Performance Assessment of Heterogeneous Irrigation Schemes in India

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ABSTRACT

Most irrigation schemes in India are performing poorly as seen from the average irrigation efficiency in the range of 30-40% for these projects. Hence it is necessary to study the performance assessment of these schemes to investigate the reasons and improve the performance subsequently. There are different kinds of performance measures that may vary spatially over the irrigation scheme. Hence it is necessary to use a framework for finding out the final performance index (FPI) that combines important performance measures. Hence this study was undertaken. Mula Irrigation Scheme in Ahmednagar District of Maharashtra State, India was identified after verifying that most of the needed data was available. The six performance indicators viz. Productivity, Equity, Adequacy Reliability, Flexibility and Sustainability were identified as the important one for obtaining the information on the relative preference from the farmers and first three were considered for obtaining the allocation plans.

The performance of different irrigation schemes is assessed with the help of Area and Water Allocation Model (AWAM). The performance measures viz. productivity, equity, adequacy and excess were obtained by formulating the irrigation strategies based on 1. Irrigation amount: Full depth irrigation (FDI), Fixed depth irrigation (FxDI) and Variable depth irrigation (VDI), 2. Irrigation frequency (14 days, 21 days, 28 days and 35 days), 3. Water distribution: Free water distribution (FWD), Equitable distribution of seasonal water (EDSW) and Equitable distribution of intra-seasonal water (EDIW) and 4. Cropping distribution (Free cropping distribution and Fixed cropping distribution). The yield response of crops to different criteria such as soil, irrigation interval, irrigation strategy and irrigation depth, were analysed.

It is found for wheat grown on all considered soils, the variable irrigation depth strategy provided better performance of irrigation scheme in terms of productivity and results in higher irrigation water use efficiency. It is concluded though that the application of water according to the variable irrigation depth strategy is operationally and from a management point of view not convenient and in current situation may not be adoptable. Though the fixed depth irrigation strategy is found to be less productive based on this research for Mula irrigation scheme, it is more convenient for operation compared to other strategies as it does not involve adoption of separate schedules for different crops.

In general the area and net benefit productivity values are higher in fixed depth irrigation followed by variable depth and then full depth. The productivity values are higher in case of free cropping distribution compared to fixed cropping distribution. The equitable water distribution resulted in lower productivity compared to free water distribution. No specific trend of equity with the irrigation interval was found. Equity values are higher in case of fixed depth of irrigation compared to full depth. The equity values are higher in case of fixed cropping distribution compared to free cropping. The equity values are as expected higher or unity for equitable water distribution compared to free water distribution. The adequacy values are higher in full depth of irrigation followed by variable depth irrigation and fixed depth irrigation. It is observed that the productivity and equity are almost inversely proportional to each other. Hence the hypothesis that productivity and equity conflicts with each other holds true.

Further, Analytic Hierarchy Process (AHP) was used to assign weights of different performance measures by determining the farmers' relative preference of different performance measures. The average weights of different performance measures (monetary productivity, equity in water distribution and adequacy) were obtained for farmers from different reaches from the weights obtained from AHP analysis, and considerable differences were found between the weights for the head, middle and tail reaches. The values of the performance indicators were obtained from the simulation-optimization modeling (AWAM model). The different indicators were combined into a final overall performance indicator (FPI) of irrigation management in an irrigation scheme from the farmers' perspective. The FPI was computed for head, middle and tail reach farmers using the weights obtained from AHP by compromise programming.
It is interesting to note that the strategies that best met the farmers' preferences (highest FPI), were same for middle reach and tail reach farmers however it is different for head reach. It is also interesting to note that the preferences of the head, middle and tail reach farmers, irrespective of their relative location in irrigation scheme, were best met by strategies which include the equitable distribution of water. For middle and tail reach farmers, full depth irrigation would give the highest FPI, while for head reach farmers optimised fixed depth would be best. It is also seen that for head and middle reach farmers a strategy with fixed cropping distribution and free water distribution would be worst for meeting the preferences of head and middle reach farmers while for tail reach farmers a strategy with free water and free cropping distribution would be worst.

The mean values of the weights for head, middle and tail reach farmers were Productivity = 0.33, Equity = 0.31 and Adequacy = 0.36. With these weights, the highest FPI (0.85) was obtained with an irrigation strategy of 'Full depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer'.

Considering the different depth of irrigations (FxDI, VDI and FDI) the VDI and FDI are practically difficult to execute due to the data required for calculations and operational requirements of the irrigation canals. Using FxDI, a strategy with high FPI (0.83) was identified as the best feasible irrigation strategy to implement for the entire irrigation scheme: 'Fixed depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer'.

It was found that this best feasible irrigation strategy for the entire scheme was not sensitive to the weights assigned to the performance measures.

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III. ABBREVIATIONS

A	:	Area
Acc	:	Acceptability Measure
ADL	:	Allowable depletion Level
AGSM	:	Agriculture Sub-Model
AHP	:	Analytical Hierarchical Process
AI	:	Adequacy
A_i	:	Area allocated for irrigation or irrigated of i^{th} allocation unit
a_{ij}	:	Relative importance factor
a_{ij}	:	The judgment value
AMC	:	Available Moisture Content
AQ	:	Adequacy for the irrigation scheme
ASCE	:	American Society of Civil Engineers
AU	:	Allocation Unit
AVHRR	:	Advanced Very High Resolution Radiometer
AWAM	:	Area and Water Allocation Model
BID	:	Bojili Irrigation District
CCA	:	Culturable Command Area
CF	:	Consumed Fraction
CI	:	Consistency Index
CO_2	:	Carbon Dioxide
CP	:	Compromise programming
CP-A	:	Crop production per unit area productivity
CP-W	:	Crop production per unit used water productivity
CR	:	Coefficient of Relation
CRYB	:	Crop Yield Benefit
CS	:	Crop-Soil
CSR	:	Crop-Soil-Region
CV	:	Coefficient of Variation
CWR	:	Crop Water Requirement
D	:	Deep Drainage
Da_i	:	The value of parameter (water allocated in ha-m at allocation unit level) by which equity is measured, computed for ith allocation unit
Dd_i	:	The value of the parameter to which equity should be proportional, assigned to ith allocation unit (culturable command area of ith allocation unit in ha.)
DE	:	Distribution Efficiency
DGI	:	General Irrigation Department
Dist	:	Distributory
Dist.	:	District
DM	:	Decision Maker
DO	:	Direct Outlet
DP	:	Dynamic Programming
DPR	:	Delivery Performance Ratio
$dS\ m^{-1}$	:	deciSiemens per metre i.e. unit of soil salinity
DSI	:	Directorate of State Hydraulic Works
DSIRR	:	Decision Support System for Irrigation
DSS	:	Decision Support System
E	:	Evaporation
EDIW	:	Equitable distribution of intra-seasonal water based on CCA of AU

EDSW	:	Equitable distribution of seasonal water allocation based on CCA of AU
EFC	:	Effectiveness of Fee Collection
EI	:	Equity
ELECTRE	:	ELimination and Choice Translating Reality
ET	:	Evapotranspiration
Eta	:	Actual Evapotranspiration
Etm	:	Maximum Evapotranspiration
EX	:	Excess for the irrigation scheme
FAO	:	Food and Agriculture Organisation
FC	:	Field Capacity
FDL	:	Full Depth Irrigation
f_i	:	Actual value for indictor i
f_i^b	:	Best value for indictor i
f_i^w	:	Worst value for indictor i
FPI	:	Final overall Performance Indicator
FSS	:	Financial Self-Sufficiency
FxDi	:	Fixed Depth Irrigation
FWD	:	Free water distribution
GCA	:	Gross Command Area
GDP	:	Gross Domestic Product
GDSS	:	Group Decision Support System
GIS	:	Geographical Information System
GLEAMS	:	Groundwater Loading Effects of Agricultural Management Systems
Govt.	:	Government
Ha	:	Hectare
IA-CCA	:	Irrigated area per unit of culturable command area productivity
ICA	:	Irrigated Command Area
ICUC	:	Irrigation Consumptive Use Coefficient
IPTRID	:	(Secretariat Food and Agriculture Organization of the United Nations Rome)
IR	:	Irrigation Ratio
IRMOS	:	Irrigation Management and Optimization System
IRS-1C	:	Indian Remote Sensing Satellite-1C
ISDS	:	Intra-season Dry Spell
IWMI	:	International Water Management Institute
IWMS	:	Integrated Water Management Scheme
J	:	Total number of irrigations during the irrigation season/year
Km	:	Kilomete
la_i	:	Actual allocation proportion for ith allocation unit
LBC	:	Left bank canal
ld_i	:	Desired allocation proportion for ith allocation unit
LISS-III	:	Linear Imaging and Self Scanning-III
LP	:	Linear Programming
LQD	:	Loma de Quinto irrigation District
M	:	Metre
M ha	:	Million Hectare
M ha-m	:	Million Hectare-metre
M. S.	:	Maharashtra State
M.L.B.C.	:	Mula Left Bank Canal
M.P.K.V.	:	Mahatma Phule Krishi Vidyapeeth

M.R.B.C.	:	Mula Right Bank Canal
MAUT	:	Multi Attribute Utility Theory
MAVT	:	Multi-Attribute Value Theory
MCDA	:	MULTI Criteria Decision Approach
MCDM	:	Multi Criteria Decision Making
MCEM	:	Multi-Criteria Evaluation Methods
MHRC	:	Mahi Right Bank Canal
Mm	:	Millimetre
MODERATO	:	Management-oriented model
MODIS	:	Moderate resolution Imaging Spectrometer
Na	:	Total number of allocation unit
NB-A	:	Net benefits per unit area productivity
NB-W	:	Net benefits per unit used water productivity
NDVI	:	Normalized Difference Vegetation Index
$\mathbf{NDVI}_{ave}$	:	average Normalized Difference Vegetation Index
NGO	:	Non Government Organisation
NIR	:	Net Irrigation Requirement
No.	:	Number
NOAA	:	National Oceanic and Atmospheric Administration
O & M	:	Operation and Maintenance
Oaa	:	Actual output (total area estimated for irrigation in ha for the existing schedule)
OASIS	:	Options Analysis in Surface Irrigation Systems
Oat	:	Targeted output
Oba	:	Actual output (total net benefits in currency-unit estimated for the existing schedule)
Obt	:	Targeted output or output of management strategy with maximum output
DS	:	Off-season Dry Spell
P	:	Balance factor
P2P	:	Partition-2P
PM	:	Performance Measure
Prga	:	Area productivity (gross)
Prgm	:	Monetary productivity (gross)
PROMETHEE	:	Preference Ranking Organization Method for Enrichment Evaluations
R.L.	:	Reduced Level
$\mathbf{R}^2$	:	Regression Coefficient
RA	:	Resource Allocation sub model.
$\overline{Ra^{bq}}$	:	Average of allocation ratios of the best quarter
$\mathbf{Ra}_i$	:	Allocation ratio of i^{th} allocation unit
RAP	:	Rapid Appraisal Process
RBC	:	Right bank canal
RBDD	:	Red Bluff Diversion Dam
RCI	:	Random Consistency Index
RF	:	Recoverable Fraction
RI	:	Rate of Irrigation
RIS	:	Relative Irrigation Water Supply
RPIP	:	Research Program on Irrigation Performance
RS	:	Remotely Sensed

RWH	:	Rain Water Harvesting
SAWAS	:	inter-Seasonal Agricultural Water Allocation System
SBPP	:	Scenario-Based Policy Planning
SCP	:	Societé du Canal de Provence
SDP	:	Stochastic Dynamic Programming
SEBAL	:	Surface Energy Balance Algorithm for Land
sec	:	Second
SIMIS	:	Scheme Irrigation Management Information System
SIPI	:	Seasonal Irrigation Performance Index
STOPROM-2	:	Stochastic extension of PROMETHEE-2
SWAB	:	This sub-model simulates soil moisture in the soil root zone and estimates the actual crop evapotranspiration and the other related parameters and the irrigation requirement (depth) per irrigation
SWAGMAN	:	Salt Water And Groundwater MANagement
SWAP	:	Soil-Water-Atmosphere-Plant Model
T	:	Crop Transpiration
Tal.	:	Taluqa
UA	:	Users' Association
UK	:	United Kingdom
Unix	:	Uniplexed Information and Computing Services
USA	:	United States of America
USC	:	Upper Swat Canal
V	:	Reservoir volume (m cubic m)
Va_{ji}	:	Volume of water allocated to i^{th} allocation unit during j^{th} irrigation
VDI	:	Variable Depth Irrigation
V_i	:	Volume of water allocated or delivered to the i^{th} allocation unit
Vr_{ji}	:	Volume of water needed according to maximum demand to i^{th} allocation unit during j^{th} irrigation
W	:	Weight
WA	:	Weighted Average
WaDI	:	Water Delivery for Irrigation
WCoG	:	Centroid measure
WDC	:	Water Delivery Capacity
WiFS	:	Wide Field Sensor
WLV	:	Watershed of the Lagoon of Venice
WMIDD	:	Wellton-Mohawk Irrigation and Drainage District
WMU	:	Water Management Unit
WRC	:	Water Research Commission
WP	:	Wilting Point
WU	:	Water Use
WUE	:	Water Use Efficiency
λ_{max}	:	Maximum eigen value of judgment matrix
θ_o	:	Moisture Content
L_i	:	Distance metric of alternative
W_i	:	Weight of indictor i
$\overline{Ra^{pq}}$	:	Average of allocation ratios of the poorest quarter

1. INTRODUCTION

1.1 Preamble

In India the productivity of irrigated agriculture is more than two to three times the productivity of rainfed agriculture. Therefore to meet the food demand of ever increasing population, the development of water resources through construction of irrigation schemes was started since 1951 in India. The average annual water availability of country is assessed as 1869 billion cubic meters (BCM) and total utilizable water resource is assessed as 1123 BCM, out of which 690 BCM is surface water which being used for irrigation and domestic purposes with the help of 352 major, 1037 medium and many minor irrigation schemes and 433 BCM is replenishable ground water resources (Ministry of Information and Broadcasting. Government of India, 2011). India's created irrigation potential has increased from 22.6 M ha in 1951 to about 90 M ha at the end of 1995-96 to 108.21 M ha at the end of March 2010 (Ministry of Information and Broadcasting. Government of India, 2011). Against this, the utilisation of irrigation potential at the end of 1995 was 78.5 M ha. The large gap of over 10 M ha between potential created and utilised is a matter of concern. The main reason for this is lower irrigation efficiencies. Most irrigation projects are operating at a low efficiency in the range of 30-40%, thereby losing 60-70% of the irrigation water during conveyance. It is estimated that even after achieving the full irrigation potential, nearly 50% of the total cultivated area will remain rainfed. The other reasons for low irrigation efficiency being the inappropriate on farm development works and strategies; changes in cropping pattern (shifting to more water intensive crops); inappropriate hydrological planning (pre irrigation); sedimentation of reservoir; irrigation losses in different processes etc.

Thus India has made huge investments in creating the infrastructure for irrigation over the last half century, realizing its importance for increasing the food production for the constantly growing population. This investment in irrigation schemes, together with other improved crop production technologies such as use of fertilizers, hybrid varieties, plant protection techniques etc, made India almost self-sufficient in food production. However still there is a perception that these irrigation schemes do not perform up to the expectation or achieve the goals. This is also evidenced by the fact there is a huge gap of about 15.54 M ha between irrigation potential created and utilised in India’s tenth plan (2002-2007) (Ministry of Information and Broadcasting. Government of India, 2011).

The performance of the irrigation scheme is the result of a large number and variety of activities such as planning, design, construction, operation of facilities, maintenance and application of water to the land or irrigation water management. “Irrigation Water Management” in irrigation scheme is the most important activity once the irrigation potential has been created. It is as important as the creation itself; else the huge investment made in creation of infrastructure will be wasted. The increasing water demand for irrigation to meet the growing demands of the population, competition and priorities of water allocation to non agricultural sectors, limitation to the development of new water resources due to rapidly increasing cost, technical infeasibility and environmental concern have now focused the attention towards the efficient management of the water resources available in the irrigation scheme. The huge gap of created and utilised irrigation potential in India also emphasizes the importance of efficient irrigation water management.

Efficient management of the water resources or irrigation water management within the irrigation schemes involves firstly planning, in which the allocation plan for distribution of land and water resources to different crops up to tertiary level and water delivery schedules in terms of timing and amount of water delivery according to allocation plan are decided based on the set objectives/targets; secondly operation, in which the plan finalized at planning stage is implemented or modified and implemented and thirdly evaluation, in which the related data is collected during operation and analyzed to know the performance. Therefore the irrigation water management in irrigation scheme needs to be viewed from the planning of management to its execution. The success of irrigation water management in the irrigation scheme depends on appropriateness of these processes.

Therefore it is necessary to measure the performance of different processes in irrigation water management for knowing and continuously improving the performance of the irrigation water management in irrigation scheme; to know the relationship amongst different performance measures and also the relative importance and preference of different performance measures to different stakeholders in irrigation schemes. It is also necessary to know how to obtain the optimal policy which includes the trade-off amongst different performance measures according to the preferences of different stakeholders. Hence the present study entitled “Performance Assessment of Heterogeneous Irrigation Schemes in India” is proposed.

1.2 Irrigation Scenario in India and Maharashtra

India is tropical country and rainfall in India is confined mainly to the southwest monsoon months of June to September. The rainfall is irregular and has spatial and temporal variation causing droughts in some parts of the country and floods in others at the same time (Figure 1.1). The all India annual average rainfall is 1,170 mm but it varies from 100 mm (about five rain days) in the western deserts to 11,000 mm (about 50 rain days) in the north-eastern region. Fifty per cent of the average annual precipitation takes place in about 15 days and less than 100 hours altogether in a year (Chaturvedi, 2001). Thus it reveals that there exists great spatio-temporal variability in distribution of precipitation all over India.

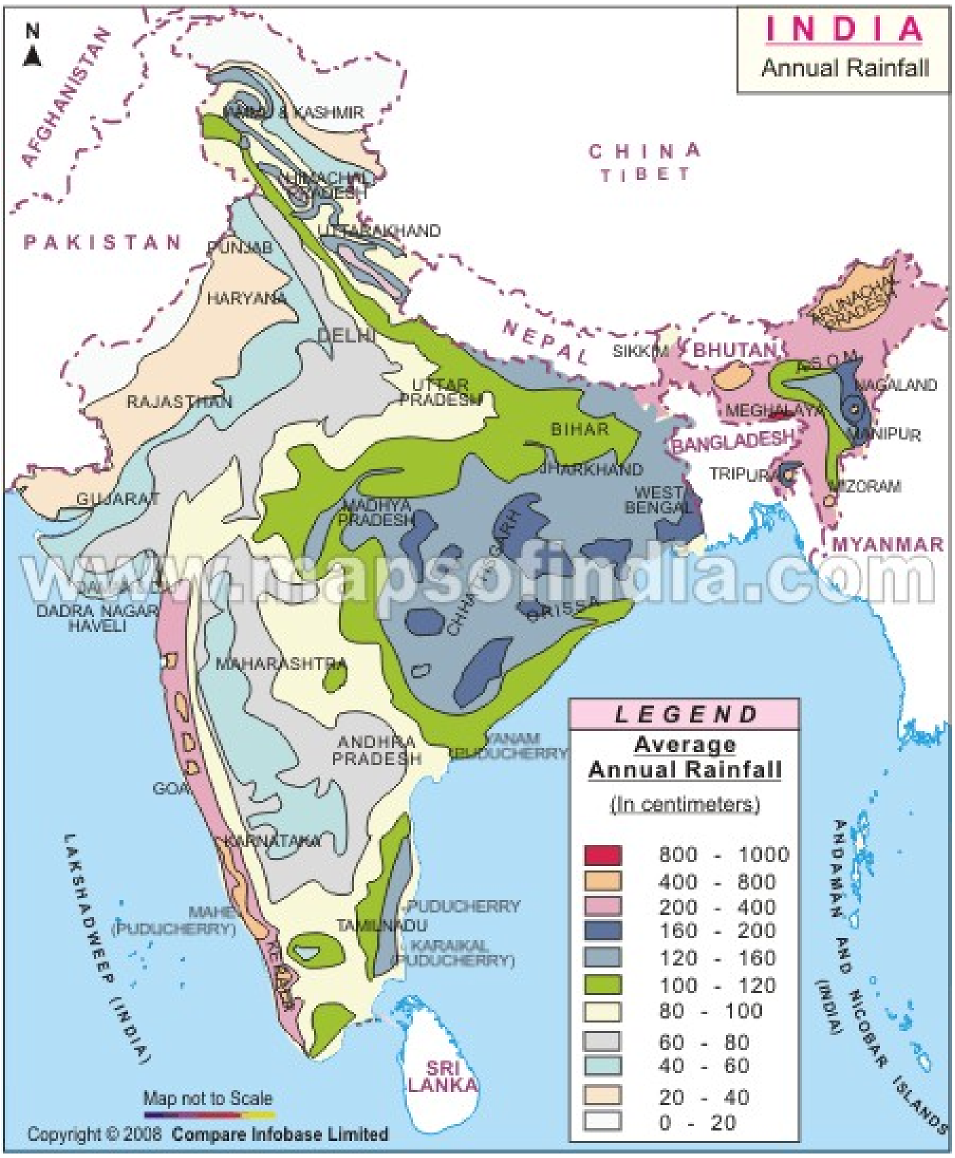


Figure 1.1 Average annual rainfall of India

The average rainfall of the Maharashtra State is approximately 1360 mm. Nearly 88% of the total average rainfall occurs between June to September, while nearly 8% occurs between October to December and 4% after December. As shown in Figure 1.2, there is a considerable variation in the reliability of the rains in different parts of the State of Maharashtra. The steep decline in the rainfall to East of Sahyadri is strikingly noticeable. In the 30 to 50 km wide belt the average rainfall is observed to be less than 650 mm (as low as only 500 mm at some places). Thereafter, the rainfall increases steadily towards east and the average rainfall in the easternmost districts is observed to be 1400 mm (Water Resources Department, Government of Maharashtra, India, 2006).

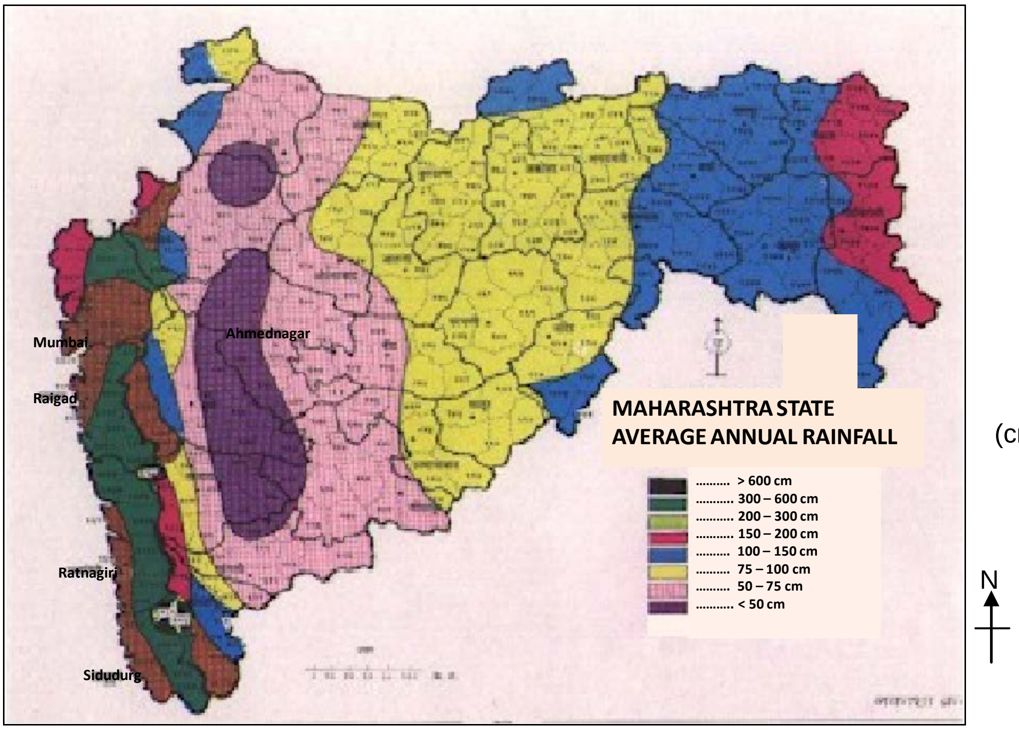


Figure 1.2 Average annual rainfall of Maharashtra

Irrigation has, therefore, been recognised as a vital input for agriculture, contributing not only directly by meeting the evapotranspiration needs of plants, but also indirectly by recharging ground water which can be used by crops at a later date. Irrigation constitutes the main use of water and is thus the focal issue in water resources development. As of now, irrigation use in India is 84 per cent of the total water use. However, due to growing population, the per capita water availability is continuously declining from 5176 m^3 in 1951 to 1820 m^3 in 2001 and 1703.6 m^3 in 2005 (Central Water Commission, India, 2005) and many areas of the country are already facing water stress. Any strategy for integrated development of water resources and its management will necessarily have to go beyond the technical issues to include economic, social and administrative issues. Therefore understanding and addressing the irrigation sector's problems and assessing its performance are thus important for shaping of the future irrigation strategy.

1.2.1 Available Water Resources

The total availability for use from surface and ground water sources in India is 112.2 M ha m (69.0 M ha-m from surface water resources and 43.2 M ha-m from groundwater resources) (Ministry of Information and Broadcasting. Government of India, 2009). The ultimate irrigation potential of the country from major and medium projects is estimated as 58.46 M ha (A project with a culturable command area (CCA) of more than 10,000 ha. is categorised as a major project and that with area between 2,000 ha. and 10,000 ha. as a medium project) and from minor irrigation projects is estimated as 81.43 M ha, of which 17.38 M ha. is from surface water minor irrigation schemes and 64.05 M ha from ground water schemes (A project with culturable area less than 2,000 ha. is a minor irrigation project). The total ultimate irrigation potential is thus 139.89 M ha. (58.46 + 81.43) (Ministry of Information and Broadcasting. Government of India, 2009).

Maharashtra is one of the major states of India and occupies about 9.4 % of the total geographical area of India. The geographical area of the State is 30.8 M ha and cultivable area is 22.5 M ha. The created irrigation potential of the state during pre-plan period (before 1950) was 0.274 M ha. The productivity of irrigated agriculture is more than 2 to3 times the productivity of rainfed agriculture in India (Sinha et al., 1985). This shows the importance of irrigated agriculture in India. Realising the paramount importance of adequate, timely and guaranteed water supply for increasing the agriculture production that plays a key role in alleviating rural poverty, the State has created 3.913 M ha irrigation potential using surface water resources by 2004 through 53 major, 312 medium and 2457 state sector minor irrigation projects. Besides 55 major, 121 medium, 852 State Sector minor projects and 48 lift irrigation projects are under construction in the State (Water Resources Department, Government of Maharashtra, India, 2006). The gross irrigated area in 2008-2009 was 4.037 M ha. (Ministry of Information and Broadcasting. Government of India, 2011). The ultimate irrigation potential, through surface water and ground water resources, has been estimated as 12.6 M ha (Maharashtra Water and Irrigation Commission, 1999). However it is estimated that only 30% of the CCA of the Maharashtra State can be brought under irrigation with this ultimate irrigation potential (Sodal, 2004). As stated earlier, as the irrigated agriculture plays an important role in increasing production, it is necessary to bring more area under irrigation to increase the agricultural production. The social, economic and environmental costs of creating new irrigation potential are tremendous. These costs together with the limitations on ultimate irrigation potential require improving the performance of irrigation schemes in Maharashtra

The above facts indicate the importance of irrigation in the agriculture sector and the improved performance of the irrigation projects in Maharashtra and India.

1.2.2 Different Systems of Water delivery in India

Depending on the type of schemes the water distribution system for irrigation can be different for surface irrigation and groundwater projects. The important models of distribution of water below outlets in surface irrigation commands developed over time in India on the basis of requirements and experience are (Mandavia 1998):

The **warabandi or osrabandi system** of Punjab, Haryana, Rajasthan and Uttar Pradesh;
The **shejpali and block** systems of Maharashtra and Gujarat and satta system of Bihar; and
The **localised system** for paddy areas in the southern states of Andhra Pradesh, Karnataka, Tamil Nadu, etc.

Warabandi or osrabandi (Chambers, 1988 and Mandvia, 1998)

The word warabandi originated from two vernacular words, wara and bandi, meaning `turn' and `fixation' respectively. As such, warabandi literally means `fixation of turn' for supply of water to the farmers. Osrabandi is a synonym of warabandi. Under this system of management, the available water, whatever its volume, is equitably allocated to all farmers in the command irrespective of location of their holdings. The share of water is proportional to the holding area in the outlet command and allocated in terms of time interval as a fraction of the total hours of the week. Whereas the term warabandi is commonly used in Haryana, Punjab and Rajasthan, this system of water distribution is usually referred to as osrabandi in Uttar Pradesh.

Shejpali, block and satta systems (Chambers, 1988 and Mandvia, 1998)

The main feature of these systems is that the government enters into some sort of agreement with the farmers for supplying water to them. The farmers file applications and the government issues permits for the supply of water and the two together constitute the agreement. The shejpali and the block systems are practised in Maharashtra, Gujarat and parts of Karnataka, whereas the satta system was evolved and is still in use in the Sone command area in Bihar, which is one of the oldest irrigation systems of the country. The word satta means agreement. The satta system includes the features of both the shejpali and the block systems.

Under the shejpali system the water is distributed according to a predetermined date in each rotation. A preliminary programme is drawn up every year depending on the availability of water. Farmers submit applications for supply of water indicating the crops they wish to grow and the areas under them. Water is then apportioned on the basis of the crops and the overall demand. Proportionate reductions in the irrigated area proposed by the farmers are made if the demand is found to be higher than the water available. A schedule, known as shejpali, fixing the turns to different farmers for the sanctioned crop area is prepared for each rotation. The farmers at the tail-end of the command are served first, those at the head of the watercourse are served last. The irrigation interval depends on the rate of water consumption by the crops, i.e. high water consuming crops may be supplied water in each rotation, whereas the lighter crops on the same outlet may get irrigation on alternate rotations. The schedule so made is notified in advance and every farmer of the command has prior information about his turn of supply. The system is called `rigid shejpali' if the duration of supplying water to the various fields along with the date is also recorded on the permits issued to the farmers for sanctioned areas. This checks the tendency of the farmers to overdraw water.

Under the block system, a long-term arrangement for supply of water is done particularly on perennial crops, but irrigation from season to season proceeds through shejpali. One third of each block is to have sugarcane and the remaining two thirds is to be used for seasonal crops. The blocks are sanctioned for six to twelve years. There is assured supply of water for a long period under this system and farmers therefore can go for land development and plan their cultivation well.

The localised system for paddy areas (Chambers, 1988 and Mandvia, 1998)

In most of the irrigation projects of southern and north-eastern states as well as in the states of West Bengal, Orissa, Bihar and Jammu & Kashmir, where paddy is the main crop, the irrigation below the outlets proceeds from one field to the other through surface flooding. The individual holdings are thus irrigated one after the other or even more than one field is irrigated at a time. Such a method of water distribution is prevalent in many of the outlet commands (where warabandi has not been introduced) in the Chambel Irrigation Project of Rajasthan. However, in Tamil Nadu and some other states, the farmers have a rotational system of water distribution in the outlet commands of some irrigation projects on one and a half days to four days basis for paddy crop and a longer interval for other crops. In this case, the water allocation is for a specified crop in a season and penalty is levied for deviation.

1.3 Performance of Irrigation Water Management

Benchmarking is a continuous process of measuring one's performance and practices against the best competitors and is a sequential exercise of learning from other's experience. It is the process of comparison with relevant and achievable internal standards as measured against the previous achieved goals or the future desirable targets (or external ones set by other similar organisations). Performance of irrigation water management can be viewed as the important step of benchmarking. Comparative performance indicators make it possible to see how well irrigated agriculture is performing at the subsystem, system, basin or national scale. The comparative performance indicators enable policy makers and planners to know how productive their use of water and land for agriculture is. They help answer important strategic questions, such as: What types of systems are getting the most from limited water and land resources? Which part of the system is productive? What are the gaps that need to be addressed for improving the performance? How much should we invest in irrigated agriculture, and how? At the same time, they provide a cost-effective means of tracking performance in individual systems.

As a tool for measuring the relative performance of irrigation systems or tracking the performance of individual systems the performance indicators help. Gorantiwar and Smout (2005) provided the detailed framework for the performance assessment of the irrigation schemes. Different performance measures of importance are: productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency. These performance measures vary temporally and spatially. Different stakeholders may have different views on the performance measures as:

Policy makers and planners to evaluate how productively land and water resources are being used for agriculture, and to make more informed strategic decisions regarding irrigation and food production.

Irrigation managers to identify long-term trends in performance, to set reasonable overall objectives and to measure progress.

Researchers to compare irrigation systems and identify factors that lead to better performance.

Donor agencies, governments and NGOs to assess the impact of interventions in the irrigation sector and to design more effective interventions.

Farmers to improve their net benefits

Thus it is necessary to know the interrelationships amongst the different performance measures and behaviour of these measures in irrigation schemes to enable to plan for the management of scarce water resources in an irrigation scheme to further improve the performance of the irrigation water management of the irrigation scheme.

1.4 Hypothesis and Objectives

1.4.1 Hypothesis

For irrigation schemes under rotational water supply:

1. The different performance measures of irrigation water management in the irrigation scheme (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency) conflict with each other.
2. The relative importance of different performance measures varies between locations within the irrigation scheme i.e. head, middle and tail reach.
3. The optimum allocation policies (i.e. the model allocates land and water resources optimally to different crops grown on different soils in different allocation units, with the help of irrigation programmes obtained for different Crop-Soil-Region) for different performance measures can be obtained by evaluating different irrigation strategies (i.e. the existing irrigation schedule specified for the particular Crop-Soil-Region (CSR) unit is the irrigation strategy for that CSR unit).
4. It is possible to obtain the suitable policy by identifying the tradeoff amongst different performance measures.

1.4.2 Objectives

1. To study the relative importance of performance measures to farmers (water users) in different locations in an irrigation scheme (Mula Irrigation Scheme in Maharashtra, India).
2. To study the performance of irrigation water management in irrigation schemes in terms of different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency).
3. To provide the guidelines for improving the performance of irrigation water management in irrigation schemes.
4. To test a technique for obtaining the suitable optimal policy based on the relative preferences of the farmers to different performance measures in allocation process.

As described in Chapter 3, Mula Irrigation Scheme was chosen as the case study for investigation.

1.5 Structure of this thesis

The **Chapter - 2 Review of literature** provides brief review on studies done in the past on performance assessment of different irrigation schemes by several researchers. Firstly the different performance measures used by different research scientists are reviewed followed by their application in performance assessment of different irrigation schemes. Further the different models developed (Area and Water Allocation Model (AWAM), Management-Ooriented Model (MODERATO), An inter-seasonal agricultural water allocation system (SAWAS), Scheme irrigation management information system (SIMIS), Soil-Water-Atmosphere-Plant (SWAP), Surface Energy Balance Algorithm for Land (SEBAL) etc.) and their approaches (stochastic dynamic programming, linear programming, multi- criteria decision making, etc.) for Performance Assessment are discussed. After that different studies on the use of multi criteria decision making (MCDM) and analytical hierarchical process (AHP) for final performance of irrigation schemes are reviewed.

In the **Chapter - 3 Methodology** the methodologies used and tested for knowing the relative importance of performance measures to different stakeholders (water users) and the technique for obtaining the suitable optimal policy by including the tradeoff amongst different performance measures and stakeholders in allocation process are described. The chapter sequentially describes the selection of irrigation schemes and data collection. Further it explains the steps used for assessment of the performance of irrigation water management, analysis of the performance results, finding out the relative preference to different performance measures by different stakeholders (water users), knowing the different performance measures and final performance in response to different irrigation strategies and the tradeoff analysis of the performance measures.

The **Chapter - 4 Results and discussion- AHP analysis** explains the use of Analytical hierarchical process to obtain the preference and intensity of preference of one performance measures compared to another performance measures from different stakeholders. This incorporates how the questionnaire is designed, how the responses of different stakeholders to the questionnaire are obtained and how the responses to obtain the weights to different performance measures are analysed.

The **Chapter - 5 Result and discussion (Based on AWAM Model) (II),** the performance measures obtained with the help of AWAM model are presented and discussed. The results with respect to the values of the performance measures obtained and importance given by different stakeholders were used to obtain the suitable optimum policy. The response of different criteria such as soil, irrigation interval, irrigation strategy, irrigation depth, crops to water use and actual yield are analysed. Further the trade-off analysis is performed.

Chapter - 6 Results and Discussion (Final Performance of the Mula Irrigation Scheme) (III) enumerates the performance results in terms of productivity, equity, adequacy and excess were obtained for different irrigation intervals, irrigation strategies and cropping distributions

The **Chapter - 7 Conclusion** summarises the entire research work done and concludes the output of this study.

Further in **Chapter - 8 Bibliography** enumerates the detail list of the information sources referred and used in this research study.

The performance measures along with their different attributes suggested by different researchers are tabulated and presented in **Appendix-A.** The details of different performance measures used by researches/managers are tabulated and presented in **Appendix-A1**. **Appendix-A2** contains the values of different performance measures estimated for different irrigation schemes. Further the Questionnaire for using AHP to assign weights to different performance measures and their attributes is given in the **Appendix-C. Appendix-B** contains the data of Mula right bank canal (MRBC) network. **Appendix-B1** contains Schematic layout of outlets, minors, distributaries and Branch canals in Mula Right Bank Canal (MRBC) at Level-1 and **Appendix-B2** contains Schematic layout of Mula Right Bank Canal (MRBC) network showing the locations where groups of farmers were interviewed to know their preferences of performance measures for AHP analysis. **Appendix-C** contains the questionnaire and **Appendix-C1** contains an example of relative preference of different performance measures of irrigation scheme using AHP. **Appendix-D** contains Final Performance Index (FPI) values for Head, Middle and Tail Reaches for all irrigation strategies considered in the study. **Appendix-D1** contains the crop-area allocation under different irrigation strategies for the Mula Right Bank Canal scheme. **Appendix-D2** and **Appendix-D3** contain the Final Performance Index Values for different irrigation strategies using mean weights to performance measures.

Appendix -D4 (1 to 4) contains Final Performance Index Values for different irrigation strategies using equal weights and different combinations of weights to different performance parameters.

2. REVIEW OF LITERATURE

2.1 Preamble

The aim of this research study is to assess the performance of irrigation water management of heterogeneous irrigation schemes in India. The heterogeneous irrigation schemes as defined by Smout and Gorantiwar (2005b) are the large surface irrigation schemes with several crops, soils, and a large network of canals with varying characteristics - design capacities, efficiencies, command area, length, duration of operation, etc. According to them as the schemes in semiarid and arid regions are further associated with limited water supply and operate under rotational water distribution, the irrigation management in such cases is a complex process. It is necessary to assess the performance of such schemes to enable the irrigation managers to know how good or bad the scheme is performing. The performance assessment also highlights on the causes of low performance and provides the information on enhancing the performance of the irrigation schemes. In the past several researchers provided different indicators for the performance assessment and worked on the performance assessment of irrigation schemes that varied from simple to heterogeneous in nature. This chapter attempts to provide brief review on these studies.

In this study the analytical hierarchical process (AHP) is proposed to be used for obtaining the information on the relative preference of different performance measures and their importance by water users in terms of weights. AHP has been used in the past for obtaining the information for knowing the relative preference of different criteria in irrigation water management. This chapter also reviews these studies. In addition to this, the multi criteria decision making (MCDM) is proposed for developing the methodology for obtaining the overall performance index. The MCDM methodologies used for irrigation water management are also reviewed in this chapter.

2.2 Performance Parameter

Different researchers involved in management of irrigation schemes suggested various performance measures. These measures and their definition vary from region to region. Further many studies are reported in literatures, that present, the values of different performance measures for the irrigation schemes were studied. The first part of this section presents reviews on performance measures and second part presents the use of these performance measures for different irrigation schemes.

2.2.1 Performance measures

It is necessary to know the performance of the irrigation schemes that enable to help the irrigation managers to improve the performance of the schemes. Historically productivity was the important and widely used performance measures. However later realizing the importance water scarcity and social issues, the other performance measures were also included. This section reviews these performance measures along with their definition and formulae.

Earlier studies mostly proposed the performance measures that are to be determined on the basis of measurements to be made or survey. The examples are the performance measures that are proposed by **Abernethy (1986)** which include equity, regularity, reliability and durability; **Chambers (1988)** which includes productivity, equity and stability; **Uphoff (1988)** which includes productivity, equity, harmony, environmental sustainability and economic sustainability or cost effectiveness; and **Abernethy (1989)** which includes productivity, equity, profitability, sustainability and quality of life. Later on the researchers included the performance measures that can be determined from the simulation modeling studies. Such measures are useful to know the current performance and estimate these performance measures for different irrigation scenarios.

According to **Clemmens and Bos (1990)**, there are several different parameters that can be measured and used to describe the performance of water delivery service. These are: flow rate, volume, duration, pressure, and frequency. Scheme conditions and objectives dictate which ones to consider for the performance assessment. Authors characterized the overall performance of an irrigation water delivery system into two components *viz.* the delivery schedule and operations. They proposed the ratio of intended to required water (volume, rate, duration, etc.) for performance of the delivery schedule and ratio of actual to intended water for the performance of operations. The overall performance needs to be estimated by the product of these two ratios; the actual divided by the required water. Further they provided the statistical relations to determine the irrigation performance in terms of equity, adequacy and reliability.

Plusquellec et al.(1990) proposed water availability, water use efficiencies (conveyance, field application and overall efficiencies), equity of water distribution, cropping intensity and crop yields and project economic rates of return as the performance measures.

Molden and Gates (1990) proposed adequacy, efficiency, dependability, and equity of water delivery as the performance measures of the irrigation schemes. Adequacy assesses whether the requirement has been met by the amount of water delivered. Efficiency is a measure for the excess of water delivered in comparison with the requirements. Dependability expresses the degree of temporal variability of irrigation delivery compared to requirements. Equity is a measure for the spatial uniformity of water deliveries and shows the fairness of water delivery across delivery points.

Small and Svendsen (1990) presented a framework for conceptualizing irrigation performance. They categorized performance according to their purposes, with significant differences among those that monitor operational performance, those that facilitate interventions to improve performance, and those that promote accountability within an operating agency. Thus they identified three distinct categories of performance measures. These are: process measures, impact measures and output measures. Process measures of performance relate to a system's internal operations and procedures. Output measures of performance examine the quantity and quality of the system's final outputs. Impact measures of performance pertain to the effects that the system's outputs induce in its larger environment.

Bos *et al.* (1994) presented a framework for irrigation managers that can be used in assessing performance of irrigation, and recommended a specific set of indicators for measuring performance that they believed to be most practical, useful, and generally applicable. The primary focus of the authors was on the management of canal systems for agricultural production but they also described the indicators that can be used for assessing long term performance, including physical, economic and social sustainability. They proposed several performance measures in their framework *viz.* water supply performance (conveyance indicators, maintenance indicators, utility of water supplied, and equity), agricultural productivity (area indicators and production indicators) and economic, social and environmental performance (economic viability, social viability and environmental sustainability and drainage). Area indicators of productivity proposed by the author are irrigated area performance as the ratio of actual area irrigated to target area and cropping intensity performance as the ratio of actual cropping intensity and target cropping intensity; and production indicators are production performance as the ratio of total production to target production, yield performance as the ratio of actual yield to target yield and water productivity performance as the ratio of actual water productivity to target water productivity. They emphasized on the necessity of having an incentive system that encourages managers to improve performance.

While reviewing the performance assessment of irrigation schemes in California, USA, **Purkey and Wallender (1994)** found two types of performance indicators commonly in use. These are: related to the operation of a water delivery system and on-farm irrigation performance. Water delivery system performance includes irrigated area performance, fee collection performance, conveyance efficiency, distribution efficiency, efficiency of infrastructure and total financial viability; and on-farm irrigation performance includes application efficiency and distribution uniformity.

Gorantiwar (1995) proposed the productivity, equity, stability and sustainability as the performance measures at scheme and below scheme levels for knowing the seasonal and intra-seasonal performance of the irrigation schemes in semi arid tropics under rotation water supply. He proposed productivity by all those forms through which it can be included while obtaining the allocation plans i.e. total net benefits, total area irrigated, total crop production for the single crop case, net benefits per unit area irrigated, crop production per unit of area irrigated for a single crop, crop production per unit water used for a single crop, net benefits per unit water used, maximum irrigated area per unit of culturable command area. He proposed the equity for area, water, crop production and net benefits. According to him the equity can be included to be proportional to area, water requirement or other aspects (such as family size) while obtaining the allocation plans. He proposed different formulae for the measurement of seasonal and intra seasonal equity at scheme and below scheme level. Stability and sustainability were proposed for obtaining the long term allocation plans.

Bos (1997) summarized the performance indicators used in the Research Program on Irrigation Performance (RPIP). RPIP quantify and test around 40 multidisciplinary performance indicators related to water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economic and management. Author stated that these indicators are sufficiently enough to evaluate the irrigation and drainage performance. He provided the detailed methodology for assessing these performance indicators and also proposed to measure and to collect the field data and analyzed the measured and collected data to know these measures.

In an attempt to standardize the definitions and approaches to quantify various performance measures, the ASCE Task Committee on defining Irrigation Efficiency and Uniformity provided a set of performance measures (**Burt *et al.* 1997**). These measures are: Irrigation efficiency, Irrigation consumptive use coefficient, irrigation sagacity, distribution uniformity, application efficiency, adequacy and potential application efficiency. They also proposed the spatial (field, farm, scheme, basin) and temporal intervals (irrigation event, season etc) for assessing these performance measures. According to the authors many of theses performance measure can be measured with the help of water balance studies for which authors have provided a detailed methodology.

Bastiaanssen and Bos (1999) reviewed different performance measures that can be determined from remote sensing determinants such as actual evapotranspiration, soil water content and crop growth that reflect the overall water utilization at a range of scales, up to field level. Crop evapotranspiration includes water originating from irrigation supply, water from precipitation, groundwater and water withdrawn from the unsaturated zone. The different performance measures proposed to be determined by remote sensing data are: adequacy (crop water stress index, relative water supply, water deficit index evaporative fraction and soil moisture); equity (water application per unit area, CV of evapotranspiration, CV of evaporative fraction, CV of depleted fraction); reliability (temporal variation of the evaporative fraction); productivity (actual evapotranspiration over water applied, yield over water applied, yield over evapotranspiration); sustainability (irrigation intensity, water-logging, salinity of top soil).

