CONJUNCTIVE USE PLANNING FOR SAPON IRRIGATION PROJECT OF INDONESIA

A DISSERTATION

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

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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December, 2002

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled " **CONJUNCTIVE USE PLANNING FOR SAPON IRRIGATION PROJECT OF INDONESIA**", in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** in **WATER RESOURCES DEVELOPMENT (CIVIL)**, submitted in the Water Resources Development Training Centre, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out from 16th July 2002 to 30th November 2002 under the supervision of **Dr. Deepak Khare**, Associate Professor, WRDTC, Indian Institute of Technology Roorkee, Roorkee (U.A).

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

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

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ACKNOWLEDGEMENT

From the core of my heart, I wish to express my deep sense of gratitude to my esteemed guide **Dr. Deepak Khare,** Associate Professor WRDTC, Indian Institute of Technology Roorkee, Roorkee for his benevolent guidance, constant encouragement and keen interest throughout the preparation of this dissertation.

I extend my sincere thanks to **Prof. Devadutta Das**, Professor & Head WRDTC, Indian Institute of Technology Roorkee, Roorkee for helping and making me available the adequate departmental facilities.

I am also grateful to all faculty members WRDTC, Indian Institute of Technology Roorkee, Roorkee for their valuable teaching and continuous encouragement during entire course of the study, which will always remain a cherished memory in my mind.

Special thanks to my friend **Mr. J. Deva Sundar**, trainee officer, state Hyderabat for his valuable guidance and suggestion at every stage in preparation of this dissertation.

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

At last but not least, I feel very fortunate to have such a loving wife **Inge Maylanie,** and children **Nabila Wahyu Utami** and **Risq Wandi Sayyed Qamil** who inspired me to do this course. I am deeply grateful for their understanding, unflinchingly and patience during our stay in Roorkee for this course and providing me moral encouragement and dynamics support.

Above all my solemn thanks to GOD

(EDIWAHYUNAN)

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LIST OF NOTATIONS

Z = Objective Function

C_j = Unit contribution rate or cost coefficient

a_{ij} = Technological coefficient or structural coefficient

b_i = Given resource (right hand side value) or Linear vector stipulation

x_j = Decision (activity) variable

m = Number of system constraint

n = Number of decision variable

nz = Number of zones

nc = Number of crops

A_{ij} = Area of j^{th} crop for i^{th} zone (ha)

Y_j = Yield of j^{th} crop (kg/ha)

P_j = Price of j^{th} crop (Rs/kg)

CCL_j = Total cost of cultivation for j^{th} crop excluding the cost of water

NB_j = Net benefits for j^{th} crop excluding the cost of water

CSC_i = Unit capital cost of surface water for i^{th} zone (Rs/ha-m)

CSO_i = Unit operation and maintenance (O/M) cost of surface water for i^{th} zone (Rs/ha-m)

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

SW_{ik} = Surface water allocation for i^{th} zone during k^{th} time interval (ha-m)

CGT_{ik} = Total cost of groundwater for i^{th} zone during k^{th} time interval (Rs/ha-m)

GWT_{ik} = Groundwater allocation for i^{th} zone during k^{th} time interval (ha-m)

WR_{jk} = Water requirement of j^{th} crop for k^{th} time period (m)

A_{ij} = Area of j^{th} crop for k^{th} zone (ha)

SW_{jk} = Surface water allocations i^{th} zone during k^{th} time interval (ha-m)

GW_{jk} = Groundwater water allocation for i^{th} zone during k^{th} time interval (ha-m)

$\lambda_{j,kw}$ = Land use coefficient for j^{th} crop in kw^{th} time

$\lambda_{j,kd}$ = Land use coefficient for j^{th} crop in kd^{th} time

kw = a month of wet season (say November)

kd = a month of dry season (say April)

CCA_i = Culturable Command Area for i^{th} zone (ha)

SW_{ik} = Surface water allocation for i^{th} zone during k^{th} time interval (ha-m)

Es_{dmi} = Efficiency of surface water system for distributaries and minor for i^{th} zone.

Es_{ci} = Conveyance efficiency of canal for i^{th} zone.

SWA_k = Surface water available at the head of canal for k^{th} time interval (ha-m).

GW_{jk} = Groundwater water allocation for i^{th} zone during k^{th} time interval (ha-m)

μ = The mining allowance (=1 when no mining is allowed)

P_{ij} = The ratio of area of j^{th} crop in i^{th} zone and CCA of i^{th} zone.

ABSTRACT

Natural resources are the basis for strength, growth and the very future of every nation. Water and land are the key resources and human has been pioneer in the use of these resources. Optimal use of available surface water and groundwater in any area will be provided better utilization of available resources and more benefits in the area. This study describes LP based optimization model to optimize land and water resources of a study area for sustainable agricultural development. The combined and integrated management of surface water and groundwater for optimal utilization of available water resources is called conjunctive use.

The present study is directed to planning of surface water and groundwater resources system conjunctively to meet irrigation demand in Sapon Irrigation Project of Indonesia. The project has gross command area of 4917 ha. The irrigated area by this project is 2250 ha, and remaining the area for fulfill the crop water requirement depend on rainwater. The major portion of rainwater occurs during wet season period (i.e. November, December, January and February). In other months of the year rainfall occurs very less, which cannot fulfill the crop water requirement. Therefore shortage of rainwater during the dry season period causes a strong needs to plan and investigate the utilization of groundwater potential for agricultural purpose. At present these is no groundwater development in the command.

The main aim of the present study is to arrive at an optimal cropping pattern for optimal use of land and water resources for maximization of net benefits. The " LINDO" optimization package has been used to solve linearised model and to get the optimal allocation of land and surface water and groundwater conjunctively. Model has been used for allocation of water on existing cropping pattern and proposed cropping pattern. First trial to solve the existing cropping pattern without groundwater supply and crops area constraint, and to get the optimal crop. Basis on the existing cropping pattern to solve the solve the proposed cropping pattern with groundwater supply and crop area constraint and to meet the maximum net benefits. After extensive study on different case of the proposed cropping pattern, the optimal plan giving maximum net benefits of Rs. 101,115.300 millions, utilization of surface and groundwater 4981 ha-m and 3330 ha-m respectively, whereas the optimal of land use for wet season 70% optimal

area under paddy, and 10 % shift to each crop, 1st dry season 30%, 40%, and 10% optimal area under paddy, groundnut, and other each crop respectively, and 2nd dry season 40% optimal area under groundnut and 20% other each crop. So, this case is suggested to adopted and implemented for the area under study.

CHAPTER – 1

INTRODUCTION

1.1. GENERAL

The quantity and quality of available water resources have been recognized as limiting factor in the development of most arid and semi arid regions. Recent experiences have shown that these limiting, factor may also apply in the more humid areas previously thought to be immune to water storage problems. The optimum utilization of existing water resources is therefore of ever increasing importance. As the population is increasing rapidly, the corresponding agricultural production need to be increased. This realization has led to the development of high yielding varieties of crops, increase reliance on chemical fertilizer and more intensive irrigation. All these measures have increased considerably the water requirement for irrigation. To meet the increased requirement a large number of water resources projects incorporating, a dam or a weir and a network of canal have been implemented.

Conjunctive Use is the combined and integrated management of surface and groundwater for optimal utilization of available water resources. In other word, conjunctive use of surface and groundwater offers a great potential for enchanted and assured water supply at minimum cost.

The present work, it is proposed to study the implementation of conjunctive use policy in Sapon Irrigation Project of Indonesia. The project has gross common area of 4917 ha. The irrigated area by this project is 2250 ha. At present these is no groundwater development in the command. Therefore it is proposed to investigate the utilization of Groundwater potential for irrigation. In the present work conjunctive use practices be involved and feasibility of this concept be analyzed.

In any canal command, in general, surface water utilization meets the normal water requirement and groundwater utilization meets the requirement in lean periods.

The possibilities of the problem defined above, can be avoided by joint or coordinated use of the surface water and groundwater. Conjunctive use is combined use of the available recourses so as to obtain the advantages of each resource.

When surface water and groundwater are used conjunctively various advantages can be obtained vis., the limited water resources are conserved more, with less surface storage, smaller drainage system, and smaller surface water distribution system can be adopted, the cost of lining of canals is greatly reduced.

The concept of conjunctive use is relatively new especially for our country i.e. Indonesia. Number of water resources project have been implemented in Indonesia and when different problems were faced by the concerned project authorities, then only the idea of conjunctive use emerged. The conjunctive use planning and management is necessary to achieve maximum return from cropping activities of any area in addition to the solution of the problems of water logging and water table depletion.

Considering the above mentioned aspects an attempt has been made in the present work to study the conjunctive use planning for a small water resources project in Sapon basin.

1.2. SCOPE OF STUDY

Conjunctive use of two sources of irrigation has not been adopted in the planning and design of existing irrigation project (i.e. Sapon Project) with the result that the performance of this project has always been sub-optimal and, in fact, has been deteriorating over the years. It is now widely believed that the strategy of conjunctive use irrigation would enhance the viability, credibility and utility oh this importance projects, particularly in the lower reaches, and improve its performance significantly. There have rapid developments in the field of optimization studies for water resources utilization and its planning and management. This study illustrates the use of feasibility study for conjunctive use of surface water and groundwater in Sapon Irrigation Project of Indonesia.

1.3. OBJECTIVE OF THE STUDY

It is obvious that availability of land and water are more or less static in nature whereas our need for food item are dynamic and nature because of growing population.

More over horizontal expansion of cultivable land is not possible. Therefore only alternative to increase the food production is the optimum utilization of both resources. The primary objective of present study is to allocate optimally the land and water resources (surface and groundwater conjunctively) to secure food security for the present and the near future under various physical and social constraints.

The main objective of the study are :

(i). To study the literature related to conjunctive use planning

(ii). To study the project area and acquire the necessary data

(iii). To examine the existing cropping pattern with the available resources (i.e. water and land)

(iv). Formulation the system model to arrive at optimal allocation of surface water and groundwater with an optimal cropping pattern.

(v). Allocation of land to various crops so that the net benefits are maximum satisfying food requirement and employment opportunities for the population and near future of the study area using surface water and groundwater conjunctively.

1.4. ORGANIZATION OF DISSERTATION

The study is presented in six chapters. The content of these chapters are briefly outlined below,

Chapter – 1 : It deals with the introduction of the issue, highlights the scope of the study, objective of study and organization of dissertation

Chapter – 2 : It deals with literature review pertaining to solution technique of conjunctive use models.

Chapter – 3 : It deals with the data related to study area, irrigation system, crop season and cropping pattern and groundwater availability etc.

Chapter – 4 : It deals with Methodology and Formulation pertaining to objective of Study, Conjunctive Use (Advantages and disadvantages) and mathematical Model

Chapter – 5 : It deals with result and discussion obtained from the model runs.

Chapter – 6 : It gives conclusions based on the analysis for study area. Dissertation end and recommendations for further study.

CHAPTER – 2

LITERATURE REVIEW

2.1. GENERAL

Attempts have been made by different researchers to study the optimal allocation of land, water and other resources. Although advantage of conjunctive utilization of these two forms of total water resources were recognized more than 50 years ago. Conklin – 1964, Kazman – 1951, Banks – 1953, Valentine – 1965, and Fowler – 1964 recognized the above said fact i.e. surface water and groundwater are two part of the total water resources and advocated their joint use in water resources planning.

The various analytical approaches towards optimizing conjunctive use of water resources may broadly be grouped into four categories. The first of these considers the problem from a resources allocation viewpoint and makes use of mathematical programming techniques for optimization. In the second approach, groundwater basin simulation and various feasible alternative plans of surface and groundwater use are presented in term of a groundwater basin operation and the optimum combination selected according to the criteria of economic optimization. The third approach is a combination of the above two, and fourth approach is non Linear Programming Technique.

2.2. SOLUTION TECHNIQUE

The solution technique for conjunctive use management are based on different optimization method vis., Dynamic Programming, Simulation, Linear Programming and Non-Linear Programming Techniques.

2.2.1. Dynamic Programming Model

Different models are developed, so many authors have been using this technique. Hall and Buras (1961) described the suitability of Dynamic Programming to multistage decision problem regarding water allocation to different alternative uses, choice among alternative reservoir sites. Buras (1963) solved the problem of getting optimal policies by using the Dynamic Programming.

Burt (1964) had stressed on of optimization of pumping, recharge and direct surface water application policies through the Dynamic Programming. Aron (1969) had extended the work of Buras (1963) and Dracup (1966), and prepared a Dynamic Programming model for optimal operation of a surface and groundwater system.

Onta et al (1991) has given a new approach to conjunctive use of surface and groundwater by three steps modeling. Thus the long term a stochastic Dynamic Programming optimization model first determined operational conjunctive use policies.

2.2.2. Simulation Models

Brederhoeft and Young (1970) stressed mainly on interdependent characteristic of groundwater system through Simulation Techniques. Thus presented a simulation approach for determining an optimal temporal withdrawal policy for groundwater basin. Later they extended their work to conjunctive use, by incorporating hydrologic simulation model with an economic model, which represent response of irrigation water user to variations in the water supply and cost (Young and Brederhoeft, 1972).

O'mara and Duloy (1984) had examined alternative policies for achieving more efficient conjunctive use in Indus basin through Simulation model. Latif and James (1991) had prepared the Simulation Models which includes the water logging and salination criteria to maximize the benefits under dynamic water supply for long term conditions.

Chaves – Morales, et al (1992) given a planning model for conjunctive use of irrigation water from a multipurpose reservoir and an aquifer and the allocation cropped area. They concentrated on profits for the farmers in the irrigation district, reservoir and aquifer operating schedule for one year planning horizon and hydropower generation.

2.2.3. Linear Programming Models

Castle and Lindeborg (1961) defined optimal operation policies on the basis of maximizing beneficial use as determined by a Linear Programming model. An assumption was made to the production function of water that " Water users in the two agricultural areas would expand their inputs of other production factor in proportion to increase in the amounts of available water". A model is formulated in the linear fashion required by Linear Programming approach based on this assumption. This concept has been utilized by Dracup (1966) and subsequently Milligan (1970).

A mathematical model for a groundwater and surface water system was formulated by Dracup (1966) which was solved by parametric Linear Programming. This included sensitivity analysis on the cost coefficient 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 irrigated project. Milligan (1970) has also used Linear Programming model for a surface water and groundwater system operation. Milligan divided aquifer in horizontal slice to linearize the groundwater cost function so that the cost of pumping from each slice can be taken as constant. Nieswand and Grandstorm (1971) had prepared a set of chance constrained Linear Programming model for optimal use of surface and groundwater. They have shown that this technique is vary useful to those models which are stochastic in nature.

Vadula (1985) presented a water allocation model for the upper cauvery river basin in India. In this study Linear Programming is used to determine reservoir release, groundwater pumping targets and optimal cropping patterns.

Pandyal and Das Gupta (1987) has developed a model to simulate the operation of surface water for Tinoa river basin and groundwater reservoir in Southerm Nepal. This problem solved as a mixed integer programming problem in which objective function minimizes the maximum relative shortage of irrigation water in any month was transformed into a linear programming model.

2.2.4. Non-Linear Programming Models

Kashyap (1982) has solved the conjunctive use problem by using the Non-Linear programming technique to arrive at an optimal conjunctive use policies, incorporating spatially and temporarily distributed groundwater withdrawals for a predefined pattern of surface water availability and spatially distributed cropping pattern.

Wills et. al (1989) presented a Non-Linear Programming conjunctive use model in which the considered the production cost including the distribution cost of river water. The cost of groundwater considered as Non-Linear because the lift is dependent on the withdrawals. In this study, net benefits from the production of three crops were maximized.

Matsukawa et. al (1992) developed conjunctive use model, which incorporates the hydraulic of surface water and groundwater system, water supply, hydropower and groundwater cost and benefits objectives. Constrains of the planning model, included hydropower production limits, water grading constraint on the combined surface water and groundwater.

2.3. CONCLUDING REMARKS

The literature review reveals that in conjunctive use model, system approach and its frame works of mathematical models have been widely used by various investigators.

The Dynamic Programming was applied for conjunctive use in the early stages (Buras, 1963: Burt, 1964; Aron, 1969), but the unsuitable of this approach is related to the regional analysis, because of dimensionality problem resulting from the large number of state variables associated with groundwater modeling.

Simulation models have given same solution if these problems by incorporating full scale distributed parameters, but it only always the comparison of direct maximization or minimization of a particular objective. An array of feasible solution is obtained by this technique, from which a near optimal solution is identified.

The model based on Non-Linear Programming by Wills et. al (1989) allows the most general formulation, but computer requirement and the convergence rate of the algorithm are major obstacles in the solution of large scale practical problems.

Linear Programming (LP) models used by many investigators have given satisfactory solution of conjunctive use planning problems in general. However, they have a limitation of linearising the objective function and constraint. The Linear Programming model proposed by Roger and Smith (1970) used by many subsequent investigators vis,. Khare (1994) seems to have an edge over other LP formulations considering the derived result.

The mathematical models of different varieties are available which can solve complex problem involving complexity and extensive data requirements, however these models are still unknown to the practicing engineers and planner, particularly in developing countries. It is not always certain that the result obtained from sophisticated and expensive models would much better then those obtained from less detailed models related to conjunctive use. By considering above discussion, attempt has been made to study conjunctive use management by using Linear Programming model for allocation policies.

CHAPTER – 3

THE STUDY AREA

3.1. GENERAL

The area selected for the study is Sapon Area lies between 163° 13' to 163° 46' N Latitude and 14° 67' to 14° 83' E Longitudes in Kulon Progo Regency, Yogyakarta Province, Indonesia. The study area has a geographical area of 65.4 sq km out of which 49.2 sq km (4920 ha) are cultivable. Fig. 3.1 shows the study area on index map of Yogyakarta Province.

The area is bounded hydrologically by the river Sapon in the east, Indonesia ocean in the south, Pengasih irrigation area in the west and Papah irrigation area in the south. This area lies in the Lendah Sub district comprises 4 block irrigation (see Fig. 3.2). Block wise distribution of study area is given in Table 3.1.

Table 3.1. Block wise distribution of study area

SI. No.	Name of Block	Total Block Area (ha)	Contribution to Study area			
			Area with Irrigation Lined (Ha)	Area with Irrigation Unlined (Ha)	Total area (Ha)	%
1	Pandowan	1876	554	634	1188	63.33
2	Wonokasih	2608	646	673	1319	50.58
3	Ngremang	1963	662	837	1499	76.36
4	Banaran	1503	388	523	911	60.61
	Total	7950	2250	2667	4917	

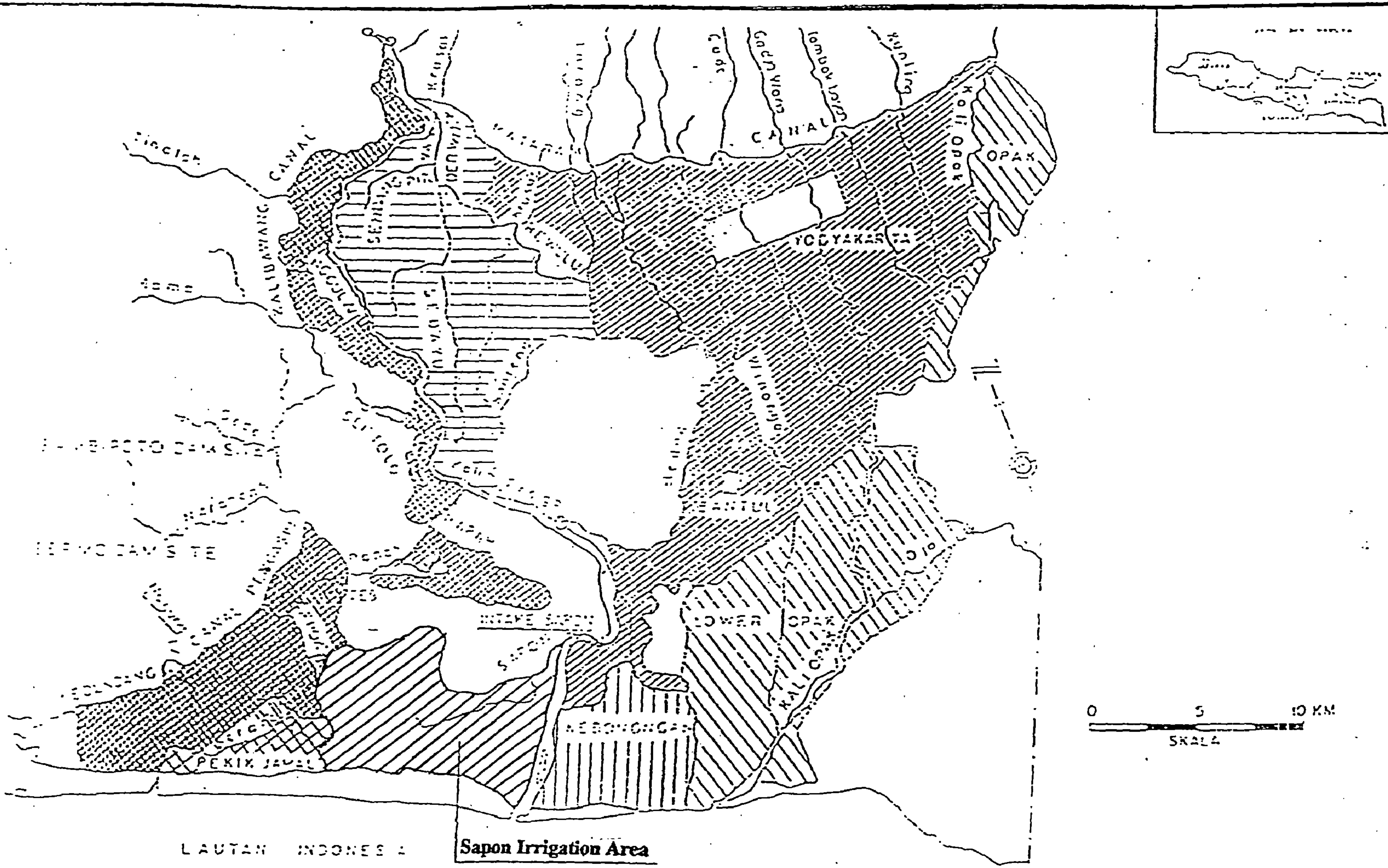


Figure 3.1. Location Map of Study

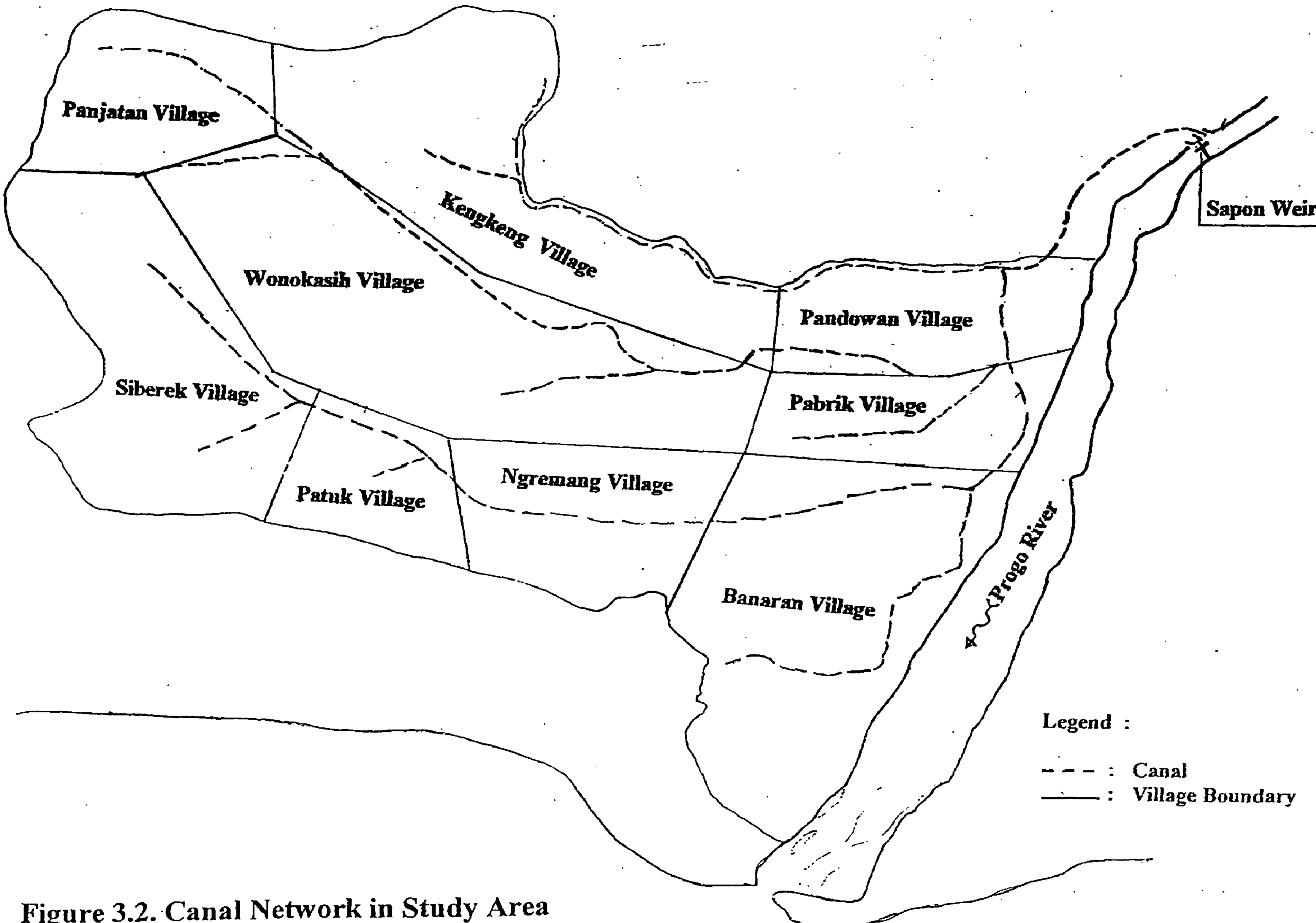


Figure 3.2. Canal Network in Study Area

3.2. CLIMATE AND RAINFALL

The mean maximum temperature and mean minimum temperature of the area are 30 ^0C and 20 ^0C respectively. Most of the rainfall occurs during monsoon period i.e in the months of November, December, January, and February. The rainfall observed in Sapon Station around the area under study as per available records. The average annual rainfall in the area from 1987 to 1998 is 1575 mm given in Table 3.2 and mean monthly temperature, relative humidity, wind speed, actual sun shine hours are given in Table 3.3.

3.3. SOILS CHARACTERISTICS

The characteristics of the soil in study area are young alluvium, deposit by the Sapon river and its tributaries. The texture is generally light to medium loam and clay loam. Although there are quite large variations, the same soil types and associations occur almost throughtout the command. The soils are fertile and their characteristics are in no way a constraint for agricultural development. The thickness of fertile topsoil varies from 2.0 meters to 5.0 meters.

3.4. CROP SEASON AND CROPPING PATTERN

3.4.1. Crop Season

In the study area nearly 90% and 10% land area is flat and medium upland respectively. There are three crops season in the study area, rainy season is considered from November to February, 1st dry season from March to June, and 2nd dry season from July to October. Most area rainy season are paddy, mungbean, and maize, and 1st dry season crop are paddy, soybean, mungbean, maize, and groundnut, whereas 2nd dry season crops are soybean, and mungbean. In addition to these crops like vegetable are also grown in a small part of the area.

The following are the main crops grown in the study area :

- Paddy
- Soybean
- Mungbean
- Maize and Groundnut

Table 3.2. Monthly Rainfall Data Sapon Station in mm

Year	Month												Total
	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
1987	341.90	261.30	166.00	103.65	71.00	20.10	6.40	2.60	2.85	43.50	314.10	417.00	1750.40
1988	337.60	243.30	186.40	96.10	30.30	24.00	6.54	3.20	79.35	55.40	236.90	332.40	1631.49
1989	455.40	365.50	116.30	102.64	96.30	69.10	4.10	2.05	13.25	83.00	209.10	352.40	1869.14
1990	305.80	215.10	103.80	99.40	63.20	53.00	6.00	6.40	11.30	81.40	279.60	336.10	1561.10
1991	315.70	240.40	133.30	101.94	80.50	39.10	9.36	8.15	28.44	82.55	215.30	299.60	1554.34
1992	257.00	307.50	161.90	125.90	78.50	48.70	11.47	9.98	73.00	98.00	205.00	281.40	1658.35
1993	281.00	229.00	111.50	125.40	54.00	36.20	5.45	4.83	22.15	56.30	217.70	240.00	1383.53
1994	279.00	318.70	155.60	127.40	62.14	52.75	6.85	8.08	35.15	50.90	194.20	193.70	1484.47
1995	265.20	213.70	120.60	98.00	38.20	29.90	10.30	8.36	41.20	63.70	352.70	242.00	1483.86
1996	335.20	214.90	129.00	63.72	33.40	43.80	7.05	9.20	47.73	17.10	296.20	239.30	1436.60
1997	333.30	244.90	107.70	88.60	14.80	0.00	0.00	0.00	0.30	15.45	191.70	345.10	1341.85
1998	297.20	205.20	201.30	101.50	58.60	29.60	7.80	6.30	110.30	56.70	319.90	361.50	1755.90
Average	317.03	254.96	141.12	102.85	56.75	37.19	6.78	5.76	38.75	58.67	252.70	303.38	1575.92

Table 3.3. Mean Monthly Agroclimatological Data in Study Area

Month	Air Temperature ^{o}C			Relative Humidity (Rh)			Average Wind Speed (m/sec)	Actual Sun Shine (hours)
	Max.	Min.	Mean.	Max.	Min.	Mean.		
January	28.39	20.80	24.60	78.51	61.39	68.60	1.39	46.92
February	28.71	20.50	24.60	87.36	63.36	75.36	1.45	44.88
March	28.79	19.00	23.89	83.65	63.00	73.33	1.19	40.29
April	29.30	23.30	26.30	81.00	63.10	72.05	1.07	41.45
May	28.84	22.20	25.52	73.32	62.90	68.11	0.94	52.77
June	28.35	23.90	26.12	72.00	63.93	67.70	0.85	63.07
July	28.29	21.40	24.85	69.00	62.13	65.57	1.04	72.31
August	28.40	21.40	24.90	68.00	61.23	64.62	1.33	71.23
September	29.65	24.20	26.93	68.00	62.37	65.19	1.33	70.54
October	30.10	24.50	27.30	68.00	65.45	66.73	1.23	69.54
November	28.39	20.60	24.49	69.00	62.07	65.53	1.13	47.88
December	28.01	21.00	24.51	70.00	63.03	66.52	1.41	46.29

3.4.2. Existing Cropping Pattern

As far as cropping pattern in the study area it is a predominantly paddy growing area, maize, soybean, mungbean and groundnut are the other important cereal crops.

In rainy season all the area can be grown, whereas in 1st dry season and 2nd dry season the area can be grown 40% and 25% respectively. The existing cropping pattern in the study area is given in Table 3.4. while taken from Project Report (Source Department of Agriculture Yogyakarta Province).

