick et al. 1998). In the United States, traditional doctrines are often criticized as being inadequate in light of current and anticipated management problems (Cox 1982).

Although legal constraints to conjunctive use management could be difficult to overcome, appropriate adjusted economic prices and incentives may help to self-regulate groundwater and surface water use to match conjunctive use objectives (Jenkins 1992). The relative prices of surface and ground water can be adjusted so that water users should pay lower electricity rates for groundwater pumping in drought periods and higher rates in wet periods (Basagaoglu et al. 1999, after Boyd 1991).

1.5 OBJECTIVE OF THE THESIS

The main objective of this study is to find ways of how to effectively and efficiently manage conjunctive use of surface- and ground-water resources in a canal command, thereby avoiding or minimizing waterlogging, wastage of water and salinization.

An optimal strategy for groundwater recharge is a pattern of releases of canal water that maximizes infiltration into the command area. This strategy would be implemented in the late summer and fall when excess water is evacuated from the reservoir to increase flood control storage.

The following objectives are outlined for the thesis:

(i) To Review literature

(ii) To collect data and process it

(iii) To conduct economic analysis of Surface and Ground water

(iv) To formulate conjunctive use model

(v) To determine allocation plan of Surface and Ground water

(vi) To conduct sensitivity analysis

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

There is a significant volume of work covering conjunctive use operations and most studies show considerable benefits over independent management of surface and ground water supplies. The following section provides a very brief summary of a few of the relevant articles covering a very active area of research and investigation.

2.2 CONJUNCTIVE USE MODELS

Based on the technique used, conjunctive use models developed earlier may be classified as, dynamic programming models, simulation models, linear programming models, hierarchical optimization models, nonlinear models, and more recently computer and GIS-based models.

Dynamic programming (DP) has been used because of its advantages in modeling sequential decision making processes, and applicability to nonlinear systems, ability to incorporate stochasticity of hydrologic processes and obtain global optimality even for complex policies (Buras, 1963; Aron, 1969; Cochran and Butcher, 1970; Coskunoglu and Shetty, 1981; Onta et al., 1991; Provencher and Burt, 1994). However the "Curse of dimensionality" seems to be the major reason for limited use of dynamic programming (DP) in conjunctive use studies. These studies considered physical systems as lumped. Jones et al. (1987) used a dynamic programming (DP) algorithm to reduce computational burden for unsteady, nonlinear (unconfined), ground water system management problems.

Simulation approaches provided a framework for conceptualizing, analyzing and evaluating stream-aquifer systems. Since the governing partial differential equations for complex heterogeneous groundwater and stream-aquifer systems are not amenable to closed form analytical solution, various numerical models using finite difference or finite element methods have been used for solution (Chun et al., 1964; Bredehoeft and Young, 1970, 1983; O'Mara and Duloy, 1984; Latif and James, 1991; Chaves-Morales et al., 1992).

Hierarchical optimization models were developed by Maddock (1972, 1973); Haimes and Dreizin (1977); Morel-Seytoux (1975); Yu and Haimes (1974); and Paudyal and Gupta (1990). Maddock (1974) provides a general study of conjunctive use operations for a generic stream and aquifer system with uncertain supplies and demands. He offers that it is possible to develop management and operating rules to optimally manage (by reducing cost) the system over time.

Gorelick (1983) distinguish two categories of combined management models with distributed aquifer simulation: hydraulic management models and policy evaluation and allocation models. Hydraulic management models are principally concerned with managing flow, heads and mass transport in the aquifer. In contrast, policy evaluation and allocation models are mainly concerned with the economically efficient allocation of surface and groundwater resources.

Despite the fact that most conjunctive use management problems are nonlinear in nature, application of nonlinear programming (NLP) has been rather limited. This may be because of the complexity and the slow rate of convergence of the nonlinear programming (NLP) algorithms, difficulty in considering stochasticity and possibility of getting a local instead of global optimization solution (Yeh, 1992). Willis et al. (1989); Matsukawa et al. (1992) are among those who used nonlinear programming for conjunctive use modeling.

Matsukawa et al. (1992) provide a more specific study of conjunctive use through the development of a conjunctive use planning and management model and its application to the Mad River basin on the north coast of California. The optimization model incorporates the ground water and surface water hydraulics with the costs and benefits of water supply, irrigation, hydropower, and ground water.

A great variety of conjunctive use optimization models are available in literature. Such models typically use linear, non-linear or dynamic techniques with a dynamic balance of relevant quantities (e.g. water flow, contaminant mass), appropriate constraints, and a single (usually economic) or a multiple (e.g. economic, social, target demand) objective (Lall 1995).

Belaineh et al. (1999) present a simulation/optimization model that integrates linear reservoir decision rules, detailed simulations of stream/aquifer system flows, conjunctive use of surface and ground water, and delivery via branching canals to water users. State variables, including aquifer hydraulic head, stream flow, are represented through discretized convolution integrals and influence coefficients. Reservoir storage branching canal flows and interflows are represented using embedded continuity equations. Results of application indicate that the more detail used to represent the physical system, the better the conjunctive management.

Azaiez and Hariga (2000) developed a model for a multi-reservoir system, where the inflow to the main reservoir and the demand for irrigation water at local areas are stochastic. High penalty costs for pumping ground water are imposed to reduce the risk of total depletion of the aquifer as well as quality degradation and seawater intrusion. The problem is analyzed for a single period with a single decision-maker approach. Deficit irrigation is allowed in maximizing expected total profit for the entire region. A nonlinear stochastic problem with linear constraints is formulated and an iterative procedure that generates an optimal operating policy is proposed. Model application is illustrated with a hypothetical example.

Marino (2001) discussed simulation and optimization models and decision-support tools that have proven to be valuable in the planning and management of regional water supplies. Also conjunctive water management issues in California as well as water management approaches for effectively dealing with climatic change are discussed.

Barlow et al. (2003) developed conjunctive-management models that couple numerical simulation with linear optimization to evaluate trade-offs between groundwater withdrawals and stream flow depletions for alluvial-valley stream-aquifer systems representative of those of the northeastern United States. The model developed for a hypothetical stream-aquifer system was used to assess the effect of inter-annual hydrologic variability on minimum monthly stream flow requirements. The conjunctive-management model was applied to a stream-aquifer system of central Rhode Island.

Rao et al. (2004) developed a regional conjunctive use model for a near-real deltaic aquifer system, irrigated from a diversion system, with some reference to hydrogeoclimatic conditions prevalent in the east coastal deltas of India. The combined simulation-optimization model proposed in this study is solved as nonlinear, nonconvex combinatorial problem using a simulated annealing algorithm and an existing sharp interface model. The computational burden is managed within practical time frames by replacing the flow simulator with artificial neural networks and using efficient algorithm guidance.

2.2.1 Linear Programming Models

Linear programming has been the most widely used technique in conjunctive use optimization models. It has been extensively used by different researchers.

Castle and Lindeborg (1961) defined optimal operation on the basis of maximizing beneficial use as determined by linear programming model. An assumption was made to production function for water that "Water users in the two agricultural areas would expand their inputs of other production factor in proportion to increase the amount of available water." A model formulated in linear fashion required that the linear programming approach be based on this assumption. This concept has been used by Dracup (1996) and subsequently by Miligan (1970). A mathematical model for groundwater and surface water system was formulated by Dracup (1966) that was solved by parametric linear programming. This includes sensitivity analysis on the cost coefficients and the significance of the shadow prices.

Roger and Smith (1970) formulated a linear programming model to arrive at the optimal allocation of groundwater and canal water for conjunctive use planning for an irrigation project. The ground water response was considered as lumped. Nieswand and Granstrom (1971) developed a set of chance constrained linear programming (LP) models for the conjunctive use of surface waters and ground waters for the Mullica River basin in New Jersey. Miligan (1970) has also used linear programming models for surface water and groundwater system operation.

Lakshminarayana and Rajagopalan (1977) have also applied linear programming models based on smith's model to Bari Doab in Punjab. The model determines the extent of allocation of irrigated area to alternative crops and amount of seasonal water releases from the two sources, i.e. canal and tubewells such that benefits from the system are maximized. The model was a deterministic one and the dynamic response of the ground water aquifer was not considered.

Boster and Martin (1979) modeled representative irrigated farms in Arizona to predict agricultural adjustments to new water from the central Arizona project. The linear programming model developed has broad application to similar water-resource projects involving the conjunctive use of multiple water sources of different qualities through mixing the waters.

Tyagi and Narayana (1981) presented a linear programming conjunctive-use model to allocate surface and ground water for irrigation of agricultural crops applied to an area in India where an alkali-land-reclamation program was in progress. The reallocation of land and water resources resulted in increased income of the project area by 14%. A sensitivity analysis of the data used was also conducted.

Vedula (1985) presented a water allocation model for the upper Cauvery River Basin in India. In his study linear programming was used to determine reservoir release, groundwater pumping targets and optimal cropping pattern.

2.2.2 Non-Linear Programming Models

Nonlinearities may arise due to the physical representation of the system or the cost structure for surface and groundwater use. Some important nonlinearity is:

- For a confined aquifer system, the confining equation is linear; hence, the resulting set of finite difference (or finite element) equations is also linear. For unconfined aquifers the relation between pumping and drawdown is nonlinear. However, we can assume linear behaviour of the system when transmissivity and storage coefficients and the boundary conditions remain constant in time.
- Stream-aquifer interaction can be represented by a linear function of stream stage and groundwater elevation where groundwater level is at or above the streambed. However, the stream stage is a nonlinear function of discharge or

reservoir release. Basagaoglu and Marino (1999a, 1999b) used time-variant response equations to incorporate stream stage variations into the management model, using a linear approximation of Manning's equations.

For nonlinear systems, nonlinear programming (NLP) and differential DP (dynamic programming) has been applied (Yeh 1981). Alternatively separable programming techniques may lead to solutions using quadratic programming or by LP using piecewise approximations of the resulting quadratic functions. Applications of classical DP to groundwater management problems is usually restricted to lumped parameter models, due to the constraints imposed by the "curse of the dimensionality" (Bellman 1957). Jones et al. (1987) developed a differential DP algorithm to overcome the dimensionality problem for solving a large scale, nonlinear optimization models.

Complex and detailed groundwater management decisions require groundwater to be represented at a level of detail afforded only by simulation models. In coupled simulation-optimization models, a simulation model reproduces the response of the aquifer and this information is used by the optimization model, usually and economic management model. The models either exchange data at each time step being the simulation model external or response characteristic of the aquifer are incorporated into the surface water model using the response matrix approach.
Kashyap and Chandra (1982) solved the conjunctive use problem by using the non-linear programming technique to arrive at optimal conjunctive policies, incorporating spatially and temporary groundwater withdrawal for a predefined pattern of surface water availability and cropping pattern.

Khan (1982) presented a nonlinear model for managing irrigated agriculture with different quality waters. The objective of the model was to maximize the net benefits subject to constraints on water supply, water blending, land availability, hydrologic balance, salt balance, and root-zone salinity. The problem formulation resulted in a nonlinear objective function, and khan used generalized geometric programming to solve it. Gupta et al. (1987) used a similar approach to develop a model for conjunctive use through blending of poor-quality ground water and good-quality canal water in the Indian Punjab. Again, due to the nonlinearity of the objective function, generalized geometric programming (GGP) was used.

Latif (1988) developed a dynamic conjunctive-use model to maximize the water user's return under limited and varying water supply for long-term conditions. Salt distribution in the root zone and its effect on the crop yield were also modeled. Concepts of limited and stressed irrigation were used to maximize net return. The model was used to study different water-supply and management options. Results indicated that returns can be significantly increased by conjunctive use. The model can then be used to quantify salt loading from the irrigated area.

Willis, Finnay and Zang (1989) presented a conjunctive use model, in which he considered the production cost including the distribution cost of river water. The cost of groundwater was considered as non-linear because the lift is dependent on the withdrawals. In this study the net benefits from crops were maximized.

2.2.3 Other Models

Additionally, there are models other than discussed earlier, which have been used for the solution of conjunctive use problems. Some empirical methods have also been used. Some of the models have been applied for temporal allocation of Groundwater. Some of such works are presented in this section.

MODFLOW (McDonald and Harbough, 1988) is a predominantly simulation model that solve the governing partial differential equations of groundwater flow using Finite element (FE) or Finite difference (FD) techniques. By FE or FD, the spatial and time domain of the aquifer are discretized, and the groundwater flow equation is approximated by a system of linear equations to be solved sequentially in an iterative process with a given time step.

Lumped parameter groundwater models have also been used in economic models, typically to analyze the economic impacts of groundwater extraction on agricultural production (Provencher and Burt, 1994).

AQUATOOL is a decision support system for water resource planning and management, used for the design of operational policies in complex systems such as those of the Segura and Jucar river basins, in the southeast of Spain, with significant problem of water scarcities and important surface-ground water interaction (Andreu et al., 1994).

Hoeksema and Kitanidis (1985) presented a statistical method for estimating how parameters are spatially distributed and interrelated. They attempted to correlate changes in parameter values and changes in location with the first and second statistical moments.

Carrerra and Neuman (2004) also suggested a statistical approach for calibrating a groundwater model. In this they suggested that an inverse problem is solved using maximum likelihood theory based on some prior knowledge of aquifer parameters.

Pulido-Velazquez, Jenkins, and Lund presented a more recent and specific study of the potential economic values of conjunctive use and water banking in southern California (Pulido-Velazquez, Jenkins, and Lund, 2004). This study examines the interrelated benefits derived from conjunctive use and water market transfers and shows there is considerable value to be gained from the simultaneous application of both.

Analytical, numerical and analog models have been used to analyze groundwater system with greater accuracy. This requires a distributed model, so that the spatial distribution of the aquifer and its hydrodynamic properties, the boundary conditions and the situation of external stresses, located in a point or distributed over a certain surface can be considered. Analytical model estimates the system's response explicitly. However, analytical models are only available for very simple cases, for homogeneous and isotropic aquifers; therefore, they are only useful for very preliminary studies, or where aquifer properties are not well known. Numerical models are needed for non-homogeneous aquifers, complex geometry and/or boundary conditions.

In many cases, it is necessary to simplify models and adapt them to the level of available data. Frequently, there is not enough hydrological information (either of surface water or groundwater), operational, economical, nor about the future demand evolution. In many cases it is possible to quantify stream-aquifer interaction by simple and operational expressions that yield adequately accurate results. The *Embedded Pluricellular Model* (Sahuquillo and Andreu, 1988, Pulido et al. 2001) is a versatile conceptual model based on a semi-analytical solution of the differential groundwater flow equation for linear systems, as presented in the Analog method with the state equation of the unicellular model. This approach gives the solution to the problem of determining the stream-aquifer interaction in terms of a state vector. The interaction between surface and ground water in any aquifer that can be assumed linear is analogous to the drainage of an infinite series of virtual cells or deposits with drainage coefficients α_i, among which the external stresses (pumping or recharge) are distributed proportionally to the allotment factors β_i. These coefficients can be calculated analytically in certain cases, or can be calibrated in others, as for kart aquifers (Estrela and Sahuquillo, 1997). Then, it can be applied the same calculation process as in the unicellular case, just aggregating the results. For most practical cases, only a few cells are required to obtain satisfactory results.

Despite the many different optimization models and techniques that have been applied, most conjunctive use optimization work reported in literature deal with hypothetical problems, simple cases or steady state problems. The lack of large-scale complex real-world conjunctive use optimization studies is probably due to the great size of the problem resulting when many nodes-cells and long time periods are under consideration for modeling groundwater flow and the interaction between surface and ground water. Most conjunctive use models reported are created "adhoc" for particular problem. Only a few examples of generalized simulation models (in the way of decision support system) for conjunctive use management including groundwater flow and surface and ground water interaction have been reported (Andreu et al. 1996; Labadie et al. 1998). Generally, the models that can reproduce more detailed surface and ground water interaction do not account for economic aspects of water allocation. Lastly, there is an absolute absence of generalized large-scale optimization models for conjunctive use in which the surface and ground water interactions is included with significant detail.

2.3 CONCLUDING REMARKS

A study of the existing literature shows that there is no single comprehensive model developed for irrigation of multiple crops in which reservoir operation and irrigation allocation decisions at field level are integrated, and in which a conjunctive use policy for the irrigated area, apportioning the surface and ground water components, taking into account the distributed parameter characteristics of the aquifer and the soil moisture dynamics at the crop level, is embedded. The present study is an attempt in this direction and in the identification of a stable conjunctive use policy for canal command areas.

Full development and implementation of conjunctive use of surface and ground water must overcome operational, institutional, physical and legal constraints. Simulation and optimization models are being used to assess the benefits of conjunctive use management and to identify, "optimal" operation policies or the capacity expansion of the system. Despite the proliferation of conjunctive use models with different system analysis techniques, efficient large-scale optimization models are missing. One of the most difficult problems to overcome is the efficient integration of simulation models of aquifer in large-scale optimization models.

STUDY AREA AND DATA ACQUISITION

3.1 GENERAL

The study area lies in the command of Omkareshwar Left Bank Canal (OLBC). The OLBC branches from the left bank of Narmada River at Omkareshwar dam in the Khandwa district of Madhya Pradesh, with a head discharge of 18.6m^3/s. The length of common carrier is 10.64 km, and the length of left bank canal is 53.34 km. This encompasses Gross command area of 34,600 ha, and Culturable command area of 26,555 ha. The entire length of the branch canal and distributaries is 148.98 km. Until recently, the chosen canal command had no surface water delivery. All the irrigation water requirements were met by groundwater alone.

3.2 LOCATION

The command area of OLBC lies between the Narmada River and the left bank canal, which serves mainly khandwa and Khargone district of Madhya Pradesh. The command area of OLBC lies between latitude 22°5'N to 22°15'N and longitudes 75°30'E to 76°8'E. Fig. 3.1 shows the location of OLBC command. The detailed layout of the canal system of the study area is shown in Fig. 3.2.

3.3 HYDRO-METEOROLOGICAL DATA OF THE STUDY AREA

3.3.1 Climate

The climate of the command area is semi-arid, sub-tropical monsoon. Extreme heat is experienced during summer season. During winter season, the climate is mild. The summer temperature in May reaches a maximum of 48°C (Year 1959), while the minimum winter temperature recorded in the month of December was 3.3°C (Year 1936) at Khandwa observatory. The average annual rainfall is 730 mm as compared to the entire Malwa region, which is around 1267 mm. The average annual rainfall in the command area varies from 857 mm to 600 mm. The normal average rainfall is given in Table 3.1 for the different rain gauge stations in the study area.

3.3.2 Humidity

The relative humidity as observed at Khandwa and Punasa observatory is very low in dry weather, 12%, and is a maximum in the monsoon season, above 87.5%.

3.3.3 Wind

The study area experience storms during the hot summer season of May and June. During the month of June, the average wind speed is around 13 km/hr. The lowest wind speed is in the month of November and December, which is around 4 km/hr.

3.4 TOPOGRAPHY

In general, the topography of the area on the left bank canal between Satpuras and the river is plain, but not on the right bank, which is between Vindhyans and the river, it is rolling and undulating.

3.5 SOILS

The soils of the area have been broadly classified as medium black.

3.6 GEO-HYDROLOGY OF THE AREA

The area is geologically classified into three zones – Basaltic Flow I, Basaltic Flow II and Alluvium. The Alluvium area occurs on the northern portion adjacent to the Narmada River. There are several dykes (generally running East-West) in the northern portion. The dykes act as flow barriers. The aquifer is treated as shallow and unconfined for the entire study area. It is observed that below a layer of weathered Basalt and vesicular Basalt, a thick layer of massive Basalt occurs, the top of which may be taken as the bottom of shallow aquifer.

3.7 GROUNDWATER RESOURCES OF THE STUDY AREA

The OLBC command is presently irrigated by groundwater. The groundwater department (GWD) of Madhya Pradesh is engaged in measuring the groundwater depths at various observation wells. The water depth is recorded towards the end of May and is known as pre-monsoon water level. The post- monsoon water depths are recorded in the month of October. Data of pre-monsoon and post-monsoon depths of water table are given in Table 3.2.

3.8 SURFACE WATER RESOURCES OF THE STUDY AREA

The study area is expected to receive surface water from Narmada River which flows from East to West in the canal command. The discharge at the head of the main canal is 18.60m³/s, and the length of the main canal is 64.28 km. The length of the branch canal and distributaries is 148.98 km. The total proposed culturable command area of the OLBC is 26,555 ha; whereas, the gross command area is 34,600 ha. The surface water availability has been worked out month-wise and will be used in the conjunctive use planning studies.

TABLE 3.1

SEASONAL RAINFALL (in mm) OF MAHESHWAR, KASRAWAD AND BARWAHA RAIN GAUGE STATIONS

YEAR	MAHESHWAR		KASRAWAD		BARWAHA	
	NM	M	NM	M	NM	M
1990-91	170.00	1218.90	87.60	704.20	26.80	823.30
1991-92	20.60	783.10	0.00	515.00	0.00	627.60
1992-93	86.50	817.70	73.60	808.00	67.80	577.20
1993-94	68.60	967.00	43.00	854.00	52.00	1066.50
1994-95	12.20	1236.20	12.00	1011.20	1.00	1028.20
1995-96	-	915.00	-	955.00	-	950.00

NM – Non Monsoon Season **M- Monsoon Season**

TABLE 3.2
SEASONAL GROUNDWATER ELEVATION (RL in metres)

VILLAGE	1990	1991		1992	
	POST-	PRE-	POST-	PRE-	POST-
MAHESHWAR	153.42	150.68	150.47	148.17	150.72
KASRAWAD	169.72	167.42	171.02	158.97	173.42
MANDLESHWAR	160.49	154.39	150.94	152.69	153.34
KATARGAON	177.2	171.65	174.95	170.40	175.05
MORTAKKA	171.10	167.75	169.15	166.96	169.25
SAILANEE	205.15	199.75	200.55	197.95	200.30
SULGAON	209.90	209.45	210.05	209.00	209.60
DHANGAON	211.80	208.05	208.65	206.70	206.70
JAMKOTA	258.71	256.91	257.01	254.19	257.11
BARWAHA	18668	180.68	182.88	177.43	182.58
BEDIA	19635	190.55	195.00	182.95	195.15
THIBGAON	213.81	212.51	213.01	211.71	213.21
BELKAWADA	213.93	209.13	211.58	207.00	213.78
DHAMNOD	155.25	154.80	154.80	154.80	154.80
DHARAMPURI	140.70	140.70	141.15	136.20	136.20
THIKARI	165.85	162.90	163.40	160.60	163.01

VILLAGE	1993		1994		1995	
	PRE-	POST-	PRE-	POST-	PRE-	POST-
MAHESHWAR	148.42	151.17	148.78	153.10	151.78	152.58
KASRAWAD	169.42	173.42	169.32	173.87	169.72	174.32
MANDLESHWAR	151.69	152.94	152.50	156.64	153.99	155.14
KATARGAON	170.40	175.05	171.05	175.95	174.85	174.75
MORTAKKA	166.95	168.55	167.15	170.70	167.50	168.45
SAILANEE	197.85	201.15	198.10	203.40	199.65	202.95
SULGAON	208.95	203.75	203.75	203.70	203.50	203.75
DHANGAON	206.70	206.70	206.70	206.70	206.70	206.70
JAMKOTA	254.91	258.11	254.91	257.60	256.60	257.21
BARWAHA	179.18	183.18	177.48	183.98	179.88	182.58
BEDIA	189.90	196.70	189.30	197.20	192.95	185.15
THIBGAON	211.71	218.56	211.72	218.32	211.87	214.42
BELKAWADA	207.03	213.83	209.03	214.38	209.13	213.83
DHAMNOD	154.80	154.80	154.80	154.80	154.80	154.80
DHARAMPURI	136.20	136.20	136.20	136.20	136.20	136.20
THIKARI	160.30	162.05	160.80	163.96	151.34	151.34