Hales and Burton (1999) proposed several performance measures, many of them to be assessed by the modeling. These are: potential evapotranspiration demand at offtake, total volume allocated at intake (MCM), total effective rainfall (MCM), relative water supply, over-supply ratio, unsatisfied demand ratio, relative evapotranspiration, total crop yield loss, gross crop value at maximum yield, pre-harvest cost of crops, net crop value at maximum yield, potential net value at present yield, relative yield (gross), relative profitability, specific yield ($/MCM) and conveyance efficiency

While assessing the performance of water users' associations in the Lower Tunuyan area, Argentina, **Bustos et al (2001)** proposed to use fee collection ratio (actually collected service fees/total billed service fees) as proposed by Bos (1994) as the main indicator. They however concluded that an up-to-date water user's register is needed to charge the actual user with the correct fee and estimate this particular performance indicator.

Malano and Burton (2001) while describing the guidelines for benchmarking performance in the irrigation and drainage sector provided many indicators that they grouped in four categories *viz.* irrigation service delivery - system operation, irrigation service delivery - financial indicators , productive efficiency and environmental performance. The indicators under "irrigation service delivery - system operation" include total annual volume of irrigation water delivery (m3/year), annual irrigation water delivery per unit command area (m3/ha), annual irrigation water delivery per unit irrigated area (m3/ha), annual main system water delivery efficiency, annual relative water supply, annual relative irrigation supply, water delivery capacity and security of entitlement supply. Irrigation service delivery - financial indicators include cost recovery ratio, maintenance cost to revenue ratio, total MOM cost per unit area ($/ha), total cost per person employed on water delivery ($/person), revenue collection performance, staffing numbers per unit area (Persons/ha) and average revenue per MCM of irrigation water supplied ($/m3). The type "productive efficiency" includes gross annual agricultural production (tonnes), total annual value of agricultural output ($), output per unit serviced area ($/ha), output per unit irrigated area ($/ha), output per unit irrigation supply ($/m3), output per unit water consumed ($/m3). Environmental performance indicators include water quality: salinity (irrigation water, mmhos/cm), water quality: Salinity (drainage water, mmhos/cm), water quality: biological (irrigation water, mg/litre), water quality: Biological (drainage water, mg/litre), water quality: chemical (irrigation water, mg/litre), water quality: chemical (drainage water, mg/litre), average depth to water table (m), change in water table depth over time (m), salt balance (tonnes). The indicators provided by Malano and Burton, however do not include the performance indicators related to equity and adequacy which are very important in the assessment of performance of irrigation scheme.

Ray et al (2002) proposed the performance evaluation measures based on multi-temporal remote sensing (RS) data-based crop inventory, generation of vegetation spectral index profiles and crop evapotranspiration estimation. These are: adequacy (based on relative water supply), equity (based on NDVI), agricultural productivity (cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land and productivity of water)

According to **Plantey and Molle (2003),** the principles of public service management needs to be followed while assessing the performance of the irrigation scheme. According to this principle the objectives of the performance should be: continuity, equity, sustainability and transparency, to guarantee the quality of services at minimum cost. They have proposed water balance indicators (Conveyance and distribution efficiency ratios as measured outflow over measured inflow; and water delivery performance as actually delivered volume/intended delivered volume", "dependability of supply", "regularity of deliveries), maintenance indicators (reliability), environmental indicators (water quality, compliance with environmental regulations safety), commercial indicators (rate of recovery, quickness of payment) and financial indicators ("financial self-sufficiency). They have also presented the detailed description of different indicators along with definitions and formulae.

Perry (2005) proposed a methodology to determine the irrigation performance in terms of reliability and productivity using evapotranspiration mapping with the help of remote sensing. According to author, out of 57 indicators published by International Water Management Institute (Rao, 1993), majority of the indicators were based on the measurements of the physical parameters (flow rate, irrigation schedules, yields, canal seepage, irrigation depths etc) at field, project or wider scale. The author stated that the simplest one performance indicator to measure and understand is the management effectiveness which is a ratio of (irrigation delivery + effective rainfall) and (evapotranspiration + seepage and deep percolation). Measurements for these variables at various points in irrigation scheme and at regular intervals provide an indication of whether water availability exceeds or fall short of demand. Reliability provides the inducement for farmers to invest in higher productivity – to the benefit of themselves and society, which is also very useful guideline for managers and system designers. Author remarked that Remote Sensing efficiently help to address spatial monitoring of seasonal trends in ET which can be used in determination of reliability and productivity. Understanding the relationship between reliability and productivity has important implications for the productivity of water in agriculture.

Yercan *et al.* (2004) defined irrigation management transfer as "*the transfer of authority and responsibility to manage irrigation systems from government agencies to water users organizations*". According to authors comparisons of indicators should be made between systems which have undergone transfer versus system and those which have not over the same period of time. They have proposed following criteria for this purpose:

1. Physical performance criteria: the rate of irrigation (RI) = irrigated land (ha)/˙Irrigable land (ha) and sustainability of irrigated land = irrigated land (ha)/initial irrigated land (ha).

2. Economic performance criteria: the effectiveness of fee collection (EFC) = collected fee/total fee and financial self-sufficiency (FSS) = annual fee revenue/total annual expenditures.

According to **Gorantiwar and Smout (2005a)**, the studies of the performance assessment of irrigation schemes have gained momentum since the late 1980s due to the common perspective that the resources (land and water) in irrigation schemes are not being managed appropriately. They considered "irrigation water management" as one of the activities of the irrigation scheme. They proposed a framework for the performance assessment of irrigation water management in heterogeneous irrigation schemes, based on earlier studies made in this direction. Framework consists of three phases of irrigation water management namely planning, operation and evaluation for assessment of performance for which two types of allocative measures (productivity and equity) and five types of scheduling measures (adequacy, reliability, flexibility, sustainability and efficiency) are proposed. The authors provided the detailed methodologies for estimating these performance measures for the scheme as a whole and at different levels below scheme during different phases of irrigation water management. They also addressed the seasonal and intra-seasonal performance measures during different phases of irrigation water management.

While examining the socio-economic and financial performances of irrigation schemes under the Ogun-Oshun River Basin and Rural Development Authority in Nigeria **Olubode-Awosola et al (2006)** proposed performance indices based on the indicators proposed by Bos (1997). These are: fee collection index as the ratio of irrigated fees collected and irrigation fees due, user's stake index as the ratio of number of active project farmers and total number of project farmers, relative water cost index as the ratio of irrigation cost per ha and total production cost per ha, relative irrigation profit index as the ratio of irrigated cropping profit per ha rain-fed cropping profit per ha, financial self-sufficiency index as the ratio of actual income to total recurrent expenditure on irrigation related services and financial self-sufficiency index as the ratio of actual income to total recurrent expenditure on irrigation related services.

Akkuzu *et al* (2007) assessed the water delivery performance of four Water User Associations(WUA) in the Gediz Basin Irrigation System, Turkey by devising the four performance measures based on the remote sensing techniques namely: irrigation ratio (actual irrigated area/projected irrigation area), water use ratio (actual water use/target water use), average Normalized Difference Vegetation Index ($NDVI_{ave}$) and coefficient of variation of NDVI for equity in water delivery. The authors elaborated in detail how to estimate the NDVI values with the help of remote sensing data for the determination of performance measures.

Clemmens and Molden (2007) suggested that crop-scale irrigation uniformity can be examined at a project scale by understanding how field, farm and project irrigation systems contribute to non uniformity. In this process they proposed two performance measures related to water supply. These are: annual relative water supply (RWS), which is the ratio of total water supply and crop water requirement; and annual relative irrigation water supply (RIS) which is the ratio of irrigation water supply to crop irrigation water requirement.

Based on the review of the literature on the performance measures, **Latif and Tariq (2009)** described different performance indicators to assess performance of irrigation schemes. These are: relative water supply (the ratio of total water supply to total water demand at field level), water delivery capacity (canal capacity to deliver water at the system head to the peak consumptive use demand), delivery performance ratio (the ratio of the actual discharge and design or authorized discharge) and reliability (ability of a system to deliver design irrigation supplies in a given time span).

The studies reported in this section are summarized in APPENDIX - A. The different persforamnce measures as used by different researchers are shown in Box 2.1. It is seen from the above referred studies and information provided in table 2.1 that several performance indicators have been proposed to know the performance of irrigation schemes. These performance measures need to be measured at field level, scheme level or at wider scale i.e. basin level. Along with the spatial variation, these measures also have temporal variation such as for the irrigation event or intrasesonal period, irrigation season or year. Some measures are to be measured during operation (such as adequacy) and some after the irrigation season (such as productivity). The framework proposed by Gorantiwar and Smout (2005a) is based on the previous studies reported by Abernethy (1986), Chambers (1988), Abernethy (1989), Clemmens and Bos (1990), Molden and Gates (1990) and Bos et al. (1994) that are based on the extensive field observations. Therefore while estimating the performance indicators in this study, the guidelines of the framework proposed by Gorantiwar and Smout (2005a) will be considered.

The reviews show that the authors focused on the estimation of performance measures such as productivity (economic efficiency or total values such as net returns etc.), equity, adequacy, reliability, sustainability, efficiency (various types), dependability etc. The different performance indices addressed by different authors are given below.

Productivity: Isidoro et al 2004, Gorantiwar (1995), Small and Rimal 1996 , Bos et al 1997, Bastiaanssen et al 1999, Ray et al 2002, Perry 2005, Gorantiwar and Smout 2005a, Mujumdar and Vedula 1992, Sarma and Rao 1997, Levite and Sally 2002, Roost 2002, Raju and Pillai 1999.

Equity: Makin et al 1991 , Molden et al 1990, Gorantiwar (1995), Bos et al 1997, Bastiaanssen et al 1999, Ray et al 2002, Gorantiwar and Smout 2005a, Akkuzu et al 2007, Bhutta and Velde 1992, Kalu et al 1995, Renault 1999, Syme et al 1999, Jahromi et al 2000, Santhi and Pundarikanthan 2000, Levite and Sally 2002, Roost 2002, Evans 2003 (income distribution), Unal 2004, Vandersypen et al 2006, Gaur 2008 (spatial).

Reliability: Makin et al 1991, Perry 2005, Gorantiwar and Smout 2005a, Latif and Tariq 2009, Mujumdar and Vedula 1992, Jahromi et al 2000, Perry 2005.

Adequacy: Makin et al 1991 , Molden et al 1990, Burt et al 1997, Bastiaanssen et al 1999, Ray et al 2002, Gorantiwar and Smout 2005a, Akkuzu et al 2007, Renault 1999, Santhi and Pundarikanthan 2000, Unal 2004, Vandersypen et al 2006, Raju and Pillai 1999, Jahromi et al 2000(Ability).

Efficiency: Isidoro et al 2004 (distribution), Molden et al 1990, Purkey et al. 1994(conveyance, distribution and application), Bos 1997 (water use), Burt et al 1997 (Irrigation and application),Hales and Burton 1999(conveyance), Malano and Burton (2001) (productive), Plantey and Molle. 2003 (conveyance and distribution), Gorantiwar and Smout 2005a, Kalu et al 1995, Renault 1999, Evans 2003 (land and water use), Unal 2004, Parsinejad et al 2009(application).

Dependability: Vandersypen et al 2006; Molden et al 1990, Unal 2004, Vandersypen et al 2006.

The above facts show that the productivity, equity and adequacy measures are important and addressed by most of the researchers. In this study also the focus is provided on theses three performance measures; though the methodology developed includes all types of the performance measures.

Box 2.1. The different performance measures as proposed by different researchers.

2.2.2 Performance measures: Application

In previous section the different performance measures proposed by various researchers were presented. Predominantly the researchers proposed productivity, equity and adequacy performance measures for performance evaluation. This section describes the use and applications of these proposed performance measures to know the performance of different irrigation schemes.

2.2.2.1 Application of performance measures at scheme level

2.2.2.1.1 Seasonal performance measurement

Mujumdar and Vedula (1992) evaluated the performance *Malaprabha* Reservoir Project, Krishna River Basin, Karnataka, India using Stochastic dynamic programming (SDP). They used three performance indicators namely reliability, resiliency and productivity index. The performance of the reservoir is evaluated when it is operated with optimal operating policies over a sufficiently long period of time. Three different optimal operating policies were derived, having increasing mathematical complexity. Two of the three policies, policy II and Policy III, incorporate a detailed soil moisture dynamics model as an integral part of SDP. Policy III considers, in addition, an optimal allocation of water among the irrigated crops when there is competition of water. The reservoir releases are simulated under each optimal operating policy using synthetically generated inflows, and a comparison of the system performances is made. When initial moisture content (θo) was taken at highest value (i.e. Field Capacity) for policy I, II, and III the reliability indices were found to be 0.63, 0.95 and 0.99 respectively and the resiliency values were found to be 0.45, 0.96 and 0.95 respectively. For lower value of θo both policy II and III resulted in higher reliability (0.87 and 0.89 respectively) and resiliency index values were 0.68 and 0.22 for policy II and III respectively. Thus they concluded that the performance under policy II and III was always better than policy I in terms of reliability and resiliency, and depended heavily on θo. The sub-optimization used in policy III did not found helpful to increase productivity where it is likely to occur large water deficit in critical growth stage of crop resulting low crop yield. However the policy II which allocated water proportional to individual crop requirement resulted in high productivity index. They stated that including soil moisture dynamics in optimization model deriving operating policy for reservoir enhances the performance of system.

Makadho (1996) suggested a methodology for quantifying timeliness indicators in smallholder irrigation systems in Zimbabwe. The indices were used to compare the performance of some types of smallholder irrigation schemes in Zimbabwe. The results indicated that applying measures of timeliness helped to assess water management practices across scheme types. The methodology they followed in the study differentiated between timely irrigation deliveries which crop water requirements (CWR) and surplus water supplies due to poor timeliness which could not be used by the crop, hence denoting wastage. They revealed that timeliness indices provided more information regarding management practices than simple measures of total water applications over a given season.

Small and Rimal (1996) studied the effect of alternative water distribution rules on irrigation system performance based on a simulation analysis that reflected physical and economic conditions typically found in rice irrigation systems in Asia. They evaluated the irrigation performance implications for alternative water distribution rules for dry season under varying degrees of water shortage. They found that economic efficiency and equity among farmers within the portion of the irrigation system in any given season as complementary, and not competing objectives. According to them economic efficiency and equity among all farmers within the command area of the irrigation system are largely complementary strategies at the lower levels of water shortage, but with increasing shortage, significant tradeoffs develop between these objectives.

Hales and Burton (1999) used computer water management model, IRMOS for diagnostic analysis and performance enhancement of the Rio Cobre Irrigation Scheme, Jamaica which supplies water to 5000 ha command area and around 400 farmers. Authors compared the performance of irrigation scheme for optimal water allocation policy with that for the existing actual one; given the same cropping pattern, rainfall, climatic conditions and water supply. They evaluated the performance in terms of total volume allocated, total effective rainfall, Relative water supply, Supply:demand ratios, Relative yield, Relative profitability, Specific yield, conveyance efficiency. They collected the field data such as canal discharges, gauge readings, cropping patterns, crop yields and daily evaporation and rainfall also the derived data such as canal seepage losses, irrigation efficiencies and crop yields. The performance was evaluated seasonally at scheme level. They revealed that the relative water supply for optimal water allocation during the study period was 1.08, in comparison with 1.19 for the actual allocation (which signified 8% over-allocation) implying a better overall match between supply and demand for Water Management Units (WMUs). A water allocation was found to be more equitable, though supplies remained limited resulting in some WMUs having RWS values <0.8. The unsatisfied demand ratio in the optimal mode during periods of water shortage was 30% for optimal water allocation in comparison with 38% for the actual allocation. Under the optimal allocation the relative evapotranspiration (ETa/ETm) was increase to 86% from that of the 74% for actual one which resulted 25% increase in the relative yield. The optimal water allocation policy improved significantly the relative profitability to 85% from that of 59% for the actual allocation. The potential net income improved from 59% for actual allocation to 85 % for optimal allocation. The specific yield was found to be increased over the actual allocation by 45% implicating the more efficient use of water as the optimal allocation policy allocated less water where it was least required and more water where it will have a more telling impact on crop production. Further they stated that any measures for improvement in the specific yield (without changing the cropping pattern) would involve making more water available to the crops at certain times during the season.

The comparison that the authors made of actual performance with the output derived from the optimal water allocation is valuable in setting targets against which the actual performance can be assessed. They further identified constraints in the scheme which can be improved by a variety of measures which include modifying the water allocation policy, operational procedures and physical components of the scheme. It was revealed from the analysis that despite the fact that operating under an optimal water allocation policy requires more data, better monitoring and a higher caliber of staff, the potential benefits far outweigh the additional costs. They concluded that the modeling to identify underperformance followed by management (rather than infrastructural) interventions can be a valid way forward to improve scheme performance.

Jahromi *et al.* (2000) assessed performance of canal network at tertiary level in an irrigation district in the *Doroodzan* Irrigation System in Iran using the delivery performance ratio. Authors used equity, reliability and ability (adequacy) indicators to evaluate the performance of the canals located at head, middle and tail end of irrigation district during five consecutive irrigation cycles. For the performance assessment they used monthly water balance components and real time climatic data processed using the CROPWAT program. The values of delivery system's ability, equity and reliability performance at tertiary turnout level in the Hamoon Irrigation District were found to be 1.0, 0.08 and 0.16 respectively. It shows a better reliability performance than the equity performance in water delivery at the tertiary outlets. The actual overall efficiency of the total system was determined as 0.33 for the study period, which was less than the expected ratio (0.50) depicting the deficit in water supply. It might because of an improper scheduling of the water or the fluctuations in availability of water at the source or operational problems with the multipurpose *Doroodzan* Reservoir or combinations of two or more. To overcome the problem they suggested to reduce the flow from the *Doroodzan* Reservoir relatively during the off-peak months and to improve the delivery schedule for the whole system on the basis of the real crop water requirements. They also remarked that the individual results at one level can not necessarily give the same information about the other level.

Bustos et al. (2001) evaluated the functioning of 19 Users' Associations (UA's) in the *Tunuyan* region, Argentina on the basis of an 85-question questionnaire and related interviews. Field data were collected by means of an 89-item questionnaire. All questionnaires were completed during in-depth interviews with the inspectors of the UA's. The questionnaire was organized around the following topics namely (1) distribution of water: use of maps, name of farmer and location of property, type of rotation systems, use of information from the users' register for water rights. (2) identification of user needs: irrigated crops, percentage of the farm area irrigated with each turn, flow rates and canal water level. (3) management and control: knowledge of the rotation schedules. (4) collection of the irrigation water charge: the users' ledger, billing. (5) social factors: seniority of the inspector, communication with water users and with the General Irrigation Department (DGI). The knowledge and know-how that contribute to an inspector's performance in four inter-related areas were studied: knowledge to identify water users; knowledge to meet users' needs; knowledge to control water distribution; and knowledge to determine the irrigation water rate.

From the information collected the management know-how of the UA's was not found to be appropriate for the new tasks involved in managing the larger command areas (average 4000 ha). The fee collection ratio was very less which can be improved by emphasizing the modernization of infrastructure and system management investments and not the bureaucracy. An up-to-date water users' register is needed to charge the actual user with the correct fee. Participation of farmers in the UA was found to be decreasing sharply with increase in farm size. Some of the contacts between farmers and the UA are related to farmer knowledge of on-farm irrigation technology. Authors suggested that the formal training for on-farm irrigation should be provided to reduce the number of conflicts among small farmers. Finally they concluded that the rising population in the Mendoza Province of Argentina and the increasing demand of water by other groups of users (urban, industrial and environmental), available water resources must be managed more effectively by both the DGI and the UA's. They gave stress on modernization of the irrigation system and management capabilities of inspectors. For that they recommended the sufficient availability of funds to UA's.

Levite and Sally (2002) assessed seasonal performance of *Olifants* river basin in South Africa at basin level at the basin level with a special focus on opportunities for revitalizing and expanding smallholder irrigation systems that are currently performing poorly and in many instances going out of production. The performance indicators used were, namely: Productivity, equity and sustainability. It was found that while stimulating economic growth, equity among different users was not given significant attention. About 90% of the population of the basin was excluded from access to water when the present pattern of water allocations was developed. According to them the recently enacted water law is very progressive and aimed to ensure greater equity in access to water so that the benefits accruing from different water uses will be felt by a larger number of users. They remarked that the economics plays key role in the allocation of water rights. Further they stressed on need to take account of equity in the sharing of water at every stage and also a need to further investigate the links between access to water and socio-economic benefits (for the society) of small-scale water resource development.

Roost (2002) studied on performance enhancement of *Bojili* Irrigation District (BID), a large-scale irrigation scheme in Yellow River basin, China. He developed an irrigation model, OASIS (Options Analysis in Surface Irrigation Systems) to conceptualize and test irrigation interventions in a medium to large-scale irrigation system. The model integrated all main factors of the water balance within an irrigation project (including non-process depletion from fallow lands and non-crop vegetation) and recycling of irrigation return flows (thus allowing conjunctive canal, groundwater and drainage water use). The performance was assessed using the performance indicators: water use efficiency, productivity and equity under actual and hypothetical conditions of land use, infrastructure and water management.

Simulation output following the equitable principle resulted an increase in productivity of available water to 5.01 Yuan/m3 from actual value of 4.93 Yuan/m3. Under the simulated conditions, groundwater pumping and, to a much lesser extent, drainage reuse provide the flexibility required to maintain the overall water availability at a relatively constant level, thereby preventing important losses of production. There appears the trade-off between flexibility and energy, or alternatively between flexibility and irrigation costs. This tradeoff might also extend to water quality, notably in the downstream divisions, where groundwater is of lesser quality. He has also observed that although the 'high efficiencies' scenario achieves a slightly higher overall production than the 'equity' scenario; it does so in a much less equitable manner. This scenario actually disadvantages downstream divisions in a both direct and indirect way. The first, direct disadvantage relates to the defined upstream priority for main canal water allocation. The second disadvantage is a side effect of the former: downstream divisions are allocated less water in an 'efficient' canal system, which results in limited groundwater recharge, and thus limited potential for sustained groundwater use. Yet, it is precisely in such situations of unfair canal water allocation that groundwater is more critically needed downstream. Beyond the evident social benefits, he suggested that improving water allocation equity is also a way to raise water productivity in the study area.

Unal et al. (2004) studied the performance of water delivery system at tertiary canal level for the Menemen Left Bank Irrigation System, Gediz Basin, Turkey in terms of adequacy, efficiency, dependability and equity indicators. These indicators were calculated for the nine territories (located in the head, middle and tail sections of the system) for the 6-month irrigation seasons of 1999 and 2000, using measured water deliveries and calculated crop water requirements. Equity for year 1999 and 2000 were 0.67 and 0.74 respectively. Adequacy for year 1999 and 2000 were 0.53 and 0.57 respectively. Efficiency for year 1999 and 2000 were 0.83 and 0.84 respectively. Dependability for year 1999 and 2000 were 0.81 and 0.73 respectively. The values of the indicators obtained depicted that the water delivery performance to the territories in each irrigation season was worse for adequacy, dependability and equity than for efficiency. They observed that when the irrigation season and the system were taken as a whole, the calculated indicator average values were found to be "poor" for adequacy, dependability and equity, and "fair" for efficiency. The results, revealing strong similarities between the years, illustrated that there has been a systemic water delivery problem in the system. The analysis of results of the spatial and temporal dimensions of the performance indicators showed that factors causing this problem resulted from the part from management, and physical structure. They made following suggestions to improve the poor performance of the system:

1. Crop production planning should be done according to actual water availability.
2. Excessive water use should be prevented through farmers' education and awareness.
3. The water available in reservoir alongwith that in river over season should be taken under consideration together while preparing an irrigation programme. Which will solve the problem of over or insufficient supply from reservoir over season.
4. A tertiary level water delivery plan should be prepared, and strictly adhered to by the Menemen Left Bank Irrigation Association and the village irrigation committees.
5. Either the capacity of existing canals should be increased or new canals should be built in order to overcome the insufficient water delivery capacity of tertiaries.

Smout and Gorantiwar (2005a) studied the performance of irrigation water management during the area and water allocation with a case study of an irrigation scheme in the semi-arid region of India. The allocation plans and the corresponding water delivery schedules during the allocation process were estimated with the help of a simulation–optimisation model for different allocation rules based on cropping distributions (free and fixed), water distributions (free and fixed-area proportionate), irrigation depth (full, fixed depth and variable depth irrigation) and irrigation interval (from 14 to 35 days). The performance measures of productivity (in terms of net benefits and area irrigated), equity (in water distribution), adequacy and excess were assessed for these different allocation plans and schedules. These were further compared with the performance measures of the existing rule (fixed depth irrigation at a fixed interval). The analysis revealed that these performance measures are in some cases complimentary and in other cases conflicting with each other. Therefore, it would be appropriate for the irrigation managers to understand fully the nature of the variation in performance measures for different allocation rules prior to deciding the allocation plans for the irrigation scheme.

Gaur et. al. (2008) used an integrated approach to assess changes in the performance of head, middle, and tail reaches of the left main canal command of *Nagarjuna Sagar*, Andhra Pradesh, India. The performance was evaluated in terms of spatial equity of canal flow and land use with water supply shocks during water surplus (2000–2001), normal(2001–2002), and deficit (2002–2003) years. They used three years (2000-2003) canal release data, census statistics and high temporal resolution 8–10 days moderate resolution imaging spectrometer (MODIS) 500 m resolution satellite imagery. The impact of water scarcity on land use pattern, delineated by MODIS images with moderate spatial resolution, was comparable with the census statistics, while the MODIS data also identified areas with changes and delays in the rice crop area, which is critical in assessing the impact of canal operations. A 60% reduction in water availability during the drought resulted in 40% land being fallowed in the left-bank canal command area. From the results authors suggested that head reach areas receiving high supply rates during a normal year experienced the highest risks of fluctuations in water supply and cropped area during a water short year compared to downstream areas, which had chronically low water supply, and better adaptive responses by farmers. Contrary to expectations, the spatial distribution of canal flows among the three major zones of the command area was more equitable during low-flow years due to decreased flow at the head reach of the canal and relatively smaller decreases in tail-end areas.

They suggested that equitable allocations could be achieved by improving the water distribution efficiency of the canal network during normal years and by crop diversification and introduction of alternative water sources during water shortage years. The study identified areas susceptible to decreases in water supplies by using modern techniques, which can help in decision-making processes for equitable water allocation and distribution and in developing strategies to mitigate the effects of water supply shocks on cropping patterns and rural livelihoods. The water distribution was found to be highly inequitable with very large flows in the head zone and very low flows in tail reaches in normal and surplus years with 33–40% loss of water supplied from the head regulator of the main canal through the canal distribution network, which reduced to 17% during the deficit year. Contrary to expectation, the spatial distribution of canal flows among the three major zones of the command area was more equitable during the low flow year. This was due to decreased flow in the head reach of the canal and less canal distribution losses, which reduced the skewed water use of normal and surplus years. During the water deficit year, a 60% reduction in water availability resulted in 40% of the cropped area being fallowed in the left canal command. MODIS images identified areas impacted by low canal releases and showed a widespread shift from double to single cropping, particularly in the head and middle zones during the deficit year; from normal sowing paddy variety to late sowing paddy variety and to rainfed crops or fallow. The head reach of the command had larger spatial and temporal variability in canal supplies and land use than middle and tail end. These identified areas susceptible to decreases in water supply could help in decision-making processes for equitable water allocation and distribution. The findings primarily suggested improving the water distribution efficiency of the irrigation network during normal years and conjunctive water use and crop diversification during water shortage years. The large impact of canal flows on cropping patterns in head reaches suggests that adaptive strategies for water scarcity need to be developed to supplement canal flows during times of shortage. However, a better understanding of the surface-groundwater interaction is required, since groundwater levels are highly responsive to canal flows. The equitable allocations can be evolved to share water shortage through diversification in cropping pattern supported by economical incentives. However, according to authors, further investigation is needed to maximize the productivity and value of these alternatives, which currently compare very poorly with rice and sugarcane cultivation.

2.2.2.1.2 Intra-seasonal performance measurement

As described in section 2.2.1 above, Gorantiwar (1995) investigated productivity, equity, stability and sustainability as measures for the seasonal and intra-seasonal performance of the irrigation schemes in semi arid tropics under rotation water supply.

Onta *et al.* (1995) used a linear programming (LP) based optimization model and a simulation model for knowing the performance of the *Kankai* irrigation system in Nepal, With equal preference to the objectives, a management strategy with equal share of water among the project sub areas was found to be the most satisfactory alternative under water shortage conditions. They found that the existing water allocation policy is not economically efficient. They commented that the deficit irrigation in early paddy could be attractive under favorable hydrologic scenario, particularly if accompanied by measures to improve existing irrigation system efficiency.

Balasubramaniam *et al.* (1996) attempted real time analysis approach through LP modeling of existing situation and the best allocation policy for the *Aralikottai* tank system to bridge the gap wide between an ideal situation and actual conditions existing. The actual conditions were simulated at each sluice command level whereas the best operational policy was attempted for the entire system as a whole. The analysis was conducted separately for a drought year (1988) and a surplus year (1990) with the available five year data from 1988 to 1992. They majorly concluded that the late transplantation of the rice crop and the excess water application during the periods of water availability (Leading to water stress during the last stages of crop maturity) were the causes of the meagre benefits in a drought year. Also, in a surplus year the excess water application over the entire cropping season resulted in under utilization of land resources and moderate benefits. They revealed that the existing status of irrigation can be improved to obtain the maximum benefits from the tank command area based on the quantification done.

Plantey and Molle (2003) presented different performance indicators. These indicators are: water balance indicators, water delivery performance indicators, maintenance indicators, environmental indicators, commercial indicators and financial indicators. They further studied the performance assessment of scheme of the network of canals and pressurised pipes of the public and private company: "*Societé du Canal de Provence*" (SCP). According to a State Concession decree, this company is due to provide a pre-established level of service to its customers, and be financially sustainable. Its technical and maintenance services have installed a network of measurements and data collection devices and defined a specific set of performance indicators to verify achievement of these two goals. The overall efficiency of Canal de Provence conveyance system appears to remain equal or greater than 95% (with 2 or 3% standard deviation), and close to 85% when considering the conveyance plus distribution systems. On the average for 10 years, the *rate of recovery* of water charges is 99.75%. The purpose is to keep this level of performance, and focus on the *quickness of payment*.

Isidoro et al. (2004) evaluated the irrigation performance of the irrigation scheme, *Ebro* River Basin, northeast Spain. The command area of the scheme was 5282 ha. The authors particularly estimated the performance in terms of efficiencies (distribution efficiency, system and on farm consumptive use coefficient). They adopted the water balance approach in which the data such as water diverted for irrigation, which includes the irrigation ditches operational losses; precipitation; direct water releases of the Monegros Canal into the drainage system; surface runoff and groundwater inflows from outside the study area; municipal and industrial wastewaters; canal seepage, surface drainage outflow, evapo-transpiration in the whole surface of the study area and deep percolation and groundwater outflows from the system were used. They measured the performance monthly and at scheme level. The values of the performance measures (average of two years 1995 and 1996) *viz.* distribution efficiency, system and on farm consumptive use coefficients were found to be 83%, 51% and 61%, respectively. Further from the studies of the performance measures they concluded that the current water allocation to the irrigation scheme could be reduced by 8% for an improved consumptive use coefficient of 65%, and by 30% for an improved consumptive use coefficient of 85%. However according to authors there is a need to undertake modernization programme for the irrigation scheme for improving consumptive use coefficient.

Yercan et al. (2004) carried out the comparative performance analysis at scheme level in *Gediz* river basin in Turkey before and after irrigation management transfer, where authority and responsibility to manage irrigation systems were transferred from government agencies to water users' organizations. The performance was evaluated in terms of the rate of irrigation, sustainability of irrigated land, the effectiveness of fee collection (EFC) and financial self-sufficiency. Rate of irrigation indicates what level of irrigable land is irrigated. The transfer process affected positively the rate of irrigation on the overall schemes. A rate of irrigation was found to be good as there is an increasing tendency from 51 to 57% on the average rate of irrigation in overall schemes. The rate of sustainability in irrigated land was decreased according to the situation of before and after management transfer. The decrease in sustainability may not be the impact of management transfer alone or the land degradation. Authors stated the factors affecting sustainability such as less rainfall, salination, misusing of land, etc. The rate of fee collection was between 15 and 30% before transfer process implicating the inadequate performance of system. The rate of fee collection was higher than 75% after transfer program which is the sign of fully mature and sustainable system. The financial self-sufficiency of fees collected to cover operating and maintenance budgets increased dramatically after transfer process. The average fee collection percentage was 15% before transfer, whereas this rate was increased approximately to 90% after transfer. The profit from the cost recovery was used for infrastructure investment costs such as machinery, equipment, etc. As it can be seen from the data, the cost of irrigation was paid by users. After the transfer process, the participation of the users has been achieved by means of cost recovery. Authors remarked that the participation is a process in which stakeholders influence policy not only in decision making but also in budgeting of organizations.

Akkuzu *et al* (2007) assessed the water delivery performance of four Water User Associations (WUA) in the *Gediz* Basin Irrigation System, Turkey on annual, seasonal and monthly level using the performance measures based on the remote sensing techniques namely: irrigation ratio (actual irrigated area/projected irrigation area), water use ratio (actual water use/target water use), average Normalized Difference Vegetation Index ($NDVI_{ave}$) and coefficient of variation of NDVI for equity in water delivery. The authors elaborated in detail how to estimate the NDVI values with the help of remote sensing data for the determination of performance measures. For the performance assessment they used data from General Directorate of State Hydraulic Works (DSI), actual flow records and Images from NOAA-16/AVHRR. Adequacy in the form of average Irrigation Ratio (IR) was found to be 77% and 76% for year 2004 and 2005 respectively. Adequacy in the form of $NDVI_{AVE}$ was 0.32 to 0.42 and 0.26 to 0.42 for year 2004 and 2005 respectively. Equity in the form of CV($NDVI_{AVE}$) ranged from 0.14 to 0.23 and 0.14 to 0.30 for year 2004 and 2005 respectively representing the same equity level for both years. From the IR values they concluded that the WUAs located at the end of canal did not received adequate water. They also observed that adequacy for the WUA related to its location on main canal rather than its distance from the source.

Prasad and et al. (2006) carried out of performance assessment in Olifants River basin, South Africa with respect to equity and productivity. They observed the different perceptions associated with equity and water productivity and limitations in prevalent assessment methods with the view to develop and reveal realistic methodologies for equity and productivity assessment in data-scarce contexts. They revealed that demonstrated methodologies for assessing equity and productivity, are not only useful in data-scarce contexts, but are also insightful for initiating several policy measures and for exploring the relationship between equity and water productivity. Among the three dimensions of equity coefficient : 1. Sector; 2. Variation in water use per capita; and 3. Variation in water use per unit area; water use per capita and water use per unit area were found to be considered equally important irrespective of the sectors. However, the agricultural sector has the highest equity coefficient of 0.372 compared to those in the rest of the sectors. This indicates that among the four sectors, the spatial distribution of water entitlement per unit area and per person (implicitly access to water and use) is most equitable (least skewed) in the agriculture sector compared to the same in other sectors. The highest inequity (i.e., the least equity coefficient of 0.053) across different tertiary catchments is observed in the water supply service sector. In addition, in this study these computation results provide several other insights and opportunities to explore appropriate policy measures in the context of integrated water resources management. For instance, in the case of Olifants, the agricultural sector performed the best in terms of equity, with the highest coefficient (0.372). This indicates a sector that has contributed to improving equity conditions in the basin with respect to extent of water use per capita and water use per unit area. Nevertheless, water productivity (2.25 rand/ m^3) in the agricultural sector is comparatively dismal, with a consumption rate of more than 70% of available water, which indicates a need for examining possibilities for improvement.

They have further indicated that the industrial sector has the highest water productivity (rand 260/m^3), and hence provides, at the margin, an economically promising venue for promoting water allocation and use. However, the industrial sector showed the poorest performance in equity (0.083), which indicates that water has not been equitably allocated in this sector within the basin, and hence may need suitable measures from the equity point of view. Using these results and taking the implications a bit further, one may also explore the relationship between equity and water productivity. It should be noted, however, that the computational results for equity and water productivity, discussed above, are expressed in different units and therefore cannot be readily compared (Lévite and Sally, 2002). Usually, the Pearson product moment correlation coefficient is used for assessing correlations among datasets. Computation of the correlation coefficient of the two datasets, i.e., equity coefficients and water productivity in the four sectors, yields a value of −0.457. Empirically, this suggests that there is a strong but negative correlation between the two sets of information. Alternatively, it implies that there may be a significant trade-off between equity and productivity. This inference may in turn imply that promoting equity might take a toll on water productivity and vice versa. However, it is not necessarily true. There is no mutual dependency between the two sets of computational results. For instance, an increase of say 10% in water productivity in all tertiary catchments has no effect on the skewness in water entitlements across those catchments, and hence on the equity coefficients. This means that the equity coefficient will remain the same despite an increase or decrease in water productivities. This clarifies that, although there seems to be a negative correlation between equity and productivity, there is no causality. Thus, as also argued by Howe (1996), improvement in equity does not necessarily come at the detriment of productivity, nor vice versa.

Kalu *et al.* (1995) studied the issues related to equity and efficiency in irrigation water distribution and found that, irrigation water distribution policy should be both efficient and equitable. In most irrigation projects water distribution, particularly during the dry period fails to achieve one objective while trying to improve another, especially in unlined canal projects with a high seepage rate. According to them how to improve both is a complex task. A methodology for choosing an appropriate water distribution policy in public irrigation projects considering both objectives of equity and efficiency is described. Water distribution policies were generated through an optimization model by varying the level of irrigation and the proportion of area of each field plot to be irrigated. Then a simulation model was employed to evaluate the consequences with respect to efficiency and equity measures. Finally a multi-objective analysis was carried out to select a compromise solution. This methodology was applied to select a water distribution policy for irrigating wheat in a case study project.

Renault (1999) established analytical relationships between the control of canal water depth, the sensitivity of irrigation delivery structures, and the resulting internal performance at the system level. One system sensitivity indicator is derived for both adequacy and efficiency, and two for equity (coefficient of variation and Theil information index). The behavior of three different irrigation systems in Sri Lanka and Pakistan was studied with both analytical system indicators and numerical hydraulic simulations. These global system indicators can be used to define the precision level required to achieve a given performance, to estimate actual performance from recorded precision at regulators, and to diminish the system sensitivity, improving the performance for a given precision. He further mentioned that operating policies can be inferred from sensitivity information of irrigation systems without the necessity of a complex irrigation operation model.

2.2.2.2 Application of performance measures below scheme level

2.2.2.2.1 Seasonal performance measurement

Palmer et al. (1991) conducted the performance assessment of *Wellton-Mohawk* Irrigation and Drainage District (WMIDD), southwestern Arizona, USA which is characterized by well operated irrigation project along with a high-quality, fully concrete-lined canal system, a very flexible delivery scheduling process and predominantly high-flow-rate level basins on-farm irrigation systems. The performance of water delivery system was assessed in terms of Timeliness (days between the ordered and actual delivery date), Flow Rate adequacy (average rate actually measured, to the rate ordered by the farmer) and duration adequacy (as a measure of how well the actual time of delivery compared to that intended by the farmer i.e. ratio of actual measured duration and ordered duration). The data were obtained through monitoring of lateral canals, examining water order reports and bills, and conducting a diagnostic analysis of the water delivery and on farm irrigation systems through interviews. From the timeliness indicator values obtained it was found that 72% of deliveries occurred within the allowed plus or minus one day of the ordered date. The remaining 28% of deliveries were more than one day earlier or later than the ordered date, particularly in summer when demand is high. It was found that farmers used the official ordering process only about half the time, but more often in the late summer than in the spring. The mean value for flow rate adequacy was 0.96 which means that on average, the measured rates were 4% less than ordered. From the distribution of flow rate adequacy values it was observed that despite the average performance of 0.96, most deliveries did not accurately reflect farmers' orders. The average duration adequacy was found to be 0.98 which means that farmers in most cases end delivery when planned, regardless of the flow rate received. The overall district project Water Use Efficiency was found to be greater than 60%. However, two biggest shortfalls observed were the lack of sufficient flow measurements at intermediate points within the district and the lack of good water accounting which are very common. Further they remarked that the performance assessment of such complex irrigation district can be very useful for engineers to design and upgrade the irrigation delivery systems, by helping them to understand the day-to-day decision-making and actions taken to meet district and farm objectives, and the effects of those actions.

Sarma and Rao (1997) evaluated an irrigation performance of the command area of the *Paladugu* major distributary in the *Nagarjunasagar* Right Canal Command Area in Andhra Pradesh, India for single season (July – December) from 1979 to 1982. It was done to assess the impact of Integrated Water Management Scheme (IWMS) which was introduced in 1980 for the study area. They used performance indicators such as water supply-requirement ratio and other indices such as irrigation intensity, crop productivity and cropping pattern. From the performance analysis it was found that the irrigated area increased from 533 ha in 1979 to 674 ha in 1985, corresponding to an increase of the irrigation intensity from 79% to 100% resulting in increased crop production. Yields of paddy and cotton went up by more than 100%. The IWM Scheme contributed to increase productivity per unit of water supplied.

Arora and Gajri (1998) evaluated the performance of combination of a simple and universal crop growth simulator (SUCROS of van Keulen et al., 1982) with a water balance model (WBM of Arora et al., 1987) with some modifications to analyse wheat yield responses to variable climatic and water supply regimes. Crop aspects of the model included gross CO_2 assimilation, maintenance respiration, assimilate partitioning, dry biomass production, green area growth and senescence. Water balance aspects considered were soil evaporation (E), canopy interception, evaporation (I), crop transpiration (T), and deep drainage (D). Extensive evaluation of the model showed close agreement between measured and simulated grain yield for most water supply regime with yields ranging from 0.6 to 6.2 t/ha. Probability distribution analysis of grain yield indicated low yields with large variance in rainfed environments. They revealed that supplemental irrigation and higher soil water retentivity increases mean grain yield and reduces the effects of annual rainfall variability and also suggested that the model can be applied appropriately to optimize the water use at field scale.

Godswill *et al.* (1998) analysed the water management performance of small holder irrigation systems in Zimbabwe. The government and farmer managed systems were compared in terms of their ability to match desired with actual water supply. Desired supply was defined as crop water requirements adjusted downwards by rainfall where relevant. The Theil measure of accuracy of forecasts was used to calculate the error committed by each system in trying to match water supply and demand. The analysis shows that, everything else being equal, the farmer managed system performed better than the government system in matching supply and demand. They suggested that the farmer managed systems should be encouraged for future small holder irrigation development in Zimbabwe.

Syme *et al.* (1999) defined the components of fairness in the allocation of water to environmental and human uses. According to them water allocation has become increasingly controversial as competition has increased. Based on the research programme of seven studies over 10, they found that the public's universal fairness principles in contrasting allocation case studies were relatively stable over a decade, and provide criteria for judging allocation decisions. Water was consistently seen as a public good; the environment was seen to have rights to water; and procedural issues were important in allocation decision-making. The most recent four studies have shifted to the local or situational fairness contexts. They concluded from their four studies that local procedural justice issues, particularly those pertaining to public involvement for local people in decision-making, were significant determinants of judgments of the fairness of the decisions. Economic considerations had some importance, but were not the over-riding issues, and water markets were seen as unacceptable processes for water allocation or re-allocation. The research also provided evidence that self-interest is tempered by pro-social motivations such as fairness when making water-allocation decisions. Finally, it was evident that the public could make relatively complex judgments which used dimensions that go beyond the scope of traditional social psychological definitions of equity and procedural justice.

Santhi and Pundarikanthan (2000) developed a model for planning canal scheduling of rotational irrigation based on multi-criteria approach. They considered various criteria in the model for rotational water distribution such as equity, adequacy, timeliness and locational or convenience of operation; represented in terms of weights assigned to each distributary canal based on each of these criteria. They assigned weights less than 1.00 and they were either constant or dynamic with respect to the time of operation. The criteria being independent of each other, the final weight was obtained on a multiplicative basis (by multiplying the individual weights) for each distributary canal. The distributary canals were ranked for operation based on the final weight. The applicability of this model was demonstrated with the left bank main canal of the *Sathanur* Irrigation Project in the State of Tamil Nadu in India.

The equity in case of present model was found to be greater than actual one. Modified inter-quartile ratios, a measure of equity computed were 1.19 (model) and 1.76 (manual), which indicated that inequity in water distribution can be reduced from 76% in the conventional scheduling to 19% in the present model. They stated that the inequity is observed because of the canal losses are accounted on a gross basis while estimating the demand in the conventional scheduling and not accounted for the actual length of the canals. Adequacy in the form of supply to demand ratio can be improved upto 0.95±1.05with the model from present value of 0.85±5.90. The present low value of supply to demand ratio indicating the inefficiency in water utilization is might be due to the duty-based operation which is a very approximate way of estimating the irrigation requirement. They observed the timing of water deliveries not to be matching with the crop needs in the case of the conventional manual procedure whereas the proposed model could meet the crop needs. The releases were found to be more than the demand in the beginning of the season and less than the demand at the end of the season (critical period), which might considerably affect the crop production in the case of conventional scheduling. They remarked that it is not necessary to use all the performance indicators (criteria) for irrigation scheduling in all the systems. Depending on the system's objective, it is also possible to consider only a few of the different performance indicators (criteria) among them and use the same model with some modifications. The water distribution pattern obtained from the developed model was more effective in fulfilling the multiple objectives compared to the conventional scheduling procedure used. The concept can be extended to any level of rotational distribution, starting from main canal down to farm outlets.

Murray-Rust and Mark Svendsen (2001) studied the performance of locally managed irrigation in Turkey (*Gediz* case study) and observed that during the first four years after management transfer there has been a continued improvement in irrigation performance.

While the area cropped using surface water has only marginally improved, yields and water productivity have shown significant increases. According to them these benefits can be attributed in part to favorable market conditions for cotton and grapes, but also to a management system that values level of service so that farmers are not constrained by uncertainties in water deliveries. They further opined that the individual systems are managed quite differently within the *Gediz* Basin showing that there is scope for considerable diversity in Irrigation Associations practices without affecting the resulting performance of systems.