3.4.3. Proposed Cropping Pattern

The existing cropping pattern of the study area in mainly paddy crop orinted pattern, where as soybean, mungbean, maize and groundnut are produced in less quantity at the present. So a cropping pattern having all the above varieties suited to the soil of the study area is proposed comprising of paddy, soybean, mungbean, maize during wet season and paddy, soybean mungbean, maize, groundnut, and vegetable during 1st dry season and 2nd dry season. The proposed crops for study area given below in Table 3.5.

Table 3.5. Proposed cropping pattern for study area

SI. No.	Name of Crops	Season
1.	Paddy, Soybean, Mungbean, Maize,	Wet season
2.	Paddy, Soybean, Mungbean, Maize, and Groundnut	1st dry season
3.	Soybean, Mungbean, Maize, and Groundnut	2nd dry season

The model will be run to work out and suggest a suitable cropping pattern to meet the food requirement as worked out above within the resource availability constraints. Considering the socio-economic aspects of study area certain crop constraint will be imposed in the model such as the paddy area will be limited to 70% of total area for wet season and rest of the area will be met by the production of soybean, mungbean, maize and vegetable. Likewise for 1st dry season the paddy area will be limited to 30% and 2nd dry season the area will be growing with soybean, mungbean, maize, groundnut and vegetable.

Table 3.4. Existing crop area and cropping pattern in study area

SI. No.	Name of Crop	Zone 1		Zone 2		Zone 3		Zone 4		Total	
		Area with Irr. Lined (Ha)	Area with Irr. Unlined (Ha)	Area with Irr. Lined (Ha)	Area with Irr. Unlined (Ha)	Area with Irr. Lined (Ha)	Area with Irr. Unlined (Ha)	Area with Irr. Lined (Ha)	Area with Irr. Unlined (Ha)	Area with Irr. Lined (Ha)	Area with Irr. Unlined (Ha)
A	**Wet Season**										
1	Paddy	400	253	480	270	515	335	303	208	1698	1066
2	Mungbean	104	220	60	235	82	292	35	183	281	930
3	Maize	50	160	106	169	65	210	50	132	271	671
B	**1st Dry Season**										
1	Paddy	158	0	185	0	190	0	110	0	643	0
2	Soybean	113	0	132	0	135	0	80	0	460	0
3	Mungbean	87	0	102	0	105	0	60	0	354	0
4	Maize	60	0	75	0	73	0	45	0	253	0
5	Groundnuts	75	0	60	0	80	0	40	0	255	0
C	**2nd Dry Season**										
1	Soybean (c)	146	0	170	0	175	0	103	0	594	0
2	Mungbean (c)	50	0	102	0	115	0	50	0	317	0
3	Groundnuts ©	96	0	80	0	65	0	78	0	319	0

3.5. CROP CALENDAR AND CROP WATER REQUIREMENT

Crop calendar and monthly water requirement of various crops are important information for conjunctive use planning model. The crop calendar defines the date of planting the crop up to harvesting. The agricultural calendar has been borrowed from the existing practices. The calendar of the area conforms to the traditional farming. The rainy season normally stars by early November and last for 4 or 5 months. Similarly the availability of surface water from Sapon canal starts from 1st week of November. The crop calendar month wise is given in Figure. 3.3.

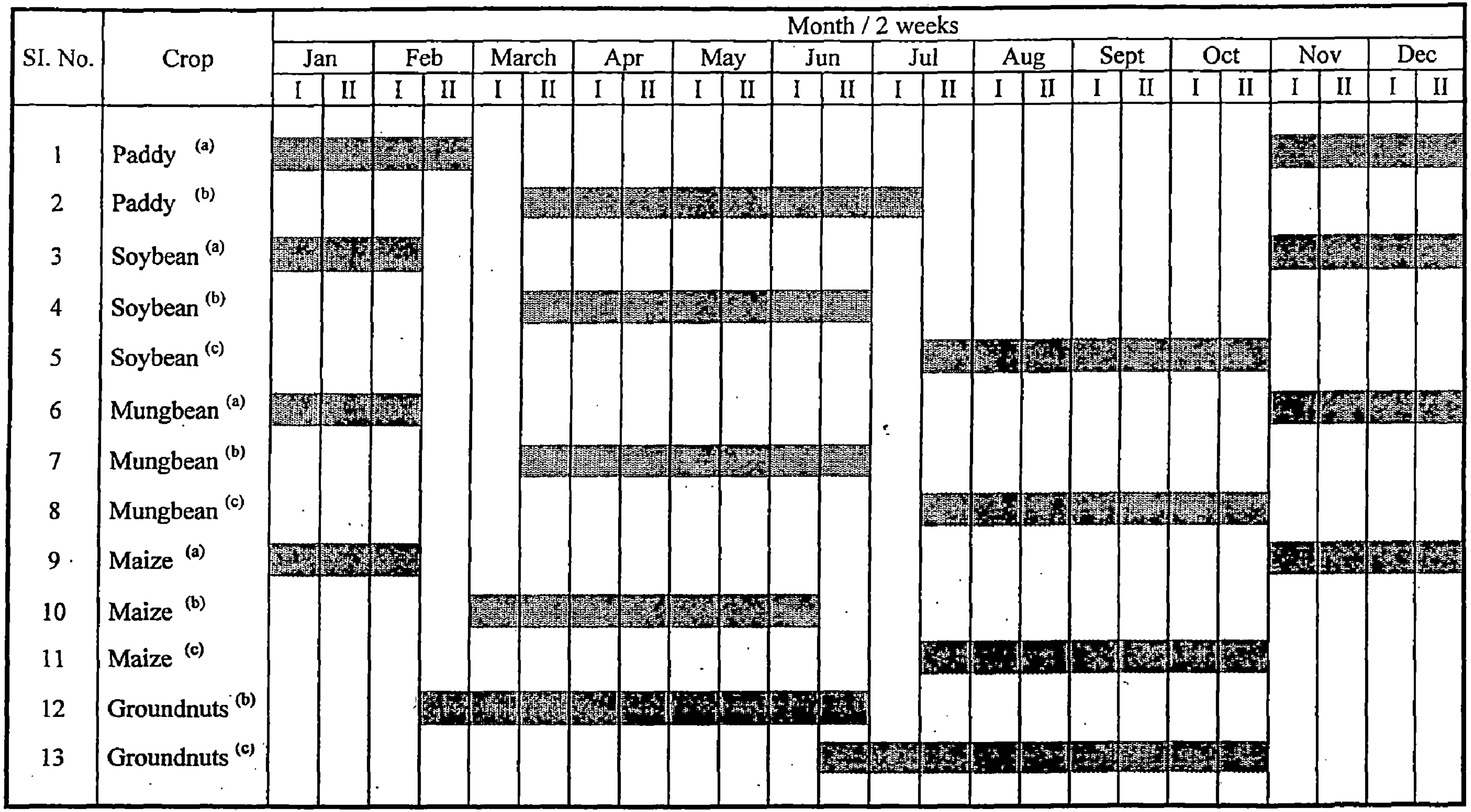
The assessment of water requirement for various crops is an important factor in choice of crops and one of the basic necessities for crop planning in a command area. The crop water requirement for the study area has been taken from the Project Report. Modified Penman method has been used to compute the crop water requirement taking into consideration the crop calendar. The month wise crop water requirements for different crops in meter are given in Table 3.6. Whereas monthly crop water required for existing copping pattern under project are given in Table 3.7.

3.6. SURFACE WATER OF THE STUDY AREA

The Progo river, one of the major rivers flowing in Yogyakarta province which is flowing from North to south. The Regency which are mainly irrigated by this river are Kulon Progo, Temanggung, Magelang, Muntilan, and Sleman. The total culturable command area of Sapon is 2250 ha and geographical area 80 sq.km. The discharge at the head in the main canal is 3.95 cumecs and length of the main canal is 8.33 km. The length of distribution is 35.17 km.

The Sapon canal irrigation shall run from 1st week of November up to end of January at full supply discharge of 3.95 cumecs. Thereafter it will run at 1.950 cumecs i.e at 50% of full supply discharge during February, March, April, and May. In June and July supply discharge decrease of 1.00 cumecs and August up to end of October supply discharge it will run at 0.70 cumecs. The detail regarding allocation and availability of water from Sapon Canal are given in Table 3.8.

Figure 3.3. Crop Calendar in Study Area (Month Considered from 15th day)



(a) = Wet Season

(b) = 1st Dry Season

(c) = 2nd Dry Season

Table 3.6. Water Requirement for different Crops (in meters)

SI. No.	Crops	Month												Total
		Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
A	**Wet Season**													
1	Paddy	0.2636	0.1126	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.3163	0.2941	0.9866
2	Soybean	0.1246	0.0825	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0968	0.0732	0.3771
3	Mungbean	0.1205	0.0680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0968	0.0606	0.3459
4	Maize	0.0912	0.0714	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0842	0.0481	0.2949
B	**1st Dry Season**													
1	Paddy	0.00	0.00	0.3163	0.2941	0.2636	0.1126	0.00	0.00	0.00	0.00	0.00	0.00	0.9866
2	Soybean	0.00	0.00	0.0968	0.0732	0.1246	0.0825	0.00	0.00	0.00	0.00	0.00	0.00	0.3771
3	Mungbean	0.00	0.00	0.0968	0.0606	0.1205	0.0680	0.00	0.00	0.00	0.00	0.00	0.00	0.3459
4	Maize	0.00	0.00	0.0842	0.0481	0.0912	0.0714	0.00	0.00	0.00	0.00	0.00	0.00	0.2949
5	Groundnuts	0.00	0.00	0.0847	0.0801	0.1107	0.0951	0.00	0.00	0.00	0.00	0.00	0.00	0.3706
C	**2nd Dry Season**													
1	Soybean	0.00	0.00	0.00	0.00	0.00	0.00	0.0968	0.0732	0.1246	0.0825	0.00	0.00	0.3771
2	Mungbean	0.00	0.00	0.00	0.00	0.00	0.00	0.0968	0.0606	0.1205	0.0680	0.00	0.00	0.3459
3	Maize	0.00	0.00	0.00	0.00	0.00	0.00	0.0842	0.0481	0.0912	0.0714	0.00	0.00	0.2949
4	Groundnuts	0.00	0.00	0.00	0.00	0.00	0.00	0.0847	0.0801	0.1107	0.0951	0.00	0.00	0.3706

Table 3.7. Crop Water Requirement for Existing Croping Pattern Under Project (Ha-m)

Sl. No.	Crops	Month												Total
		Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
1	Paddy	448	191	203	189	169	72	0.00	0.00	0.00	0.00	537	499	2310
2	Soybean	0.00	0.00	45	47	80	53	57	43	74	49	0.00	0.00	448
3	Mungbean	34	19	34	21	43	24	31	19	38	22	27	17	329
4	Maize	25	19	21	12	23	18	0.00	0.00	0.00	0.00	23	13	155
5	Groundnuts	0.00	0.00	22	20	28	24	27	26	35	30	0.00	0.00	213
	Total	506	230	325	290	343	192	115	88	148	101	587	529	3454

Table 3.8. Allocation and Availability of Water in Study Area

SI. No.	Period	Discharge (cumecs)	Volume of Water Allocated (Ha-m)	Seepage losses in main canal (20%) (Ha-m)	Volume of Water Available (Ha-m)
1	November	3.950	1023.84	204.77	819.07
2	December	3.950	1057.97	211.59	846.37
3	January	3.950	1057.97	211.59	846.37
4	February	1.950	471.74	94.35	377.40
5	March	1.950	505.44	101.09	404.35
6	April	1.950	522.29	104.46	417.83
7	May	1.950	505.44	101.09	404.35
8	June	1.000	259.20	51.84	207.36
9	July	1.000	267.84	53.57	214.27
10	August	0.700	187.49	37.50	149.99
11	September	0.700	181.44	36.29	145.15
12	October	0.700	187.49	37.50	149.99

Total Allocation during the year	6228.14
Total Losses in main canal	1245.63
Water available at outlet head	4982.52

3.7. GROUNDWATER RESOURCES OF THE STUDY AREA

The Sapon area is dominantly irrigated by surface water, but for last two years irrigation by groundwater has been done, specially in area which grows only in wet season. There are 7 observations well under this area. The water table is recorded towards the middle of October and is known as pre monsoon water level. The post monsoon water levels are recorded in the month of February. Data of pre monsoon and post monsoon depth of water table has been obtained from Groundwater Development and Conservation Project Yogyakarta. The depth to water table for 7 observations well in study area given in Table 3.9. and Figure 3.4. to Figure 3.5.

Table 3.9. Depth to Water Table in Study Area

Location of Observation well	Ground level meter at msl	Pre Monsoon 2000	Post Monsoon 2001	Pre Monsoon 2001	Post Monsoon 2001
Kengkeng	97.465	8.174	4.819	8.295	5.882
Wonokasih	88.330	7.963	4.823	7.544	4.212
Panjatan	94.128	8.851	4.338	8.991	4.585
Siberek	86.801	7.118	3.497	7.300	3.761
Patuk	86.373	7.740	3.639	7.836	3.718
Ngremang	85.984	5.326	3.225	6.285	2.673
Banaran	86.410	6.307	3.162	7.028	3.720

3.7.1. Aquifer Characteristic

Alluvium of considerable thickness exists in the entire area of study. Geophysical surveys indicate thickness of 1000 – 1500 meter of alluvial strata nearing the river Progo increasing towards North. These indicate immense groundwater potentialities in the study area. The sub-surface hydro-geological information is available to depth of about 100 m only. In general, there are considerable lithological variations in the alluvial strata, sometimes even in neighboring areas, particularly at shallower depths.

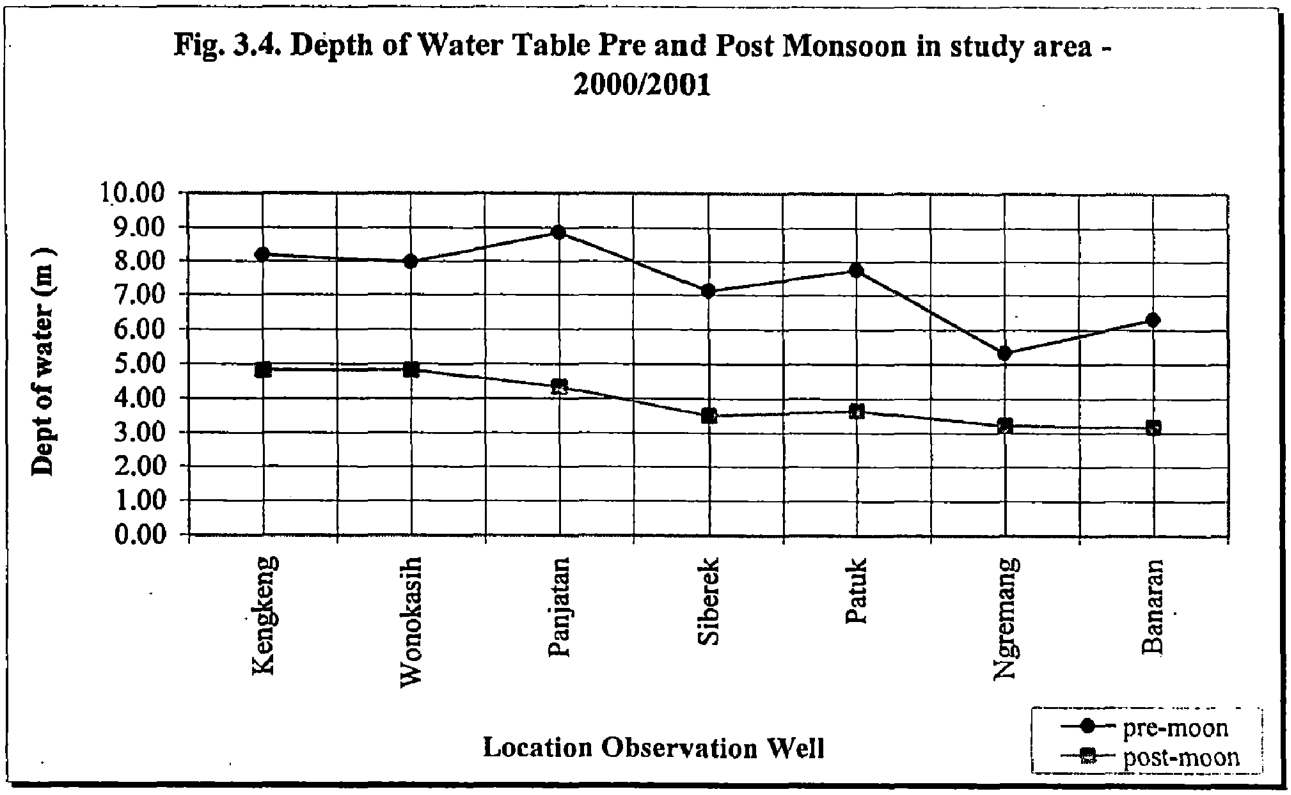


Fig. 3.4. Depth of Water Table Pre and Post Monsoon in study area - 2000/2001
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Dept of water (m)
Kengkeng
Wonokasih
Panjatan
Siberek
Patuk
Ngremang
Banaran
Location Observation Well
pre-moon
post-moon

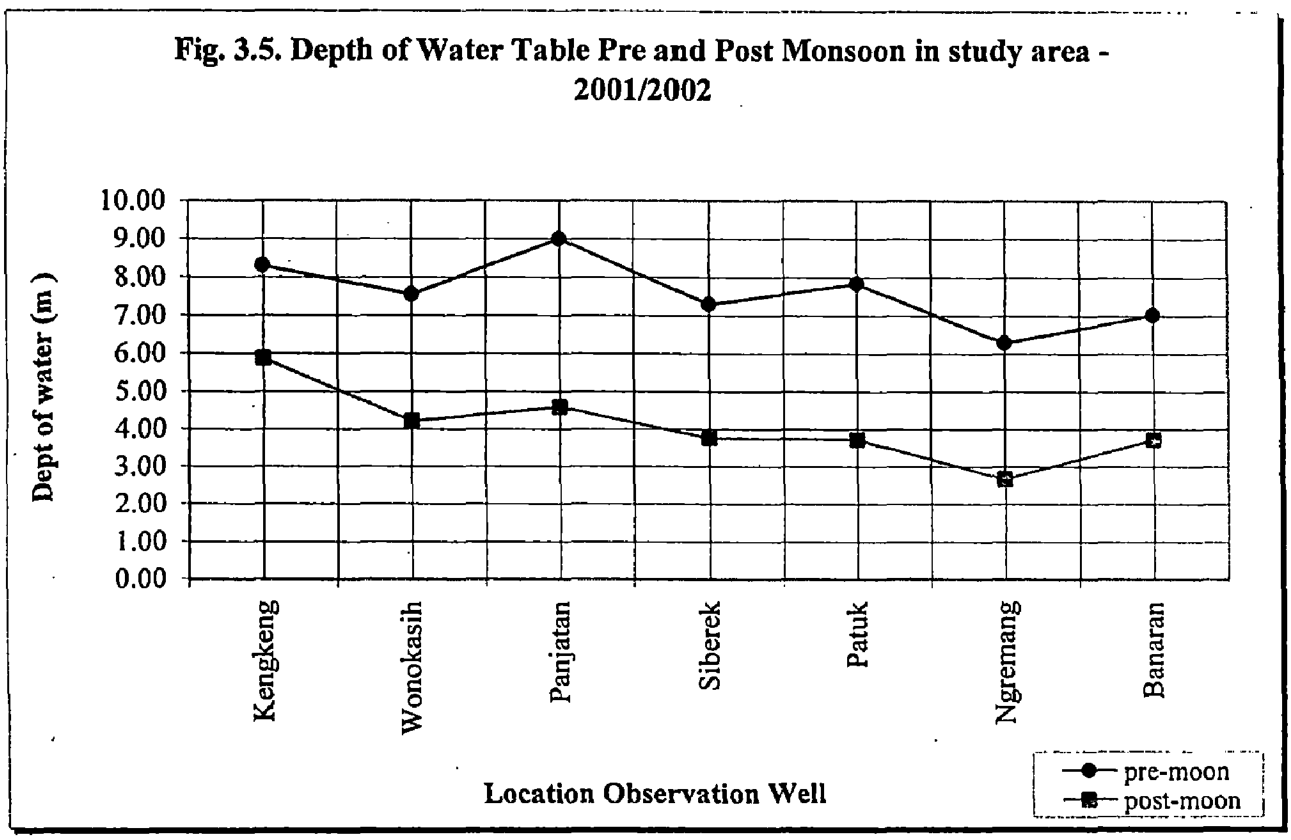


Fig. 3.5. Depth of Water Table Pre and Post Monsoon in study area - 2001/2002
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Dept of water (m)
Kengkeng
Wonokasih
Panjatan
Siberek
Patuk
Ngremang
Banaran
Location Observation Well
pre-moon
post-moon

The whole study area is suitable for shallow cavity tube wells as there is confining clay layer. The discharge of tube wells varies between 140 m^3/hr to 175 m^3/hr at drawdown ranging between 2.0 – 4.0 meters. The average values of storage coefficient (Sy) and Transmissitivity (Txx, Tyy) are 0.163 and 1200 – 1500 m^2/day, (source, Groundwater Development and Conservation Project Yogyakarta)

3.7.2. Groundwater Recharge

Annual groundwater recharge is one of the most important parameter for conjunctive use planning. This includes all possible components of recharge and quantification of inflows. In the present study annual recharge is computed on the basis of data available in the study area. Recharge parameters based on a study carried out in study area (Groundwater Development and Conservation Project Yogyakarta). Average recharge from rainfall is assumed to be 20% of annual rainfall. Recharge from canal seepage is 75% of seepage loss. The conveyance efficiency of main canal is 80%, so seepage loss is assumed to be 20%. Therefore recharge due to seepage from canal above outlet is 75% of canal water flow. Seepage loss from field channels is assumed as 30% of water available at outlet (surface water and groundwater) of this seepage loss 75% is assumed as recharge. Recharge from field irrigation is taken as 25% the water applied to the field (surface water and groundwater). Based on the assumptions recharge coefficient for surface water, calculation total groundwater recharge by rainfall infiltration methods as follows:

- Recharge due to rainfall

$$a = \frac{0.75 \times 7950 \times 1575 \times 20}{1000 \times 100} = 1878 \quad \text{Ha-m}$$

- Recharge due to losses in main canal

$b = 0.75 \times 0.20 \times 6228 = 934$ Ha-m

- Recharge due to losses in distribution channels

$c = 0.75 \times 0.30 \times 4982 = 1121$ Ha-m

- Recharge due to field seepage

$d = 0.25 \times 3738 = 935$ Ha-m

Total a + b + c + d = 4868 Ha-m

- Evapotranspiration and sub surface outflow at rate of 20%

  e = 0.20 x 4868 = 974 Ha-m

- Net Recharge available groundwater development

  f = 4868 – 974 = 3894 Ha-m

- Recoverable recharge as assumed at 80% of net recharge

  g = 0.80 x 3894 = 3115 Ha-m

- Mining allowed as assumed at 10 % of recoverable recharge

  h = 0.10 x 3115 = 315 Ha-m

Therefore the total groundwater availability is 3430 ha-m, approximately 3450 ha-m. Hence the earlier Figure 3450 Ha-m can safely be adopted and would be used as constraint.

3.8. WATER IRRIGATION CHARGES

The cost of providing surface water and groundwater for irrigation various crops have been worked based on total cost- capital and operation and maintenance. Surface water charges are very much less than groundwater charges. Similarly the irrigation charges are different for different crops. Water irrigation charges in study area given on Table 3.10.

3.9. NET BENEFITS

Based on the agricultural input and production crops in study area, (given in Table3.11.), net benefits per hectare from varies crops given in Table 3.12

Table 3.10. Average Unit Cost of Irrigation Water on the basis of Total and O&M Cost

Si. No.	Crops	Delta (m)	Irr. Charges (Rs./Ha)	O & M Charges (Rs./Ha)	Total cost (Rs./Ha)	Unit Cost of Water (Rs./Ha-m)
A	**Surface Water**					
1	Paddy	1.0340	540	160	700	676.98
2	Soybean	0.3921	300	160	460	1173.17
3	Mungbean	0.3569	300	160	460	1288.88
4	Maize	0.3574	300	160	460	1287.07
5	Groundnuts	0.4252	300	160	460	1081.84
	Average					1101.59
B	**Ground Water**					
1	Paddy	1.0340	860	480	1340	1295.94
2	Soybean	0.3921	600	480	1080	2754.40
3	Mungbean	0.3569	600	480	1080	3026.06
4	Maize	0.3574	600	480	1080	3021.82
5	Groundnut	0.4252	600	480	1080	2539.98
	Average					2527.64

Table 3.11. Agricultureal input and Production of Different Crops in the Syudy Area

SI. No.	Crops	Labour Human with bullock / machine (Rs./ha)	Seed (Rs./ha)	Fertilizer (Rs./ha)	Miscellaneous (incl. (Plan. Protection, Rodent control,+ Nursery Prep.*) (Rs./ha)	Total (Rs./ha)	Grain Yield 10^3 x kg/ha
1	Paddy	5375	150	2342	625 + 520*	9012	4.5
2	Soybean	3800	360	1625	580	6365	1.5
3	Mungbean	4175	525	1775	580	7055	1.3
4	Maize	4000	200	2300	600	7100	4.0
5	Groundnuts	4450	1225	2125	600	8400	1.2

Table 3.12. Net Benefits per hectare varies crops (excluding cost of water)

SI. No.	Crops	Grain Yield (kg/ha)	Unit Price (Rs/kg)	Total receipts (Rs./ha)	Cost of cultivation (Rs./ha)	Income Tax 2.5 % Grain Yield	Net Benefits (Rs./ha)
1	Paddy	4500	4.25	19125	9012	478	9635
2	Soybean	1500	8.50	12750	6365	319	6066
3	Mungbean	1300	11.25	14625	7055	366	7204
4	Maize	4000	3.00	12000	7100	323	4577
5	Groundnut	1200	14.25	17100	8400	428	8272

CHAPTER – 4

METHODOLOGY AND FORMULATION

4.1. GENERAL

Water resources in any project area are to be used in such a way so as to maximize the advantages generated from crops from the area. In case of cropping activity mainly supported by canal water, the use of groundwater needs to be examined. The present study is an attempt to study the conjunctive use operation for a canal command project of Indonesia. The present chapter describes the various issues of conjunctive use and the formulation of model.

4.2. CONJUNCTIVE USE

Conjunctive use can be defined as the coordinated and planed utilization of two or more sources of water. The concept of conjunctive use is a way of thinking about water utilization. Optimum beneficial use of water can be obtained by conjunctive use. Conjunctive use implies not only the use of several different sources of water but also their exploitation through efficient use in techno-economic terms.

Most attention has been given the following two combination of conjunctive water use,

1). Surface and sub-surface sources of water and

2). Urban effluent and surface sources of water.

Whenever more than one resource is used a proper management is vital. The conjunctive use of surface and groundwater in an optimal manner offers a greater potential for enhanced and assured water supplies of acceptable quality at minimum cost. It increases total yield, reliability of supply, and general efficiency of water system.

4.3. CONJUNCTIVE USE OF SURFACE AND GROUNDWATER

Surface and groundwater are two components of hydrological cycle, different but interrelated hydrologic, economic and environmental characteristics. Development of either without concern for the other has serious environmental and economic implications. Surface irrigation alone can lead to water logging unless expensive drainage arrangements are made which was a sad experience over vast regions in Pakistan (White House Report, 1964). Groundwater development alone may result in under mining of the aquifer which in turn causes permanent damage to the vegetal cover as well as to the environment. On the other hand, conjunctive use of surface and groundwater can led to significant economic advantages and can redress the undersized environmental impact. For instance in semi-arid regions, conjunctive use will offset the deficits in the dry season and enable storage and recharge of excess water in the wet season. This could be on a yearly basis or on a long-term basis leading to the possibility investigation of droughts and floods. Conjunctive use can lead to significant economic gains (Caturvedy, 1973, Minhas et.al. 1971).

4.4. ADVANTAGES OF CONJUNCTIVE USE

The solution lies in planned conjunctive use of surface and groundwater with proper cropping pattern to derive the optimum benefit in agriculture production.

Todd (1980) has discussed merits and demerits of conjunctive use surface and groundwater. Following are the advantages of conjunctive use system :

1). Groundwater conservation : Operation of both surface and groundwater reservoir provides for large water storage.

2). Small surface storage : Groundwater storage can provide for water requirement during a series of dry year.

3). Smaller surface distribution system : Greater utilization of groundwater from widely distributed wells.

4). Smaller drainage the system : Pumping from wells aids in controlling the water table.

5). Reduced canal lining : Seepage from canal is in asset because if provides artificial recharge to groundwater.

6). Greater flood control : Release of storage surface water from artificial recharge requires less control reservation and furnishes both water conservation and flood control.

7). Ready integration with existing development : Generally conjunctive operation occurs after extensive basin development, but integration can be made to increase water supplies without less of investment in existing pumping plant.

8). Storage development facilities : Final completion of project may require 20 to 40 year, hence development by stages desirable as it reduces the idle potential of the project, stage construction of surface reservoir is costly, but can be minimized with smaller reservoir.

9). Smaller evapotranspiration losses : Greater under ground storage with lowered groundwater level reduces losses.

10) Greater control over outflow : Surface waste and sub-surface out flow are reduced by conjunctive use thereby providing greater water conservation.

11) Improvement of power load and pumping plant use factor : In areas which can be severed by either surface or groundwater, surface water can be released for irrigation during peak power demand period to effect a saving in project cost.

12) Less danger from dam failure : Should failure ever occur, the smaller the dam reservoir storage, the smaller the damage.

13) Reduction in weed seed distribution : With a smaller surface distribution system there is less opportunity for spread of noxious weed seeds.

14) Better timing of water distribution : An irrigation prefers to have water available when he wants it, as from a pump, than to take water on schedule from surface conduits.

4.5. DISADVANTAGES OF CONJUNCTIVE USE

1). Less hydroelectric power : Smaller surface reservoir generate less energy and conjunctive use operation provides less power.

2). Greater power consumption : More pumping and from greater depths.

3). Decreased pimping efficiency : Large fluctuations in groundwater levels reduce pumping efficiency.

4). Greater water salinization : Natural and artificial recharge groundwater contain more dissolved solids than surface water does.

5). More complex project operation : Greater supervision of project operation is required and artificial recharge work need careful management.

6). More difficult cost allocation : Varying water supplies from two different sources require analysis to fix equitable water rates.

7). Artificial recharge is required : This is costly to operate, difficult to accomplish on land containing relatively impermeable sub soil, and occupies land otherwise available for agricultural purpose.

4.6. MATHEMATICAL MODEL

Linear Programming approach is used in the present study to optimize net benefit under the constraints of resource availability to meet the requirement of employment generation, food production in the command area of Sapon Irrigation Project. In Linear Programming model coefficients (e.g. unit profit contribution of each product, the amount of source required per unit of product, and amount of available resource) are assumed to be know with certainty. In other word Linear Programming implicitly assumes a decision problem in a static time period.