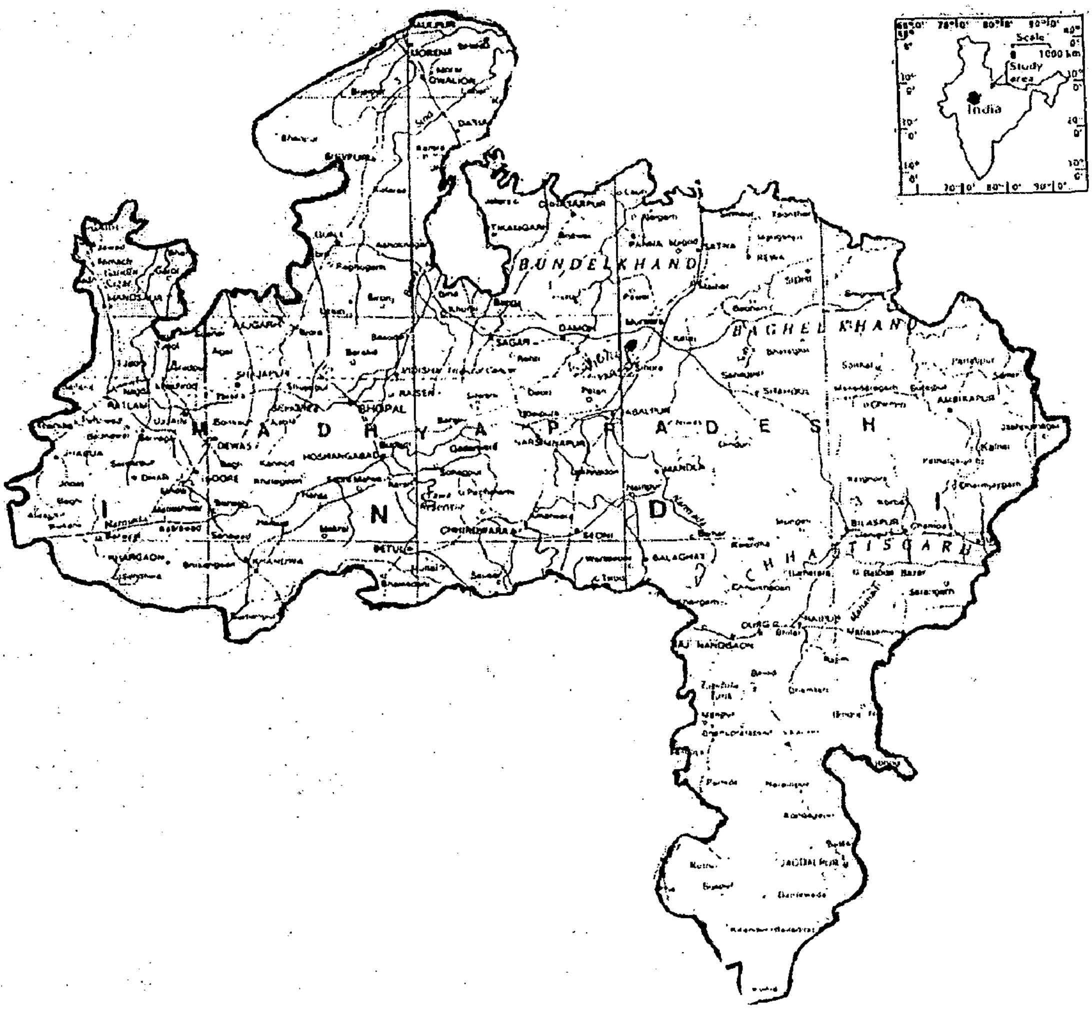

Fig: 3.1 LOCATION PLAN OF THE STUDY AREA

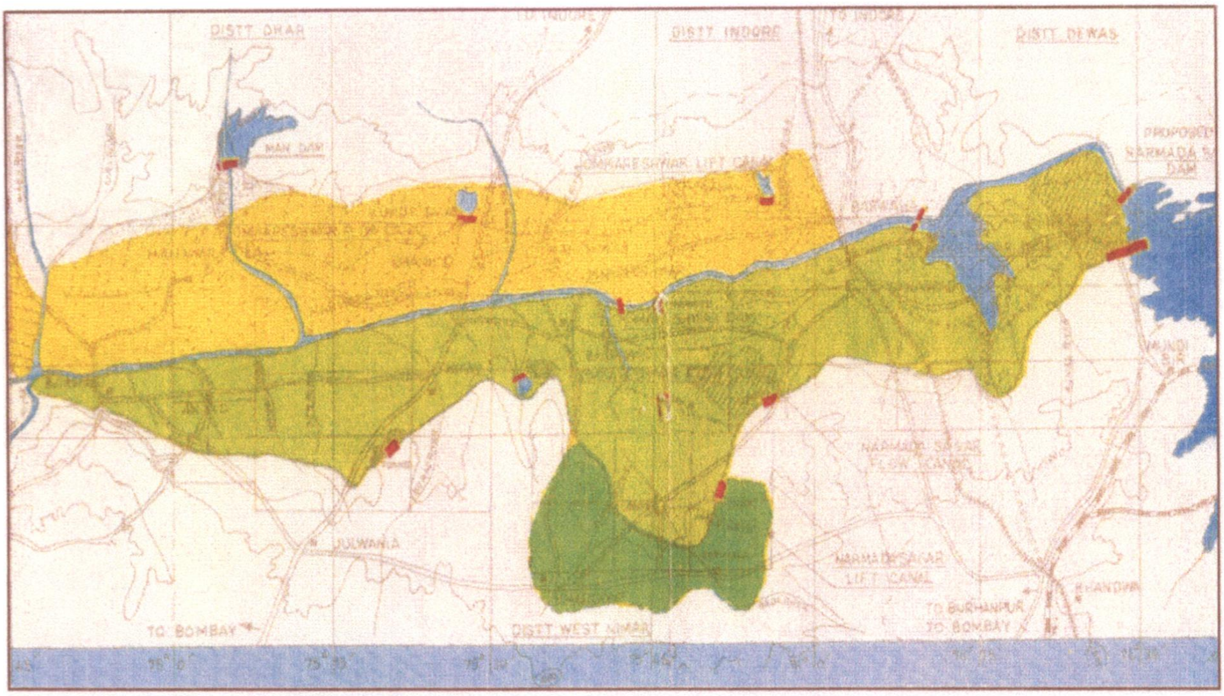

Fig. 3.2 LAYOUT PLAN OF OMKARESHWAR PROJECT

CHAPTER 4

ECONOMICS OF SURFACE & GROUND WATER

4.1 GENERAL

Different kinds of operating strategies exist to accomplish effective conjunctive use of surface and ground water sources. One form of conjunctive use that is becoming very important is groundwater banking. This involves storing surface water and runoff in times of abundance in aquifers and releasing the banked water by pumping when surface water is in short supply. Groundwater banking is a cost-effective method for increasing supply in some areas without constructing costly new facilities.

The main economic difference between ground and surface water projects is that, in general, initial investments are much lower for groundwater, but operation and maintenance costs are higher. In surface water, the initial investment is usually high and the operation and maintenance costs are small. The traditional criterion for economically efficient allocation of a resource over time is to summarize benefits and costs to a present value through a discount factor. It has been observed that higher discount rates give greater amount of resources allocated to earlier periods. However, a lower rate favours investments in projects involving a greater component of surface water, where groundwater projects are economically preferable for cases with limited capital and a high interest rate. The costs of transportation and distribution should also be considered, which often tend to favour ground water.

4.2 POTENTIAL ECONOMIC BENEFITS

The economic benefits of Conjunctive use include new yield, greater supply reliability, storing water close to users, and increased flood control benefits.

4.2.1 Potential for New Yield

Conjunctive use operations may allow the capture or use of additional yield from existing surface and ground water supplies. New yield can be made available primarily from increased capture of high monsoon flows that may spill from the Reservoir/Canal system down the canal command area. Capturing this water would mostly contribute new yield.

The economic benefits of the new yield depend entirely upon how the additional water is used. At present the area is largely agricultural so any additional water supplies may be used to irrigate additional acreage, improve reliability, or for transfer out of the area. However, the areas population and level of development will continue to increase in the future and new yield also may become a source for municipal or industrial supply.

Additionally, as water marketing continues to develop and water transfers and exchanges become more frequent and accepted, new yield may become a direct source of revenue to the region.

4.2.2 Flood Control Benefits

Conjunctive use operations can also increase flood control benefits provided by Narmada Reservoir. Additional flood protection could be gained by drawing down the reservoir to the top of its inactive pool. By releasing water at the proper rates during the draw-down period, a significant portion of monsoon flow could be stored in the aquifer for use in the subsequent irrigation seasons. This operation would provide additional flood control storage in the reservoir and also reduce spills.

4.2.3 Supply Reliability

A primary purpose of most conjunctive use operations is to improve the reliability of water supply to users. The ***"buffer"*** value created by groundwater can be quite significant. This is particularly beneficial for areas with significant agricultural water demands. The buffer value is more important in agricultural areas with permanent crops because of high costs of establishing permanent crops.

4.3 POTENTIAL ECONOMIC COSTS

The potential economic costs of conjunctive use may include, but not limited to, fixed costs, pumping costs, flood damage costs, recharge cost and externalities which may include resettlement and rehabilitation costs.

4.3.1. Fixed Costs

Fixed costs include the capital cost for installing and developing a well field (which become sunk cost once the infrastructure is ready), the depreciation of investments, staff expenditure and fixed maintenance costs. The variable costs corresponds to the energy used in pumping and the accelerated maintenance associated with mechanical wear. In spite of this, there are likely to be significant fixed costs incurred to establish additional wells to ensure that areas previously irrigated with surface water can receive adequate groundwater supplies in periods of reduced surface water flows. Likewise, additional surface conveyance facilities may be required to service areas traditionally on groundwater during periods with excess surface water supplies.

4.3.2 Pumping Costs

Most Conjunctive use operations incur additional pumping costs for water users. The exception is when "in-lieu" recharge is the sole method of recharge and water that would normally be pumped is left in the aquifer as credit when additional surface water supplies are available. However, the additional surface water may not likely be available during times of high demand. Therefore, there will be additional pumping cost with conjunctive use operations. The pumping cost is proportional to the total quantity pumped and the total lift. The energy required for extracting water from a well has the following five components: the sub-regional average depth to water, the pumping drawdown created in the aquifer formation surrounding the well, the head losses due to flow restrictions along the well borehole, well pack and well screens (well losses), the additional discharge pressure required and the pumping plant efficiency.

4.3.3 Flood Damage Costs

While conjunctive use operations may provide increased surface water storage for flood protection, operation may simultaneously increase flooding by raising groundwater levels and reducing aquifer storage space for rain percolation. However, the amount of deep percolation occurring during storms is likely a small amount of the total flood volume and therefore additional flood damages can be ignored.

4.3.4 Externalities

Conjunctive use operations have the potential to affect others not involved in the direct economic exchange. These externalities can take the form of environmental damage, flooding of overlying lands, reduced groundwater quality, damage to the aquifer through subsidence and compactions, and impacts to overlying wells. In the Omkareshwar canal command, the most likely and significant is effect on displacement and resettlement of human and animal population. This is likely to incur a huge cost on the project. Conjunctive use operations often result in a large range of groundwater elevation changes than what typically occurs without conjunctive use. This effect can be particularly damaging in severe draughts when increased reliance on groundwater can draw the water table down below the depth of residential wells.

Conjunctive use may also create environmental externalities, mostly due to the variability of groundwater levels. High levels during recharge may create ephemeral wetland areas, while during draught; levels may drop below tree root zones. Estimating and assigning a cost or benefit to environmental externalities is extremely difficult and beyond the scope of the present analysis.

4.3.5 Recharge Cost

Recharge cost is highly variable, depending on the methods used and the site available for the recharge program. In the Omkareshwar command, the methods used may include surface spreading and enhanced natural recharge. The cost of artificial recharge must include the operation and maintenance (O&M) cost, the water diversion cost and the opportunity cost of the water itself and of the land that is taken.

4.3.6 Surface Water Supply Operating Costs

Cost of surface water is based on the cost of canal and distribution system designed for surface water allocation to various zones. It is assumed that surface water is distributed uniformly over the entire command. The unit cost for each zone is computed by considering the total volume of water supplied by the surface water supply system and capital cost and the operation and maintenance costs (O/M) of the system. The capital cost of the surface water supply system was converted into annual cost by considering useful life of the system and the discount rate. The annual allowance in the case of constant depreciation is given by (Gonzalez):

$$AF = \frac{r(1+r)^n}{(1+r)^n - 1} \qquad \dots (4.1)$$

Where, AF is the annuity factor, r is the discount factor and n is useful life of the system in years.

The following components are considered in calculating the capital cost of surface water supply system:

(i) Headworks

(ii) Omkareshwar left bank main canal (OLBC)

(iii) Branches, Distributaries and Minors

(iv) Watercourses and Drainage

(a) Calculation of unit cost of headwork

(i) Cost of Headworks of Omkareshwar = Rs. 1431.83 Lacs

The total discharge from the Omkareshwar Headwork is 144.892 cumecs. Out of which only 18.6 cumecs is available at the head of main canal. The rest of the discharge is assigned to the right bank canal. Hence if the cost share of headworks is proportioned according to the discharge in these two canals, we get for the OLBC:

$$\frac{1413.83}{144.892} \times 18.6 = \text{Rs.}183.8\,\text{Lacs}$$

(ii) Cost of OLBC = Rs. 4237.42 Lacs

Total cost = 4237.42 + 183.8

= Rs. 4421.00 Lacs

These costs of different structures were based on the price level of 1987. Modifying it for the present study, we get Rs.11052.00 lakhs (Banks, H.O., 2002). Useful life of Headworks has been assumed as 100 years and the discount rate as 12% based on existing practices to calculate the annuity factor as:

$$\text{AF} = \frac{0.12*(1+0.12)^{100}}{\{(1+0.12)^{100} - 1\}}$$

$$= 0.11$$

Thus the annual investment cost = 11052 * 0.11

= Rs. 1215.72

The volume of water in OLBC at head is 41783.0ha-m

The discharge from the OLBC is 18.6 cumecs, and it is proposed to run the canal for 260 days in a year. So the total discharge from the canal is

$= 18.6 * 260 * 60 * 60$

$= 41783.0$ha-m

Therefore, the unit cost (i.e. the annual cost per unit volume of water at the outlet) is given as:

$$= \frac{1215.72 * 10^5}{41783.0}$$

= 2909.6 Rs/ha-m

(b) Calculation of operating and maintenance (O&M) costs

The Operation and Maintenance cost (O&M) costs has been calculated considering the annual working expenses for the irrigation system as 150 Rs/ha-m of the proposed area of irrigation and for additional repairs of 1.0% of the capital cost share of headworks and main canal.

The proposed area for irrigation by OLBC is 34600 ha, and CCA is 26555 ha. The corresponding working expenses will be Rs. 39.83 lacs (150 * 26555). The cost share of headworks and main canal is Rs. 11052.2 lacs. The cost towards additional repairs comes out to be Rs. 110.468 lacs (1.0 * 11052.2 / 100). Therefore, the total O&M costs would be Rs. 150.33 lacs. The total volume of water available at the outlet from the OLBC is 41783.2ha-m. The unit cost at the outlet level of all the zones would be Rs.359.00 ha-m (150.2/41783.0). The unit cost so obtained (Table 4.1), is then converted to unit cost considering the conveyance efficiency of each zone as given in Table 4.2

TABLE 4.1

VARIATION OF UNIT COST WITH DEPTH TO WATER TABLE

HEAD (m)	UNIT ANNUAL CAPITAL COST (Rs/ha-m)	UNIT O&M COST (Rs/ha-m)	UNIT TOTAL COST (Rs/ha-m)
4	6851.54	1423.39	8283.93
6	7053.14	2077.78	9130.93
8	7131.54	2732.17	9863.71
10	7243.54	3386.55	10630.09
12	7355.54	4040.93	11396.47
14	7467.54	4695.32	12162.86
16	7523.54	5349.71	12873.24
18	7691.54	6004.08	13695.62
20	7859.54	6658.47	14518.01
25	7915.54	8294.43	16209.97

TABLE 4.2

COST OF SURFACE WATER

ZONE No.	CONVEYANCE EFFICIENCY (%)	TOTAL UNIT COST (Rs/ha-m)	O & M COST (Rs/ha-m)
1	98.00	3336.00	367.00
2	95.24	3425.60	377.80
3	94.23	3469.40	381.80

(c) Total unit cost of surface water system

The total cost has been calculated for each zone based on the unit costs for the different components of distributary system. As shown, the total unit costs consist of the unit costs of annual capital investment and O&M. These unit costs would now be used in the allocation model for the conjunctive use of surface and ground water.

The capital cost = Rs.2909.6/ha

The O&M cost = Rs. 359.8/ha

The total cost = Rs. 3269.2/ha

4.4 COST-BENEFIT ANALYSIS

It is possible to perform a preliminary cost-benefit analysis based on estimated or assumed values for new yield, water and crop prices, pumping cost, flood damage cost, etc. following are the details of the assumptions made to estimate benefits and costs and provides a preliminary analysis.

4.4.1 Benefits of New Yield

It is difficult to quantify the new yield from conjunctive use operations. The actual volume of water available in any one year varies with hydrology and water demand and is known to vary from zero to the maximum irrigation water demand. There are losses involved in the recharge process as water is intercepted in the root zone, evaporates from the command area or flows all the way to nearby streams/rivers. A commonly used estimate for recharge losses is 15% (USACE 2002). The new yield is actually represented by the additional volume that percolates to the aquifer under conjunctive use release pattern. Therefore it is assumed that 60% (USACE 2002) of the water that reaches the aquifer is new yield, the other 40% (USACE 2002) having previously percolated during non-conjunctive use release. It is likely that this additional yield would be used to irrigate additional acreage in this region, as water supply is typically the limiting constraint to agriculture. The highest value for any new yield captured through conjunctive use is likely to be realized through water marketing.

4.4.2 Flood Damage Reduction

There may be some additional benefits from reduced flood damage. It is possible to make estimates of the expected reductions in flood damages from conjunctive use operations. However, these estimates require significant data and modeling effort. For the purpose of this preliminary estimate, it would be assumed that the damage reduction benefit is approximately equal to the damage increase that may be seen because of raised groundwater levels. Additionally, the increase in flood storage due to conjunctive use operations is a relatively small volume. Therefore, there is no net benefit or cost from flood damages.

4.4.3 Fixed Capital Costs

Field wells are required to extract water from storage by pumping the new yield to other users. The major costs to develop these well fields include land purchases or long-term leases, well drilling, and pumps. The cost of withdrawing groundwater from subsurface reservoir comprises of 'Fixed capital cost' and 'Recurring cost'. Fixed cost includes the cost of exploration, drilling and installing the complete system, whiles recurring costs include energy charges, operation and maintenance (O&M) costs.

The capital cost may be expressed as:

$$\mathbf{CC = f\,(D, w, d, s, M)} \qquad \ldots (4.2)$$

Where,

CC = Capital cost

D = Total depth of bore

W = Depth to water table below ground level

d = Diameter of well

s = Drawdown

M = Material of tube well assembly

The recurring cost depends on the duration of the operation of well, energy cost, labour cost, etc. It can be expressed as:

$$\mathbf{RC = f\,(Q, H, m, t, n, e)} \qquad \ldots (4.3)$$

Where,

RC = Recurring cost

Q = Discharge of tube well

H = Total head

m = Maintenance cost

t = Number of working hours per year

n = Efficiency of tube well

e = Unit cost of energy

Well drilling costs can be estimated in price per meter drilled. Values differ based on location, well diameter, and requirements for casings and screening. Approximate values for Omkareshwar Canal command area are Rs.200.00 per meter based on well depths of approximately 30 meters to the bottom of the existing unconfined aquifer, this result in a total drilling cost of Rs.6000.00. Purchase and installation of a pump is also required and estimated at approximately Rs.12500.00 per pump. Table 4.3 gives a summary of groundwater cost.

The total fixed capital costs can be discounted and annualized over the expected life of the well to provide an annual cost in present value for end uses. Assuming a 75-year well life, and a discount rate of 4%, the annual cost is calculated as:

$$\text{Annual Payment} = \text{Present value cost} * \frac{\{i*(1+i)^n\}}{\{(1+i)^n - 1\}} \qquad \ldots (4.4)$$

Where i is the discount rate and n is the well life. This provides an annual cost of Rs.6668.70 for the well fields. The choice of a discount rate depends largely on the type of financing expected.

TABLE 4.3

THE COST OF GROUNDWATER IS WORKED OUT AS FOLLOWS:

Sr No.	Description	Amount Rs
1	Drilling charges for 100mm dia. Bore up to an average depth of 30 m	6000.00
2	PVC casing pipe 6 inch size @ Rs.200/ m for 6 m	1200.00
3	GI Pipe 2" size @ Rs.320/m for an average depth of 25 m with all coupling and other accessories	8000.00
4	3 HP Pump set with all accessories	12500.00
5	Pump shed with brick wall and tin shed	4000.00
	Total	**31700.00**
	Annualized capital cost + Energy charges 30700*0.1315(CRF) + 3060	9728.70
	Power required in kwh = 3HP*0.75	2.25
	Total power required in kwh = 160days * 10hr * 2.25	3600.00
	Minimum tariff per kwh in Rs.	0.85
	Total energy cost 3600 * 0.85	3060.00
	Cost per hectare meter (3060/1.28)	2391.00
	(for 8000 lps @ 10hrs pumping per day for 160 days need 1.28 hectares meter draft as per GEC – 1997 Report) from an average depth of 30 m.	
	O&M @ 4% of capital cost	921.00
	Total maintenance cost of groundwater in Rs. (2391 + 921)	3312.00

4.4.4 Pumping Costs

Average annual pumping costs can be estimated as the cost to recover the yield. This method ignores the cost to recover any additional water stored in the aquifer that would historically be delivered by surface conveyance, but it is difficult to estimate this volume with presently available data.

Pumping costs have been estimated for numerous studies and models with a typical value being around Rs. 5.85/ac-ft*ft (Knapp and Olson 1995). It is recognized that this cost would not be incurred every year and that when surface supplies are reduced, it will be higher. However, this estimate should provide the average annual additional pumping cost created by conjunctive use operations.

4.4.5 Operation and Maintenance Cost

The required horse power for the tube well can be obtained as:

Horse power required,

$$\mathbf{HPR = Q * H / (0.076 * n)} \quad \text{.... (4.5)}$$

Where,

Q = Discharge in m^3/s

H = Total head or lift (m)

n = Overall efficiency of pump and motor which is taken as 45% for the present study.

(i) Annual operation cost:

The annual operation cost (AOC) is calculated as:

$$\mathbf{AOC = 0.746 * HP * PT * PR} \quad \text{... (4.6)}$$

Where,

HP = Horse power required

PT = Annual pumping hours

PR = Rate of power (Rs/Kwh)

(ii) Annual maintenance cost:

Annual maintenance cost (AMC) is computed as 2% of the capital cost

Total operation and maintenance cost (O&MC) is calculated as:

$$\mathbf{O\&MC = AOC + AMC} \quad \text{... (4.7)}$$

Hence the total annual cost is obtained as:

Total Annual Cost **(TAC) = (ACC + O&MC)** ... (4.8)

(iii) Unit Cost of groundwater

The unit cost can be determined by dividing the total annual cost by the total volume of annual pumped water.

4.5 FINANCING OPTIONS

Use of the underlying aquifer for recharge discourages the need for dedicated recharge ponds or injection wells both of which incur capital cost. However, a complete conjunctive use operation may still have capital costs associated with additional wells or surface conveyance facilities.

Based on the cost-benefit analysis, it is evident that local water agencies will need government assistance to finance the project. Additional funding options are available through state government. Nevertheless, if these funding sources are not available, it is still possible to implement conjunctive use management with individual farmers drilling the needed wells over time (especially to ensure supplies for permanent crops), though this plan may meet with local opposition. In reality the new wells could be drilled over a period of years, thereby reducing the money needed to begin operations and reducing the overall project costs.

CHAPTER 5
CONJUNCTIVE USE MODEL

5.1 GENERAL

The conjunctive use model determines the maximum available withdrawals from major streams for supplementing groundwater to meet the total water demand. In essence of this the objective is to estimate the "sustainable yield"- indefinite groundwater withdrawals without compromising the integrity of the aquifer or streamflow in the Narmada River. The results of the optimization model can provide water managers and policy makers with information that can be used to assist in management of water resources.

A conjunctive use model is developed to simulate optimized surface water and groundwater withdrawals while maintaining hydraulic-head and streamflow constraints, thus determining the "sustainable yield" for the aquifer. The conjunctive use optimization model or "optimization model" is developed for the Omkareshwar Canal command using linear programming technique.

5.2 AVAILABILITY OF WATER RESOURCES

5.2.1 Groundwater Availability

Groundwater availability depends mainly on annual recharge from rainfall and conveyance losses, which can not be ascertained very accurately. Based on available literature, we assume suitable values for conveyance losses and different components of recharge factors. Recharge factors from State Groundwater Department are used for the present study.

(i) Recharge from rainfall

Recharge from rainfall depends on soil characteristics, surface condition and crop cover. An average rainfall recharge factor of 20% (USACE 2002) has been taken for the present study and is used for subsequent computations.

(ii) Recharge due to conveyance losses from canals and watercourses

Recharge from conveyance losses from canals is taken as 70% (USACE 2002).