Ines and Droogers (2002) followed inverse modeling approach to quantify irrigation system characteristics and operational management characteristics of the *Bata* Minor (an offtake from the *Sirsa* Branch) of the *Bhakra* Irrigation System at *Kaithal*, Haryana, India for 2000-2001 *rabi* season. A Genetic Algorithm loaded stochastic physically based soil-water-atmosphere-plant model (SWAP) was developed for the inverse problem and used in the study. They used the direct observable data (land cover, leaf area index, digital elevation model and evapotranspiration), non-visible data such as soil characteristics, groundwater depth and irrigation practices. The remotely sensed (RS) data was used to obtain spatial data required for hydrological models. The study they have explored the option of using inverse modeling to obtain these non-RS-visible data. They found that the good agreement with the inventoried data such as soil hydraulic properties, sowing dates, groundwater depths, irrigation practices and water quality. The derived data could be used to predict the state of the system at any time in the cropping season, which can be used to evaluate operational management strategies. They have finally concluded that further studies should go beyond the characterization of the system and the current irrigation practices, and should focus on improved water management to increase the water productivity at irrigation system level.

Ray et al. (2002) evaluated the performance *Mahi* Right Bank Canal (MHRC) command (212,000 ha) in Gujarat, India, using Multi-temporal remote sensing (RS) data-based crop inventory, generation of vegetation spectral index profiles and crop evapotranspiration estimation. They computed three RS based performance indices namely, adequacy (AI), equity (EI) and water use efficiency (WUE) at distributory level for Rabi season of 1995-96 using the Indian Remote Sensing Satellite (IRS)-1C Linear Imaging and Self Scanning-III (LISS-III) data and Wide Field Sensor (WiFS) data. Adequacy in terms of relative water supply for various distributories ranged from 0.58 to 3.54. The distributaries located mostly towards the head of the main and branch canals were found to be receiving the high amounts of water with adequacy greater than 1. While the distributaries located towards the tail end of MRBC, received water between 0.5 and 0.9 of crop requirement; which indicates that the water in canals does not reach the tail end. The agricultural productivity in terms of efficiency of water to produce crop growth ranged from 0.3 to 2.0/m3. It was found that the command areas provided with excessive volumes of water were found to be less efficient than the command areas which received less water. Hence they concluded that over-irrigation does not increase productivity proportionately. Equity/head-to-tail difference EI was evaluated by observing the head-to-tail difference in two distributaries. They have studied the differences in cropped area and crop vigor between head and tail zones of two distributaries. Equity for two different distributories was found to be decreasing from Zone I to Zone III as: Distributory 1: from 57.9% to 40.5%; Distributory 2: from 56.6% to 41.4%. It was also found that the crop vigor, as expressed by the average NDVI values, was lower in zones towards the tail end of both distributaries. Further they concluded that the MRBC irrigation system resulted in two to three-fold increase in the gross cropped area and average crop yield and the generation of a high net additional income for the region. However, in the last 40 years, there has been an increase in the problems of water logging and salinity due to non-uniform distribution system of irrigation water. The present performance analysis showed that RS-based performance indicators could identify the problem distributaries in the MRBC, an intensively managed and studied irrigation system. The performance evaluation has shown the discrepancies and relative ranking of the distributaries vis-a-vis crop water requirements. The water applied is also not equitably distributed, the head getting more than the tail end. It has also been found that a greater application of water does not result in higher crop vigor as observed by RS data.

Evans et. al. (2003), dealt with the problems of inefficiency and inequity in water allocation in the *El Angel* watershed, located in Ecuador's Sierra region. They designed a comprehensive, crop-livestock mathematical programming model to maximize aggregate gross margin from agricultural production in the El Angel watershed, constraints being the limited supplies of land, labor and water. They evaluated the current system of water management along with other five alternative water allocation scenarios with respect to efficiency in land and water use and equity in income distribution.

They have found that although water is the primary constrained resource downstream, in the upstream zones, land is far more scarce. As the existing distribution of water rights did not consider these facts, differences was found to be neither efficient nor equitable. To enhance the efficiency (resource use) and equity (income distribution) they suggested (1) a shift of water to the lower zone, and (2) the use of lower levels of irrigation intensity upstream. They also recommended that, the scenarios that result in the most efficient use of resources also bring the greatest degree of equity in income distribution, indicating that these may be complementary, not conflicting, goals. The productivity is found to be largely dependent (a producer's ability to obtain and utilize water resources to earn income) upon the farmers' proximity to the water's source; where upstream farmers were lacking the incentive to use water efficiently, and in the face of uncertainty, downstream farmers have an incentive to use water illegally. According to authors, achieving efficiency in resource use and equity in income distribution requires a significant transfer of water resources to the lower zone, largely accomplished through a shift to lower irrigation intensity crop activities upstream. However, at this time, the design and implementation of a policy to stimulate such a shift would be a difficult task, given the vastly different conditions faced by upstream and downstream users and the resulting incentives for water use. An alternative would be to make a one-time investment in technology to modernize the canals and improve levels of efficiency, thereby reducing the locational discrepancies between zones.

Vandersypen et al (2006) compared the irrigation performance at tertiary level in rice schemes of the *Office du Niger*, Mali in 1995 with the situation nearly 10 years later (2004). Major physical rehabilitations and economic and institutional reforms carried out from the 1980s onwards succeeded in making a success story of the *Office du Niger*. They analyzed the irrigation performance in the light of the interventions implemented and current water management practices using the performance indicators such as Adequacy, Dependability and Equity. The interventions succeeded in establishing a good adequacy of water supply (0.96 for 1995 and 0.92 for 2004), thus creating the necessary conditions for boosting rice production. Because of the minimal management strategies of farmers and water bailiffs, efficiency is however low and shows no sign of improving between 1995 (0.51) and today (0.56). Dependability values were found to be 0.78 and 0.71 for year 1995 and 2004 respectively. While Equity values for year 1995 and 2004 were 0.63 and 0.54 respectively. Thus dependability and equity were found to be beyond the thresholds accounting for 'poor' (0.25 for dependability and 0.2 for equity), but given that water supply is generally adequate, these indicators appear less relevant. When an alternative calculation procedure was used for situations where water is not scarce, results of the adapted indicators showed satisfactory levels of dependability and equity (i.e. indicators between 0.11 and 0.20). Measures aimed at increasing efficiency will inevitably be costly, but are redeemed justified. Certainly, even though water is not a limiting factor during the main growing season until today, this is to change soon as the irrigated surface will be strongly expanded. Authors suggested to increase irrigation efficiency which will also help to solve the recurrent drainage problems that trouble the harvest in the rice schemes of the *Office du Niger*.

Clemmens and Molden (2007) suggested that crop-scale irrigation uniformity can be examined at a project scale by understanding how field, farm and project irrigation systems contribute to non uniformity. They also discussed the interrelation between project scale uniformity and the relative irrigation water supply, and their combined impact on project productivity. They provided an example which relates internal measures of project performance (e.g., water distribution operations) and external measures of project performance (e.g., project-wise water productivity). They have attempted to develop a quantitative approach for estimating the impact of internal performance indicators on water productivity. They used data from the RAP (Rapid Appraisal Process) process (Burt and Styles 1999) to infer water uniformity and then relate this to project productivity. (The Rapid Appraisal Process allows qualified personnel to systematically and quickly determine key indicators of irrigation projects.) The primary indicators used to determine the suitability of the water supply for agricultural production is the annual relative water supply (RWS). According to authors, for examining the adequacy of the irrigation water supply, the annual relative irrigation water supply (RIS) can be used. Because of the importance of economic viability of irrigation projects, they preferred performance indicators related to crop value, such as, value of crops produced per unit of irrigation water supplied.

Parsinejad et al. (2009) examined the performance of the *Sefidrood* irrigation and drainage network, *Guilan* Province, Iran. They evaluated the application water efficiency of paddy fields for 13 different sites throughout the network, based on field measurements of water inflow and outflow, deep percolation and calculation of evapotranspiration, for cases where the outflow was considered as a loss, i.e. at field scale, and for cases where a percentage of the outflow was considered as recoverable water, i.e. regional scale. They depicted the application water efficiency at field scale, for the western, central and eastern section of the *Sefidrood* Irrigation Network was 38, 41 and 34%, respectively. However at regional scale, where 80% of the outflow was taken as recoverable water, the above values were found to be 52, 51 and 46%, respectively. Computation of consumed fraction (CF) and recoverable fraction (RF=1-CF) portrayed that about 60% of water is potentially available for reuse for the entire network. They have found that a large portion of the water delivered to rice paddy fields is conventionally considered as a loss. When they combined the results with the conveyance and distribution losses, the degree of the problem was found to be more apparent.

Smout and Gorantiwar (2005a) also studied seasonal performance measurement of irrigation water management during the area and water allocation with a case study of an irrigation scheme in the semi-arid region of India (see sections 2.2.1 and 2.3).

2.2.2.2.2 Intra-seasonal performance measurement

Makin *et al.* (1991) evaluated the performance of *Kraseio* Project, *Suphanburi,* Thailand after introduction of computer assisted irrigation. The command area of this scheme is 20,000 ha. The performance assessment was conducted for two seasons at scheme level using different indicators, namely: actual versus targeted supply, equity, reliability and adequacy measures. Over the two seasons they demonstrated the importance of regular feedback of performance information, in terms of increased awareness by project staff of operating constraints and their ability to quantify project performance. They reported that with an introduced computerized irrigation scheduling the accuracy of information about areas greatly improved, more realistic targets were set and the numbers of complaints from farmer groups about inadequate supplies were decreased. It was also revealed that the complaints from tail end farmers were due to inadequate supplies and not because of their desire for more water than was their share. The effective command area (including areas upstream of the river barrage) was approximately 20% greater than the nominal command area. They stated that advised target flows based on a systematic method of estimating water requirements and weekly monitoring of actual performance has enabled the scheme management at *Kraseio* to make routine assessments of system operations. The higher degree of unreliability of supplies at the main canal headworks was found because of irregular pattern of pumped abstractions in the reach downstream of the reservoir. Accordingly the actions were taken to alleviate the problem. Further authors remarked that it is very important to set clear objectives for gate keepers, to enable quick identification of system constraints.

Bhutta and Velde (1992) studied the equity of water distribution of the canal operation in the Lower *Chenab* Canal system in Punjab Province, Pakistan. The equity in terms of the delivery performance ratio (DPR) (ratio of actual discharge received at the outlet, to its design or sanctioned discharge) was measured at distributary levels for 3 distributaries :Mananwala and Lagar Distributaries in the head reach of the Gugera Branch Canal and Pir Mahal Distributary at the very tail of this Branch. Actual discharges were measured for selected outlets on those distributaries were measured daily throughout 1988. The DPR values for Mananwala Distributary outlets in the head and middle reach was 223% while that for tail outlets was 50% of their sanctioned discharges. The DPR value for *Lagar* distributary ranged from 150% to 8% of design discharge and for *Pir Mahal* distributary outlets it varied between 272% and 18% of design discharge. Results obtained showed that variation at the head of distributaries greatly exceeded the original design criteria. The data also indicated that two design assumptions for outlets were no longer valid: continuous full supply water level in the distributary and outlet modular flow conditions. Field distributaries were substantially inequitable in terms of water distribution. They also stated that the outlets in the channels head reaches commonly drew 3 to 6 times greater share of total supplies than that did the tail outlets. In spite of perennial canal operation some outlets were found to be dry for up to 90% of the total operational days in a year. The authors remarked that the better operational procedures at the distributary level could considerably enhance the water supply conditions in the tail reaches.

Raju and Pillai (1999) evaluated the performance of *Sri Ram Sagar* Project, a major irrigation scheme in Andhra Pradesh, India at distributory level using Multi-criterion

Decision Making (MCDM) approach. The performance assessment was done in terms of eight criterion namely onfarm development works, adequacy of water, supply of inputs, conjunctive use of water resources, productivity, farmers' participation, economic impact and social impact. They used two Multi-criterion Decision Making methods, namely, Multi Attribute Utility Theory (MAUT) and Stochastic extension of PROMETHEE-2 (STOPROM-2) and Taguchi experimental design technique to minimise the computational burden in the sensitivity analysis. The responses from two irrigation management experts were utilised as input to two MCDM methods. The weightages of the criteria, on-farm development works, adequacy of water, supply of inputs, conjunctive use of water resources, productivity, farmers' participation, economic impact and social impact for expert 1 were 0.0826, 0.12, 0.0477, 0.0823, 0.1783, 0.0478, 0.2788, 0.1625 and values for expert 2 were 0.0449, 0.0435, 0.1001, 0.0671, 0.2088, 0.1509, 0.2091, 0.1756. It is observed that economic impact, productivity and social impact are given top priorities by the experts. In MAUT method the ranking pattern being is quite vigorous to effect the scaling constraints however the STOPROM-2 method can better deal with the uncertainties in the evaluations of different Criteria. The methodology developed can make better use of group discussions in decision making process. They have finally stated that the proposed methodology can serve as a model to choose the best one for formulating guide lines for improving the efficiency and performance of other schemes at distributor level.

Dechmi et al. (2003) assessed the irrigation performance of *Loma de Quinto* irrigation district (LQD), located in *Zaragoza* (Spain) at cadastral plot level with sprinkler irrigated system for three irrigation seasons. The performance of irrigation was assessed through statistical analyses of field data, district records on WU and farmers' interviews in terms of on-farm water use (WU) and net irrigation requirements (NIR) and seasonal irrigation performance index (SIPI). A seasonal irrigation performance index (SIPI), defined as the percentage of NIR to seasonal water billing, was determined at each plot and for each of the three study years. The district average SIPI (computed in all plots) was 155, 95 and 131 for the years 1989, 1995 and 1997, respectively. The average inter-annual SIPI amounted to 127%, indicating that crops in the district were consistently water stressed. An analysis of the SIPI for the main crops in the district revealed that water stress was more intense in drought resistant and/or heavily subsidised crops (SIPI for sunflower was 142%). The average WU was 477, 995 and 585 mm, for the 1989, 1995 and 1997 years, respectively. However this variability in water application could not be adequately explained by the aridity of the study years or the changes in the cropping pattern. The average irrigation interval (12.3 days) and irrigation depth (44 mm) were found to be too high for some of the soils in the district. Irrigation interval and the depth of irrigation were adjusted by farmers as per the seasonal change in irrigation requirements. Author further stated the major hurdles in the local water management problems such as: the high cost of irrigation water in relation to crop revenues, the technical deficiencies of the irrigation systems, and the limitations imposed by climate and soils.

Latif and Tariq (2009) assessed the performance of *Maira* Branch Canal of the Upper Swat Canal (USC) System in Pakistan in terms of relative water supply (RWS), water delivery capacity (WDC), delivery performance ratio and reliability after and before the transfer of irrigation management from government-managed to farmers'-managed system. While assessing the relative water supply, the cropping intensity was found to be 170% which was less than 185% that designed for the system. During the period of October to December 2005 and March to April 2006, RWS values were much higher than required indicating a more liberal irrigation supply, which results in over-irrigation of crops. This situation may lead to waterlogging and other environmental problems in the study area. They remarked that moderate efforts are needed to bring the water supply closer to crop water requirements by involving Farmers Organisations in operation of the irrigation system. The water delivery capacity (WDC) of all the six distributaries was 0.85, indicating that the intake has sufficient capacity to deliver an adequate supply and the system has the potential to satisfy 85% of peak crop water requirements, although it is designed for peak demand. The value close to one indicates that capacity is not constrained to meet the crop water demand but there may be difficulties in meeting short-term peak demand (Molden et al., 1998). The *Mira* Branch of the Upper Swat Canal (USC) is designed as a combination of upstream and downstream control systems. Farmers overcome the capacity constraint by adjusting the cropping pattern and their cropping intensity. The average delivery performance ratio (DPR) found to be varying from 0.78 to 0.83 during the summer and from 0.63 to 0.73 during winter months. It was found that all the distributaries, irrespective of their locations, are drawing approximately 70–80% of their design discharges. Reasonable equity of water distribution at tertiary level is achieved during operation of the irrigation system except in January and February, when the system is closed for annual maintenance. The DPR values for March and April are low because after the annual closure the inflow is increased gradually according to the principles of operating alluvial channels. Cropping intensity as well as crop yield were found to be increased significantly due to rehabilitation of the irrigation system and enhanced water allowance. During 2004–05 the irrigation service fee collected was approximately 60% of the irrigation service fee assessed, but it was very much less for the following year.

Smout and Gorantiwar (2005a) also studied intra-seasonal performance measurement of irrigation water management during the area and water allocation with a case study of an irrigation scheme in the semi-arid region of India (see sections 2.2.1 and 2.3).

The studies reviewed in this section indicate that several researchers and personnel involved in the irrigation water management realized the importance of the irrigation performance and attempted to know the performance of irrigation schemes. The different performance measures used by the researchers/managers along with their details are presented in APPENDIX - A1. Some of the researchers also proposed the measures to improve the performance which are also depicted in the table and Box 2.2(a) and Box 2.2(b). On most occasions productivity was considered as the important performance indicator. Most of the studies focused on one or two performance indicators (APPENDIX - A1). The values of the performance measures that were estimated by different irrigation schemes are presented in APPENDIX - A2.

However this study proposes that the performance measures related to productivity, equity and water supply need to be measured or addressed simultaneously. The performance measures were addressed mostly at the scheme level. Some researchers addressed the performance measures at lower levels. The Box 2.3 shows the spatial level of performance measures addressed by different researchers. Performance measures also vary during the season; however most of the studies addressed the performance measures at seasonal level and few at intra-seasonal level (Box 2.4).

Measurement of performance measures at different spatial and temporal levels need the data based on the current and/or historical observations. The data requirements for the estimation of all the performance measures at finer temporal and spatial scale are huge. The data can be collected/measured/estimated for the estimation of different performance measures are narrated below. Historical observations are generally obtained from the records and registers. Accordingly the source of the data that were used by different researchers are presented in Table 2.1.

The irrigation methods used in most of the irrigation schemes are the surface irrigation method as seen from the APPENDIX - A1. The irrigation schemes along with the irrigation methods used are presented in Table 2.2. In the command area of most of the irrigation schemes in Maharshtra, the surface irrigation methods are adopted. The case study irrigation project chosen for this study, Mula irrigation project practices the surface irrigation methods.

However as the water distribution has both temporal and spatial variation, it is necessary to know the performance measures at different instance of time and at different parts of the irrigation scheme. This study specifically aims towards this aspect.

Some of the researchers/managers suggested the measures to improve the performance of the irrigation scheme as below:

Palmer et al (1991): The shortfalls observed were the lack of water measurement records at intermediate points in the system and lack of thorough water accounting. These shortfalls appeared to have had only a minor effect on overall district objectives.

Arora and Gajri (1998): The model can be applied appropriately to optimize the water use at field scale.

Godswill et al (1998): Farmer managed systems should be encouraged for future small holder irrigation development in Zimbabwe.

Hales and Burton (1999): The modeling to identify underperformance followed by management (rather than infrastructural) interventions can be a valid way forward to improving scheme performance.

Raju and Pillai (1999): Group decision making concept can be effectively incorporated in the decision making process.

Renault (1999): Operating policies can be inferred from sensitivity information of irrigation systems without the necessity of a complex irrigation operation model.

Syme et al (1999): Procedural issues were important in allocation decision-making. The most recent four studies have shifted to the local or situational fairness contexts.

Jahromi et al (2000): The equity and reliability performance was illustrated by using the spatial and temporal variation of the expected overall efficiency at the district level.

Santhi and Pundarikanthan (2000): "The potential of the model can be well observed when the distribution canals are larger in number and vary in discharge capacity.

Bustos et al (2001): It is necessary to modernize the management capabilities of canal inspectors of UA's and to provide support for the technical staff advising and planning the inspectors' decisions.

Murray-Rust and Svendsen (2001): There is scope for considerable diversity in Irrigation Associations practices without affecting the resulting performance of systems.

Ines and Droogers (2002): Further studies should go beyond the characterization of the system and the current irrigation practices, and should focus on improved water management to increase the water productivity at irrigation system level.

Levite and Sally (2002): There is a need to further investigate the links between access to water and socio-economic benefits (for the society) of small-scale water resource development.

Box 2.2 (a). Authors suggestions for improving the performance measures

Ray et al (2002): The integration of RS data and GIS tools to regularly compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system.

Roost (2002): Suggested that improving water allocation equity is also a way to raise water productivity in the study area.

Evans et al (2003): An alternative would be to make a one-time investment in technology to modernize the canals and improve levels of efficiency, thereby reducing the locational discrepancies between zones.

Plantey and Molle (2003): The purpose is to keep this level of performance, and focus on the quickness of payment.

Unal et al (2004): A tertiary level water delivery plan should be prepared, and strictly adhered to by the Menemen Left Bank Irrigation Association and the village irrigation committees.

Yercan et al (2004): Participation of different stakeholders influence policy not only in decision making but also in budgeting of organizations.

Gaur et al (2008): Further investigation is needed to maximize the productivity and value of these alternatives, which currently compare very poorly with rice and sugarcane cultivation.

Latif and Tariqu (2009): The findings may be considered as indicative only, as the system has only been transferred recently.

Parsinejad et al (2009): The water distribution has both temporal and spatial variation, it is necessary to know the performance measures at different instance of time and at different parts of the irrigation scheme.

Box 2.2 (b). Authors suggestions for improving the performance measures

Performance measures were estimated at different spatial levels

The performance measures were either measured at scheme level or the lower levels such as tertiary level or unit level. The scheme level estimation provides the information about the entire scheme and are helpful for knowing the performance of the scheme as a whole and comparing the performance of one scheme with another; while lower level estimation of performance measures informs the locations/parts of the scheme where the performance is at desired level or below desired level and the measures that need to be undertaken to enhance the performance of the part of the scheme which is giving low performance measures.

Scheme level: Isidoro et al 2004, Gorantiwar, 1995, Burt et al 1997, Yercan et al 2004, Roost 2002, Levite and Sally 2002, Makadho 1996, Small and Rimal 1996, Kalu et al 1995, Mujumdar and Vedula 1992, Bustos et al. 2001, Smout and Gorantiwar 2005a, Olubode-Awosola 2006, Akkuzu et al 2007, Balasubramaniam et al 1996, Hales and Burton 1999, Jahromi et al 2000, Unal et al 2004, Gaur et al 2008.

Lower level: Makin et al. 1991, Gorantiwar, 1995, Raju et al 1999, Bhutta and Velde 1992, Sarma and Rao 1997, Arora and Gajri 1998, Godswill et al Ranjan 1998, Raju and Pillai 1999, Santhi and Pundarikanthan 2000, Murray-Rust and Svendsen. 2001, Ray et al 2002, Evans et al 2003, Dechmi et al. 2003, Smout and Gorantiwar, 2005a, Vandersypen et al 2006, Clemmens and Molden 2007, Latif and Tariq 2009, Parsinejad et al 2009.

The objective of the study is to investigate the different performance measures for different parts of the scheme and compare these with each other; and also compute the overall performance index by providing the weightage to each performance measure under consideration for different parts of the scheme. Hence in this study the performance measures are estimated at lower levels.

Box 2.3. Spatial level of estimation of performance measures addressed by different researchers.

Performance measures were estimated at different temporal levels

The performance measures are either estimated at seasonal level or intra-seasonal level. Some types of the performance measures such as productivity can only be estimated at seasonal level. The seasonal level performance measures provide the information on overall performance but do not guide particularly on how to improve the performance. The intra-seasonal performance measures provide the information about the performance measures at each canal rotation; month, week etc thus guiding which part of the season is more important to improve the performance of the scheme.

Seasonal: Majumdar and Vedula, 1992, Gorantiwar, 1995, Gaur et al 2008, Parsinejad et al 2009, Clemmens and Molden 2007, Evans et al 2003, Roost 2002, Ray et al 2002, Levite and Sally 2002, Ines and Droogers 2002, Murray-Rust and Svendsen 2001, Jahromi et al 2000, Santhi and Pundarikanthan 2000, Hales and Burton 1999, Godswill et al 1998, Arora and Gajri 1998, Sarma and Rao 1997, Small and Rimal 1996, Makadho 1996, Mujumdar and Vedula 1992, Smout and Gorantiwar 2005a.

Intraseasonal: Makin et al. 1991, Gorantiwar, 1995, Balasubramaniam et al 1996, Raju and Pillai 1999, Dechmi et al. 2003, Isidoro et al 2004, Latif and Tariq 2009, Yercan et al. 2004 and Smout and Gorantiwar, 2006.

In this study as the main focus was to provide the information on improving the performance of the scheme, it is necessary to know what is happening and when. Therefore the temporal scale of intra seasonal performance measures was chosen.

Box 2.4. Temporal level of estimation of performance measures addressed by different researchers.

Table 2.1. The source of data used for estimating the performance measures

Author	Data collected
Isidoro et al 2004	water diverted for irrigation, which includes the irrigation ditches operational losses; precipitation; direct water releases of the Monegros Canal into the drainage system; surface runoff and groundwater inflows from outside the study area; municipal and industrial wastewaters; canal seepage, surface drainage outflow, evapo-transpiration in the whole surface of the study area and deep percolation and groundwater outflows from the system.
Makin al 1991	Office record
Palmer et al 1991	Data were obtained through monitoring of lateral canals, examining water order reports and bills, and conducting a diagnostic analysis of the water delivery and onfarm irrigation systems through interviews.
Bhutta et al 1992	Data from Punjab Irrigation Department. Flow conditions for three distributaries and of selected outlets served by each were measured daily throughout 1988, and data were converted to discharges.
Mujumdar and Vedula (1992)	Office record
Balasubramaniam et al 1996	The analysis was conducted separately for a drought year (1988) and a surplus year (1990) with the available five year data from 1988 to 1992.
Sarma and Rao 1997	Based on the availability of field data,
Arora and Gajri 1998	Field data
Godswill et al 1998	Field data
Hales and Burton 1999	Field data
Raju and Pillai 1999	Office data and field data
Renault 1999	field and office data
Syme et al 1999	Office and field data
Jahromi and Feyen 2000	Field data and office data. Monthly water balance components and real time climatic data processed using the CROPWAT program

Author	Data collected
Santhi and Pundarikanthan 2000	Office record
Bustos et al 2001	Data collection was done by means of 89-item questionnaire, interviewing 19 inspectors of Users' Associations (UA's). The questionnaire was organized around : Distribution of water, identification of user needs, management and control, social factors
Murray-Rust and Svendsen 2001	Office record
Ines and Droogers 2002	Remotely sensed (RS) data and observable data
Levite and Sally 2002	Office record
Ray et al 2002	Indian Remote Sensing Satellite (IRS)-1C Linear Imaging and Self Scanning-III (LISS-III) and Wide Field Sensor (WiFS) data.
Dechmi et al 2003	field data, district records on WU and farmers' interviews records of irrigation practices for three different irrigation seasons
Evans et al 2003	Office record
Plantey and Molle 2003	Files of contracts, complaints reports, specific enquiries
Yercan et al2004	Office data and field data. Official reports of Turkish Republic State Hydraulic Works and audited annual reports of WUAs.
Vandersypen et al 2006	Field data
Clemmens and Molden 2007	RAP (Rapid Appraisal Process) process
Gaur et al 2008	Canal release data combined with census statistics moderate resolution imaging spectrometer (MODIS)
Latif and Tariq 2009	Field data, office records, conducting interviews
Parsinejad et al 2009	Field data
Akkuzu et al 2007	Data from General Diroctorate of State Hydraulic Works(DSI), Actual flow records, Images from NOAA-16/AVHRR

Table 2.2. The irrigation methods that were being adopted in different irrigation schemes for which the performance measures were estimated.

Irrigation scheme	Irrigation method
Ebro River Basin, La Violada irrigation District (Spain)	: Border and sprinkler
Nazare medium irrigation project, Maharashtra, India	: Surface
Kraseio Irrigation project, Thailand	: Surface
Wellton-Mohawak Irrigation District(WMIDD), Southwestern Arizona	: Surface
Three distributaries in the Lower Chenab Canal system in Punjab Province, Pakistan.	: Surface
Nagarjuna Sagar Right Canal (NSRC) irrigation project in Andhra Pradesh, India	: Surface
Rio Cobre Irrigation Scheme, Jamaica.	: Surface
Sri Ram Sagar Project, Andhra Pradesh, India	: Surface
Doroodzan Irrigation System, Iran	:Surface
Sathanur Irrigation Project , Tamil Nadu, India.	:Surface
Olifants river basin, South Africa	:Surface
Mahi River command, Gujarat, India	: Surface
Bojili Irrigation District (BID), Yellow River basin, China	: Surface
Loma de Quinto irrigation district (LQD), Zaragoza, Spain	: Sprinkler
El Angel watershed, Sierra region, Ecuador	: Surface
Societé du Canal de Provence, France	: Surface
Menemen Left Bank Irrigation System, Gediz Basin, Turkey	: Surface
Gediz river basin, Turkey	: Surface
Office du Niger, Mali	: Surface
Maira Branch Canal , Upper Swat Canal System, Pakistan	: Surface
Sefidrood irrigation and drainage network, Guilan Province, Iran	: Surface

2.3 Models used for Performance Assessment

The previous sections described the different performance measures and the studies that used theses performance measures for knowing the performance of the irrigation schemes. Several models have been developed for the estimation of the performance measures. The models (simulation/optimization) and techniques used for knowing the performance measures are reviewed in this section.

Vedula and Mujumdar (1992) developed stochastic dynamic programming (SDP) for estimating the performance measures viz. reliability, resiliency and productivity index when the scheme is operated with optimal operating policies over a sufficiently long period of time.

Onta *et al.* (1995) developed a linear programming (LP) based optimization model and a simulation model in a typical diversion type irrigation system for land and water allocation during the dry season and knowing the performance. In their model, optimum cropping patterns for different management strategies are obtained by LP model for different irrigation efficiencies and water availability scenarios. The simulation model yields the risk-related irrigation system performance measures (i.e. reliability, resiliency and vulnerability) for the management policies defined by the optimization model. The alternative strategies are evaluated in terms of all performance criteria (i.e. net economic benefit, equity and reliability) simultaneously through a trade-off analysis using a multi- criteria decision making method (compromise programming).

Gulati and Murty (1997) developed a model for optimal distribution of water in the canal command areas and finding out the productivity. Water production functions in the form of polynomial expressions were developed from existing experimental information. Using the production functions, water distribution was indicated in order to obtain maximum returns. They revealed that higher returns can be obtained from canal command areas by a suitable modification of the existing water release pattern at the outlet.

Mujumdar and Teegavarapu (1998) developed an integrated model for short-term yearly reservoir operation for irrigation of multiple crops. The model optimizes a measure of annual crop production, starting from the current period in real time. Reservoir storage at the beginning of a period, inflow during the previous period, crop soil moisture values and crop production already achieved up to the beginning of the period are used as inputs to the model. The solution specifies the reservoir release and optimal irrigation allocations to individual crops during an intra-seasonal period. They found that the developed model overcome some of the limitations of an earlier model developed by Mujumadar & Ramesh (1997) by replacing the two dynamic programming (DP) formulations with a single linear programming (LP) formulation.

Droogers *et al.* (1999) estimated the productivity of water resources at three different scales: field, irrigation scheme and river basin system. They used two hydrological models – one on field scale and another for river basin scale and used remote sensing data was used for the land cover classification, the irrigated area and the leaf area index for potential crop transpiration calculations. They considered four performance indicators namely (1) yield over transpiration, (2) yield over evapo-transpiration, (3) yield over flow volume, and (4) yield over depleted water. From their study they concluded that if irrigation performance indicators only are used at a local scale, a misleading picture can be given on the regional scale effectiveness in using water resources.

Droogers *et al.* (2000) studied the use of simulation models to evaluate irrigation performance including water productivity, risk and system analyses and found that, worsening water scarcity will increase pressure to use water more productively. According to them, some important aspects are often ignored: the total water balance approach, productivity of water, food security, and irrigation-system level analyses. These four approaches were evaluated using a detailed agro-hydrological model applied to an irrigation system in western Turkey. Emphasis was placed on the two dominant crops in the area: cotton and grapes. According to the classical point of view, the only result would be to irrigate the cotton with 1000 mm and the grapes with 800 mm. From the water productivity point of view, however, the water productivity of grapes appeared to be maximal without any irrigation; while for the cotton, irrigation at 600 mm maximizes water productivity. To minimize risks and increase yield stability, grapes perform better than cotton. Finally, from the irrigation system point of view, decisions can be made about the desirable cropping pattern and the distribution of water between crops. According to them with limited amounts of water available for irrigation, a cropping pattern consisting mainly of grapes is desired; while with higher water availability, a mixture of cotton and grapes is preferable.

Santhi and Pundarikanthan (2000) developed a planning model for canal scheduling of rotational irrigation based on multi-criteria approach. The various independent criteria considered were equity, adequacy, timeliness and locational or convenience of operation; represented in terms of weights. The final weight was obtained on a multiplicative basis (by multiplying the individual weights) for each distributary canal. Further the distributary canals were ranked for operation based on the final weight. The present model can also be used to get different scheduling scenarios (water distribution pattern) by varying the number of rotations, duration of each rotation and percentage of discharge through the distributary canals. The concept can be extended to any level of rotational distribution, starting from main canal down to farm outlets. This model is useful for planning and operating rotational water distribution system having multiple objectives. The potential of the model can be well observed when the distribution canals are larger in number and vary in discharge capacity.

Salman *et al.* (2001) worked on an inter-seasonal agricultural water allocation system (SAWAS) in the Jordan valley in Jordan. They introduced a linear programming optimization model for analyzing inter- seasonal allocation of irrigation water in quantities and quantities and their impact on agriculture production and income. The SAWAS model is a developed version of the Agriculture Sub-Model (AGSM). In the study, they stressed water scarcity as a problem that arises when water is not found in proper quantity and quality at the appropriate place and time. The model is designed to serve as a decision-making tool for planners of agricultural production on both the district and the regional level. It generates an optimal mix of water demanding activities that maximized the net agricultural income of the districts and gave the water demands under various prices. It also provides the planner with tools to carry out 'what-if' experiments and to generate optimal water demand curves. A principal feature of SAWAS is the use of demand and the benefits from water together with costs and optimization within the agricultural sector to specify the optimal usage of different water qualities. They revealed that agricultural planner can use the outputs of SAWAS in order to bridge the gap between the limited water resources and the increased agricultural production in an area that suffered from severe water scarcity.

Prasad and *et al.* (2002) developed the model for optimal irrigation planning under water scarcity. The specific objective of the model is to allocate the available land and water resources in a multi-crop and multi-season environment and to obtain irrigation weeks requiring irrigation of a fixed depth of 40 mm. The problem is solved in four stages. First, weekly crop water requirements are calculated from the evapotranspiration model by the Penman-Monteith method. Second, seasonal crop water production functions are developed using the single-crop intra-seasonal allocation model for each crop in all seasons. Third, allocations of area and water are made at seasonal and inter-seasonal levels by deterministic dynamic programming, maximizing the net annual benefit from the project. And fourth, once optimal seasonal allocations have been attained, irrigation scheduling is performed by running a single-crop intraseasonal allocation model. Optimal cropping pattern and irrigation water allocations are then made with full and deficit irrigation strategies for various levels of probability of exceedance of the expected annual water available. They have found that the optimization approach can significantly improve the annual net benefit with a deficit irrigation strategy under water scarcity.

Mateos at el. (2002) worked on SIMIS (Scheme Irrigation Management Information System), the FAO decision support system for irrigation scheme management which can be used either as a management tool or as a training tool. SIMIS uses a coherent modelling approach in all of its component modules based on the water balance, together with capacity constraints. It allows the simulation of different cropping patterns, irrigation network designs, water-distribution modalities, and water-distribution schedules which is applicable to any branched irrigation distribution system, but it mainly addresses open canal systems. It also provides a module for assessing irrigation planning scenarios and management alternatives. The SIMIS approach is based on simple water balance models with capacity constraints. SIMIS also facilitates in the administrative aspects of managing irrigation schemes (accounting, calculating water charges, controlling maintenance activities) and in assessing their performance. Performance indicators module of SIMIS aids performance assessment based on operational parameters. Four groups of such performance indicators are distinguished related to: the water distribution, agricultural intensity, maintenance, and financial matters. SIMIS a user-friendly software helps user to visualize geo-referenced information (inputs and outputs) through the geographic information system (GIS) contained within SIMIS. The irrigation network components can be entered with the help of the GIS.

Bazzani (2005) worked on an integrated decision support system for irrigation and water policy design. The Decision Support System for Irrigation (DSIRR) is a DSS for the economic-environmental assessment of agricultural activity focusing on irrigation, designed to answer both public and private needs. The program simulates the economically driven decision processes of farmers, permitting an accurate description of production and irrigation in terms of technology and agronomics. Distinct farm models can be constructed to describe the relevant production system in the catchment. Short and long term analyses can be conducted, the latter with endogenous investment choices. Solutions are found by applying multicriterial mathematical programming techniques. Farm models run under a graphical interface, which allows the user to quantify, by farm type, the utilization of water, labour and machinery, considering different types of soils, irrigation systems, water-yield functions and seasonality. Data are aggregated at catchment scale. Richness of information produced, flexibility and simplicity of use make DSIRR a useful tool for more sustainable agriculture and the definition of a sound water policy.

Smout and Gorantiwar (2005b) developed the area and water allocation model, AWAM, which incorporates deficit irrigation for optimizing the use of water for irrigation. This model was developed for surface irrigation schemes in semiarid regions under rotational water supply. It allocates the land area and water optimally to the different crops grown in different types of soils up to the tertiary level or allocation unit. The model has four phases. In the first phase, all the possible irrigation strategies are generated for each crop-soil-region combination. The second phase prepares the irrigation program for each strategy, taking into account the response of the crop to the water deficit. The third phase selects the optimal and efficient irrigation programs. In the fourth phase of the model, irrigation programs are modified by incorporating the conveyance and the distribution efficiencies. These irrigation programs are then used for allocating the land and water resources and preparing the water release schedule for the canal network. The model considers the allocation of the water to the tertiary level, incorporation of the different efficiencies at appropriate stages, and consideration of the capacity of the canal network to carry water make the resource allocation plan adaptable in practice for the planning and operation of irrigation schemes under rotational water supply. The model has a provision to estimate different performance measures at different temporal and spatial scales.

Prasad and et al. (2006) developed an optimal irrigation planning model to allocate the available land and water resources in a multi-crop and multi-season environment and to obtain irrigation weeks requiring irrigation of a fixed depth. Firstly the weekly crop water requirements are estimated from the Penman-Monteith evapotranspiration model and the seasonal crop water production functions are developed using the single-crop intra-seasonal allocation model. Further water and area are allocated at seasonal and inter-seasonal levels by deterministic dynamic programming, maximizing the net annual benefit from the project. Finally, after achieving the optimal seasonal allocations irrigation scheduling is developed based on a single-crop intra-seasonal allocation model.

Optimal cropping pattern and irrigation water allocations are determined based on two irrigation strategies namely full and deficit irrigation, for various levels of probability of exceedance of the estimated annual water availability. Authors observed that the annual net benefit can be considerably augmented by following the optimization approach with a deficit irrigation strategy under water scarcity. They recommended that the low water-consuming crops should be allocated with a maximum area under deficit irrigation for low water availability. The study indicates that the model presented can be used to determine the optimal water resources allocation as well as the optimal planting area across various crops in a season and among various seasons in a year. Solving the problem at various sub-levels i.e. inter-seasonal, seasonal, and intra-seasonal, the obstacles of dimensions can be overcome, and the model can be adopted in arid and semiarid areas for better water management. For a large irrigation system the command area being heterogeneous in terms of soil types and the crops grown however authors assumed the soil properties to be uniform over the entire command area to simplify the numerical procedure. Further they assured that it is not a limitation of the model, and the crop specific and soil specific area and water allocation can be achieved by considering the soil type as an additional stage in the dynamic programming problem.

The reviews of different studies reported in this section and summarized in Box 2.3 clearly show that the researchers have developed and presented different models based on simulation and optimization approaches for irrigation water management. These models also enable to compute the performance indicators. Out of different models presented in this section, AWAM model presented by Smout and Gorantiwar (2005b) enable to allocate the resources up to tertiary level and hence able to compute the performance measures at different parts of the irrigation schemes. AWAM model incorporates deficit irrigation for optimizing the use of water for irrigation. This model is developed for semi-arid region and surface irrigation scheme under rotational water supply. It allocates land and water optimally to different crops grown on different soils and at different region/locations and enables the allocation up to tertiary level.

The earlier researchers have also developed some models and used for allocation of land and water optimally which are described in Chapter 2 in Section 2.3. Some of those are: Onta et. al. (1995) developed a linear programming (LP) optimization model and a simulation model in a typical diversion type irrigation system for land water allocation. However, it is not for surface type of storage irrigation scheme. Salman et.al. (2001) introduced linear programming optimization model and worked on inter-seasonal water allocation. They assessed the impact on production and income. However, they did not work on seasonal. Mateos at el. (2002) worked on Scheme Irrigation Management Information System (SIMIS). It allows a simulation of different cropping patterns, irrigation network designs, water distribution modalities and water distribution schedules. However, in this study the different type soils are considered and SIMIS- a user friendly software helps user to visualize geo-referred information (inputs and outputs) the GIS. Droogers et al. (2000) studied the use of simulation models to evaluate irrigation performance including water productivity, risk and system analysis. In this study the emphasis was placed on the two dominant crops in the area i.e. cotton and grapes. Therefore considering the limitations of other models and suitability of AWAM over other models, the AWAM is used for the present study.

Several researchers developed the model for the simulation of different parameters required for the estimation of the performance measures. These are summarized below.

Area and Water Allocation Model (AWAM)	: Developed by Gorantiwar 1995, Gorantiwar and Smout 2003 ; Used by Smout etal 2003, Smout and Gorantiwar 2005b
Management-Ooriented Model (MODERATO)	: Developed by Bergez et al 2001a ; Used by Bergez et al 2004
An inter-seasonal agricultural water allocation system (SAWAS)	: Used by Salman et al 2001
Scheme irrigation management information system (SIMIS)	: Developed by Sagardoy et al 1994 ; Used by Mateos et al 2002
Soil-Water-Atmosphere-Plant (SWAP)	: Developed by Van Dam et al 1997 ; Used by Droogers and Bastiaanssen 2002
Surface Energy Balance Algorithm for Land (SEBAL)	: Developed by Bastiaanssen et al 1998 ; Used by Droogers and Bastiaanssen 2003

Box 2.5. The models used by different researchers for the estimation of the parameters that are required for the computation of the performance measures.

2.4 Use of AHP and Multi Criteria Decision Making

As stated in the Chapter 1, one of the objectives of the study is to know the relative importance of the different performance measures. There are several methods for finding out the relative preference of different stakeholders to performance measures. These are rank method, analytical hierarchical process (AHP) etc. However AHP has been found to be widely used in different sectors for knowing the relative preference. As there is more than one criterion for knowing the performance as indicated by different performance measures, it is necessary to use multi criteria decision making (MCDM) for knowing the overall performance of the irrigation schemes. The different studies on the use of MCDM and AHP are reported in this section.

Prathapar *et al.* (1997) developed a hierarchical multicriteria framework, *SWAGMAN Options* (Salt Water And Groundwater MANagement) to discover the profitable non rice land uses to reduce water table rise and salinization in irrigation areas of southeastern Australia. The concerned study area has affected by the heavy water table rise because of recharge from rice cultivation which has intensified the damage potential of water-logging and soil salinization, and threatened the long-term irrigated agriculture productivity. The sensitivity of maximum area allocated to rice crop per farm, rice field water use limit, rainfall conditions, optimal depth, critical salinity, initial piezometric levels, and weights associated with the objective functions on subsurface drainage and farm net returns was studied in the *Camarooka* Project Area in New South Wales, Australia using the *SWAGMAN Options*. It was observed that the current practice of monoculturing rice (30% of a farm area) leads to shallow water tables in an average rainfall year. However, the increase in shallow water table area due to increase in rice area was not linear and found to be asymptotic beyond 30% of the farm area allocated to rice. They stated that introducing non-rice crops land uses will be helpful to lower the water table and to increase the net returns substantially. Among the non-rice land uses they recommended that balancing the rice production with maize and canola to the level so that rice field water use is less than 1400 mm will minimize the water table rise, lessen the subsurface drainage requirements and improve farm profitability. An increase in rice field using 1600 mm of water, results into water table rise and diminished returns. However, the net returns found to be lowered in dry years due to a reduced area under irrigation and converse was true for wet years. They also observed that increase in critical soil salinity by 1 dS m^{-1} to 2 dS m^{-1} dose not influence the net returns. With increase in the optimal depth the net returns are diminished and drainage volume is increased. It was concluded that increasing the weight for maximizing net returns (W_1) from 0.5 to 1.0 does not affect the net returns significantly but results into increased drainage requirements. However, when the weight for maximizing discharge is increased from 0.5 to 1.0; the net returns are reduced significantly but no considerable change in drainage requirement is observed.

Anand Raj and Nagesh Kumar (1998) proposed a methodology to rank river basin planning and development alternatives under multi-criterion environment using fuzzy numbers for *Krishna* river basin in India. A set of 7 alternative systems with 8 main objectives

(National or Regional development, water requirement, flood protection, utilization of resources, enhancement of environment, recreational enhancement, returns and flexibility) which are further subdivided into 18 criteria, were considered for ordering or ranking them employing the opinion (preference structure) of three experts: an academician, a field engineer and an official from Ministry of Water Resources, using fuzzy numbers. Experts were provided required relevant information about criteria, reservoirs, alternative systems and associated purposes, advantages, and problems. The fuzzy weights (Wi) of alternatives (Ai) were computed using standard fuzzy arithmetic. The utility of each alternative was decided using concept of maximizing set and minimizing set. They found that the final ranking depends on utility values along with vertices of membership functions of the respective alternatives. Among the 7 alternatives considered alternative A4 was found to be the best alternative, A7 is the next, while alternative A3 ranked as the last.

Berbel and Ocafia (1998) developed a Multiple Criteria Decision-Making (MCDM) approach to production analysis for irrigated farms in Southern Spain. They used different criteria : maximisation of net income (W1), minimisation of hired labour (W2), minimisation of working capital requirements (W3) and optimising the MAXIMIN for the period 1988 – 1992 (W4); where MAXIMIN is maximization of net income with minimization of hired labour and working capital. The combined approach of identifying the weights and using them simultaneously or iteratively was followed. Using the cluster analysis farmers were grouped according to their socioeconomic characteristics and technical and natural production resources. The farmers from the clusters were allowed to give weights to the decision criteria. Then the weighted goal programming was applied to the weights given by the different types of farmers to the objectives in the decision process, and the relationships between the type of farm operator and the production plans were defined. From the comparison of simulated crop plans with actual crop plans the study area was confirmed to be quite heterogeneous in production plans as a consequence of variations in socio-economic and technical characteristics of farm enterprises. The variation of crop plans could be explained by differences in objective weights caused by differences in the farmers' value orientation. The methodology facilitates a deep understanding of the influence of socio-economic and technical heterogeneity on production decisions. They remarked that it highly impossible to directly link value orientation to criteria by direct questioning, and this opened up an interesting field of research. This framework combined with empirical models can be a useful tool for the analysis of policies such as stabilisation programs, water management schemes, direct or indirect regulations or agricultural support programs. They stated that the human capital (experience, education, and age) is at least as important to explain agricultural output as technical and natural capital availability. Finally they concluded that there are some interesting avenues of research, as to study the evolution of weights in a period of time. In the specific case of irrigated agriculture, it may be applied to analyse the projected demand on natural resources (i.e. water, fertiliser) using the weighted goal programming approach instead of the classical profit-maximising hypothesis. According to authors for the MCDM community, some discussion on the meaning of weights and uses of weights for economic and management models is convenient.