A Linear Programming model may be either of maximization or minimization type. The basic difference between maximization and minimization model of Linear Programming is the direction of inequalities of the system constraints. The system constraints may be of ($\leq$) or (=) or ($\geq$) type, decision variable may be non negative or unrestricted in sign.

If a problem involves 'n' number of decision variables and 'm' number of constraint the typical Linear Programming model can be formulated mathematically as follow :

Maximization or Minimization

$$Z = C_1 X_1 + C_2 X_2 + \dots\dots\dots + C_n X_n$$

Subject to :

$$a_{11}.x_1 + a_{12}.x_2 + \ldots\ldots\ldots\ldots + a_{1n}.x_n \le \text{ or } = \text{ or } \ge b_1$$

$$a_{21}.x_1 + a_{22}.x_2 + \ldots\ldots\ldots\ldots + a_{2n}.x_n \le \text{ or } = \text{ or } \ge b_2$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$a_{m1}.x_1 + a_{m2}.x_2 + \ldots\ldots\ldots\ldots + a_{mn}.x_n \le \text{ or } = \text{ or } \ge b_m$$

$$x_1, x_2, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, x_n \ge 0$$

The model can be formulated in a more general from as :

Maximization or Minimization

$$Z = \sum_{j=1}^{n} Cj \,.\, xj$$

Subject to :

$$\sum_{j=1}^{n} aij \,.\, xj \le \text{ or } = \text{ or } \ge bj$$

$$xj \ge 0$$

where,

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

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

where ;

C_j = Unit contribution rate or cost coefficient

a_{ij} = Technological coefficient or structural coefficient

b_i = Given resource (right hand side value) or Linear vector stipulation

x_j = Decision (activity) variable

m = Number of system constraint

n = Number of decision variable

4.7. CONJUNCTIVE USE MODEL

This requires use of optimization model, involving an objective function subjected to variety of constraints.

Linear Programming technique is used as an optimization model for present study using LINDO 6.1 software package. The package has been used to arrive at the optimal allocations of surface water and groundwater with the optimal cropping pattern, satisfying a series of constraints. In this section the objective function and constraints have been discussed.

4.7.1. Formulation of the Objective Function

The objective function has been formulated for maximizing the net benefits generated from the cropping activity in the study area.

The objective function has the following components.

4.7.1.1. Benefits

Benefits from cropping crops can be written as :

$$\sum_{i=1}^{nz}\sum_{j=1}^{nc} Aij \times (Yj \times Pj - CCLj)$$

or

$$\sum_{i=1}^{nz}\sum_{j=1}^{nc} Aij \times NBj \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

Where,

nz = Number of zones

nc = Number of crops

A_{ij} = Area of j^{th} crop for i^{th} zone (ha)

Y_j = Yield of j^{th} crop (kg/ha)

P_j = Price of j^{th} crop (Rs/kg)

CCL_j = Total cost of cultivation for j^{th} crop excluding the cost of water

NB_j = Net benefits for j^{th} crop excluding the cost of water

4.7.1.2. Cost of surface water

The cost of surface water has been calculated based on the discharge availability at outlet. The unit cost of surface water has been taken as the same for all the months during which the surface water is availability for irrigation. Therefore the total cost of providing surface water can be expressed as :

$$\sum_{i=1}^{nz}\sum_{j=1}^{12}\{CSC_i + CSO_i\} \times SW_{ik}$$

or

$$\sum_{i=1}^{nz}\sum_{j=1}^{12} CST_i \times SW_{ik} \quad \ldots\ldots \quad (4.2)$$

Where,

CSC_i = Unit capital cost of surface water for i^{th} zone (Rs/ha-m)

CSO_i = Unit operation and maintenance (O/M) cost of surface water for i^{th} zone (Rs/ha-m)

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

SW_{ik} = Surface water allocation for i^{th} zone during k^{th} time interval (ha-m)

4.7.1.3. Cost of groundwater

Cost analysis of groundwater has been carried out based on the data in the study area. The valuee of unit cost has been presented in Chapter – 3. Thus the cost of providing groundwater can be written as :

$$\sum_{i=1}^{nz}\sum_{j=1}^{12} CWT_i \times GW_{ik} \quad \ldots\ldots \quad (4.3)$$

Where,

CGT_{ik} = Total cost of groundwater for i^{th} zone during k^{th} time interval (Rs/ha-m)

GWT_{ik} = Groundwater allocation for i^{th} zone during k^{th} time interval (ha-m)

Using equation (4.1), (4.2) and (4.3) the final from of the objective function can be expressed as :

$$\text{Maximize } Z = \sum_{i=1}^{nz}\sum_{j=1}^{nc} A_{ij} \times NB_j - \sum_{i=1}^{nz}\sum_{k=1}^{12} CST_i \times SW_{ik} - \sum_{i=1}^{nz}\sum_{k=1}^{12} CGT_i \times GW_{ik} \quad \ldots\ldots (4.4)$$

The above objective function would be subjective to a variety of constraints discussed in the following section.

4.7.2. Constraints

4.7.2.1. Water requirement constraints

The total monthly water requirement of the crops in each zone shall be met by surface water and groundwater allocations in respective months. The water requirement have been considered at the outlet level in the present investigation and shown in Table 3.6. Therefore, constraints for water requirement of crops can be written as.

$$\sum_{j=1}^{nc} WR_{jk} \times A_{ij} = SW_{ik} + GW_{ik} \qquad \forall\ i,k \quad \dots\dots (4.5)$$

Where,

WR_{jk} = Water requirement of j^{th} crop for k^{th} time period (m)

A_{ij} = Area of j^{th} crop for k^{th} zone (ha)

SW_{jk} = Surface water allocations i^{th} zone during k^{th} time interval (ha-m)

GW_{jk} = Groundwater water allocation for i^{th} zone during k^{th} time interval (ha-m)

4.7.2.2. Area availability constraints

For each zone the Culturable Commanded Area (CCA) has been workout. The total area for all the crops cannot exceed the CCA of the particular zone for all the months. Since only two cropping seasons have been considered in the present study. Wet season and dry season, only two constraints one for a month of wet season (say November) would be effective. These constraints can be written as follows :

$$\sum_{j=1}^{nc} \lambda_{j.kw} \times A_{ij} \le CCA_i \quad \text{for} \quad kw \quad \dots\dots (4.6)$$

$$\sum_{j=1}^{nc} \lambda_{j.kd} \times A_{ij} \le CCA_i \quad \text{for} \quad kd \quad \dots\dots (4.7)$$

Where,

$\lambda_{j,kw}$ = Land use coefficient for j^{th} crop in kw^{th} time

$\lambda_{j.kd}$ = Land use coefficient for j^{th} crop in kd^{th} time

kw = a month of wet season (say November)

kd = a month of dry season (say April)

CCA_i = Culturable Command Area for i^{th} zone (ha)

4.7.2.3. Surface water available constraints

In the Sapon area, canal would run only during the period November to April. The month wise availability of surface water at the head of canal has been given in Table.3.8. The conveyance efficiency is taken as 80% i.e. only 80% of head discharge is availability at the outlet. Then this constraint can be written as :

$$\sum_{i=1}^{nz} \frac{SW_{ik}}{\left(ES_{dmi} \times ES_{ci}\right)} \leq SWA_k \qquad \forall\, k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.8)$$

Where,

SW_{ik} = Surface water allocation for i^{th} zone during k^{th} time interval (ha-m)

ES_{dmi} = Efficiency of surface water system for distributaries and minor for i^{th} zone.

ES_{ci} = Conveyance efficiency of canal for i^{th} zone.

SWA_k = Surface water available at the head of canal (ha-m) for k^{th} time interval (ha-m).

4.7.2.4. Groundwater Availability Constraints

The total water pumped annually from the groundwater resources of the study area should not exceed the annual recharge without allowing mining. Thus the constraints on groundwater availability for all the zone of the study area can be written as :

$$\sum_{i=1}^{nz} \sum_{k=1}^{12} GW_{ik} \leq \mu \times GWA \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.9)$$

Where,

GW_{jk} = Groundwater water allocation for i^{th} zone during k^{th} time interval (ha-m)

μ is the mining allowance (=1 when no mining is allowed)

4.7.2.5. Crop Area Constraints

These constraint are imposed on each individual crop such that,

$$A_{ij} = P_{ij} \times CCA_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.10)$$

Where,

P_{ij} = The ratio of area of j^{th} crop in i^{th} zone and CCA of i^{th} zone.

4.8. MODEL AND DATA REQUIREMENT

To study different situation and condition under defined objectives of securing self sufficiency in flood, maximizing net benefits, and providing employment opportunities with conjunctive use of surface and groundwater a Linear Programming (LP) model is considered. The objective function is maximization of net benefits with constraints as discussed above. It will be subject to other usual land and water constraints. The groundwater is considered as a single reservoir of capacity equal to specific yield and so dynamics of groundwater is not considered. For running such a model lot of field data of various type outlined below is required. Attempt has been made to collect it from Project Report and various organization and the output for various alternatives planned are presented in subsequent chapter.

a). Hydrological and Geo-hydrological

This comprises patterns of rainfall, water tables, groundwater storage/recharge and aquifer characteristic. This data was collected from Groundwater Development and Conservation Project Yogyakarta.

b). Canal Operation and Irrigation

Information of canal operation from Sapon Weir to the study area through Sapon Irrigation Canal System in various crops season has been collected from Project Report.

c). Existing Tube Well

Operation, capacities, depth, number and other relevant information on existing tube wells in the study area in general have been collected from Groundwater Development and Conservation Project Yogyakarta.

d). Groundwater Utilization

Data related groundwater and groundwater recharge calculated based on existing practices and given in previous chapters.

e). Productivity and Cost

Crop yield per hectare, groundwater rate per-hectare, surface water rate per-hectare various crops, cultivation cost and benefit from crops etc are collected.

CHAPTER – 5

RESULT AND DISCUSSIONS

5.1. GENERAL

The main aim of present study is to know the feasibility allocate optimally water resources (surface water and groundwater conjunctively) and to propose a cropping pattern and to allocate optimally of land. The Linear Programming (LP) model used for the said purpose is given in Chapter – 4. Through the model runs, appropriate cropping pattern and allocate optimally the land to meet the demand of water resources at maximum benefits.

Initially models is run for existing conditions i.e taking the existing cropping pattern and present use of land and availability of surface water. It is also found that the optimal cropping pattern with maximum benefits and present surface water use. Thereafter the models is run with proposed cropping pattern and land use basically optimal cropping pattern in existing condition. The objective function of the Linear Programming (LP) model is taken as maximization of net benefits and it is subject to usual land and water constraint.

5.2. MODEL RESULT AND DISCUSSION OF DIFFERENT CASES

The Conjunctive use model has been used to investigate different case for conjunctive use planning. The following cases have been investigated in the present study.

(i) Existing cropping pattern with the present condition

(ii) Proposed cropping pattern with different alternatives of utilization of surface and groundwater.

5.2.1. Existing Cropping Pattern

This case was taken up to find out the optimal cropping pattern in the study areas, if groundwater supply is not available. In this case the source of water is from surface water storage only. The full requirement has to be met from surface water storage. In this trial run all the groundwater allocation variables set to zero. According to the objective of study to know feasibility allocate optimally water resources and land use to meet the maximum net benefits, therefore no crops area constraint was considered. The results of runs are given in Table 5.1 and Figure 5.1 to Figure 5.5.

Objective function value as found is Rs. 45,061.420 millions and surface water utilization is 4038.44 ha-m, whereas optimal cropping pattern in wet season, 1st dry season and 2nd dry season is paddy, paddy-groundnut, and groundnut respectively.

5.2.2. Proposed Cropping Pattern

On the basis of existing condition and crops area constraint approximating meeting the optimal cropping pattern etc, was developed and tested on the model under proposed cropping pattern.

In this case has been workout by running the model with surface water and groundwater allocation, and different percentage of crop area in 1st dry season.

Case 1. Under proposed cropping pattern considering 27.5%, 27.5% and 15% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

The objective function value obtained in this run of Rs. 99,466.960 millions and the utilization of surface water and groundwater are 4981 ha-m and 3307 ha-m respectively against the corresponding availabilities of 4982 ha-m and 3450 ha-m, the over all results are show in Table 5.2 and Figure 5.6 to Figure 5.10.

Case 2. Under proposed cropping pattern considering 25%, 30% and 15% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

The objective function value obtained under this run slightly increased of Rs. 99,514.550 millions. The surface water and groundwater utilized are 4981 ha-m and 3156 ha-m respectively against the corresponding availabilities of 4982 ha-m and 3450 ha-m, the over all results are show in Table 5.3 and Figure 5.11 to Figure 5.15.

Case 3. Under proposed cropping pattern considering 30%, 25% and 15% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

The objective function value obtained in this run decreased of Rs. 99,480.540 millions. The surface water and groundwater utilized are 4981 ha-m and 3231 ha-m respectively. Details are provided in Table 5.4 and Figure 5.16 to Figure 5.20.

Case 4. Under proposed cropping pattern considering 35%, 35% and 10% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

The objective function value obtained under this run decreased of Rs. 100,839.600 millions. The surface water and groundwater utilized are 4981 ha-m and 3450 ha-m respectively. Results of this run are given in Table 5.5 and Figure 5.21 to Figure 5.25.

Case 5. Under proposed cropping pattern considering 30%, 40% and 10% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

In this run the result are very interesting that the objective function value is increased up to Rs. 101,115.300 millions, and total utilization of surface water and groundwater are 4981 ha-m and 3330 ha-m respectively. The over all results of this run are given in Table 5.6 and Figure 5.26 to Figure 5.30.

Case 6. Under proposed cropping pattern considering 40%, 30% and 10% optimal area in 1st dry season under paddy, groundnut, and other each crop respectively.

The objective function value obtained under this run decreased of Rs. 99,690.330 millions. The surface water and groundwater utilized are 4981 ha-m and 3450 ha-m respectively. Results of this run are given in Table 5.7 and Figure 5.31 to Figure 5.35.

5.3. CONCLUDING REMARKS

In the present chapter the concept of conjunctive use modeling has been described. Conjunctive use model requires an optimization model and utilization of water resources. Unit cost of groundwater more than unit cost of surface water. The net benefit for each crop in study area shows that the paddy crop has maximum benefit.

The total utilization surface water and groundwater for different alternative is presented in Figure 5.36. It can be seen from this figure that surface water utilization is constant whereas minor change of groundwater is there for various cases.

The above runs and when different case are compared, indicated that the proposed cropping pattern in case 5 considering 30%, 40% and 10% optimal area in 1^{st} dry season under paddy, groundnut and other each crop respectively, given the maximum benefits. Accordingly with the availability of surface water and groundwater storage in study it is area feasible to implement conjunctive use of surface water and groundwater. It may be noted that all the above alternatives have been tried by keeping in view the requirement of food grain in Indonesia.

Table 5.1 Optimal Allocation of SW for Existing of Cropping Pattern Under Project without crop area constraint and Groundwater Supply

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy (C1)	554	646	662	388	2250
Mungbean (C3)	0	0	0	0	0
Maize (C4)	0	0	0	0	0
1st Dry Season					
Paddy (C5)	447	0	583	0	1030
Soybean (C6)	0	0	0	0	0
Mungbean (C7)	0	0	0	0	0
Maize (C8)	0	0	0	0	0
Groundnuts (C9)	46	554	0	335	935
2nd Dry Season					
Soybean (C10)	0	0	0	0	0
Mungbean (C11)	0	0	0	0	0
Groundnuts (C13)	292	352	355	231	1230

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	146.03	0.00	170.29	0.00	174.50	0.00	102.28	0.00	593.10	0.00
Feb	62.38	0.00	72.74	0.00	74.54	0.00	43.69	0.00	253.35	0.00
March	145.30	0.00	46.92	0.00	184.40	0.00	28.37	0.00	405.00	0.00
April	135.16	0.00	44.38	0.00	171.46	0.00	26.83	0.00	377.83	0.00
May	122.93	0.00	61.33	0.00	153.68	0.00	37.08	0.00	375.02	0.00
June	54.71	0.00	52.69	0.00	65.65	0.00	31.86	0.00	204.90	0.00
July	24.73	0.00	29.81	0.00	30.07	0.00	19.57	0.00	104.18	0.00
August	23.39	0.00	28.20	0.00	28.44	0.00	18.50	0.00	98.52	0.00
Sept.	32.32	0.00	38.97	0.00	39.30	0.00	25.57	0.00	136.16	0.00
Oct.	27.77	0.00	33.48	0.00	33.76	0.00	21.97	0.00	116.97	0.00
Nov.	162.93	0.00	204.33	0.00	209.39	0.00	122.72	0.00	699.38	0.00
Dec.	162.93	0.00	189.99	0.00	194.69	0.00	114.11	0.00	661.72	0.00
Total	1100.59	0.00	973.11	0.00	1359.88	0.00	592.56	0.00	4026.14	0.00

Fig. 5.1. Optimal Allocation SW
for existing of Cropping Pattern Zone 1

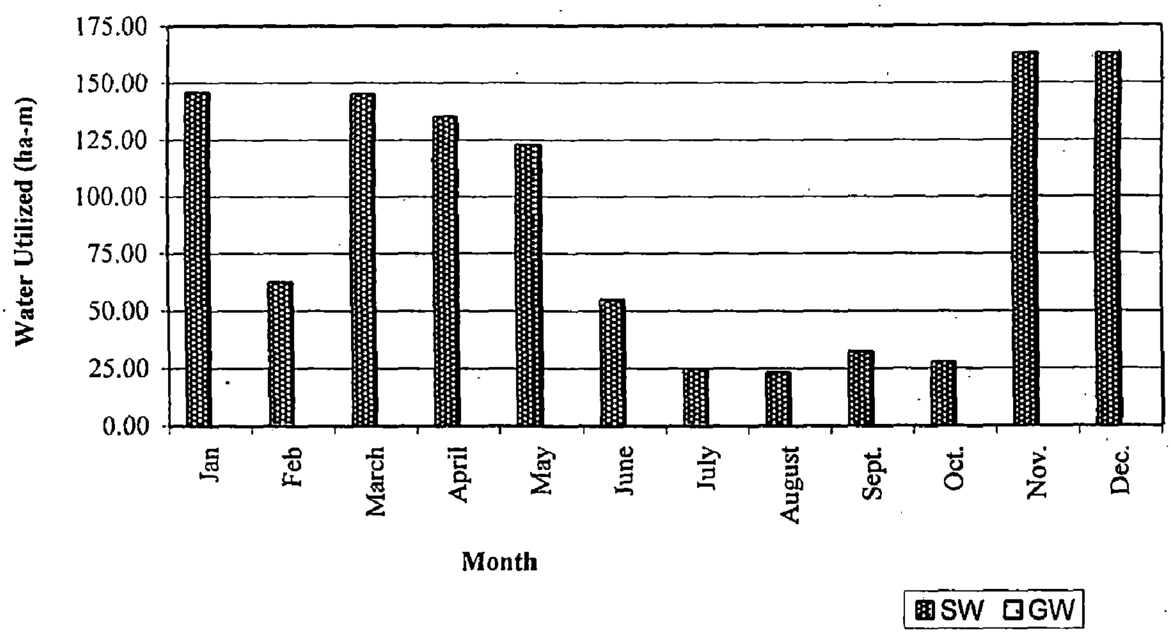


Fig. 5.2. Optimal Allocation SW
for 1th Alternative of Cropping Pattern Zone 2

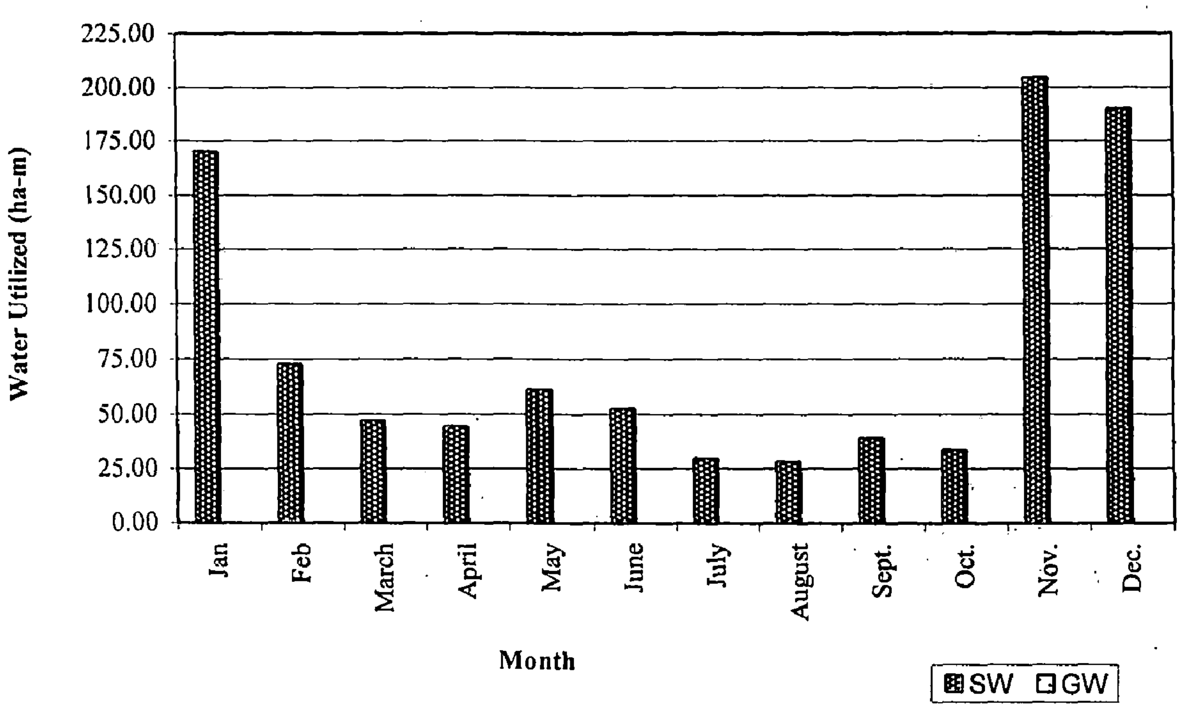


Fig. 5.3. Optimal Allocation SW
for existing of Cropping Pattern Zone 3

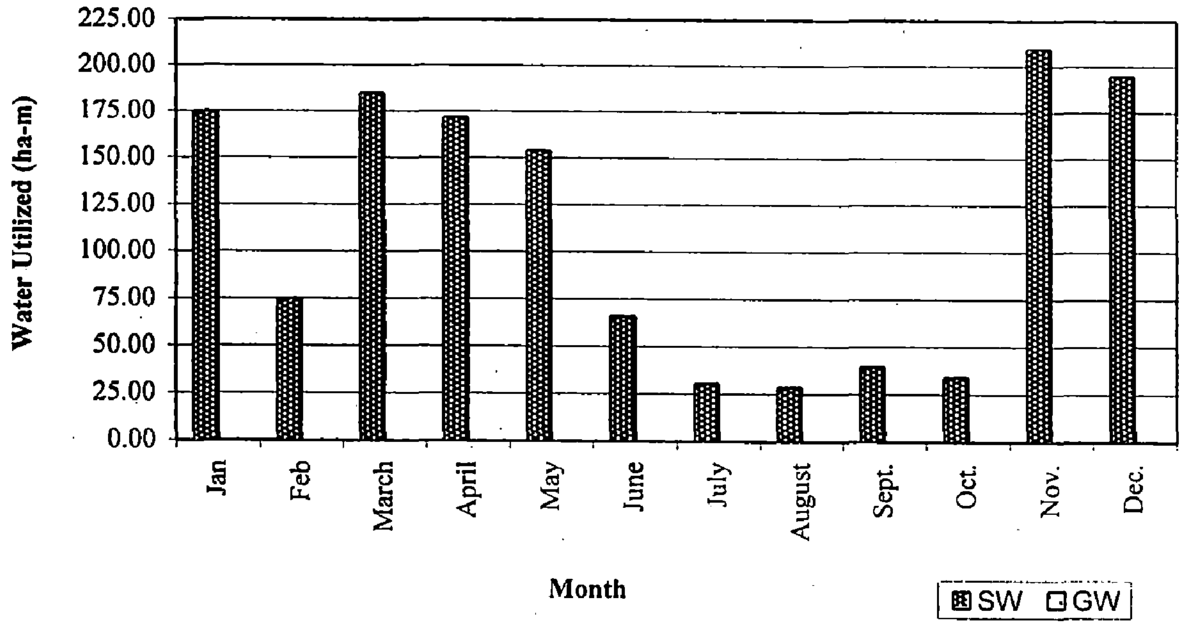
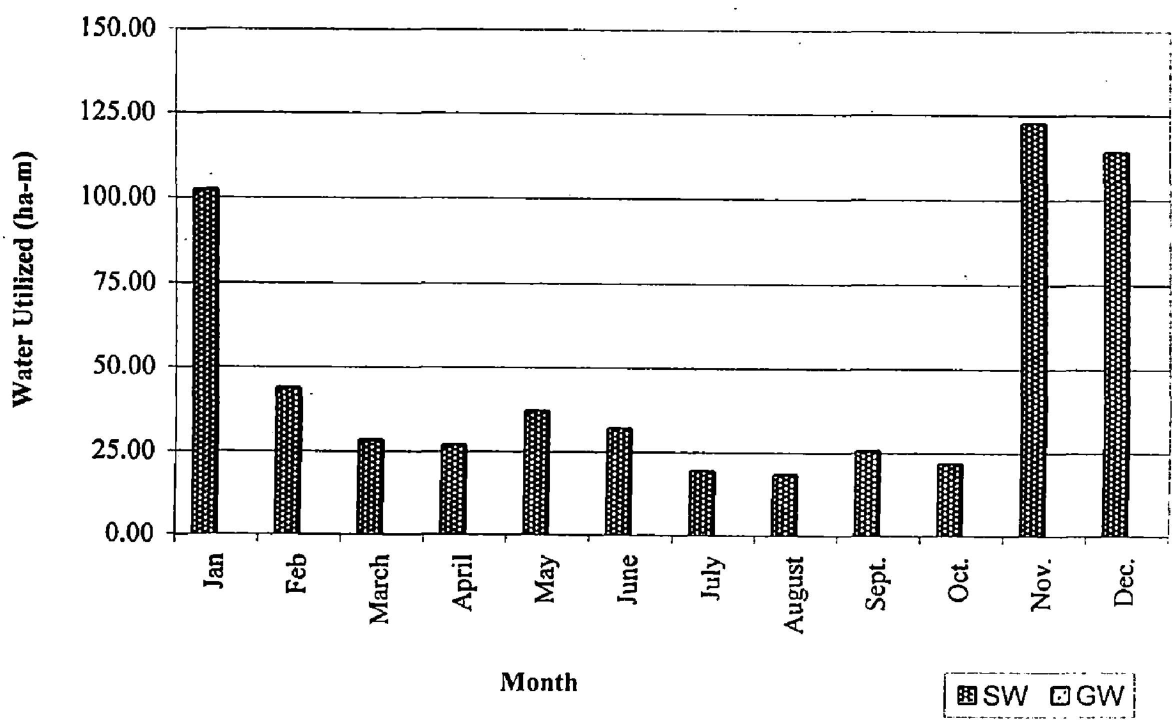
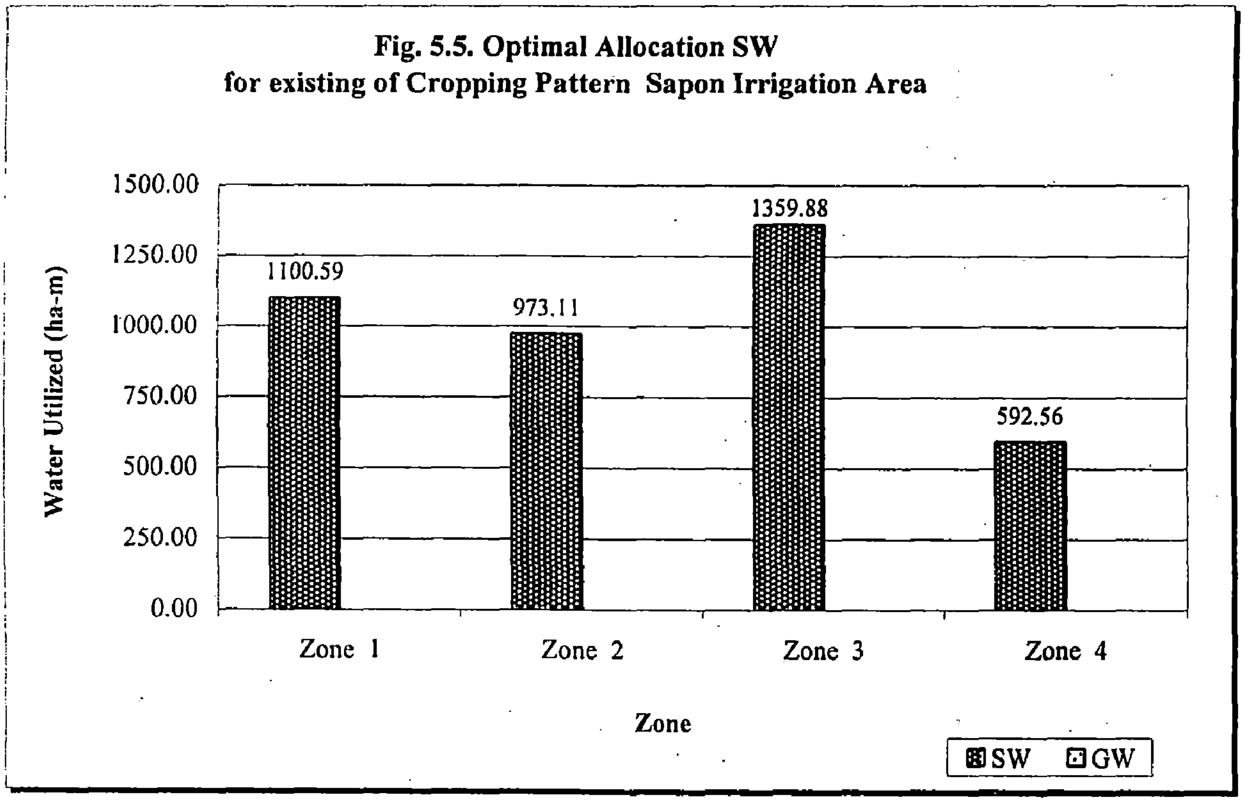


Fig. 5.4. Optimal Allocation SW
for existing of Cropping Pattern Zone 4





Water Utilized (ha-m)
1500.00
1250.00
1000.00
750.00
500.00
250.00
0.00
1100.59
973.11
1359.88
592.56
Zone 1
Zone 2
Zone 3
Zone 4
Zone
SW
GW

Table 5.2 Optimal Allocation of SW & GW for Case 1 Under Proposed Cropping Pattern, considering
(Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 27.5%, 27.5% and 15% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)
Net benefits Rs. 99,480.540 millions