Similarly, recharge from watercourses has been taken as 75% (USACE 2002). The losses from the main canal, distributaries and minors will reach the groundwater storage.

(iii) Recharge due to field losses

Surface water availability will be determined under different water availability conditions. We assume that 30% (USACE 2002) losses takes place in the fields and out of this 80% (USACE 2002) infiltrates into the groundwater storage reservoir. Based on these assumptions, recharges from field losses are determined.

(iv) Return flow from groundwater irrigation

It is further assumed that 90% (USACE 2002) of the total recharge from rainfall, canals and field seepage can be taken as groundwater available for irrigation. Additionally, there will be recharge from watercourses as well as from agricultural fields. 10% (USACE 2002) conveyance losses from watercourses (for groundwater irrigation) have been assumed. Also 75% (USACE 2002) of conveyance losses will go to groundwater storage. Therefore 90% (USACE 2002) of the total recharge from losses can be assumed as Groundwater available for irrigation purpose.

***Sample calculations for 100% surface water availability**

(i) Rainfall recharge

(GCA) * (Normal Rainfall) * (Recharge factor)

(36,400 ha) * (0.91 m) * (0.20) = **6625.00 ha-m**

(ii) Return flow from groundwater draft

(Groundwater draft) * (Infiltration factor from irrigated field) * (Recharge component)

(2257.6 ha-m) * (0.30) * (0.80) = **542.00 ha-m**

(iii) With surface water availability, the recharges are:

(a) Recharge through canal system

Surface water at the head = 41783.00 ha-m

Conveyance efficiency considered as 72%

Thus surface water at outlet = 0.72 * 41783.00

= 30084.00 ha-m

Conveyance losses = 41783 – 30084

= 11699.00ha-m

70% of these losses available as groundwater recharge = 0.70 * 11699

= **8189.00 ha-m**

(b) Recharge through water courses

Water available at outlet = 30084.00 ha-m

Water available at field = 0.75 * 30084.00

= 22563.00 ha-m

Losses through water courses = 30084 – 22563

= 7521.00 ha-m

75% of this is available as groundwater recharge = 0.75 * 7521

= **5640.75 ha-m**

(c) Recharge due to field losses

Water available at field = 22563.00 ha-m

Losses @ 30% = 0.30 * 22563

= 6769.00 ha-m

80% of this is recharged to groundwater = 0.80 * 6769

= **5415.20 ha-m**

Total groundwater available = 6625 + 542 + 8189 + 5640 + 5415.20

= **26411.20 ha-m**

Assuming 10% of groundwater for domestic purposes, the remaining 90% can be used as groundwater available for irrigation = 0.90 * 26411.20

Groundwater available for irrigation = **23770.08 ha-m**

Return flow from groundwater irrigation = .030 * 0.80 * 23770.08

= 5704.82 ha-m

Thus the return flow is **5704.82 ha-m**

Therefore the total availability of groundwater can be considered without mining as;

= 0.9 *(23770.08 + 5704.82)

= 26527.41 ha-m

Therefore the groundwater available with surface water can be considered as 26,000.00 ha-m. The groundwater available for different conditions are shown in Table 5.1

TABLE 5.1

GROUNDWATER AVAILABILITY UNDER DIFFERENT SURFACE WATER CONDITIONS (in ha-m)

GROUND	Existing	100% SW	90% SW	80% SW	75% SW	70% SW	50% SW
WATER	7632.00	26,000.00	24,265.02	22,332.01	21,365.54	20,399.04	16,533.04

5.2.2 Surface water availability

The monthly availability of surface water at head of Omkareshwar left bank canal command is given in Table 5.2

5.3 OPTIMIZATION MODEL FORMULATION

The Optimization model is formulated as a linear programming problem with the objective of obtaining optimum allocation of water from wells and from streams subject to: (1) maintaining streamflow at or above minimum specified rates; (2) maintaining ground water levels at or above specified levels. Steady-state conditions are selected (rather than transient conditions) because the maximum withdrawals are intended to represent sustainable yield of the system (a rate that can be maintained indefinitely). The decision variables are the water and land resources. These variables are regulated so that they are not exceeded beyond the permitted limits. Constraints on hydraulic head and streamflow assigned must be satisfied for a feasible solution of the objective function.

5.3.1 Formulation of the Objective Function

The Objective of the optimization model is to maximize net benefits from crops thereby minimizing the cost of surface and ground water. The objective function of the optimization model has the form:

Maximize Z = (Net Benefits – Cost of SW – Cost of GW) ... (5.1)

Where **SW** is the surface water and **GW** is the groundwater, respectively.

5.3.2 Constraints

The general constraints in a conjunctive use model are as follows:

(i) Streamflow constraints

Streamflow constraints are specified as the minimum amount of flow required in the Stream/River. i.e. Surface water allocation ≤ Surface water available, for each month.

(ii) Groundwater availability constraint

Groundwater allocation ≤ Groundwater available

(iii) Crop water requirement constraint

Water requirement of crops for each month ≤ Surface water + Groundwater

(iv) Area availability constraint

Cropping area ≤ CCA

(v) Crop area constraint

Area under each crop ≤ Crop intensity * CCA

5.3.3 Formulation of the Objective Function

(i) Benefits from crops can be written as

$$\sum_{i=1}^{n} A_{i,j} B_j \qquad \dots (5.2)$$

Where,

$A_{i,j}$ = Area of j^{th} crop for the i^{th} zone in ha.

B_j = Net Benefit of j^{th} crop excluding cost of water in Rs/ha.

(ii) Cost of surface water

$$\sum_{i=1}^{n} CST_i * SW_{i,k} \qquad \dots (5.3)$$

Where,

CST_i = Total cost of surface water for i^{th} zone in Rs/ha-m

$SW_{i,k}$ = Surface water allocations for i^{th} zone during k^{th} period in ha-m.

(iii) Cost of groundwater

The cost of the groundwater can be worked out as:

$$\sum_{i=1}^{n} CGT_i * WGT_{i,k} \quad \ldots (5.4)$$

Where,

CGT_i = Cost of groundwater for i^{th} zone in Rs/ha-m

$WGT_{i,k}$ = Groundwater allocations for i^{th} zone during k^{th} period in ha-m

The Objective Function is therefore written as:

$$\textbf{Max Z} = \sum_{i=1}^{n} A_i B_i - \sum_{i=1}^{n} CST_i * SW_i - \sum_{i=1}^{n} CGT_i \quad \ldots (5.5)$$

5.3.4 The Constraints are:

(i) Water requirement constraints

$$\sum_{i=1}^{n} WR_{ik} * A_{ij} = SW_{ik} + GW_{ik} \quad \ldots (5.6)$$

Where,

WR_{ik} = Water requirement for i^{th} zone during k^{th} period in m.

A_{ij} = Area of i^{th} zone for j^{th} crop in ha.

SW_{ik} = Surface water allocation in i^{th} zone during k^{th} period in ha-m

GW_{ik} = Groundwater allocation for i^{th} zone during k^{th} period in ha-m

(ii) Area availability constraint

The area availability constraints can be written as:

$$\sum_{i=1}^{n} \lambda_{j,kr} A_{ij} \leq CCA_i \quad \ldots (5.7)$$

Where,

A_{ij} = Area of i^{th} zone for j^{th} crop in m

CCA_i = Culturable command area for i^{th} zone in ha

$\lambda_{j,kr}$ = Land use coefficient for j^{th} crop in kr^{th} period.

(iii) Surface water availability constraint

The surface water availability can be written as:

$$SW_{i,k} \leq SWA_k \qquad \dots (5.8)$$

Where,

$SW_{i,k}$ = Surface water allocation for i^{th} zone in k^{th} period in ha-m

SWA_k = Surface water availability at canal head in k^{th} period in ha-m

(iv) Groundwater availability constraint

The constraints on groundwater availability for all the zones of the study area can be written as:

$$\sum_{i=1}^{n} GW_{i,k} \leq \alpha \, GWA_{i,k} \qquad \dots (5.9)$$

Where,

$GW_{i,k}$ = Groundwater allocations for i^{th} zone in k^{th} period in ha-m

α = mining allowance (=1 when mining is not allowed)

$GWA_{i,k}$ = Groundwater available for i^{th} zone in k^{th} period in ha-m

5.4 WATER REQUIREMENT OF CROPS

Water requirement of crops depends on meteorological parameters, the type of crop and the growth stage of the crop. Water requirements for chosen crops in the study area have been computed using Modified Penman method. A program based on FAO guidelines is used for computing net water requirement. Net water requirement can be obtained by subtracting effective rainfall from consumptive use of crops. Irrigation water requirement is determined from water requirement by considering field application efficiency as 70% for all crops. Monthly water requirements determined for selected crops are given in Table 5.3. Water requirements of crops, considering losses in water courses and agriculture field were estimated at the outlet.

5.5 NET BENEFITS FROM DIFFERENT CROPS EXCLUDING THE COST OF WATER

Gross receipts and cost of cultivation were considered for determining net benefits from crops of the study area. The yields of various crops were considered as fixed quantities obtained by averaging the corresponding yield for a period of five years. On the basis of the survey of the study area, cost of fertilizers, seeds, tractors ploughing, harvesting, threshing, nursery preparation (where applicable), and plant protections were considered for estimation of expenditures. The total receipt from a crop has been obtained from the yield of the main crop and the by-products and their respective market prices. Benefits are then computed from yield in quintal (qui), gross receipts in Rupees/ha and actual cost of cultivation per hectare and are given in Table 5.4.

5.6 MODEL LIMITATIONS

The model is used to investigate potential conjunctive use operations between Omkareshwar reservoir/canal-aquifer systems in the canal command area. Confidence in the model results will be ascertained when release patterns from the reservoir down the canal command are tested. The model should be considered more conceptual than predictive because of the limited data and the short period of this study. The model is developed for a specific set of land uses. Significant changes in land use and irrigation methods would require revised calculations of recharge. However, with new land use data, it would not be very difficult to update the model. Recharge values can be adjusted to include precipitation during other times of the year.

5.7 METHOD OF OBTAINING RESULTS

The cost of surface and ground water per hectare are used in the objective function together with the net benefits obtained from crops. The monthly allocation of surface and ground water available in the entire study area are taken as constraints. The different cases and model results of various scenarios are presented in subsequent chapters.

TABLE 5.2

MONTHLY AVAILABILITY OF SURFACE WATER

MONTH	Water Availability Conditions (ha-m)		
	100% SW	75% SW	50% SW
JANUARY	4017.60	2169.00	1446.00
FEBRUARY	4017.60	2169.00	1446.00
MARCH	2410.56	1301.00	868.00
APRIL	2410.56	1301.00	868.00
MAY	2410.56	1301.00	868.00
JUNE	2410.56	1301.00	868.00
JULY	4017.60	2169.00	1446.00
AUGUST	4017.60	2169.00	1446.00
SEPTEMBER	4017.60	2169.00	1446.00
OCTOBER	4017.60	2169.00	1446.00
NOVEMBER	4017.60	2169.00	1446.00
DECEMBER	4.17.60	2169.00	1446.00
Total	**30083.00**	**22562.00**	**15041.00**

TABLE 5.4

BENEFITS OF VARIOUS CROPS (EXCLUDING THE COST OF WATER)

CROPS	YIELD (qu/ha)	GROSS RECEIPTS (Rs/ha)	COST OF CULTIVATION (Rs/ha)	NET BENEFIT (Rs/ha)
Wheat	42.00	31500.00	10268.75	21231.25
Sugarcane	880.00	13750.00	26362.50	111137.50
Maize	47.00	18800.00	7812.50	10987.50
Cotton	9.00	23625.00	9218.75	14406.25
Groundnut	23.00	74750.00	10331.25	64418.75
Gram	32.00	40000.00	7943.75	32056.25
Berseem	30.00	20250.00	4286.25	15963.75
Jowar	32.00	20400.00	5423.75	14976.25
Chilli	350.00	109375.00	33656.25	75718.75
Soyabean	25.00	2500000	8449.04	16551.00
Moong	76.00	8369.60	4364.20	4005.40
Vegetables	200.00	21272.00	101250.00	79978.00

TABLE 5.3
WATER REQUIREMENTS OF CROPS (in mm)

S.No.	CROP	JAN	FEB	MAR	APR	MAY	JUN	ULY	AUG	SEP	OCT	NOV	DEC	TOTAL
1	**COTTON**	-	-	-	-	228	10	20	19	111	225	95	-	**708**
2	**CHILLI**	-	-	-	-	-	-	61	13	102	225	105	-	**506**
3	**MAIZE**	-	-	-	-	-	-	63	18	97	58	-	-	**236**
4	**WHEAT**	165	141	-	-	-	-	-	-	-	101	63	69	**539**
5	**GRAM**	71	-	-	-	-	-	-	-	-	76	78	64	**289**
6	**SUGARCANE**	163	207	134	174	229	29	21	14	74	181	128	146	**1500**
7	**BERSEEM**	154	178	113	-	-	-	-	-	-	97	48	61	**651**
8	**VEGETABLE**	-	-	-	-	-	-	69	6	135	93	-	-	**303**
9	**GROUNDNUT**	-	170	225	294	-	-	-	-	-	-	-	-	**689**
10	**SOYABEAN**	-	-	-	-	-	-	-	-	118	222	101	31	**472**
11	**JOWAR**	-	-	-	-	-	-	15	6	20	215	6	0	**262**
12	**MOONG**	-	-	195	312	72	-	-	-	-	-	-	-	**579**
	FOR HIGH YIELDING CROPS													
1	**COTTON**	-	-	-	-	285	12.5	25	23.75	138.75	281	118	-	**884**
2	**WHEAT**	206	176	-	-	-	-	-	-	-	126	79	86	**673**
3	**SUGARCANE**	204	259	168	217	286	36	26	18	92	226	160	183	**1875**
4	**GROUNDNUT**	-	212	281	367	-	-	-	-	-	-	-	-	**860**
5	**PADDY**	-	-	-	-	-	72	336	276	252	156	-	-	**1092**

CHAPTER 6

MODEL RESULTS AND ANALYSIS

6.1 GENERAL

The optimization model provides estimates of sustainable yield from both surface and ground water. Sustainability is used to define the quantity of water – both surface and ground – that can be withdrawn indefinitely by reaching system equilibrium. This chapter describes the results obtained from different runs of conjunctive use model.

6.2 DIFFERENT SCENARIOS CONSIDERED IN DETERMINING THE MODEL RESULTS

For the present work, a number of scenarios involving different availabilities of surface water, groundwater and cropping pattern are presented to assess the model response to the proposed scenario and the optimum values to be obtained in each of the cases. A sensitivity analysis is also performed on the model by considering cases where groundwater mining is allowed up to 15%. Availability of surface and ground water for different scenarios are given in Table 6.1. Following is a brief description of the different scenarios considered:

(i) Existing Cropping pattern with the present condition (i.e. without the availability of surface water)

(ii) Scenario with 100% Surface Water, Groundwater, and with the introduction of high yielding varieties of crop.

(iii) Scenario with 100% Surface Water, Groundwater, and with the introduction of high yielding varieties of crop and Paddy.

(iv) Scenario with 75% Surface Water, Groundwater, and with the introduction of high yielding varieties of crop.

(v) Scenario with 75% Surface Water, Groundwater and with the introduction of high yielding varieties of crop and Paddy.

(vi) Scenario with 50% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops.

(vii) Scenario with 50% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops and Paddy.

TABLE 6.1

AVAILABILITY OF GROUNDWATER UNDER DIFFERENT SURFACE WATER CONDITIONS

S No.	SCENARIO	GROUND WATER (ha-m)	SURFACE WATER (ha-m)	TOTAL (ha-m)
I	Existing Condition (No SW Available)	7632.00	-	7632.00
II	100% Surface Water Available	26000.00	41783.00	67783.00
III	90% Surface Water Available	24265.02	37604.70	61869.72
IV	80% Surface Water Available	22332.01	33426.40	55758.41
V	75% Surface Water Available	21365.54	31337.25	52702.79
VI	70% Surface Water Available	20399.04	29248.10	49647.14
VII	50% Surface Water Available	16533.04	20891.50	37424.54

6.2.1 Existing Cropping Pattern with the Present Condition (i.e. without the availability of Surface Water.

The entire water requirements of crops are met by rainfall and groundwater alone. Since the farmers have to rely only on groundwater, the full water requirements of the crops will not be met. The level of irrigation at present is 62% (Khare, 1998) and hence yield of crops is lower. This case is analyzed to access the behaviour of groundwater and net benefits if the canal is not introduced.

It is seen that if the present trend of withdrawals of groundwater are continued and surface water is not introduced in the study area, the depth of water table will fall far below the permissible level, which will result in increased pumping cost. The net benefits are worked out to be Rs. 28854.55 lakhs. The results are presented in Table 6.2 & Table 6.3. The allocation plan is presented in Fig. 6.1.

TABLE 6.2

CROP AREAS IN EACH ZONE UNDER EXISTING CROPPING PATTERN (ha)

CROP CODE	CROP	CROP AREA IN ZONE (in Hectares)			
		ZONE-1	ZONE-2	ZONE-3	Total
C1	COTTON	2826.00	1800.00	2700.00	7326.00
C2	CHILLI	73.50	46.83	70.74	191.07
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	908.46	1221.30	864.30	2994.06
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	49.98	31.84	48.56	130.38
C7	BERSEEM	155.08	98.81	149.26	403.15
C8	VEGETABLES	23.52	14.98	22.63	61.13
C9	GROUNDNUT	675.47	430.36	650.10	1755.93
C10	SOYABEAN	441.00	240.98	424.44	1146.42
C11	JOWAR	1323.36	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
Total		5796.01	3691.50	5559.73	**15047.24**

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TABLE 6.3

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE UNDER EXISTING CONDITIONS (IN HECTARE METER)

ZONE/ MONTH	**GROUNDWATER (ha-m)**				**SURFACE WATER (ha-m)**			
	ZONE-1	ZONE-2	ZONE-3	**Total**	ZONE-1	ZONE-2	ZONE-3	Total
JAN	90.55	109.09	86.38	286.03	-	-	-	-
FEB.	137.08	132.32	131.28	400.68	-	-	-	-
MARCH	113.81	72.54	109.61	295.96	-	-	-	-
APRIL	141.02	89.90	135.84	366.76	-	-	-	-
MAY	353.92	225.44	338.32	917.67	-	-	-	-
JUNE	32.84	20.92	31.61	85.37	-	-	-	-
JULY	61.43	39.12	58.94	159.49	-	-	-	-
AUG	335.66	213.77	321.08	870.52	-	-	-	-
SEPT.	350.39	223.10	336.07	909.56	-	-	-	-
OCT.	586.33	411.93	561.57	1559.83	-	-	-	-
NOV	487.19	352.05	466.32	1305.60	-	-	-	-
DEC.	168.31	152.21	161.35	481.87	-	-	-	-
Total	2858.53	2042.40	2738.38	**7639.31**	-	-	-	-

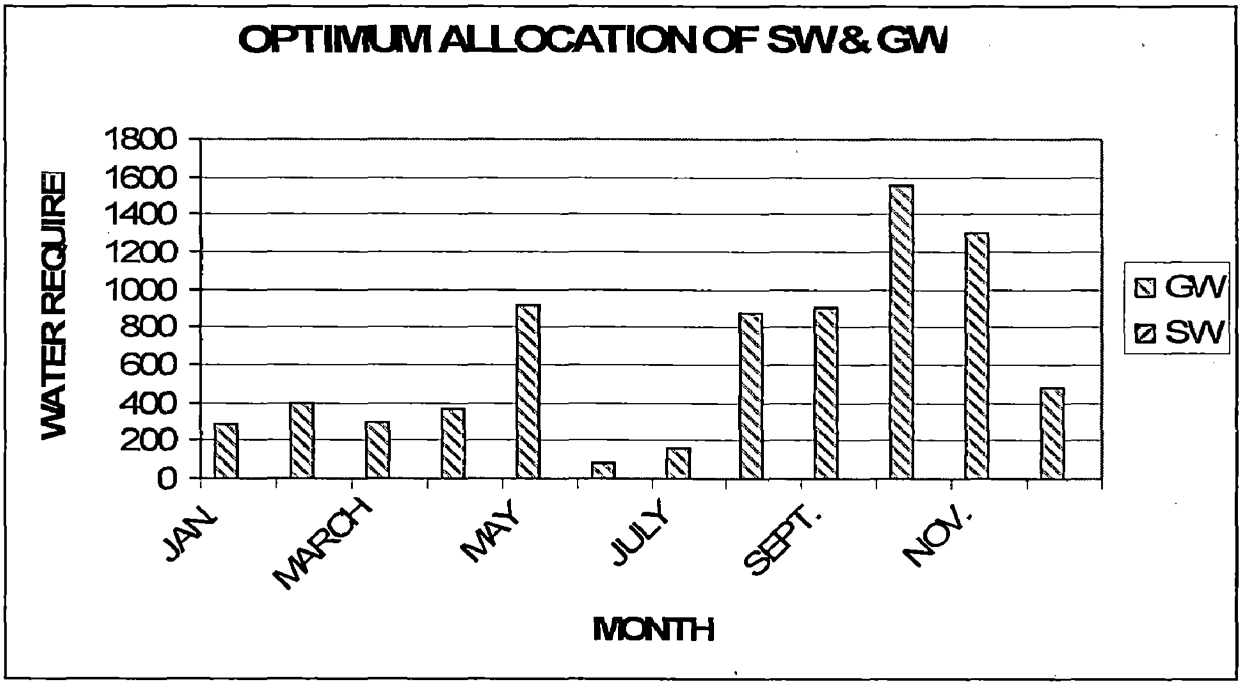

FIG. 6.1 GRAPH SHOWING THE ALLOCATION OF SURFACE AND GROUND WATER UNDER EXISTING CROPPING PATTERN

6.2.2. Scenario with 100% Availability of Surface Water, Groundwater, and with the introduction of high yielding varieties of crops.

With the introduction of surface water, the full crop water requirements can be met. The yield of crops will also increase. In this case the level of irrigation can be considered as 100%. Losses of surface water through the canal network will increase the groundwater recharge. Under this condition, the groundwater availability is estimated to be 26,000ha-m, whiles the surface water available is 41,783ha-m.

With the introduction of surface water, the cropping pattern is revised by introducing high yielding variety of crops, but not Paddy. The net benefits will increase substantially to Rs. 80629.50 lahks. Tables 6.4 & Table 6.5 summarizes the results, whereas the optimal allocations are represented in Fig. 6.2.