Giupponi and *et al.* (1999) developed a multicriteria analysis system to create risk maps of agricultural pollution due to alternative cultivation systems in the Watershed of the Lagoon of Venice (WLV) in Italy. Multi-criteria evaluation was aimed to determine the significance of the low input cultivation techniques subsidized by the European Union for the reduction of pollution risks of surface and groundwater. They have considered different criteria i.e. pollution of drinking water (index RD), toxicity for mammals (index MT), toxicity for aquatic life (index NT) and eutrophication (index ER). Results of a field scale simulation model for agricultural diffuse pollution were used to compile a matrix of environmental impacts, in terms of pollution indices. The most widespread combinations of typical environments (as defined by combinations of soil and climate variables) and alternative land uses (types of crops and cultivation systems) were described in the impact matrix. Land use in terms of crop distribution was based on census data. Two alternative cultivation systems were defined on the basis of the recent changes to the European Common Agricultural Policy: ordinary and eco-compatible. Two alternative sets of cultivation techniques were compared using the pollution-risk maps created with simulation model GLEAMS (Groundwater Loading Effects of Agricultural Management Systems). Geographical Information System was used to consider the spatial features of pollution phenomena, vulnerability of the land and risk for water resources. However, the results obtained proved the great potential of eco-compatible practices to minimize the risks for surface and groundwater (-15 and -50%, respectively). They stated that the developed framework integrated with a socio-economic component can be effectively adopted as a decision support tool that can be used along with local decision makers. It would then be possible to spatially simulate, for instance, possible effects of proposed regulations, or to run iterations with varying weights of the attributes, reflecting different priorities of the stakeholders involved (e.g. protection of aquatic life or of an aquifer). The application to the study area gave a deeper understanding of pollution phenomena due to agricultural activities and their spatial distribution. They stated that with quality input data and a better calibration of the simulation models can improve the results, thus obtaining tools increasingly capable of representing the peculiarities of the current farming systems and their interactions with the various cultivation environments.

Bender and Simonovic (2000) studied a fuzzy compromise approach for decision making in water resource systems planning under uncertainty. The approach allowed various sources of uncertainty and aimed to offer a flexible form of group decision support. The traditional technique to evolve discrete alternatives i.e. ELECTRE method was compared with the fuzzy compromise approach to demonstrate the benefits of multicriteria decision analysis technique which considered subjectivity within its proper context while maintaining an intuitive and transparent technique to rank the alternatives. The fuzzy compromise approach reviewed a family of possible conditions and supported group decisions through fuzzy sets designed to react collective opinions and conflicting judgments. Ranking of alternatives was attained using fuzzy ranking measures designed to illustrate the effect of risk tolerance differences among decision makers. They used two distinct ranking measures namely a centroid measure, and a fuzzy comparison measure based on a fuzzy goal. The centroid measure (WCoG) was mentioned to be easily understood, but the acceptability measure (Acc) allowed parametric control more specifically designed to model level of risk aversion from decision makers. A fuzzy compromise approach was found to be comparatively more advantageous over traditional (non-fuzzy) MCDA techniques. The fuzzy compromise approach facilitates the direct, and often intuitive incorporation of vague and imprecise forms of uncertainty to the decision making process. By allowing a degree of fuzziness, more realism can be added to the evaluation without compromising on the technique's ability to disseminate alternative preferences.

Gomez-Limon and Berbel (2000) carried out multicriteria analysis of derived water demand functions for Mid Duero Valley command area in Spain. They derived a water-demand function by simulating the probable impact of the policy based upon the water price on agricultural production and further analysing the economic, social and environmental connotations of such a water policy. They established a methodology for deriving water-demand functions where farmers' behavior is explained by a utility function with several conflicting criteria (profit maximisation, risk minimisation, management complexity minimisation) which extended the traditional profit-maximising assumption. They followed a weighted-goal programming approach to estimate a surrogate utility function for the farmer's decision process; which in turn was used to estimate the value of water demand in irrigated crop production using utility-derived demand functions. In brief, they tentatively established a set of objectives which were believed to be most vital for farmers. Then the pay-off matrix for the concerned objectives was determined. Further a set of weights that optimally reflect farmers' preferences were estimated using the matrix. Finally they assured that in order to build more realistic models, multicriteria techniques should be adopted for further analyses of irrigated agriculture. Analytical tool they have outlined in this study can be treated as a valid methodology for dealing with farmers' utility functions and thus for producing more realistic policy-impact simulations.

Mahmoud and Garcia (2000) created a computer program to compare the different multicriteria evaluation methods for the *Red Bluff* diversion dam. Five Multi-Criteria Evaluation Methods (MCEMs), each of which is capable of evaluating alternatives in a resource management setting; included Weighted Average (WA), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II), Compromise Programming (CP), Elimination and Choice Translating Reality (ELECTRE II) and Analytical Hierarchy Process (AHP). Each of the MCEMs was applied to an array of different management alternatives for andromodous fish migration through the Red Bluff Diversion Dam (RBDD) along the Sacramento River in California. After analysing the results MCEMs were ranked based on (1) the consistency of results, (2) the amount of interaction required by the user and (3) the degree of usability by technical and nontechnical professionals. WA was found to be the method of choice when applied within the boundaries of the study undertaken.

According to authors, the MCEMs are meant to illustrate the trade-offs among different alternative solutions when evaluated by technical and nontechnical professionals and maximize agreement between all interested stakeholders including Red Bluff community members, fisherman on the Sacramento River, farmers, ranchers, environmental groups, and representatives of government agencies. Selecting the best MCEM requires understanding and the acceptability of the method by the decision makers (DM) in order to maximize the method utility and effectiveness. They stated that each method has its own strengths and weaknesses. (1) For the CP method, even thought the method is easy to understand and needed minimum interaction with the user, being sensitive to the number of alternatives it is inconsistent. (2) The PROMETHEE II method is an attractive method where the DM can set a preference function that can determine preferred alternatives. (3) In ELECTRE II method criterion is appraised even if it has a weight equal to zero which can mislead the DM, since the discordance calculation does not consider the value of the weights. They stated another disadvantage of this method that it ranks last in its ability to be understood by the users. (4) For the amount of interaction required by the user AHP was found to be ranked last. Using the Saaty scale (Table 3.1) it required a great amount of interaction between the method and the user which limits the user continuing the analysis, if no alternative is ranked as being greater. Moreover, the method is comparatively complex to understand as that of WA or CP. (5) However, WA method being consistent, easy to understand and requires little interaction from the user was preferred for evaluating solution alternatives for the concerned problem. The linearity and the additive assumption for the utility function were considered acceptable to the DM.

Liu and Stewart (2004) studied an object-orientated modelling of decision support systems (DSSs) for general multicriteria decision making (MCDM) in natural resource management. They integrated DSS modelling approach into the uniform framework based on object orientation for both MCDM and DSS modelling. The general system requirements for DSSs for MCDM in natural resource management decision problems were confined based on the understanding of the fundamental functions and the system environment of DSSs. Primary classes, including decision elements and DSS components, for both MCDM decision analysis and DSS modelling were then identified. These classes were modelled with classes of object orientation for the purpose of decision facilitation and DSS development. The general

DSS system infrastructure was designed having decision making processes been analysed. In addition, DSS evaluation principles can be applied to the requirement analysis to ensure that these principles are met by the DSS under development. Proposed DSS model proposed was validated by developing a practical system for water resources management in South Africa under contract to the South African Water Research Commission (WRC). The Multi-Attribute Value Theory (MAVT) based approach called scenario-based policy planning (SBPP) was used as MCDM method in WRC DSS. The WRC DSS is a group DSS (GDSS) based on the Internet which allows a group of decision makers working together as a team to share information interactively, to generate ideas and actions, to choose alternatives and to negotiate solutions. WRC DSS supports most of the decision making processes: problem structuring, evaluation and aggregation. At the phase of problem structuring, the problem under consideration is identified and defined in terms of criteria, alternatives, and other related data. The evaluation and aggregation phases included the module to elicit subjective judgments or value functions for evaluating alternatives, and the module to elicit weights for measuring the trade-offs amongst criteria. They also calculated the weighted value of each alternative. Finally, the sensitivity of the weighted value to weights was examined.

Karami (2006) examined the significance of Analytic Hierarchy Process (AHP) to select an appropriate irrigation method for four provinces: *Fars, Bushehr, Kohkiloye-va-Boyerahmad and Chaharmahal-va-Bakhteyar*i, of Iran. Farmers in the study area were divided into four groups using cluster analysis. AHP was adopted to determine the priority of three irrigation methods (border, basin and sprinkler) for each group of farmers. Then, the optimum decision regarding the use of irrigation methods was determined for each group. Farmers' actual judgments while selecting the irrigation method were compared to the AHP results in order to analyse the percent of farmers who have made an appropriate decision. It was discovered that the highest priority of irrigation methods differed with respect to farmers groups. The aptness of the decision of each farming group, regarding selection of irrigation methods, was determined. From the overall analysis of selection of irrigation methods it was revealed that 74% of farmers made an appropriate decision (about 16% by adopting and 58% by not adopting sprinkler irrigation). A total of 26% of farmers had made an inappropriate decision in the selection of irrigation methods. These included inappropriate adopters (14%) and non-adopters (12%).

It was proposed that the extension organizations should use cluster analysis to classify farmers to recommendation domains and use the multi-criteria decision tools (AHP) to determine the priority of irrigation methods for each target group of farmers, in order to reduce the risk of promoting inappropriate decisions. Further they suggested that, farmers' consultation will be more beneficial while selecting the criteria for inclusion in the AHP model. The farmers being unable to use decision software independently, extension agents should be trained to use the decision tools. It will help them to select the appropriate irrigation method for promotion (among farmers of a particular recommendation domain) in extension programs and help individual farmers to select appropriate irrigation methods with rationale.

Gorantiwar and Smout (2010) described the approach based on AHP for finding out farmers' relative preference to performance measures. The approach developed by them has been used in this study to choose between various possible performance measures (see section 3.2.4).

The Analytic Hierarchy Process is a structured technique for dealing with complex decisions and therefore is applicable to current multi-level multi-criterion decision making. The AHP helps decision makers to find one that best suits their goal rather than prescribing a "correct" decision. The capability of the AHP distinguishes from other decision making techniques which are mostly dependent on ranking. In ranking method we have to rank different options at one time which may not give consistent results (as the farmers may find it difficult to compare many alternatives). In AHP we compare only two options at a time and hence provide more consistent results.

It is seen from the studies reported in this section that AHP has the potential to find out the relative preference of different options in multi criteria environment and MCDM methods are able to consider different options. Hence in this study it is proposed to use AHP and MCDM approaches for knowing the relative preference of different performance measures and analyzing those, respectively.

2.5 Closing

The studies reviewed in this Chapter though not complete but are representative. These studies indicate that there are several indicators that need to be considered while assessing the performance measures of irrigation scheme. There are several methodologies that can be used to asses the performance assessment. These include modelling (simulation and/or optimisation) and actual field measurements. In this study the framework proposed by Gorantiwar and Smout (2005a) will be used as the base for performance assessment. The simulation-optimisation model, Area and Water Allocation Model (AWAM) developed by Gorantiwar (1995) and Smout and Gorantiwar (2005a) along with actual field data collection/measurements will be used to evaluate certain parameters required for the performance assessment.

The studies conducted by Chari et al. (1994), Bastiaanssen et al.(1999), Bastiaanssen and Bos (1999) and Ray et al. (2002) indicate that the remote sensing technique has the advantages for estimation of irrigation performance. At the same time, however the remote sensing technique may prove costlier as the data of remote sensing images is still the constraint in using this technology. Some studies, eg. those by Dechmi et al. (2003) studied the performance of irrigation scheme that use sprinkler irrigation system. However the methodologies adopted by them would provide guidance for estimating the performance parameters of surface irrigation systems.

Further as there are more than one performance indicators that need to be considered simultaneously, it is necessary to know which of them has to be given more preference. The AHP method is suitable for knowing the preference of one performance measures over another. At the same time multi criteria decision making process need to be used to find out the overall performance of the irrigation water management by taking in to consideration different performance indicators.

3 METHODOLOGY

3.1 Introduction

The major objective of this study is to study the performance of the irrigation water management and devise a technique for obtaining the suitable optimal policy by including the tradeoff amongst different performance measures and stakeholders in allocation process. To validate the techniques devised, it is necessary to select the irrigation schemes and test the methodologies on the observations obtained over the selected irrigation schemes.

The detailed objectives as stated in Chapter 1 are:

1. To study the relative importance of performance measures to farmers (water users) in different locations in an irrigation scheme (Mula Irrigation Scheme in Maharashtra, India).
2. To study the performance of irrigation water management in irrigation schemes in terms of different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency).
3. To provide the guidelines for improving the performance of irrigation water management in irrigation schemes.
4. To test a technique for obtaining the suitable optimal policy based on the relative preferences of the farmers to different performance measures in allocation process.

In this regard three irrigation schemes were identified after the consultation with the officials from the Department of Irrigation, Government of Maharashtra, India. These schemes were:

- Ghod Major Irrigation scheme
- Sina Medium Irrigation Scheme
- Mangi Medium Irrigation Scheme

The study involved the collection of the data that was required for the computation of the various irrigation performance parameters from the historical observations. It was expected that these observations could be available from the official records of these irrigation schemes. However upon several visits and enquires, it was revealed that the observations were not recorded continuously on these schemes and the observations were not available for many parameters that are required for the computation of the irrigation performance. Apparently it was due to the fact that these schemes were relatively newly established and the data management systems were not in place. Hence it was decided to change the irrigation schemes.

Accordingly the 'Mula Major' irrigation scheme which was long established since was selected. The details of this scheme are described in this chapter section 3.5.

The methodologies developed by Gorantiwar (1995) and Smout and Gorantiwar (2006) that were used for knowing the relative importance of performance measures to different stakeholders (water users) and the technique for obtaining the suitable optimal policy by including the tradeoff amongst different performance measures and stakeholders in allocation process are described in this chapter section 3.6.

The methodology used to test the hypothesis and achieve the objectives of the study consists of:

1. Selection of irrigation schemes and data collection
2. Assess the performance of irrigation water management
3. Analyse the performance results
4. Find out the relative preference to different performance measures by farmers at different locations in Mula irrigation scheme.
5. Know the different performance measures and final performance in response to different irrigation strategies
6. Tradeoff analysis of the performance measures.

3.2 Performance Assessment of Irrigation Water Management

The methodology proposed by Gorantiwar and Smout (2010) for performance assessment of the irrigation scheme has been used, to meet the objectives of the study. This methodology consists of the following steps.

1. Identification of performance measures and their hierarchical structure
2. Computation of the performance measures
3. Compute the values of performance measures by AWAM developed by Gorantiwar (1995) and Smout and Gorantiwar (2005a)
4. Relative preference of performance measures
5. Multicriteria decision making for evaluating the final performance

The performance of irrigation scheme will be assessed with the help of model, Area and Water Allocation Model (AWAM) (Gorantiwar 1995) and framework for assessment developed at Loughborough University (Gorantiwar and Smout 2006 and Smout and Gorantiwar, 2006).

3.2.1 Identification of performance measures and their hierarchical structure

The literature cited in Chapter 2 (Review of Literature) indicates that the productivity and adequacy are the widely referred performance parameters. In water scarcity regions, equity was also considered. Therefore these three performance indicators viz. productivity, adequacy and equity were considered for obtaining the allocation plans. However in the framework developed by Gorantiwar and Smout (2006), reliability, flexibility and sustainability were also considered. Hence while obtaining the information on the relative importance of different performance parameters, additionally these three parameters were also considered.

Thus following six performance indicators were identified as the important one for obtaining the information on the relative preference from the farmers and first three were considered for obtaining the allocation plans.

1. Productivity
2. Equity
3. Adequacy
4. Reliability
5. Flexibility
6. Sustainability

As described by Gorantiwar and Smout (2006), these performance measures have the following attributes:

Productivity: Net benefits per unit area productivity, Crop production per unit area productivity, Net benefits per unit used water productivity, Crop production per unit used water productivity, Irrigated area per unit of culturable command area productivity.

Equity: Area, Water, Net Benefits, Crop Productivity

Adequacy: Seasonal Adequacy, Intra Seasonal Adequacy

Reliability: Seasonal Reliability, Intra seasonal Reliability

Flexibility: Flexibility in irrigation amount, Flexibility in irrigation frequency

Sustainability: Crop occupancy sustainability, Irrigated area sustainability, Groundwater (rise) sustainability, Groundwater (fall) sustainability, Problematic area sustainability

The hierarchical structure of these performance measures that lead to final performance of the irrigation scheme is shown in Figure 3.1 (Gorantiwar and Smout, 2010). In this study, however only three performance measures viz. productivity, equity and adequacy with their different attributes will be considered.

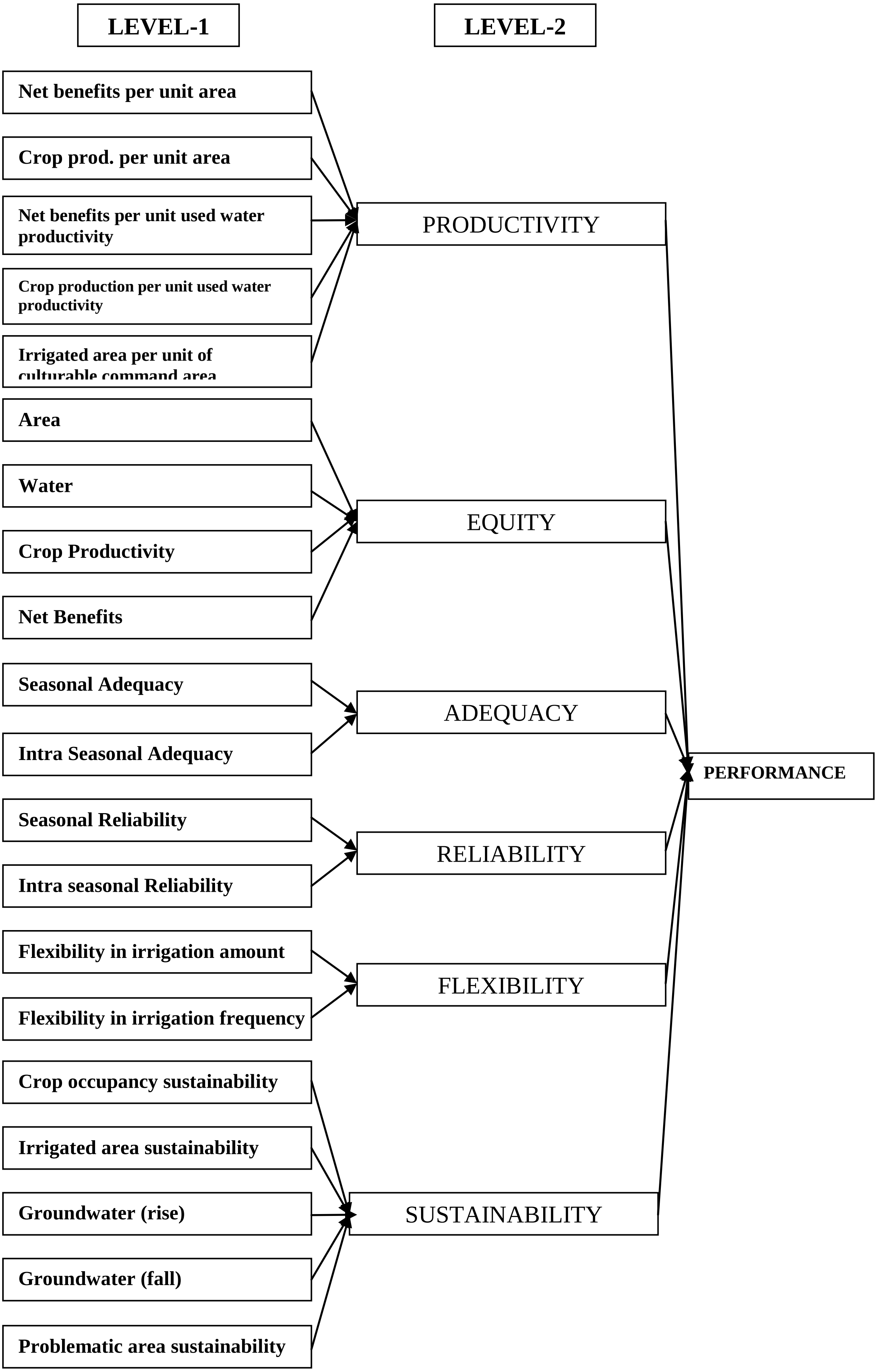


Figure 3.1. Different performance measures and their hierarchical structure

Firstly, from review of literature it is seen that the productivity and adequacy are the widely referred performance parameters. In water scarcity regions, equity was also considered. Secondly, we did not get the data to compute other performance parameters. Additionally AWAM estimates only productivity, equity and adequacy and not other parameters. Therefore these three performance indicators viz. productivity, adequacy and equity will be considered for obtaining the allocation plans. However, if the data was available, other performance parameters could be estimated from the results obtained from AWAM or AWAM could be updated to consider those. While obtaining the information on the relative importance of different performance parameters, additionally reliability, flexibility and sustainability these three parameters will also be considered.

3.2.2 Computation of the performance measures

The performance assessment of irrigation schemes will be performed with the help of the framework proposed by Gorantiwar and Smout (2005a). They proposed two types of performance measures. These are: the allocative type comprising productivity and equity; and the scheduling type comprising adequacy (excess), reliability, flexibility and sustainability.

In this study allocative performance measures i.e. productivity and equity and scheduling performance measures adequacy will be determined. The definitions and methodology proposed by Gorantiwar and Smout (2005a) are reproduced below.

3.2.2.1 Productivity

The productivity is related to output from the system in response to the input added to the system and there are several indicators of productivity. The principle output of the scheme is the crop produce or its economic equivalence and the area irrigated. These need to be assessed seasonally or annually. The productivity can be indicated by measuring these outputs in gross terms or relative to input utilized. In this study the productivity will be estimated as described below.

- *monetary productivity (based on net benefits):*

$$\Pr gm = \frac{OBa}{OBt} \tag{3.1}$$

where,

Prgm = monetary productivity (gross)

OBa = actual output (total net benefits in currency-unit estimated for the existing schedule)

OBt = targeted output or output of management strategy with maximum output

- *area productivity (based on area irrigated):*

$$\Pr ga = \frac{OAa}{OAt} \tag{3.2}$$

where,

Prga = area productivity (gross)

OAa = actual output (total area estimated for irrigation in ha for the existing schedule)

OAt = targeted output (culturable command area of Scheme)

3.2.2.2 Equity

Gorantiwar and Smout (2005a) defined equity as "the distribution of input resources in the irrigation scheme (area and water) or the resulting output (crop production or net benefits) among the users (farmers, outlet) in a fair manner which is prescribed in the objectives of the irrigation scheme in the form of social welfare." Thus the issues in equity in irrigation water management are multiple: whether there should be equity or inequity; the resources to be targeted for equity (whether it should be area irrigated, water delivered or expected returns in terms of crop production or net benefits) and the base of equity (land holding, water rights, water requirement of the area, land price, family size etc). In this study equity will be determined as described below.

- *equity (based on the allocation proportion by area):*

$$\mathrm{Ei} = \frac{\overline{\mathrm{Ra}^{pq}}}{\overline{\mathrm{Ra}^{bq}}} \tag{3.3}$$

where

Ei = equity for the irrigation scheme

$\overline{Ra^{bq}}$ = average of allocation ratios of the best quarter

$\overline{Ra^{pq}}$ = average of allocation ratios of the poorest quarter

$$Ra_i = \frac{\lambda a_i}{\lambda d_i} \tag{3.4}$$

where,

Ra_i = allocation ratio of i^{th} allocation unit

λa_i = actual allocation proportion for i^{th} allocation unit

λd_i = desired allocation proportion for i^{th} allocation unit

$$\lambda d_i = \frac{\Delta d_i}{\sum_{i=1}^{na} \Delta d_i} \tag{3.5}$$

where,

Δd_i = the value of the parameter to which equity should be proportional, assigned to i^{th} allocation unit (culturable command area of i^{th} allocation unit in ha.)

na = total number of allocation units

$$\lambda a_i = \frac{\Delta a_i}{\sum_{i=1}^{na} \Delta a_i} \tag{3.6}$$

where,

Δa_i = value of parameter (water allocated in ha-m at allocation unit level) by which equity is measured, computed for i^{th} allocation unit

$\Delta a_i = V_i * A_i$

A_i = Area allocated for irrigation or irrigated of i^{th} allocation unit

V_i = Volume of water allocated or delivered to the i^{th} allocation unit

3.2.2.3 Adequacy

Adequacy deals with water supply to the crop relative to its demand. Gorantiwar and Smout

(2005a) proposed two separate measures for describing supply of water in relation to demand. These are: adequacy and excess. They defined adequacy as "the ratio of the water allocated or supply from all the sources (irrigation, effective rainfall, capillary water etc.) and the demand due to all the processes (consumptive use, losses, land preparation, leaching for draining accumulated chemicals or salts, other special needs etc) over a specific time period for a specific crop grown in a specific area". In this study adequacy and excess will be determined as described below.

- *adequacy (based on the ratio of supply to crop water requirements):*

Intraseasonal-Allocation unit

$$AQia_{ji} = \min\left(\frac{Va_{ji}}{Vr_{ji}}, 1\right) \tag{3.7}$$

where,

$AQia_{ji}$ = adequacy during j^{th} irrigation for i^{th} allocation unit

Va_{ji} = volume of water allocated to i^{th} allocation unit during j^{th} irrigation

Vr_{ji} = volume of water needed according to maximum demand to i^{th} allocation unit during j^{th} irrigation

Seasonal-Allocation unit

$$AQa_i = \left(\frac{\sum_{j=1}^{J} \min\left(Va_{ji}, Vr_{ji}\right)}{\sum_{j=1}^{J} Vr_{ji}}\right) \tag{3.8}$$

where,

AQa_i = adequacy for i^{th} allocation unit

J = total number of irrigations during the irrigation season/year

Intraseasonal-Scheme

$$AQi_i = \left(\frac{\sum_{i=1}^{na} \min\left(Va_{ji}, Vr_{ji}\right)}{\sum_{i=1}^{na} Vr_{ji}}\right) \tag{3.9}$$

where,

AQi_{ii} = adequacy during i[th] irrigation for the scheme

na = total number of allocation unit

Scheme

$$AQ = \left(\frac{\sum_{i=1}^{na} \sum_{j=1}^{J} \min\left(Va_{ji}, Vr_{ji}\right)}{\sum_{i=1}^{na} \sum_{j=1}^{J} Vr_{ji}} \right) \tag{3.10}$$

where

AQ = Adequacy for the irrigation scheme

3.2.2.4 Excess

Intraseasonal-Allocation unit

$$EXia_{ji} = \max\left(\frac{Va_{ji} - Vr_{ji}}{Vr_{ji}}, 0 \right) \tag{3.11}$$

where,

$EXia_{ji}$ = excess during j[th] irrigation for i[th] allocation unit

Seasonal-Allocation unit

$$EXa_{i} = \left(\frac{\sum_{j=1}^{J} \max\left(Va_{ji} - Vr_{ji}, 0\right)}{\sum_{j=1}^{J} Vr_{ji}} \right) \tag{3.12}$$

where,

EXa_{ji} = excess for i[th] allocation unit

Intraseasonal-Scheme

$$EXi_{i} = \left(\frac{\sum_{i=1}^{na} \max\left(Va_{ji} - Vr_{ji}, 0\right)}{\sum_{i=1}^{na} Vr_{ji}} \right) \tag{3.13}$$

where,

EXi_{ii} = excess during i^{th} irrigation for the scheme

Scheme

$$EX = \left(\frac{\sum_{i=1}^{na} \sum_{j=1}^{J} \max\left(Va_{ji} - Vr_{ji}, 0\right)}{\sum_{i=1}^{na} \sum_{j=1}^{J} Vr_{ji}} \right) \qquad (3.14)$$

where,

EX = Excess for the irrigation scheme

3.2.3 Model to compute the values of performance measures

AWAM model (Area and water allocation model) for the assessment of performance of the irrigation scheme has been described by Gorantiwar (1995); Smout and Gorantiwar (2005b) and Gorantiwar and Smout (2005a). The model is described briefly below.

The AWAM model has the following four phases and is executed for each set of irrigation interval over the irrigation season as shown in Figure 3.1 (A) (Gorantiwar et al 2006).

The four phases of AWAM model as described by Gorantiwar (1995) and Smout and Gorantiwar (2005b) are:

1. Phase 1. Generation of irrigation strategies
2. Phase 2. Preparation of irrigation programmes with SWAB-CRYB sub models for each irrigation strategy generated in Phase 1
3. Phase 3. Selection of optimal and efficient irrigation programmes from those prepared in Phase 2
4. Phase 4. Optimum allocation of resources which comprises three stages;

Stage-1: Preparation of irrigation programmes for each Crop-Soil-Region (CSR) unit of each allocation unit by modifying the irrigation programmes of the corresponding CSR.

Stage-2: Allocation of land and water resources to each CS unit of each allocation unit with objective of maximizing productivity and constrains with the Resource Allocation (RA) sub model. Inclusion of equity constrains for maximization of equity.

Stage-3: Preparation of canal water release schedules.

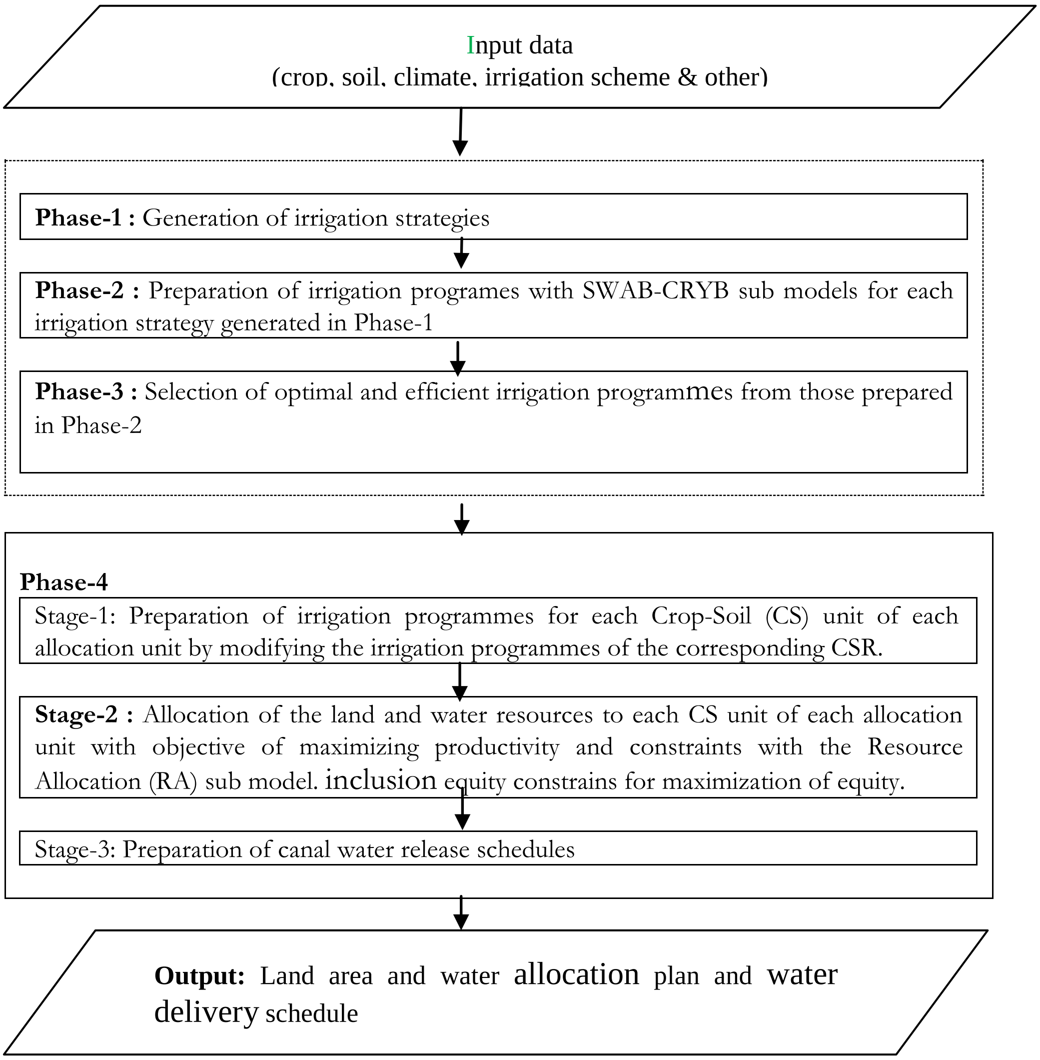


Figure 3.1 (A) Flow chart: Area and Water allocation (AWAM) model (Source: Gorantiwar et al. 2006)

These four phases of AWAM model are described below.

1. Generation of irrigation strategies: The area of the irrigation scheme with similar climate (Region), soil (Soil group) and crop is termed a Crop-Soil-Region (CSR) unit, but this is not a physical division of the irrigation scheme.

The irrigation strategies need to be generated for the optimum allocation of water that needs estimates of the output obtained from several possible ways of irrigating the crop. These several ways are described as irrigation strategies and are generated in Phase 1 for each Crop-Soil-Region unit and for a given set of irrigation intervals.

However if the existing irrigation schedule is to be evaluated, there is no need to generate the irrigation strategies. The existing irrigation schedule specified for the particular CSR unit is the irrigation strategy for this CSR unit.

2. Preparation of irrigation programme: The irrigation programme which consists of information on yield/benefits and irrigation requirement (depth) per irrigation is prepared for each irrigation strategy generated in Phase 1, from the following two sub-models.
• SWAB: This sub-model simulates soil moisture in the soil root zone and estimates the actual crop evapotranspiration and the other related parameters and the irrigation requirement (depth) per irrigation.
• CRYB: This sub-model estimates crop yield and net benefits. Irrigation programmes are prepared for each Crop-Soil-Region unit for the given irrigation strategy such as full irrigation (irrigation to fill the root zone to field capacity) or a given irrigation depth for each irrigation.

3. Selection of irrigation programmes: Phases 1 and 2 may generate many irrigation programmes for the optimum allocation of irrigation water. Not all of them are important and all cannot be considered in the fourth phase due to computational limitations. Therefore, this phase selects the efficient irrigation programmes which give the maximum production and net benefits according to certain criteria This step is skipped if a single irrigation strategy is given for each Crop-Soil-Region unit or irrigation scheme.

4. Optimum allocation of resources: The entire irrigation scheme is physically divided into a number of smaller units called “Allocation Units” (AU) over which land and water resources are allocated. The climate is assumed to be uniform over the allocation unit, but the allocation unit may include different soils and crops. The climatic conditions may be different for different allocation units. The need to divide the irrigation scheme into several allocation units arises due to the heterogeneous nature and large extent of the irrigation scheme and in order to make allocation of resources, water delivery schedules and management of the irrigation scheme efficient. The largest possible size of the allocation unit is equivalent to the size of the irrigation scheme itself. The smallest size of the allocation unit is the individual farm. The intermediate sizes are the command areas of the secondary, tertiary and quaternary canals or groups of these canals. This phase of the model based on linear programming allocates land and water resources optimally to different crops grown on different soils in different allocation units, with the help of the irrigation programmes obtained for different Crop-Soil-Region (CSR) units from Phases 1, 2 and 3 for different objectives. This is done through the following three stages.

• Preparation of irrigation programmes for each Crop-Soil (CS) unit (a unit in allocation unit with similar Crop and Soil) of each allocation unit by modifying the irrigation programmes of the corresponding Crop-Soil-Region unit considering the distribution and conveyance efficiencies.
• Allocation of the resources based on linear programming to each Crop-Soil (CS) unit of each allocation unit with chosen objective(s) and constraints with the Resource Allocation (RA) sub model. Thus, this stage gives optimum allocation plan.
• The preparation of a water release schedule for the canal system for the selected allocation plan.

3.2.4 Relative preference of performance measures

As stated before different performance measures, viz, productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency may conflict with each other. Therefore it is necessary to find out the final performance of the scheme that will consider the contribution of all the performance measures. Therefore the nature of problem becomes multi criteria decision making, if we consider each performance measures as one criterion. As different performance measures further have attributes, it is also necessary to consider the contribution of different attributes. So the problem now becomes multi-level multi criterion decision making. As shown in Figure 3.1, there are two levels. At level-2, these are main performance measures and at level-1 these are attributes of main performance measures. For multi level multi criterion decision making, to decide upon the selection of particular irrigation strategy it is necessary to find out the final performance of different irrigation strategies and select the irrigation strategy that gives maximum final performance. However, while doing this it is necessary to know the combination of different performance measures at different levels in the forms of weights.

Analytic Hierarchy Process (AHP) has been proposed in this study to know the weights of different performance measures by knowing the relative preference of different performance measures. The Analytic Hierarchy Process (AHP) was proposed by Saaty (1980) and therefore called as the Saaty method. The Analytic Hierarchy Process is a structured technique for dealing with complex decisions and therefore is applicable to current multi-level multi-criterion decision making. The AHP helps decision makers to find one that best suits their goal rather than prescribing a "correct" decision. Optimal performance depends on the performance measures used, and literature review shows that researchers have used various different performance measures in the past. Gorantiwar and Smout (2009) described the approach based on AHP for finding out farmers' relative preference to performance measures. The approach developed by them has been used in this study to choose between various possible performance measures.

For this purpose it is necessary to structure the problem by building approximate hierarchy. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them with one another; two at a time, with respect to their impact on an element above them in the hierarchy for example, if we consider the hierarchy of performance measures shown in Figure 3.1, productivity, equity, adequacy, reliability, flexibility and sustainability are the elements at level-2. At level-2 productivity and equity are compared with respect to influence of productivity and equity on performance. In the similar way area equity, water equity, crop production equity and net benefits equity are the elements at level-1. Area equity and water equity are compared with respect to their influence on equity. It is the essence of the AHP that human judgments, together with the underlying information can be used in performing the evaluations and the success of AHP depends on how successfully the information is extracted or derived from the respondents/stake holders/decision makers.

Different steps to be followed for finding out the relative performance of different performance measures by AHP are described in detail by Gorantiwar and Smout (2010), based on Vairavamoorthy et al (2006). These are used in this study and reproduced below.

Step 1-Setting up the performance measures: Final performance index is the function of several performance measures. The performance measures to be considered are set up in this step in the form of hierarchy.

Step 2-Perform pair wise comparisons for performance measures: The stakeholders (e.g. farmer or irrigation manager in this case) compare two performance measures as a pair (for example productivity and equity) for all combinations of pair. The pair wise comparison is performed with a judgement scale presented in Table 3.1. Each pair wise comparison assigns a numerical value to the pair corresponding to the relative importance between the two performance measures.

Table 3.1. Scale for pair wise comparisons (Saaty 1977 and Saaty 1994)

Comparative Importance	Definition	Explanation
1	Equally important	Two performance measures equally influence the parent decision element.
3	Moderately more important	One performance measure is moderately more influential than the other.
5	Strongly more important	One performance measure has stronger influence than the other.
7	Very strongly more important	One performance measure has significantly more influence over the other.
9	Extremely more important	The difference between influences of the two performance measures is extremely significant.
2, 4, 6, 8	Intermediate judgment values	Judgment values between equally, moderately, strongly, very strongly, and extremely.
Reciprocals	If 'a_{ij}' is the judgment value when i_{th} performance measure is compared to j_{th} performance measure, then '$1/a_{ij}$' is the judgment value when j_{th} performance measure is compared to i_{th} performance measures. In other words, $a_{ji}=a/a_{ij}$	

Step 3-Prepare a matrix (judgement matrix) for performance measures: A matrix with the performance measures listed at the top and on the left is prepared. Based on pair wise comparison (Step-2), the matrix is then filled in with numerical values obtained from Table 3.1 denoting the importance of the factor on the left relative to the importance of the factor on the top. A high value means that the factor on the left is relatively more important than the factor at the top. When a factor is compared with itself the ratio of importance is obviously one. This results in a diagonal line across the matrix. The resulting matrix is known as the judgement matrix. This matrix is shown below. In this matrix when performance measure, PM1 is compared with itself, the ratio of importance is 1. However when PM1 is compared with PM2 the ratio is a_{12} and for reverse comparison is $1/a_{12}$.

	PM_1	PM_2	PM_3	PM_4	…….	PM_n
PM_1	1	a_{12}	a_{13}	a_{14}		a_{1n}
PM_2	$1/a_{12}$	1	a_{23}	a_{24}		a_{2n}
PM_3	$1/a_{13}$	$1/a_{23}$	1	a_{34}		a_{3n}
PM_4	$1/a_{14}$	$1/a_{24}$	$1/a_{34}$	1		a_{4n}
:						
:						
PM_n	$1/a_{1n}$	$1/a_{2n}$	$1/a_{3n}$	$1/a_{4n}$		1

(Note PM- Performance measure such as productivity, equity....)

Step 4-Compute the priority vector for performance measures: The geometric mean of each row is calculated. This is performed by multiplying the elements in each row with each other and then taking the n^{th} root, where n is the number of elements in the row. This forms the vector of geometric mean. The elements of this vector are then normalized by dividing them with the sum. The resulting normalized vector is an approximated maximum eigenvector, herein named as priority vector.

Step 5-Assess consistency of pair wise judgments: One of the most practical issues in AHP is that the non-consistency in pair wise comparisons. However it is the beauty of AHP that for a particular group of elements, it is possible to know whether the comparisons were consistent or otherwise. If all the comparisons are perfectly consistent, then the following expression should hold true for any combination of comparisons of the judgement matrix.

$$a_{ij} = a_{ik} \times a_{kj}$$

where a_{ij} is relative importance factor (tabulated values in Table 3.2) of i to j.

However, perfect consistency rarely occurs in practice. Consistency ratio (CR) is commonly used to reflect the degree of consistency of judgment matrix. The CR is calculated by following equations.

$$CI = \frac{\lambda_{\max} - n}{(n-1)}$$

$$CR = \frac{CI}{RCI}$$

where *CI* is consistency index, $\lambda_{\max}$ is maximum eigenvalue of judgment matrix, *RCI* is random consistency index and *n* is the number of factor (Table 3.2).

Table 3.2. RCI values for different values of n.

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

(Saaty 1977 and Saaty 1994)

Maximum eigenvalue ($\lambda_{\max}$) is obtained by adding the columns in the judgment matrix and multiplying the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained earlier.

Step 6-Compute the relative weights/ranks: If the CR of the judgement matrix is satisfactory (less than 0.10 in this study), the priority vector values will be assigned as relative weights of factors. In case of non consistent results it is necessary to perform the pair wise comparison again.

3.2.5 Multicriteria decision making for finding out the final performance

When there are more than one criterion involved in the decision making, the process of decision making becomes multicriteria decision making (MCDM). This is the multiple-criteria decision making technique combines the available, often completely different, performance indicators into a final performance indicator (FPI). Considering the nature of study and involvement of different parameters; the MCDM process needs to be used to find out the overall performance of the irrigation water management. Following the approach set out by Gorantiwar and Smout (2010), the selected MCDM technique for the study is compromise programming (CP) for first level.

Vairavamoorthy et al (2006) described compromise programming developed by Zeleny (1973) that employs single level non-normalized distance based methodology to rank a discrete set of solutions according to their distances from an ideal solution. This is reproduced below.

Compromise programming includes solutions that are closest to the ideal solution as determined by some measure of distance. It consists of identifying the different attributes or indicators or performance measures (for example, productivity, equity etc.) that contribute to "final performance index" (FPI) of irrigation management in an irrigation scheme. The weights are assigned to each performance measure that reflects the relative importance of that performance measure compared to other performance measures. The compromise programming also uses weights to reflect the importance of maximal deviation between the indices. This is called as balancing factor. The deviation is a measure of difference between the observed value of variable and some other variable. Balancing factor (p) is the degree of compromise between indicators of the same group. The values of the indicators are obtained from the simulation-optimization modeling (AWAM model). The weights are obtained by analytical hierarchical process (AHP). In this study the balancing factor is considered as one meaning that the same importance was given for the maximal deviation between the indices. FPI is then obtained by calculating the distance that determines the closeness to the ideal solution with the help of ideal and worst values for each of the indicators, weights and balancing factors. FPIs are obtained for different alternatives or management options and the preferred option would be the one that is nearest to the ideal point in terms of the distance.

Compromise programming uses equation (3.15) (Zeleny1973) to rank a discrete set of solution according to their distance from an ideal solution. One compromise distance for each alternative of the problem is obtained. (In this case different alternatives are irrigation strategies).

$$L_j = \left\{ \sum_{i=1}^{n} \left[w_i^p \left(\frac{f_i - f_i^w}{f_i^b - f_i^w} \right)^p \right] \right\}^{\frac{1}{p}} \tag{3.15}$$

where L_j is distance metric of alternative, w_i is weight of indictor *I*, p is balance factor (described below), f_i^b is best value for indictor *I*, f_i^w is worst value for indictor *I* and f_i is actual value for indictor *i*

However for multi level problem (as in this study), the entire problem needs to be arranged in hierarchal way (Figure 3.1) and compromise programming needs to be used at each level. Using compromise programming at multi-level forms the composite programming.

Bardossy et al. (1985) developed *composite programming* that deals with problems of a hierarchical nature at different levels (i.e., when certain criteria contain a number of sub-criteria). Composite programming extends a compromise programming to a normalised multilevel methodology.

Composite programming generates distance metrics of each sub-criterion within the same group, and then combines the distance metrics of each sub-criterion to form a single composite distance metric. Then the process sequentially proceeds with the successive levels until final level composite distance metric is reached. In this way one composite distance metric is obtained for each alternative. Mathematical representation of the composite programming (Bardossy et al.1985) is given below.