Season / Crops		Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season						
Paddy	(C1)	832	923	1049	638	3442
Soybean	(C2)	119	132	150	91	492
Mungbean	(C3)	119	132	150	91	492
Maize	(C4)	119	132	150	91	492
	Total	**1189**	**1319**	**1499**	**911**	
1st Dry Season						
Paddy	(C5)	326	363	412	250	1351
Soybean	(C6)	179	198	225	137	739
Mungbean	(C7)	179	198	225	137	739
Maize	(C8)	178	197	225	137	737
Groundnuts	(C9)	326	363	412	250	1351
	Total	**1188**	**1319**	**1499**	**911**	
2nd Dry Season						
Soybean	(C10)	238	264	300	183	985
Mungbean	(C11)	238	264	300	182	984
Maize	(C12)	237	263	299	182	981
Groundnuts	(C13)	475	528	600	364	1967
	Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	32.56	226.68	287.69	0.00	326.96	0.00	198.78	0.00	846.00	226.68
Feb	120.02	0.00	133.22	0.00	31.73	119.67	92.03	0.00	377.00	119.67
March	180.37	0.00	200.48	0.00	0.00	227.72	24.15	114.16	405.00	341.88
April	154.50	0.00	171.80	0.00	91.70	103.40	0.00	118.47	418.00	221.87
May	182.13	0.00	202.37	0.00	19.50	210.37	0.00	139.65	404.00	350.02
June	107.36	0.00	17.32	101.94	0.00	135.50	82.33	0.00	207.00	237.44
July	0.00	106.26	79.92	38.05	134.08	0.00	0.00	81.49	214.00	225.80
August	0.00	81.29	47.42	42.85	102.58	0.00	0.00	62.34	150.00	186.48
Sept.	0.00	132.53	0.00	147.14	145.00	22.22	0.00	101.63	145.00	403.52
Oct.	0.00	97.91	108.72	0.00	41.28	82.28	0.00	75.08	150.00	255.28
Nov.	296.14	0.00	295.79	32.83	0.00	373.47	227.08	0.00	819.00	406.30
Dec.	266.29	0.00	295.47	0.00	80.06	255.74	204.19	0.00	846.00	255.74
Total	1339.36	644.68	1840.20	362.82	972.88	1530.37	828.55	692.81	4981.00	3230.68

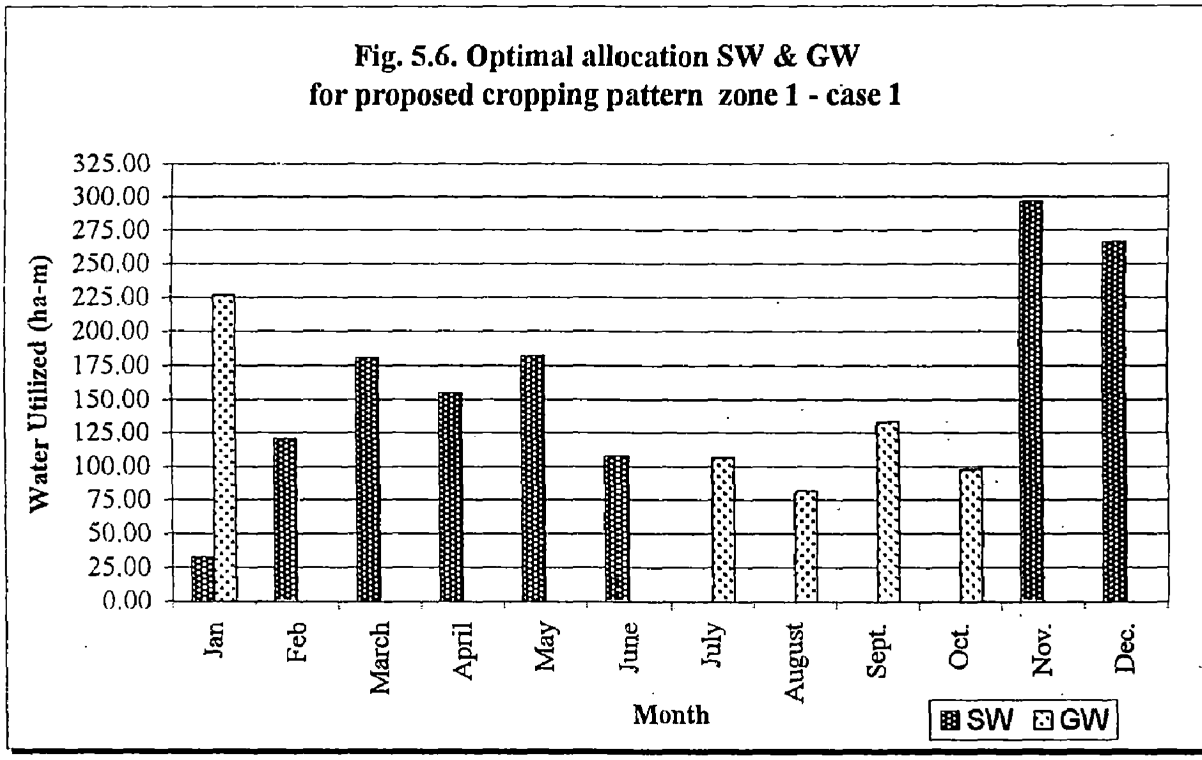


Fig. 5.6. Optimal allocation SW & GW
for proposed cropping pattern zone 1 - case 1
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

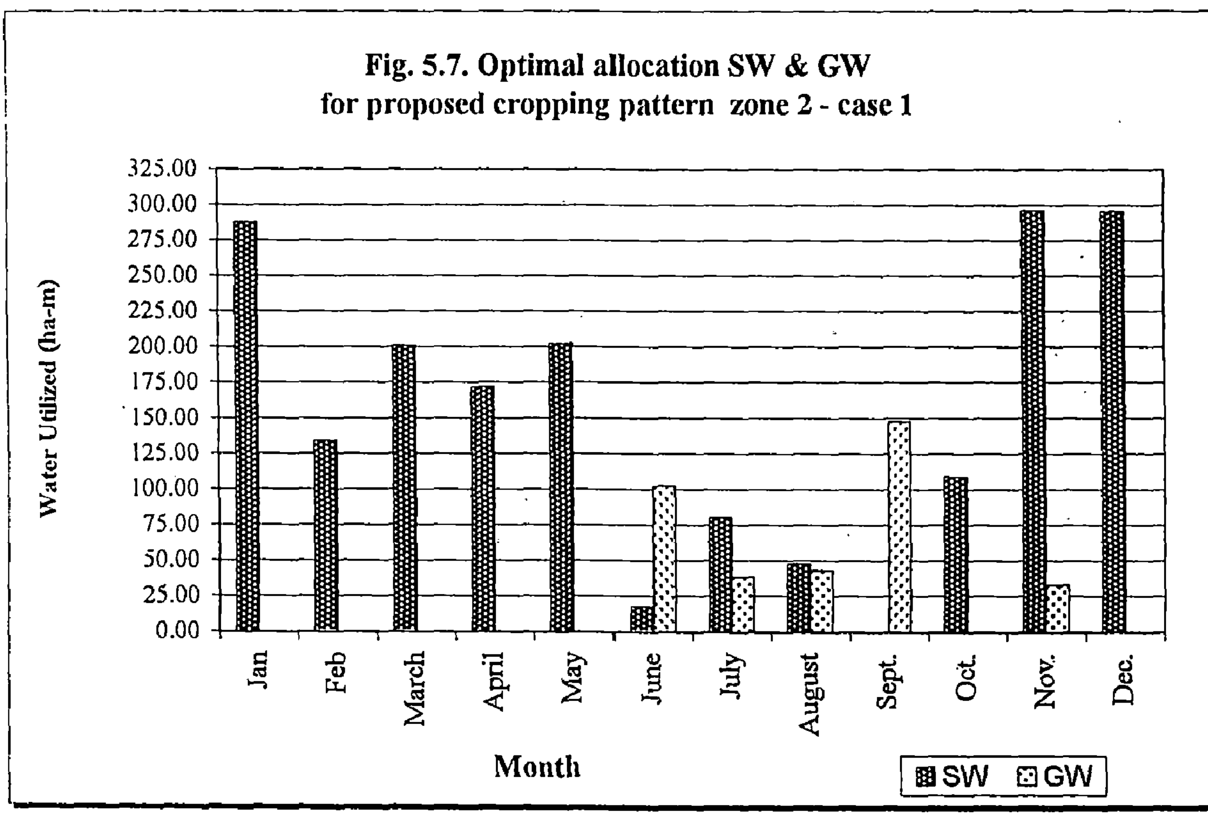


Fig. 5.7. Optimal allocation SW & GW
for proposed cropping pattern zone 2 - case 1
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

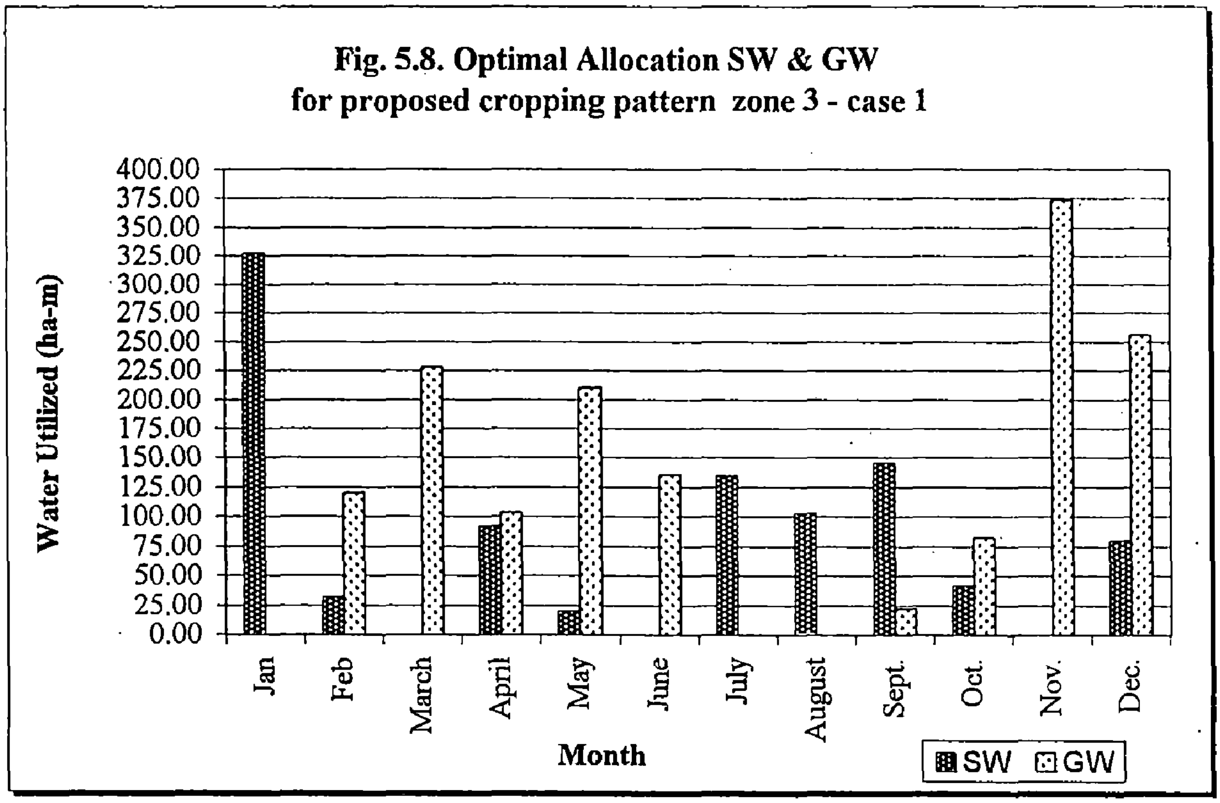


Fig. 5.8. Optimal Allocation SW & GW
for proposed cropping pattern zone 3 - case 1
Water Utilized (ha-m)
400.00
375.00
350.00
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

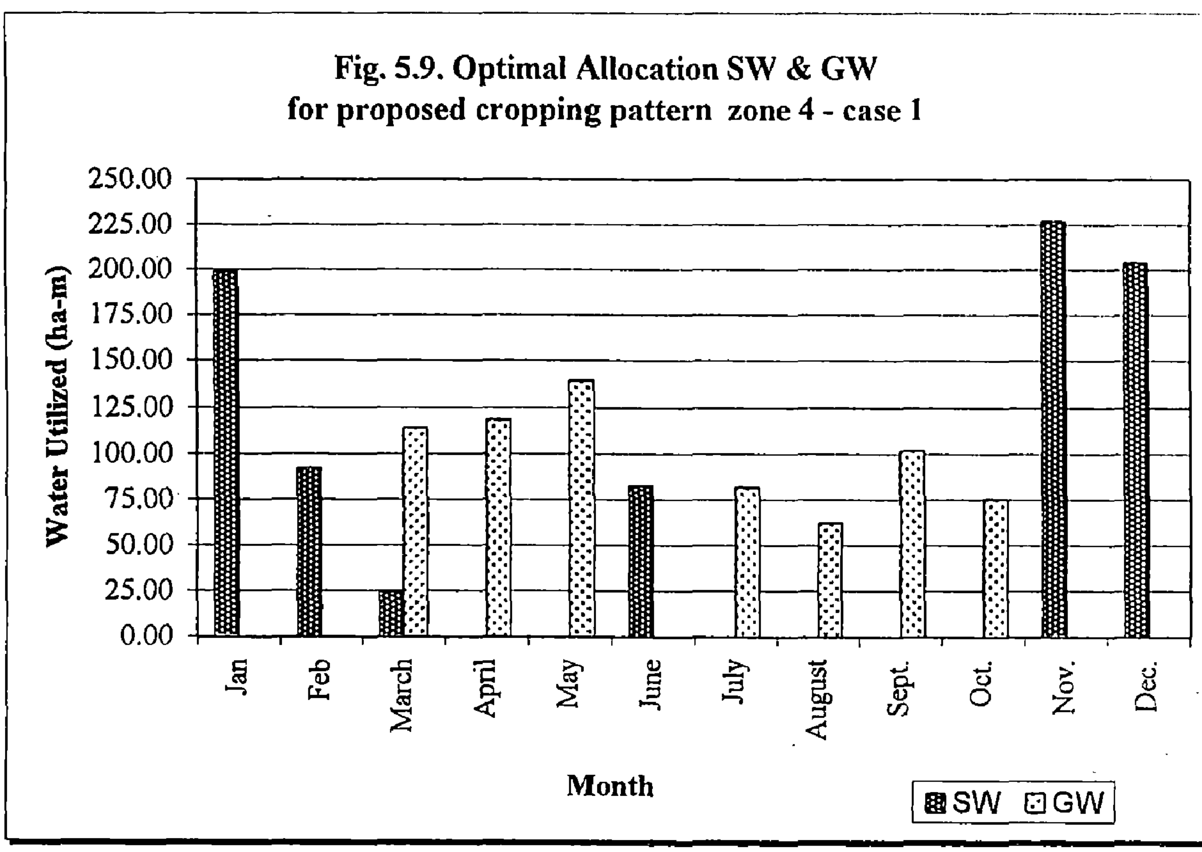


Fig. 5.9. Optimal Allocation SW & GW
for proposed cropping pattern zone 4 - case 1
Water Utilized (ha-m)
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

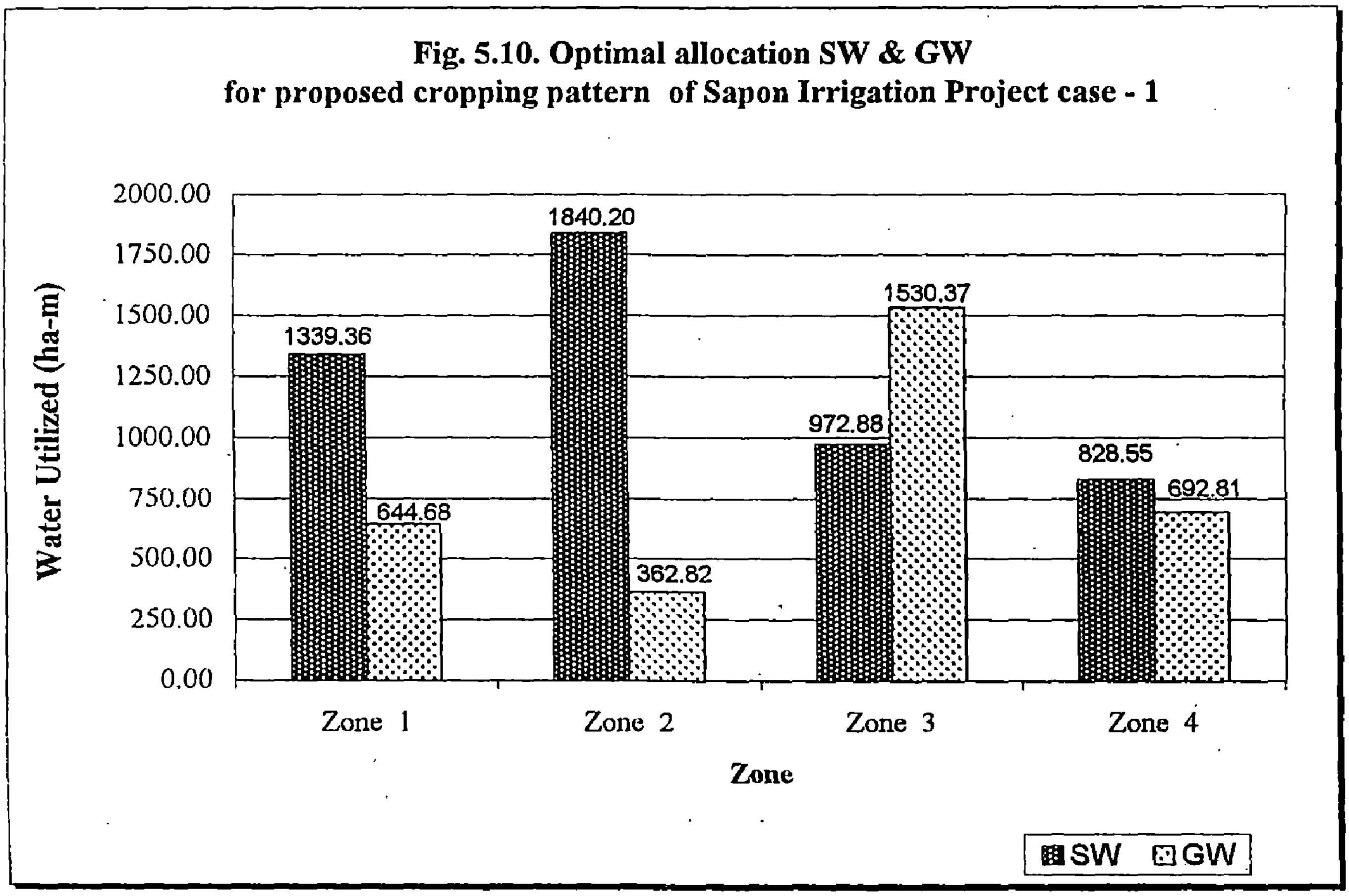


Fig. 5.10. Optimal allocation SW & GW
for proposed cropping pattern of Sapon Irrigation Project case - 1
Water Utilized (ha-m)
2000.00
1750.00
1500.00
1250.00
1000.00
750.00
500.00
250.00
0.00
1339.36
644.68
1840.20
362.82
972.88
1530.37
828.55
692.81
Zone 1
Zone 2
Zone 3
Zone 4
Zone
SW
GW

Table 5.3 Optimal Allocation of SW & GW for Case 2 Under Proposed Cropping Pattern, considering (Wet Season 70% area for paddy, and 10% area shift to each crop)

(1st Dry Season 25%, 30% and 15% optimal area under paddy, groundnut and other each crop respectively)

(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)

Net Benefit Rs. 99,514.550 millions

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy	832	923	1049	638	3442
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	132	150	91	491
Total	**1188**	**1319**	**1499**	**911**	
1st Dry Season					
Paddy	297	330	375	228	1230
Soybean	179	198	225	137	739
Mungbean	178	198	225	137	738
Maize	178	197	224	136	735
Groundnuts	356	396	450	273	1475
Total	**1188**	**1319**	**1499**	**911**	
2nd Dry Season					
Soybean	238	264	300	183	985
Mungbean	238	264	300	182	984
Maize	237	263	299	182	981
Groundnuts	475	528	600	364	1967
Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	32.56	226.68	287.69	0.00	326.96	0.00	198.78	0.00	846.00	226.68
Feb	120.02	0.00	133.22	0.00	31.73	119.67	92.03	0.00	377.00	119.67
March	173.65	0.00	192.84	0.00	38.51	180.64	0.00	133.21	405.00	313.85
April	139.47	8.86	164.74	0.00	0.00	187.21	113.79	0.00	418.00	196.07
May	0.00	177.71	197.32	0.00	70.37	153.87	136.30	0.00	404.00	331.58
June	0.00	106.88	118.68	0.00	6.35	128.52	81.96	0.00	207.00	235.40
July	106.26	0.00	107.74	10.24	0.00	134.08	0.00	81.49	214.00	225.80
August	0.00	81.29	0.00	90.27	102.58	0.00	47.42	14.92	150.00	186.48
Sept.	0.00	132.53	145.00	2.14	0.00	167.22	0.00	101.63	145.00	403.52
Oct.	0.00	97.91	108.72	0.00	41.28	82.28	0.00	75.08	150.00	255.28
Nov.	296.14	0.00	295.79	32.83	0.00	373.47	227.08	0.00	819.00	406.30
Dec.	266.29	0.00	295.47	0.00	80.06	255.74	204.19	0.00	846.00	255.74
Total	1134.39	831.87	2047.21	135.48	697.84	1782.70	1101.56	406.33	4981.00	3156.37

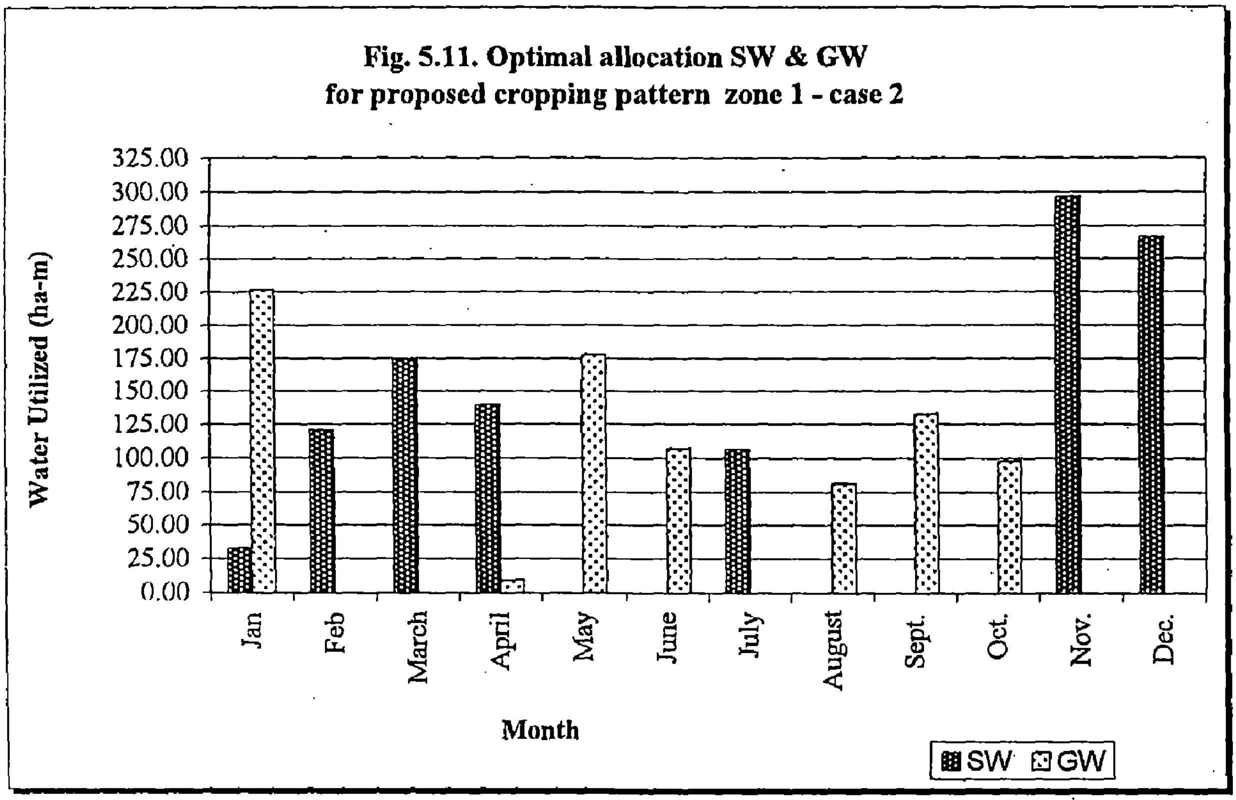


Fig. 5.11. Optimal allocation SW & GW
for proposed cropping pattern zone 1 - case 2
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

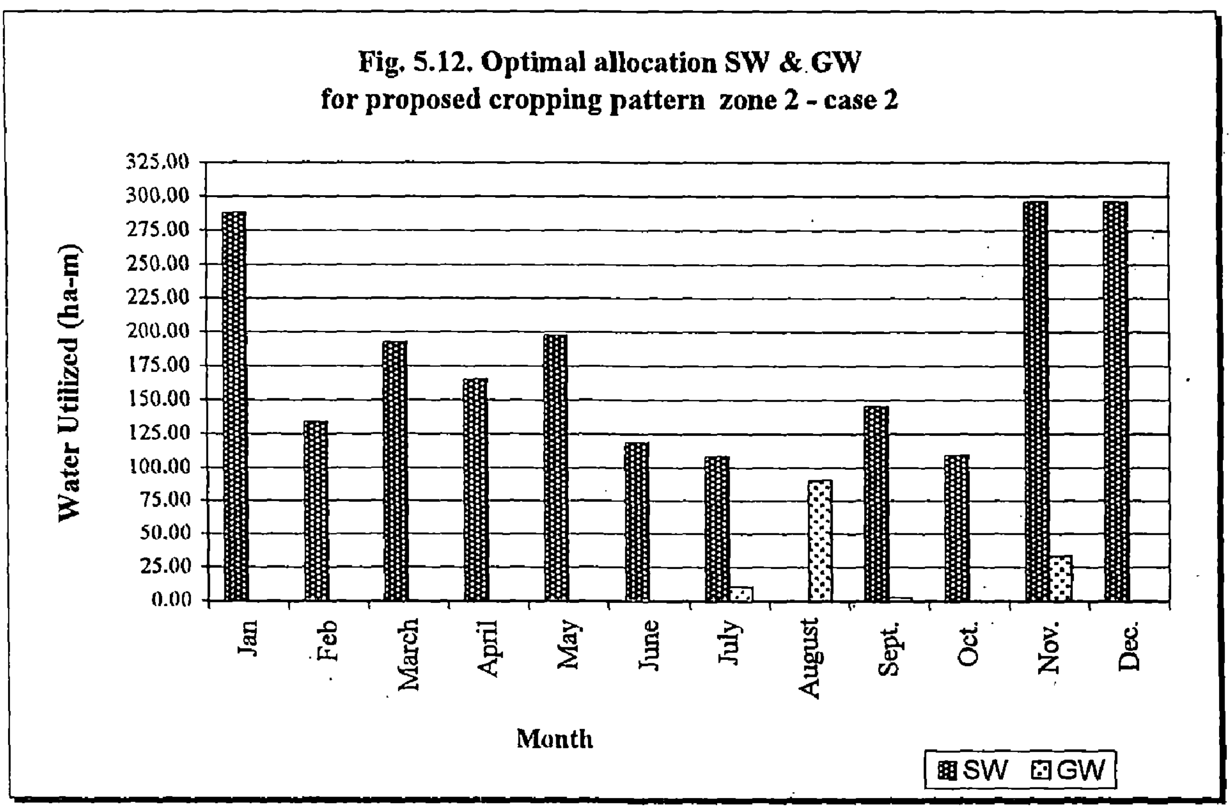


Fig. 5.12. Optimal allocation SW & GW
for proposed cropping pattern zone 2 - case 2
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

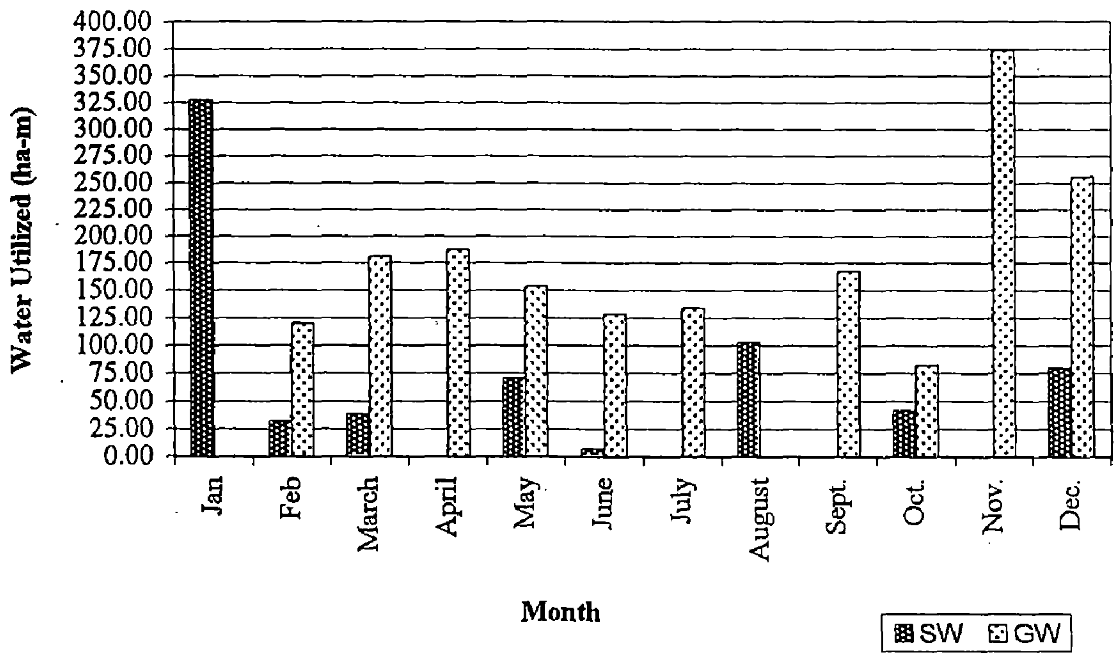


Fig. 5.13. Optimal allocation SW & GW for proposed cropping pattern zone 3 - case 2