TABLE 6.4

CROP AREAS IN EACH ZONE WITH THE INTRODUCTION OF SURFACE WATER (ha)

CROP CODE	CROP	CROP AREA IN EACH ZONE (in Hectares)			
		ZONE-1	**ZONE-2**	**ZONE-3**	**TOTAL**
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450.00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
TOTAL		14459.56	9487.30	13893.07	**26555.00**

TABLE 6.5

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3482.00	785.81	804.52	680.09	2270.42
FEB.	1016.55	1216.88	1116.21	3349.64	662.18	594.23	730.11	1986.52
MAR.	1025.14	986.26	1064.02	3075.42	620.00	713.25	521.49	1854.74
APRIL	1162.72	1245.38	1080.05	3488.15	732.00	804.25	650.31	2186.56
MAY	1141.96	1024.89	1259.02	3425.87	866.67	902.15	831.18	2600.00
JUNE	1254.85	1171.25	1087.65	3513.75	766.70	780.00	753.40	2300.10
JULY	1354.25	951.49	1153.00	3458.74	656.10	720.12	592.10	1968.32
AUG.	1118.75	1218.08	1317.40	3654.23	814.56	800.21	785.38	2400.15
SEPT.	1152.16	1245.87	1058.38	3456.41	754.12	812.14	648.32	2214.58
OCT.	1095.85	1283.11	1189.56	3568.52	665.78	714.56	616.98	1997.32
NOV.	1165.85	1221.68	1277.51	3665.04	688.54	954.28	423.85	2066.67
DEC.	1235.48	1305.62	1104.13	3645.23	745.24	812.25	597.23	2154.72
Total	13784.22	14084.86	13913.92	**41783.00**	8757.70	9411.96	7830.44	**26000.0**

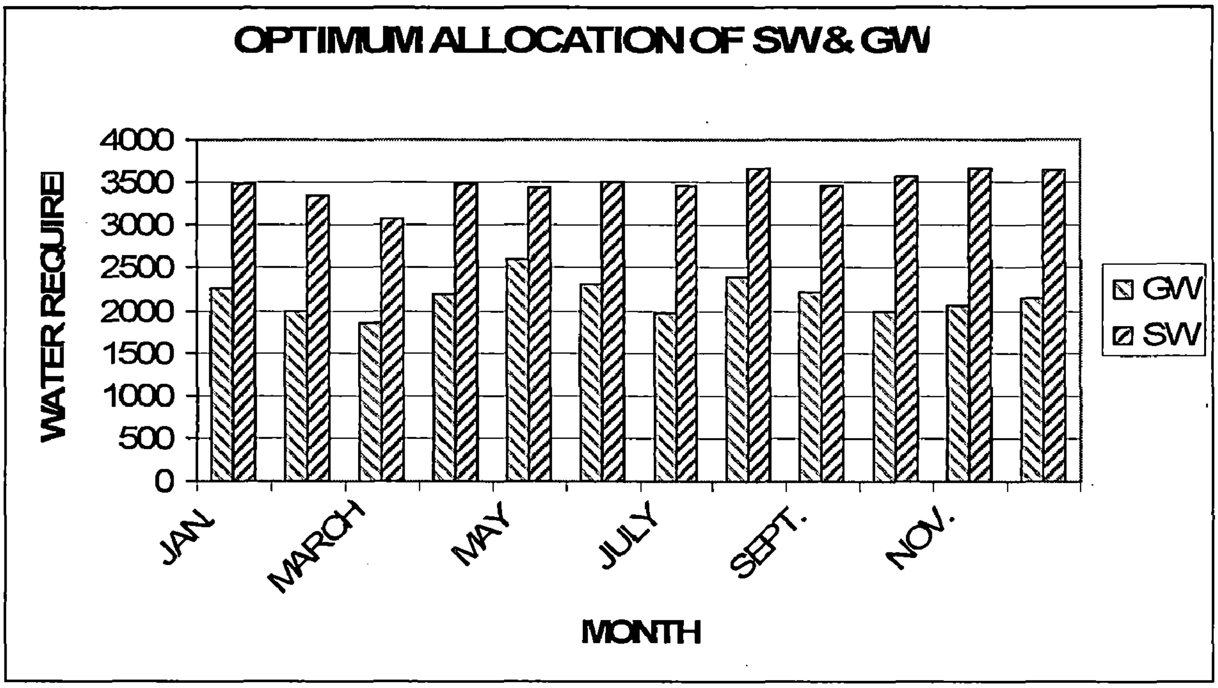

FIG. 6.2 GRAPH SHOWING THE ALLOCATION OF SURFACE AND GROUND WATER FOR 100% AVAILABILITY OF SURFACE WATER

6.2.3 Scenario with 100% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops and Paddy.

With the introduction of surface water, the cropping pattern is revised by introducing high yielding variety of crops and Paddy. The surface and ground water availability remains the same as in the scenario described in section 6.2.2. The net benefits obtained by introducing Paddy are Rs. 90255.85 lakhs. Table 6.6 summarizes the crop area for each zone. The table for monthly allocation of surface and ground water in this scenario remains the same as in described in Section 6.2.2, since the total water (surface and ground) remains same.

TABLE 6.6

CROP AREAS IN EACH ZONE WITH THE INTRODUCTION OF SURFACE WATER AND PADDY (ha)

CROP CODE	CROP	CROP AREA IN EACH ZONE (in ha)			
		ZONE-1	ZONE-2	ZONE-3	Total
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450.00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
C13	PADDY	1323.00	842.00	1273.67	3439.03
Total		15782.56	10329.30	15166.74	**29994.00**

6.2.4 Scenario with 75% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops.

In this scenario, the surface water availability is assumed to be only 75% of its normal value. The level of irrigation remains at 100%. The groundwater recharge would decrease marginally in comparison with the normal condition (when 100% surface water was available). The surface water is estimated to be 31,337.25 ha-m while the groundwater available is estimated to be 21,365.54 ha-m. The conjunctive use model is used to obtain optimal cropping pattern and the allocation of surface and ground water. The results are presented in Table 6.7 & Table 6.8. The net benefits are calculated to be Rs. 60983.58 lakhs, whereas the optimal allocations are shown in Fig. 6.3.

TABLE 6.7

CROP AREAS IN EACH ZONE WITH 75% AVAILABILITY OF SURFACE WATER (ha)

CROP CODE	**CROP**	**CROP AREA IN EACH ZONE (in Hectares)**			
		ZONE-1	**ZONE-2**	**ZONE-3**	**TOTAL**
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450.00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
TOTAL		14459.56	9487.30	13893.07	**26555.00**

TABLE 6.8

MONTHLY OPTIMUM ALLOCATION OF SURFACE AND GROUND WATER IN EACH ZONE IN HECTARE METER (ha-m)

ZONE/ MONTH	GROUNDWATER (ha-m)				SURFACE WATER (ha-m)			
	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN.	662.44	672.15	652.73	1987.32	884.48	870.62	856.34	2611.44
FEB.	581.71	598.45	564.96	1745.12	847.40	854.71	840.10	2542.21
MAR.	566.25	574.78	557.72	1698.75	778.54	781.56	775.52	2335.62
APRIL	593.49	654.12	532.85	1780.46	841.52	865.47	817.64	2524.63
MAY	548.45	551.24	545.66	1645.35	828.05	854.17	801.93	2484.16
JUNE	526.82	564.87	488.77	1580.46	817.05	854.32	779.88	2451.25
JULY	551.62	581.98	521.27	1654.87	884.79	912.54	857.05	2654.38
AUG.	615.25	642.38	588.12	1845.75	924.00	914.68	903.34	2742.02
SEPT.	584.75	654.05	515.45	1754.25	900.25	964.26	833.07	2697.58
OCT.	561.82	574.28	549.37	1685.47	915.29	958.08	872.50	2745.87
NOV.	580.08	612.58	547.59	1740.25	934.10	964.74	903.47	2802.31
DEC.	597.52	612.45	582.59	1792.56	915.26	935.87	894.65	2745.78
Total	6970.20	7293.33	6647.08	**21365.54**	10470.73	10731.02	10135.49	**31337.25**

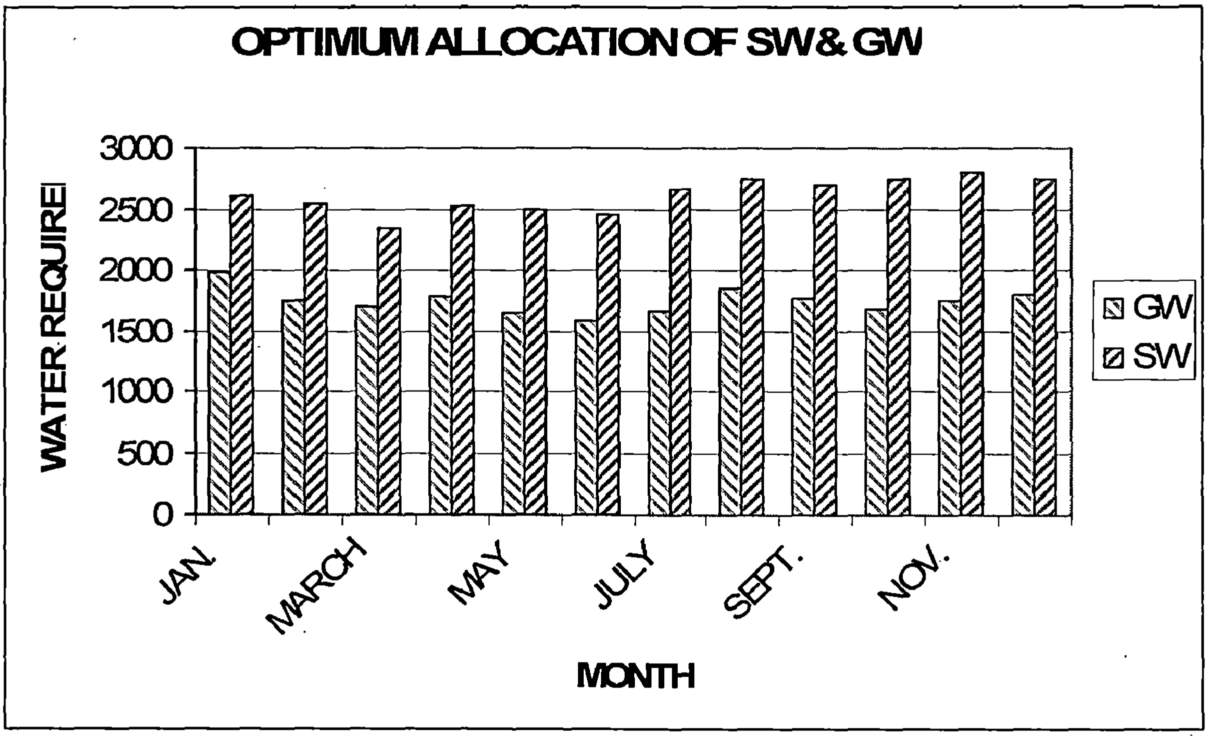

FIG. 6.3 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 75% AVAILABILITY OF SURFACE WATER

6.2.5 Scenario with 75% Surface Water, Groundwater and with the introduction of high yielding varieties of crops and Paddy.

With the introduction of surface water, the cropping pattern is revised by introducing High yielding varieties of crops and Paddy. The surface and ground water availability remains the same as in scenario presented in section 6.2.4. The area allocated to each crop in each zone is revised by conjunctive use model due to introduction of paddy. The net benefits obtained by introducing Paddy are Rs.68033.28 lakhs. Table 6.9 summarizes the new zonal areas for each crop. The table for monthly allocation of surface and ground water in this scenario remains the same as in described in Section 6.2.4, since the total water (surface and ground) remains same.

TABLE 6.9

CROP AREAS IN EACH ZONE WITH THE INTRODUCTION OF SURFACE WATER AND PADDY (ha)

CROP CODE	CROP	CROP AREA IN EACH ZONE (in ha)			
		ZONE-1	ZONE-2	ZONE-3	Total
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450:00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
C13	PADDY	1323.00	842.00	1273.67	3439.03
Total		15782.56	10329.30	15166.74	**29994.00**

6.2.6 Scenario with 50% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops.

In any situation, if the surface water supplies are reduced to half of the designed supplies, the groundwater recharge would decrease substantially than that of the situation where the full design supply was available. The estimated groundwater available under this condition is around 16,533.04 ha-m, while the surface water available is estimated to be around 20,891.50 ha-m. With the available surface and ground water, the conjunctive use model is used to obtain the optimal cropping pattern and the allocation of surface and ground water. The results are presented in Table 6.10 & Table 6.11. The allocation plan is shown in Fig. 6.4. The cropping pattern is revised under this condition by introducing high yielding varieties of crops. The net benefits are obtained as Rs. 50874.58 lakhs.

TABLE 6.10

CROP AREAS IN EACH ZONE WITH THE INTRODUCTION OF 50% SURFACE WATER & HIGH YIELDING CROPS

CROP CODE	CROP	CROP AREA IN ZONE in Hectares			
		ZONE-1	ZONE-2	ZONE-3	TOTAL
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450.00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
TOTAL		14459.56	9487.30	13893.07	**26555.00**

TABLE 6.11

MONTHLY OPTIMUM ALLOCATION OF SURFACE AND GROUND WATER IN EACH ZONE IN HECTARE METER

ZONE / MONTH	GROUNDWATER (ha-m)				SURFACE WATER (ha-m)			
	ZONE-1	ZONE-2	ZONE-3	TOTAL	ZONE-1	ZONE-2	ZONE-3	TOTAL
JAN.	500.42	499.92	499.44	1499.78	621.65	613.65	605.65	1840.95
FEB.	520.42	614.25	422.96	1557.63	580.20	605.24	555.14	1740.58
MAR.	514.44	520.15	517.73	1552.32	551.43	561.03	541.82	1654.28
APRIL	475.81	482.54	466.90	1425.25	595.07	600.12	590.02	1785.21
MAY	445.28	462.18	428.39	1335.85	583.54	590.42	576.66	1750.62
JUNE	421.64	512.62	324.66	1258.92	566.66	574.12	559.20	1699.98
JULY	400.28	394.48	388.68	1183.44	600.42	612.05	588.78	1801.25
AUG.	342.15	337.51	332.88	1012.54	570.45	584.25	556.66	1711.36
SEPT.	384.78	412.54	357.03	1154.35	552.93	564.87	540.94	1658.74
OCT.	448.45	501.32	395.58	1345.35	615.07	654.98	575.16	1845.21
NOV.	514.12	524.06	504.20	1542.38	563.26	660.52	466.00	1689.78
DEC.	521.74	542.18	501.31	1565.23	571.18	590.24	552.12	1713.54
TOTAL	5489.53	5803.75	5139.76	**16533.04**	6971.86	7211.49	6708.15	**20891.50**

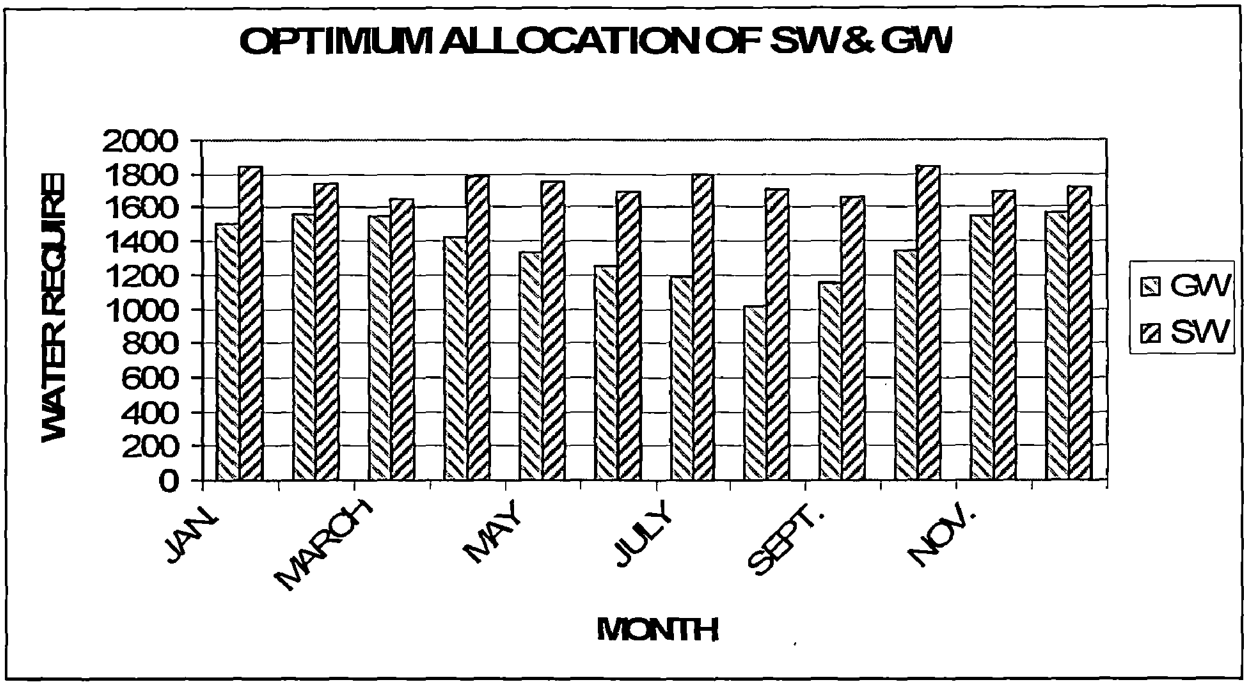

FIG. 6.4 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 50% AVAILABILITY OF SURFACE WATER

6.2.7 Scenario with 50% Surface Water, Groundwater, and with the introduction of high yielding varieties of crops and Paddy.

In the case of surface water availability at the level of 50% of its normal value, the cropping pattern may be revised by introducing high yielding variety of crops and Paddy to maximize the net returns. The surface and ground water availability in this case remains the same as in scenario 6.2.6. The net benefits obtained by introducing Paddy are Rs.57742.65 lakhs. Table 6.12 summarizes the new crop areas in each zone. The table for monthly allocation of surface and ground water in this scenario remains the same as in described in Section 6.2.6, since the total water (surface and ground) remains same.

TABLE 6.12

CROP AREAS IN EACH ZONE WITH THE INTRODUCTION OF SURFACE WATER AND PADDY (ha)

CROP CODE	CROP	CROP AREA IN EACH ZONE (in ha)			
		ZONE-1	ZONE-2	ZONE-3	Total
C1	COTTON	3673.00	2340.00	3510.00	9523.00
C2	CHILLI	73.50	46.83	70.74	191.00
C3	MAIZE	186.70	119.00	180.00	485.70
C4	WHEAT	3857.71	2765.88	3755.70	10379.00
C5	GRAM	36.75	23.42	35.37	95.54
C6	SUGARCANE	2297.44	1188.70	2260.93	5747.07
C7	BERSEEM	250.00	120.00	200.00	570.00
C8	VEGETABLES	100.00	70.0070.00	70.00	240.00
C9	GROUNDNUT	2000.00	1550.00	1900.00	5450.00
C10	SOYABEAN	441.00	280.98	424.44	1146.42
C11	JOWAR	1323.00	842.00	1273.67	3439.03
C12	MOONG	220.00	140.49	212.22	572.71
C13	PADDY	1323.00	842.00	1273.67	3439.03
Total		15782.56	10329.30	15166.74	**29994.00**

6.3 COMPARISON OF THE DIFFERENT SCENARIOS

The different scenarios and their optimal benefits are summarized in Table 6.13, to analyze the effect of water availability and introduction of Paddy with other crops in optimal cropping pattern on the benefits accrued from the study area. The results given in Table 6.13 clearly indicate that benefits obtained at same water availability are different in cases of introduction of paddy with other crops and non introduction of paddy in the study area. The benefits in the cases where paddy is introduced in optimal cropping pattern are more than the benefits obtained from optimal cropping patterns suggested without paddy at the same level of total water availability. Hence the scenarios with introduction of paddy in optimal cropping pattern are selected for the sensitivity analysis of the model and its results.

TABLE 6.13

SUMMARY OF RESULTS FOR THE DIFFERENT SCENARIOS

S No.	DESCRIPTION	NET BENEFITS Rs. Lakhs
I	Existing Cropping Pattern with Present Condition (i.e. No SW)	28854.55
II	Scenario with 100% SW, GW and with the introduction of high yielding crops	80629.50
III	Scenario with 100% SW, GW and with the introduction of high yielding crops and Paddy	90255.85
IV	Scenario with 75% SW, GW and with the introduction of high yielding crops	60983.58
V	Scenario with 75% SW, GW and with the introduction of high yielding crops and Paddy	68033.28
VI	Scenario with 50% SW, GW and with the introduction of high yielding crops	50874.58
VII	Scenario with 50% SW, GW and with the introduction of high yielding crops and Paddy	57742.65

6.4 SENSITIVITY ANALYSIS OF SCENARIOS

A sensitivity analysis on some of the selected scenarios is performed to determine the model response to changes in groundwater constraints when mining is allowed up to 15%. The availability of water under different conditions is given in Table 6.14. The scenarios to be considered in this regard include:

(i) Scenario with 100% Surface Water availability and considering 0%, 5%, 10% and 15% Groundwater mining.

(ii) Scenario with 90% Surface Water availability and considering 0%, 5%, 10% and 15% Groundwater mining.

(iii) Scenario with 80% Surface Water availability and considering 0%, 5%, 10% and 15% Groundwater mining.

(iv) Scenario with 70% Surface Water availability and considering 0%, 5%, 10% and 15% Groundwater mining.

TABLE 6.14

GROUNDWATER AND SURFACE WATER AVAILABILITY UNDER DIFFERENT MINING CONDITIONS (ha-m)

S No.	SCENARIO	SURFACE WATER (ha-m)	GW CONDITION (ha-m)		TOTAL (ha-m)
			Mining	GWA (ha-m)	
I	100% SW	41783.00	0%	26000.00	67783.00
		41783.00	5%	27300.00	69083.00
		41783.00	10%	28600.00	70383.00
		41783.00	15%	29900.00	71683.00
II	90% SW	37604.70	0%	24265.02	61869.72
		37604.70	5%	25478.27	63082.97
		37604.70	10%	26691.52	64296.22
		37604.70	15%	27904.77	65509.47
III	80% SW	33426.40	0%	22332.01	55758.41
		33426.40	5%	23448.61	56875.01
		33426.40	10%	24565.21	57991.61
		33426.40	15%	25681.81	59108.21
IV	70% SW	29248.10	0%	20399.04	49647.14
		29248.10	5%	21418.99	50667.09
		29248.10	10%	22438.94	51687.04
		29248.10	15%	23458.90	52707.00

6.4.1. Scenario with 100% surface water availability, and high yielding varieties of crops and Paddy, and considering 0%, 5%, 10% and 15% groundwater mining

With 100% Surface water and 0% groundwater mining, the net benefits are Rs.90,255.85 lakhs. In this case, the groundwater available is estimated to be 26,000.00 ha-m and the surface water is 41,783.00 ha-m. The groundwater mining affects the net benefits and is studied in different cases described below:

(i) Allowing 5% Groundwater mining

With 5% Groundwater mining, the available groundwater is estimated to be 27,300.00 ha-m and the Surface Water available is 41,783.00 ha-m The net benefits obtained are Rs.92,476.14 lakhs. Table 6.15 and Fig. 6.5 summarizes the results.

TABLE 6.15

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3482.00	785.81	804.52	680.09	2378.76
FEB.	1016.55	1216.88	1116.21	3349.64	662.18	594.23	730.11	2094.85
MAR.	1025.14	986.26	1064.02	3075.42	620.00	713.25	521.49	1963.07
APRIL	1162.72	1245.38	1080.05	3488.15	732.00	804.25	650.31	2294.89
MAY	1141.96	1024.89	1259.02	3425.87	866.67	902.15	831.18	2708.33
JUNE	1254.85	1171.25	1087.65	3513.75	766.70	780.00	753.40	2408.33
JULY	1354.25	951.49	1153.00	3458.74	656.10	720.12	592.10	2076.65
AUG.	1118.75	1218.08	1317.40	3654.23	814.56	800.21	785.38	2508.48
SEPT.	1152.16	1245.87	1058.38	3456.41	754.12	812.14	648.32	2322.91
OCT.	1095.85	1283.11	1189.56	3568.52	665.78	714.56	616.98	2105.65
NOV.	1165.85	1221.68	1277.51	3665.04	688.54	954.28	423.85	2175.00
DEC.	1235.48	1305.62	1104.13	3645.23	745.24	812.25	597.23	2263.05
Total	13784.22	14084.86	13913.92	**41783.00**	8757.70	9411.96	7830.44	**27300.0**

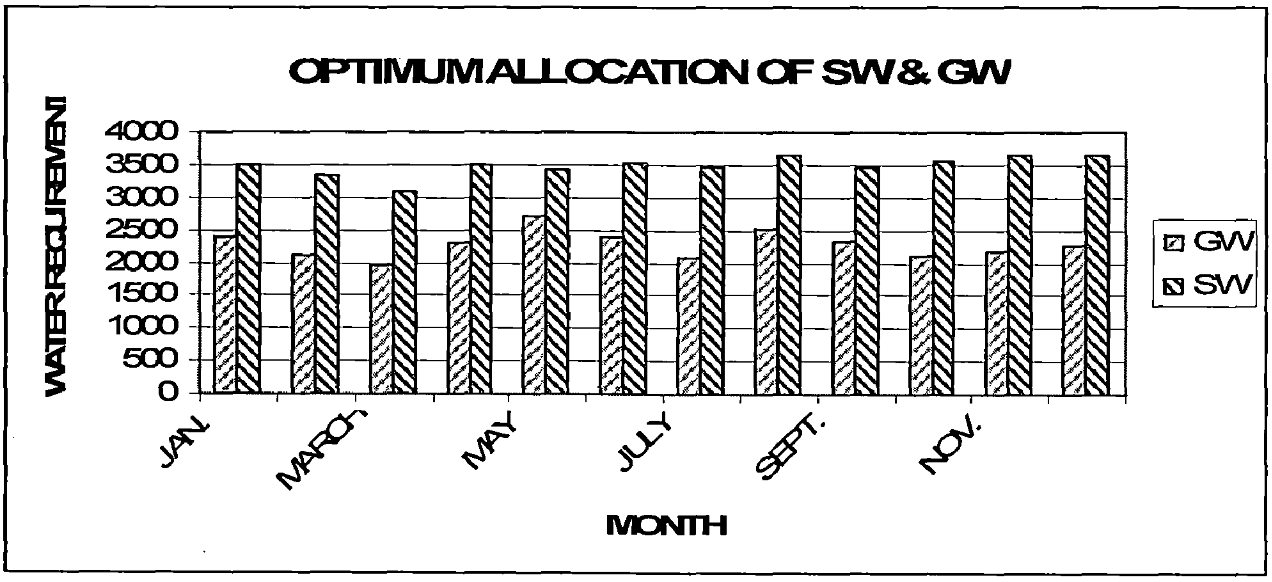

FIG. 6.5 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 100% AVAILABILITY OF SURFACE WATER & 5% GW MINING

(ii) Allowing 10% Groundwater mining

With 10% Groundwater mining, the available groundwater is estimated to be 28,600.00 ha-m and the surface water available is 41,783.00 ha-m. The net benefit obtained is Rs.95,427.51 lakhs.