Normalization that is needed to consider different levels is performed by equation (3.16).

$$S_i = \frac{f_i - f_i^w}{f_i^b - f_i^w} \tag{3.16}$$

Composite distance for j^{th} group of indictors is obtained by substituting equation (3.16) into equation (3.15), and ignoring the exponent *p* on the weight *w* (Bardossy and Duckstein 1992). The composite distance, L_j, is the distance between the actual point of indicator and the ideal one (Woldt and Bogardi 1992):

$$L_j = \left[\sum_{i=1}^{n_j} w_{j,i} S_{j,i}^{p_j} \right]^{1/p_j} \tag{3.17}$$

Where L_j= composite distance metric for B+1 level group j of B level indicators; $S_{j,i}$= normalized value of the B level indictor i in the B+1 level group j of B level indicators; n_j=number of B level indicators in group j; $w_{j,i}$=weights expressing the relative importance of B level indicators in group j such that their sum is 1; and p_j=balancing factors among indicators for group j.

The value of Lj at final level is the final performance index (FPI).

Balance factors: Balance factor (*p* in equation 3.15) determines the degree of compromise between indicators of the same group. Low balance factors are used for a high level of compromise among indicators of the same group (Jones and Barnes 2000). The guidelines for using balance factor is given below (Jones and Barnes, 2000)

- A balance factor of 1 for a perfect compromise between indicators of that group.
- A balance factor of 2 for the moderate level of compromise
- A balance factor greater than 3 for minimal compromise.

AHP method allows the subjective evaluation of different elements. In this study AHP method was used.

3.3 Analysis of Performance Results

Gorantiwar and Smout (2010) developed different management scenarios. These scenarios will be used in this study for finding out the performance results. These are described below.

The performance results will be obtained for different management scenarios (for example on the irrigation interval) and irrigation strategies (for example existing against the improved). In the management scenario, the combination of different irrigation intervals (7, 14, 21, 28, 35 days) in *Rabi* season and summer season will be considered. In the irrigation strategy different depths of irrigation and different water distribution options will be considered for free and fixed cropping distribution. These include:

Irrigation amount: The following options were considered**:**

1. Full irrigation (Fl-I):
2. Fixed depth irrigation (Fx-I)
3. Optimized deficit irrigation (ODI)

Irrigation frequency: Different combinations of irrigation interval (7, 14, 21, 28, 35 days) in Rabi season and Summer season

Water distribution: The following options were considered:

1. Free water distribution (FWD)
2. Equitable distribution of seasonal water allocation based on CCA of AU (EDSW)
3. Equitable distribution of intraseasonal water based on CCA of AU (EDIW)

Cropping distribution: The following two options were considered.

1. Free cropping distribution
2. Fixed cropping distribution

The results will be obtained at scheme level, main canal (right bank) level, secondary and tertiary levels. The performance results will be analyzed in terms of productivity, equity, adequacy and excess for knowing whether these performance measures conflict with each other.

3.4 Final Performance Indicator (FPI) and Trade off Analysis

The relative importance of different performance measures is different to different stakeholders (water users) in irrigation scheme. Final performance Index (FPI) for each irrigation strategy depends on this preference. FPIs will be obtained for different alternatives and the preferred alternative would be the one that is nearest to the ideal point or the desired value. The tradeoff analysis will be performed for different performance measures and irrigation strategies using the values of derived FPIs.

3.5 Mula Irrigation Scheme

The three irrigation schemes viz. Ghod Irrigation scheme, Sina Irrigation Scheme and Mangi Irrigation Scheme were selected by consulting the irrigation authorities as stated before. However the following data which was necessary to evaluate the performance measures of the scheme were not available.

The reservoir and canal release data such as the schedules that specify the canal opening time, closing time and discharge in the canal and closing and opening times for each outlet for each irrigation rotation and outlet capacity.

Cropping distribution data such as field wise crops irrigated, the area irrigated under each crop in each outlet command area, the irrigation rotations utilised for irrigating each crop, sowing and harvesting weeks of all the crops which were provided with water, the maximum crop yield.

As these were the important data for this study, it was decided to change the irrigation scheme. Several meetings were organized with the irrigation authorities regarding the availability of the data. Mula Irrigation Scheme in Ahmednagar District of Maharashtra State was then identified after assurance by the concerned irrigation authorities that most of the needed data could be made available. However as the extent of the scheme is very large, it was decided to make attempts to collect the data for selected canal network of the Mula irrigation scheme.

The Mula irrigation scheme is located on the Mula River, a sub-tributary of the Godavari. The dam has a gross storage capacity of 767 Mm^3 and a live storage of 609 Mm^3 and has a planned capacity to irrigate 80,810 ha in 149 drought prone villages in Ahmednagar district. The project serves the command area through two main canals, the MLBC (Mula Left Bank Canal) and the MRBC (Mula Right Bank Canal) and their branch canals serving an area of 10,100 ha and 70,710 ha respectively. The MLBC was mainly intended to strengthen and stabilise the command of Pravara right bank canal and so the study concentrates on the MRBC.

The minors and direct outlets taking off from the MRBC itself serve an area of 28,075 ha. The first two branch canals taking off from the MRBC serve an area of 33,215 ha. The third branch, known as the Pathardi branch, takes off at the tail end of the MRBC and runs for 53 km serving an area of 11,400 ha, but only for eight months (July to February). The command area of the MRBC is divided into 5 sub-divisions known as Rahuri, Newasa, Ghodegaon, Kukana and Amarapur sub-divisions and we may take Rahuri sub-division as comprising the head reach, Newasa and Ghodegaon as comprising the middle reach and Kukana and Amarapur as comprising the tail reach of the project. The approved design crop pattern comprises 5% area under perennials (mostly sugarcane), 20% two-seasonals, 30% Kharif seasonals, 42% Rabi seasonals and 3% Hot Weather (HW) seasonals. The rainfall in the command area is scanty, the average rainfall being below 600 mm. It is not uniformly distributed over the monsoon period. The formation of Water Users' Associations (WUAs) has proceeded to a relatively much larger degree within the Mula system - 61 WUAs have been registered so far and about 56 have started functioning. About 14 WUAs are in the process of getting their registration (Development Support Centre, Ahmedabad, 2003).

3.5.1 Salient features of Mula Irrigation Scheme

Salient features of Mula irrigation scheme is given below.

1. Location : On Mula River
2. a. Catchment area : 2274 km^2
   b. Annual rainfall : 5000mm in upper area, 500mm in lower area
3. Yield
   a. Maximum : 1773 Mm^3
   b. Minimum : 358 Mm^3
   c. Average : 942 Mm^3
   d. 70% Dependable : 767 Mm^3
4. Storage
   a. Gross : 767 Mm^3
   b. Live : 609 Mm^3
   c. Sill : 127 Mm^3
5. Utilization
   a. Gross : 825 Mm^3
   b. Net : 749 Mm^3
   c. Lake losses : 76 Mm^3
6. Dam
   a. Type : Earthen
   b. Length : 2857m
7. Spillway
   a. Type : Masonry (gated)
   b. Length : 134 m
   c. Maximum flood : 5943 cumecs
   d. Gate : Radial, 11Nos.12.2mx7.62m
8. Submergence
   a. Area : 5296ha
   b. Villages : 4 villages, 13 hamlets
9. Command
   a. GCA (Gross Command Area) : 127187 ha
   b. CCA (Culturable Command Area) : 118202 ha
   c. ICA (Irrigated Command Area) : 80810 ha

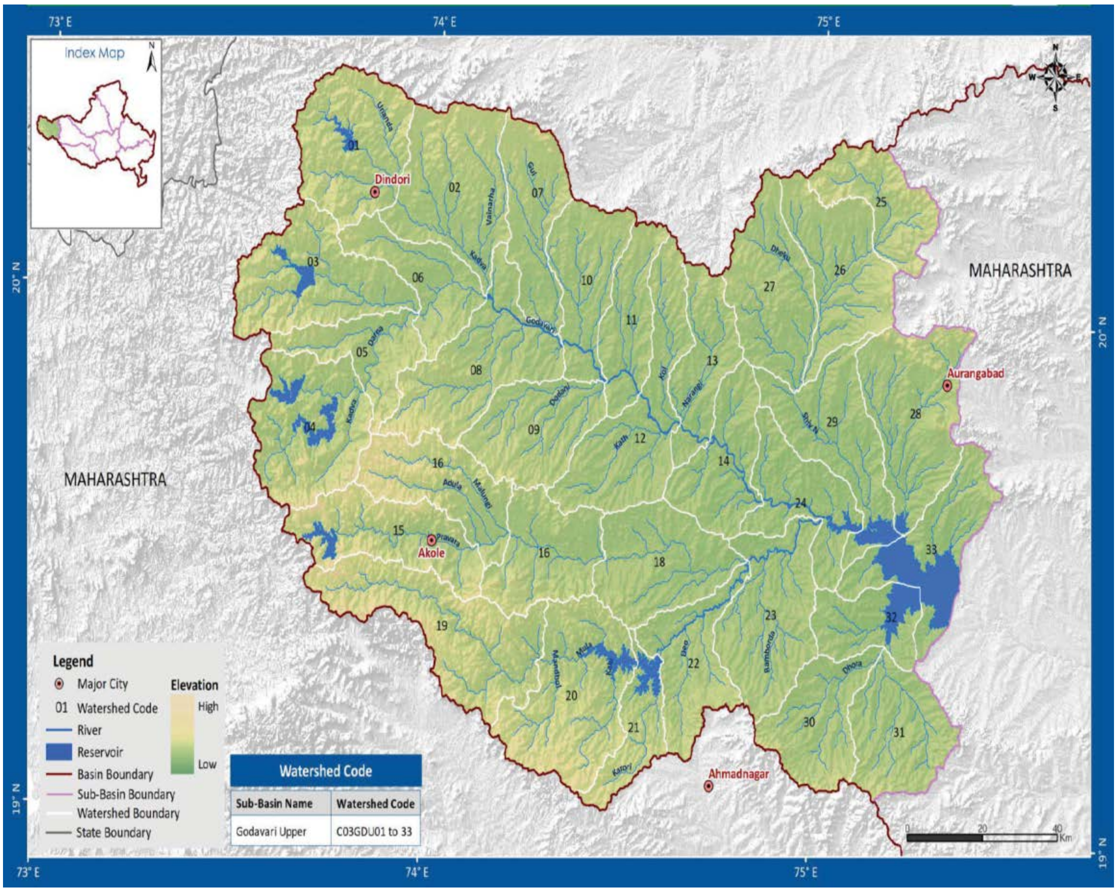


Figure 3.2 Image of Godavari upper sub-basin and watersheds (Mula Watershed indicated by Code: 20)

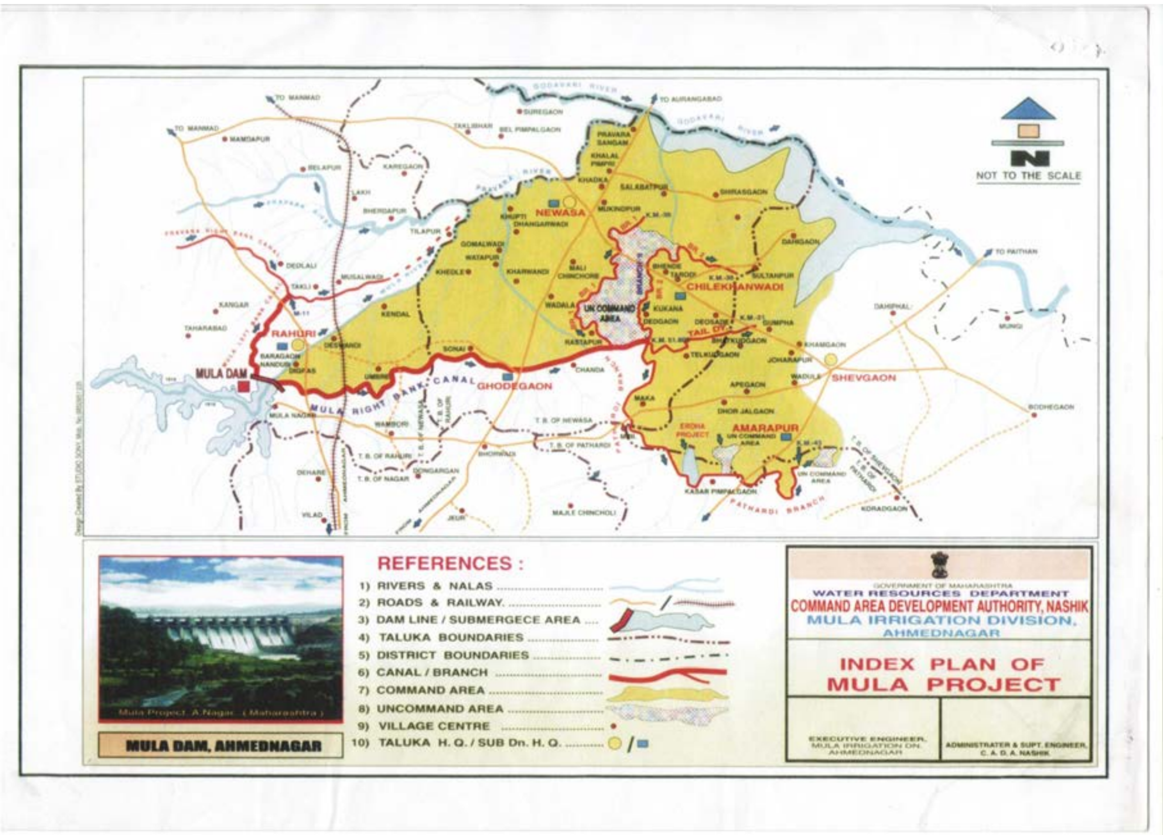


Figure 3.2 (A) Index map of Mula irrigation scheme

10. Canal		M.R.B.C.	M.L.B.C.
a. GCA	:	110183 ha	17044 ha
b. CCA	:	103749 ha	14453 ha
c. ICA	:	70690 ha	10120 ha
d. Length	:	58 km	18 km
e. Capacity	:	46.7 (cumecs)	8.5 (cumecs)

The Image of Godavari upper sub-basin and watersheds (Mula Watershed indicated by Code: 20) and the index map of Mula irrigation scheme are shown in Figures 3.2 and 3.2(A) respectively. Schematic layout (map) of the scheme, showing the LBC and RBC, Branches, Distributaries and Minor Canals is given in APPENDIX-B1.

3.5.2 Secondary Data Collection and Analysis

Following data have been collected for the Mula irrigation scheme.

Climatological data

Water release data

Crop data

Soil data

Reservoir data

3.5.2.1 Climatological data

The climatological data in respect of minimum temperature, maximum temperature, minimum relative humidity, maximum relative humidity, wind speed, sunshine hours, and rainfall on daily basis were collected from the meteorological observatory of the Indian Meteorological Department located in the command area of Mula irrigation scheme. The data were collected from the year 1977 to 2011. These data are required for estimating the reference crop evapotranspiration for computing the crop evapotranspiration; and evaporation from the open water body for computing the reservoir evaporation in AWAM model. The reference crop evapotranspiration is estimated by the Penman Monteith method and evaporation from the open water body by Penman method. These calculations are performed within AWAM model itself.

The weekly averages of these data is presented in Table 3.3 and shown graphically from Figures 3.3 to 3.8.

Table 3.3. The weekly averages of the meteorological parameters in the command area of Mula irrigation scheme.

Week	Month	Tmax (⁰C)	Tmin (⁰C)	Rhmax (%)	Rhmin (%)	WV (km/hr)	BSSH (hour)	Total RF (mm)	Total PE (mm)	Total ETr (mm)
1	01-Jan To 07-Jan	28.15	9.2	80.51	34.75	3.29	8.69	16.5	26.36	21.64
2	08-Jan To 14-Jan	28.33	5.11	79.82	35.84	3.52	8.83	17.7	27.36	22.3
3	15-Jan To 21-Jan	29.11	8.1	78.37	34.25	3.53	9.08	28.2	28.83	23.78
4	22-Jan To 28-Jan	29.57	9.63	78.2	32.51	3.74	9.44	4.5	30.93	25.67
5	29-Jan To 04-Feb	29.94	10.1	76.67	30.54	3.88	9.38	16.3	33.24	27.42
6	05-Feb To 11-Feb	30.44	10.01	74.5	28.81	4	9.52	60.3	34.99	29.15
7	12-Feb To 18-Feb	31.08	11.53	74.69	28.11	4.28	9.44	18.2	38.54	31.21
8	19-Feb To 25-Feb	31.76	11.59	72.12	26.37	4.32	9.75	15.2	41.99	33.7
9	26-Feb To 04-Mar	33.25	14.23	69.85	24	4.36	9.75	26	45.28	38.79
10	05-Mar To 11-Mar	34.06	14.21	66.88	23.68	4.67	9.73	38.2	48.8	39.93
11	12-Mar To 18-Mar	34.73	11.89	66.3	23.7	4.43	9.78	35.1	51.71	42.72
12	19-Mar To 25-Mar	35.91	14.71	64.34	22.19	4.81	9.74	33.1	58.18	46.35
13	26-Mar To 01-Apr	36.25	15.17	61.73	21.88	5.19	9.88	24.3	61.75	48.31
14	02-Apr To 08-Apr	37.17	16.96	62.64	22.36	5.24	9.76	46.1	64.99	50.63
15	09-Apr To 15-Apr	37.59	20.47	62.58	22.87	5.74	9.63	80.9	68.73	52.34
16	16-Apr To 22-Apr	38.31	21.54	61.39	21.91	6.62	10.08	55	75.01	56.24
17	23-Apr To 29-Apr	38.74	21.59	60.92	23.05	6.68	12.09	1.7	78.68	60.42
18	30-Apr To 06-May	38.89	21.97	62.4	23.22	7.58	13.27	79.7	80.21	62.42
19	07-May To 13-May	39.1	21.29	65.73	24.73	8.26	9.58	142.2	83.08	58.07
20	14-May To 20-May	38.84	22.66	68.31	25.9	9.47	9.46	180.5	84.04	57.91
21	21-May To 27-May	38.31	23.09	71.71	28.19	10.07	9.2	136.5	82.35	55.94
22	28-May To 03-Jun	37.6	23.76	75.95	33.66	10.16	8.83	348.3	75.89	50.68
23	04-Jun To 10-Jun	36.08	22.66	81.17	42.4	10.4	7.43	1319	64.08	43.7
24	11-Jun To 17-Jun	33.96	22.23	83.68	52.13	10.07	6.05	1293.7	50.84	35.9
25	18-Jun To 24-Jun	32.68	23.54	83.97	54.16	12.7	4.88	793.7	48.79	32.24
26	25-Jun To 01-Jul	33.35	22.63	84.04	56.16	12.9	4.27	703	48.05	30.81
27	02-Jul To 08-Jul	31.22	22.11	85.01	59.49	12.36	4.21	743.5	42.44	29.16
28	09-Jul To 15-Jul	30.96	21.79	85.31	60.11	11.85	3.7	701.2	40.55	27.67
29	16-Jul To 22-Jul	30.47	22.74	85.41	62.14	12.38	3.65	641.5	38.96	26.89
30	23-Jul To 29-Jul	30.19	22.09	85.98	63.45	11.38	3.48	644.6	36.36	25.78
31	30-Jul To 05-Aug	30.11	22.04	86.19	62.91	11.62	3.32	599.4	34.99	25.88
32	06-Aug To 12-Aug	29.66	22.31	87.03	64.5	11.76	3.61	575.05	33.76	25.25
33	13-Aug To 19-Aug	29.86	21.81	87.02	61.88	11.22	4.29	469.43	34.51	26.87
34	20-Aug To 26-Aug	30.22	21.7	87.27	60.57	9.18	4.82	1069.6	35.47	27.27
35	27-Aug To 02-Sep	30.09	21.39	90.83	62.32	8.68	4.34	1027.1	34.13	25.95
36	03-Sep To 09-Sep	30.22	18.84	87.52	59.89	8.22	5.21	967.8	33.05	27.3
37	10-Sep To 16-Sep	30.79	20.77	87.49	56.61	6.68	5.61	1318.4	34.75	28.15
38	17-Sep To 23-Sep	31.14	19.61	88.38	58.07	5.81	6.19	1431.2	34.78	28.48
39	24-Sep To 30-Sep	31.17	20.21	89.28	57.52	4.73	6.23	1592.12	31.7	27.47
40	01-Oct To 07-Oct	31.58	20.31	87.53	51.57	4.38	6.75	964	31.65	28.29
41	08-Oct To 14-Oct	31.94	20.13	84.47	46	3.97	7.94	801.5	33.22	30.01
42	15-Oct To 21-Oct	31.7	20.7	81.03	40.83	3.82	8.12	403.9	32.88	29.59
43	22-Oct To 28-Oct	31.39	15.83	81.52	38.08	3.71	8.55	428.9	32.74	28.87
44	29-Oct To 04-Nov	30.93	14.27	79.61	38.23	4.02	8.03	186.9	32.37	27.28
45	05-Nov To 11-Nov	30.54	13.53	79.97	40.03	3.94	8.09	228.8	29.89	25.61
46	12-Nov To 18-Nov	29.87	12.33	79.57	42.13	3.82	8.31	296.7	28.91	24.34
47	19-Nov To 25-Nov	29.56	8.91	79.84	38.03	3.63	8.32	144.1	27.36	23.48
48	26-Nov To 02-Dec	29.42	14.41	80.12	38.14	3.42	8.6	211.1	27.61	23.12
49	03-Dec To 09-Dec	28.91	10.64	81.74	37.26	3.31	9.09	173.8	26.52	22.47
50	10-Dec To 16-Dec	28.57	8.73	80.01	34.78	3.34	8.6	42.4	26.07	21.62
51	17-Dec To 23-Dec	28.49	8.29	81.82	34.88	3.21	8.51	9.3	25.1	21.24
52	24-Dec To 31-Dec	28.14	6.99	81.86	35.45	3.15	8.67	37.1	28.92	23.97

(Note: Tmax is daily maximum temperature; Tmin is daily minimum temperature; Rhmax is daily maximum relative humidity; Rhmin is daily minimum relative humidity, WV is daily wind velocity; BSSH is daily bright sun shine hours; RF is rainfall and ETr is reference crop evapotranspiration)

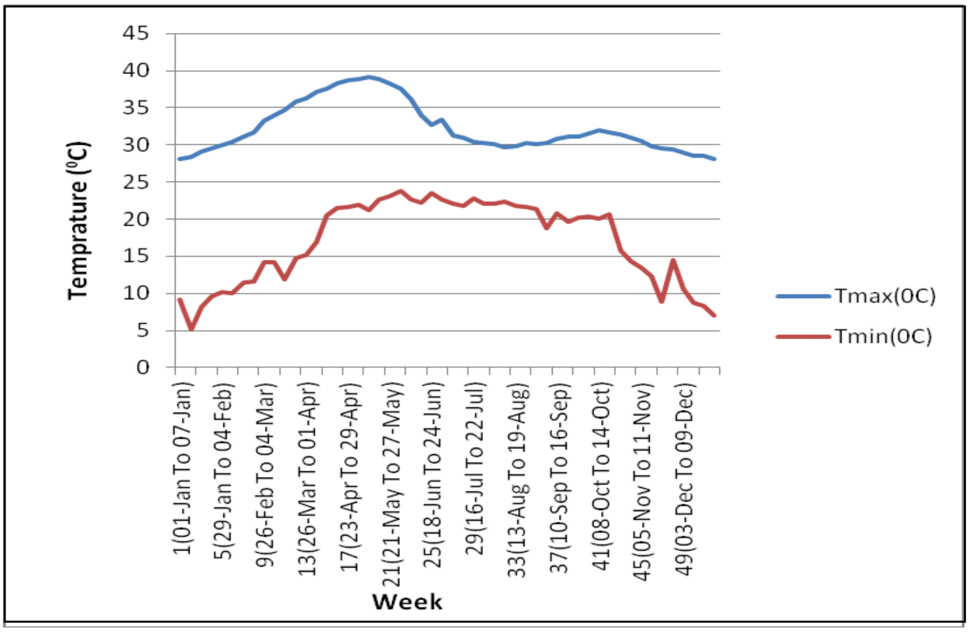


Figure 3.3. The average weekly variation of the maximum and minimum temperatures for the command area of Mula irrigation scheme

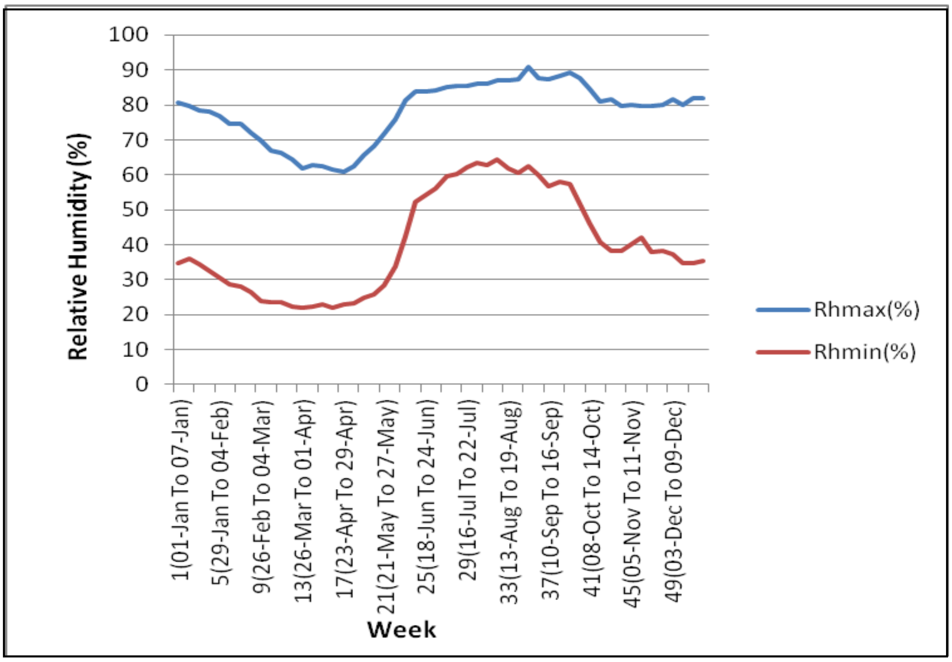


Figure 3.4. The average weekly variation of the maximum and minimum relative humidity for the command area of Mula irrigation scheme

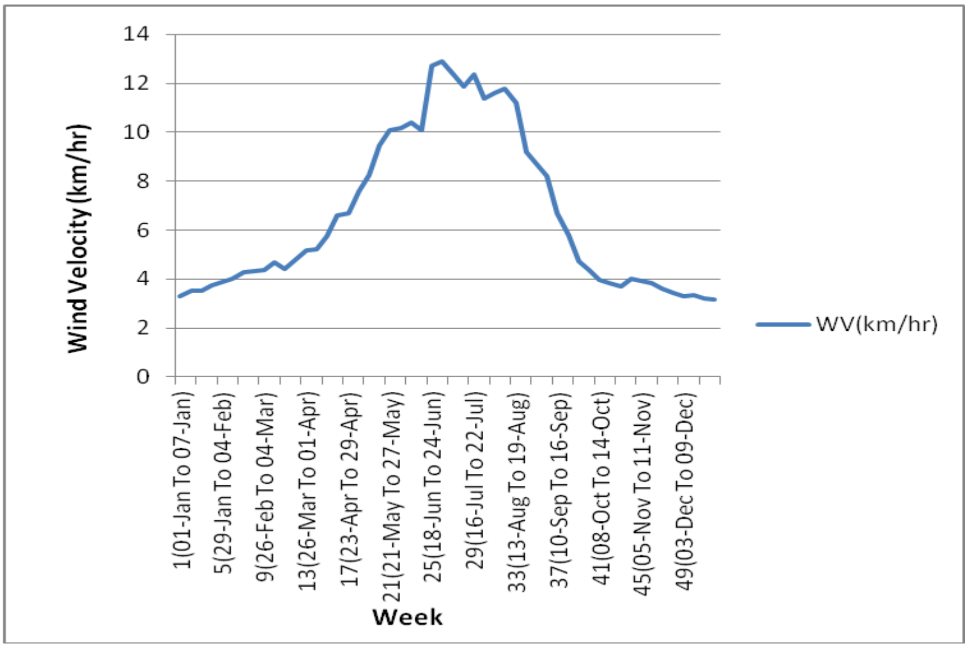


Figure 3.5. The average weekly variation of the wind velocity (km/hr) for the command area of Mula irrigation scheme

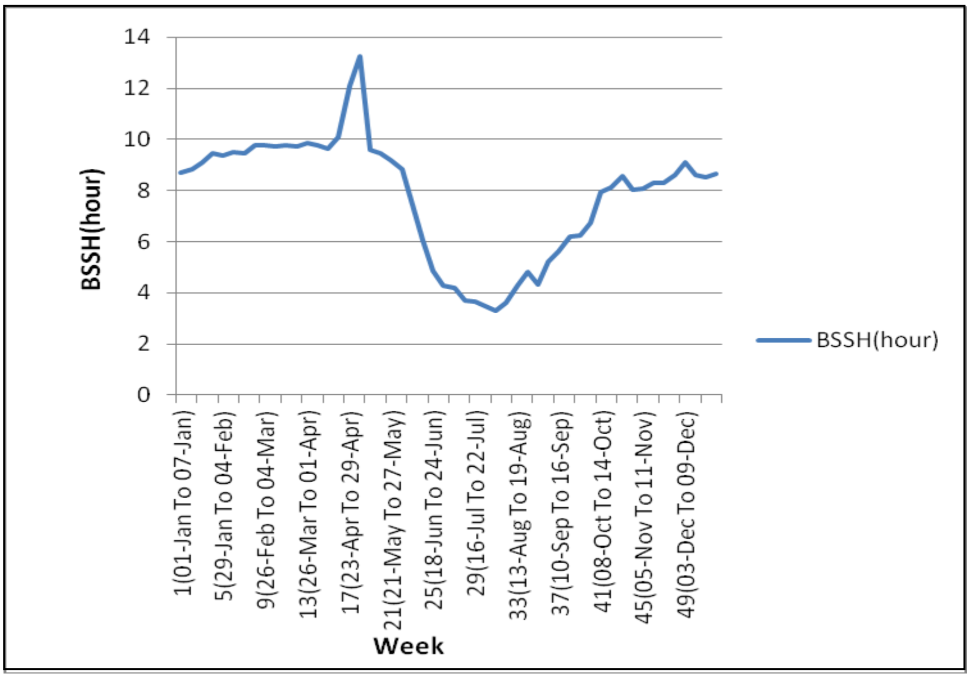


Figure 3.6. The average weekly variation of the bright sunshine hours (BSSH) for the command area of Mula irrigation scheme

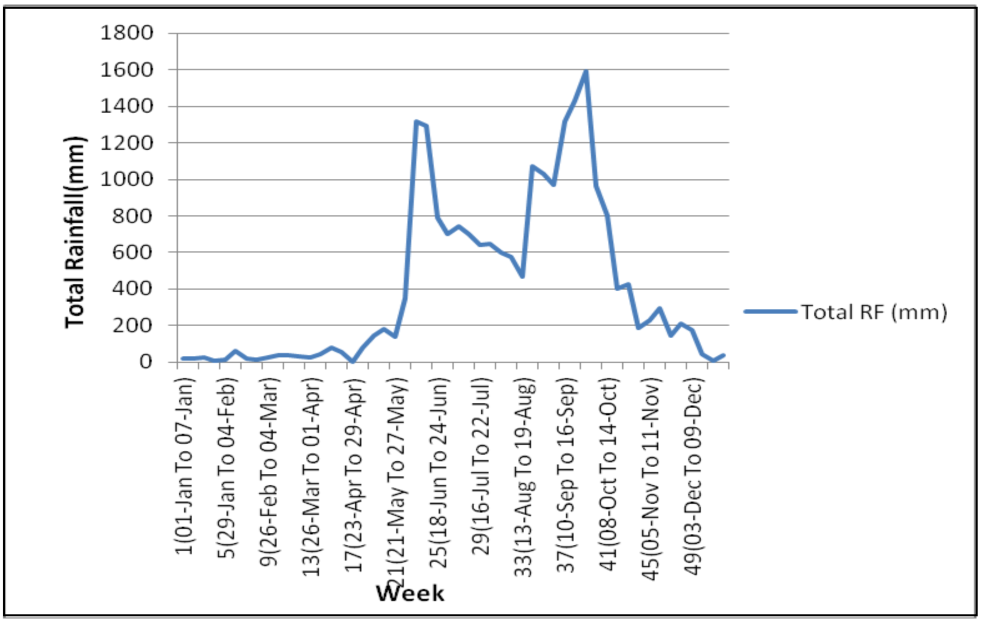


Figure 3.7 The average weekly variation of the total rainfall (mm) for the command area of Mula irrigation scheme

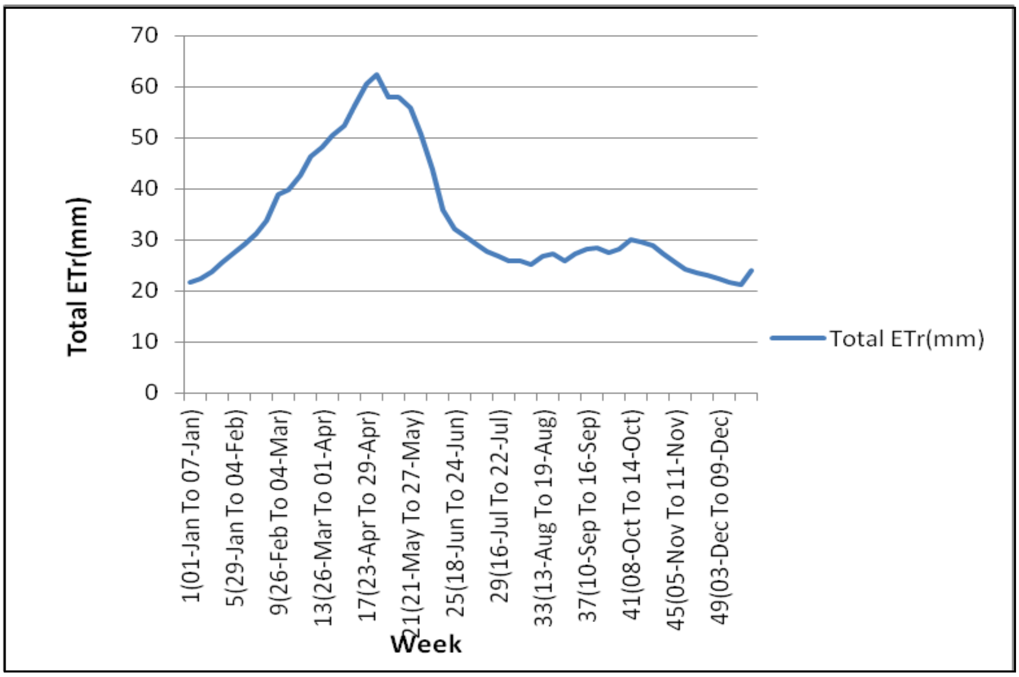


Figure 3.8 The average weekly variation of the total reference crop evapotranspiration (ETr) (mm) for the command area of Mula irrigation scheme

It is seen from Table 3.3 and Figures 3.3 to 3.8 that the weekly maximum temperature 28.14 to 39.10^{0}C and minimum temperature 5.11 to 23.76^{0}C, the maximum and minimum relative humidity 60.92 to 90.83% and 21.88 to 64.50 %, maximum and minimum wind velocities 12.90 and 3.15 kmph, maximum and minimum bright sunshine hours 13.27 and 3.32 h, maximum and minimum total rainfall 1592.12 and 1.70 mm, maximum and minimum pan evaporation 84.04

and 25.10 mm and maximum and minimum evapotranspiration 62.42 and 21.24 mm were observed respectively.

3.5.2.2 Crop details

Predominantly nine crops are grown in the command area of Mula irrigation scheme, viz. gram, sorghum, wheat, sunflower, onion, cabbage, maize (grain), maize (fodder) and groundnut. The details of these crops required for the simulation of crop yield and computation of the net benefits derived from these crops due to the irrigations provided according to the chosen or derived irrigation strategies. These are described in this section.

The sowing/planting dates and the root zone characteristics in terms of initial root depth (i.e. the root depth at the time of planting/sowing), maximum root depth and the days required to reach the maximum root depth are presented in Table 3.4. The root zone depth equation (linear root growth model) proposed by Fereres *et al.* (1981) is used for the estimation of root zone depth over the crop growth period. This equation is:

$$Z_t = Zo + (Zm - Zo)\ (t / tm)$$

Where,

Z_t = Depth of root zone on t^{th} day (mm)

Zm = Maximum depth of root zone during crop growth period (mm)

Zo = Initial depth of root zone (depth of sowing) (mm)

tm = The day at which crop attains Zm after sowing

T = Total crop period (days)

Table 3.4. Planting and sowing dates and root zone data for different crops (Gorantiwar 1995)

Sr. No.	Crop	Sowing / Planting Day	Day of Harvesting	Root Zone Depth in mm		
				Initial	Maximum	Days
1	Gram	24 October	13 February	150	800	55
2	Sorghum	16 October	01 February	100	1200	50
3	Onion	19 October	18 February	150	400	30
4	Wheat	30 October	16 March	150	900	50
5	Sunflower	18 March	30 July	150	1200	60
6	Groundnut	17 march	04July	150	1200	40
7	Maize	18 November	02 April	150	1000	50
8	Fodder maize	30 November	02 March	150	900	50
9	Cabbage	30 October	20 January	150	900	50

The daily values of crop coefficient are required for the estimation of crop water requirement. These values are available locally for some crops in the equation forms (Patil and Gorantiwar, 2011) which are given below. The crop coefficient values for the crops for which the locally derived values were not available were obtained from FAO (Doorenbos and Pruitt, 1984). The FAO values are available as per crop growth stages. These are presented in Table 3.5.

Wheat

$$Kc_t = 10.092\left(\frac{t}{T}\right)^5 -20.039\left(\frac{t}{T}\right)^4 +12.871\left(\frac{t}{T}\right)^3 -7.0936\left(\frac{t}{T}\right)^2 +3.7412\left(\frac{t}{T}\right) +0.5942$$

Gram

$$Kc_t = 2.3266\left(\frac{t}{T}\right)^5 +8.5503\left(\frac{t}{T}\right)^4 -24.573\left(\frac{t}{T}\right)^3 +14.708\left(\frac{t}{T}\right)^2 -1.8175\left(\frac{t}{T}\right) +0.8965$$

Sorghum

$$Kc_t = -22.954\left(\frac{t}{T}\right)^5 + 57.946\left(\frac{t}{T}\right)^4 - 50.496\left(\frac{t}{T}\right)^3 + 14.968\left(\frac{t}{T}\right)^2 + 0.3574\left(\frac{t}{T}\right) + 0.44$$

Groundnut

$$Kc_t = 3.1713\left(\frac{t}{T}\right)^4 - 7.91878\left(\frac{t}{T}\right)^3 + 4.56019\left(\frac{t}{T}\right)^2 + 0.42008\left(\frac{t}{T}\right) + 0.367$$

Maize

$$Kc_t = 38.824\left(\frac{t}{T}\right)^5 -104.47\left(\frac{t}{T}\right)^4 +95.634\left(\frac{t}{T}\right)^3 -34.434\left(\frac{t}{T}\right)^2 + 4.2563\left(\frac{t}{T}\right) + 0.8218$$

Where

Kc_t is the crop coefficient of wheat on t^{th} day; t is day and T is total crop growth period in days

Table 3.5. The stage wise crop coefficient values (Doorenbos and Pruitt, 1984**)**

Crop	**Stage**					
		1	**2**	**3**	**4**	**5**
Onion	Duration	01-20	21-45	46-65	66-90	91-110
	Crop coefficient	0.0	0.2	0.9	0.7	0.2
Sunflower	Duration	01-25	26-55	56-80	81-120	121-135
	Crop coefficient	0.0	0.2	0.55	0.45	0.2
Fodder maize	Duration	01-15	16-45	46-80	81-90	
	Crop coefficient	0.3	1.0	1.2	1.0	
Cabbage	Duration	01-20	21-50	51-75	76-80	
	Crop coefficient	0.7	1.0	1.05	0.95	

The crop yields are simulated from the actual crop evapotranspiration as estimated by the SWAB sub-model of AWAM using the yield response factor and stage wise crop production function proposed by Stewart and et al (1976) given below.

$$\frac{Ya}{Ym} = 1 - \sum_{s=1}^{ns} Ky_s \left[\frac{ETm_s - ETa_s}{ETm_s} \right]$$

Where,

Ya = Actual crop yield (kg ha $^{-1}$)

Ym = Potential crop yield (kg ha $^{-1}$)

s = Subscript for crop growth stage

Ky_s = Yield response factor of s^{th} stage

ns = Number of stages

ETm_s = Maximum crop ET of s^{th} stage (mm)

ETa_s = Actual crop ET of s^{th} stage (mm)

The stage wise yield response factors as obtained from Doorenbos and Kassam (1979) are presented in Table 3.6.

Table 3.6. The stage wise yield response factors for different crops (Doorenbos and Kassam, 1979)**.**

Crop		Stage					
		1	2	3	4	5	6
Gram	Duration	1-20	21-45	46-65	66-90	91-110	
	Yield response factor	0.0	0.2	0.9	0.7	0.2	
Sorghum	Duration	1-25	26-55	56-80	81-120	121-135	
	Yield response factor	0.0	0.2	0.55	0.45	0.2	
Onion	Duration	1-30	31-90	91-120			
	Yield response factor	0.45	0.8	0.3			
Wheat	Duration	1-10	11-25	26-65	66-80	81-110	111-120
	Yield response factor	0.0	0.2	0.75	0.75	0.5	0.0
Sunflower	Duration	1-15	16-40	41-60	61-90	91-110	111-120
	Yield response factor	0.0	0.25	0.5	1.0	0.8	0.0
Groundnut	Duration	1-15	16-50	51-90	91-120	121-135	
	Yield response factor	0.0	0.2	0.8	0.6	0.2	
Maize	Duration	1-15	16-55	56-75	76-110	111-120	
	Yield response factor	0.0	0.4	1.5	0.5	0.2	
Fodder maize	Duration	1-15	16-45	46-80	81-90		
	Yield response factor	0.4	0.4	1.3	0.5		
Cabbage	Duration	1-20	21-50	51-75	76-80		
	Yield response factor	0.2	0.4	0.45	0.6		

The other details such as cost of cultivation and the prices of the produce and bi produce are obtained from the local market and used in the AWAM model.

3.5.2.3. Soil data

Four types of the soils viz. silty, silty clay, clay and deep clay predominantly exist in the command area of Mula irrigation scheme. The detail irrigation properties of the soils were collected and are shown in Table 3.7

Table 3.7. The irrigation properties of different soils in the command area

Soil	Properties	Layer				
		1	2	3	4	5
Silty	Depth (mm)	200	300			
	Volumetric Field capacity	0.20	0.22			
	Volumetric Wilting point	0.12	0.12			
Silt clay	Depth (mm)	250	300	350		
	Volumetric Field capacity	0.28	0.30	0.32		
	Volumetric Wilting point	0.15	0.16	0.18		
Clay	Depth (mm)	200	250	350	300	
	Volumetric Field capacity	0.36	0.38	0.40	0.40	
	Volumetric Wilting point	0.18	0.20	0.20	0.22	
Deep clay	Depth (mm)	250	250	250	250	300
	Volumetric Field capacity	0.40	0.40	0.40	0.40	0.40
	Volumetric Wilting point	0.21	0.21	0.21	0.21	0.21

3.5.2.4 Reservoir data

The AWAM model needs the stage-area-volume relationship for reservoir balance of AWAM model. AWAM updates the daily volume of water in reservoir with the help of reservoir balance equation. The inputs of water to the reservoir are river inflows and direct rainfall over the surface area of reservoir; and outputs of water are canal water delivery, evaporation, seepage and the spillage. Once the reservoir volume is updated then with the help of depth-volume relationship, the depth is found and then with the help of depth-area relationship, the area is estimated. The value of area is needed to know the evaporation losses from the reservoir and contribution of direct rainfall to the reservoir storage.

The storage in reservoir and corresponding reservoir surface area at different stages or depth of water in the reservoir are required for the reservoir water balance. These values are presented in Table 3.8.