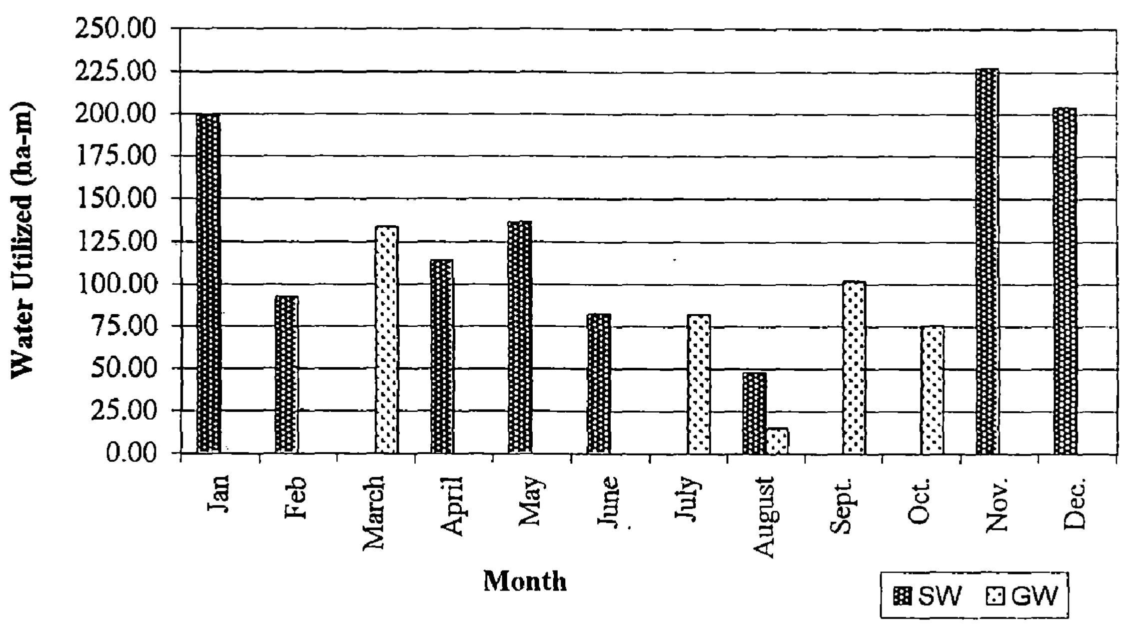


Fig. 5.14. Optimal allocation SW & GW for proposed cropping pattern zone 4 - case 2

Fig. 5.15. Optimal allocation SW & GW for proposed cropping pattern of Sapon Irrigation Project case - 2

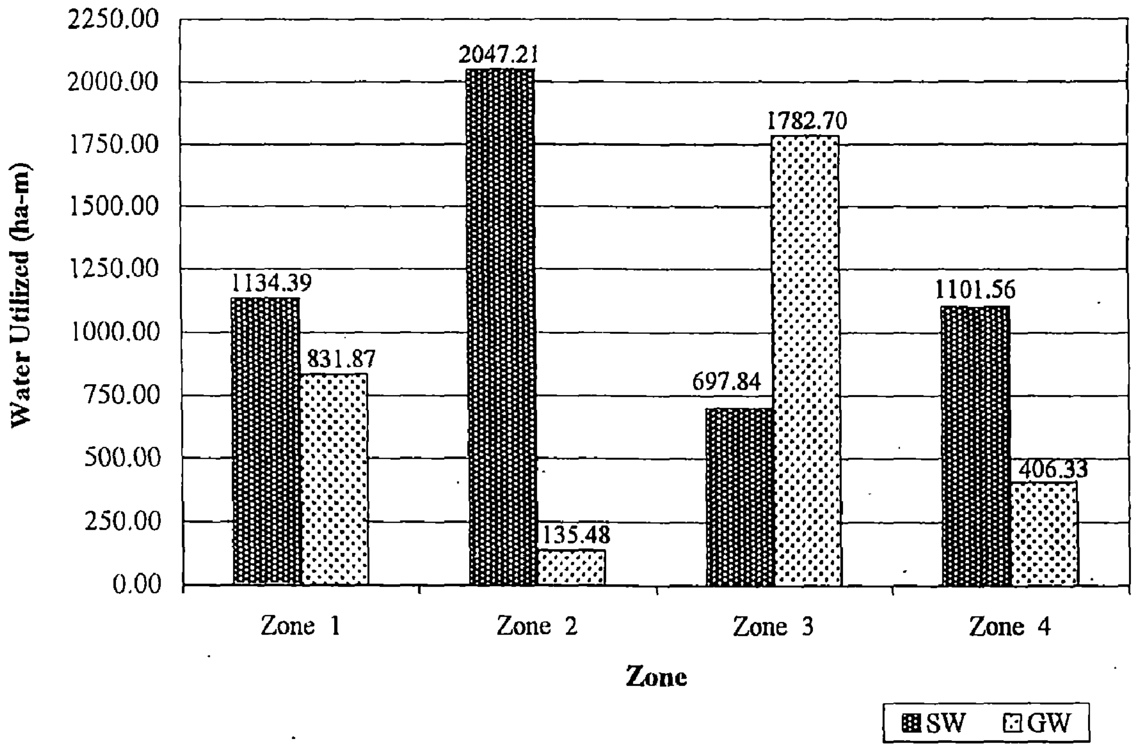


Table 5.4 Optimal Allocation of SW & GW for Case 3 Under Proposed Cropping Pattern considering
(Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 30%, 25% and 15% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)
Net Benefits Rs. 99,466.960 millions

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy	832	923	1049	638	3442
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	132	150	91	491
Total	**1188**	**1319**	**1499**	**911**	
1st Dry Season					
Paddy	356	396	450	273	1475
Soybean	179	198	225	137	739
Mungbean	178	198	225	137	738
Maize	178	197	224	136	735
Groundnuts	297	330	375	228	1230
Total	**1188**	**1319**	**1499**	**911**	
2nd Dry Season					
Soybean	238	264	300	183	985
Mungbean	238	264	300	182	984
Maize	237	263	299	182	981
Groundnuts	475	528	600	364	1967
Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	32.56	226.68	287.69	0.00	326.96	0.00	198.78	0.00	846.00	226.68
Feb	120.02	0.00	133.22	0.00	31.73	119.67	92.03	0.00	377.00	119.67
March	187.32	0.00	208.13	0.00	0.00	236.52	9.56	134.08	405.00	370.60
April	35.87	125.08	178.86	0.00	203.26	0.00	0.00	123.42	418.00	248.50
May	186.73	0.00	207.41	0.00	9.85	225.86	0.00	143.18	404.00	369.04
June	0.00	107.91	0.00	119.84	136.19	0.00	70.81	11.94	207.00	239.69
July	106.26	0.00	107.74	10.24	0.00	134.08	0.00	81.49	214.00	225.80
August	0.00	81.29	0.00	90.27	102.58	0.00	47.42	14.92	150.00	186.48
Sept.	0.00	132.53	0.00	147.14	145.00	22.22	0.00	101.63	145.00	403.52
Oct.	0.00	97.91	108.72	0.00	41.28	82.28	0.00	75.08	150.00	255.28
Nov.	0.00	296.14	218.45	110.16	373.47	0.00	227.08	0.00	819.00	406.30
Dec.	266.29	0.00	295.47	0.00	80.06	255.74	204.19	0.00	846.00	255.74
Total	935.06	1067.54	1745.69	477.65	1450.38	1076.36	849.87	685.74	4981.00	3307.29

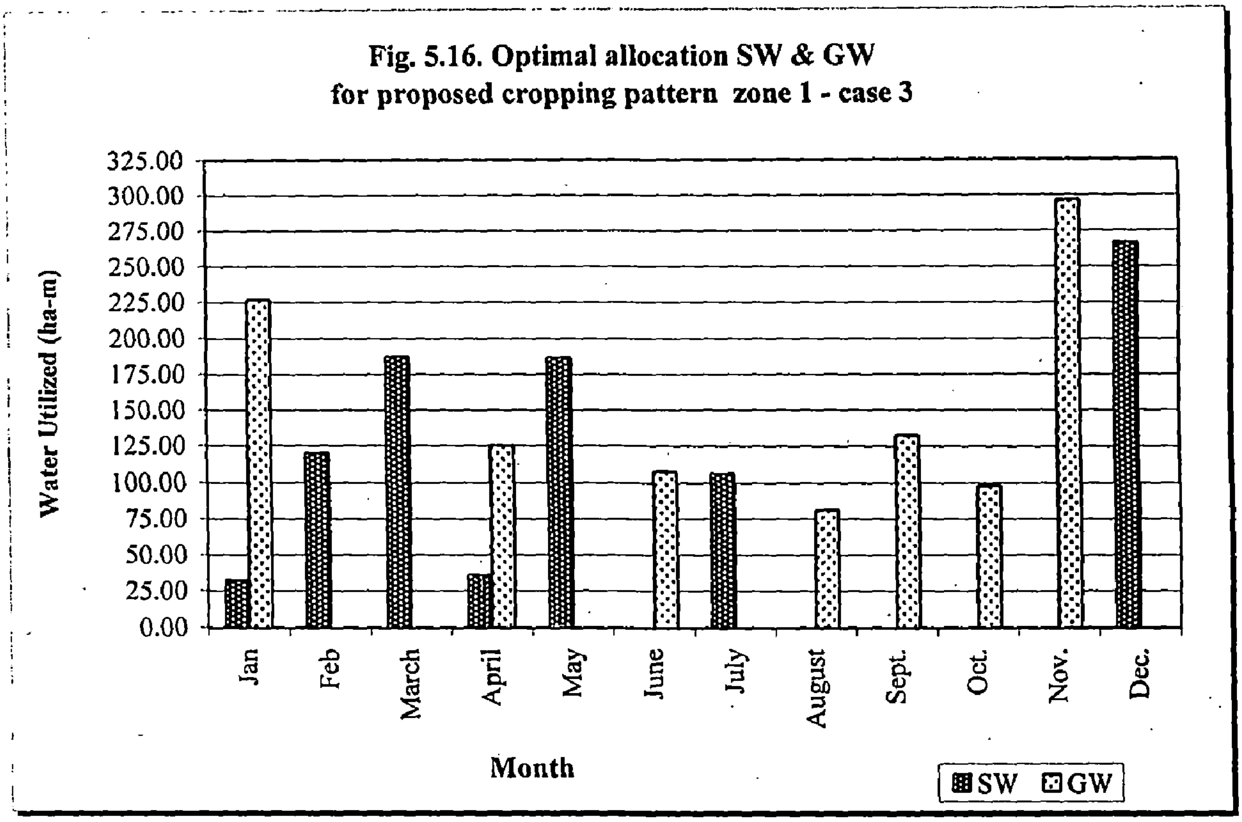


Fig. 5.16. Optimal allocation SW & GW
for proposed cropping pattern zone 1 - case 3
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

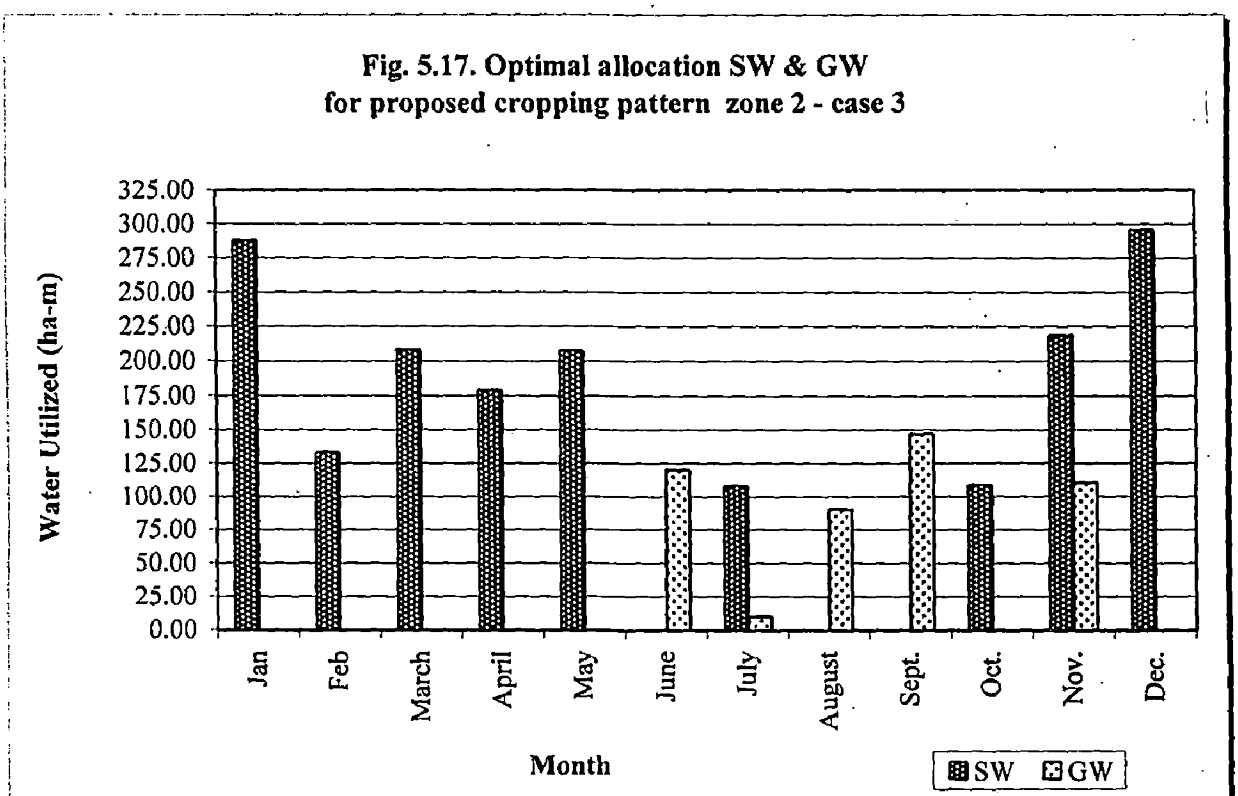


Fig. 5.17. Optimal allocation SW & GW
for proposed cropping pattern zone 2 - case 3
Water Utilized (ha-m)
325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Jan
Feb
March
April
May
June
July
August
Sept.
Oct.
Nov.
Dec.
Month
SW
GW

Fig. 5.18. Optimal allocation SW & GW for proposed cropping pattern zone 3 - case 3

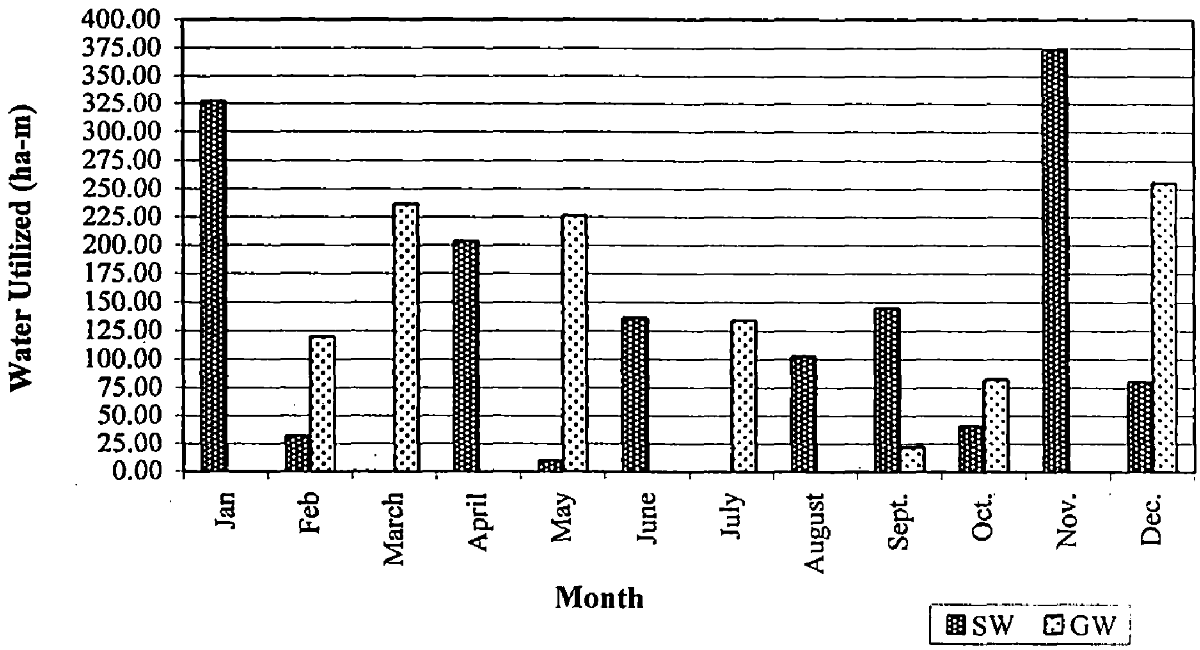


Fig. 5.19. Optimal allocation SW & GW for proposed cropping pattern zone 4 - case 3

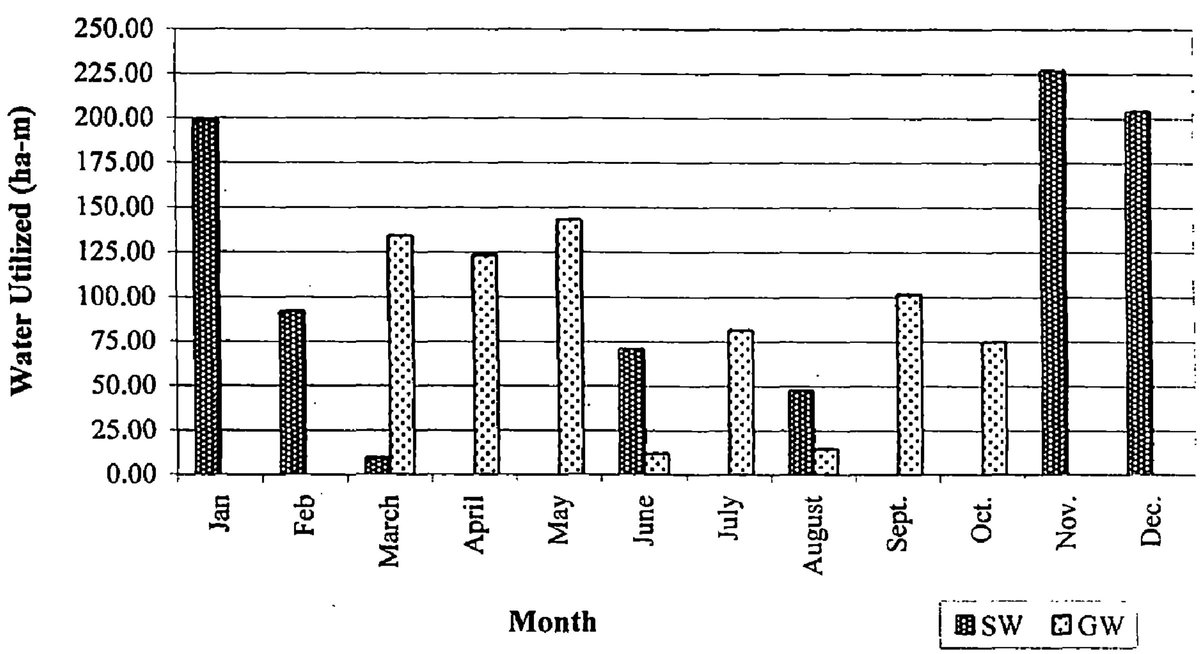


Fig. 5.20. Optimal allocation SW & GW for proposed cropping pattern of Sapon Irrigation Project case -3

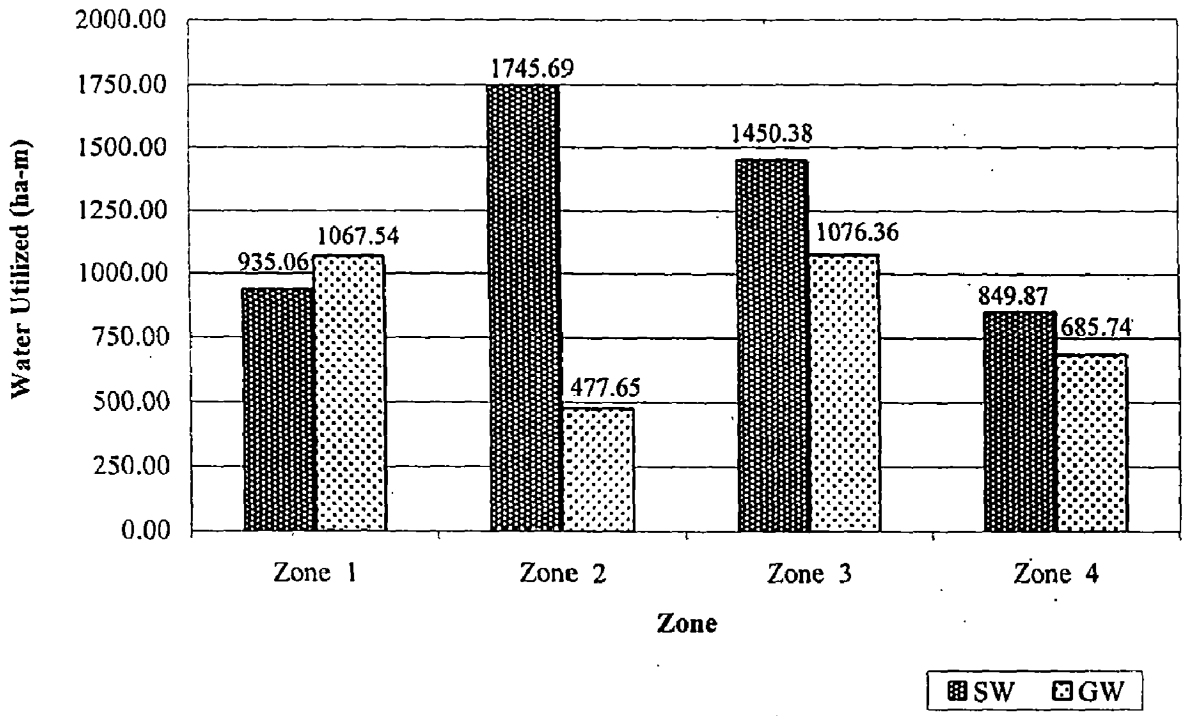


Table 5.5 Optimal Allocation of SW & GW for Case 4 Under Proposed Cropping Pattern considering (Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 35%, 35% and 10% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)
Net Benefits Rs. 100,839.600 millions

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy	800	923	1049	638	3410
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	132	150	91	491
Total	**1156**	**1319**	**1499**	**911**	
1st Dry Season					
Paddy	416	396	525	319	1656
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	131	149	91	489
Groundnuts	416	462	525	319	1722
Total	**1188**	**1253**	**1499**	**911**	
2nd Dry Season					
Soybean	238	264	300	183	985
Mungbean	238	264	300	182	984
Maize	237	263	299	182	981
Groundnuts	475	528	600	364	1967
Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	32.56	218.00	287.69	0.00	326.96	0.00	198.78	0.00	846.00	218.00
Feb	0.35	115.97	133.22	0.00	151.40	0.00	92.03	0.00	377.00	115.97
March	0.00	199.79	152.89	68.96	252.11	0.00	0.00	153.20	405.00	421.95
April	177.27	0.00	196.84	0.00	43.89	179.80	0.00	135.92	418.00	315.72
May	195.64	0.00	208.36	8.86	0.00	246.86	0.00	150.00	404.00	405.73
June	0.00	112.74	120.55	4.63	0.00	142.26	86.45	0.00	207.00	259.62
July	14.54	91.73	117.98	0.00	0.00	134.08	81.49	0.00	214.00	225.80
August	81.29	0.00	6.37	83.89	0.00	102.58	62.34	0.00	150.00	186.48
Sept.	132.53	0.00	0.00	147.14	0.00	167.22	12.47	89.16	145.00	403.52
Oct.	0.00	97.91	0.00	108.72	74.92	48.64	75.08	0.00	150.00	255.28
Nov.	116.92	168.80	328.61	0.00	373.47	0.00	0.00	227.08	819.00	395.88
Dec.	256.61	0.00	295.47	0.00	293.93	41.87	0.00	204.19	846.00	246.06
Total	1007.69	1004.94	1847.99	422.21	1516.68	1063.30	608.64	959.55	4981.00	3450.00

Fig. 5.21. Optimal allocation SW & GW
for proposed cropping pattern zone 1 - case 4

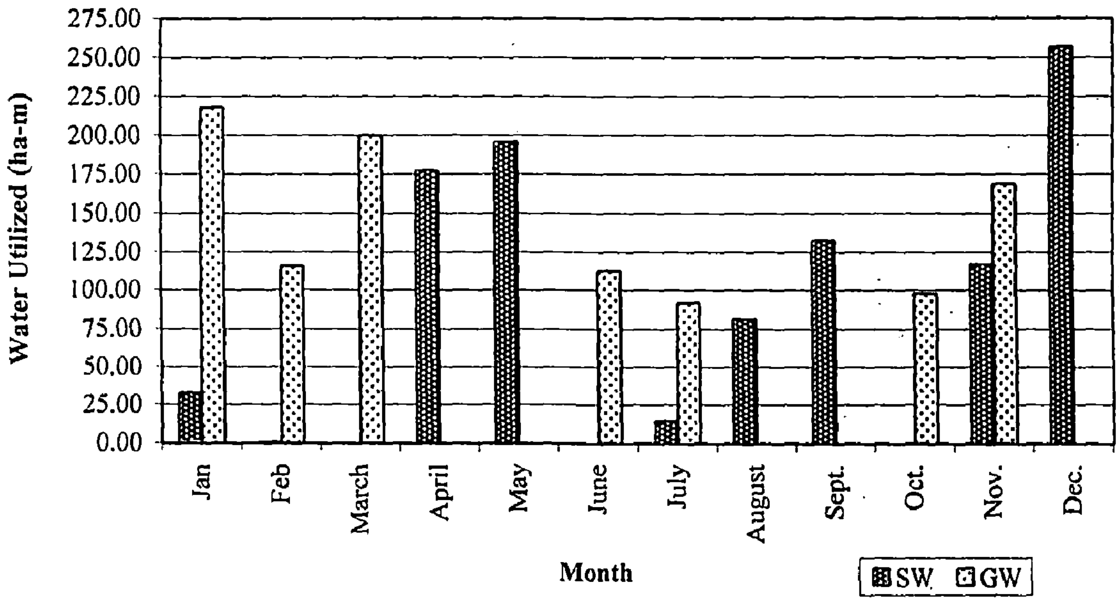


Fig. 5.22. Optimal allocation SW & GW
for proposed cropping pattern zone 2 - case 4

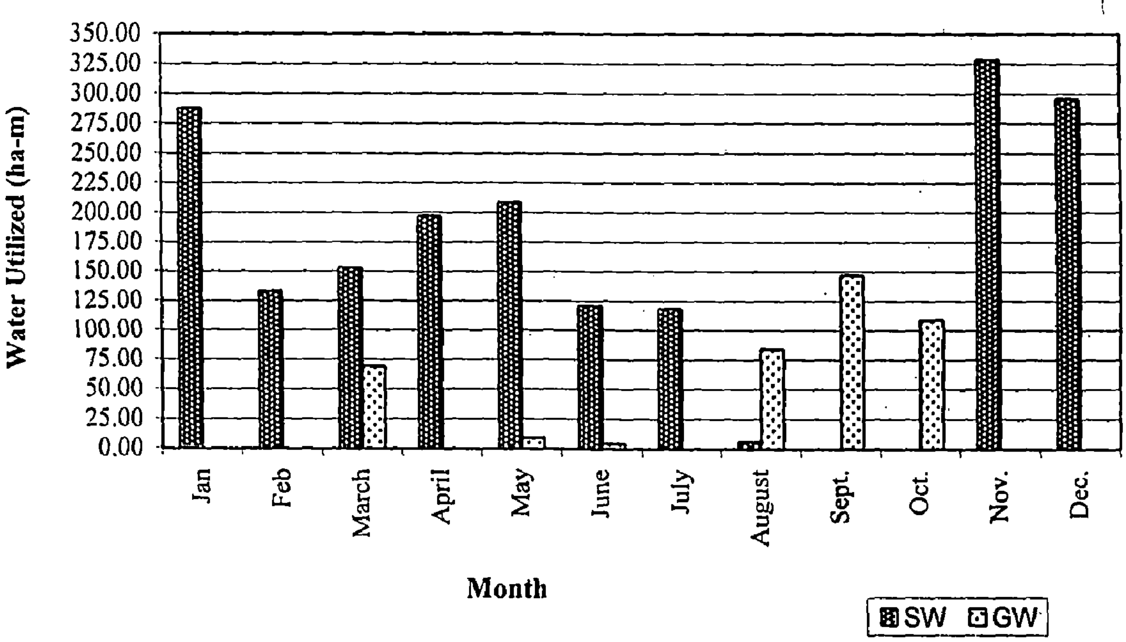


Fig. 5.23. Optimal allocation SW & GW for proposed cropping pattern zone 3 - case 4

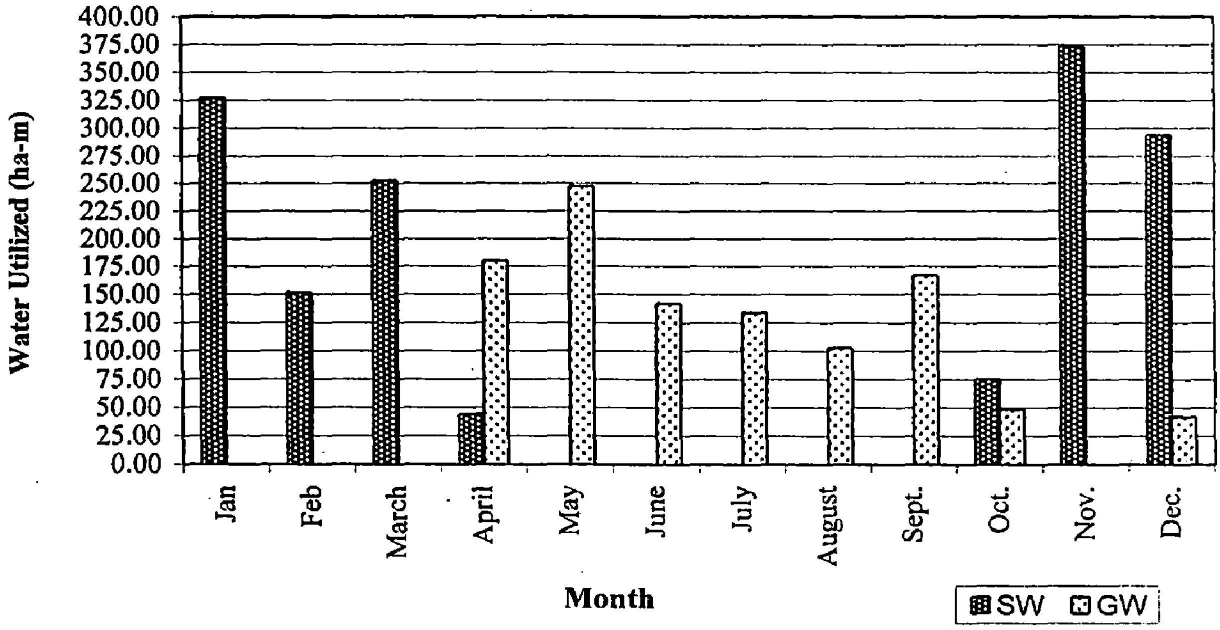
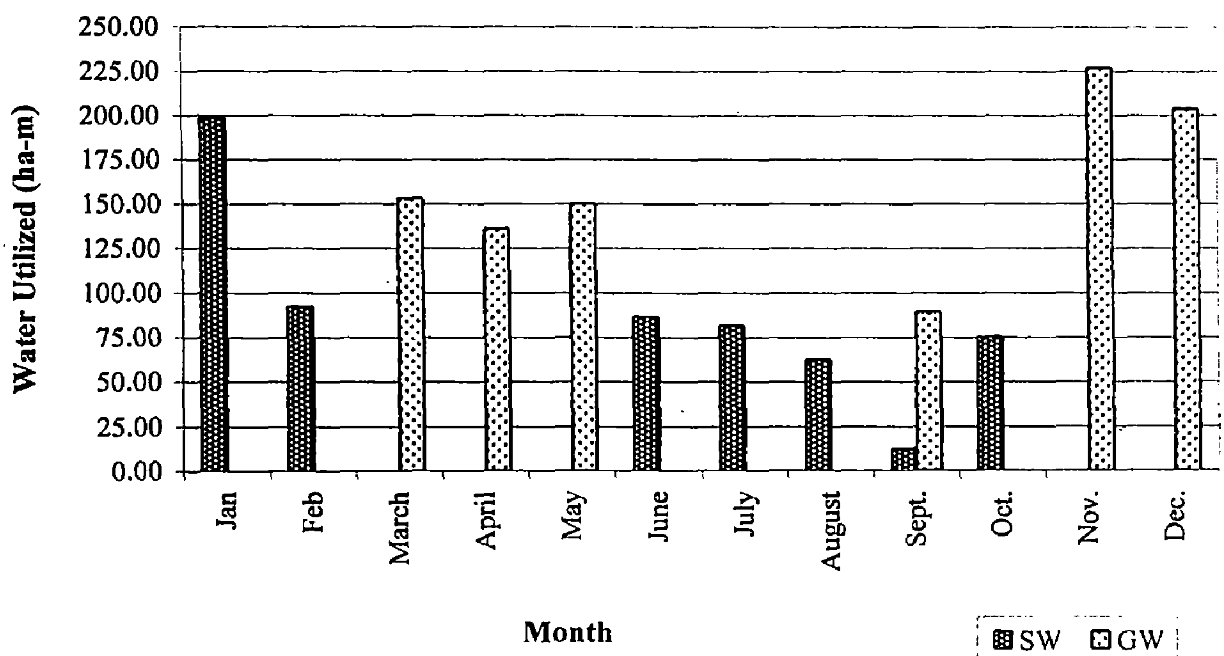