TABLE 6.16

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3482.00	785.81	804.52	680.09	2487.09
FEB.	1016.55	1216.88	1116.21	3349.64	662.18	594.23	730.11	2203.18
MAR.	1025.14	986.26	1064.02	3075.42	620.00	713.25	521.49	2071.40
APRIL	1162.72	1245.38	1080.05	3488.15	732.00	804.25	650.31	2403.22
MAY	1141.96	1024.89	1259.02	3425.87	866.67	902.15	831.18	2816.66
JUNE	1254.85	1171.25	1087.65	3513.75	766.70	780.00	753.40	2516.66
JULY	1354.25	951.49	1153.00	3458.74	656.10	720.12	592.10	2184.98
AUG.	1118.75	1218.08	1317.40	3654.23	814.56	800.21	785.38	2616.81
SEPT.	1152.16	1245.87	1058.38	3456.41	754.12	812.14	648.32	2431.24
OCT.	1095.85	1283.11	1189.56	3568.52	665.78	714.56	616.98	2213.98
NOV.	1165.85	1221.68	1277.51	3665.04	688.54	954.28	423.85	2283.33
DEC.	1235.48	1305.62	1104.13	3645.23	745.24	812.25	597.23	2371.38
Total	13784.22	14084.86	13913.92	**41783.00**	8757.70	9411.96	7830.44	**28600.0**

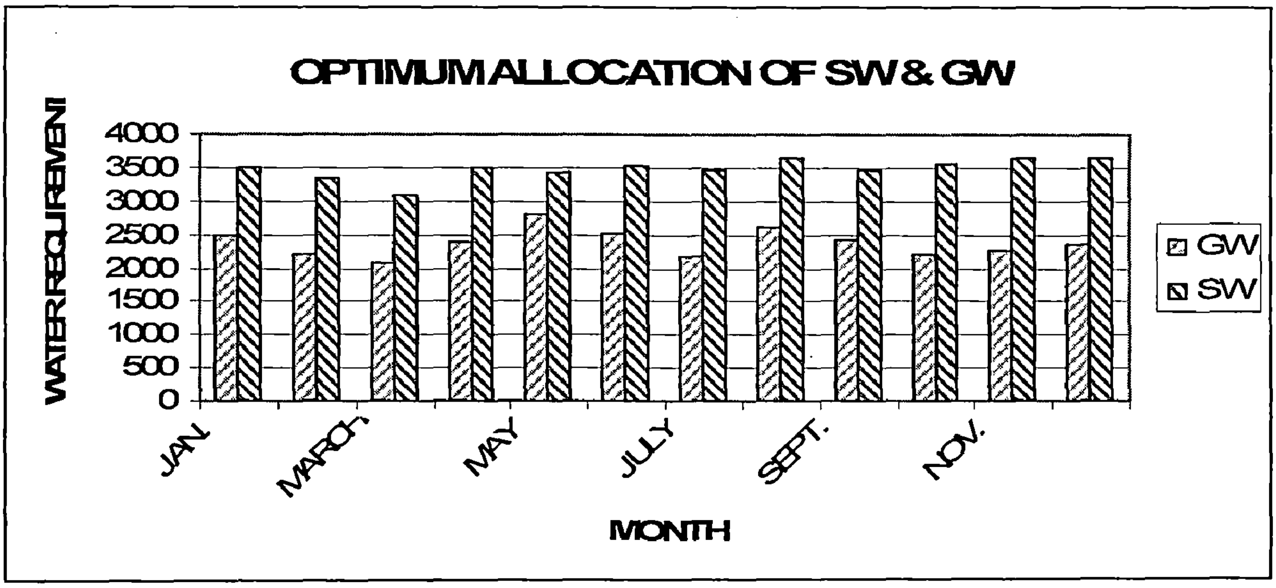

FIG. 6.6 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 100% AVAILABILITY OF SURFACE WATER & 10% GW MINING

(iii) Allowing 15% Groundwater mining

With 15% Groundwater mining, the available groundwater is estimated to be 29,900.00 ha-m and the surface water available is 41,783.00 ha-m. The net benefit obtained is Rs.97,205.55 lakhs.

TABLE 6.17

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3482.00	785.81	804.52	680.09	2595.42
FEB.	1016.55	1216.88	1116.21	3349.64	662.18	594.23	730.11	2311.51
MAR.	1025.14	986.26	1064.02	3075.42	620.00	713.25	521.49	2179.73
APRIL	1162.72	1245.38	1080.05	3488.15	732.00	804.25	650.31	2511.55
MAY	1141.96	1024.89	1259.02	3425.87	866.67	902.15	831.18	2924.99
JUNE	1254.85	1171.25	1087.65	3513.75	766.70	780.00	753.40	2624.99
JULY	1354.25	951.49	1153.00	3458.74	656.10	720.12	592.10	2293.31
AUG.	1118.75	1218.08	1317.40	3654.23	814.56	800.21	785.38	2725.14
SEPT.	1152.16	1245.87	1058.38	3456.41	754.12	812.14	648.32	2539.57
OCT.	1095.85	1283.11	1189.56	3568.52	665.78	714.56	616.98	2322.31
NOV.	1165.85	1221.68	1277.51	3665.04	688.54	954.28	423.85	2391.66
DEC.	1235.48	1305.62	1104.13	3645.23	745.24	812.25	597.23	2479.71
Total	13784.22	14084.86	13913.92	**41783.00**	8757.70	9411.96	7830.44	**29900.0**

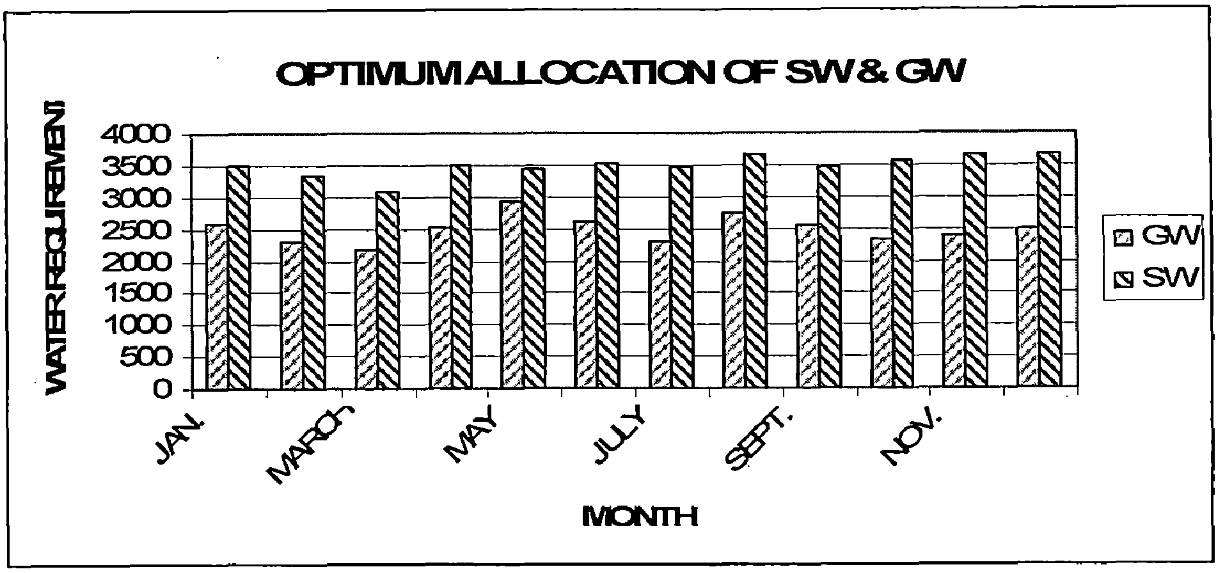

FIG. 6.7 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 100% AVAILABILITY OF SURFACE WATER & 15% GW MINING

6.4.2 Scenario with 90% Surface Water availability, and high yielding crops and paddy, and considering 0%, 5%, 10% and 15% Groundwater mining

With 90% Surface water and 0% groundwater mining, the net benefit is Rs. 79,743.65 lakhs. In this case, the groundwater available is estimated to be 24,265.02 ha-m and the surface water is 37,604.70 ha-m.

TABLE 6.18

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/ MONTH	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3133.81	785.81	804.52	680.09	2125.84
FEB.	1016.55	1216.88	1116.21	3001.45	662.18	594.23	730.11	1841.93
MAR.	1025.14	986.26	1064.02	2727.23	620.00	713.25	521.49	1710.15
APRIL	1162.72	1245.38	1080.05	3139.96	732.00	804.25	650.31	2041.97
MAY	1141.96	1024.89	1259.02	3077.68	866.67	902.15	831.18	2455.41
JUNE	1254.85	1171.25	1087.65	3165.56	766.70	780.00	753.40	2154.42
JULY	1354.25	951.49	1153.00	3110.55	656.10	720.12	592.10	1823.73
AUG.	1118.75	1218.08	1317.40	3306.04	814.56	800.21	785.38	2255.56
SEPT.	1152.16	1245.87	1058.38	3108.22	754.12	812.14	648.32	2069.99
OCT.	1095.85	1283.11	1189.56	3220.33	665.78	714.56	616.98	1852.73
NOV.	1165.85	1221.68	1277.51	3316.85	688.54	954.28	423.85	1922.08
DEC.	1235.48	1305.62	1104.13	3297.04	745.24	812.25	597.23	2010.13
Total	13784.22	14084.86	13913.92	**37604.70**	8757.70	9411.96	7830.44	**24265.02**

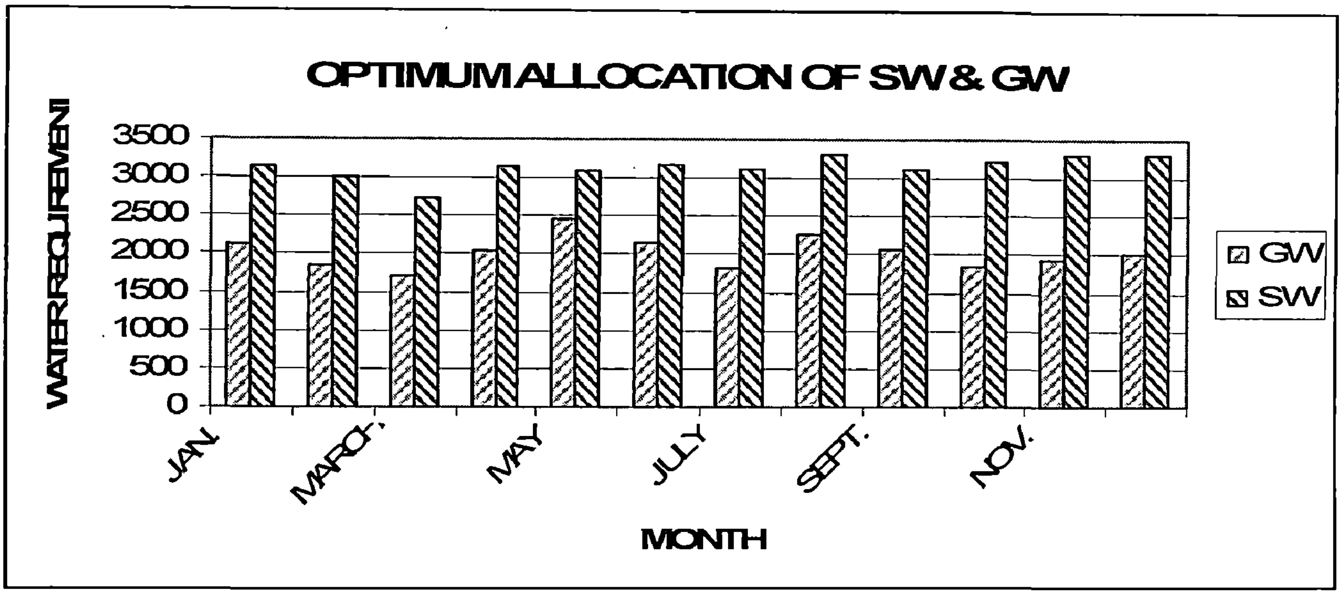

FIG. 6.8 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 90% AVAILABILITY OF SURFACE WATER & 0% GW MINING

(i) Allowing 5% Groundwater Mining

With 5% Groundwater mining, the available groundwater is estimated to be 25,478.27 ha-m and the Surface Water available is 37,604.70 ha-m. The net benefit obtained is Rs.81,657.52 lakhs.

TABLE 6.19

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3133.81	785.81	804.52	680.09	2226.94
FEB.	1016.55	1216.88	1116.21	3001.45	662.18	594.23	730.11	1943.03
MAR.	1025.14	986.26	1064.02	2727.23	620.00	713.25	521.49	1811.25
APRIL	1162.72	1245.38	1080.05	3139.96	732.00	804.25	650.31	2143.07
MAY	1141.96	1024.89	1259.02	3077.68	866.67	902.15	831.18	2556.51
JUNE	1254.85	1171.25	1087.65	3165.56	766.70	780.00	753.40	2255.52
JULY	1354.25	951.49	1153.00	3110.55	656.10	720.12	592.10	1924.83
AUG.	1118.75	1218.08	1317.40	3306.04	814.56	800.21	785.38	2356.66
SEPT.	1152.16	1245.87	1058.38	3108.22	754.12	812.14	648.32	2171.09
OCT.	1095.85	1283.11	1189.56	3220.33	665.78	714.56	616.98	1953.83
NOV.	1165.85	1221.68	1277.51	3316.85	688.54	954.28	423.85	2023.18
DEC.	1235.48	1305.62	1104.13	3297.04	745.24	812.25	597.23	2111.23
Total	13784.22	14084.86	13913.92	**37604.70**	8757.70	9411.96	7830.44	**25478.27**

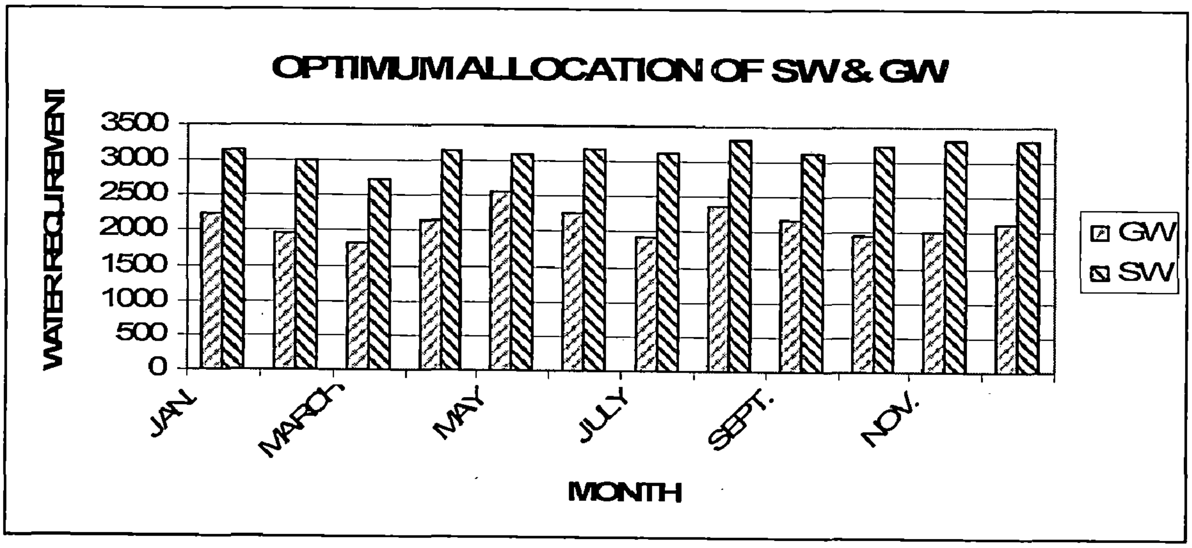

FIG. 6.9 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 90% AVAILABILITY OF SURFACE WATER & 5% GW MINING

(ii) Allowing 10% Groundwater Mining

With 10% Groundwater mining, the available groundwater is estimated to be 26, 691.52 ha-m and the Surface water available is 37, 604.70 ha-m. The net benefit obtained is Rs.83,778.68 lakhs.

TABLE 6.20

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3133.81	785.81	804.52	680.09	2328.04
FEB.	1016.55	1216.88	1116.21	3001.45	662.18	594.23	730.11	2044.13
MAR.	1025.14	986.26	1064.02	2727.23	620.00	713.25	521.49	1912.35
APRIL	1162.72	1245.38	1080.05	3139.96	732.00	804.25	650.31	2244.17
MAY	1141.96	1024.89	1259.02	3077.68	866.67	902.15	831.18	2657.61
JUNE	1254.85	1171.25	1087.65	3165.56	766.70	780.00	753.40	2356.62
JULY	1354.25	951.49	1153.00	3110.55	656.10	720.12	592.10	2025.93
AUG.	1118.75	1218.08	1317.40	3306.04	814.56	800.21	785.38	2457.76
SEPT.	1152.16	1245.87	1058.38	3108.22	754.12	812.14	648.32	2272.19
OCT.	1095.85	1283.11	1189.56	3220.33	665.78	714.56	616.98	2054.93
NOV.	1165.85	1221.68	1277.51	3316.85	688.54	954.28	423.85	2124.28
DEC.	1235.48	1305.62	1104.13	3297.04	745.24	812.25	597.23	2212.33
Total	13784.22	14084.86	13913.92	**37604.70**	8757.70	9411.96	7830.44	**26691.52**

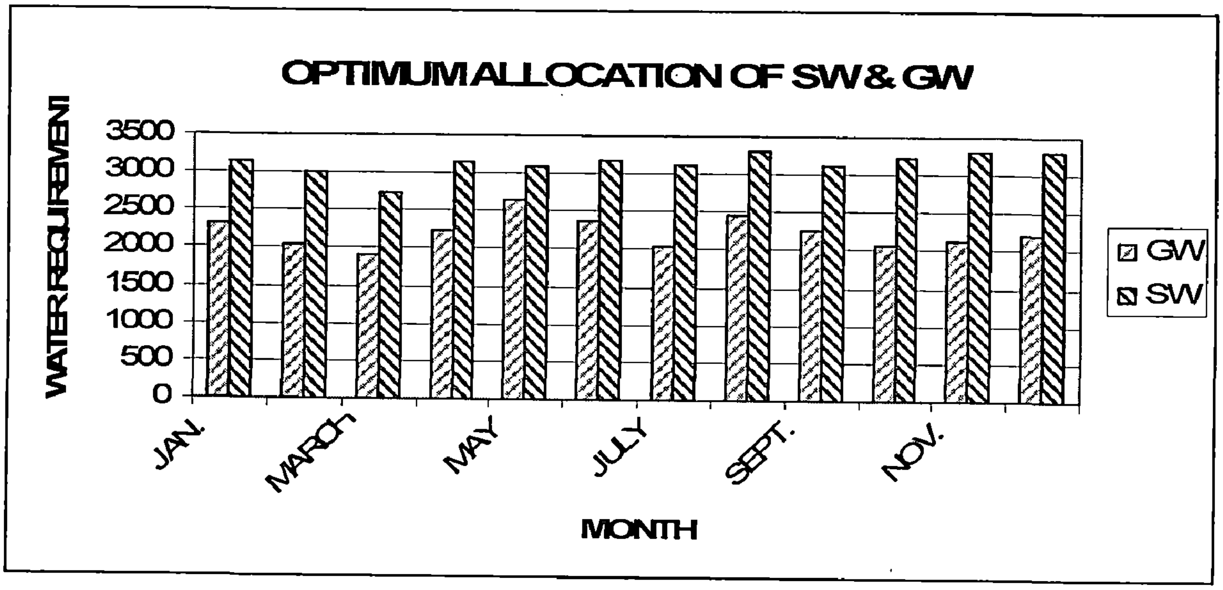

FIG 6.10 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 90% AVAILABILITY OF SURFACE WATER & 10% GW MINING

(iii) Allowing 15% Groundwater Mining

With 15% Groundwater mining, the available groundwater is estimated to be 27,904.77 ha-m and the Surface water available is 37, 604.70 ha-m. The net benefit obtained is Rs.85723.63 lakhs.

TABLE 6.21

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	3133.81	785.81	804.52	680.09	2429.14
FEB.	1016.55	1216.88	1116.21	3001.45	662.18	594.23	730.11	2145.23
MAR.	1025.14	986.26	1064.02	2727.23	620.00	713.25	521.49	2013.45
APRIL	1162.72	1245.38	1080.05	3139.96	732.00	804.25	650.31	2345.27
MAY	1141.96	1024.89	1259.02	3077.68	866.67	902.15	831.18	2758.71
JUNE	1254.85	1171.25	1087.65	3165.56	766.70	780.00	753.40	2457.72
JULY	1354.25	951.49	1153.00	3110.55	656.10	720.12	592.10	2127.03
AUG.	1118.75	1218.08	1317.40	3306.04	814.56	800.21	785.38	2558.86
SEPT.	1152.16	1245.87	1058.38	3108.22	754.12	812.14	648.32	2373.29
OCT.	1095.85	1283.11	1189.56	3220.33	665.78	714.56	616.98	2156.03
NOV.	1165.85	1221.68	1277.51	3316.85	688.54	954.28	423.85	2225.38
DEC.	1235.48	1305.62	1104.13	3297.04	745.24	812.25	597.23	2313.43
Total	13784.22	14084.86	13913.92	**37604.70**	8757.70	9411.96	7830.44	**27904.77**

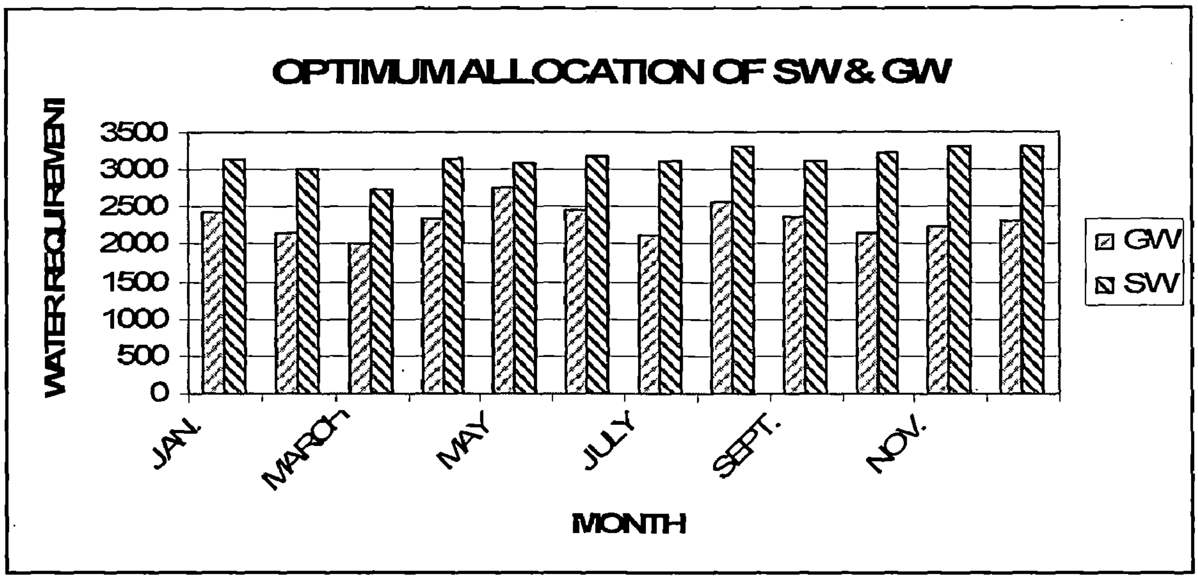

FIG. 6.11 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 90% AVAILABILITY OF SURFACE WATER & 10% GW MINING

6.4.3 Scenario with 80% Surface Water availability, and high yielding crops and paddy, and considering 0%, 5%, 10% and 15% Groundwater mining

With 80% Surface water and 0% groundwater mining, the net benefit is Rs. 72047.24 lakhs. In this case, the groundwater available is estimated to be 22,332.01 ha-m and the surface water is 33,426.40 ha-m.