Table 3.8. Stage-area-volume relationship for reservoir of Mula irrigation scheme (The survey from year 2000 to 2011)

R.L. (m)	Depth (m) from the reference point	Incremental depth (m)	Area (ha)	Average area (ha)	Incremental volume (ha-m)	Total Volume above reference point(ha-m)
1668	0		0			
1730	62	62	756	378	22954.27	22954.27
1731	63	1	794	775	243.712	23197.98
1732	64	1	832	813	252.2136	23450.20
1733	65	1	870	851	266.3829	23716.58
1734	66	1	908	889	277.7183	23994.30
1735	67	1	947	927.5	289.0538	24283.35
1736	68	1	985	966	300.3892	24583.74
1737	69	1	1023	1004	311.7247	24895.46
1738	70	1	1061	1042	323.0601	25218.52
1739	71	1	1099	1080	334.3955	25552.92
1740	72	1	1138	1118.5	345.731	25898.65
1741	73	1	1182	1160	362.7341	26261.39
1742	74	1	1234	1208	374.0696	26635.45
1743	75	1	1271	1252.5	388.2389	27023.69
1744	76	1	1316	1293.5	402.4082	27426.10
1745	77	1	1361	1338.5	413.7436	27839.85
1746	78	1	1405	1383	427.9129	28267.76
1747	79	1	1450	1427.5	442.0822	28709.84
1748	80	1	1494	1472	456.2515	29166.09
1749	81	1	1539	1516.5	470.4208	29636.51
1750	82	1	1584	1561.5	481.7563	30118.27
1751	83	1	1623	1603.5	495.9256	30614.19
1752	84	1	1662	1642.5	507.261	31121.46
1753	85	1	1701	1681.5	518.5965	31640.05
1754	86	1	1740	1720.5	529.9319	32169.98

R.L. (m)	Depth (m) from the reference point	Incremental depth (m)	Area (ha)	Average area (ha)	Incremental volume (ha-m)	Total Volume above reference point(ha-m)
1755	87	1	1779	1759.5	541.2674	32711.25
1756	88	1	1818	1798.5	555.4367	33266.69
1757	89	1	1858	1838	566.7721	33833.46
1758	90	1	1897	1877.5	578.1075	34411.57
1759	91	1	1936	1916.5	589.443	35001.01
1760	92	1	1975	1955.5	603.6123	35604.62
1761	93	1	2031	2003	617.7816	36222.40
1762	94	1	2086	2058.5	637.6186	36860.02
1763	95	1	2142	2114	651.7879	37511.81
1764	96	1	2198	2170	671.6249	38183.44
1765	97	1	2253	2225.5	685.7942	38869.23
1766	98	1	2309	2281	705.6313	39574.86
1767	99	1	2365	2337	719.8006	40294.66
1768	100	1	2420	2392.5	736.8037	41031.47
1769	101	1	2476	2448	756.6408	41788.11
1770	102	1	2532	2504	770.8101	42558.92
1771	103	1	2593	2562.5	790.6471	43349.56
1772	104	1	2655	2624	810.4841	44160.05
1773	105	1	2717	2686	827.4873	44987.54
1774	106	1	2778	2747.5	847.3243	45834.86
1775	107	1	2840	2809	867.1613	46702.02
1776	108	1	2902	2871	884.1645	47586.19
1777	109	1	2964	2933	904.0015	48490.19
1778	110	1	3025	2994.5	923.8385	49414.03
1779	111	1	3093	3059	940.8417	50354.87
1780	112	1	3149	3121	960.6787	51315.55
1781	113	1	3204	3176.5	977.6819	52293.23
1782	114	1	3259	3231.5	991.8512	53285.08
1783	115	1	3317	3288	1011.688	54296.77
1784	116	1	3369	3343	1028.691	55325.46
1785	117	1	3424	3396.5	1042.861	56368.32

R.L. (m)	Depth (m) from the reference point	Incremental depth (m)	Area (ha)	Average area (ha)	Incremental volume (ha-m)	Total Volume above reference point(ha-m)
1786	118	1	3479	3451.5	1062.698	57431.02
1787	119	1	3534	3506.5	1076.867	58507.88
1788	120	1	3589	3561.5	1093.87	59601.75
1789	121	1	3644	3616.5	1110.873	60712.63
1790	122	1	3699	3671.5	1127.876	61840.50
1791	123	1	3773	3736	1150.547	62991.05
1792	124	1	3847	3810	1173.218	64164.27
1793	125	1	3921	3884	1195.889	65360.16
1794	126	1	3995	3958	1218.56	66578.72
1795	127	1	4069	4032	1241.231	67819.95
1796	128	1	4143	4106	1261.068	69081.02
1797	129	1	4217	4180	1286.573	70367.59
1798	130	1	4291	4254	1309.244	71676.83
1799	131	1	4365	4328	1329.081	73005.91
1800	132	1	4439	4402	1354.585	74360.50
1801	133	1	4522	4480.5	1377.256	75737.76
1802	134	1	4605	4563.5	1405.595	77143.35
1803	135	1	4688	4646.5	1428.266	78571.62
1804	136	1	4771	4729.5	1456.604	80028.22
1805	137	1	4855	4813	1479.275	81507.50
1806	138	1	4938	4896.5	1504.78	83012.28
1807	139	1	5021	4979.5	1533.119	84545.39
1808	140	1	5104	5062.5	1555.789	86101.18
1809	141	1	5187	5145.5	1581.294	87682.48
1810	142	1	5270	5228.5	1606.799	89289.28
1811	143	1	5385	5327.5	1643.639	90932.92
1812	144	1	5500	5442.5	1674.812	92607.73
1813	145	1	5614	5557	1714.486	94322.21
1814	146	1	5729	5671.5	1745.658	96067.87
1815	147	1	5844	5786.5	1782.498	97850.37
1816	148	1	5959	5901.5	1816.505	99666.87

R.L. (m)	Depth (m) from the reference point	Incremental depth (m)	Area (ha)	Average area (ha)	Incremental volume (ha-m)	Total Volume above reference point(ha-m)
1817	149	1	6073	6016	1850.511	101517.39
1818	150	1	6188	6130.5	1887.351	103404.74
1819	151	1	6303	6245.5	1921.357	105326.09
1820	152	1	6417	6360	1958.198	107284.29
1821	153	1	6532	6474.5	1992.204	109276.50
1822	154	1	6647	6589.5	2026.21	111302.71
1823	155	1	6761	6704	2060.217	113362.92
1824	156	1	6876	6818.5	2097.057	115459.98

The graphical relationships between depth and area and depth and volume are shown in Figures 3.9 and 3.10, respectively. AWAM needs the depth-area and depth-volume relationship in the following form:

Depth-Area : $A = a_1D+a_2$

Depth-Volume: $V = b_1D+b_2$

Where A= reservoir surface area (ha)

V = reservoir volume (ha-m)

D= stage in the reservoir (m)

a_1,a_2,b_1,b_2 are constants of equation.

The relationships for reservoir of Mula irrigation scheme are:

Depth-Area: A = 61.91 D-3547 ($R^2 = 0.974$)

Depth-Volume: V = 949.1 D – 48079 ($R^2 = 0.945$)

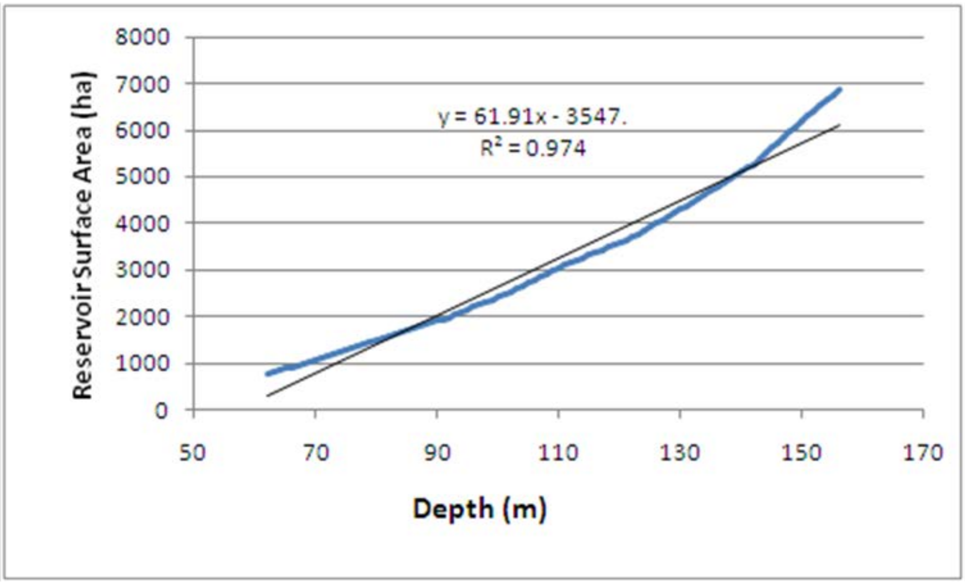


Figure 3.9. The depth-area relationship for reservoir of Mula Irrigation Scheme

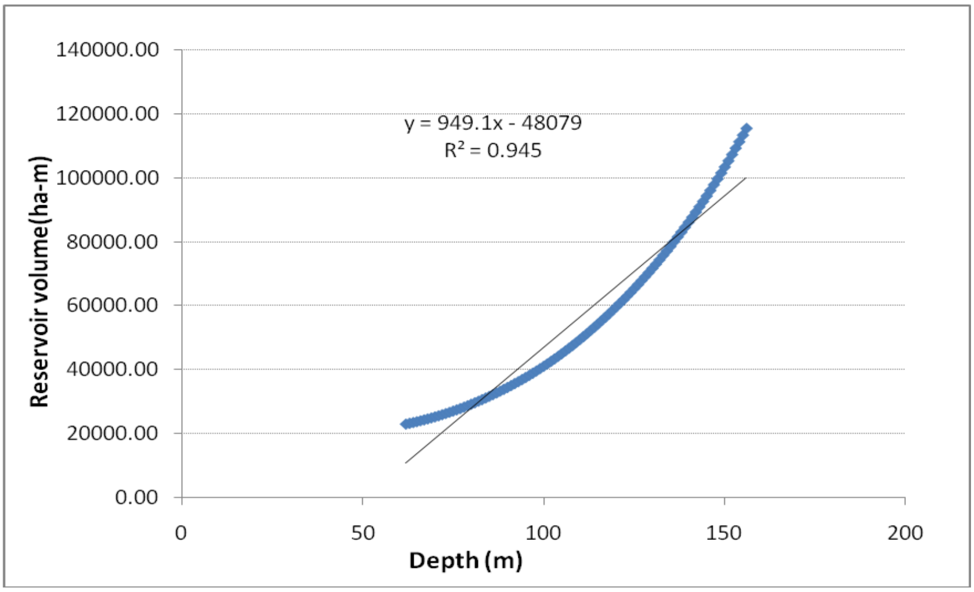


Figure 3.10. The depth-volume relationship for reservoir of Mula irrigation scheme

The relationship between storage volume and surface area of the Mula reservoir which is required for computing the surface area of the reservoir from the daily updated reservoir volume as a result of reservoir of water from the reservoir for irrigation or other purposes is shown in Figure 3.11. The relationship is

$A = 0.065\ V - 410.08$ $(R^2 = 1)$

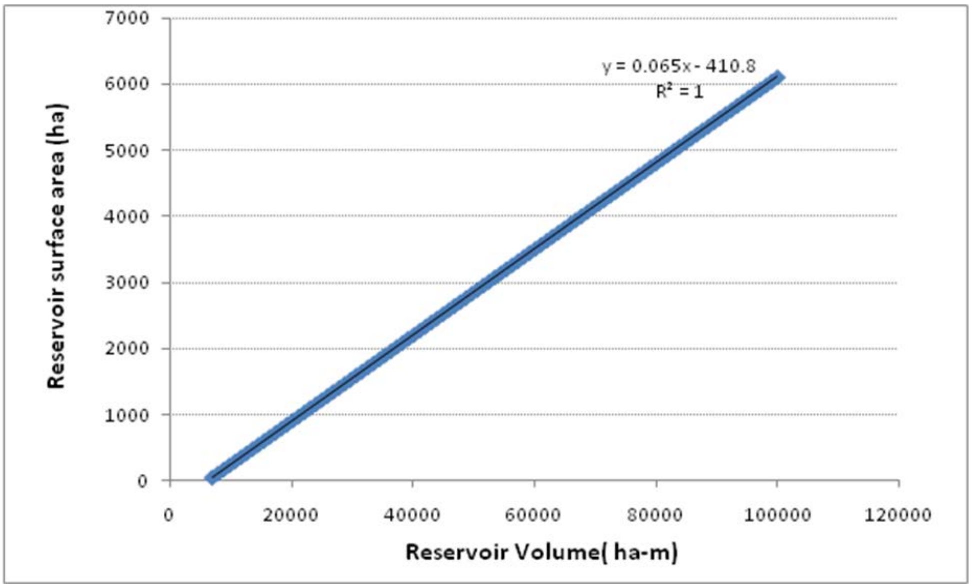


Figure 3.11. The reservoir volume and reservoir surface area relationship for Mula reservoir

3.5.2.5 Command area data

Two main canals emerge from the Mula reservoir. These are Mula right bank and Mula left bank canals. However Mula right bank canal (MRBC) was chosen for this study. The canal network of MRBC is up to tertiary level. These data are presented in Appendix B**.** The summary of these data for the canal at first level (i.e. outlets/sub branches of MRBC) are presented in Table 3.9.

3.6 Primary Data Collection and Analysis for this Study

The data required for irrigation performance modeling are collected by attending to each sub-divisional office of the Maharashtra State Irrigation Department situated in the head, middle and tail reach of MRBC. The photocopies of the registers/files containing the required data were prepared and the validity of the data was discussed with the office bearers. The data required for the AHP analysis (i.e. to obtain the relative preferences and weights of different performance measures at each level) are obtained from different stakeholders by 1. Preparation of questionnaire, 2. Obtaining the response of stakeholders to questionnaire and 3. Analysing the their responses to obtain the weights to different performance measures.

Table 3.9 The details of the outlet/sub canals at first level.

The unit name/number	Soil type	Command area (ha)	Off take distance (m)	Off take capacity (m3/s)
1	Silt	51	2470	0.01842
2	Silt clay	62	2470	0.02125
3	Silt clay	1020	5760	0.57074
4	Silt clay	76	6430	0.022
5	Silt	276	7210	0.09635
6	Clay	473	9340	0.041
7	Silt clay	1650	9710	0.7697
8	Silt clay	95	10800	0.0317
9	Silt clay	400	11840	0.2508
10	Silt clay	130	12270	0.05639
11	Silt clay	136	12960	0.05639
12	Silt clay	102	13680	0.03174
13	Silt clay	57.94	14650	0.02834
14	Silt clay	32.16	16590	0.03061
15	Silt clay	200.45	17350	0.08218
16	Silt	1793.90	18390	0.85016
17	Deep clay	2319	19450	1.04853
18	Deep clay	57.97	21120	0.05923
19	Silt clay	665.59	21430	0.22671
20	Deep clay	56.36	22380	0.05498
21	Clay	70.40	22830	0.03004
22	Clay	140.08	23680	0.03401
23	Deep clay	62.54	25390	0.03401
24	Deep clay	552.87	25390	0.35423
25	Deep clay	6451	26530	2.70634
26	Deep clay	98	29000	0.03174
27	Deep clay	101	29190	0.03174
28	Deep clay	141	30620	0.03401
29	Deep clay	2614	32188	2.09989
30	Deep clay	138	33020	0.13631
31	Deep clay	251	33420	0.10089
32	Deep clay	230	34790	0.10089

The unit name/number	Soil type	Command area (ha)	Off take distance (m)	Off take capacity (m3/s)
33	Deep clay	77	34850	0.03004
34	Deep clay	77	34850	0.03004
35	Deep clay	2256	45400	1.08112
36	Deep clay	130	47200	0.13631
37	Deep clay	697	48119	0.22671
38	Deep clay	140	49700	0.13631
39	Deep clay	495	51403	0.35423
40	Deep clay	21079	56110	5.95111
41	Deep clay	25206	61142	7.08465
42	Deep clay	16643	61142	5.38433
43	Deep clay	8567	61142	3.11725

4. RESULTS AND DISCUSSION (AHP Analysis)I

Analytical hierarchical process (AHP) was used in this study for obtaining the relative preference of farmers to different performance measures. The methodology is followed for the purpose as it is described in Chapter 3, section 3.2.4. To obtain the relative preference of different performance measures and weights of different performance measures at each level. AHP involves obtaining the preference and intensity of preference of one performance measures compared to another performance measures from different stakeholders. Thus obtaining weights by AHP involves three processes.

1. Preparation of questionnaire
2. Obtaining the response of stakeholders to the questionnaire
3. Analyzing the response to obtain the weights.

Different stakeholders involved in the process of irrigation water management are farmers, irrigation officials and policy makers. In the present study the end users of irrigation scheme i.e. farmers were considered to obtain preference of different performance measures and their intensity over each other. The process used to obtain the responses from farmers is elaborated in this chapter.

4.1 Preparation of questionnaire

The questionnaire was prepared in consultation with the Departments of Agricultural Extension Education, Department of Agricultural Economics, Department of Irrigation and Drainage Engineering of Mahatma Phule Krishi Vidyapeeth, Rahuri Irrigation officials from the State department of Water Resources and as proposed by Smout and Gorantiwar (2010). The purpose of the questionnaire was to know the relative preference of farmers in irrigation scheme to different performance measures (productivity, equity, adequacy, reliability, flexibility and sustainability) in different parts of the irrigation scheme.

The important task was to develop the questionnaire that should be clearly understood by the farmers and then obtaining the information from the farmers either by providing them the questionnaire or interviewing with them. Initially the meeting was organised with the different stake holders (i.e. selective farmers, academicians of agricultural university, government irrigation officers and extension workers etc.) regarding the format and the skeleton of the questionnaire. After thorough discussion with them, the first draft of format was prepared.

Three farmers were selected as the contact farmers to test the questionnaire. The procedure that was adopted to obtain the response was:

1. Convert the questionnaire in local language (*Marathi*)
2. Handover the questionnaire to farmers and request them to answer the questionnaire or provide the response
3. Discuss with the farmers the difficulties in filling the questionnaire and suggestions to modify the same.

Repeating this process three times (07.11.2010, 21.11.2010 and 28.11.2010), in the next meeting with the selective farmers and the officials of the irrigation department the format of the questionnaire was finalised and was converted in to local language-*Marathi*.. The questionnaire that was finalised is presented in Appendix-C.

4.2 Obtaining the response of farmers to the questionnaire

It was decided to obtain the responses from the farmers at head, middle and tail reaches of the Mula Right Bank Canal of Mula Irrigation Scheme. Again each reach of the canal was divided in to head, middle and tail portions. The canals at tertiary level were selected from each reach i.e. head, middle and tail. These water courses were further divided in to head, middle and tail portions.

Thus three water courses each were selected from the head, middle and tail reaches of the main canal (thus total 9 watercourses). Each watercourse was further divided in to three portions *viz.* head middle and tail. Thus total 27 groups were formed i.e. 3 groups each from head, middle and tail portions of 9 watercourses.

The combinations of the selected group of farmers from the main canal are shown in Figure 4.1. The details of the 27 group of farmers are presented in Table 4.1.

The selected group of farmers were located sparsely in the command area of Mula Irrigation Scheme. Therefore before approaching these farmers, it was decided to select one trial group of farmers from the outlet adjoining to the University (Mahatma Phule Agricultural University, Rahuri). Accordingly the tail portion of Direct Outlet No.2 A on Mula Right Bank Canal (MRBC) was selected. This was particularly done to know the difficulties that would be encountered while collecting the information from the selected farmers groups.

Five farmers were selected on the tail portion of this trial outlet and the questionnaire in local language was handed over to them on 05.12.2010. The filled in (completed) questionnaires were collected from them after about two hours. The responses to the questionnaires were examined. However it was found that the questionnaires were not filled in properly as:

1. Many responses were not the ones expected from the tail end farmers for example they reported higher preferences for productivity compared to equity
2. Some responses were partly filled in
3. Some response were not filled in at all

After discussion with farmers, it was realised that the farmers did not understand the questions properly. However this was the format that was finalised in agreement with the contact farmers initially. It was realised that as the contact farmers were contacted many times in the discussions and meetings, they were aware of the problem. However the farmers selected randomly did not understand the mechanism of the performance of irrigation.

Later on it was decided to interview the farmers instead of just handing over the questionnaires to farmers. Accordingly on 12.12.2010, five farmers from the head portion of the trial outlet were contacted. However interviewing them too was not found appropriate primarily due to:

1. Responses were non-uniform
2. It took lot of time to interview the farmers individually
3. Farmers asked many questions back which were not related to the AHP questionnaire (example includes: when the seeds will be available from the University, which insecticides should be used, whether Government will offer subsidy on inputs)
4. The farmers had lot of confusion to understand different performance measures and their attributes.
5. Inconsistency in responses
6. The process took 3 days.

The matter was again discussed with the officials from the Department of Water Resources and University Departments (of Extension Education; and Irrigation and Drainage Engineering). After giving much thought, it was decided that instead of approaching the farmers individually, arrange the group meetings with maximum number of the farmers for each selected group, describe them the entire situation, tell them the purpose and describe each question and obtain the common response from them.

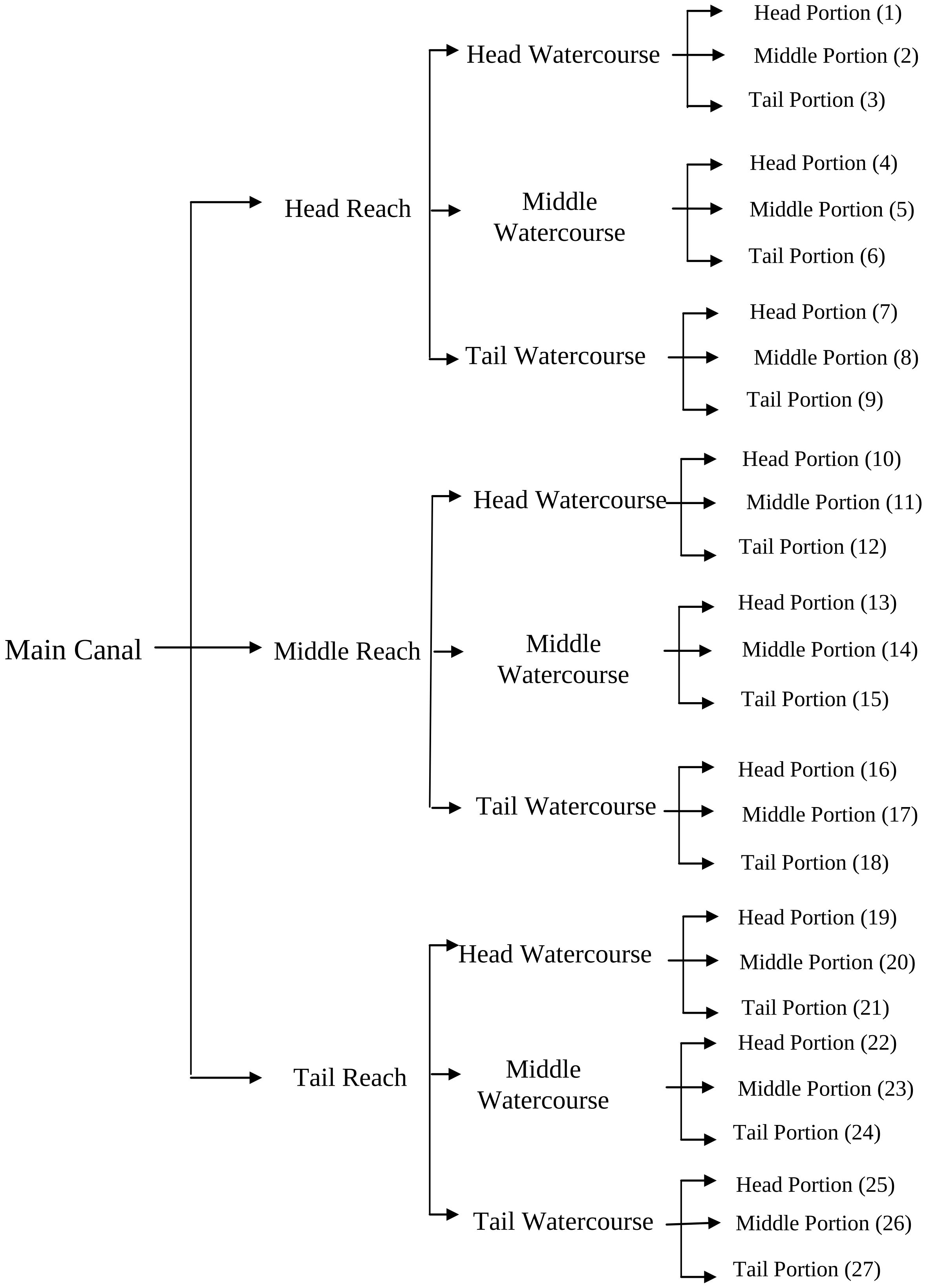


Figure 4.1 The combinations of the selected group of farmers from the main canal

Table 4.1 The details of the 27 group of farmers for obtaining the responses to AHP questionnaire

Group No.	Canal at 1st Level	Canal at 2nd Level	Canal at 3rd Level
1 (Head-Head-Head)	RBC	-	DO1 (head reach)
2 (Head-Head-Middle)	RBC	-	DO1 (middle reach)
3 (Head-Head-Tail)	RBC	-	DO1 (tail reach)
4 (Head-Middle-Head)	RBC	Minor 1	Sub Minor 1 (head reach)
5 (Head-Middle-Middle)	RBC	Minor 1	Sub Minor 1 (middle reach)
6 (Head-Middle-Tail)	RBC	Minor 1	Sub Minor 1(tail reach)
7 (Head-Tail-Head)	RBC	Dist 1	Minor 2 (head reach)
8 (Head-Tail-Middle)	RBC	Dist 1	Minor 2 (middle reach)
9 (Head-Tail-Tail)	RBC	Dist 1	Minor 2 (tail reach)
10 (Middle-Head-Head)	RBC	-	DO12 (head reach)
11 (Middle-Head-Middle)	RBC	-	DO12 (middle reach)
12 (Middle-Head-Tail)	RBC	-	DO12 (tail reach)
13 (Middle-Middle-Head)	RBC	Sonai Dist	Sub Minor 1 (head reach)
14 (Middle-Middle-Middle)	RBC	Sonai Dist	Sub Minor 1 (middle reach)
15 (Middle-Middle-Tail)	RBC	Sonai Dist	Sub Minor 1 (tail reach)
16 (Middle-Tail-Head)	RBC	Sonai Dist	Left Minor 4 (head reach)
17 (Middle-Tail-Middle)	RBC	Sonai Dist	Left Minor 4 (middle reach)
18 (Middle-Tail-Tail)	RBC	Sonai Dist	Left Minor 4 (tail reach)
19 (Tail-Head-Head)	RBC	Branch 2	DO 1 (head reach)
20 (Tail-Head-Middle)	RBC	Branch 2	DO 1 (middle reach)
21 (Tail-Head-Tail)	RBC	Branch 2	DO 1 (tail reach)
22 (Tail-Middle-Head)	RBC	Branch 2	DO 6 (head reach)
23 (Tail-Middle-Middle)	RBC	Branch 2	DO 6 (middle reach)
24 (Tail-Middle-Tail)	RBC	Branch 2	DO 6 (tail reach)
25 (Tail-Tail-Head)	RBC	Branch 2	DO 14 (head reach)
26 (Tail-Tail-Middle)	RBC	Branch 2	DO 14 (middle reach)
27 (Tail-Tail-Tail)	RBC	Branch 2	DO 14 (tail reach)

Schematic layout of Mula Right Bank Canal (MRBC) network showing the locations where 27 groups of farmers were interviewed to know their preferences of performance measures is given in APPENDIX- B2.

Accordingly the farmers from the tail and middle portions of the trial outlets were approached on 17.12.2010 at 0830 hours (i.e. before they leave the homes/village to farms or for some other works). 22 farmers were present for this meeting. Before the start of the session, we were faced with barrage of questions as:

1. Whether we came from Government or insurance agency
2. Whether we are visiting them to work out the crop losses due to heavy rains
3. How much they will be compensated for?
4. When the Government officials will visit them?
5. When they will get electricity connection?
6. What about transport etc?

Just about we were thinking that probably, this idea too will fail, one amongst them (he was one of the farmers to whom we had handed over questionnaire for obtaining the response before) stood and tried to explain the purpose that this group is nothing to do with Government Schemes or facilities but have come to study and investigate the causes of as to why we don't get the water for irrigation when we need. He virtually narrowed down the topic to our interest.

Then we (with other faculty members of Department of Irrigation and Drainage Engineering and post graduate students from this Department) narrated the purpose properly and discussed each question with all the farmers together and made out the common response from them. This procedure worked nicely and we were confident that we are getting the proper information. Many times if some farmers did not understand, other farmers who understood explained to others in a language that was understood to the farmers. This helped us a lot to get quick and proper responses. The entire process took only 4 hours.

It was decided to contact all the 27 groups of farmers. Before contacting each group, it was made sure that one lead farmer is selected from each group and that farmer is narrated with the purpose beforehand. The Government Department of Irrigation helped to contact the lead farmers. However during the actual meetings with farmers, there was no representative of the Government Departments (as during the initial meetings, the actual subject deviated many times in their presence). In this way the 27 groups were contacted. The schedule of dates that was followed is provided in Table 4.2. The list of the farmers who attended the meeting and provided the responses for selected group is given in Table 4.3 as an example.

Table 4.2 The schedule followed for obtaining the responses from 27 groups

Sr. No	Group No.	Date of visit/interview	No. of farmer
1	1 (Head-Head-Head)	06.02.2011	15
2	2 (Head-Head-Middle)	06.02.2011	17
3	3 (Head-Head-Tail)	12.02.2011	13
4	4 (Head-Middle-Head)	12.02.2011	27
5	5 (Head-Middle-Middle)	13.02.2011	25
6	6 (Head-Middle-Tail)	13.02.2011	16
7	7 (Head-Tail-Head)	16.02.2011	10
8	8 (Head-Tail-Middle)	30.01.2011	09
9	9 (Head-Tail-Tail)	30.01.2011	11
10	10 (Middle-Head-Head)	23.01.2011	14
11	11 (Middle-Head-Middle)	22.01.2011	34
12	12 (Middle-Head-Tail)	22.01.2011	07
13	13 (Middle-Middle-Head)	16.01.2011	27
14	14 (Middle-Middle-Middle)	16.01.2011	18
15	15 (Middle-Middle-Tail)	09.01.2011	10
16	16 (Middle-Tail-Head)	09.01.2011	33
17	17 (Middle-Tail-Middle)	09.01.2011	39
18	18 (Middle-Tail-Tail)	08.01.2011	20
19	19 (Tail-Head-Head)	08.01.2011	18
20	20 (Tail-Head-Middle)	02.01.2011	15
21	21 (Tail-Head-Tail)	02.01.2011	06
22	22 (Tail-Middle-Head)	26.12.2010	40
23	23 (Tail-Middle-Middle)	26.12.2010	10
24	24 (Tail-Middle-Tail)	25.12.2010	11
25	25 (Tail-Tail-Head)	25.12.2010	08
26	26 (Tail-Tail-Middle)	19.12.2010	26
27	27 (Tail-Tail-Tail)	19.12.2010	24

Some of the feedbacks received from the farmers are narrated ahead.

Valuable comments/feedback received from the farmers of Tail reach of Mula Right Bank Canal, Mula Irrigation Scheme, Tal. Rahuri Dist. Ahmednagar (M.S.) India. (Group No. 25 Tail-Tail-Head)

- Rotation should be as per the demand
- Delivery of equal quantum of water should be observed during the specified time
- Canal should be Constructed up to the tail end for assured quantity of irrigation water
- Water should be delivered up to the field of farmers by the Water Resource department

- Conveyance losses should be properly checked at upper reaches so that optimum quantity will be discharged to the tail end
- There should be security protection to avoid illegal leakages of irrigation water during its transit. Water delivery system should be operated as per the actual requirement, site and time specific and seasonal requirement
- There is urgent need of training to the farmers/stake holders regarding efficient use of irrigation water
- The water charges should be on the volumetric basis to avoid/minimise irrigating the fields with excess water

Valuable comments/feedback received from the farmers of Middle reach of Mula Right Bank Canal, Mula Irrigation Scheme, Tal. Rahuri Dist. Ahmednagar (M.S.) India. (Group No. 17 Middle-Tail-Middle)

- Water should be delivered as per demand of farmers
- Water should be delivered as per the requirement of the crop
- The officers from the Agricultural Universities and from the Agricultural Department should be involved in planning and delivery system of irrigation water
- The involvement of politician should be strictly restricted
- Rotational supply should be modified as per the need and change climate in the specific season

Valuable comments/feedback received from the farmers of Head reach of Mula Right Bank Canal, Mula Irrigation Scheme, Tal. Rahuri Dist. Ahmednagar (M.S.) India. (Group No.7 Head-Tail-Head)

- Irrigation schedules need to be operated as per the plan
- Water may be delivered as per the requirement of crop
- Regular maintenance of minor/ distributaries are essential
- Drainage line is urgently required
- Water delivery and management should be as per the climate change
- The problematic land should be immediately reclaimed
- Productivity should be increased
- The high water table should be lowered down

Table 4.3 The details of farmers interviewed

Group. No.	Date Interviewed	Name of the Farmer
23 (Tail-Middle-Middle)	26.12.2010	Sanjay Sahebrao Ghule
		Shivaji Ramdas Kande
		Dharmanath Raghunath Palave
		Kisan Ramrao Sanap
		Babasaheb Vitthal Londhe
		Gokul Uttam Bhatane
		Navnath Kundalik Khedkar
		Baban Karbhari Bhujbal
		Ajinath Pacharane
		Dnyandeo Laxman Korade
15 (Middle-Middle-Tail)	09.01.2011	Gitaram Bhausaheb Aher
		Subhash Kacharu Gaikwad
		Ginandeo Trimbak Dahatonde
		Dasharath Bhanudas Pund
		Popat Bhanudas Javale
		Bhausaheb Macchindra Thite
		Babasaheb Pundlik Javale
		Jhumbarrao Shelake
		Thakaji Gangadhar Virdhar
		Pradip Dnyandeo Dahatonde
7 (Head-Tail-Head)	16.02.2011	Mahadeo Vishvanath Tandale
		Ganpat Kondiram Jamdade
		Balasaheb Tukaram Jagtap
		Suresh Manik Darandale
		Bhausaheb Nivrutti Dahiphale
		Vitthal Bhagat Vehlekar
		Tulasidas Keru Bhome
		Mahadeo Hari Gaadakh
		Devrao Khandu Devlile
		Babasaheb Kisandeo Gadakh

Some of the Photograph of the meetings are shown below:


Giving neat understanding about the purpose of study, questionnaire etc to tail reach farmers



Giving neat understanding about the purpose of study, questionnaire etc to middle reach farmers


Giving neat understanding about the purpose of study, questionnaire etc to head reach farmers

4.3 Analyzing the response to obtain the weights

27 sets of full responses to questionnaires thus were obtained using the methodology described in section 4.2. These were analyzed to know the weights of each performance measures at each level. The procedure adopted is described in Chapter-3. The procedure with example is narrated below.

It is necessary to know the relative preference of each performance indicators in each of the group at each level of the hierarchical structure of the performance indicators. Once the hierarchical structure is formed and the questionnaire has been prepared, AHP is conducted in following six steps (Saaty, 1980)

1. Step 1-Setting up the performance measures in the form of hierarchy
2. Step 2-Perform pair wise comparisons for performance measures
3. Step 3-Prepare a matrix (judgement matrix) for performance measures
4. Step 4-Compute the priority vector for performance measures:
5. Step 5-Assess consistency of pair wise judgments (Comparison of alternatives)
6. Step 6-Compute the relative weights/ranks

The proposed hierarchy structure is presented in Figure 3.1. In the proposed hierarchical structures there are two levels. At level-2 there are six performance measures viz. productivity, equity, adequacy, reliability, flexibility and sustainability. At level -1 each of these indicators has attributes as explained in Chapter-3.

It is necessary to find out the weights of these indicators at each level. To explain the entire process, the productivity group at level-2 has been selected that following attributes at level 1.

- Net benefits per unit area productivity (NB-A)
- Crop production per unit area productivity (CP-A)
- Net benefits per unit used water productivity (NB-W)
- Crop production per unit used water productivity (CP-W) and
- Irrigated area per unit of culturable command area productivity(IA-CCA)

The procedure used in obtaining the relative weights for each factor is described below.

4.3.1. Setting up the hierarchy

The hierarchy for productivity group at level-2 with its attributes at level-1 is shown in figure 4.2.

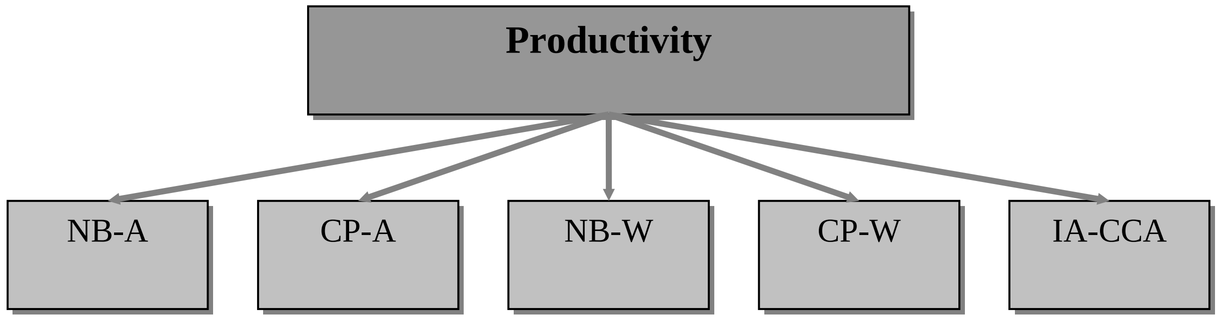


Figure 4.2. Establishing the hierarchy of the problem.

4.3.2. Pairwise Comparisons

The Analytic Hierarchy Process (AHP) method does not require the respondent (farmers in this case) to quantify precisely the level of importance, but the respondent is required to carry out pairwise comparisons among factors to give the relative importance of each pair according to established nine-point intensity scale systems shown in Table 3.1. Thus this step, the factors are compared with each other to determine the relative importance of each factor in the accomplishing the overall goal. The structure of the questionnaire to aid the respondent to determine the relative importance of each factor over another according to Scale system (modified to 5 point scale) is presented in Appendix-C. Here, the nine point scale is modified to five point scale as proposed by Smout and Gorantiwar (2010) to give a simpler scale for the stakeholders to give their relative preferences of each factor over the other. The five point scales corresponds to points 1, 3, 5, 7 and 9 in Table 3.1 and 3.2. The responses to the questionnaire were obtained by using the procedure described in section 4.2

4.3.3. Matrix for Factors

A matrix with the factors (in our example Net benefits per unit area productivity (NB-A), Crop production per unit area productivity (CP-A), Net benefits per unit used water productivity (NB-W), Crop production per unit used water productivity (CP-W) and Irrigated area per unit of culturable command area productivity(IA-CCA)) listed at the top and on the left is prepared. Based on surveyed information and the resulting informed judgment of the decision-maker (Step-2), the matrix is then filled in with numerical values denoting the importance of the factor on the left relative to the importance of the factor on the top. A high value means that the factor on the left is relatively more important than the factor at the top. The numerical values were taken from the responses obtained from groupNo.1 (i.e. head reach of MRBC, head reach of secondary canal, head reach of tertiary canal, Head-Head-Head). In Table 4.4 for example, NB-A is considered to be three times as important as NB-W, whereas NB-W is only one third as important as the NB-A. When a factor is compared with itself the ratio of importance is obviously one, resulting in a diagonal line across the matrix. The resulting matrix is known as the judgment matrix.

Table 4.4. The judgment matrix for the factors

	NB-A	**CP-A**	**NB-W**	**CP-W**	**IA-CCA**
NB-A	1	1	3	1	3
CP-A	1	1	1	1/3	3
NB-W	1/3	1	1	3	1
CP-W	1	3	1/3	1	5
IA-CCA	1/3	1/3	1	1/5	1

The NB-W and IA-CCA are considered as the factor which influences productivity most (productivity in turn influences the performance), followed by NB-A, CP-A and CP-W.

4.3.4. Priority vector for factors

In the matrix (Table 4.4) to get an overall priority value for each factor is prepared. AHP computes an overall priority value or weight for each decision element based on the pairwise comparisons using mathematical techniques such as

- Eigenvalue
- Mean Transformation and
- Row Geometric Mean

In the present study Row Geometric Mean technique for computing the weights under AHP has been employed. The procedure is described below.

Row Geometric Mean: In this step, the geometric mean of each row (i.e., the elements in each row are multiplied with each other and then the *n*th root is taken, where *n* is the number of elements in the row) is calculated. This forms the vector of geometric mean. The elements of this vector are then normalized by dividing them with the sum. The resulting normalized vector is an approximated maximum eigenvector, herein named as priority vector. The calculations for the example are presented below:

The vector of geometric mean

NB-A : $(1 \times 1 \times 3 \times 1 \times 3)^{1/5}$ = 1.55

CP-A : $(1 \times 1 \times 1 \times 0.333 \times 3)^{1/5}$ =0.99

NB-W : $(0.33 \times 1.00 \times 1 \times 3.00 \times 1.00)^{1/5}$ = 0.99

CP-W : $(1.0 \times 3.0 \times 0.333 \times 1 \times 5)^{1/5}$ = 1.37

IA-CCA $(0.33 \times 0.33 \times 1.0 \times 0.20 \times 1)^{1/5}$ = 0.46

Total = 5.36

The Priority vector

NB-A : 1.55/5.36 = 0.28

CP-A : 0.99/5.36 = 0.18

NB-W : 0.99/5.36 = 0.18

CP-W : 1.37/5.36 = 0.25

IA-CCA : 0.46/5.36 = 0.08

Total = 1.00

4.3.5. Consistency of Pair wise Judgments

It is quite possible that when two elements are compared for different pairs, this comparison is non consistent. If all the comparisons are perfectly consistent, then the following expression is valid for any combination of comparisons of the judgment matrix.

$$a_{ij} = a_{ik} \times a_{kj} \quad (4.1)$$

where a_{ij} = relative importance factor (tabulated values in Table 4.5) of decision criteria i to j.

The Table 4.4 is reproduced below (Table 4.5) with values of i and j.

Table 4.5. The judgment matrix for the factors

j \ i		**NB-A** 1	**CP-A** 2	**NB-W** 3	**CP-W** 4	**IA-CCA** 5
NB-A	1	1 a_{11}	1 a_{12}	3 a_{13}	1 a_{14}	3 a_{15}
CP-A	2	1 a_{21}	1 a_{22}	1 a_{23}	1/3 a_{24}	3 a_{25}
NB-W	3	1/3 a_{31}	1 a_{32}	1 a_{33}	3 a_{34}	1 a_{35}
CP-W	4	1 a_{41}	3 a_{42}	1/3 a_{43}	1 a_{44}	5 a_{45}
IA-CCA	5	1/3 a_{51}	1/3 a_{52}	1 a_{53}	1/5 a_{54}	1 a_{55}

If i=1; j=2

$a_{12} = 1$

$a_{13} = 3$

$a_{32} = 1$

According to equation (4.1), a_{12} should be equal to a_{13} x $a_{32.}$

If the responses are not obtained carefully there is always possibility of inconsistency.

Consistency ratio (CR) is commonly used to reflect the degree of consistency of judgment matrix. The CR is calculated as follow:

$$CI = \frac{\lambda_{\max} - n}{(n-1)} \tag{4.2}$$

$$CR = \frac{CI}{RCI} \tag{4.3}$$

where *CI* = consistency index; $\lambda_{\max}$ = maximum eigenvalue of judgment matrix; *RCI*= Random Consistency index as given in Table 3.2; *n*= the number of factor.

Maximum eigenvalue ($\lambda_{\max}$) is obtained by adding the columns in the judgment matrix and multiplying the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained earlier. The procedure is explained below.

Adding the columns in the judgment matrix (from Table 4.4)

NB-A	CP-A	NB-W	CP-W	IA-CCA
3.66	6.33	6.33	5.53	13

Vector of priorities

NB-A	0.28
CP-A	0.18
NB-W	0.18
CP-W	0.25
IA-CCA	0.08

Multiplication and addition

NB-A	3.66 x 0.28	1.05
CP-A	6.33 x 0.18	1.20
NB-W	6.33 x 0.18	1.20
CP-W	5.53 x 0.25	1.43
IA-CCA	13.0 x 0.08	1.17
	$\lambda_{\max}$	6.07

$$CI = \frac{6.07 - 5}{(5 - 1)} = 0.2675$$

$$CR = \frac{0.2675}{1.12} = 0.2388$$

The pairwise comparisons in a judgment matrix in AHP are considered to be adequately consistent if its CR is less than 0.10 (Saaty, 1980). If CR is greater than 0.10, there is a need for further evaluation of the pairwise comparison in judgment

4.4 Results of AHP

The special software from Gorantiwar (personal communication) was used to analyze the pair wise comparison to obtain the weights by using the method described in Section 4.3 by using M.S. Excel ®. All the twenty seven questionnaires were analyzed to obtain the weights of all the performance measures with the help of developed software. In case of inconsistent results, the farmers were again consulted for the groups of performance measures for which the inconsistent results were obtained. After obtaining the revised response, the AHP analysis was again performed for those groups. In case of inconsistent results after second round, the farmers were not consulted again, but the inconsistent weights were retained.
The weights of performance measures are presented and discussed in the subsequent sections.

4.4.1 Weights at level-2

These results for Level-2 performance measures are presented in Table 4.6.

Table 4.6. The weights of different performance measures at Level-2

Group No.	Location	Performance Measures (Level-2)					
		Productivity	Equity	Adequacy	Reliability	Flexibility	Sustainability
1	Head-Head-Head	0.27	0.05	0.05	0.23	0.15	0.25
2	Head-Head-Middle	0.29	0.05	0.07	0.07	0.26	0.26
3	Head-Head-Tail	0.31	0.05	0.06	0.09	0.29	0.2
4	Head-Middle-Head	0.26	0.03	0.06	0.14	0.21	0.29
5	Head-Middle-Middle	0.43	0.04	0.04	0.16	0.1	0.24

Group No.	Location	Performance Measures (Level-2)					
		Productivity	Equity	Adequacy	Reliability	Flexibility	Sustainability
6	Head-Middle-Tail	0.29	0.04	0.07	0.07	0.29	0.23
7	Head-Tail-Head	0.29	0.03	0.06	0.17	0.22	0.22
8	Head-Tail-Middle	0.3	0.03	0.06	0.17	0.22	0.23
9	Head-Tail-Tail	0.41	0.03	0.05	0.16	0.17	0.18
10	Middle-Head-Head	0.11	0.05	0.19	0.23	0.23	0.18
11	Middle -Head-Middle	0.08	0.03	0.09	0.3	0.39	0.18
12	Middle -Head-Tail	0.18	0.04	0.18	0.27	0.2	0.13
13	Middle -Middle-Head	0.19	0.04	0.18	0.2	0.19	0.2
14	Middle -Middle-Middle	0.12	0.04	0.07	0.19	0.52	0.04
15	Middle -Middle-Tail	0.12	0.04	0.05	0.16	0.58	0.05
16	Middle -Tail-Head	0.08	0.04	0.18	0.23	0.23	0.23
17	Middle -Tail-Middle	0.25	0.04	0.15	0.19	0.19	0.19
18	Middle -Tail-Tail	0.25	0.04	0.15	0.19	0.19	0.19
19	Tail-Head-Head	0.07	0.29	0.19	0.2	0.21	0.03
20	Tail -Head-Middle	0.05	0.28	0.2	0.25	0.19	0.04
21	Tail -Head-Tail	0.04	0.39	0.1	0.35	0.08	0.05
22	Tail -Middle-Head	0.06	0.39	0.1	0.32	0.08	0.05
23	Tail -Middle-Middle	0.05	0.25	0.29	0.25	0.06	0.11
24	Tail -Middle-Tail	0.04	0.24	0.27	0.2	0.2	0.04
25	Tail -Tail-Head	0.04	0.33	0.16	0.29	0.13	0.04
26	Tail -Middle-Middle	0.06	0.24	0.22	0.22	0.22	0.03
27	Tail -Tail-Tail	0.06	0.23	0.23	0.23	0.23	0.03

(The figures in bracket indicate the inconsistent results of first round; the figures in italic indicate the inconsistent results of second round)

The average values of different performance measures over the entire command area of Mula Right Bank Canal are shown in Figure 4.3. It is seen from the figure that on an average flexibility and reliability are more important followed by productivity sustainability, adequacy and equity.