Fig. 5.24. Optimal allocation SW & GW for proposed cropping pattern zone 4 - case 4



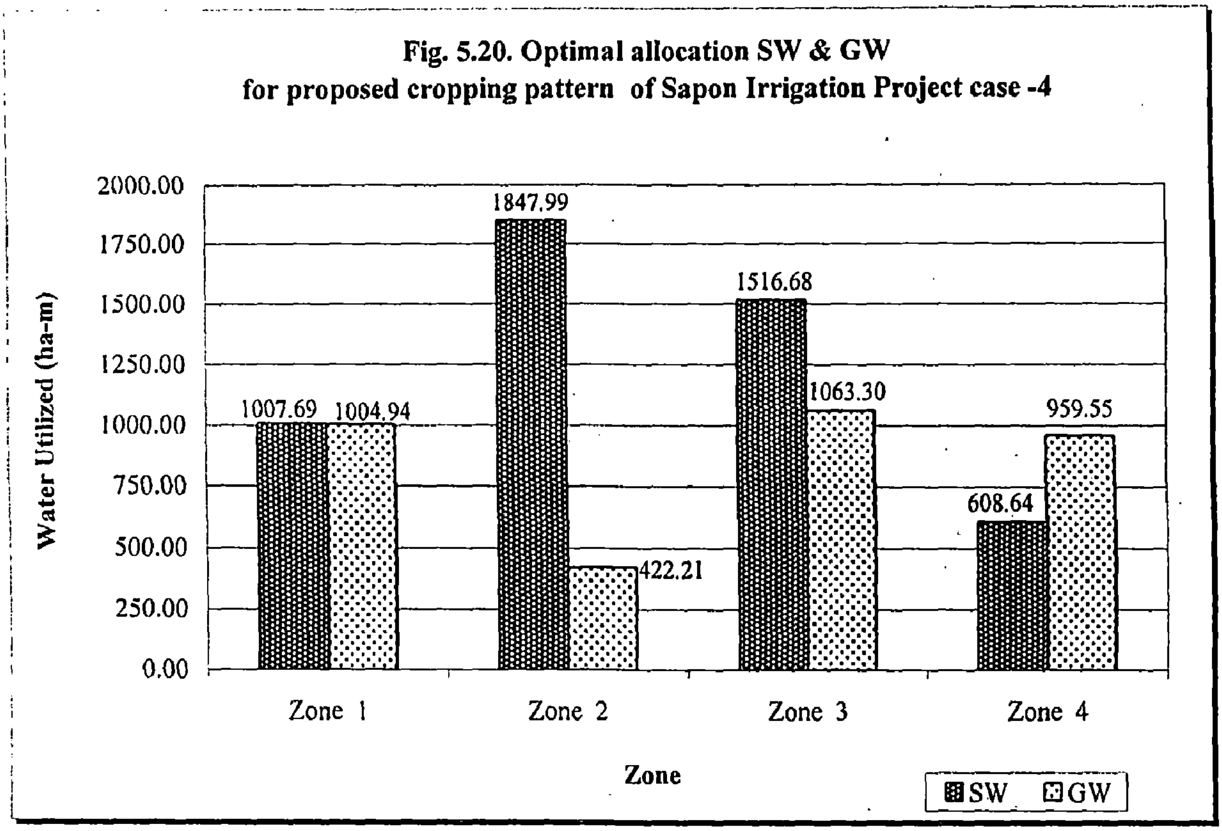


Fig. 5.20. Optimal allocation SW & GW
for proposed cropping pattern of Sapon Irrigation Project case -4
Water Utilized (ha-m)
2000.00
1750.00
1500.00
1250.00
1000.00
750.00
500.00
250.00
0.00
1847.99
1516.68
1063.30
1007.69
1004.94
959.55
608.64
422.21
Zone 1
Zone 2
Zone 3
Zone 4
Zone
SW
GW

Table 5.6 Optimal Allocation of SW & GW for Case 5 Under Proposed Cropping Pattern considering (Wet Season 70% area for paddy, and 10% area shift to each crop)

(1st Dry Season 30%, 40% and 10% optimal area under paddy, groundnut and other each crop respectively)

(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop);

Net Benefits Rs. 101,115.300 millions

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy	832	923	1049	638	3442
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	132	150	91	491
Total	**1188**	**1319**	**1499**	**911**	
1st Dry Season					
Paddy	356	396	450	273	1475
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	131	149	91	489
Groundnuts	475	528	600	365	1968
Total	**1187**	**1319**	**1499**	**911**	
2nd Dry Season					
Soybean	238	264	300	183	985
Mungbean	238	264	300	182	984
Maize	237	263	299	182	981
Groundnuts	475	528	600	364	1967
Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	32.56	226.68	287.69	0.00	326.96	0.00	198.78	0.00	846.00	226.68
Feb	120.02	0.00	133.22	0.00	31.73	119.67	92.03	0.00	377.00	119.67
March	185.81	0.00	206.56	0.00	12.63	222.11	0.00	142.55	405.00	364.66
April	109.20	55.14	182.72	0.00	0.00	207.64	126.08	0.00	418.00	262.78
May	0.00	186.35	207.14	0.00	196.86	38.53	0.00	142.97	404.00	367.85
June	0.00	111.59	124.02	0.00	82.98	57.97	0.00	85.64	207.00	255.20
July	0.00	106.26	117.98	0.00	96.02	38.05	0.00	81.49	214.00	225.80
August	81.29	0.00	0.00	90.27	68.71	33.87	0.00	62.34	150.00	186.48
Sept.	0.00	132.53	145.00	2.14	0.00	167.22	0.00	101.63	145.00	403.52
Oct.	0.00	97.91	26.44	82.28	123.56	0.00	0.00	75.08	150.00	255.28
Nov.	296.14	0.00	295.79	32.83	0.00	373.47	227.08	0.00	819.00	406.30
Dec.	10.55	255.74	295.47	0.00	335.80	0.00	204.19	0.00	846.00	255.74
Total	835.57	1172.22	2022.02	207.52	1275.25	1258.53	848.16	691.69	4981.00	3329.96

Fig. 5.26. Optimal allocation SW & GW for proposed cropping pattern zone 1 - case 5

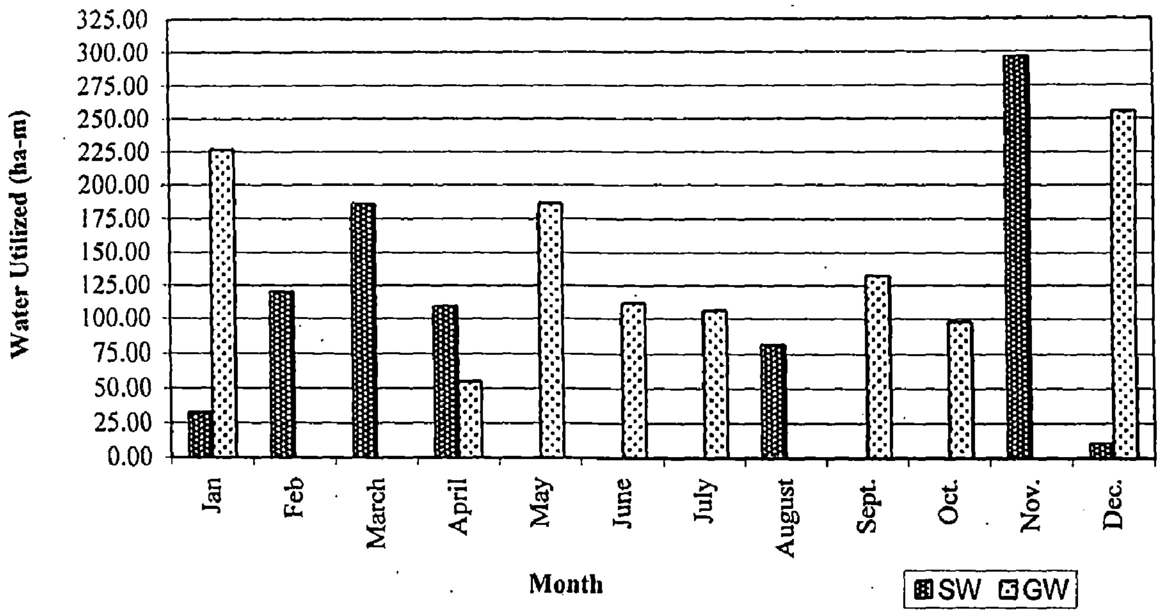


Fig. 5.27. Optimal allocation SW & GW for proposed cropping pattern zone 2 - case 5

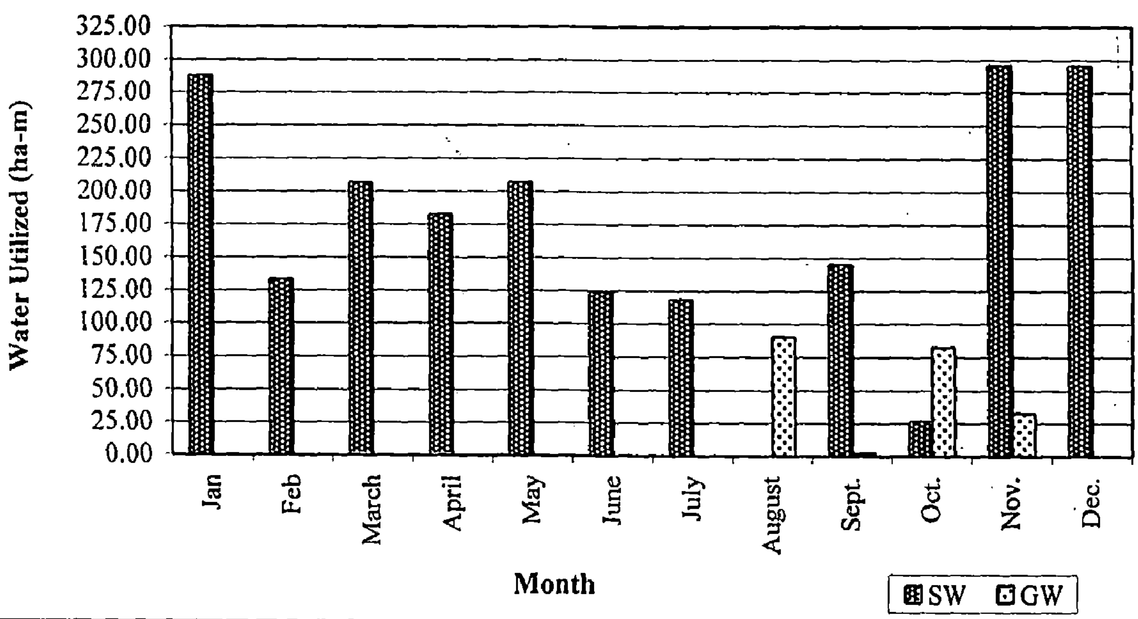


Fig. 5.28. Optimal allocation SW & GW
for proposed cropping pattern zone 3 - case 5

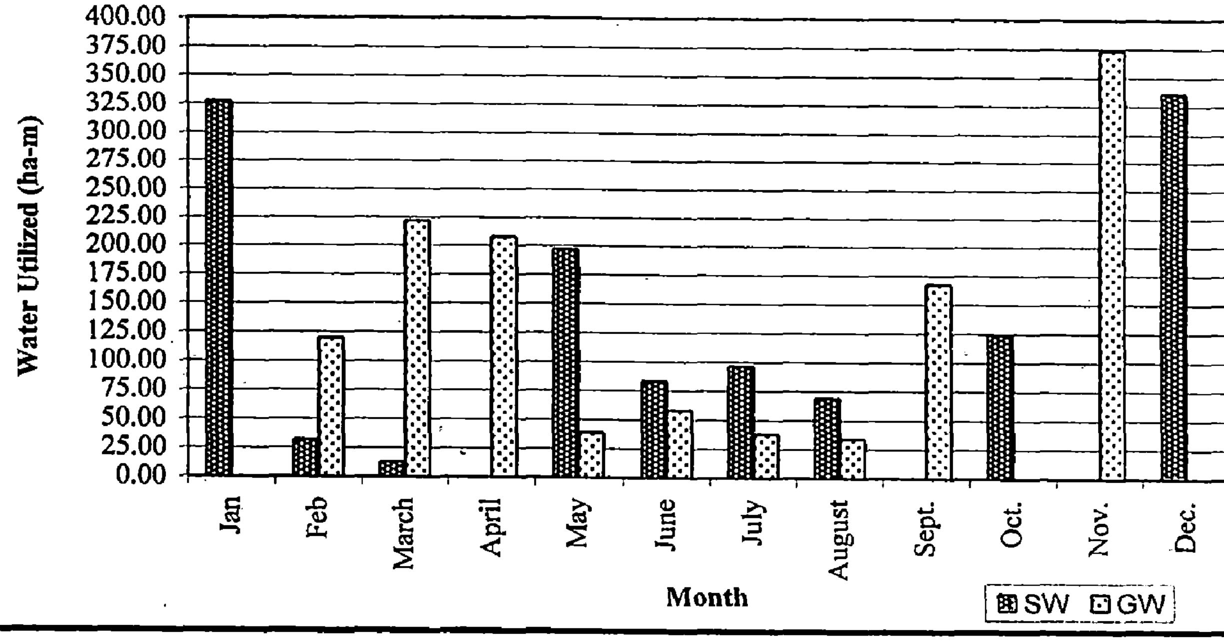


Fig. 5.29. Optimal allocation SW & GW
for proposed cropping pattern zone 4 - case 5

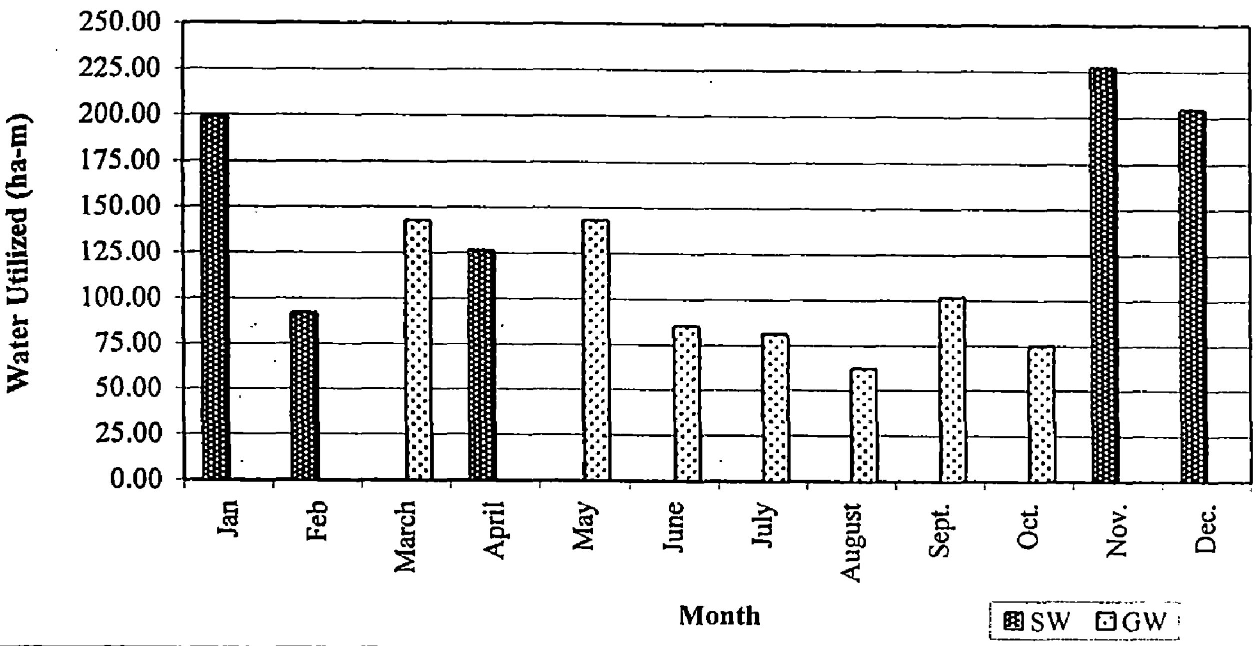


Fig. 5.30. Optimal allocation SW & GW for proposed cropping pattern of Sapon Irrigation Project case -5

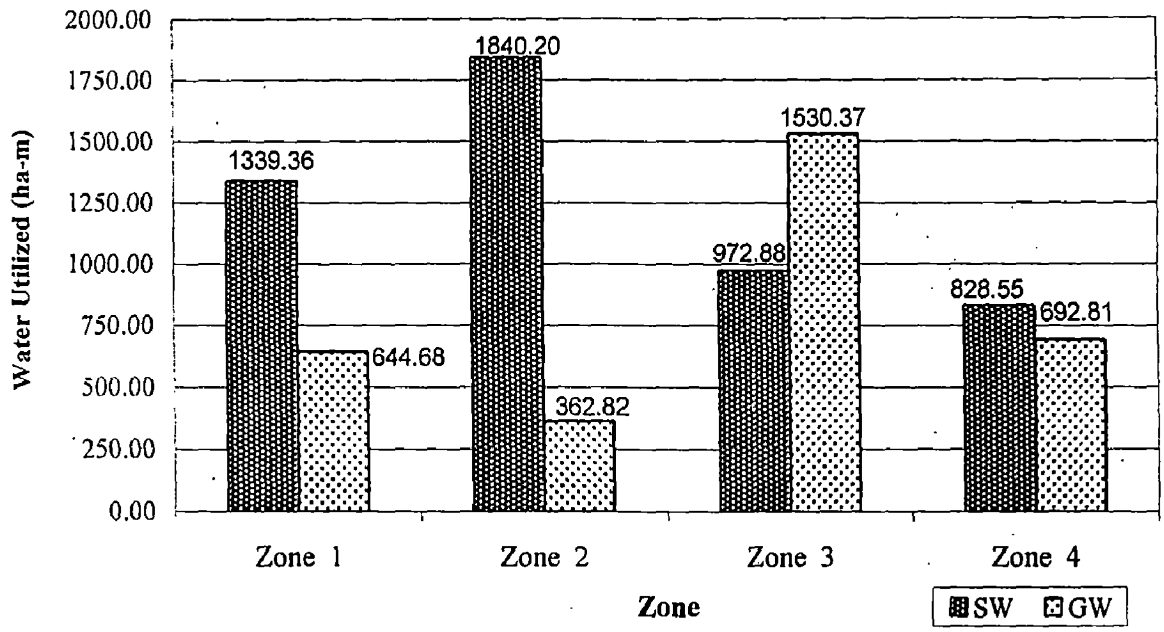


Table 5.7 Optimal Allocation of SW & GW for Case 6 Under Proposed Cropping Pattern considering
(Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 40%, 30% and 10% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)
Net Benefits Rs. 99,690.330 millions

Season / Crops	Zone 1 (ha)	Zone 2 (ha)	Zone 3 (ha)	Zone 4 (ha)	Total
Wet Season					
Paddy	832	923	1049	452	3256
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	132	150	91	491
Total	**1188**	**1319**	**1499**	**725**	
1st Dry Season					
Paddy	475	528	600	365	1968
Soybean	119	132	150	91	492
Mungbean	119	132	150	91	492
Maize	118	131	149	91	489
Groundnuts	356	396	450	273	1475
Total	**1187**	**1319**	**1499**	**911**	
2nd Dry Season					
Soybean	238	264	300	183	985
Mungbean	238	264	300	182	984
Maize	237	263	299	182	981
Groundnuts	475	528	600	364	1967
Total	**1188**	**1319**	**1499**	**911**	

Month	Water Utilised in ha - m								Total	
	Zone 1		Zone 2		Zone 3		Zone 4			
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Jan	81.63	177.61	287.69	0.00	326.96	0.00	149.71	0.00	846.00	177.61
Feb	120.02	0.00	133.22	0.00	52.69	98.71	71.07	0.00	377.00	98.71
March	0.00	213.37	237.13	0.00	4.01	265.47	163.85	0.00	405.00	478.84
April	0.00	189.81	210.97	0.00	207.03	32.71	0.00	145.77	418.00	368.29
May	0.00	204.55	227.32	0.00	176.68	81.65	0.00	157.04	404.00	443.23
June	0.00	113.68	119.75	6.59	0.00	143.57	87.25	0.00	207.00	263.83
July	14.54	91.73	117.98	0.00	0.00	134.08	81.49	0.00	214.00	225.80
August	59.73	21.56	90.27	0.00	0.00	102.58	0.00	62.34	150.00	186.48
Sept.	0.00	132.53	43.37	103.77	0.00	167.22	101.63	0.00	145.00	403.52
Oct.	26.44	71.47	0.00	108.72	123.56	0.00	0.00	75.08	150.00	255.28
Nov.	0.00	296.14	277.33	51.28	373.47	0.00	168.20	0.00	819.00	347.42
Dec.	266.29	0.00	295.47	0.00	134.80	200.99	149.44	0.00	846.00	200.99
Total	568.65	1512.44	2040.49	270.36	1399.21	1226.97	972.65	440.23	4981.00	3450.00

Fig. 5.31. Optimal allocation SW & GW
for proposed cropping pattern zone 1 - case 6

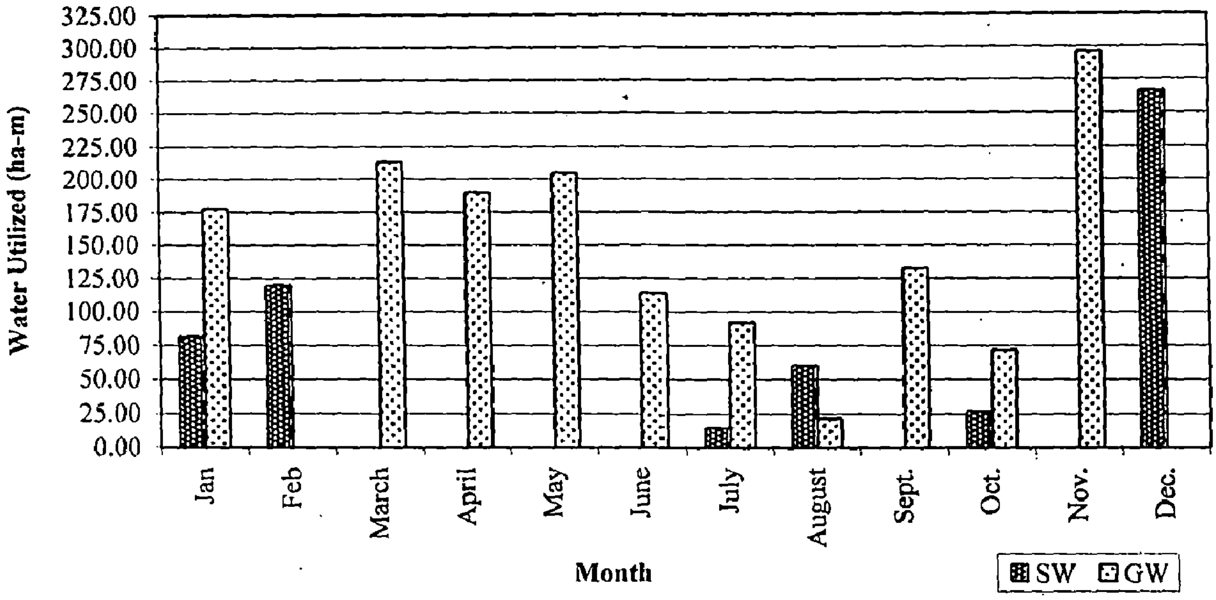


Fig. 5.32. Optimal allocation SW & GW
for proposed cropping pattern zone 2 - case 6

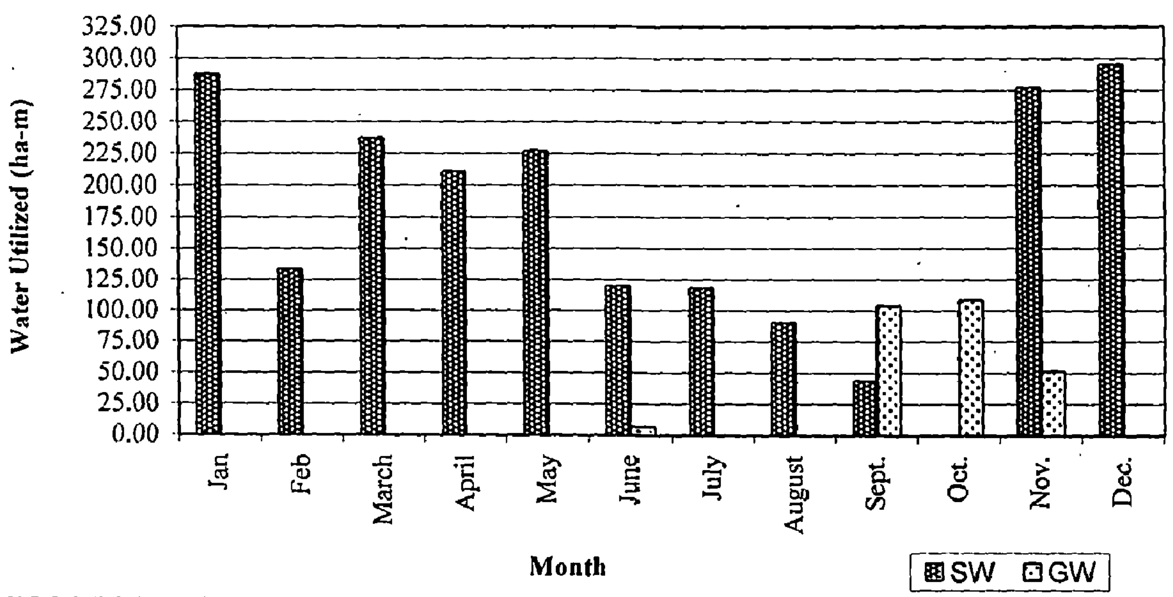


Fig. 5.33. Optimal allocation SW & GW for proposed cropping pattern zone 3 - case 6

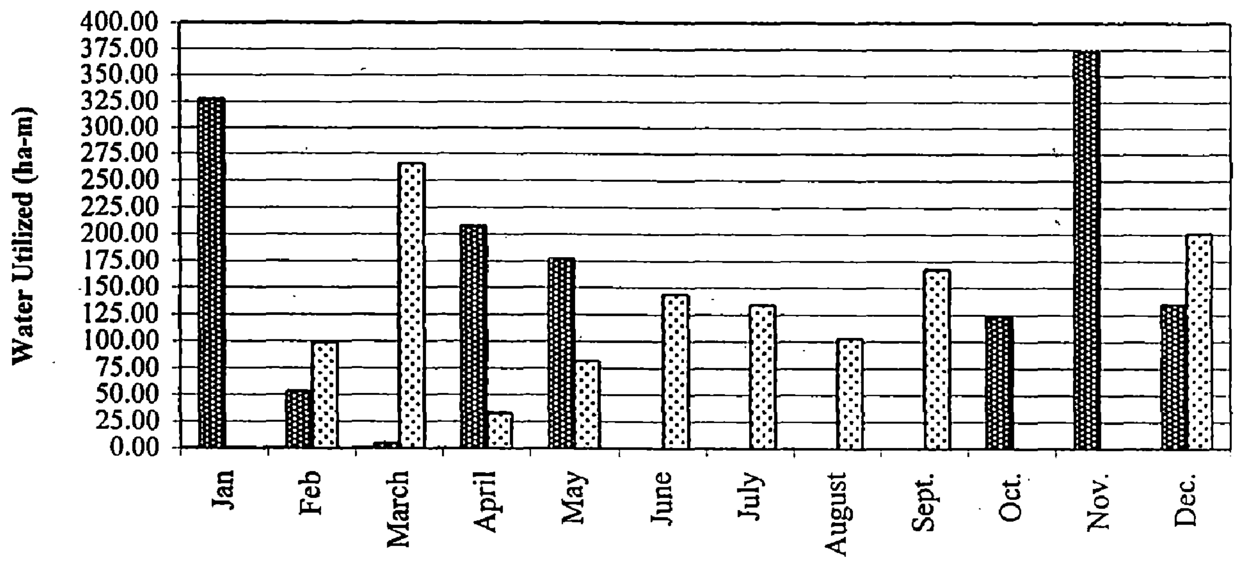
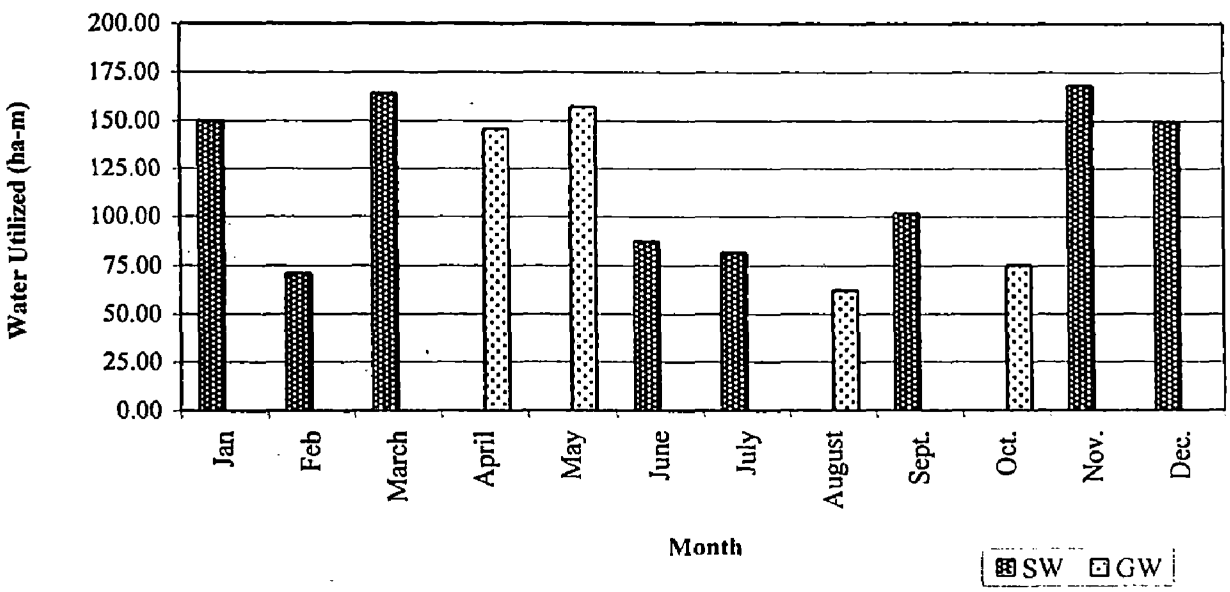