TABLE 6.22

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2785.62	785.81	804.52	680.09	1964.75
FEB.	1016.55	1216.88	1116.21	2653.26	662.18	594.23	730.11	1680.84
MAR.	1025.14	986.26	1064.02	2379.04	620.00	713.25	521.49	1549.06
APRIL	1162.72	1245.38	1080.05	2791.77	732.00	804.25	650.31	1880.88
MAY	1141.96	1024.89	1259.02	2729.49	866.67	902.15	831.18	2294.32
JUNE	1254.85	1171.25	1087.65	2817.37	766.70	780.00	753.40	1993.33
JULY	1354.25	951.49	1153.00	2762.36	656.10	720.12	592.10	1662.64
AUG.	1118.75	1218.08	1317.40	2957.85	814.56	800.21	785.38	2094.47
SEPT.	1152.16	1245.87	1058.38	2760.03	754.12	812.14	648.32	1908.90
OCT.	1095.85	1283.11	1189.56	2872.14	665.78	714.56	616.98	1691.64
NOV.	1165.85	1221.68	1277.51	2968.66	688.54	954.28	423.85	1760.99
DEC.	1235.48	1305.62	1104.13	2948.85	745.24	812.25	597.23	1849.04
Total	13784.22	14084.86	13913.92	**33426.40**	8757.70	9411.96	7830.44	**22332.01**

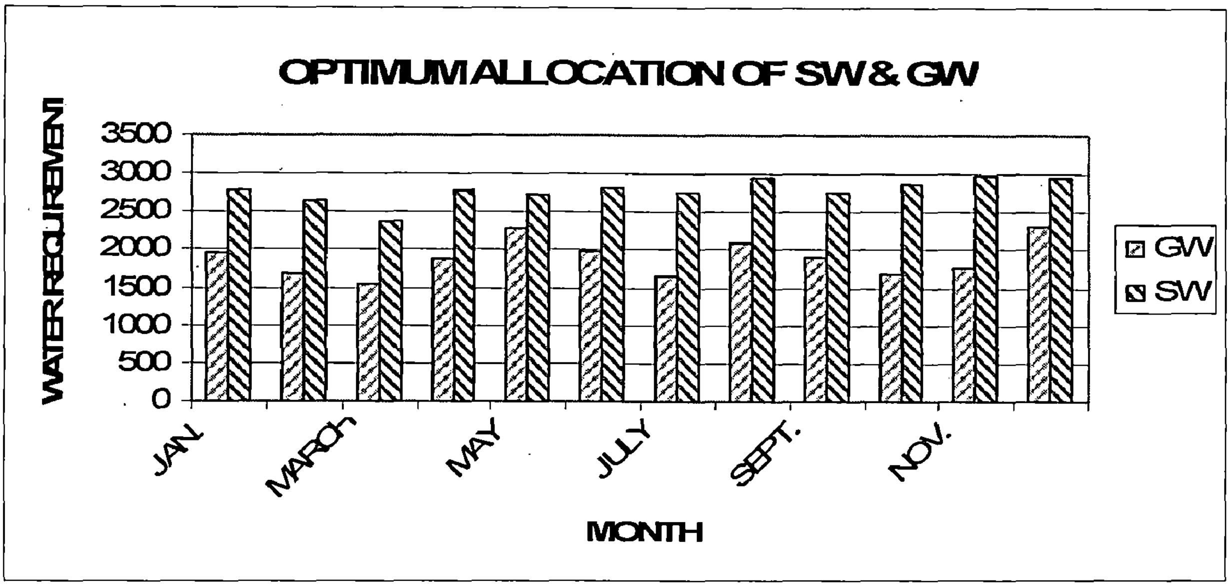

FIG. 6.12 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 80% AVAILABILITY OF SURFACE WATER & 0% GW MINING

(i) Allowing 5% Groundwater Mining

With 5% Groundwater mining, the available groundwater is estimated to be 23,448.61 ha-m and the surface water available is 33,426.40 ha-m. The net benefit obtained is Rs.73,862.83 lakhs.

TABLE 6.23

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2785.62	785.81	804.52	680.09	2057.80
FEB.	1016.55	1216.88	1116.21	2653.26	662.18	594.23	730.11	1773.89
MAR.	1025.14	986.26	1064.02	2379.04	620.00	713.25	521.49	1642.11
APRIL	1162.72	1245.38	1080.05	2791.77	732.00	804.25	650.31	1973.93
MAY	1141.96	1024.89	1259.02	2729.49	866.67	902.15	831.18	2387.37
JUNE	1254.85	1171.25	1087.65	2817.37	766.70	780.00	753.40	2086.38
JULY	1354.25	951.49	1153.00	2762.36	656.10	720.12	592.10	1755.69
AUG.	1118.75	1218.08	1317.40	2957.85	814.56	800.21	785.38	2187.52
SEPT.	1152.16	1245.87	1058.38	2760.03	754.12	812.14	648.32	2001.95
OCT.	1095.85	1283.11	1189.56	2872.14	665.78	714.56	616.98	1784.69
NOV.	1165.85	1221.68	1277.51	2968.66	688.54	954.28	423.85	1854.04
DEC.	1235.48	1305.62	1104.13	2948.85	745.24	812.25	597.23	1942.09
Total	13784.22	14084.86	13913.92	**33426.40**	8757.70	9411.96	7830.44	**22332.01**

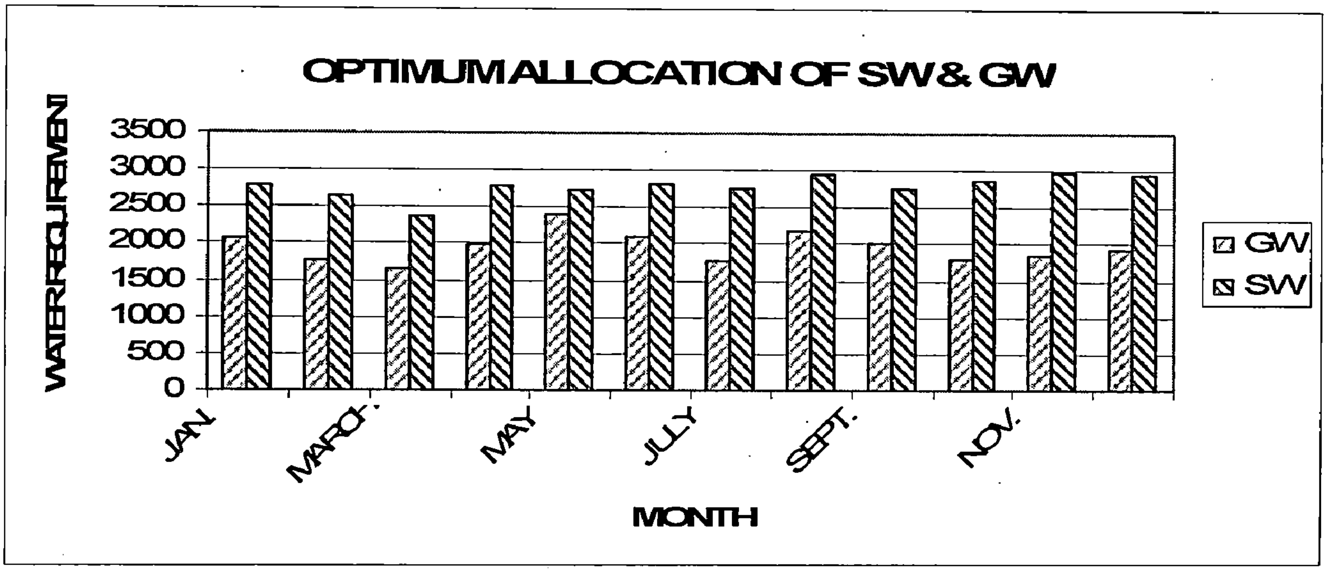

FIG. 6.13 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 80% AVAILABILITY OF SURFACE WATER & 5% GW MINING

(ii) Allowing 10% Groundwater Mining

With 10% Groundwater mining, the available groundwater is estimated to be 24,565.21 ha-m and the surface water available is 33,426.40 ha-m. The net benefit obtained is Rs.75,995.43 lakhs.

TABLE 6.24

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2785.62	785.81	804.52	680.09	2243.90
FEB.	1016.55	1216.88	1116.21	2653.26	662.18	594.23	730.11	1959.99
MAR.	1025.14	986.26	1064.02	2379.04	620.00	713.25	521.49	1828.21
APRIL	1162.72	1245.38	1080.05	2791.77	732.00	804.25	650.31	2160.03
MAY	1141.96	1024.89	1259.02	2729.49	866.67	902.15	831.18	2573.47
JUNE	1254.85	1171.25	1087.65	2817.37	766.70	780.00	753.40	2272.48
JULY	1354.25	951.49	1153.00	2762.36	656.10	720.12	592.10	1938.79
AUG.	1118.75	1218.08	1317.40	2957.85	814.56	800.21	785.38	2373.62
SEPT.	1152.16	1245.87	1058.38	2760.03	754.12	812.14	648.32	2188.05
OCT.	1095.85	1283.11	1189.56	2872.14	665.78	714.56	616.98	1970.79
NOV.	1165.85	1221.68	1277.51	2968.66	688.54	954.28	423.85	2040.14
DEC.	1235.48	1305.62	1104.13	2948.85	745.24	812.25	597.23	2128.19
Total	13784.22	14084.86	13913.92	**33426.40**	8757.70	9411.96	7830.44	**24565.21**

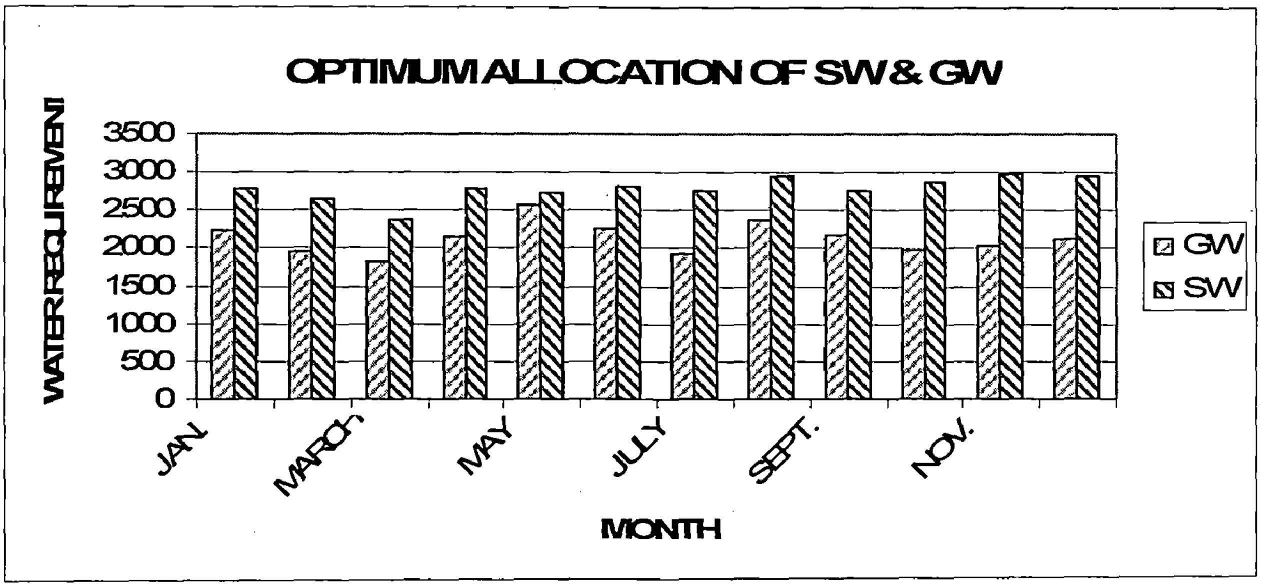

FIG. 6.14 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 80% AVAILABILITY OF SW & 10% GW MINING

(iii) Allowing 15% Groundwater Mining

With 15% Groundwater mining, the available groundwater is estimated to be 25,681.81 ha-m and the surface water available is 33,426.40 ha-m. The net benefit obtained is Rs.77,457.26 lakhs.

TABLE 6.25

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2785.62	785.81	804.52	680.09	2336.95
FEB.	1016.55	1216.88	1116.21	2653.26	662.18	594.23	730.11	2053.04
MAR.	1025.14	986.26	1064.02	2379.04	620.00	713.25	521.49	1921.26
APRIL	1162.72	1245.38	1080.05	2791.77	732.00	804.25	650.31	2253.08
MAY	1141.96	1024.89	1259.02	2729.49	866.67	902.15	831.18	2666.52
JUNE	1254.85	1171.25	1087.65	2817.37	766.70	780.00	753.40	2365.53
JULY	1354.25	951.49	1153.00	2762.36	656.10	720.12	592.10	2031.84
AUG.	1118.75	1218.08	1317.40	2957.85	814.56	800.21	785.38	2466.67
SEPT.	1152.16	1245.87	1058.38	2760.03	754.12	812.14	648.32	2281.10
OCT.	1095.85	1283.11	1189.56	2872.14	665.78	714.56	616.98	2063.84
NOV.	1165.85	1221.68	1277.51	2968.66	688.54	954.28	423.85	2193.19
DEC.	1235.48	1305.62	1104.13	2948.85	745.24	812.25	597.23	2221.24
Total	13784.22	14084.86	13913.92	**33426.40**	8757.70	9411.96	7830.44	**24565.21**

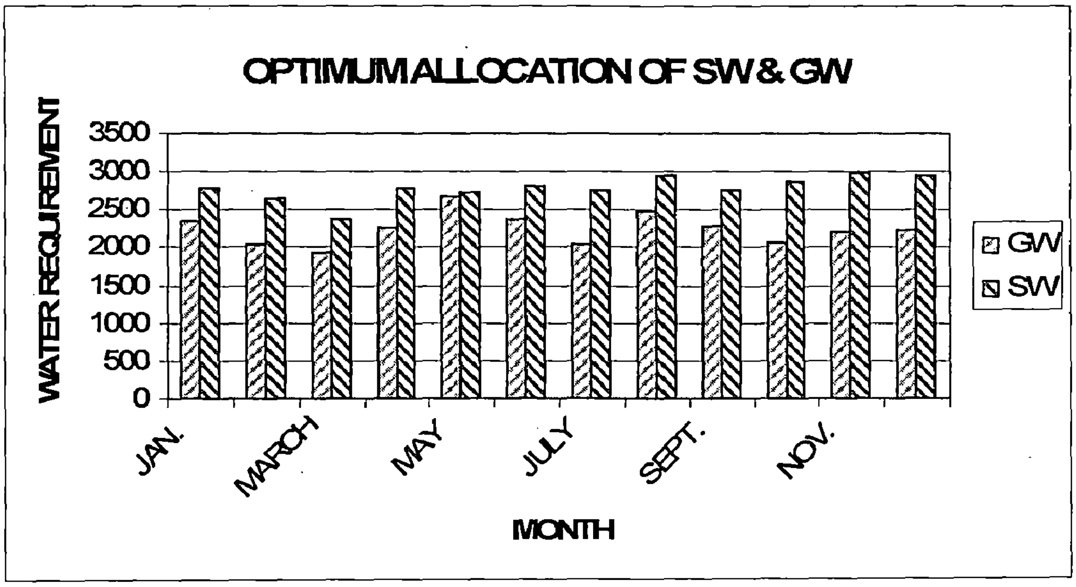

FIG. 6.15 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 80% AVAILABILITY OF SW & 15% GW MINING

6.4.4 Scenario with 70% Surface Water availability, and high yielding crops and paddy, and considering 0%, 5%, 10% and 15% Groundwater mining

With 70% Surface water and 0% groundwater mining, the net benefit is Rs. 64,645.22 lakhs. In this case, the groundwater available is estimated to be 20399.04 ha-m and the surface water is 29,248.10 ha-m.

TABLE 6.26

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2437.43	785.81	804.52	680.09	1989.77
FEB.	1016.55	1216.88	1116.21	2305.07	662.18	594.23	730.11	1705.86
MAR.	1025.14	986.26	1064.02	2030.85	620.00	713.25	521.49	1574.08
APRIL	1162.72	1245.38	1080.05	2443.58	732.00	804.25	650.31	1905.90
MAY	1141.96	1024.89	1259.02	2381.30	866.67	902.15	831.18	2319.34
JUNE	1254.85	1171.25	1087.65	2469.18	766.70	780.00	753.40	2018.35
JULY	1354.25	951.49	1153.00	2414.17	656.10	720.12	592.10	1684.66
AUG.	1118.75	1218.08	1317.40	2609.66	814.56	800.21	785.38	2119.49
SEPT.	1152.16	1245.87	1058.38	2411.84	754.12	812.14	648.32	1933.92
OCT.	1095.85	1283.11	1189.56	2523.95	665.78	714.56	616.98	1716.66
NOV.	1165.85	1221.68	1277.51	2620.47	688.54	954.28	423.85	1846.01
DEC.	1235.48	1305.62	1104.13	2600.66	745.24	812.25	597.23	1874.06
Total	13784.22	14084.86	13913.92	**29248.10**	8757.70	9411.96	7830.44	**20399.04**

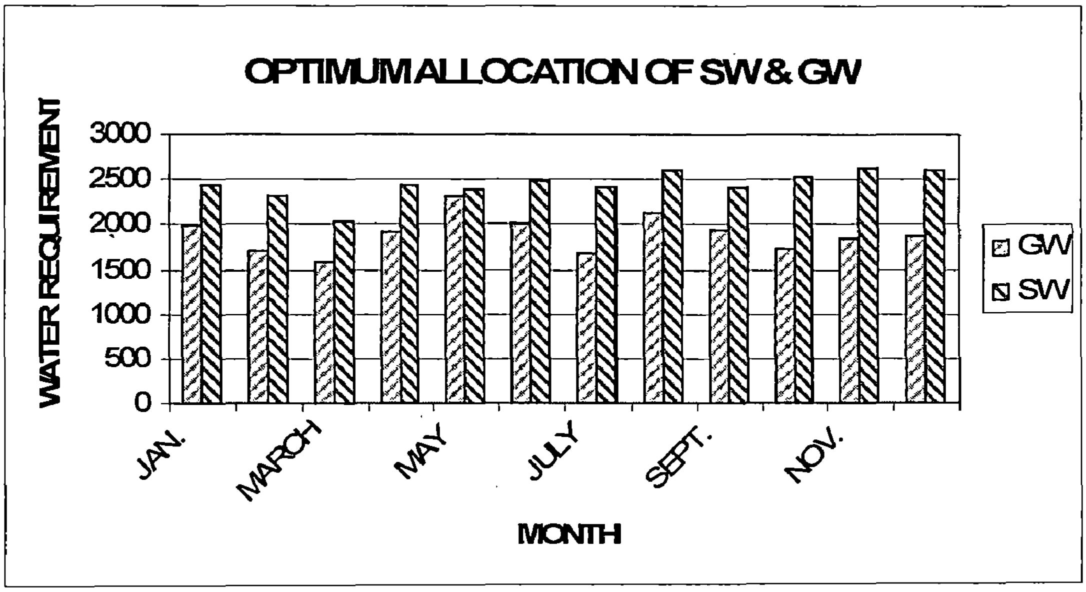

FIG. 6.16 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 70% AVAILABILITY OF SW & 0% GW MINING

(i) Allowing 5% Groundwater Mining

With 5% Groundwater mining, the available groundwater is estimated to be 21,418.99 ha-m and the surface water available is 29,248.10ha-m. The net benefit obtained is Rs.66,293.67 lakhs.

TABLE 6.27

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	**SURFACE WATER (ha-m)**				**GROUNDWATER (ha-m)**			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2437.43	785.81	804.52	680.09	2074.77
FEB.	1016.55	1216.88	1116.21	2305.07	662.18	594.23	730.11	1790.86
MAR.	1025.14	986.26	1064.02	2030.85	620.00	713.25	521.49	1659.08
APRIL	1162.72	1245.38	1080.05	2443.58	732.00	804.25	650.31	1990.90
MAY	1141.96	1024.89	1259.02	2381.30	866.67	902.15	831.18	2404.34
JUNE	1254.85	1171.25	1087.65	2469.18	766.70	780.00	753.40	2103.35
JULY	1354.25	951.49	1153.00	2414.17	656.10	720.12	592.10	1769.66
AUG.	1118.75	1218.08	1317.40	2609.66	814.56	800.21	785.38	2204.49
SEPT.	1152.16	1245.87	1058.38	2411.84	754.12	812.14	648.32	2018.92
OCT.	1095.85	1283.11	1189.56	2523.95	665.78	714.56	616.98	1801.66
NOV.	1165.85	1221.68	1277.51	2620.47	688.54	954.28	423.85	1931.01
DEC.	1235.48	1305.62	1104.13	2600.66	745.24	812.25	597.23	1959.06
Total	13784.22	14084.86	13913.92	**29248.10**	8757.70	9411.96	7830.44	**21418.99**

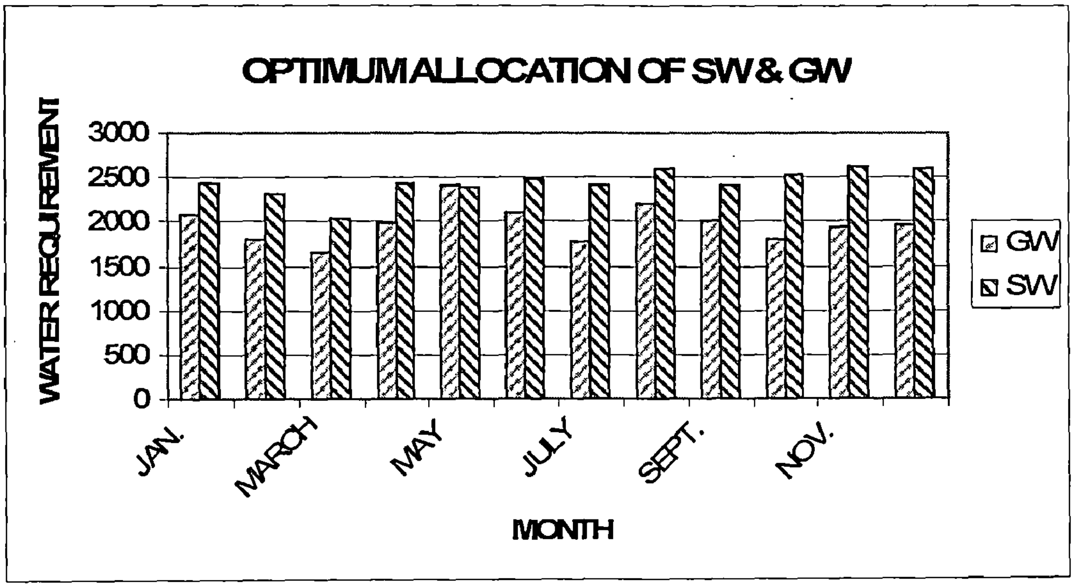

FIG. 6.17 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 70% AVAILABILITY OF SW & 5% GW MINING

(ii) Allowing 10% Groundwater Mining

With 10% Groundwater mining, the available groundwater is estimated to be 22,438.94ha-m and the surface water available is 29,248.10ha-m. The net benefit obtained is Rs.67,993.84 lakhs.