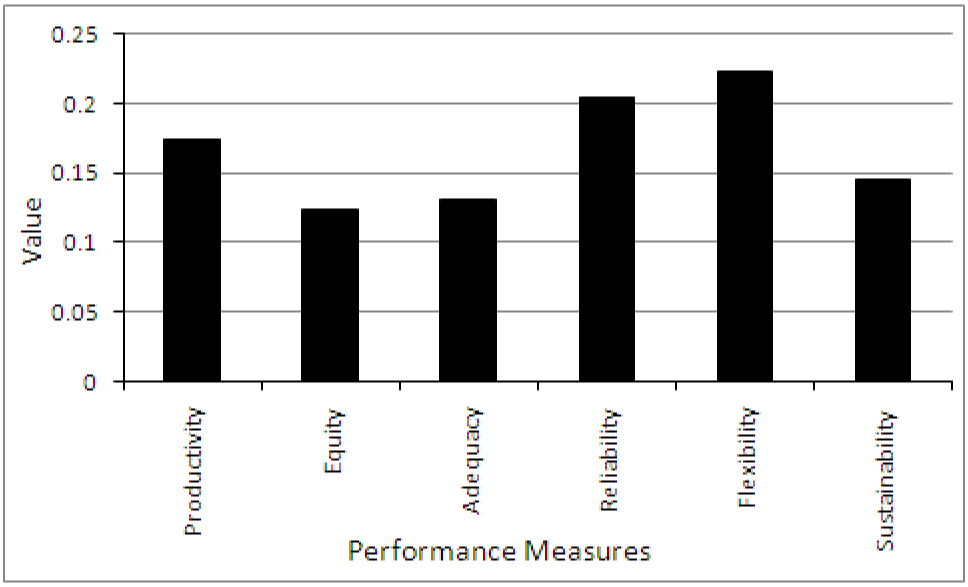


Figure 4.3. Variation of different performance measures in canal command area of Mula Right Bank Canal.

The average values of different performance measures over head, middle and tail reaches of the Mula Right Bank canal are presented in Figure 4.4. It is seen from the figure that the productivity is more important in head reach where as in middle and tail reaches, other performance measure are important. Equity is least important in head reach, where as in tail reach equity is the most important. Middle reach farmers also indicated the preference to equity compared to productivity. Adequacy is important in middle and tail reaches compared to head reach. The similar trend is found for reliability. Head reach farmers showed more importance to sustainability compared to middle and tail reaches. In general productivity and equity are found to be conflicting in different reaches. Overall productivity, sustainability and flexibility showed the similar trend i.e. these indicators are important for head reach farmers compare to middle and tail reach farmers. On the other hand equity, adequacy and reliability are more important for middle and tail reach farmers compared to head reach farmers.

Considering the complex relationship amongst these indicators to different farmers in different locations of the command area, it is necessary to investigate their influence on the final performance of the irrigation water management for different irrigation strategies and select the appropriate strategy.

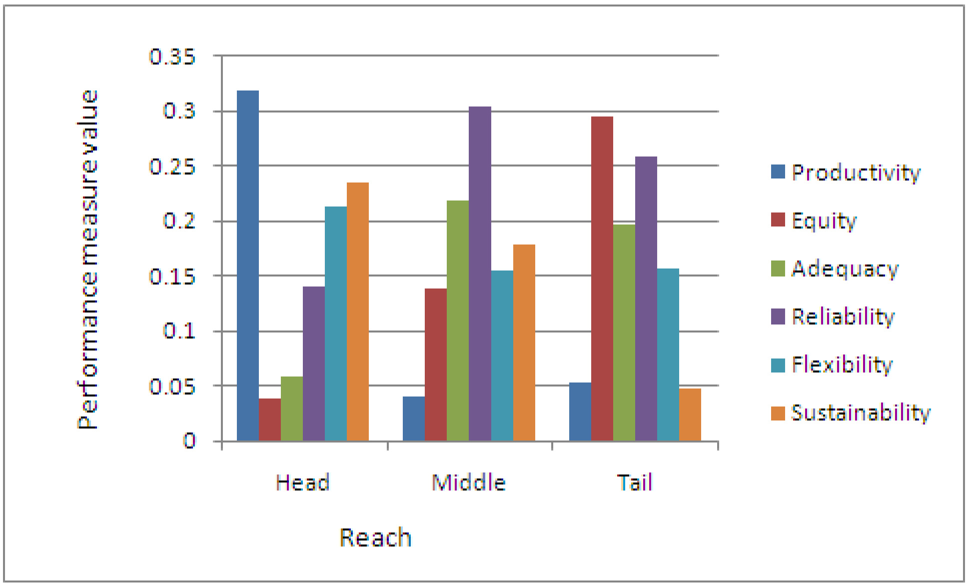


Figure 4.4 Variation of different performance measures in head, middle and tail reaches of Mula Right Bank Canal.

The different performance measures in head reaches at secondary level of Mula Right Bank Canal at head, middle and tail reaches of Mula Right Bank Canal are presented in Table 4.7

Table 4.7. The weights of different performance measures in head reaches at secondary level at head, middle and tail reaches of the main Canal.

Reach of main canal	Productivity	Equity	Adequacy	Reliability	Flexibility	Sustainability
Head	0.27	0.05	0.05	0.23	0.15	0.25
Head	0.26	0.03	0.06	0.14	0.21	0.29
Head	0.29	0.03	0.06	0.17	0.22	0.22
Middle	0.11	0.05	0.19	0.23	0.23	0.18
Middle	0.19	0.04	0.18	0.2	0.19	0.2
Middle	0.08	0.04	0.18	0.23	0.23	0.23
Tail	0.07	0.29	0.19	0.2	0.21	0.03
Tail	0.06	0.39	0.1	0.32	0.08	0.05
Tail	0.04	0.33	0.16	0.29	0.13	0.04

It is seen from the table 4.7 that even if the farmers are at the head reaches of the secondary level, but if they are at the tail reach of the main canal, the equity is important for them compared to productivity. Adequacy is also important to them. In short theses farmers are showing the behavior of tail farmers on average terms.

4.4.2 Weights at level-1 of productivity group

The weights of different indicators of productivity group at level 1 are presented in Table 4.8.

Table 4.8 The weights of different performance measures of productivity group at Level-1

Group No.	Location	Productivity group				
		Net benefits per unit area productivity	Crop production per unit area productivity	Net benefits per unit used water productivity	Crop production per unit used water productivity	Irrigated area per unit of culturable command area productivity
1	Head-Head-Head	(0.29) 0.29	(0.19) 0.19	(0.19) .019	(0.26) .0.26	(0.09).0.19
2	Head-Head-Middle	0.36	0.15	0.23	0.15	0.12
3	Head-Head-Tail	0.23	0.19	0.29	0.19	0.1
4	Head-Middle-Head	0.31	0.09	0.31	0.14	0.14
5	Head-Middle-Middle	0.15	0.15	0.15	0.36	0.19
6	Head-Middle-Tail	0.26	0.39	0.13	0.15	0.06
7	Head-Tail-Head	0.2	0.2	0.2	0.2	0.2
8	Head-Tail-Middle	0.18	0.28	0.31	0.11	0.12
9	Head-Tail-Tail	0.14	0.51	0.11	0.07	0.17
10	Middle-Head-Head	0.33	0.32	0.19	0.07	0.1
11	Middle-Head-Middle	0.22	0.39	0.14	0.12	0.13
12	Middle-Head-Tail	0.31	0.28	0.12	0.24	0.05
13	Middle-Middle-Head	0.26	0.26	0.19	0.19	1
14	Middle-Middle-	0.19	0.36	0.12	0.09	0.05
15	Middle-Middle-Tail	0.17	0.41	0.22	0.1	0.1
16	Middle -Tail-Head	0.2	0.2	0.2	0.2	0.2
17	Middle-Tail-Middle	0.15	0.55	0.08	0.11	0.11
18	Middle -Tail-Tail	0.15	0.55	0.08	0.11	0.11
19	Tail-Head-Head	0.12	0.24	0.15	0.24	0.24
20	Tail -Head-Middle	0.15	0.24	0.12	0.24	0.24
21	Tail -Head-Tail	0.34	0.23	0.12	0.25	0.06
22	Tail -Middle-Head	0.22	0.08	0.33	0.31	0.06
23	Tail-Middle-Middle	0.18	0.07	0.25	0.25	0.25
24	Tail -Middle-Tail	0.29	0.12	0.29	0.12	0.19
25	Tail -Tail-Head	0.09	0.14	0.41	0.24	0.12
26	Tail-Middle-Middle	0.2	0.2	0.2	0.2	0.2
27	Tail -Tail-Tail	0.19	0.19	0.3	0.16	0.16
	Average	0.22	0.26	0.20	0.18	0.17

The results showed no strong preference for one productivity performance measure over the other, though the farmers rated “Crop production per unit area productivity” as most important overall.

It is seen from the Table 4.8 that inconsistent results were obtained for one location in first round. The productivity at Level-1 was inconsistent for Group No. 1 and Location Head-Head-Head. These farmers were contacted again. However for same location, inconsistent results were obtained in second round also.

4.4.3 Weights at level-1 of equity group

The weights of different indicators of equity group at level 1 are presented in Table 4.9.

Table 4.9. The weights of different performance measures of equity group at Level-1

Group No.	Location	Equity group			
		Area	Water	Net Benefits	Crop productivity
1	Head-Head-Head	(0.32) *0.32*	(0.16) *0.16*	(0.24) *0.24*	(0.28) *0.28*
2	Head-Head-Middle	0.43	0.29	0.11	0.17
3	Head-Head-Tail	0.39	0.39	0.13	0.08
4	Head-Middle-Head	0.10	0.16	0.28	0.46
5	Head-Middle-Middle	0.18	0.18	0.24	0.41
6	Head-Middle-Tail	0.40	0.06	0.23	0.31
7	Head-Tail-Head	0.12	0.05	0.41	0.41
8	Head-Tail-Middle	0.12	0.04	0.42	0.42
9	Head-Tail-Tail	0.08	0.08	0.42	0.42
10	Middle-Head-Head	0.30	0.05	0.33	0.33
11	Middle -Head-Middle	0.23	0.10	0.34	0.34
12	Middle -Head-Tail	0.31	0.06	0.31	0.31
13	Middle -Middle-Head	0.07	0.07	0.43	0.43
14	Middle -Middle-Middle	0.30	0.10	0.30	0.30
15	Middle -Middle-Tail	0.32	0.07	0.28	0.32
16	Middle -Tail-Head	0.08	0.08	0.42	0.42
17	Middle -Tail-Middle	0.32	0.10	0.42	0.16
18	Middle -Tail-Tail	0.32	0.10	0.42	0.16
19	Tail-Head-Head	0.06	0.63	0.15	0.15
20	Tail -Head-Middle	0.11	0.65	0.12	0.12
21	Tail -Head-Tail	0.11	0.68	0.11	0.11
22	Tail -Middle-Head	0.13	0.58	0.13	0.15
23	Tail -Middle-Middle	0.13	0.63	0.13	0.13
24	Tail -Middle-Tail	0.l2	0.56	0.12	0.20
25	Tail -Tail-Head	0.10	0.70	0.10	0.10
26	Tail -Middle-Middle	0.13	0.63	0.13	0.13
27	Tail -Tail-Tail	0.14	0.47	0.11	0.28
	Average	0.20	0.28	0.25	0.26

The results showed no strong preference for one equity performance measure over the other, though the farmers rated "Water Equity" as most important overall.

It is seen from the Table 4.9 that inconsistent results were obtained for one location in first round. The equity at Level-1 was inconsistent for Group No. 1 and Location Head-Head-Head. These farmers were contacted again. However for same location, inconsistent results were obtained in second round also.

4.4.4 Weights at level-1 of adequacy group

The weights of different indicators of adequacy group at level-1 are presented in Table 4.10.

Table 4.10 The weights of different performance measures of adequacy group at Level-1

Group No.	Location	Adequacy group	
		Seasonal adequacy	Intraseasonal adequacy
1	Head-Head-Head	0.50	0.50
2	Head-Head-Middle	0.13	0.88
3	Head-Head-Tail	0.17	0.83
4	Head-Middle-Head	0.13	0.88
5	Head-Middle-Middle	0.75	0.25
6	Head-Middle-Tail	0.17	0.83
7	Head-Tail-Head	0.17	0.83
8	Head-Middle-Middle	0.17	0.83
9	Head-Tail-Tail	0.83	0.17
10	Middle-Head-Head	0.17	0.83
11	Middle -Head-Middle	0.17	0.83
12	Middle -Head-Tail	0.13	0.88
13	Middle -Middle-Head	0.50	0.50
14	Middle -Middle-Middle	0.83	0.17
15	Middle -Middle-Tail	0.88	0.13
16	Middle -Tail-Head	0.50	0.50
17	Middle -Tail-Middle	0.50	0.50
18	Middle -Tail-Tail	0.50	0.50
19	Tail-Head-Head	0.50	0.50
20	Tail -Head-Middle	0.50	0.50
21	Tail -Head-Tail	0.50	0.50
22	Tail -Middle-Head	0.17	0.83
23	Tail -Middle-Middle	0.25	0.75
24	Tail -Middle-Tail	0.50	0.50
25	Tail -Tail-Head	0.50	0.50
26	Tail -Middle-Middle	0.50	0.50
27	Tail -Tail-Tail	0.50	0.50
	Average	0.41	0.59

The results showed no strong preference for one adequacy performance measure over the other, though the farmers rated "Intra-seasonal adequacy" as most important overall.

4.4.5 Weights at level-1 of reliability group

The weights of different indicators of reliability group at level 1 are presented in Table 4.11.

Table 4.11. The weights of different performance measures of reliability group at Level-1

Group No.	Location	Reliability group	
		Seasonal Reliability	Intraseasonal Reliability
1	Head-Head-Head	0.25	0.75
2	Head-Head-Middle	0.50	0.50
3	Head-Head-Tail	0.50	0.50
4	Head-Middle-Head	0.17	0.83
5	Head-Middle-Middle	0.17	0.83
6	Head-Middle-Tail	0.50	0.50
7	Head-Tail-Head	0.50	0.50
8	Head-Tail-Middle	0.50	0.50
9	Head-Tail-Tail	0.83	0.17
10	Middle-Head-Head	0.13	0.88
11	Middle -Head-Middle	0.17	0.83
12	Middle -Head-Tail	0.17	0.83
13	Middle -Middle-Head	0.50	0.50
14	Middle -Middle-Middle	0.83	0.17
15	Middle -Middle-Tail	0.75	0.25
16	Middle -Tail-Head	0.50	0.50
17	Middle -Tail-Middle	0.50	0.50
18	Middle -Tail-Tail	0.50	0.50
19	Tail-Head-Head	0.50	0.50
20	Tail -Head-Middle	0.75	0.25
21	Tail -Head-Tail	0.17	0.83
22	Tail -Middle-Head	0.50	0.50
23	Tail -Middle-Middle	0.50	0.50
24	Tail -Middle-Tail	0.75	0.25
25	Tail -Tail-Head	0.13	0.88
26	Tail -Middle-Middle	0.50	0.50
27	Tail -Tail-Tail	0.50	0.50
	Average	0.45	0.55

The results showed no strong preference for one reliability performance measure over the other, though the farmers rated "Intra-seasonal Reliability" as most important overall.

4.4.6 Weights at level-1 of flexibility group

The weights of different indicators of flexibility group at level 1 are presented in Table 4.12.

Table 4.12. The weights of different performance measures of flexibility group at Level-1

Group No.	Location	Flexibility group	
		Flexibility in irrigation amount	Flexibility in irrigation frequency
1	Head-Head-Head	0.17	0.83
2	Head-Head-Middle	0.50	0.50
3	Head-Head-Tail	0.75	0.25
4	Head-Middle-Head	0.50	0.50
5	Head-Middle-Middle	0.25	0.75
6	Head-Middle-Tail	0.50	0.50
7	Head-Tail-Head	0.50	0.50
8	Head-Tail-Middle	0.50	0.50
9	Head-Tail-Tail	0.83	0.17
10	Middle-Head-Head	0.17	0.83
11	Middle -Head-Middle	0.13	0.88
12	Middle -Head-Tail	0.17	0.83
13	Middle -Middle-Head	0.50	0.50
14	Middle -Middle-Middle	0.88	0.13
15	Middle -Middle-Tail	0.83	0.17
16	Middle -Tail-Head	0.50	0.50
17	Middle -Tail-Middle	0.50	0.50
18	Middle -Tail-Tail	0.50	0.50
19	Tail-Head-Head	0.25	0.75
20	Tail -Head-Middle	0.50	0.50
21	Tail -Head-Tail	0.50	0.50
22	Tail -Middle-Head	0.50	0.50
23	Tail -Middle-Middle	0.50	0.50
24	Tail -Middle-Tail	0.50	0.50
25	Tail -Tail-Head	0.50	0.50
26	Tail -Middle-Middle	0.50	0.50
27	Tail -Tail-Tail	0.50	0.50
	Average	0.46	0.50

The results showed no strong preference for one flexibility performance measure over the other, though the farmers rated "Flexibility in irrigation frequency" as most important overall.

4.4.7 Weights at level-1 of sustainability group

The weights of different indicators of sustainability group at level 1 are presented in Table 4.13

Table 4.13. The weights of different performance measures of sustainability group at Level-1

Group No.	Location	Sustainability group				
		Crop occupancy sustainability	Irrigated area sustainability	Groundwater (rise) sustainability	Groundwater (fall) sustainability	Problematic area sustainability
1	Head-Head-Head	0.24	0.19	0.24	0.05	0.29
2	Head-Head-Middle	0.28	0.23	0.18	0.08	0.23
3	Head-Head-Tail	(0.18)*0.18*	(0.23)*0.23*	(0.23)*0.23*	(0.08)*0.08*	(0.28)*.28*
4	Head-Middle-Head	0.25	0.31	0.21	0.05	0.17
5	Head-Middle-Middle	0.15	0.25	0.32	0.05	0.23
6	Head-Middle-Tail	0.18	0.28	0.25	0.07	0.22
7	Head-Tail-Head	0.24	0.24	0.24	0.05	0.24
8	Head-Tail-Middle	0.18	0.18	0.36	0.05	0.23
9	Head-Tail-Tail	0.22	0.12	0.31	0.04	0.31
10	Middle-Head-Head	0.44	0.11	0.3	0.08	0.08
11	Middle -Head-Middle	0.32	0.13	0.1	0.09	0.36
12	Middle -Head-Tail	0.47	0.22	0.14	0.1	0.07
13	Middle -Middle-Head	0.32	0.23	0.17	0.05	0.23
14	Middle -Middle-Middle	0.4	0.36	0.1	0.07	0.08
15	Middle -Middle-Tail	0.45	0.17	0.12	0.09	0.17
16	Middle -Tail-Head	0.24	0.24	0.24	0.05	0.24
17	Middle -Tail-Middle	0.24	0.24	0.24	0.05	0.24
18	Middle -Tail-Tail	0.24	0.24	0.24	0.05	0.24
19	Tail-Head-Head	0.29	0.29	0.04	0.27	0.1
20	Tail -Head-Middle	0.23	0.38	0.04	0.3	0.05
21	Tail -Head-Tail	0.19	0.29	0.06	0.4	0.06
22	Tail -Middle-Head	0.25	0.29	0.05	0.32	0.1
23	Tail -Middle-Middle	0.31	0.31	0.07	0.25	0.07
24	Tail -Middle-Tail	0.11	0.18	0.05	0.55	0.1
25	Tail -Tail-Head	0.12	0.11	0.05	0.6	0.12
26	Tail -Middle-Middle	0.27	0.3	0.06	0.3	0.07
27	Tail -Tail-Tail	0.27	0.3	0.06	0.32	0.06
	Average	0.26	0.23	0.17	0.16	0.19

The results showed that the groups on the head and middle reaches of the main canal gave high rating to “Groundwater (rise) sustainability”, whereas groups on tail reaches of the main canal gave high rating to “Groundwater (fall) sustainability”.

It is seen from the Table 4.13 that inconsistent results were obtained for one location in first round. The sustainability at Level-1 was found to be inconsistent for Group 3 at Location Head-

Head-Tail. These farmers were contacted again. However for same location, inconsistent results were obtained in second round also.

Table 4.14. The weights of different performance measures of the Sustainability group at the head portion of a watercourse (tertiary level) for the head middle and tail reaches of the main canal.

Reach of main canal	Crop occupancy sustainability	Irrigated area sustainability	Groundwater (rise) sustainability	Groundwater (fall) sustainability	Problematic area sustainability
Head	0.24	0.19	0.24	0.05	0.29
Head	0.25	0.31	0.21	0.05	0.17
Head	0.24	0.24	0.24	0.05	0.24
Middle	0.44	0.11	0.30	0.08	0.08
Middle	0.32	0.23	0.17	0.05	0.23
Middle	0.24	0.24	0.24	0.05	0.24
Tail	0.29	0.29	0.04	0.27	0.10
Tail	0.25	0.29	0.05	0.32	0.10
Tail	0.12	0.11	0.05	0.60	0.12

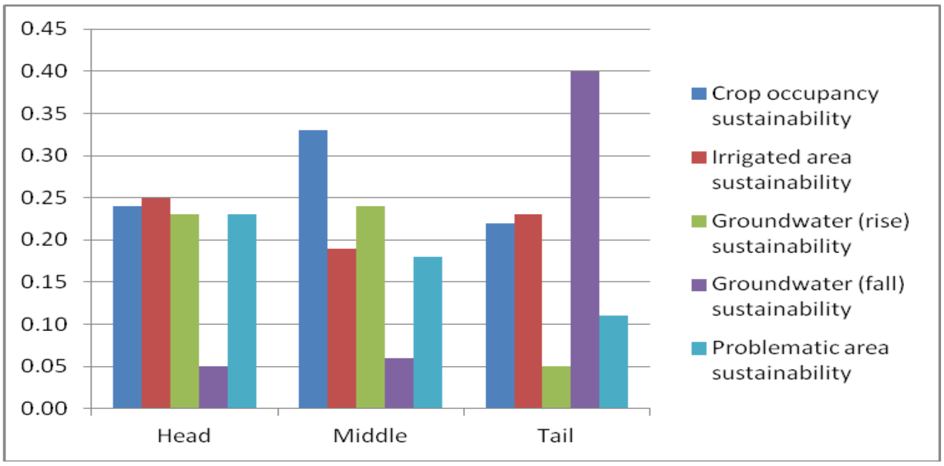


Figure 4.5: Variation of different performance measures of Sustainability group in Head, Middle and Tail reaches of Mula Right Bank Canal.

From Table 4.14 and Figure 4.5 it is revealed that for farmers at the head portion of a watercourse (tertiary level) for the head, middle and tail reaches of the main canal, the crop occupancy sustainability is more important compared to irrigated area sustainability. Farmers at Head portion of the main canal giving more importance to the ground water (rise) sustainability compared to irrigated area sustainability. On the other hand the Head portion farmers of the Tail reach of main canal giving more importance to irrigated area sustainability and ground water (fall) sustainability than other performance indicators. An example of the detailed results is presented in Appendix C1, for Group 1 (Head-Head-Head). This uses a format developed by Godfrey (2006).

5. RESULTS AND DISCUSSION (Based on AWAM Model) (II)

One of the objectives of the study is to find out the performance of irrigation water management in Mula irrigation schemes in terms of different performance measures (productivity, equity, adequacy and excess) for different irrigation strategies. . The other objective of the study is to find out the suitable optimal policy by including the tradeoff amongst different performance measures and stakeholders in allocation process. The importance of the different stakeholders for the performance measures in terms of the weights obtained by AHP analysis are presented in the previous chapter. .

As stated before, the AWAM model (Gorantiwar 1995 and Smout and Gorantiwar 2006) was used for finding out the performance measures. AWAM has the capability to consider the heterogeneity in the irrigation scheme in terms of soils, climate and characteristics of tertiary units; evaluate different irrigation strategies and obtain the optimum allocation plans for maximization of productivity, equity and adequacy. Productivity, equity and adequacy are influenced by the net benefits, crop production and water use efficiency in response to different irrigation strategies that are combinations of full irrigation to variable depth irrigation. One of the objectives of this study is to know the performance of the Mula irrigation scheme in terms of productivity, equity and adequacy and obtain the combined performance index considering the farmers preference to theses performance measures. Hence, in this chapter the strength of AWAM model to fulfill the objectives of the study is demonstrated in detail.

The information obtained is used specifically to fulfill the objectives no. 2. To study the performance of irrigation water management in irrigation schemes in terms of different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency), 3. To provide the guidelines for improving the performance of irrigation water management in irrigation schemes and by integration with AHP for no. 4. To test a technique for obtaining the suitable optimal policy based on the relative preferences of the farmers to different performance measures in allocation process to work out the final performance index. The results in respect of this analysis are presented in this chapter.

5.1 Performance measures

The performance measures viz. productivity, equity, adequacy and excess for following irrigation strategies were obtained with the help of AWAM model. The data for obtaining the values of the performance measures for Mula irrigation scheme are presented in Chapter 3. As stated in chapter 3, the performance parameters are obtained by formulating the irrigation strategies based on following considerations.

The performance results are obtained for different management scenarios (for example on the irrigation interval) and irrigation strategies (for example existing against the improved). These include:

5.1.1 Irrigation amount: The following options were considered**:**

1. Full Depth irrigation (FDI): The irrigations were applied to bring the root zone soil moisture to the FC.
2. Optimized Fixed depth irrigation (FxDI): The fixed depth of irrigation, which was same for all crops, soils and climate and over the irrigation season, was applied. The fixed depth was optimised in AWAM
3. Variable Depth Irrigation (VDI): The irrigations were applied in different optimum combinations of the depths between full depth irrigation and no irrigation.

5.1.2 Irrigation frequency: The following sets of irrigation interval were chosen.

1. 14 days 2. 21 days 3. 28 days 4. 35 days for both summer and winter season
2. 21 days in winter season and 14 days in summer season (21-14 days)
3. 28 days in winter season and 21 days in summer season (28-21 days)
4. 35 days in winter season and 28 days in summer season (35-28 days)

5.1.3 Water distribution: The following options were considered:

1. Free water distribution (FWD)(No Equity)
2. Equitable distribution of seasonal water allocation based on CCA of AU (EDSW)
   i. by considering conveyance and distribution efficiencies
   ii. by considering conveyance efficiency
   iii. without considering any efficiencies
3. Equitable distribution of intra-seasonal water based on CCA of AU (EDIW)
   i. by considering conveyance and distribution efficiencies

ii. by considering conveyance efficiency

iii. without considering any efficiencies

5.1.4 Cropping distribution: The following two options were considered.

1. Free cropping distribution (Fr-CD): No restrictions are put on the allocation of area or water or output to be obtained from the different crops. The model is therefore free to select any crops depending on which crops produce maximum total net benefits from the irrigation scheme.

2. Fixed cropping distribution (Fx-CD): Restricting the area under different crops according to particular requirement is referred to as the fixed cropping distribution. Based on the previous trend in this irrigation scheme, the fixed cropping distribution of (gram- 6%, Sorghum- 14%, Onion- 20%, Wheat-30%, Sunflower-5%, Groundnut-5%, Maize- 4%, maize-fodder- 6%, cabbage- 10%).

5.1.5 Different type of soils in the command area used for AWAM model:

Table 5.1 Different soils in the command area

Sr. No.	Name of Soil	Code
1	Silty	S001
2	Silt clay	S002
3	Clay	S003
4	Deep clay	S004

The input data files for AWAM were prepared for this purpose for all the irrigation strategies for total 43 outlets (2 branch canals, 8 distributaries, 7 minors and 26 direct outlets) (Appendix-B). The details are as described in Chapter 3 in section 3.2.3

These include:

- **wgen:** This is the input file for general data such as number of regions, soils and crops and their types
- **wregcl:** This is the in put file for the daily climatological data
- **wcrop:** This is the input file for the crop data such as planting and harvesting dates, depletion factor, crop coefficient, yield response factors, maximum yield, root zone characteristics, moisture extraction pattern etc.
- **wsoil:** This is the input file for soil data such as soil type, number of soil layers, depth, FC (FC) and wilting point (WP) for each soil layer, soil evaporation properties etc.

- **wcrso:** This is the input file for the data related to crop-soil combination such as irrigation method used, minimum and maximum depth of water that can be applied for the given crop-soil combination, different efficiencies such as application; and economic data such as cost of cultivation, cost of water, cost of application of water, price of produce and bi-produce.
- **wwater:** This is the input file for command area data such as number of units, culturable command area of each unit, soil type, outlet capacity, canal network and canal capacity, reservoir data such as maximum storage capacity, dead storage, reservoir storage-area-stage relationships, reservoir evaporation and irrigation strategy data.

5.1.6 Structure of the Results presented

In this chapter, results are presented sequentially in following manner. In section 5.2 the response of different irrigation strategies on productivity in terms of the yield and water use (Water Use Efficiency) for wheat grown on different Soils (Soil 001, 002, 003 and 004) is represented. In section 5.3 effects of different irrigation intervals (14 days, 21 days, 28 days and 35 days) on yield and water use of wheat grown on Soil 002 providing FDI is discussed. The section 5.4 discusses the response of different irrigation strategies for fixed cropping-Free water distribution (No equity) on yield and water use of wheat grown on Soil 002 with two different irrigation intervals i.e. 14 and 21 days. In the section 5.5 the effect of different depths of irrigation on yield and water use of wheat grown on Soil 002 with irrigation interval of 21 days is discussed. Here ten different depths of irrigation viz. 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm, 110 mm, 120 mm, 130 mm and 140 mm per irrigation are considered. The section 5.6 deals with the response of different crops in terms of yield and water use to three different irrigation strategies (FDI, FxDI and VDI) and two different irrigation intervals (14 days and 21 days). For that four crops viz. wheat, sunflower, gram and cabbage are considered to be grown on Soil 002.

5.2 Response of different irrigation strategies in different Soils

In this section the response of different irrigation strategies (Fixed, Full and Variable depth) to the water use and actual yield in different soils is discussed. Here a single crop i.e. wheat is considered to be grown on different soils as discussed in 5.1.5 (i.e. Soil001, Soil002, Soil003 and Soil004).

5.2.1 Wheat grown on soil 001

5.2.1.1 Fixed Depth Irrigation (FxDI)

The variation of soil moisture in the root zone of wheat when grown on Soil 001 for the fixed depth of irrigation of 70 mm (application depth of 52.5 mm i.e. considering the application efficiency (Ea) of 75%) per irrigation when irrigation interval is 21 days is shown in Figure 5.1. The depth of irrigation is the gross depth taking account of the application efficiency and the application depth is the net depth which can be stored in the root zone and be used by the crop for evapotranspiration. It is seen from the Figure 5.1 that this depth is sufficient to keep the Available Moisture Content (AMC) in the root zone above the Allowable Depletion Level (ADL) for the first 2 irrigations (day-1 and day-22 since planting) as the root zone depth is not fully developed. When the root zone is fully developed, the AMC starts dropping below the depletion level during the later part of irrigation interval up to third irrigation (day-43 since planting). However at the fourth irrigation (day-64 since planting) the soil moisture is above the depletion level though the root zone is fully developed. However as it is the latter part of the crop development stage i.e. the harvesting stage there may be less crop evapotranspiration as compared the earlier crop development stages. Also the stage wise yield response factors for wheat after duration of 111 days is 0.00. The ADL line in Figure 5.1 indicates that the fixed depth of application of 52.5 mm is not sufficient to keep the soil moisture above depletion level throughout the crop growth period. This is reflected in the yield as shown in Table 5.2. The actual crop evapotranspiration (Crop ET(actual)) for different crop growth stages were derived as described in section 3.5.2.2. Further the actual yield were simulated from the Crop ET(actual) using SWAB sub-model of AWAM (section 3.5.2.2).

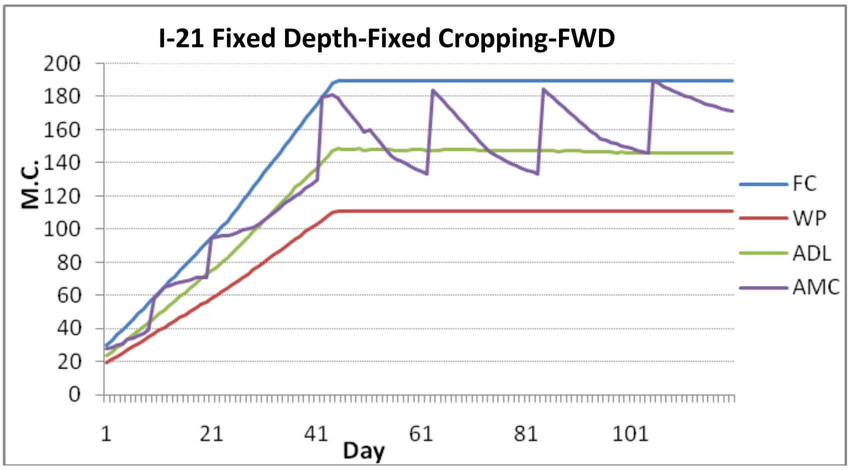


Figure 5.1 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 52.5 mm on Soil 001

Table 5.2 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 52.5 mm irrigation for irrigation interval of 21 days in Soil 001

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	18.53		
2	11-25	0.2	41.31	39.44		
3	26-65	0.75	140.27	104.77		
4	66-80	0.75	49.11	38.41		
5	81-110	0.5	68.32	51.84		
6	111-120	0	9.9	9.9		
			330.52	264.56	3500	1810

As seen from Table 5.2, the fixed depth of application of 52.5 mm per irrigation caused the stress during third and fourth growth stages and resulted in yield reduction of about 48.28 % (from maximum yield of 3500 kg/ha to 1810 kg/ha).

When the depth of application is increased from 52.5 mm to 60 mm, the AMC in the root zone of wheat is above the ADL for most of the growth period, but falls below ADL for a few days at the end of third, fourth and fifth irrigations as shown in Figure 5.2. Increasing the depth from 52.5 mm to 60.00 mm could not improve the reduction in water stress condition and hence only about 4% increase in yield over the previous condition as shown in Table 5.3. The actual yield of 1810 kg/ha at application depth of 52.5 mm per irrigation is increased to 1884 kg/ha at application depth of 60 mm per irrigation. The increase in yield of 4.0% caused at the expense of increase in irrigation depth of 10 to 30.0%.

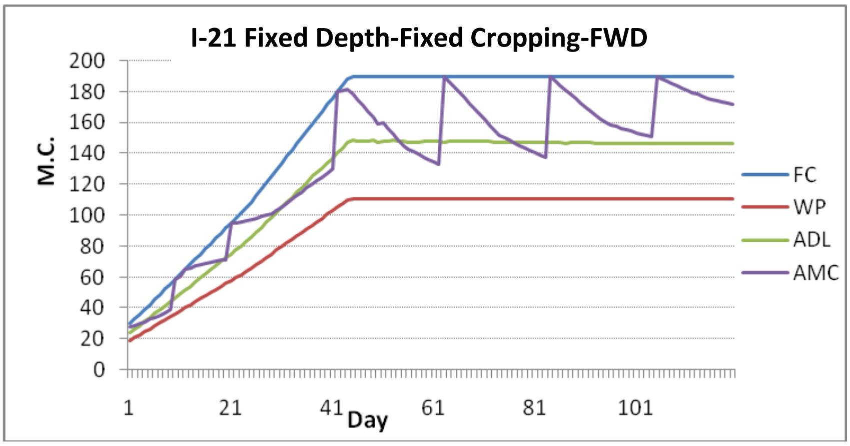


Figure 5.2 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 60 mm in Soil 001

Table 5.3 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 60 mm per irrigation for irrigation interval of 21 days in Soil 001

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	18.53		
2	11-25	0.2	41.31	39.44		
3	26-65	0.75	140.27	104.77		
4	66-80	0.75	49.11	39.55		
5	81-110	0.5	68.32	52.37		
6	111-120	0	9.9	9.9		
			330.52	262.89	3500	1884

5.2.1.2 Variable depth irrigation (VDI)

In this section two different VDI strategies giving maximum water use are considered out of several VDIs with different optimum combinations of the depths between full depth irrigation and no irrigation. The variation of soil moisture in the root zone of wheat when grown on Soil 001 for the variable irrigation depth strategy of applying FDI for first four irrigation and providing 30 % stress for fifth irrigation and no irrigation for last irrigation (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7 and dr6=0.0) per irrigation when irrigation interval is 21 days is shown in Figure 5.3.

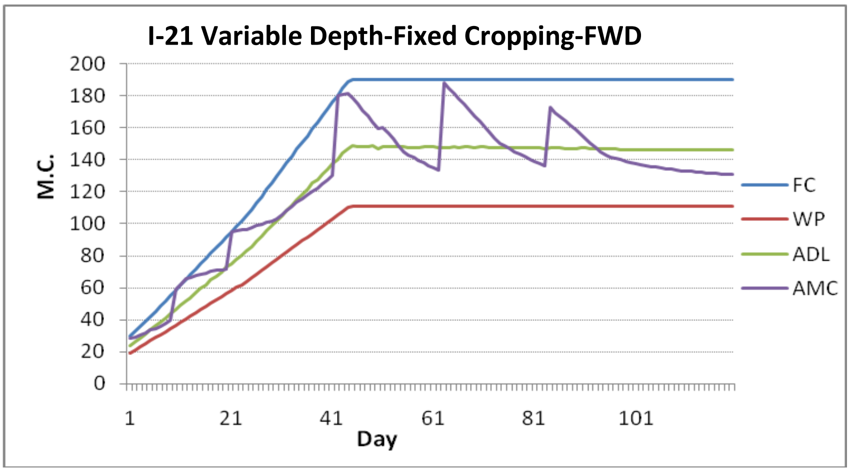


Figure 5.3 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.0) for Soil 001

It is observed from the Figure 5.3 that for first four irrigations though the irrigations were provided to bring the soil moisture to the FC, however at the end of second, third and fourth irrigations, the AMC dropped below the ADL. This has caused the stress. This indicates that the irrigation interval of 21 days is more than the one which is required not to cause any stress when water is applied to bring the soil moisture to the FC for wheat on soil 001. In this strategy 30% water stress was provided for fifth irrigation and no irrigation water was supplied for last irrigation. Therefore the AMC dropped below the ADL after half the irrigation interval. This has resulted in yield reduction of 53 % (the estimated yield is 1645 kg/ha as shown in Table 5.4). In this strategy, the total depth of irrigation is 300.0 mm and depth of application is 225.00 mm.

Table 5.4 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.0) for irrigation interval of 21 days in soil 001

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	18.53		
2	11-25	0.2	41.31	39.44		
3	26-65	0.75	140.27	104.77		
4	66-80	0.75	49.11	39.25		
5	81-110	0.5	68.32	43.64		
6	111-120	0	9.9	2.23		
			330.52	247.86	3500	1645

The variation of soil moisture in the root zone of wheat when grown on Soil 001 for the optimized variable irrigation depth strategy of applying FDI for all irrigations and no irrigation for last irrigation (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7 and dr6=0.7) per irrigation when irrigation interval is 21 days is shown in Figure 5.4.

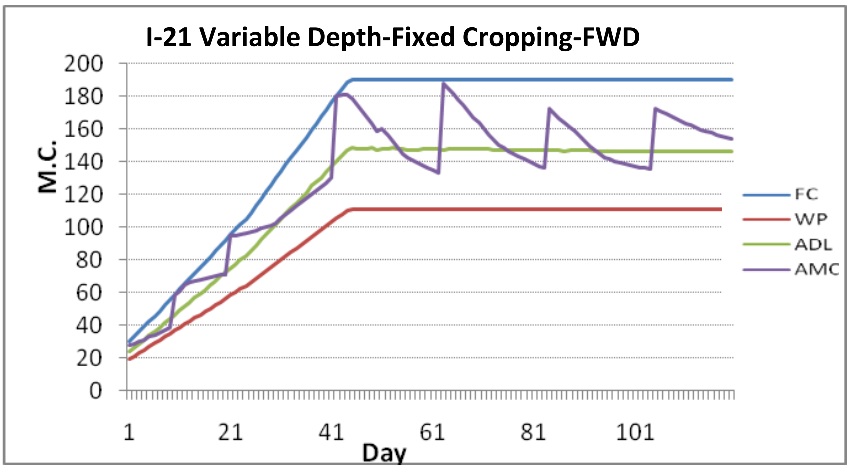


Figure 5.4 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.7) for Soil 001

It is observed from the Figure 5.4 that for first four irrigations though the irrigations were provided to bring the soil moisture to the FC, at the end of second, and all subsequent irrigations, the AMC dropped below the ADL. This has caused little water stress. This indicates that the irrigation interval of 21 days is slightly more than the one which is required not to cause any stress when water is applied to bring the soil moisture to the FC for wheat on soil 001. This has resulted in yield reduction of 48.3% (the estimated yield is 1810 kg/ha as shown in Table 5.5). In this strategy depth of irrigation is 350.0 mm and depth of application is 262.50 mm.

The VDI strategies stated above differ in the fact that for fifth and sixth irrigation the irrigation depth is 70% of the FDI. This has resulted in increase in yield of 9.00 % but at the cost of providing 14.00% more water.

Table 5.5 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.7) for irrigation interval of 21 days in Soil 001

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	18.53		
2	11-25	0.2	41.31	39.44		
3	26-65	0.75	140.27	104.77		
4	66-80	0.75	49.11	39.25		
5	81-110	0.5	68.32	50.05		
6	111-120	0	9.9	9.9		
			330.52	261.95	3500	1810

5.2.1.3 Full depth irrigation (FDI)

The variation of soil moisture in the root zone of wheat when grown on Soil 001 for the FDI of when irrigation interval is 21 days is shown in Figure 5.5.

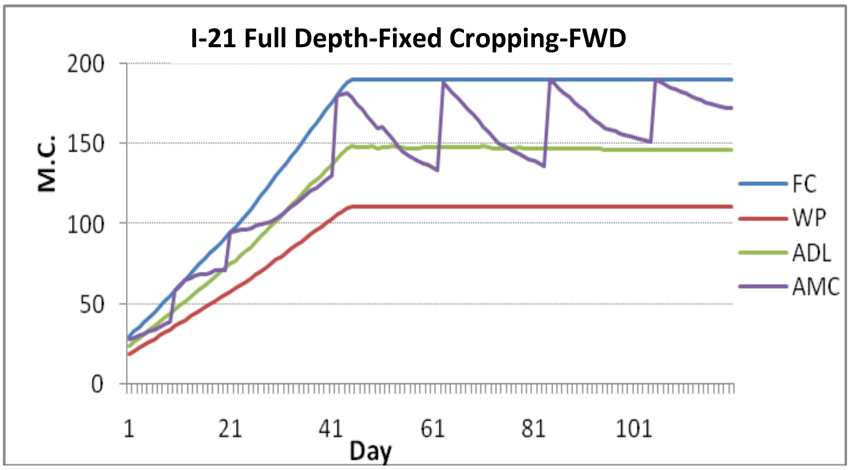


Figure 5.5 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and irrigation is FDI for Soil 001

It is seen from the Figure 5.5 that AMC is within allowable limit for most of the crop growth period but it dropped below the ADL at the end of second, third and fourth irrigations. This indicates that the irrigation interval for maximum yield should have been less than 21 days during the mid growth period of wheat. Therefore the maximum yield could not be obtained. The estimated yield with this strategy is 1864 kg/ha (Table 5.6) with the total irrigation depth of 380.00 mm and application depth of 285.00 mm.

Table 5.6 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 21 days and irrigation is FDI for Soil 001.

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	18.53		
2	11-25	0.2	41.31	39.44		
3	26-65	0.75	140.27	104.77		
4	66-80	0.75	49.11	39.25		
5	81-110	0.5	68.32	52.2		
6	111-120	0	9.9	9.9		
			330.52	264.09	3500	1864

5.2.1.4 Comparison of different irrigation strategies for wheat grown on Soil 001 for irrigation interval of 21 days:

The comparison of application depth, irrigation depth and actual yield for the selected strategies of variable depth and FxDI and FDI for wheat grown on Soil 001 for irrigation interval of 21 days are presented in Table 5.7

Fix depth irrigation that provides irrigation less moisture stress and hence it results in estimation of more crop yield. Accordingly this strategy has provided maximum actual yield amongst all the tested irrigation strategies. However the actual estimated yield by this strategy is less than the maximum yield by 46.16%. This indicates that the irrigation interval of 21 days exceeds the threshold for the water stress. The FDI strategy with a total irrigation depth of 380 mm also gives similar estimated wheat yield however it requires 20.83% less water. The FxDI strategy offers more convenience in management as it avoids the headache of rigorous calculations (Climetological parameters, soil parameters not being considered to determine the crop water requirement) while applying irrigation. One can simply apply same fixed depth of irrigation i.e. same amount of water per irrigation.

VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7 and dr6=0.7) estimated the yields near to those estimated by FxDI and FDI; but required 27.08 and 7.89 % less water compared to fixed and FDI strategy. The application of water according to the variable irrigation depth strategy is operationally and management point of view is not convenient but results in more irrigation water use efficiency. Thus as is seen for wheat grown on soil 001, the VDI strategy may provide better performance of irrigation scheme in terms of productivity (in terms of the actual yield and the irrigation water use efficiency)(Table 5.7).

Table 5.7 Comparison of different irrigation strategies for wheat grown on Soil 001 for irrigation interval of 21 days

Figure No.	Irrigation Strategy	Actual yield (Kg/ha	Application depth (mm)	Irrigation depth (mm)	Irrigation Water Use Efficiency (Kg/ha-mm)
5.1	Fixed Depth Irrigation (70 mm per irrigation)	1810	315	420	4.31
5.2	Fixed Depth Irrigation (80 mm per irrigation)	1884	360	480	3.93

5.3	Variable Depth Irrigation (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0)	1864	225	300	6.21
5.4	Variable Depth Irrigation (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.7)	1810	262.5	350	5.17
5.5	Full Depth Irrigation	1864	285	380	4.91

5.2.2 Wheat grown on (Soil 002)

5.2.2.1 Fixed Depth Irrigation

The variation of soil moisture in the root zone of wheat grown on Soil 002 for the fixed depth of irrigation of 70 mm (application depth of 52.5 mm) at irrigation interval of 21 days is shown in Figure 5.6.