Fig. 5.34. Optimal allocation SW & GW for proposed cropping pattern zone 4 - case 6



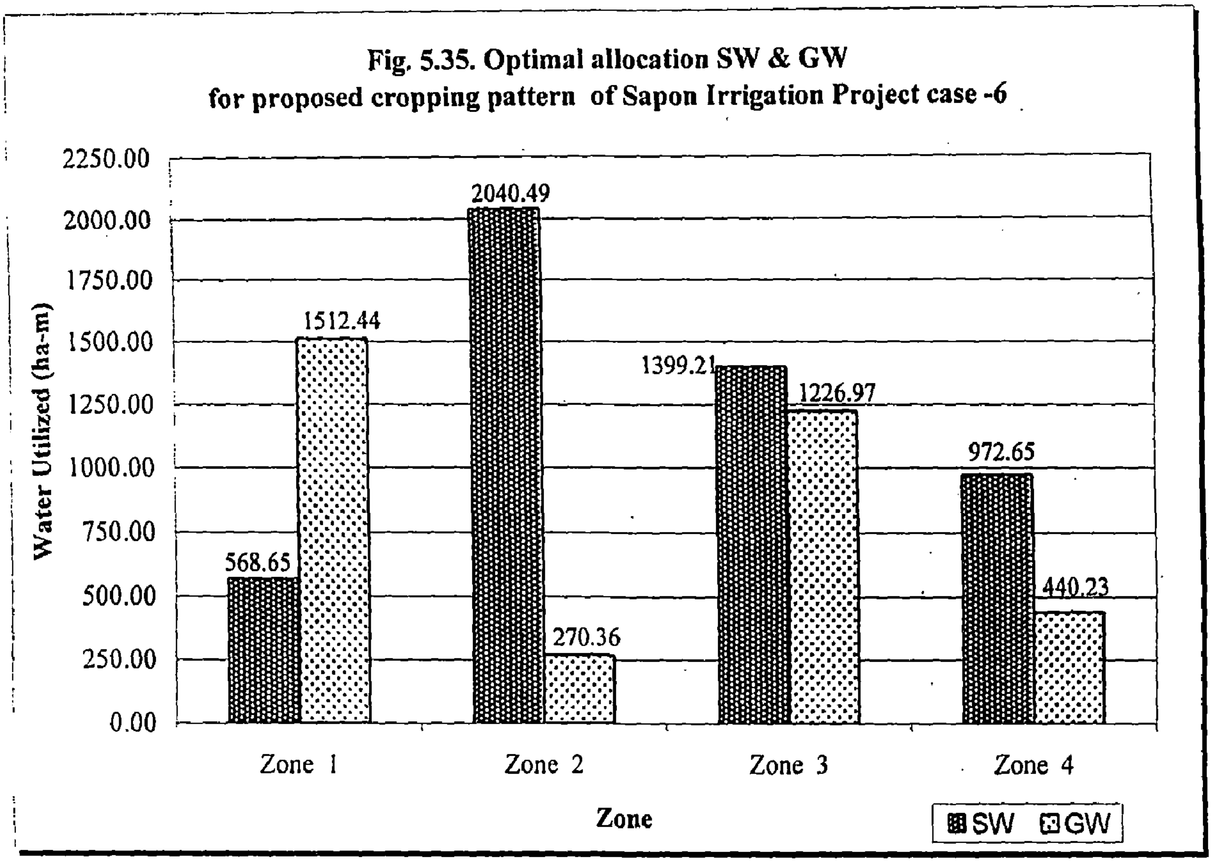
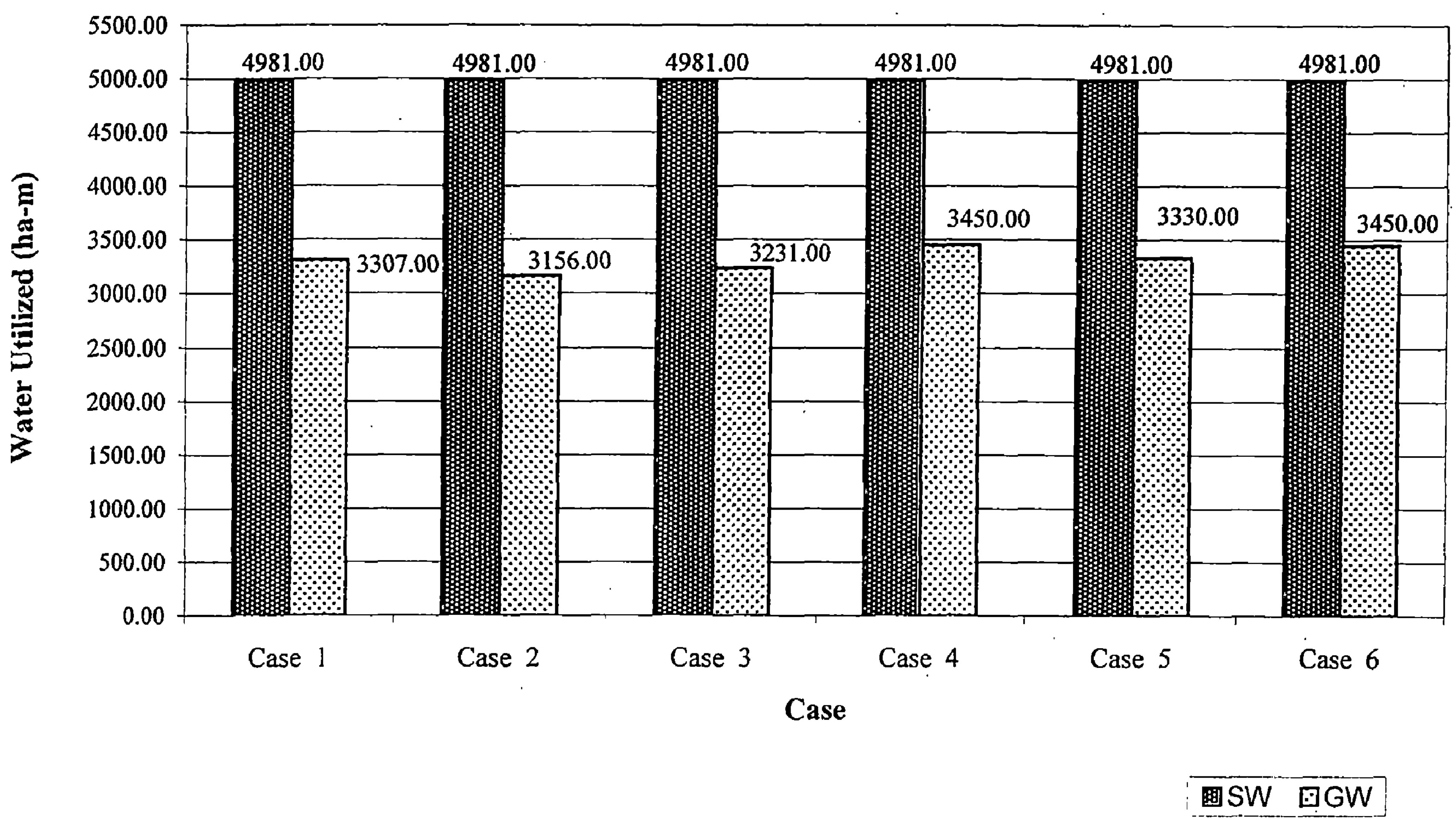


Fig. 5.35. Optimal allocation SW & GW
for proposed cropping pattern of Sapon Irrigation Project case -6
Water Utilized (ha-m)
2250.00
2000.00
1750.00
1500.00
1250.00
1000.00
750.00
500.00
250.00
0.00
568.65
1512.44
2040.49
270.36
1399.21
1226.97
972.65
440.23
Zone 1
Zone 2
Zone 3
Zone 4
Zone
SW
GW

Fig. 5.36 Surface water & ground water utilization for proposed cropping pattern in case study



CHAPTER – 6

CONCLUSIONS AND SCOPE OF FURTHER STUDY

In the foregoing chapters a study has been conducted for conjunctive use of surface water and ground water. Besides increase in benefit, food production, the conjunctive use takes advantages of surface water and ground water irrigation. Through a Linear Programming model considering ground water as a storage, the study area feasible to be implemented, conjunctive use (allocation plan of surface water and ground water conjunctively) and suitable cropping pattern has been evolved to meet present and future requirement in Sapon irrigation area in Indonesia.

6.1. CONCLUSION

Based on the present study following conclusions can be draw :

(i) Detailed study of project area i.e. Sapon Irrigation project of Indonesia conducted.

(ii) In view of static nature of surface water storage, feasibility of utilization of ground water is investigated.

(iii) Conjunctive use model has been developed and applied for the project.

(iv) The existing cropping pattern and utilization of surface water alone yields minimum return i.e. Rs. 45,061.420 millions

(v) Different alternative for changing crop area constraints in 1^{st} dry season suggested enough scope for improvement of benefits.

(vi) Based on the various cases studied, it can be suggested to adopt the case-5 i.e. 30%, 40%, and 10% area under paddy, groundnut, and other crops respectively, which yield maximum benefits of Rs. 101,115.300 millions (Fig.6.1. and Table 6.1)

6.2. SCOPE FOR FUTURE STUDY

(i) The study should be further carried by utilizing well data and more number of years to obtain behavior of aquifer in the region with the help of groundwater model.

(ii) Socio-economic data be collected and incorporated in the study.

Fig. 6.1. Net benefits for proposed cropping pattern

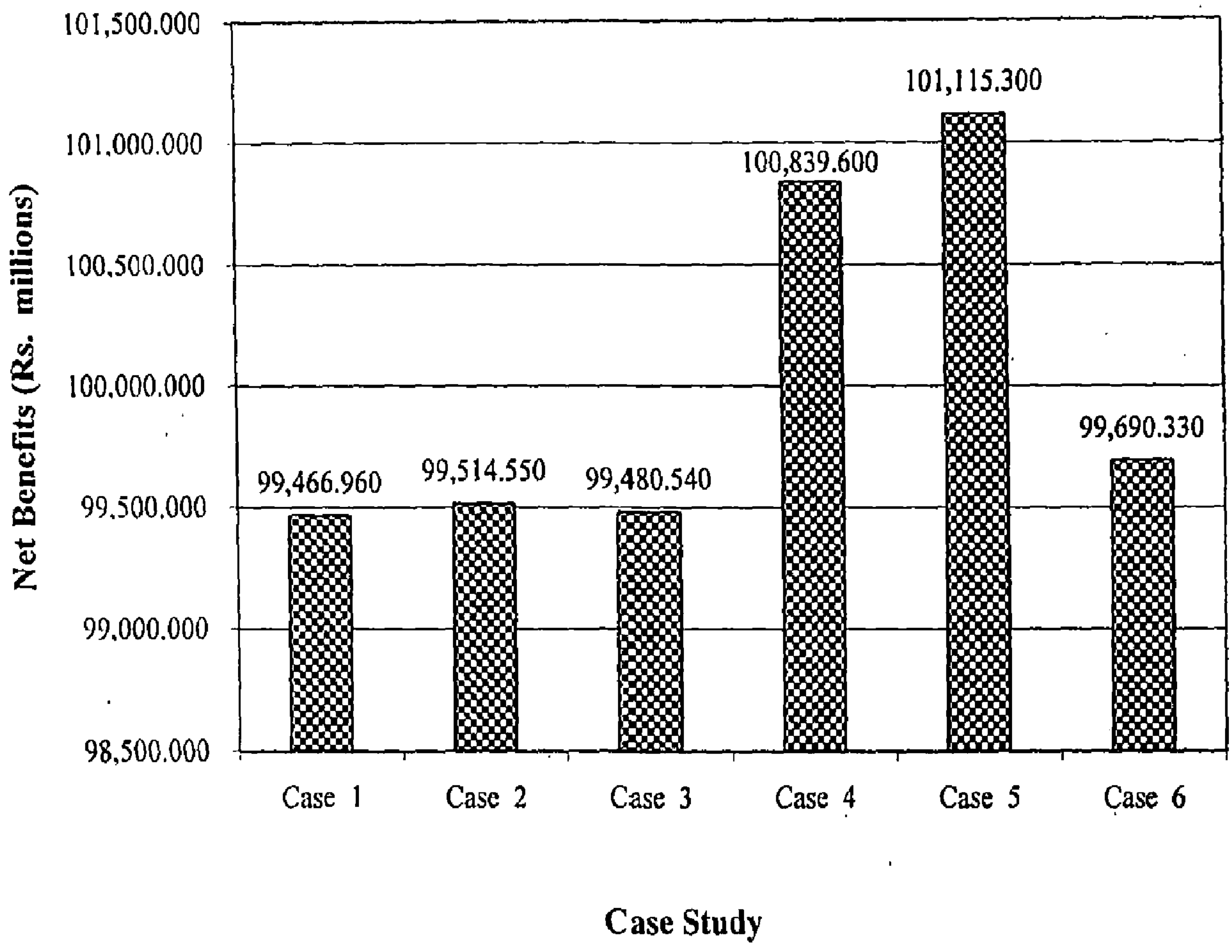


Table 6.1. Optimum allocation of Surface water and groundwater and corresponding net benefit

Sl.No.	Case of Study	Discription	Surface water utilization (Ha-m)				Groundwater utilization (Ha-m)				Net Benefits Rs. Millions
			Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4	
1	1	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 27.5%, 27.5% and 15% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	1339.36	1840.20	972.88	828.55	644.68	362.82	1530.37	692.81	99,480.540
			Total = 4980.99 Ha-m				Total = 3230.68 Ha-m				
2	2	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 25%, 30% and 15% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	1134.39	2047.21	697.84	1101.56	831.87	135.48	1782.70	406.33	99,514.550
			Total = 4981.00 Ha-m				Total = 3156.38 Ha-m				
3	3	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 30%, 25% and 15% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	935.06	1745.69	1450.38	849.87	1067.54	477.65	1076.36	685.74	99466.96
			Total = 4981.00 Ha-m				Total = 3307.29 Ha-m				
4	4	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 35%, 35% and 10% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	1007.69	1847.99	1516.68	608.64	1004.94	422.21	1063.30	959.55	100,839.600
			Total = 4981.00 Ha-m				Total = 3450.00 Ha-m				
5	5	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 30%, 40% and 10% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	835.57	2022.02	1275.25	848.16	1172.22	207.52	1258.53	691.69	101,115.300
			Total = 4981.00 Ha-m				Total = 3329.96 Ha-m				
6	6	Proposed Cropping Pattern considering Wet Season 70 % area for paddy, and 10 % area shift to each crop 1st Dry Season 25%, 30% and 15% optimal area under paddy, groundnut and other each crop respectively 2nd Dry Season 40% area for Groundnut and 20% area shift to each crop	568.65	2040.49	1399.21	972.65	1512.44	270.36	1266.97	440.23	99,690.330
			Total = 4981.00 Ha-m				Total = 3490.00 Ha-m				

ANNEXURE 1

A. INPUT DATA MODEL RUN

Under Existing Cropping Patter without Groundwater Storage and Crop Area Constraint

```
MAX   9.635 C1Z1 + 9.635 C1Z2 + 9.635 C1Z3 + 9.635 C1Z4
      + 7.204 C3Z1 + 7.204 C3Z2 + 7.204 C3Z3 + 7.204 C3Z4
      + 4.577 C4Z1 + 4.577 C4Z2 + 4.577 C4Z3 + 4.577 C4Z4
      + 9.635 C5Z1 + 9.635 C5Z2 + 9.635 C5Z3 + 9.635 C5Z4
      + 6.066 C6Z1 + 6.066 C6Z2 + 6.066 C6Z3 + 6.066 C6Z4
      + 7.204 C7Z1 + 7.204 C7Z2 + 7.204 C7Z3 + 7.204 C7Z4
      + 4.577 C8Z1 + 4.577 C8Z2 + 4.577 C8Z3 + 4.577 C8Z4
      + 8.272 C9Z1 + 8.272 C9Z2 + 8.272 C9Z3 + 8.272 C9Z4
      + 6.066 C10Z1 + 6.066 C10Z2 + 6.066 C10Z3 + 6.066 C10Z4
      + 7.204 C11Z1 + 7.204 C11Z2 + 7.204 C11Z3 + 7.204 C11Z4
      + 8.272 C13Z1 + 8.272 C13Z2 + 8.272 C13Z3 + 8.272 C13Z4
      - 1.102 SW1Z1 - 1.102 SW1Z2 - 1.102 SW1Z3 - 1.102 SW1Z4
      - 1.102 SW2Z1 - 1.102 SW2Z2 - 1.102 SW2Z3 - 1.102 SW2Z4
      - 1.102 SW3Z1 - 1.102 SW3Z2 - 1.102 SW3Z3 - 1.102 SW3Z4
      - 1.102 SW4Z1 - 1.102 SW4Z2 - 1.102 SW4Z3 - 1.102 SW4Z4
      - 1.102 SW5Z1 - 1.102 SW5Z2 - 1.102 SW5Z3 - 1.102 SW5Z4
      - 1.102 SW6Z1 - 1.102 SW6Z2 - 1.102 SW6Z3 - 1.102 SW6Z4
      - 1.102 SW7Z1 - 1.102 SW7Z2 - 1.102 SW7Z3 - 1.102 SW7Z4
      - 1.102 SW8Z1 - 1.102 SW8Z2 - 1.102 SW8Z3 - 1.102 SW8Z4
      - 1.102 SW9Z1 - 1.102 SW9Z2 - 1.102 SW9Z3 - 1.102 SW9Z4
      - 1.102 SW10Z1 - 1.102 SW10Z2 - 1.102 SW10Z3 - 1.102 SW10Z4
      - 1.102 SW11Z1 - 1.102 SW11Z2 - 1.102 SW11Z3 - 1.102 SW11Z4
      - 1.102 SW12Z1 - 1.102 SW12Z2 - 1.102 SW12Z3 - 1.102 SW12Z4
      - 2.528 GW1Z1 - 2.528 GW1Z2 - 2.528 GW1Z3 - 2.528 GW1Z4
      - 2.528 GW2Z1 - 2.528 GW2Z2 - 2.528 GW2Z3 - 2.528 GW2Z4
      - 2.528 GW3Z1 - 2.528 GW3Z2 - 2.528 GW3Z3 - 2.528 GW3Z4
      - 2.528 GW4Z1 - 2.528 GW4Z2 - 2.528 GW4Z3 - 2.528 GW4Z4
      - 2.528 GW5Z1 - 2.528 GW5Z2 - 2.528 GW5Z3 - 2.528 GW5Z4
      - 2.528 GW6Z1 - 2.528 GW6Z2 - 2.528 GW6Z3 - 2.528 GW6Z4
      - 2.528 GW7Z1 - 2.528 GW7Z2 - 2.528 GW7Z3 - 2.528 GW7Z4
      - 2.528 GW8Z1 - 2.528 GW8Z2 - 2.528 GW8Z3 - 2.528 GW8Z4
      - 2.528 GW9Z1 - 2.528 GW9Z2 - 2.528 GW9Z3 - 2.528 GW9Z4
      - 2.528 GW10Z1 - 2.528 GW10Z2 - 2.528 GW10Z3 - 2.528 GW10Z4
      - 2.528 GW11Z1 - 2.528 GW11Z2 - 2.528 GW11Z3 - 2.528 GW11Z4
      - 2.528 GW12Z1 - 2.528 GW12Z2- 2.528 GW12Z3 - 2.528 GW12Z4
SUBJECT TO
! WATER REQUIREMENT CONSTRAINTS;
    0.2636 C1Z1 + 0.1205 C3Z1 + 0.0912 C4Z1 - SW1Z1 - GW1Z1 = 0
    0.2636 C1Z2 + 0.1205 C3Z2 + 0.0912 C4Z2 - SW1Z2 - GW1Z2 = 0
    0.2636 C1Z3 + 0.1205 C3Z3 + 0.0912 C4Z3 - SW1Z3 - GW1Z3 = 0
    0.2636 C1Z4 + 0.1205 C3Z4 + 0.0912 C4Z4 - SW1Z4 - GW1Z4 = 0
    0.1126 C1Z1 + 0.0680 C3Z1 + 0.0714 C4Z1 - SW2Z1 - GW2Z1 = 0
    0.1126 C1Z2 + 0.0680 C3Z2 + 0.0714 C4Z2 - SW2Z2 - GW2Z2 = 0
    0.1126 C1Z3 + 0.0680 C3Z3 + 0.0714 C4Z3 - SW2Z3 - GW2Z3 = 0
```

0.1126 C1Z4 + 0.0680 C3Z4 + 0.0714 C4Z4 - SW2Z4 - GW2Z4 = 0
0.3163 C5Z1 + 0.0968 C6Z1 + 0.0968 C7Z1 + 0.0842 C8Z1 + 0.0847 C9Z1 - SW3Z1 - GW3Z1= 0
0.3163 C5Z2 + 0.0968 C6Z2 + 0.0968 C7Z2 + 0.0842 C8Z2 + 0.0847 C9Z2 - SW3Z2 - GW3Z2 = 0
0.3163 C5Z3 + 0.0968 C6Z3 + 0.0968 C7Z3 + 0.0842 C8Z3 + 0.0847 C9Z3 - SW3Z3 - GW3Z3 = 0
0.3163 C5Z4 + 0.0968 C6Z4 + 0.0968 C7Z4 + 0.0842 C8Z4 + 0.0847 C9Z4 - SW3Z4 - GW3Z4 = 0
0.2941 C5Z1 + 0.0732 C6Z1+ 0.0606 C7Z1 + 0.0481 C8Z1 + 0.0801 C9Z1 - SW4Z1 - GW4Z1 = 0
0.2941 C5Z2 + 0.0732 C6Z2 + 0.0606 C7Z2 + 0.0481 C8Z2 + 0.0801 C9Z2 - SW4Z2 - GW4Z2 = 0
0.2941 C5Z3 + 0.0732 C6Z3 + 0.0606 C7Z3 + 0.0481 C8Z3 + 0.0801 C9Z3 - SW4Z3 - GW4Z3 = 0
0.2941 C5Z4 + 0.0732 C6Z4 + 0.0606 C7Z4 + 0.0481 C8Z4 + 0.0801 C9Z4 - SW4Z4 - GW4Z4 = 0
0.2636 C5Z1 + 0.1246 C6Z1 + 0.1205 C7Z1 + 0.0912 C8Z1 + 0.1107 C9Z1 - SW5Z1 - GW5Z1 = 0
0.2636 C5Z2 + 0.1246 C6Z2 + 0.1205 C7Z2 + 0.0912 C8Z2 + 0.1107 C9Z2 - SW5Z2 - GW5Z2 = 0
0.2636 C5Z3 + 0.1246 C6Z3 + 0.1205 C7Z3 + 0.0912 C8Z3 + 0.1107 C9Z3 - SW5Z3 - GW5Z3 = 0
0.2636 C5Z4 + 0.1246 C6Z4 + 0.1205 C7Z4 + 0.0912 C8Z4 + 0.1107 C9Z4 - SW5Z4 - GW5Z4 = 0
0.1126 C5Z1 + 0.0825 C6Z1 + 0.0680 C7Z1 + 0.0714 C8Z1 + 0.0951 C9Z1 - SW6Z1 - GW6Z1 = 0
0.1126 C5Z2 + 0.0825 C6Z2 + 0.0680 C7Z2 + 0.0714 C8Z2 + 0.0951 C9Z2 - SW6Z2 - GW6Z2 = 0
0.1126 C5Z3 + 0.0825 C6Z3 + 0.0680 C7Z3 + 0.0714 C8Z3 + 0.0951 C9Z3 - SW6Z3 - GW6Z3 = 0
0.1126 C5Z4 + 0.0825 C6Z4 + 0.0680 C7Z4 + 0.0714 C8Z4 + 0.0951 C9Z4 - SW6Z4 - GW6Z4 = 0
0.0968 C10Z1 + 0.0968 C11Z1 + 0.0847 C13Z1 - SW7Z1 - GW7Z1 = 0
0.0968 C10Z2 + 0.0968 C11Z2 + 0.0847 C13Z2 - SW7Z2 - GW7Z2 = 0
0.0968 C10Z3 + 0.0968 C11Z3 + 0.0847 C13Z3 - SW7Z3 - GW7Z3 = 0
0.0968 C10Z4 + 0.0968 C11Z4 + 0.0847 C13Z4 - SW7Z4 - GW7Z4 = 0
0.0732 C10Z1 + 0.0606 C11Z1 + 0.0801 C13Z1 - SW8Z1 - GW8Z1 = 0
0.0732 C10Z2 + 0.0606 C11Z2 + 0.0801 C13Z2 - SW8Z2 - GW8Z2 = 0
0.0732 C10Z3 + 0.0606 C11Z3 + 0.0801 C13Z3 - SW8Z3 - GW8Z3 = 0
0.0732 C10Z4 + 0.0606 C11Z4 + 0.0801 C13Z4 - SW8Z4 - GW8Z4 = 0
0.1246 C10Z1 + 0.1205 C11Z1 + 0.1107 C13Z1 - SW9Z1 - GW9Z1 = 0
0.1246 C10Z2 + 0.1205 C11Z2 + 0.1107 C13Z2 - SW9Z2 - GW9Z2 = 0
0.1246 C10Z3 + 0.1205 C11Z3 + 0.1107 C13Z3 - SW9Z3 - GW9Z3 = 0
0.1246 C10Z4 + 0.1205 C11Z4 + 0.1107 C13Z4 - SW9Z4 - GW9Z4 = 0
0.0825 C10Z1 + 0.0680 C11Z1 + 0.0951 C13Z1 - SW10Z1 - GW10Z1 = 0
0.0825 C10Z2 + 0.0680 C11Z2 + 0.0951 C13Z2 - SW10Z2 - GW10Z2 = 0
0.0825 C10Z3 + 0.0680 C11Z3 + 0.0951 C13Z3 - SW10Z3 - GW10Z3 = 0
0.0825 C10Z4 + 0.0680 C11Z4 + 0.0951 C13Z4 - SW10Z4 - GW10Z4 = 0
0.3163 C1Z1 + 0.0968 C3Z1 + 0.0842 C4Z1 - SW11Z1 - GW11Z1 = 0
0.3163 C1Z2 + 0.0968 C3Z2 + 0.0842 C4Z2 - SW11Z2 - GW11Z2 = 0
0.3163 C1Z3 + 0.0968 C3Z3 + 0.0842 C4Z3 - SW11Z3 - GW11Z3 = 0
0.3163 C1Z4 + 0.0968 C3Z4 + 0.0842 C4Z4 - SW11Z4 - GW11Z4 = 0
0.2941 C1Z1 + 0.0606 C3Z1 + 0.0481 C4Z1 - SW12Z1 - GW12Z1 = 0
0.2941 C1Z2 + 0.0606 C3Z2 + 0.0481 C4Z2 - SW12Z2 - GW12Z2 = 0
0.2941 C1Z3 + 0.0606 C3Z3 + 0.0481 C4Z3 - SW12Z3 - GW12Z3 = 0
0.2941 C1Z4 + 0.0606 C3Z4 + 0.0481 C4Z4 - SW12Z4 - GW12Z4 = 0
!AREA AVAILABILITY CONSTRAINTS;
C1Z1 + C3Z1 + C4Z1 <= 554
C1Z2 + C3Z2 + C4Z2 <= 646
C1Z3 + C3Z3 + C4Z3 <= 662
C1Z4 + C3Z4 + C4Z4 <= 388
C5Z1 + C6Z1 + C7Z1 + C8Z1 + C9Z1 <= 493
C5Z2 + C6Z2 + C7Z2 + C8Z2 + C9Z2 <= 554
C5Z3 + C6Z3 + C7Z3 + C8Z3 + C9Z3 <= 583
C5Z4 + C6Z4 + C7Z4 + C8Z4 + C9Z4 <= 335
C10Z1 + C11Z1 + C13Z1 <= 292

```
   C10Z2 + C11Z2 + C13Z2 <= 352
   C10Z3 + C11Z3 + C13Z3 <= 355
   C10Z4 + C11Z4 + C13Z4 <= 231
!SURFACE WATER AVAILABILITY CONSTRAINTS;
   SW1Z1 + SW1Z2 + SW1Z3 + SW1Z4 <= 846
   SW2Z1 + SW2Z2 + SW2Z3 + SW2Z4 <= 377
   SW3Z1 + SW3Z2 + SW3Z3 + SW3Z4 <= 405
   SW4Z1 + SW4Z2 + SW4Z3 + SW4Z4 <= 418
   SW5Z1 + SW5Z2 + SW5Z3 + SW5Z4 <= 404
   SW6Z1 + SW6Z2 + SW6Z3 + SW6Z4 <= 207
   SW7Z1 + SW7Z2 + SW7Z3 + SW7Z4 <= 214
   SW8Z1 + SW8Z2 + SW8Z3 + SW8Z4 <= 150
   SW9Z1 + SW9Z2 + SW9Z3 + SW9Z4 <= 145
   SW10Z1 + SW10Z2 + SW10Z3 + SW10Z4 <= 150
   SW11Z1 + SW11Z2 + SW11Z3 + SW11Z4 <= 819
   SW12Z1 + SW12Z2 + SW12Z3 + SW12Z4 <= 846
!GROUND WATER AVAILABILITY CONSTRAINTS;
   GW1Z1 + GW1Z2 + GW1Z3 + GW1Z4 +
   GW2Z1 + GW2Z2 + GW2Z3 + GW2Z4 +
   GW3Z1 + GW3Z2 + GW3Z3 + GW3Z4 +
   GW4Z1 + GW4Z2 + GW4Z3 + GW4Z4 +
   GW5Z1 + GW5Z2 + GW5Z3 + GW5Z4 +
   GW6Z1 + GW6Z2 + GW6Z3 + GW6Z4 +
   GW7Z1 + GW7Z2 + GW7Z3 + GW7Z4 +
   GW8Z1 + GW8Z2 + GW8Z3 + GW8Z4 +
   GW9Z1 + GW9Z2 + GW9Z3 + GW9Z4 +
   GW10Z1 + GW10Z2 + GW10Z3 + GW10Z4 +
   GW11Z1 + GW11Z2 + GW11Z3 + GW11Z4 +
   GW12Z1 + GW12Z2 + GW12Z3 + GW12Z4 <= 0
END
```