TABLE 6.28

MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2437.43	785.81	804.52	680.09	2159.77
FEB.	1016.55	1216.88	1116.21	2305.07	662.18	594.23	730.11	1875.86
MAR.	1025.14	986.26	1064.02	2030.85	620.00	713.25	521.49	1744.08
APRIL	1162.72	1245.38	1080.05	2443.58	732.00	804.25	650.31	2075.90
MAY	1141.96	1024.89	1259.02	2381.30	866.67	902.15	831.18	2489.34
JUNE	1254.85	1171.25	1087.65	2469.18	766.70	780.00	753.40	2188.35
JULY	1354.25	951.49	1153.00	2414.17	656.10	720.12	592.10	1854.66
AUG.	1118.75	1218.08	1317.40	2609.66	814.56	800.21	785.38	2289.49
SEPT.	1152.16	1245.87	1058.38	2411.84	754.12	812.14	648.32	2103.92
OCT.	1095.85	1283.11	1189.56	2523.95	665.78	714.56	616.98	1886.66
NOV.	1165.85	1221.68	1277.51	2620.47	688.54	954.28	423.85	2016.01
DEC.	1235.48	1305.62	1104.13	2600.66	745.24	812.25	597.23	2044.06
Total	13784.22	14084.86	13913.92	**29248.10**	8757.70	9411.96	7830.44	**22438.94**

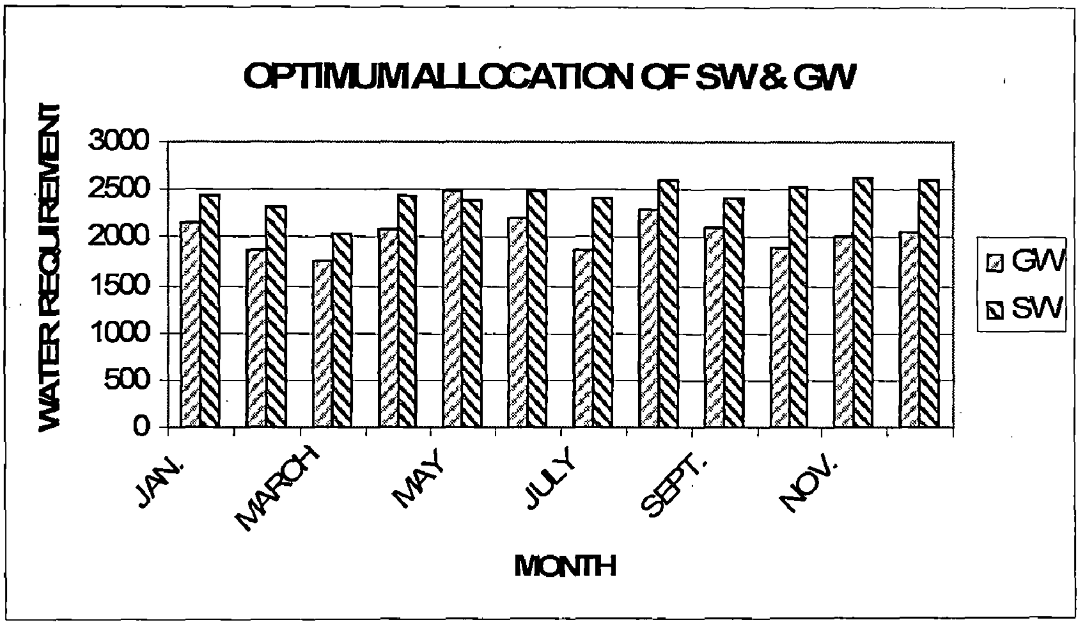

FIG. 6.18 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 70% AVAILABILITY OF SW & 10% GW MINING

(iii) Allowing 15% Groundwater Mining

With 15% Groundwater mining, the available groundwater is estimated to be 23,458.90 ha-m and the surface water available is 29,248.10ha-m. The net benefit obtained is Rs.69,508.48 lakhs.

TABLE 6.29
MONTHLY OPTIMUM ALLOCATIONS OF SURFACE AND GROUND WATER IN EACH ZONE (IN HECTARE METER)

ZONE/	SURFACE WATER (ha-m)				GROUNDWATER (ha-m)			
MONTH	ZONE-1	ZONE-2	ZONE-3	Total	ZONE-1	ZONE-2	ZONE-3	Total
JAN	1060.66	1214.35	1206.99	2437.43	785.81	804.52	680.09	2244.77
FEB.	1016.55	1216.88	1116.21	2305.07	662.18	594.23	730.11	1960.86
MAR.	1025.14	986.26	1064.02	2030.85	620.00	713.25	521.49	1829.08
APRIL	1162.72	1245.38	1080.05	2443.58	732.00	804.25	650.31	2160.90
MAY	1141.96	1024.89	1259.02	2381.30	866.67	902.15	831.18	2574.34
JUNE	1254.85	1171.25	1087.65	2469.18	766.70	780.00	753.40	2273.35
JULY	1354.25	951.49	1153.00	2414.17	656.10	720.12	592.10	1939.66
AUG.	1118.75	1218.08	1317.40	2609.66	814.56	800.21	785.38	2374.49
SEPT.	1152.16	1245.87	1058.38	2411.84	754.12	812.14	648.32	2188.92
OCT.	1095.85	1283.11	1189.56	2523.95	665.78	714.56	616.98	1971.66
NOV.	1165.85	1221.68	1277.51	2620.47	688.54	954.28	423.85	2101.01
DEC.	1235.48	1305.62	1104.13	2600.66	745.24	812.25	597.23	2129.06
Total	13784.22	14084.86	13913.92	**29248.10**	8757.70	9411.96	7830.44	**23458.90**

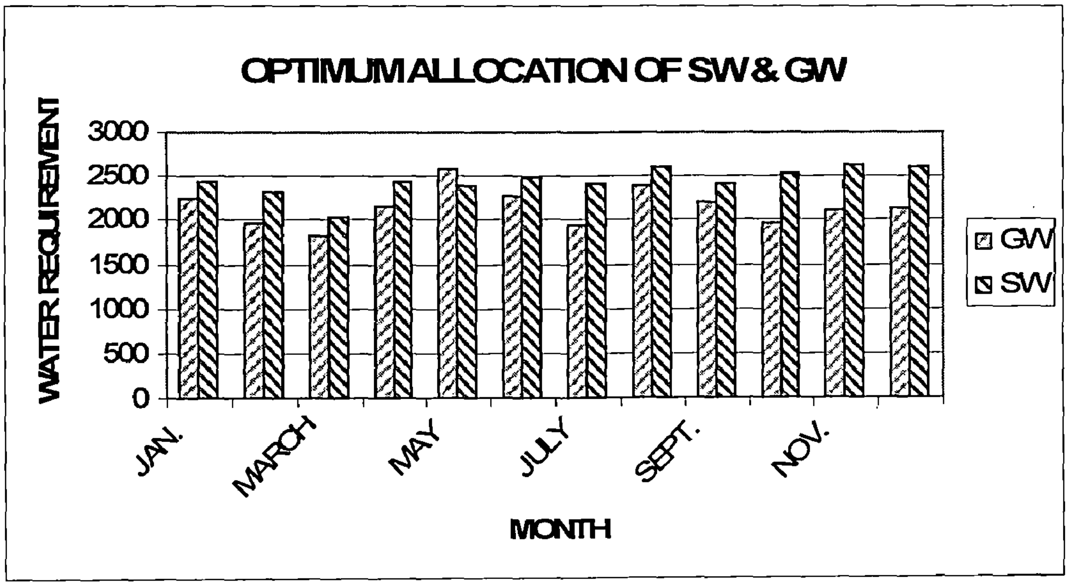

FIG. 6.19 GRAPH SHOWING THE ALLOCATION OF SURFACE & GROUND WATER FOR 70% AVAILABILITY OF SW & 15% GW MINING

Results obtained from sensitivity analysis are summarized in Table 6.30. The total water available and net benefits obtained in each case of surface water from Sections 6.3.1 to 6.3.4 are mentioned in this table.

TABLE 6.30

SUMMARY OF RESULTS FOR THE DIFFERENT SENSITIVITY SCENARIOS

S No.	SCENARIO	MINING	TOTAL WATER AVAILABLE (ha-m)	NET BENEFIT (Rs.lakhs)
I	100% SW	0%	67783.00	90255.85
		5%	69083.00	90255.85
		10%	70383.00	90255.85
		15%	71683.00	90255.85
II	90% SW	0%	61869.72	79743.65
		5%	63082.97	79743.65
		10%	64296.22	79743.65
		15%	65509.47	79743.65
III	80% SW	0%	55758.41	72047.24
		5%	56875.01	72047.24
		10%	57991.61	72047.24
		15%	59108.21	72047.24
IV	70% SW	0%	49647.14	64645.22
		5%	50667.09	64645.22
		10%	51687.04	64645.22
		15%	52707.00	64645.22

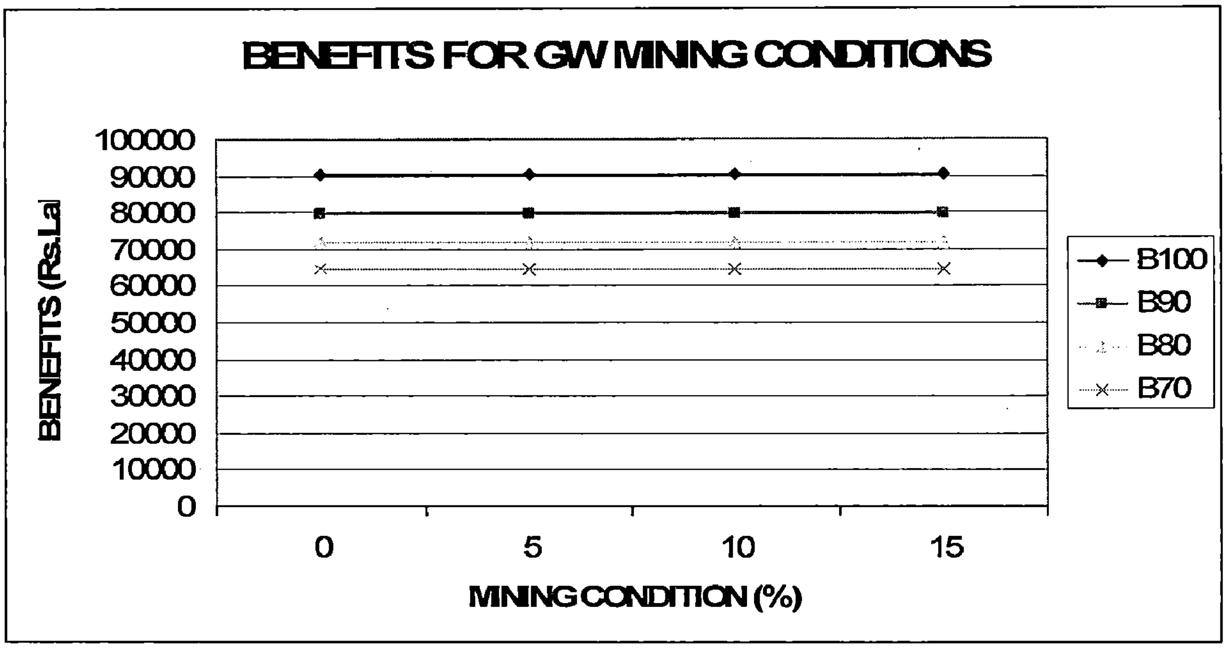

FIG. 6.20 GRAPH OF BENEFITS FOR THE DIFFERENT MINING CONDITIONS (0%, 5%, 10%, and 15%) CONSIDERED FOR 100% SW, 90% SW, 80% SW, and 70% SW AVAILABILITY

6.5 CONCLUDING REMARKS

From the forgoing analysis involving different scenarios for surface and ground water, it can be concluded that the best scenario is 100% surface water availability, and high yielding crops and Paddy, and considering 15% Groundwater mining. This scenario gave a net benefit of Rs.97,205.55 lakhs. Generally, in the sensitivity analysis considered for the various groundwater mining conditions there was an increase in net benefit of between 0 and 7.5 percent for each surface water availability condition considered.

It can be seen that if groundwater mining is continued, excessive depletion of groundwater table will take place. Consequently, the groundwater pumping cost will increase and the net benefits generated would decrease. The position of groundwater improved substantially after the introduction of canal water. The variation of groundwater for each scenario after the introduction of surface water was presented in the previous section. The quality of the groundwater could be determined to ascertain the amount of dissolved salts present so that surface water can be mixed to minimize the effect of possible salinization. The scenarios presented above will serve as a guide to planning and management of available and proposed surface and ground water. It will also help save water resources for proper utilization in the future.

CHAPTER 7
CONCLUSIONS AND SCOPE FOR FURTHER STUDY

7.1 GENERAL

The primary objective of this study was to better understand how effectively and efficiently we can plan and manage available and proposed surface and ground water resources in the Omkareshwar Canal command to obtain maximum benefits from agricultural activities. A better understanding of the stream-aquifer interaction is necessary for developing conjunctive use operations in the canal command. Release strategies from canals for improving aquifer recharge has been presented and the best scenario obtained. The model results indicate that the best scenario is 100% availability of surface water and allowing 15% groundwater mining. The benefits of the potential new yield depend on how that yield is used. It is likely that this new yield will be used for agricultural activities and environmental stream flow.

7.2 CONCLUSIONS

Based on the present study, following conclusions can be drawn:

1. To fully utilize available water resources, high yielding variety of crops and paddy were introduced. This combination resulted in optimum utilization of water.

2. Of all the scenarios presented, the one with 100% availability of surface water, groundwater, and the introduction of high yielding crops and paddy is the best option, as it gave the optimum net benefit.

3. In the absence of sufficient surface water, groundwater mining increased pumping cost and affected the overall benefits obtained from the model.

4. Priority for funding and Technical assistance should be given to conjunctive use management projects that are conducted in accordance with a groundwater management plan, increase water supplies, and have other benefits including the

sustainable use of groundwater, maintaining or improving water quality, and enhancing the environment.

5. Encourage local groundwater management authorities to manage the use of vacant aquifer space for artificial recharge that generate source water for groundwater storage by capturing water that would otherwise not be used by other water users or the environment.

6. In cases where there is no surface water or better still little surface water, groundwater mining should be allowed to about 20% in order to minimize the cost of pumping.

7. The present study, analysis and results could help serve as a guide to the utilization of surface water and groundwater in a conjunctive use policy for other regions where there may be shortage of water availability and supply.

7.3 SCOPE FOR FURTHER STUDY

Based on the present study, the following are recommended for further study:

- In a case where there is sufficient data about groundwater systems, and River bed levels, MODFLOW – Groundwater simulation software – can be used to model Groundwater in the study area.

- Studies involving the impact of introducing additional water in the Canal Command area can be carried out to access the damage/improvement in the Environmental conditions.

- Studies involving the quality of Surface and Ground water can be carried out to determine the amount of dissolved salts, if necessary, to come out with a ratio for mixing the two resources in order to reduce or minimize salt accumulation in plant root zone.

- Studies may be carried out to technically and economically justify the option of flood management using conjunctive use planning of surface and ground water in a canal command

- Sensitivity analysis of conjunctive use model may be carried out considering majority of uncertainties in natural, market and organizational variables.

- Additional areas of study and refinement include the interaction between Narmada River and the underlying aquifer in the canal command using modeling techniques.

- Studies should further be carried by utilizing well data for more number of years to obtain values of groundwater parameters to be used for groundwater modeling.

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```
                                    NEW
!LP MODEL           Annexure I
!Program for finding the optimal allocation of Surface water and Groundwater,
considering groundwater and crop area constraints
!With 100% Surface water and High Yielding Crops

  MAX 16985C1Z1 + 16985C1Z2 + 16985C1Z3
      88910C1Z1 + 88910C1Z2 + 88910C1Z3
      8790C1Z1  + 8790C1Z2  + 8790C1Z3
      11525C1Z1 + 11525C1Z2 + 11525C1Z3
      51535C1Z1 + 51535C1Z2 + 51535C1Z3
      25645C1Z1 + 25645C1Z2 + 25645C1Z3
      12771C1Z1 + 12771C1Z2 + 12771C1Z3
      11981C1Z1 + 11981C1Z2 + 11981C1Z3
      60575C1Z1 + 60575C1Z2 + 60575C1Z3
      11765C1Z1 + 11765C1Z2 + 11765C1Z3
      11425C1Z1 + 11425C1Z2 + 11425C1Z3
      3595C1Z1  + 3595C1Z2  + 3595C1Z3

      - 24060.8SW1Z1 - 24060.8SW1Z2 - 24060.8SW1Z3
      - 24060.8SW2Z1 - 24060.8SW2Z2 - 24060.8SW2Z3
      - 24060.8SW3Z1 - 24060.8SW3Z2 - 24060.8SW3Z3
      - 24060.8SW4Z1 - 24060.8SW4Z2 - 24060.8SW4Z3
      - 24060.8SW5Z1 - 24060.8SW5Z2 - 24060.8SW5Z3
      - 24060.8SW6Z1 - 24060.8SW6Z2 - 24060.8SW6Z3
      - 24060.8SW7Z1 - 24060.8SW7Z2 - 24060.8SW7Z3
      - 24060.8SW8Z1 - 24060.8SW8Z2 - 24060.8SW8Z3
      - 24060.8SW9Z1 - 24060.8SW9Z2 - 24060.8SW9Z3
      - 24060.8SW10Z1 - 24060.8SW10Z2 - 24060.8SW10Z3
      - 24060.8SW11Z1 - 24060.8SW11Z2 - 24060.8SW11Z3
      - 24060.8SW12Z1 - 24060.8SW12Z2 - 24060.8SW12Z3

      - 26000GW1Z1 - 26000GW1Z2 - 26000GW1Z3
      - 26000GW2Z1 - 26000GW2Z2 - 26000GW2Z3
      - 26000GW3Z1 - 26000GW3Z2 - 26000GW3Z3
      - 26000GW4Z1 - 26000GW4Z2 - 26000GW4Z3
      - 26000GW5Z1 - 26000GW5Z2 - 26000GW5Z3
      - 26000GW6Z1 - 26000GW6Z2 - 26000GW6Z3
      - 26000GW7Z1 - 26000GW7Z2 - 26000GW7Z3
      - 26000GW8Z1 - 26000GW8Z2 - 26000GW8Z3
      - 26000GW9Z1 - 26000GW9Z1 - 26000GW9Z3
      - 26000GW10Z1 - 26000GW10Z2 - 26000GW10Z3
      - 26000GW11Z1 - 26000GW11Z2 - 26000GW11Z3
      - 26000GW12Z1 - 26000GW12Z2 - 26000GW12Z3

      SUBJECT TO

       !SURFACE WATER AVAILABILITY CONSTRAINT

       SW1Z1 + SW1Z2 + SW1Z3 <= 1993.6
       SW2Z1 + SW2Z2 + SW2Z3 <= 1993.6
       SW3Z1 + SW3Z2 + SW3Z3 <= 1388
       SW4Z1 + SW4Z2 + SW4Z3 <= 1388
       SW5Z1 + SW5Z2 + SW5Z3 <= 1388
       SW6Z1 + SW6Z2 + SW6Z3 <= 479.96
       SW7Z1 + SW7Z2 + SW7Z3 <= 448.272
       SW8Z1 + SW8Z2 + SW8Z3 <= 540.4
       SW9Z1 + SW9Z2 + SW9Z3 <= 2892
       SW10Z1 + SW10Z2 + SW10Z3 <= 2313.6
       SW11Z1 + SW11Z2 + SW11Z3 <= 2313.6
       SW12Z1 + SW12Z2 + SW12Z3 <= 2256.8

     !GROUNDWATER AVAILABILITY CONSTRAINT
```

```
GW1Z1 + GW1Z2 + GW1Z3 +
GW2Z1 + GW2Z2 + GW2Z3 +
GW3Z1 + GW3Z2 + GW3Z3 +
GW4Z1 + GW4Z2 + GW4Z3 +
GW5Z1 + GW5Z2 + GW5Z3 +
GW6Z1 + GW6Z2 + GW6Z3 +
GW7Z1 + GW7Z2 + GW7Z3 +
GW8Z1 + GW8Z2 + GW8Z3 +
GW9Z1 + GW9Z2 + GW9Z3 +
GW10Z1 + GW10Z2 + GW10Z3 +
GW11Z1 + GW11Z2 + GW11Z3 +
GW12Z1 + GW12Z2 + GW12Z3 <= 26000

!AREA AVAILABILITY CONSTRAINT

C1Z1 + C2Z1 + C3Z1 + C4Z1 + C5Z1 + C6Z1 + C7Z1 + C8Z1 + C9Z1 + C10Z1 + C11Z1 +
C12Z1 <= 10215
C1Z2 + C2Z2 + C3Z2 + C4Z2 + C5Z2 + C6Z2 + C7Z2 + C8Z2 + C9Z2 + C10Z2 + C11Z2 +
C12Z2 <= 6508
C1Z3 + C2Z3 + C3Z3 + C4Z3 + C5Z3 + C6Z3 + C7Z3 + C8Z3 + C9Z3 + C10Z3 + C11Z3 +
C12Z3 <= 9832
C1Z1 + C2Z1 + C3Z1 + C4Z1 + C5Z1 + C6Z1 + C7Z1 + C8Z1 + C9Z1 + C10Z1 + C11Z1 +
C12Z1 <= 13940.5
C1Z2 + C2Z2 + C3Z2 + C4Z2 + C5Z2 + C6Z2 + C7Z2 + C8Z2 + C9Z2 + C10Z2 + C11Z2 +
C12Z2 <= 2464.89
C1Z3 + C2Z3 + C3Z3 + C4Z3 + C5Z3 + C6Z3 + C7Z3 + C8Z3 + C9Z3 + C10Z3 + C11Z3 +
C12Z3 <=7917.3
C1Z1 + C2Z1 + C3Z1 + C4Z1 + C5Z1 + C6Z1 + C7Z1 + C8Z1 + C9Z1 + C10Z1 + C11Z1 +
C12Z1 <= 12.7
C1Z2 + C2Z2 + C3Z2 + C4Z2 + C5Z2 + C6Z2 + C7Z2 + C8Z2 + C9Z2 + C10Z2 + C11Z2 +
C12Z2 <= 6373.7
C1Z3 + C2Z3 + C3Z3 + C4Z3 + C5Z3 + C6Z3 + C7Z3 + C8Z3 + C9Z3 + C10Z3 + C11Z3 +
C12Z3 <= 5551.58

!CROP AREA CONSTRAINTS

C1Z1 <= 3673
C2Z1 <= 73.5
C3Z1 <= 186.7
C4Z1 <= 3857.71
C5Z1 <= 36.75
C6Z1 <= 2297.44
C7Z1 <= 250
C8Z1 <= 100
C9Z1 <= 2000
C10Z1 <= 441
C11Z1 <= 1323
C12Z1 <= 220

C1Z2 <= 2340
C2Z2 <= 46.83
C3Z2 <= 119
C4Z2 <= 2765.88
C5Z2 <= 23.42
C6Z2 <= 1188.7
C7Z2 <= 120
C8Z2 <= 70
C9Z2 <= 1550
C10Z2 <= 280.98
C11Z2 <= 842
C12Z2 <= 140.49