B. OUTPUT DATA MODEL RUN

Under Existing Cropping Patter without Groundwater Storage and Crop Area Constraint

LP OPTIMUM FOUND AT STEP 15

OBJECTIVE FUNCTION VALUE

1) 45061.42

VARIABLE	VALUE	REDUCED COST
C1Z1	554.000000	0.000000
C1Z2	646.000000	0.000000
C1Z3	662.000000	0.000000
C1Z4	388.000000	0.000000
C3Z1	0.000000	1.724949
C3Z2	0.000000	1.724949
C3Z3	0.000000	1.724949
C3Z4	0.000000	1.724949
C4Z1	0.000000	4.295747
C4Z2	0.000000	4.295747
C4Z3	0.000000	4.295747
C4Z4	0.000000	4.295747
C5Z1	447.071198	0.000000
C5Z2	0.000000	0.000000
C5Z3	583.000000	0.000000
C5Z4	0.000000	0.000000
C6Z1	0.000000	2.248908
C6Z2	0.000000	2.248908
C6Z3	0.000000	2.248908
C6Z4	0.000000	2.248908
C7Z1	0.000000	1.076525
C7Z2	0.000000	1.076525
C7Z3	0.000000	1.076525
C7Z4	0.000000	1.076525
C8Z1	0.000000	3.610102
C8Z2	0.000000	3.610102
C8Z3	0.000000	3.610102
C8Z4	0.000000	3.610102
C9Z1	45.928791	0.000000
C9Z2	554.000000	0.000000
C9Z3	0.000000	0.000000
C9Z4	335.000000	0.000000
C10Z1	0.000000	2.213163
C10Z2	0.000000	2.213163
C10Z3	0.000000	2.213163
C10Z4	0.000000	2.213163
C11Z1	0.000000	1.040781
C11Z2	0.000000	1.040781
C11Z3	0.000000	1.040781

C11Z4	0.000000	1.040781
C13Z1	292.000000	0.000000
C13Z2	352.000000	0.000000
C13Z3	355.000000	0.000000
C13Z4	231.000000	0.000000
SW1Z1	146.034393	0.000000
SW1Z2	170.285599	0.000000
SW1Z3	174.503189	0.000000
SW1Z4	102.276794	0.000000
SW2Z1	62.380398	0.000000
SW2Z2	72.739601	0.000000
SW2Z3	74.541199	0.000000
SW2Z4	43.688801	0.000000
SW3Z1	145.298798	0.000000
SW3Z2	46.923801	0.000000
SW3Z3	184.402908	0.000000
SW3Z4	28.374500	0.000000
SW4Z1	135.162537	0.000000
SW4Z2	44.375401	0.000000
SW4Z3	171.460297	0.000000
SW4Z4	26.833500	0.000000
SW5Z1	122.932281	0.000000
SW5Z2	61.327797	0.000000
SW5Z3	153.678802	0.000000
SW5Z4	37.084499	0.000000
SW6Z1	54.708046	0.000000
SW6Z2	52.685402	0.000000
SW6Z3	65.645798	0.000000
SW6Z4	31.858500	0.000000
SW7Z1	24.732401	0.000000
SW7Z2	29.814402	0.000000
SW7Z3	30.068501	0.000000
SW7Z4	19.565701	0.000000
SW8Z1	23.389200	0.000000
SW8Z2	28.195200	0.000000
SW8Z3	28.435499	0.000000
SW8Z4	18.503099	0.000000
SW9Z1	32.324398	0.000000
SW9Z2	38.966400	0.000000
SW9Z3	39.298500	0.000000
SW9Z4	25.571699	0.000000
SW10Z1	27.769199	0.000000
SW10Z2	33.475201	0.000000
SW10Z3	33.760502	0.000000
SW10Z4	21.968100	0.000000
SW11Z1	175.230209	0.000000
SW11Z2	204.329803	0.000000
SW11Z3	209.390610	0.000000
SW11Z4	122.724403	0.000000
SW12Z1	162.931396	0.000000
SW12Z2	189.988586	0.000000

SW12Z3	194.694199	0.000000
SW12Z4	114.110794	0.000000
GW1Z1	0.000000	2.954093
GW1Z2	0.000000	2.954093
GW1Z3	0.000000	2.954093
GW1Z4	0.000000	2.954093
GW2Z1	0.000000	2.954093
GW2Z2	0.000000	2.954093
GW2Z3	0.000000	2.954093
GW2Z4	0.000000	2.954093
GW3Z1	0.000000	0.000000
GW3Z2	0.000000	0.000000
GW3Z3	0.000000	0.000000
GW3Z4	0.000000	0.000000
GW4Z1	0.000000	2.954093
GW4Z2	0.000000	2.954093
GW4Z3	0.000000	2.954093
GW4Z4	0.000000	2.954093
GW5Z1	0.000000	2.954093
GW5Z2	0.000000	2.954093
GW5Z3	0.000000	2.954093
GW5Z4	0.000000	2.954093
GW6Z1	0.000000	2.954093
GW6Z2	0.000000	2.954093
GW6Z3	0.000000	2.954093
GW6Z4	0.000000	2.954093
GW7Z1	0.000000	2.954093
GW7Z2	0.000000	2.954093
GW7Z3	0.000000	2.954093
GW7Z4	0.000000	2.954093
GW8Z1	0.000000	2.954093
GW8Z2	0.000000	2.954093
GW8Z3	0.000000	2.954093
GW8Z4	0.000000	2.954093
GW9Z1	0.000000	2.954093
GW9Z2	0.000000	2.954093
GW9Z3	0.000000	2.954093
GW9Z4	0.000000	2.954093
GW10Z1	0.000000	2.954093
GW10Z2	0.000000	2.954093
GW10Z3	0.000000	2.954093
GW10Z4	0.000000	2.954093
GW11Z1	0.000000	2.954093
GW11Z2	0.000000	2.954093
GW11Z3	0.000000	2.954093
GW11Z4	0.000000	2.954093
GW12Z1	0.000000	2.954093
GW12Z2	0.000000	2.954093
GW12Z3	0.000000	2.954093
GW12Z4	0.000000	2.954093

ANNEXURE 2

A. INPUT DATA MODEL RUN

Case 5 (Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 30%, 40% and 10% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)

```
MAX    9.635 C1Z1 + 9.635 C1Z2 + 9.635 C1Z3 + 9.635 C1Z4
     + 6.066 C2Z1 + 6.066 C2Z2 + 6.066 C2Z3 + 6.066 C2Z4
     + 7.204 C3Z1 + 7.204 C3Z2 + 7.204 C3Z3 + 7.204 C3Z4
     + 4.577 C4Z1 + 4.577 C4Z2 + 4.577 C4Z3 + 4.577 C4Z4
     + 9.635 C5Z1 + 9.635 C5Z2 + 9.635 C5Z3 + 9.635 C5Z4
     + 6.066 C6Z1 + 6.066 C6Z2 + 6.066 C6Z3 + 6.066 C6Z4
     + 7.204 C7Z1 + 7.204 C7Z2 + 7.204 C7Z3 + 7.204 C7Z4
     + 4.577 C8Z1 + 4.577 C8Z2 + 4.577 C8Z3 + 4.577 C8Z4
     + 8.272 C9Z1 + 8.272 C9Z2 + 8.272 C9Z3 + 8.272 C9Z4
     + 6.066 C10Z1 + 6.066 C10Z2 + 6.066 C10Z3 + 6.066 C10Z4
     + 7.204 C11Z1 + 7.204 C11Z2 + 7.204 C11Z3 + 7.204 C11Z4
     + 4.577 C12Z1 + 4.577 C12Z2 + 4.577 C12Z3 + 4.577 C12Z4
     + 8.272 C13Z1 + 8.272 C13Z2 + 8.272 C13Z3 + 8.272 C13Z4
     - 1.102 SW1Z1 - 1.102 SW1Z2 - 1.102 SW1Z3 - 1.102 SW1Z4
     - 1.102 SW2Z1 - 1.102 SW2Z2 - 1.102 SW2Z3 - 1.102 SW2Z4
     - 1.102 SW3Z1 - 1.102 SW3Z2 - 1.102 SW3Z3 - 1.102 SW3Z4
     - 1.102 SW4Z1 - 1.102 SW4Z2 - 1.102 SW4Z3 - 1.102 SW4Z4
     - 1.102 SW5Z1 - 1.102 SW5Z2 - 1.102 SW5Z3 - 1.102 SW5Z4
     - 1.102 SW6Z1 - 1.102 SW6Z2 - 1.102 SW6Z3 - 1.102 SW6Z4
     - 1.102 SW7Z1 - 1.102 SW7Z2 - 1.102 SW7Z3 - 1.102 SW7Z4
     - 1.102 SW8Z1 - 1.102 SW8Z2 - 1.102 SW8Z3 - 1.102 SW8Z4
     - 1.102 SW9Z1 - 1.102 SW9Z2 - 1.102 SW9Z3 - 1.102 SW9Z4
     - 1.102 SW10Z1 - 1.102 SW10Z2 - 1.102 SW10Z3 - 1.102 SW10Z4
     - 1.102 SW11Z1 - 1.102 SW11Z2 - 1.102 SW11Z3 - 1.102 SW11Z4
     - 1.102 SW12Z1 - 1.102 SW12Z2 - 1.102 SW12Z3 - 1.102 SW12Z4
     - 2.528 GW1Z1 - 2.528 GW1Z2 - 2.528 GW1Z3 - 2.528 GW1Z4
     - 2.528 GW2Z1 - 2.528 GW2Z2 - 2.528 GW2Z3 - 2.528 GW2Z4
     - 2.528 GW3Z1 - 2.528 GW3Z2 - 2.528 GW3Z3 - 2.528 GW3Z4
     - 2.528 GW4Z1 - 2.528 GW4Z2 - 2.528 GW4Z3 - 2.528 GW4Z4
     - 2.528 GW5Z1 - 2.528 GW5Z2 - 2.528 GW5Z3 - 2.528 GW5Z4
     - 2.528 GW6Z1 - 2.528 GW6Z2 - 2.528 GW6Z3 - 2.528 GW6Z4
     - 2.528 GW7Z1 - 2.528 GW7Z2 - 2.528 GW7Z3 - 2.528 GW7Z4
     - 2.528 GW8Z1 - 2.528 GW8Z2 - 2.528 GW8Z3 - 2.528 GW8Z4
     - 2.528 GW9Z1 - 2.528 GW9Z2 - 2.528 GW9Z3 - 2.528 GW9Z4
     - 2.528 GW10Z1 - 2.528 GW10Z2 - 2.528 GW10Z3 - 2.528 GW10Z4
     - 2.528 GW11Z1 - 2.528 GW11Z2 - 2.528 GW11Z3 - 2.528 GW11Z4
     - 2.528 GW12Z1 - 2.528 GW12Z2 - 2.528 GW12Z3 - 2.528 GW12Z4
SUBJECT TO
! WATER REQUIREMENT CONSTRAINTS;
   0.2636 C1Z1 + 0.1246 C2Z1 + 0.1205 C3Z1 + 0.0912 C4Z1 - SW1Z1 - GW1Z1 = 0
   0.2636 C1Z2 + 0.1246 C2Z2 + 0.1205 C3Z2 + 0.0912 C4Z2 - SW1Z2 - GW1Z2 = 0
```

0.2636 C1Z3 + 0.1246 C2Z3 + 0.1205 C3Z3 + 0.0912 C4Z3 - SW1Z3 - GW1Z3 = 0
0.2636 C1Z4 + 0.1246 C2Z4 + 0.1205 C3Z4 + 0.0912 C4Z4 - SW1Z4 - GW1Z4 = 0
0.1126 C1Z1 + 0.0825 C2Z1 + 0.0680 C3Z1 + 0.0714 C4Z1 - SW2Z1 - GW2Z1 = 0
0.1126 C1Z2 + 0.0825 C2Z2 + 0.0680 C3Z2 + 0.0714 C4Z2 - SW2Z2 - GW2Z2 = 0
0.1126 C1Z3 + 0.0825 C2Z3 + 0.0680 C3Z3 + 0.0714 C4Z3 - SW2Z3 - GW2Z3 = 0
0.1126 C1Z4 + 0.0825 C2Z4 + 0.0680 C3Z4 + 0.0714 C4Z4 - SW2Z4 - GW2Z4 = 0
0.3163 C5Z1 + 0.0968 C6Z1 + 0.0968 C7Z1 + 0.0842 C8Z1 + 0.0847 C9Z1 - SW3Z1 - GW3Z1 = 0
0.3163 C5Z2 + 0.0968 C6Z2 + 0.0968 C7Z2 + 0.0842 C8Z2 + 0.0847 C9Z2 - SW3Z2 - GW3Z2 = 0
0.3163 C5Z3 + 0.0968 C6Z3 + 0.0968 C7Z3 + 0.0842 C8Z3 + 0.0847 C9Z3 - SW3Z3 - GW3Z3 = 0
0.3163 C5Z4 + 0.0968 C6Z4 + 0.0968 C7Z4 + 0.0842 C8Z4 + 0.0847 C9Z4 - SW3Z4 - GW3Z4 = 0
0.2941 C5Z1 + 0.0732 C6Z1 + 0.0606 C7Z1 + 0.0481 C8Z1 + 0.0801 C9Z1 - SW4Z1 - GW4Z1 = 0
0.2941 C5Z2 + 0.0732 C6Z2 + 0.0606 C7Z2 + 0.0481 C8Z2 + 0.0801 C9Z2 - SW4Z2 - GW4Z2 = 0
0.2941 C5Z3 + 0.0732 C6Z3 + 0.0606 C7Z3 + 0.0481 C8Z3 + 0.0801 C9Z3 - SW4Z3 - GW4Z3 = 0
0.2941 C5Z4 + 0.0732 C6Z4 + 0.0606 C7Z4 + 0.0481 C8Z4 + 0.0801 C9Z4 - SW4Z4 - GW4Z4 = 0
0.2636 C5Z1 + 0.1246 C6Z1 + 0.1205 C7Z1 + 0.0912 C8Z1 + 0.1107 C9Z1 - SW5Z1 - GW5Z1 = 0
0.2636 C5Z2 + 0.1246 C6Z2 + 0.1205 C7Z2 + 0.0912 C8Z2 + 0.1107 C9Z2 - SW5Z2 - GW5Z2 = 0
0.2636 C5Z3 + 0.1246 C6Z3 + 0.1205 C7Z3 + 0.0912 C8Z3 + 0.1107 C9Z3 - SW5Z3 - GW5Z3 = 0
0.2636 C5Z4 + 0.1246 C6Z4 + 0.1205 C7Z4 + 0.0912 C8Z4 + 0.1107 C9Z4 - SW5Z4 - GW5Z4 = 0
0.1126 C5Z1 + 0.0825 C6Z1 + 0.0680 C7Z1 + 0.0714 C8Z1 + 0.0951 C9Z1 - SW6Z1 - GW6Z1 = 0
0.1126 C5Z2 + 0.0825 C6Z2 + 0.0680 C7Z2 + 0.0714 C8Z2 + 0.0951 C9Z2 - SW6Z2 - GW6Z2 = 0
0.1126 C5Z3 + 0.0825 C6Z3 + 0.0680 C7Z3 + 0.0714 C8Z3 + 0.0951 C9Z3 - SW6Z3 - GW6Z3 = 0
0.1126 C5Z4 + 0.0825 C6Z4 + 0.0680 C7Z4 + 0.0714 C8Z4 + 0.0951 C9Z4 - SW6Z4 - GW6Z4 = 0
0.0968 C10Z1 + 0.0968 C11Z1 + 0.0842 C12Z1 + 0.0847 C13Z1 - SW7Z1 - GW7Z1 = 0
0.0968 C10Z2 + 0.0968 C11Z2 + 0.0842 C12Z2 + 0.0847 C13Z2 - SW7Z2 - GW7Z2 = 0
0.0968 C10Z3 + 0.0968 C11Z3 + 0.0842 C12Z3 + 0.0847 C13Z3 - SW7Z3 - GW7Z3 = 0
0.0968 C10Z4 + 0.0968 C11Z4 + 0.0842 C12Z4 + 0.0847 C13Z4 - SW7Z4 - GW7Z4 = 0
0.0732 C10Z1 + 0.0606 C11Z1 + 0.0481 C12Z1 + 0.0801 C13Z1 - SW8Z1 - GW8Z1 = 0
0.0732 C10Z2 + 0.0606 C11Z2 + 0.0481 C12Z2 + 0.0801 C13Z2 - SW8Z2 - GW8Z2 = 0
0.0732 C10Z3 + 0.0606 C11Z3 + 0.0481 C12Z3 + 0.0801 C13Z3 - SW8Z3 - GW8Z3 = 0
0.0732 C10Z4 + 0.0606 C11Z4 + 0.0481 C12Z4 + 0.0801 C13Z4 - SW8Z4 - GW8Z4 = 0
0.1246 C10Z1 + 0.1205 C11Z1 + 0.0912 C12Z1 + 0.1107 C13Z1 - SW9Z1 - GW9Z1 = 0
0.1246 C10Z2 + 0.1205 C11Z2 + 0.0912 C12Z2 + 0.1107 C13Z2 - SW9Z2 - GW9Z2 = 0
0.1246 C10Z3 + 0.1205 C11Z3 + 0.0912 C12Z3 + 0.1107 C13Z3 - SW9Z3 - GW9Z3 = 0
0.1246 C10Z4 + 0.1205 C11Z4 + 0.0912 C12Z4 + 0.1107 C13Z4 - SW9Z4 - GW9Z4 = 0
0.0825 C10Z1 + 0.0680 C11Z1 + 0.0714 C12Z1 + 0.0951 C13Z1 - SW10Z1 - GW10Z1 = 0
0.0825 C10Z2 + 0.0680 C11Z2 + 0.0714 C12Z2 + 0.0951 C13Z2 - SW10Z2 - GW10Z2 = 0
0.0825 C10Z3 + 0.0680 C11Z3 + 0.0714 C12Z3 + 0.0951 C13Z3 - SW10Z3 - GW10Z3 = 0
0.0825 C10Z4 + 0.0680 C11Z4 + 0.0714 C12Z4 + 0.0951 C13Z4 - SW10Z4 - GW10Z4 = 0
0.3163 C1Z1 + 0.0968 C2Z1 + 0.0968 C3Z1 + 0.0842 C4Z1 - SW11Z1 - GW11Z1 = 0
0.3163 C1Z2 + 0.0968 C2Z2 + 0.0968 C3Z2 + 0.0842 C4Z2 - SW11Z2 - GW11Z2 = 0
0.3163 C1Z3 + 0.0968 C2Z3 + 0.0968 C3Z3 + 0.0842 C4Z3 - SW11Z3 - GW11Z3 = 0
0.3163 C1Z4 + 0.0968 C2Z4 + 0.0968 C3Z4 + 0.0842 C4Z4 - SW11Z4 - GW11Z4 = 0
0.2941 C1Z1 + 0.0732 C2Z1 + 0.0606 C3Z1 + 0.0481 C4Z1 - SW12Z1 - GW12Z1 = 0
0.2941 C1Z2 + 0.0732 C2Z2 + 0.0606 C3Z2 + 0.0481 C4Z2 - SW12Z2 - GW12Z2 = 0
0.2941 C1Z3 + 0.0732 C2Z3 + 0.0606 C3Z3 + 0.0481 C4Z3 - SW12Z3 - GW12Z3 = 0
0.2941 C1Z4 + 0.0732 C2Z4 + 0.0606 C3Z4 + 0.0481 C4Z4 - SW12Z4 - GW12Z4 = 0
!AREA AVAILABILITY CONSTRAINTS;
C1Z1 + C2Z1 + C3Z1 + C4Z1 <= 1188
C1Z2 + C2Z2 + C3Z2 + C4Z2 <= 1319
C1Z3 + C2Z3 + C3Z3 + C4Z3 <= 1499
C1Z4 + C2Z4 + C3Z4 + C4Z4 <= 911

C5Z1 + C6Z1 + C7Z1 + C8Z1 + C9Z1 <= 1188
C5Z2 + C6Z2 + C7Z2 + C8Z2 + C9Z2 <= 1319
C5Z3 + C6Z3 + C7Z3 + C8Z3 + C9Z3 <= 1499
C5Z4 + C6Z4 + C7Z4 + C8Z4 + C9Z4 <= 911
C10Z1 + C11Z1 + C12Z1 + C13Z1 <= 1188
C10Z2 + C11Z2 + C12Z2 + C13Z2 <= 1319
C10Z3 + C11Z3 + C12Z3 + C13Z3 <= 1499
C10Z4 + C11Z4 + C12Z4 + C13Z4 <= 911
!SURFACE WATER AVAILABILITY CONSTRAINTS;
SW1Z1 + SW1Z2 + SW1Z3 + SW1Z4 <= 846
SW2Z1 + SW2Z2 + SW2Z3 + SW2Z4 <= 377
SW3Z1 + SW3Z2 + SW3Z3 + SW3Z4 <= 405
SW4Z1 + SW4Z2 + SW4Z3 + SW4Z4 <= 418
SW5Z1 + SW5Z2 + SW5Z3 + SW5Z4 <= 404
SW6Z1 + SW6Z2 + SW6Z3 + SW6Z4 <= 207
SW7Z1 + SW7Z2 + SW7Z3 + SW7Z4 <= 214
SW8Z1 + SW8Z2 + SW8Z3 + SW8Z4 <= 150
SW9Z1 + SW9Z2 + SW9Z3 + SW9Z4 <= 145
SW10Z1 + SW10Z2 + SW10Z3 + SW10Z4 <= 150
SW11Z1 + SW11Z2 + SW11Z3 + SW11Z4 <= 819
SW12Z1 + SW12Z2 + SW12Z3 + SW12Z4 <= 846
!GROUND WATER AVAILABILITY CONSTRAINTS;
GW1Z1 + GW1Z2 + GW1Z3 + GW1Z4 +
GW2Z1 + GW2Z2 + GW2Z3 + GW2Z4 +
GW3Z1 + GW3Z2 + GW3Z3 + GW3Z4 +
GW4Z1 + GW4Z2 + GW4Z3 + GW4Z4 +
GW5Z1 + GW5Z2 + GW5Z3 + GW5Z4 +
GW6Z1 + GW6Z2 + GW6Z3 + GW6Z4 +
GW7Z1 + GW7Z2 + GW7Z3 + GW7Z4 +
GW8Z1 + GW8Z2 + GW8Z3 + GW8Z4 +
GW9Z1 + GW9Z2 + GW9Z3 + GW9Z4 +
GW10Z1 + GW10Z2 + GW10Z3 + GW10Z4 +
GW11Z1 + GW11Z2 + GW11Z3 + GW11Z4 +
GW12Z1 + GW12Z2 + GW12Z3 + GW12Z4 <= 3450
!CROP AREA CONSTRAINTS;
C1Z1 <= 832
C2Z1 <= 119
C3Z1 <= 119
C4Z1 <= 118
C1Z2 <= 923
C2Z2 <= 132
C3Z2 <= 132
C4Z2 <= 132
C1Z3 <= 1049
C2Z3 <= 150
C3Z3 <= 150
C4Z3 <= 150
C1Z4 <= 638
C2Z4 <= 91
C3Z4 <= 91
C4Z4 <= 91

C5Z1 <= 356
C6Z1 <= 119
C7Z1 <= 119
C8Z1 <= 118
C9Z1 <= 475
C5Z2 <= 396
C6Z2 <= 132
C7Z2 <= 132
C8Z2 <= 131
C9Z2 <= 528
C5Z3 <= 450
C6Z3 <= 150
C7Z3 <= 150
C8Z3 <= 149
C9Z3 <= 600
C5Z4 <= 273
C6Z4 <= 91
C7Z4 <= 91
C8Z4 <= 91
C9Z4 <= 365
C10Z1 <= 238
C11Z1 <= 238
C12Z1 <= 237
C13Z1 <= 475
C10Z2 <= 264
C11Z2 <= 264
C12Z2 <= 263
C13Z2 <= 528
C10Z3 <= 300
C11Z3 <= 300
C12Z3 <= 299
C13Z3 <= 600
C10Z4 <= 183
C11Z4 <= 182
C12Z4 <= 182
C13Z4 <= 364
END

B. OUTPUT DATA MODEL RUN

Case 5 (Wet Season 70% area for paddy, and 10% area shift to each crop)
(1st Dry Season 30%, 40% and 10% optimal area under paddy, groundnut and other each crop respectively)
(2nd Dry Season 40% area for Groundnut and 20% area shift to each crop)

LP OPTIMUM FOUND AT STEP 134

OBJECTIVE FUNCTION VALUE

1) 101115.3

VARIABLE	VALUE	REDUCED COST
C1Z1	832.000000	0.000000
C1Z2	923.000000	0.000000
C1Z3	1049.000000	0.000000
C1Z4	638.000000	0.000000
C2Z1	119.000000	0.000000
C2Z2	132.000000	0.000000
C2Z3	150.000000	0.000000
C2Z4	91.000000	0.000000
C3Z1	119.000000	0.000000
C3Z2	132.000000	0.000000
C3Z3	150.000000	0.000000
C3Z4	91.000000	0.000000
C4Z1	118.000000	0.000000
C4Z2	132.000000	0.000000
C4Z3	150.000000	0.000000
C4Z4	91.000000	0.000000
C5Z1	356.000000	0.000000
C5Z2	396.000000	0.000000
C5Z3	450.000000	0.000000
C5Z4	273.000000	0.000000
C6Z1	119.000000	0.000000
C6Z2	132.000000	0.000000
C6Z3	150.000000	0.000000
C6Z4	91.000000	0.000000
C7Z1	119.000000	0.000000
C7Z2	132.000000	0.000000
C7Z3	150.000000	0.000000
C7Z4	91.000000	0.000000
C8Z1	118.000000	0.000000
C8Z2	131.000000	0.000000
C8Z3	149.000000	0.000000
C8Z4	91.000000	0.000000
C9Z1	475.000000	0.000000
C9Z2	528.000000	0.000000
C9Z3	600.000000	0.000000
C9Z4	365.000000	0.000000
C10Z1	238.000000	0.000000

C10Z2	264.000000	0.000000
C10Z3	300.000000	0.000000
C10Z4	183.000000	0.000000
C11Z1	238.000000	0.000000
C11Z2	264.000000	0.000000
C11Z3	300.000000	0.000000
C11Z4	182.000000	0.000000
C12Z1	237.000000	0.000000
C12Z2	263.000000	0.000000
C12Z3	299.000000	0.000000
C12Z4	182.000000	0.000000
C13Z1	475.000000	0.000000
C13Z2	528.000000	0.000000
C13Z3	600.000000	0.000000
C13Z4	364.000000	0.000000
SW1Z1	32.564121	0.000000
SW1Z2	287.694397	0.000000
SW1Z3	326.961395	0.000000
SW1Z4	198.780090	0.000000
SW2Z1	120.017899	0.000000
SW2Z2	133.220596	0.000000
SW2Z3	31.729799	0.000000
SW2Z4	92.031700	0.000000
SW3Z1	185.809311	0.000000
SW3Z2	206.561798	0.000000
SW3Z3	12.628893	0.000000
SW3Z4	0.000000	0.000000
SW4Z1	109.202209	0.000000
SW4Z2	182.719101	0.000000
SW4Z3	0.000000	0.000000
SW4Z4	126.078697	0.000000
SW5Z1	0.000000	0.000000
SW5Z2	207.135590	0.000000
SW5Z3	196.864410	0.000000
SW5Z4	0.000000	0.000000
SW6Z1	0.000000	0.000000
SW6Z2	124.021797	0.000000
SW6Z3	82.978203	0.000000
SW6Z4	0.000000	0.000000
SW7Z1	0.000000	0.000000
SW7Z2	117.976601	0.000000
SW7Z3	96.023399	0.000000
SW7Z4	0.000000	0.000000
SW8Z1	81.291603	0.000000
SW8Z2	0.000000	0.000000
SW8Z3	68.708397	0.000000
SW8Z4	0.000000	0.000000
SW9Z1	0.000000	0.000000
SW9Z2	145.000000	0.000000
SW9Z3	0.000000	0.000000
SW9Z4	0.000000	0.000000

SW10Z1	0.000000	0.000000
SW10Z2	26.441397	0.000000
SW10Z3	123.558601	0.000000
SW10Z4	0.000000	0.000000
SW11Z1	296.135590	0.000000
SW11Z2	295.785187	0.000000
SW11Z3	0.000000	0.000000
SW11Z4	227.079208	0.000000
SW12Z1	10.550334	0.000000
SW12Z2	295.465088	0.000000
SW12Z3	335.795898	0.000000
SW12Z4	204.188690	0.000000
GW1Z1	226.679565	0.000000
GW1Z2	0.000000	0.000000
GW1Z3	0.000000	0.000000
GW1Z4	0.000000	0.000000
GW2Z1	0.000000	0.000000
GW2Z2	0.000000	0.000000
GW2Z3	119.672600	0.000000
GW2Z4	0.000000	0.000000
GW3Z1	0.000000	0.000000
GW3Z2	0.000000	0.000000
GW3Z3	222.111908	0.000000
GW3Z4	142.545197	0.000000
GW4Z1	55.142887	0.000000
GW4Z2	0.000000	0.000000
GW4Z3	207.641891	0.000000
GW4Z4	0.000000	0.000000
GW5Z1	186.352600	0.000000
GW5Z2	0.000000	0.000000
GW5Z3	38.529388	0.000000
GW5Z4	142.971603	0.000000
GW6Z1	111.592804	0.000000
GW6Z2	0.000000	0.000000
GW6Z3	57.965401	0.000000
GW6Z4	85.644203	0.000000
GW7Z1	106.264702	0.000000
GW7Z2	0.000000	0.000000
GW7Z3	38.052402	0.000000
GW7Z4	81.487198	0.000000
GW8Z1	0.000000	0.000000
GW8Z2	90.266304	0.000000
GW8Z3	33.873501	0.000000
GW8Z4	62.335400	0.000000
GW9Z1	132.530701	0.000000
GW9Z2	2.141598	0.000000
GW9Z3	167.218796	0.000000
GW9Z4	101.625999	0.000000
GW10Z1	97.913300	0.000000
GW10Z2	82.281609	0.000000
GW10Z3	0.000000	0.000000

GW10Z4	75.084702	0.000000
GW11Z1	0.000000	0.000000
GW11Z2	32.829311	0.000000
GW11Z3	373.468719	0.000000
GW11Z4	0.000000	0.000000
GW12Z1	255.738861	0.000000
GW12Z2	0.000000	0.000000
GW12Z3	0.000000	0.000000
GW12Z4	0.000000	0.000000

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