C1Z3 <= 3510
```

LP MODEL

Annexure II

LP OPTIMUM FOUND AT STEP 32

OBJECTIVE FUNCTION VALUE

1) 0.2885455E+09

VARIABLE	VALUE	REDUCED COST
C1Z1	0.000000	-0.000014
C1Z2	1800.000000	0.000000
C1Z3	1785.084961	0.000000
C2Z1	73.500000	0.000000
C2Z2	46.830002	0.000000
C2Z3	70.739998	0.000000
C3Z1	186.699997	0.000000
C3Z2	119.000000	0.000000
C3Z3	180.000000	0.000000
C4Z1	908.460022	0.000000
C4Z2	1221.300049	0.000000
C4Z3	864.299988	0.000000
C5Z1	36.750000	0.000000
C5Z2	23.420000	0.000000
C5Z3	35.369999	0.000000
C6Z1	49.980000	0.000000
C6Z2	31.840000	0.000000
C6Z3	48.560001	0.000000
C7Z1	155.080002	0.000000
C7Z2	98.809998	0.000000
C7Z3	149.259995	0.000000
C8Z1	23.520000	0.000000
C8Z2	14.980000	0.000000
C8Z3	22.629999	0.000000
C9Z1	675.469971	0.000000
C9Z2	430.359985	0.000000
C9Z3	650.099976	0.000000
C10Z1	441.000000	0.000000
C10Z2	240.979996	0.000000
C10Z3	424.440002	0.000000
C11Z1	1323.359985	0.000000
C11Z2	842.000000	0.000000
C11Z3	1273.670044	0.000000
C12Z1	0.000000	7775.982422
C12Z2	0.000000	7775.982422
C12Z3	0.000000	7775.982422
GW1Z1	184.534210	0.000000
GW1Z2	223.583984	0.000000
GW1Z3	176.022095	0.000000
GW2Z1	280.872864	0.000000
GW2Z2	269.543549	0.000000
GW2Z3	269.003510	0.000000
GW3Z1	176.202103	0.000000
GW3Z2	112.263084	0.000000
GW3Z3	169.645920	0.000000
GW4Z1	207.284698	0.000000
GW4Z2	132.065994	0.000000
GW4Z3	199.578842	0.000000
GW5Z1	11.445420	0.000000
GW5Z2	417.691345	0.000000
GW5Z3	418.119598	0.000000
GW6Z1	57.015419	0.000000
GW6Z2	49.286842	0.000000
GW6Z3	72.738533	0.000000
GW7Z1	38.768459	0.000000

GW7Z3	73.043121	0.000000
GW8Z1	13.097100	0.000000
GW8Z2	42.538429	0.000000
GW8Z3	46.533871	0.000000
GW9Z1	110.985825	0.000000
GW9Z2	265.773773	0.000000
GW9Z3	305.025726	0.000000
GW10Z1	530.614441	0.000000
GW10Z2	798.838257	0.000000
GW10Z3	911.419922	0.000000
GW11Z1	134.139420	0.000000
GW11Z2	292.895203	0.000000
GW11Z3	298.111145	0.000000
GW12Z1	95.463699	0.000000
GW12Z2	103.915009	0.000000
GW12Z3	91.252640	0.000000
GW7Z2	60.685890	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	20347.810547
3)	0.000000	20347.810547
4)	0.000000	20347.810547
5)	0.000000	20347.810547
6)	0.000000	20347.810547
7)	0.000000	20347.810547
8)	0.000000	20347.810547
9)	0.000000	20347.810547
10)	0.000000	20347.810547
11)	0.000000	20347.810547
12)	0.000000	20347.810547
13)	0.000000	20347.810547
14)	0.000000	20347.810547
15)	0.000000	20347.810547
16)	0.000000	20347.810547
17)	0.000000	20347.810547
18)	0.000000	27987.810547
19)	0.000000	20347.810547
20)	0.000000	20347.810547
21)	0.000000	12707.810547
22)	0.000000	20347.810547
23)	0.000000	20347.810547
24)	0.000000	20347.810547
25)	0.000000	20347.810547
26)	0.000000	20347.810547
27)	0.000000	20347.810547
28)	0.000000	20347.810547
29)	0.000000	20347.810547
30)	0.000000	20347.810547
31)	0.000000	20347.810547
32)	0.000000	20347.810547
33)	0.000000	20347.810547
34)	0.000000	20347.810547
35)	0.000000	20347.810547
36)	0.000000	20347.810547
37)	0.000000	20347.810547
38)	0.000000	12707.810547
39)	3045.989990	0.000000
40)	180.490005	0.000000
41)	1127.135132	0.000000
42)	2826.000000	0.000000
43)	0.000000	65422.757812
44)	0.000000	6185.416504

FIRST-RESULT(NO SW)

45)	0.000000	10263.779297
46)	0.000000	26175.732422
47)	0.000000	80615.781250
48)	0.000000	2717.324951
49)	0.000000	73812.609375
50)	0.000000	50399.109375
51)	0.000000	4383.008789
52)	0.000000	9645.123047
53)	220.000000	0.000000
54)	0.000000	76.400002
55)	0.000000	65888.796875
56)	0.000000	6666.736816
57)	0.000000	10263.779297
58)	0.000000	26175.732422
59)	0.000000	80554.664062
60)	0.000000	2717.324951
61)	0.000000	74339.773438
62)	0.000000	50399.109375
63)	0.000000	3420.368896
64)	0.000000	9759.723633
65)	140.490005	0.000000
66)	914.915100	0.000000
67)	0.000000	65422.757812
68)	0.000000	6185.416504
69)	0.000000	10263.779297
70)	0.000000	26175.732422
71)	0.000000	80615.781250
72)	0.000000	2717.324951
73)	0.000000	73812.609375
74)	0.000000	50399.109375
75)	0.000000	4383.008789
76)	0.000000	9645.123047
77)	212.220001	0.000000

NO. ITERATIONS= 32

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
C1Z1	14406.250000	0.000000	INFINITY
C1Z2	14406.250000	INFINITY	76.400002
C1Z3	14406.250000	76.400002	0.000000
C2Z1	75718.750000	INFINITY	65422.757812
C2Z2	75718.750000	INFINITY	65888.796875
C2Z3	75718.750000	INFINITY	65422.757812
C3Z1	10987.500000	INFINITY	6185.416504
C3Z2	10987.500000	INFINITY	6666.736816
C3Z3	10987.500000	INFINITY	6185.416504
C4Z1	21231.250000	INFINITY	10263.779297
C4Z2	21231.250000	INFINITY	10263.779297
C4Z3	21231.250000	INFINITY	10263.779297
C5Z1	32056.250000	INFINITY	26175.732422
C5Z2	32056.250000	INFINITY	26175.732422
C5Z3	32056.250000	INFINITY	26175.732422
C6Z1	111137.500000	INFINITY	80615.781250
C6Z2	111137.500000	INFINITY	80554.664062
C6Z3	111137.500000	INFINITY	80615.781250
C7Z1	15963.750000	INFINITY	2717.324951
C7Z2	15963.750000	INFINITY	2717.324951
C7Z3	15963.750000	INFINITY	2717.324951

C8Z1	79978.000000	INFINITY	73812.609375
C8Z2	79978.000000	INFINITY	74339.773438
C8Z3	79978.000000	INFINITY	73812.609375
C9Z1	64418.750000	INFINITY	50399.109375
C9Z2	64418.750000	INFINITY	50399.109375
C9Z3	64418.750000	INFINITY	50399.109375
C10Z1	16551.000000	INFINITY	4383.008789
C10Z2	16551.000000	INFINITY	3420.368896
C10Z3	16551.000000	INFINITY	4383.008789
C11Z1	14976.250000	INFINITY	9645.123047
C11Z2	14976.250000	INFINITY	9759.723633
C11Z3	14976.250000	INFINITY	9645.123047
C12Z1	4005.399902	7775.982422	INFINITY
C12Z2	4005.399902	7775.982422	INFINITY
C12Z3	4005.399902	7775.982422	INFINITY
GW1Z1	-7640.000000	INFINITY	17644.966797
GW1Z2	-7640.000000	INFINITY	17644.966797
GW1Z3	-7640.000000	INFINITY	17644.966797
GW2Z1	-7640.000000	INFINITY	15265.870117
GW2Z2	-7640.000000	INFINITY	15265.870117
GW2Z3	-7640.000000	INFINITY	15265.870117
GW3Z1	-7640.000000	39876.835938	24047.123047
GW3Z2	-7640.000000	39876.835938	24047.123047
GW3Z3	-7640.000000	39876.832031	24047.123047
GW4Z1	-7640.000000	24923.019531	171425.546875
GW4Z2	-7640.000000	24923.019531	171425.546875
GW4Z3	-7640.000000	24923.017578	171425.546875
GW5Z1	-7640.000000	0.000000	352033.968750
GW5Z2	-7640.000000	107999.757812	335.087738
GW5Z3	-7640.000000	335.087738	0.000000
GW6Z1	-7640.000000	0.000000	34785.785156
GW6Z2	-15280.000000	INFINITY	7640.000488
GW6Z3	-7640.000000	7640.000488	0.000000
GW7Z1	-7640.000000	0.000000	98181.210938
GW7Z3	-7640.000000	3820.000244	0.000000
GW8Z1	-7640.000000	0.000000	343634.250000
GW8Z2	-7640.000000	INFINITY	4021.052734
GW8Z3	-7640.000000	4021.052734	0.000000
GW9Z1	-7640.000000	0.000000	37144.140625
GW9Z2	-7640.000000	INFINITY	688.288269
GW9Z3	-7640.000000	688.288269	0.000000
GW10Z1	-7640.000000	0.000000	19743.283203
GW10Z2	-7640.000000	INFINITY	339.555573
GW10Z3	-7640.000000	339.555573	0.000000
GW11Z1	-7640.000000	0.000000	43396.125000
GW11Z2	-7640.000000	INFINITY	804.210571
GW11Z3	-7640.000000	804.210571	0.000000
GW12Z1	-7640.000000	INFINITY	44546.308594
GW12Z2	-7640.000000	INFINITY	44546.308594
GW12Z3	-7640.000000	INFINITY	44546.308594
GW7Z2	0.000000	INFINITY	3820.000244

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	0.000000	184.534210	1263.840210
3	0.000000	223.583984	1263.840210
4	0.000000	176.022095	1263.840210
5	0.000000	280.872864	1263.840210
6	0.000000	269.543549	1263.840210
7	0.000000	269.003510	1263.840210
8	0.000000	176.202103	1263.840210
9	0.000000	112.263084	1263.840210

FIRST-RESULT(NO SW)

10	0.000000	169.645920	1263.840210
11	0.000000	207.284698	1263.840210
12	0.000000	132.065994	1263.840210
13	0.000000	199.578842	1263.840210
14	0.000000	11.445420	1263.840210
15	0.000000	417.691345	1263.840210
16	0.000000	616.726379	1263.840210
17	0.000000	57.015419	1263.840210
18	0.000000	49.286842	1263.840210
19	0.000000	73.780632	1263.840210
20	0.000000	38.768459	1263.840210
21	0.000000	60.685890	1263.840210
22	0.000000	75.166466	1263.840210
23	0.000000	13.097100	1263.840210
24	0.000000	42.538429	1263.840210
25	0.000000	47.817097	1263.840210
26	0.000000	110.985825	1263.840210
27	0.000000	265.773773	1263.840210
28	0.000000	361.739044	1263.840210
29	0.000000	530.614441	1263.840210
30	0.000000	647.759888	1263.840210
31	0.000000	647.759888	1263.840210
32	0.000000	134.139420	1263.840210
33	0.000000	292.895203	1263.840210
34	0.000000	344.311066	1263.840210
35	0.000000	95.463699	1263.840210
36	0.000000	103.915009	1263.840210
37	0.000000	91.252640	1263.840210
38	7640.000000	647.759888	1263.840210
39	6919.810059	INFINITY	3045.989990
40	5050.009766	INFINITY	180.490005
41	6631.290039	INFINITY	1127.135132
42	2826.000000	INFINITY	2826.000000
43	73.500000	2497.707764	73.500000
44	186.699997	3045.989990	186.699997
45	908.460022	2344.786865	908.460022
46	36.750000	3045.989990	36.750000
47	49.980000	842.560120	49.980000
48	155.080002	1941.382690	155.080002
49	23.520000	3045.989990	23.520000
50	675.469971	1834.310791	675.469971
51	441.000000	2113.445068	441.000000
52	1323.359985	3045.989990	1323.359985
53	220.000000	INFINITY	220.000000
54	1800.000000	180.490005	914.915100
55	46.830002	180.490005	46.830002
56	119.000000	180.490005	119.000000
57	1221.300049	180.490005	1201.780884
58	23.420000	180.490005	23.420000
59	31.840000	180.490005	31.840000
60	98.809998	180.490005	98.809998
61	14.980000	180.490005	14.980000
62	430.359985	180.490005	430.359985
63	240.979996	180.490005	240.979996
64	842.000000	180.490005	842.000000
65	140.490005	INFINITY	140.490005
66	2700.000000	INFINITY	914.915100
67	70.739998	2497.707764	70.739998
68	180.000000	1690.702637	180.000000
69	864.299988	2344.786865	864.299988
70	35.369999	1904.562500	35.369999
71	48.560001	842.560120	48.560001
72	149.259995	1941.382690	149.259995

FIRST-RESULT(NO SW)

73	22.629999	1970.399292	22.629999
74	650.099976	1834.310791	650.099976
75	424.440002	2113.445068	424.440002
76	1273.670044	1789.263916	1273.670044
77	212.220001	INFINITY	212.220001

GW6Z2	0.000000	0.000000
GW6Z3	144.448929	0.000000
GW7Z1	148.899475	0.000000
GW7Z3	75.434547	0.000000
GW8Z1	84.381981	0.000000
GW8Z2	2.700000	0.000000
GW8Z3	26.676781	0.000000
GW9Z1	477.165192	0.000000
GW9Z2	9.000000	0.000000
GW9Z3	242.171066	0.000000
GW10Z1	1836.294556	0.000000
GW10Z2	104.011040	0.000000
GW10Z3	1242.816406	0.000000
GW11Z1	1211.513062	0.000000
GW11Z2	10.152121	0.000000
GW11Z3	331.766602	0.000000
GW12Z1	1338.317871	0.000000
GW12Z2	6.114560	0.000000
GW12Z3	252.444336	0.000000
SW1Z1	0.000000	30076.000000
SW1Z2	0.000000	30076.000000
SW1Z3	0.000000	30076.000000
SW2Z1	0.000000	30076.000000
SW2Z2	0.000000	30076.000000
SW2Z3	0.000000	30076.000000
SW3Z1	0.000000	30076.000000
SW3Z2	0.000000	30076.000000
SW3Z3	0.000000	30076.000000
SW4Z1	0.000000	30076.000000
SW4Z2	0.000000	30076.000000
SW4Z3	0.000000	30076.000000
SW5Z1	0.000000	30076.000000
SW5Z2	0.000000	30076.000000
SW5Z3	0.000000	30076.000000
SW6Z1	0.000000	30076.000000
SW6Z2	0.000000	30076.000000
SW6Z3	0.000000	30076.000000
SW7Z1	0.000000	30076.000000
SW7Z2	0.000000	30076.000000
SW7Z3	0.000000	30076.000000
SW8Z1	0.000000	30076.000000
SW8Z2	0.000000	30076.000000
SW8Z3	0.000000	30076.000000
SW9Z1	0.000000	30076.000000
SW9Z2	0.000000	30076.000000
SW9Z3	0.000000	30076.000000
SW10Z1	0.000000	30076.000000
SW10Z2	0.000000	30076.000000
SW10Z3	0.000000	30076.000000
SW11Z1	0.000000	30076.000000
SW11Z2	0.000000	30076.000000
SW11Z3	0.000000	30076.000000
SW12Z1	0.000000	30076.000000
SW12Z2	0.000000	30076.000000
SW12Z3	0.000000	30076.000000
GW7Z2	6.750000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	26000.000000
3)	0.000000	26000.000000
4)	0.000000	26000.000000
5)	0.000000	26000.000000

6)	0.000000	26000.000000
7)	0.000000	26000.000000
8)	0.000000	26000.000000
9)	0.000000	26000.000000
10)	0.000000	26000.000000
11)	0.000000	26000.000000
12)	0.000000	26000.000000
13)	0.000000	26000.000000
14)	0.000000	26000.000000
15)	0.000000	26000.000000
16)	0.000000	26000.000000
17)	0.000000	26000.000000
18)	0.000000	52000.000000
19)	0.000000	26000.000000
20)	0.000000	26000.000000
21)	0.000000	0.000000
22)	0.000000	26000.000000
23)	0.000000	26000.000000
24)	0.000000	26000.000000
25)	0.000000	26000.000000
26)	0.000000	26000.000000
27)	0.000000	45500.000000
28)	0.000000	26000.000000
29)	0.000000	26000.000000
30)	0.000000	26000.000000
31)	0.000000	26000.000000
32)	0.000000	26000.000000
33)	0.000000	26000.000000
34)	0.000000	26000.000000
35)	0.000000	26000.000000
36)	0.000000	26000.000000
37)	0.000000	26000.000000
38)	0.000000	0.000000
39)	1289.918701	0.000000
40)	952.650024	0.000000
41)	1712.180054	0.000000
42)	1419.620972	0.000000
43)	0.000000	19500.000000
44)	2457.172607	0.000000
45)	455.457886	0.000000
46)	2892.000000	0.000000
47)	2892.000000	0.000000
48)	1735.000000	0.000000
49)	1735.000000	0.000000
50)	1735.000000	0.000000
51)	599.950012	0.000000
52)	560.340027	0.000000
53)	675.500000	0.000000
54)	2892.000000	0.000000
55)	2892.000000	0.000000
56)	2892.000000	0.000000
57)	2821.899902	0.000000
58)	9523.000000	0.000000
59)	0.000000	62562.750000
60)	0.000000	4851.500000
61)	0.000000	7217.249512
62)	0.000000	24542.250000
63)	0.000000	72137.500000
64)	570.000000	0.000000
65)	0.000000	72100.000000
66)	0.000000	46504.750000
67)	0.000000	1002.999756
68)	0.000000	8164.250000

SECOND-RESULTS(100%SW)

69)	572.710022	0.000000

NO. ITERATIONS= 15

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
C1Z1	14406.250000	4001.749756	INFINITY
C1Z2	14406.250000	5906.250000	INFINITY
C1Z3	14406.250000	4001.749756	INFINITY
C2Z1	75718.750000	INFINITY	0.000018
C2Z2	75718.750000	402.999695	INFINITY
C2Z3	75718.750000	0.000000	INFINITY
C3Z1	10987.500000	0.000037	INFINITY
C3Z2	10987.500000	253.500061	INFINITY
C3Z3	10987.500000	INFINITY	0.000000
C4Z1	21231.250000	0.000000	0.000000
C4Z2	21231.250000	0.000000	INFINITY
C4Z3	21231.250000	0.000000	0.000000
C5Z1	32056.250000	0.000118	INFINITY
C5Z2	32056.250000	INFINITY	0.000000
C5Z3	32056.250000	0.000118	INFINITY
C6Z1	111137.500000	INFINITY	0.000000
C6Z2	111137.500000	1651.000122	INFINITY
C6Z3	111137.500000	0.000097	INFINITY
C7Z1	15963.750000	962.250122	INFINITY
C7Z2	15963.750000	962.250122	INFINITY
C7Z3	15963.750000	962.250122	INFINITY
C8Z1	79978.000000	INFINITY	0.000139
C8Z2	79978.000000	838.500305	INFINITY
C8Z3	79978.000000	0.000153	INFINITY
C9Z1	64418.750000	INFINITY	0.000000
C9Z2	64418.750000	0.000000	INFINITY
C9Z3	64418.750000	0.000000	INFINITY
C10Z1	16551.000000	0.000000	INFINITY
C10Z2	16551.000000	5577.000000	INFINITY
C10Z3	16551.000000	INFINITY	0.000074
C11Z1	14976.250000	0.000075	INFINITY
C11Z2	14976.250000	INFINITY	52.268036
C11Z3	14976.250000	52.268036	0.000000
C12Z1	4005.399902	11048.599609	INFINITY
C12Z2	4005.399902	11048.599609	INFINITY
C12Z3	4005.399902	11048.599609	INFINITY
GW1Z1	-26000.000000	0.000000	43740.906250
GW1Z2	-26000.000000	0.000899	0.000000
GW1Z3	-26000.000000	0.000000	0.000000
GW2Z1	-26000.000000	0.000000	0.000000
GW2Z2	-26000.000000	0.000000	INFINITY
GW2Z3	-26000.000000	0.000000	0.000000
GW3Z1	-26000.000000	8515.487305	0.000000
GW3Z2	-26000.000000	0.000000	INFINITY
GW3Z3	-26000.000000	0.000000	INFINITY
GW4Z1	-26000.000000	35412.175781	0.000000
GW4Z2	-26000.000000	0.000000	INFINITY
GW4Z3	-26000.000000	0.000000	INFINITY
GW5Z1	-26000.000000	17551.535156	0.000000
GW5Z2	-26000.000000	7209.606934	INFINITY
GW5Z3	-26000.000000	0.000000	INFINITY
GW6Z1	-26000.000000	0.000590	0.000000
GW6Z2	-52000.000000	44261.902344	INFINITY

GW6Z3	-26000.000000	0.000000	0.000590
GW7Z1	-26000.000000	0.000000	0.000000
GW7Z3	-26000.000000	0.000000	0.000000
GW8Z1	-26000.000000	0.000000	0.000000
GW8Z2	-26000.000000	INFINITY	22837.832031
GW8Z3	-26000.000000	0.000000	0.000000
GW9Z1	-26000.000000	0.000000	0.000000
GW9Z2	-26000.000000	INFINITY	19500.000000
GW9Z3	-26000.000000	0.000000	0.000000
GW10Z1	-26000.000000	0.000000	0.000000
GW10Z2	-26000.000000	0.001469	0.000000
GW10Z3	-26000.000000	0.000000	0.000000
GW11Z1	-26000.000000	0.000000	0.000000
GW11Z2	-26000.000000	0.002356	0.000000
GW11Z3	-26000.000000	0.000000	0.000000
GW12Z1	-26000.000000	0.000000	0.000000
GW12Z2	-26000.000000	0.002151	0.000000
GW12Z3	-26000.000000	0.000000	0.000000
SW1Z1	-30076.000000	30076.000000	INFINITY
SW1Z2	-30076.000000	30076.000000	INFINITY
SW1Z3	-30076.000000	30076.000000	INFINITY
SW2Z1	-30076.000000	30076.000000	INFINITY
SW2Z2	-30076.000000	30076.000000	INFINITY
SW2Z3	-30076.000000	30076.000000	INFINITY
SW3Z1	-30076.000000	30076.000000	INFINITY
SW3Z2	-30076.000000	30076.000000	INFINITY
SW3Z3	-30076.000000	30076.000000	INFINITY
SW4Z1	-30076.000000	30076.000000	INFINITY
SW4Z2	-30076.000000	30076.000000	INFINITY
SW4Z3	-30076.000000	30076.000000	INFINITY
SW5Z1	-30076.000000	30076.000000	INFINITY
SW5Z2	-30076.000000	30076.000000	INFINITY
SW5Z3	-30076.000000	30076.000000	INFINITY
SW6Z1	-30076.000000	30076.000000	INFINITY
SW6Z2	-30076.000000	30076.000000	INFINITY
SW6Z3	-30076.000000	30076.000000	INFINITY
SW7Z1	-30076.000000	30076.000000	INFINITY
SW7Z2	-30076.000000	30076.000000	INFINITY
SW7Z3	-30076.000000	30076.000000	INFINITY
SW8Z1	-30076.000000	30076.000000	INFINITY
SW8Z2	-30076.000000	30076.000000	INFINITY
SW8Z3	-30076.000000	30076.000000	INFINITY
SW9Z1	-30076.000000	30076.000000	INFINITY
SW9Z2	-30076.000000	30076.000000	INFINITY
SW9Z3	-30076.000000	30076.000000	INFINITY
SW10Z1	-30076.000000	30076.000000	INFINITY
SW10Z2	-30076.000000	30076.000000	INFINITY
SW10Z3	-30076.000000	30076.000000	INFINITY
SW11Z1	-30076.000000	30076.000000	INFINITY
SW11Z2	-30076.000000	30076.000000	INFINITY
SW11Z3	-30076.000000	30076.000000	INFINITY
SW12Z1	-30076.000000	30076.000000	INFINITY
SW12Z2	-30076.000000	30076.000000	INFINITY
SW12Z3	-30076.000000	30076.000000	INFINITY
GW7Z2	0.000000	INFINITY	25999.996094

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	0.000000	2130.620850	INFINITY
3	0.000000	6.783340	518.686646
4	0.000000	1193.848389	518.686646
5	0.000000	3136.341309	INFINITY

SECOND-RESULTS(100%SW)

6	0.000000	0.000000	1289.918701
7	0.000000	443.241333	1289.918701
8	0.000000	1996.357422	INFINITY
9	0.000000	0.000000	952.650024
10	0.000000	0.000000	952.650024
11	0.000000	2602.290039	INFINITY
12	0.000000	0.000000	1712.180054
13	0.000000	0.000000	1712.180054
14	0.000000	1316.079102	1419.620972
15	0.000000	0.000000	1419.620972
16	0.000000	0.000000	1419.620972
17	0.000000	166.665024	INFINITY
18	0.000000	0.000000	INFINITY
19	0.000000	144.448929	INFINITY
20	0.000000	148.899475	INFINITY
21	0.000000	6.750000	INFINITY
22	0.000000	75.434547	INFINITY
23	0.000000	84.381981	INFINITY
24	0.000000	2.700000	INFINITY
25	0.000000	26.676781	INFINITY
26	0.000000	477.165192	INFINITY
27	0.000000	59.780602	9.000000
28	0.000000	242.171066	INFINITY
29	0.000000	1836.294556	INFINITY
30	0.000000	104.011040	2457.172607
31	0.000000	1242.816406	2457.172607
32	0.000000	1211.513062	INFINITY
33	0.000000	10.152121	455.457886
34	0.000000	331.766602	INFINITY
35	0.000000	1338.317871	INFINITY
36	0.000000	6.114560	INFINITY
37	0.000000	252.444336	INFINITY
38	525.469971	1193.848389	518.686646
39	1733.160034	INFINITY	1289.918701
40	952.650024	INFINITY	952.650024
41	1712.180054	INFINITY	1712.180054
42	2735.699951	INFINITY	1419.620972
43	9.000000	59.780602	9.000000
44	3804.000000	INFINITY	2457.172607
45	465.609985	INFINITY	455.457886
46	2892.000000	INFINITY	2892.000000
47	2892.000000	INFINITY	2892.000000
48	1735.000000	INFINITY	1735.000000
49	1735.000000	INFINITY	1735.000000
50	1735.000000	INFINITY	1735.000000
51	599.950012	INFINITY	599.950012
52	560.340027	INFINITY	560.340027
53	675.500000	INFINITY	675.500000
54	2892.000000	INFINITY	2892.000000
55	2892.000000	INFINITY	2892.000000
56	2892.000000	INFINITY	2892.000000
57	2821.899902	INFINITY	2821.899902
58	9523.000000	INFINITY	9523.000000
59	191.000000	INFINITY	191.000000
60	485.700012	42365.046875	485.700012
61	10379.000000	INFINITY	7235.444824
62	95.540001	5839.203613	95.540001
63	5747.069824	6199.218262	5747.069824
64	570.000000	INFINITY	570.000000
65	240.000000	INFINITY	240.000000
66	5450.000000	INFINITY	5450.000000
67	1146.420044	11068.344727	1146.420044
68	3439.030029	11428.709961	2989.030029

69	572.710022	INFINITY	572.710022