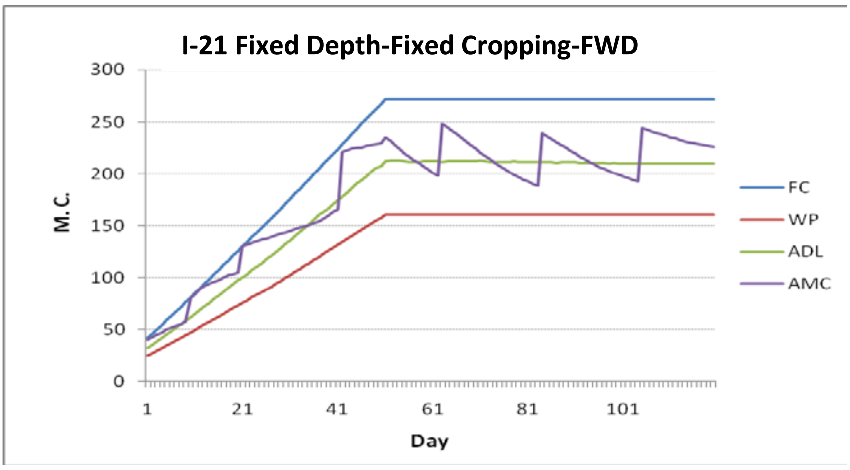


Figure 5.6 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 52.5 mm in Soil 002

It is seen from the Figure 5.6 that this depth is sufficient to keep the soil moisture in the root zone above the ADL for only first irrigation as the root zone depth is not fully developed. When the root zone is fully developed, the AMC starts dropping below the depletion level during the later part of irrigation for each irrigation interval. This indicates that the fixed depth of application is 52.5 mm is not sufficient to keep the soil moisture above depletion level throughout the crop growth period. This is reflected in the yield as shown in Table 5.8.

As seen from Figure 5.6 the fixed depth of application of 52.5 mm per irrigation caused the stress during third and fourth growth stages and the AMC is below the ADL after the first irrigation for all irrigations. This resulted in yield reduction of 16 % (from maximum yield of 3500 kg/ha to 2937 kg/ha).

Table 5.8 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 52.5 mm per irrigation for irrigation interval of 21 days in Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	128.17		
4	66-80	0.75	49.11	45.82		
5	81-110	0.5	68.32	62.05		
6	111-120	0	9.9	9.9		
			330.52	308.76	3500	2937

When the depth of application is increased from 52.5 mm to 60 mm, the soil moisture in the root zone of wheat remains within allowable limit during the first irrigation only and during rest of the irrigations the AMC remains below the ADL as shown in Figure 5.7.

However, increasing the application depth from 52.5 mm to 60.00 mm caused the reduction in water stress and hence though the AMC is below the ADL as shown in Figure 5.7, then also the increased depth of irrigation results in increase in yield as shown in Table 5.9. The actual yield of 2937 kg/ha at application depth of 52.5 mm per irrigation is increased to 3229 kg/ha at application depth of 60 mm per irrigation (Table 5.9). The increase in yield of 9.0% caused at the expense of increase in irrigation depth of 12.5 %.

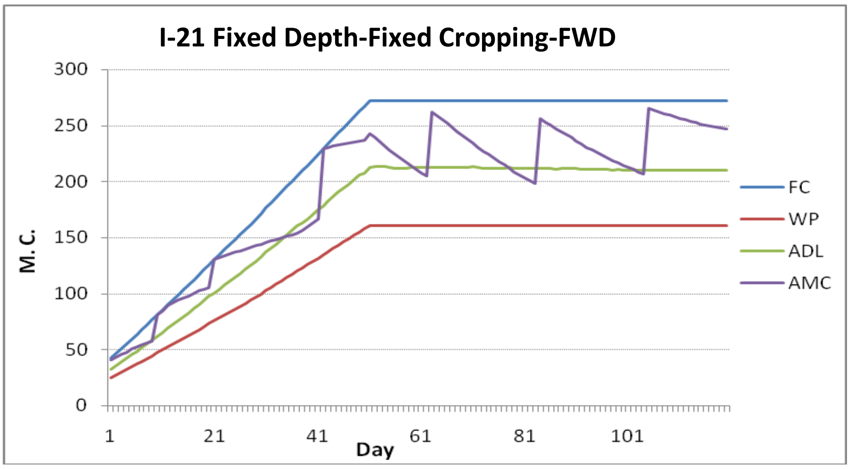


Figure 5.7 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 60 mm in Soil 002

Table 5.9 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 60 mm per irrigation for irrigation interval of 21 days in Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	129.59		
4	66-80	0.75	49.11	48.62		
5	81-110	0.5	68.32	66.57		
6	111-120	0	9.9	9.9		
			330.52	317.51	3500	3229

5.2.2.2 Variable depth irrigation

The variation of soil moisture in the root zone of wheat when grown on silty clay soil (Soil 002) for the optimized variable irrigation depth strategy - VDI (dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.5, dr6=0.0) with irrigation interval is 21 days is shown in Figure 5.8.

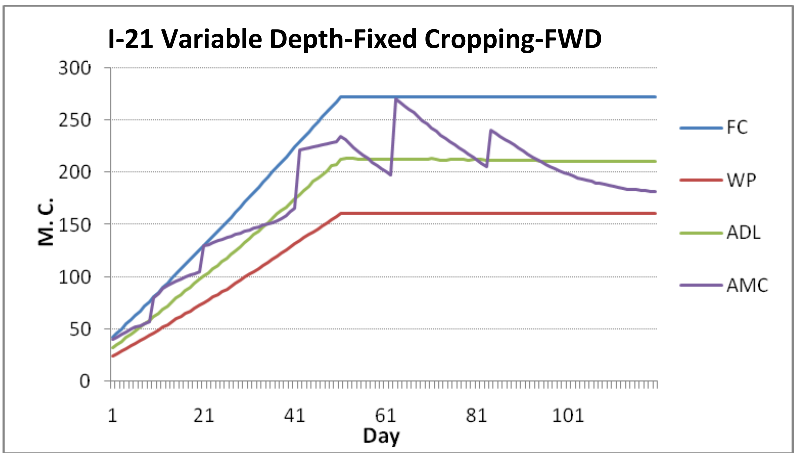


Figure 5.8 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.5, dr6=0.0) for Soil 002

It is observed from the Fig.5.8 that for first four irrigations though the irrigations were provided to bring the soil moisture to the FC, at the end of first, second and fourth irrigations, the AMC dropped below the ADL. This has caused the stress. This indicates that the irrigation interval of 21 days is more than the one which is required not to cause any stress when water is applied to bring the soil moisture to the FC for wheat on Soil 002. In this strategy AMC dropped below the allowable depletion after more than half the irrigation interval. This has resulted in yield reduction of 11% (the estimated yield is 3117 kg/ha as shown in Table 5.10). In this strategy depth of irrigation is 350 mm and depth of application is 262.50 mm.

Table 5.10 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.5, dr6=0.0) for irrigation interval of 21 days in Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	128.17		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	62.21		
6	111-120	0	9.9	5.14		
			330.52	307.46	3500	3117

The variation of soil moisture in the root zone of wheat when grown on Soil 002 for the optimized variable irrigation depth strategy – VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0 and dr6=0.0) when irrigation interval is 21 days is shown in Figure 5.9.

It is observed from the figure that for first four irrigations though the irrigations were provided to bring the soil moisture to the FC, at the end of second, and all subsequent irrigations, the

AMC dropped below the allowable depletion. This has caused little water stress. This indicates that the irrigation interval of 21 days is slightly more than the one which is required not to cause any stress when water is applied to bring the soil moisture to the FC for wheat on Soil 002. This has resulted in yield reduction of 6% (the estimated yield is 3283 kg/ha as shown in Table 5.11). In this strategy depth of irrigation is 395 mm and depth of application is 296.25 mm.

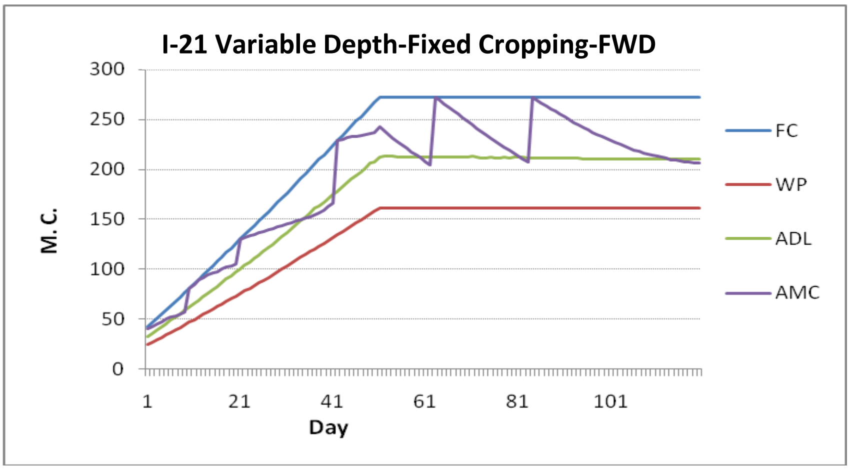


Figure 5.9 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0.0) for Soil 002

Table 5.11 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0.0) for irrigation interval of 21 days in Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	129.59		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	67.66		
6	111-120	0	9.9	7.23		
			330.52	316.41	3500	3283

The VDI strategies stated above differ in the fact that for third and fifth irrigation, the irrigation depth is 90% and 50% of the FDI respectively in first case and in second case it is FDI. This has resulted in increase in yield of 5.00 % but at the cost of providing 11.00% more water.

5.2.2.3 Full depth irrigation

The variation of soil moisture in the root zone of wheat when grown on Soil 002 for the FDI of when irrigation interval is 21 days is shown in Figure 5.10.

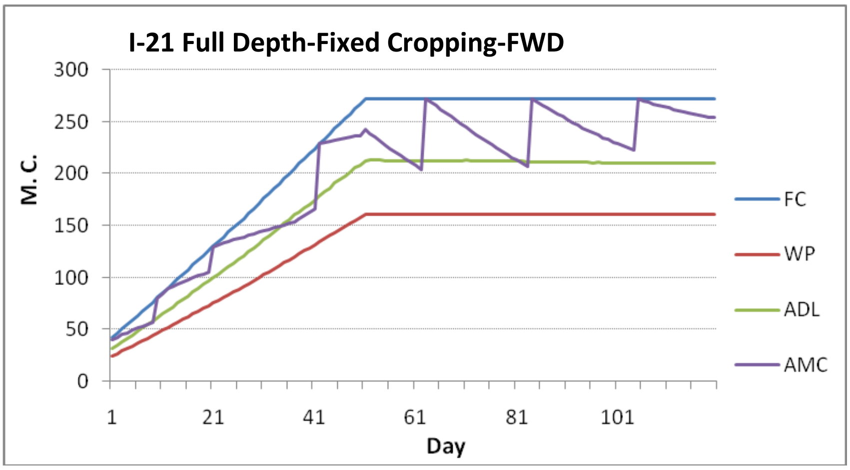


Figure 5.10 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and irrigation is FDI for Soil 002

It is seen from the figure that the moisture content dropped below the allowable moisture level at the end of second, third and fourth irrigations and for rest of the irrigation period the AMC is within allowable limit. This indicates that the irrigation should have been less than 21 days during the mid growth period of wheat. Therefore the maximum yield could not be obtained. The estimated yield with this strategy is 3292 kg/ha (Table 5.12) with the irrigation depth of 465 mm and application depth of 348.75 mm.

Table 5.12 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 21 days and irrigation is FDI for Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	129.59		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.02		
6	111-120	0	9.9	9.9		
			330.52	319.45	3500	3292

5.2.2.4 Comparison of different irrigation strategies for wheat grown on Soil 002 for irrigation interval of 21 days:

The comparison of application depth, irrigation depth and actual yield for the selected strategies of VDI, FxDI and FDI for wheat grown on Soil 002 for irrigation interval of 21 days are presented in Table 5.13.

Table 5.13 Comparison of different irrigation strategies for wheat grown on Soil 002 for irrigation interval of 21 days

Figure No.	Irrigation Strategy	Actual yield (Kg/ha)	Application depth (mm)	Irrigation depth (mm)	Irrigation Water Use Efficiency (Kg/ha-mm)
5.6	Fixed Depth Irrigation (70 mm per irrigation)	1810	315	420	4.31
5.7	Fixed Depth Irrigation (80 mm per irrigation)	3229	360	480	6.73
5.8	Variable Depth Irrigation (dr1=1.0, dr2=1, dr3=0.9, dr4=1.0, dr5=0.5, dr6=0)	3117	262.5	350	8.91
5.9	Variable Depth Irrigation (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0)	3283	296.25	395	8.31
5.10	Full Depth Irrigation	3292	348.75	465	7.08

FDI that provides irrigation to bring the soil to FC every irrigation; should cause the minimum stress and hence it results in estimation of more crop yield. Accordingly this strategy has provided maximum actual yield amongst all the tested irrigation strategies. However the actual estimated yield by this strategy is less than the maximum yield by 5%. This indicates that the irrigation interval of 21 days is more than required not to cause any stress. The VDI strategy (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0) with 395 mm depth of irrigation estimated the wheat yield 3283.1Kg/ha which is close to that obtained in FDI with saving of 15% water. In FxDI strategy (480 mm irrigation depth) the estimated yield is 3229 Kg/ha which is about 2% and 1.6% less than FDI and VDI strategy (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0) respectively. The FxDI strategy (480 mm irrigation depth) uses about 3 % and 21 % more water as that applied in FDI and VDI strategy (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0) respectively. However, the FxDI strategy is convenient to manage in the field.

The application of water according to the variable irrigation depth strategy is operationally and management point of view is not convenient but results in more irrigation water use efficiency. Thus as it is seen for wheat grown on Soil 002, the variable irrigation depth strategy may provide better performance of irrigation scheme in terms of productivity.

5.2.3 Wheat grown on Soil 003

5.2.3.1 Fixed Depth Irrigation

The variation of soil moisture in the root zone of wheat when grown on Soil 003 for the fixed depth of application of 45 mm (irrigation depth of 60 mm) per irrigation, when irrigation interval is 21 days is shown in Figure 5.11.

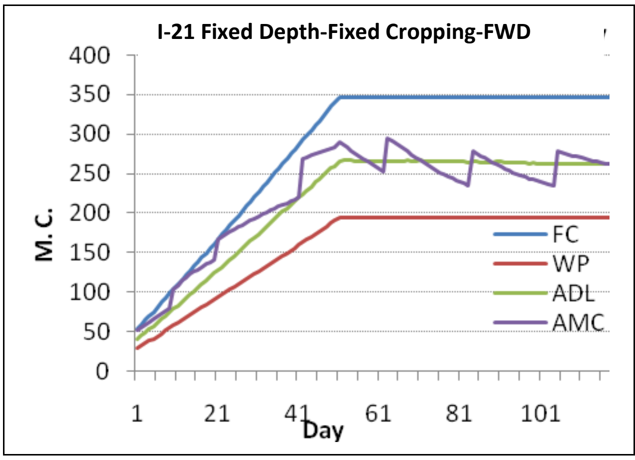


Figure 5.11 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 45 mm in Soil 003 (Di=60 mm, Da=45 mm)

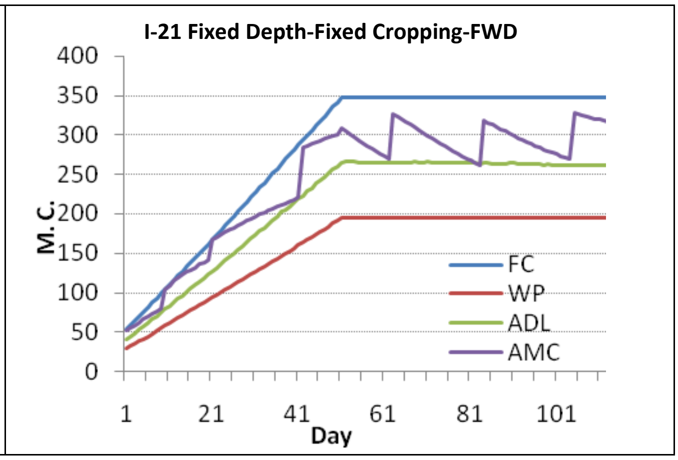


Figure 5.12 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 60 mm in Soil 003 ((Di=80 mm, Da=60 mm)

It is seen from the Figure 5.11 that this depth is sufficient to keep the soil moisture in the root zone above the depletion level for the first two irrigations as the root zone depth is not fully developed. When the root zone is fully developed, the moisture contents starts dropping below the depletion level during the later part of irrigation interval up to last irrigation. This indicates that the fixed depth of irrigation of 60 mm is not sufficient to keep the soil moisture above depletion level for most of the crop growth period. This is reflected in the yield as shown in Table 5.14.

As seen from Table 5.14, the fixed depth of application of 45 mm per irrigation caused the stress third irrigation onwards and resulted in yield reduction of about 13.14 % (from maximum yield of 3500 kg/ha to 3040 kg/ha).

Table 5.14 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 45 mm per irrigation for irrigation interval of 21 days in Soil 003

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	138.89		
4	66-80	0.75	49.11	45.18		
5	81-110	0.5	68.32	59.57		
6	111-120	0	9.9	9.89		
			330.52	316.45	3500	3040

Table 5.15 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 60 mm per irrigation for irrigation interval of 21 days in Soil 003

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.11		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.19		
6	111-120	0	9.9	9.9		
			330.52	330.23	3500	3494

When the depth of application is increased from 45 mm to 60 mm; the soil moisture in the root zone of wheat remains within allowable limit for entire growth period of wheat as shown in Figure 5.12. Increasing application depth from 45 mm to 60 mm, results in maintaining the AMC above ADL throughout the crop growth period. This situation helps in attaining actual yield of 3494 Kg/ha which is 99.8 % of the maximum yield (3500 Kg/ha.) as shown in Table 5.15. The actual yield of 3040 kg/ha at application depth of 45 mm per irrigation is increased to 3494 kg/ha at application depth of 60 mm per irrigation. The increase in yield of about 15 % caused at the expense of increase in irrigation depth of 10 to 33.33 %.

5.2.3.2 Variable depth irrigation

The variation of soil moisture in the root zone of wheat when grown on Soil 003 for the optimized variable irrigation depth strategy – VDI (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) when irrigation interval is 21 days is shown in Figure 5.13.

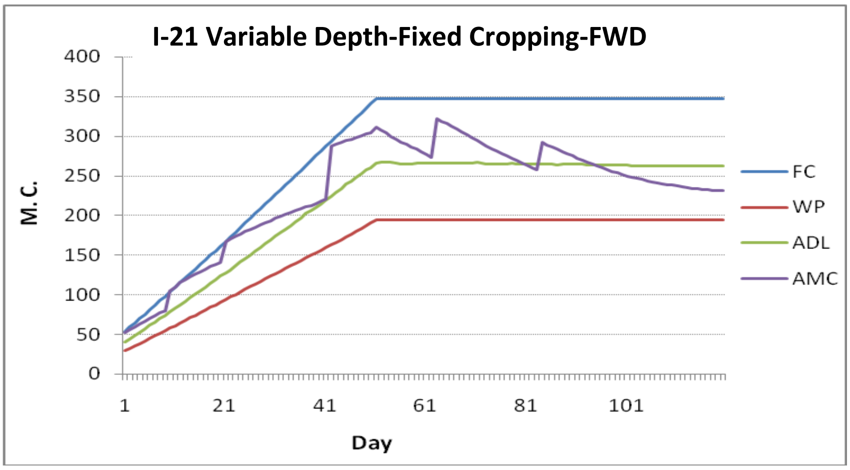


Figure 5.13 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) for Soil 003

Table 5.16 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) for irrigation interval of 21 days in Soil 003

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.11		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	63.46		
6	111-120	0	9.9	6.6		
			330.52	322.19	3500	3372

It is observed from the Figure 5.13 that during first, second and third irrigation the allowable moisture content in the root zone is above the ADL and after fourth irrigation it is below the allowable depletion level. This situation results the actual yield of 3372 Kg/ha which is 96.35 % of the maximum yield as shown in Table 5.16. In this strategy depth of irrigation is 370.0 mm and depth of application is 277.5 mm.

The variation of soil moisture in the root zone of wheat when grown on Soil 003 for the optimized variable irrigation depth strategy – VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) when irrigation interval is 21 days is shown in Figure 5.14.

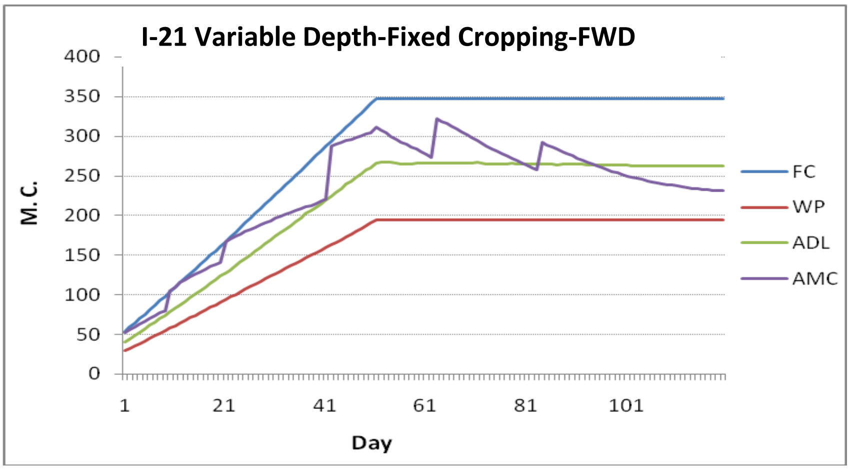


Figure 5.14 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) for Soil 003

It is observed from the Figure 5.14 that during first, second and third irrigation the allowable moisture content in the root zone is above the ADL and after fourth irrigation it is below the allowable depletion level. This situation results the actual yield of 3475 Kg/ha which is 99.29 % of the maximum yield as shown in Table 5.17. Therefore though AMC is below ADL from fourth irrigation onward then also this strategy attains almost maximum yield as the yield response factor is less responsive in that particular crop growth stage. In this strategy depth of irrigation is 395 mm and depth of application is 296.25 mm.

The VDI strategies stated above differ in the fact that for third, fourth and fifth irrigation the irrigation depth is 90%, 70% and 40% of the FDI respectively in first strategy(dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) and later strategy(dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) has 100%, 90% and 50% of FDI for respective irrigations. The later strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) resulted in increase in yield of 3.00 % by providing 6.7% more water.

Table 5.17 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) for irrigation interval of 21 days in Soil 003

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.11		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	67.47		
6	111-120	0	9.9	8.05		
			330.52	327.65	3500	3475

5.2.3.3 Full depth irrigation

The variation of soil moisture content in the root zone of wheat when grown on soil 003 for the FDI, when irrigation interval is 21 days is shown in Figure 5.15.

It is seen from the Figure 5.15 that the AMC is above ADL for entire crop growth period and for all growth stages. Therefore the actual yield of 3497 Kg/ha is obtained which is almost equal to the maximum yield as shown in Table 5.18. In this strategy the irrigation depth is 515 mm and application depth is 386.25 mm.

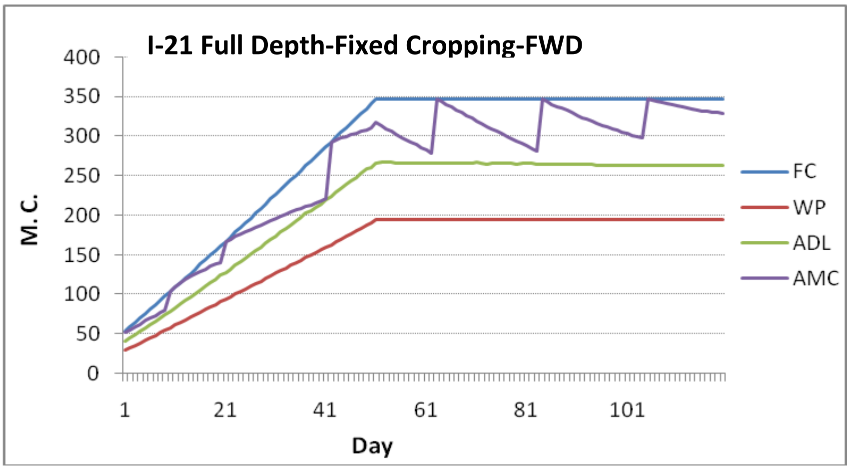


Figure 5.15 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and irrigation is FDI for Soil 003

Table 5.18 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 21 days and irrigation is FDI for Soil 003

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.11		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.32		
6	111-120	0	9.9	9.9		
			330.52	330.35	3500	3497

5.2.3.4 Comparison of different irrigation strategies for wheat grown on Soil 003 for irrigation interval of 21 days:

The comparison of application depth, irrigation depth and actual yield for the selected strategies of variable depth, FxDI and FDI for wheat grown on soil 003 for irrigation interval of 21 days are presented in Table 5.19.

Table 5.19 Comparison of different irrigation strategies for wheat grown on Soil 003 for irrigation interval of 21 days

Figure No.	Irrigation Strategy	Actual yield (Kg/ha)	Application depth (mm)	Irrigation depth (mm)	Irrigation Water Use Efficiency (Kg/ha-mm)
5.11	Fixed Depth Irrigation (60 mm per irrigation)	3040	270	360	8.44
5.12	Fixed Depth Irrigation (80 mm per irrigation)	3494	360	480	7.28
5.13	Variable Depth Irrigation (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0)	3372	277.5	370	9.11
5.14	Variable Depth Irrigation (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0)	3475	296.25	395.00	8.80
5.16	Full Depth Irrigation	3497	386.25	515	6.79

The maximum actual yield is obtained in FDI strategy i.e. 3497 Kg/ha with application depth of 386.25 mm (irrigation depth 515 mm). In this strategy the actual yield is almost equal to the maximum yield (3500 Kg/ha). In the FxDI strategy the actual yield obtained is 3494 Kg/ha with application depth of 360 mm (irrigation depth 480 mm) which is also almost equal to the maximum yield. But in FxDI strategy 6.7% water is saved.

VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) estimated the yield 3475 Kg/ha which is near to those estimated by fix(480 mm) and FDI(515mm); but required 17.70 and 23.30 % less water compared to fixed and FDI strategy respectively. The application of water according to the variable irrigation depth strategy is operationally and management point of view is not convenient but results in more irrigation water use efficiency. Thus as is seen for wheat grown on soil 003, the variable irrigation depth strategy may provide better performance of irrigation scheme in terms of productivity.

5.2.4 Wheat grown on Soil 004

5.2.4.1 Fixed Depth Irrigation

The variation of soil moisture in the root zone of wheat when grown on Soil 004 for the fixed depth of application of 45 mm (irrigation depth of 60 mm) per irrigation, when irrigation interval is 21 days is shown in Figure 5.16.

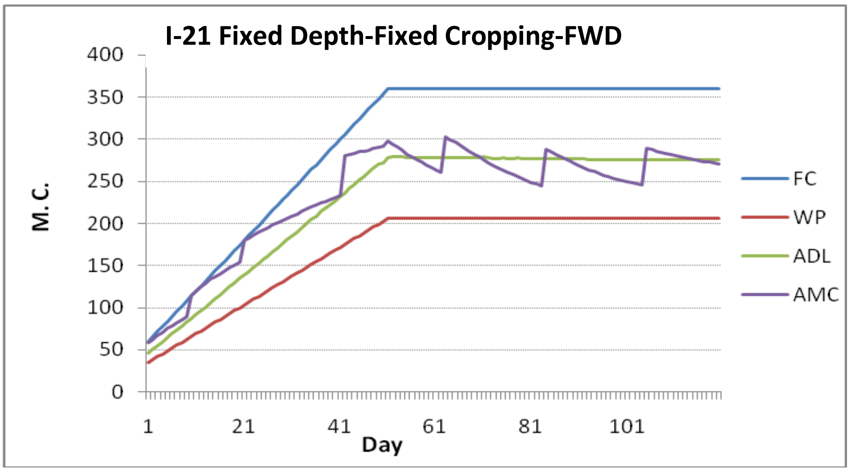


Figure 5.16 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 45 mm in Soil 004

It is seen from the Figure 5.16 that this depth is sufficient to keep the soil moisture in the root zone above the depletion level for the first two irrigations as the root zone depth is not fully developed. In case of subsequent irrigations, when the root zone is fully developed, the AMCs starts dropping below the ADL up to last irrigation. This indicates that the fixed depth of irrigation of 60 mm is not sufficient to keep the soil moisture above depletion level for most of the crop growth period. This is reflected in the yield as shown in Table 5.20.

As seen from Table 5.20, the fixed depth of application of 45 mm per irrigation caused the stress third irrigation onwards and resulted in yield reduction of about 16 % (from maximum yield of 3500 kg/ha to 2942 kg/ha).

Table 5.20 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 45 mm per irrigation for irrigation interval of 21 days in Soil 004

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	138.25		
4	66-80	0.75	49.11	44.07		
5	81-110	0.5	68.32	58.54		
6	111-120	0	9.9	9.84		
			330.52	313.6	3500	2942

When the depth of application is increased from 45 mm to 60 mm, the soil moisture in the root zone of wheat remains within allowable limit for entire growth period of wheat as shown in Figure 5.17.

Increasing application depth from 45 mm to 60 mm, results in maintaining the AMC above ADL throughout the crop growth period. This situation helps in attaining actual yield of 3498 Kg/ha which almost equal to of the maximum yield (3500 Kg/ha.) as shown in Table 5.21. The actual yield of 2942 kg/ha at application depth of 45 mm per irrigation is increased to 3498 kg/ha at application depth of 60 mm per irrigation. The increase in yield of about 19 % caused at the expense of increase in irrigation depth of 10 to 33.33 %.

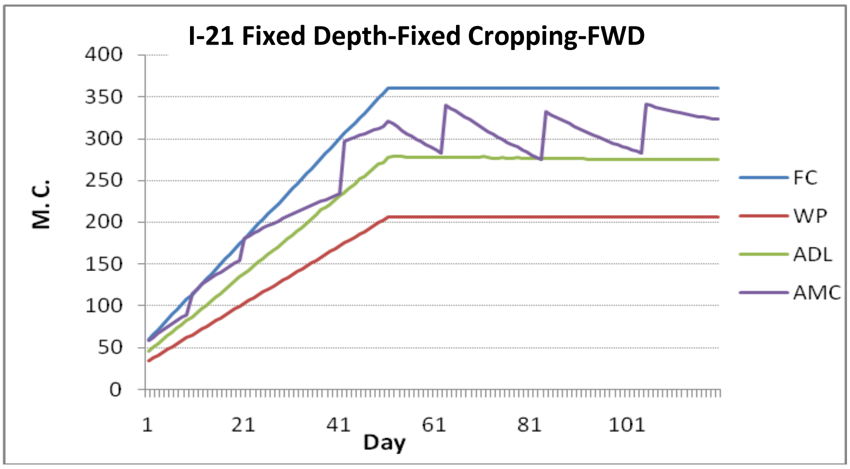


Figure 5.17 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and depth of application is 60 mm in Soil 004

Table 5.21 Yield of wheat as influenced by the irrigation strategy of fixed depth of application 60 mm per irrigation for irrigation interval of 21 days in Soil 004

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.27		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.25		
6	111-120	0	9.9	9.9		
			330.52	330.44	3500	3498

5.2.4.2 Variable depth irrigation

The variation of soil moisture in the root zone of wheat when grown on Soil 004 for the optimized variable irrigation depth strategy – VDI (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) per irrigation when irrigation interval is 21 days is shown in Figure 5.18.

It is observed from the Figure 5.18 that during first, second and third irrigation the AMC in the root zone is above the ADL and after fourth irrigation it is below the ADL. This situation results the actual yield of 3384 Kg/ha which is about 97 % of the maximum yield as shown in Table 5.22. In this strategy depth of irrigation is 375 mm and depth of application is 281.25 mm.

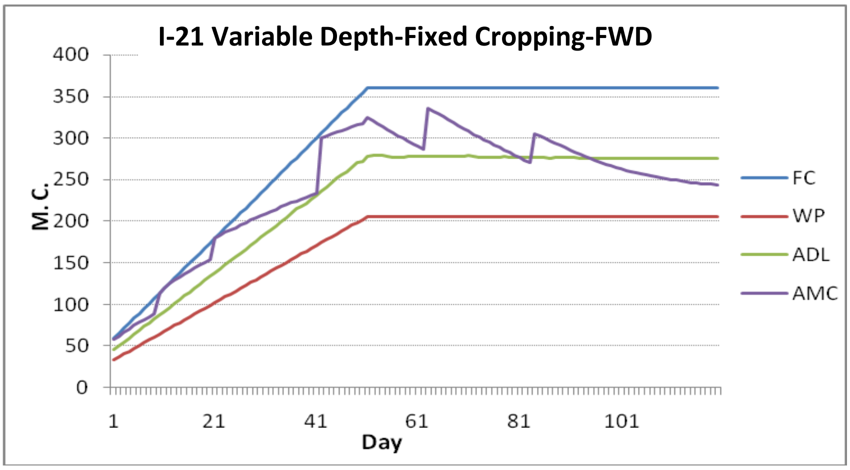


Figure 5.18 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) for Soil 004

Table 5.22 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0) for irrigation interval of 21 days in Soil 004

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.27		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	63.81		
6	111-120	0	9.9	6.69		
			330.52	322.8	3500	3384

The variation of soil moisture in the root zone of wheat when grown on Soil 004 for the optimized variable irrigation depth strategy VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) per irrigation when irrigation interval is 21 days is shown in Figure 5.19.

It is observed from the Figure 5.19 that during first, second and third irrigation the allowable moisture content in the root zone is above the ADL and after fourth irrigation it is below the ADL. This situation results the actual yield of 3403 Kg/ha which is 97.22 % of the maximum yield as shown in Table 5.23. Therefore though the AMC is below ADL from fourth irrigation onward then also this strategy attains almost maximum yield as the yield response factor is less responsive in that particular crop growth stage. In this strategy depth of irrigation is 380 mm and depth of application is 285 mm.

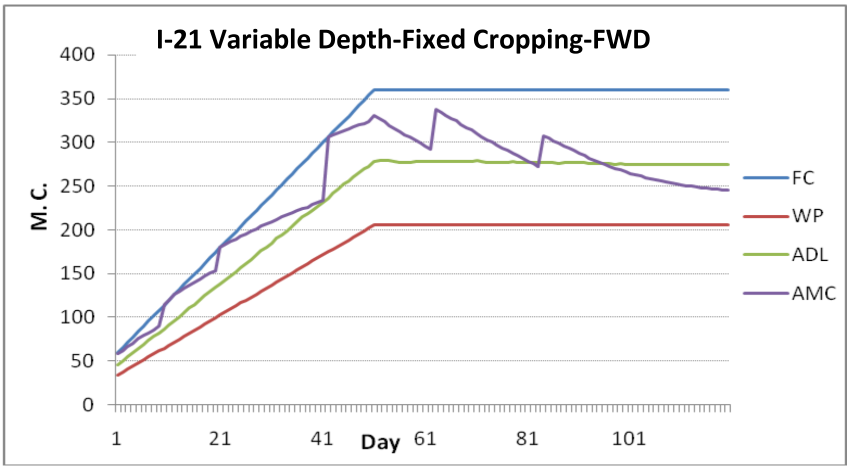


Figure 5.19 Variation of soil moisture in root zone of wheat when irrigation interval is 21 days for variable irrigation strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) for Soil 004

Table 5.23 Yield of wheat as influenced by the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) for irrigation interval of 21 days in Soil 004

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.27		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	64.53		
6	111-120	0	9.9	6.85		
			330.52	323.68	3500	3403

The VDI strategies stated above differ in the fact that in the first variable depth strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0), for third irrigation the irrigation depth is 90% of the FDI while in later strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) it is 100%. The later strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) resulted in increase in yield of only 0.5 % by providing 1% more water.

5.2.4.3 Full depth irrigation

The variation of soil moisture content in the root zone of wheat when grown on soil 004 for the FDI, when irrigation interval is 21 days is shown in Figure 5.20.

It is seen from the Figure 5.20 that the AMC is above ADL for entire crop growth period and for all growth stages. Therefore the actual yield of 3500 Kg/ha is obtained which is equal to the maximum yield as shown in Table 5.24. In this strategy the irrigation depth is 520 mm and application depth is 390 mm.

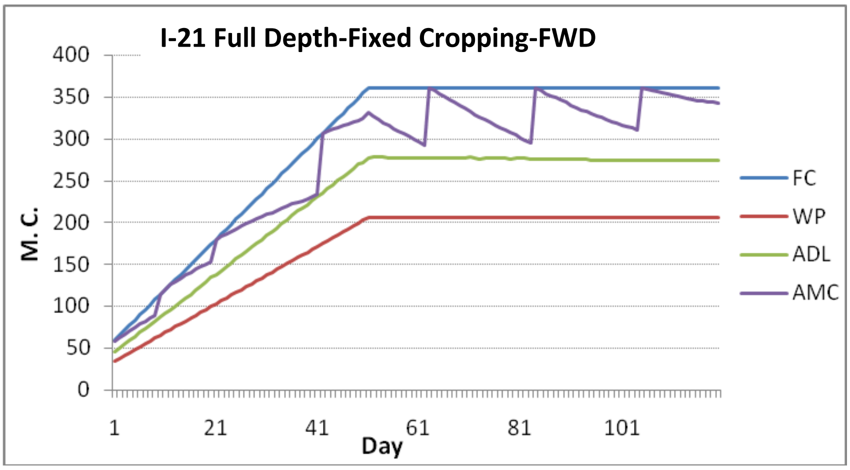


Figure 5.20 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and irrigation is FDI for Soil 004

Table 5.24 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 21 days and irrigation is FDI for Soil 004

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.6		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	140.27		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.32		
6	111-120	0	9.9	9.9		
			330.52	330.52	3500	3500

5.2.4.4 Comparison of different irrigation strategies for wheat grown on Soil 004 for irrigation interval of 21 days:

The comparison of application depth, irrigation depth and actual yield for the selected strategies of variable depth, FxDI and FDI for wheat grown on Soil 004 for irrigation interval of 21 days are presented in Table 5.25

Table 5.25 Comparison of different irrigation strategies for wheat grown on Soil 004 for irrigation interval of 21 days

Figure No.	Irrigation Strategy	Actual yield (Kg/ha)	Application depth (mm)	Irrigation depth (mm)	Irrigation Water Use Efficiency (Kg/ha-mm)
5.16	Fixed Depth Irrigation (60 mm per irrigation)	2942	270	360	8.17
5.17	Fixed Depth Irrigation (80 mm per irrigation)	3498	360	480	7.29
5.18	Variable Depth Irrigation (dr1=1.0, dr2=1.0, dr3=0.9, dr4=0.7, dr5=0.4, dr6=0.0)	3384	281.25	375	9.02
5.19	Variable Depth Irrigation (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0)	3403	285	380	8.96
5.20	Full Depth Irrigation	3500	390	520	6.73

For wheat grown on Soil 004, the FDI with application depth of 390 mm (irrigation depth 520 mm) which provides no moisture stress at all throughout the crop growth period results in maximum wheat yield (3500 Kg/ha) which is also highest among all strategies considered. Fix depth irrigation (80 mm per irrigation) also results in almost same yield (3498 Kg/ha) but saves 7.69% water than that applied in FDI. However, VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) results in 97% of maximum yield i.e. 3403 Kg/ha with about 27 % and 21% water saved that of that applied in FDI strategy and Fixed depth (80 mm per irrigation) irrigation strategy.

The application of water according to the variable irrigation depth strategy is operationally and management point of view is not convenient but results in more irrigation water use efficiency. Thus as is seen for wheat grown on Soil 004, the variable irrigation depth strategy may provide better performance of irrigation scheme in terms of productivity.

5.3 Effect of irrigation interval on yield and water use

To analyze the impact of irrigation interval on yield and water use a single crop i.e. wheat is grown on Soil 002 with full depth of irrigation and different irrigation interval viz. 14 days, 21 days, 28 days and 35 days are considered as discussed in 5.1.2.

5.3.1 Irrigation Interval 14 days

It is seen from Figure 5.21 that for wheat grown on Soil 002 with FDI and 14 days irrigation interval the moisture content is above the ADL throughout the different crop growth stages and from first irrigation to the last irrigation. Which results in obtaining the estimated yield of 3498 Kg/ha which is presented in Table. 5.26. The depth of application is 405 mm (depth of irrigation 540 mm).

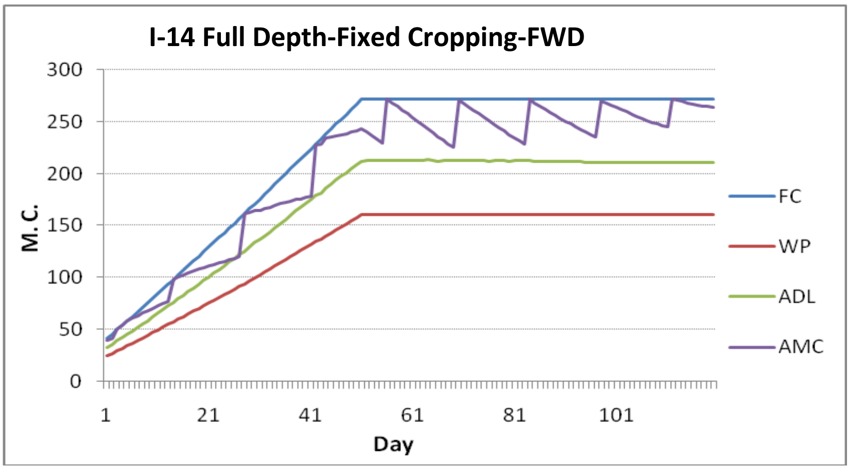


Figure 5.21 Variation of soil moisture in the root zone of wheat when irrigation interval is 14 days and irrigation is FDI for Soil 002

Table 5.26 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 14 days and irrigation is FDI for Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	19.12	19.12		
2	11-25	0.2	42.47	42.47		
3	26-65	0.75	140.2	140.07		
4	66-80	0.75	49.29	49.29		
5	81-110	0.5	74.34	74.34		
6	111-120	0	10.13	10.13		
			335.55	335.42	3500	3498

5.3.2 Irrigation Interval 21 days

It is seen from Figure 5.22 that for wheat grown on Soil 002 with FDI and 21 days irrigation interval the AMC is above the ADL only after the first and the last irrigation and results in moisture stress in the remaining irrigation. From Table 5.27 it is revealed that the estimated yield is 3292 Kg/ha which is 5.93 % less than the maximum yield. The depth of application is 348.75 mm (depth of irrigation 465 mm).

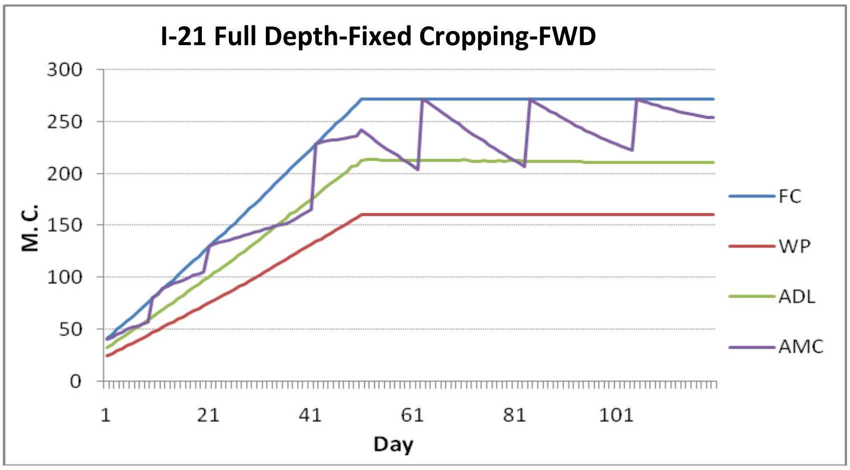


Figure 5.22 Variation of soil moisture in the root zone of wheat when irrigation interval is 21 days and irrigation is FDI for Soil 002

Table 5.27 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 21 days and irrigation is FDI for Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51		
2	11-25	0.2	41.31	41.31		
3	26-65	0.75	140.27	129.59		
4	66-80	0.75	49.11	49.11		
5	81-110	0.5	68.32	68.02		
6	111-120	0	9.9	9.9		
			330.52	319.45	3500	3292

5.3.3 Irrigation Interval 28 days

From Figure 5.23 when wheat crop grown on Soil 002 with irrigation interval 28 days and FDI it is observed that after all the irrigations during entire crop stages the AMC is below the ADL. From Table 5.28 the depth of application is 330 mm (depth of irrigation is 440 mm) and estimated yield of 2429 Kg/ha is obtained which is about 70 % of the maximum yield. It is indicative that the irrigation interval of 28 days is more than the required irrigation interval which results in moisture stress throughout the crop growth stages and affects the estimated yield.

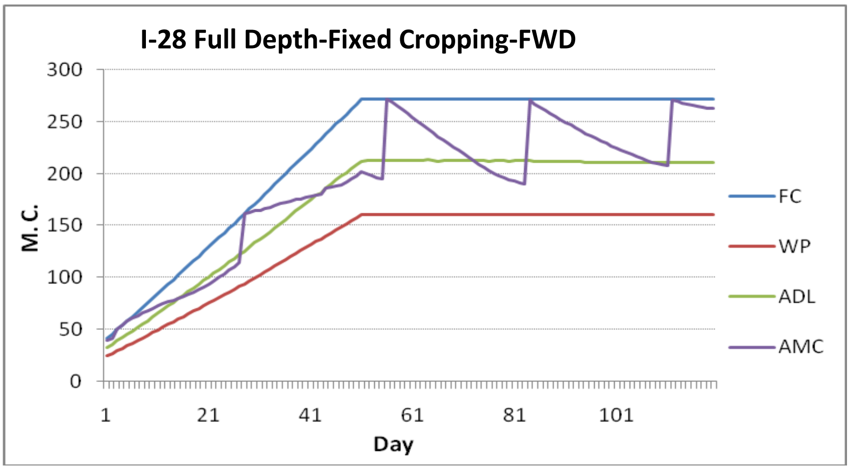


Figure 5.23 Variation of soil moisture in the root zone of wheat when irrigation interval is 28 days and irrigation is FDI for Soil 002

Table 5.28 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 28 days and irrigation is FDI for Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	19.12	19.12		
2	11-25	0.2	42.47	30.07		
3	26-65	0.75	140.2	120.94		
4	66-80	0.75	49.29	42.9		
5	81-110	0.5	74.34	67.31		
6	111-120	0	10.13	9.77		
			335.55	290.11	3500	2429

5.3.4 Irrigation Interval 35 days

It is seen from Figure 5.24 that for wheat grown on Soil 002 with FDI and 35 days interval the moisture content is below the ADL throughout the different crop growth stages and from first irrigation to the last irrigation. Which results in obtaining the estimated yield of 1548 Kg/ha (Table. 5.29) which is about only 44 % of the maximum yield. The depth of application is 296.25 mm (depth of irrigation 395 mm). It is also indicative that the irrigation interval of 35 days is more than the required irrigation interval and results in moisture stress throughout the crop growth stages and after every irrigation affecting the estimated yield severely.

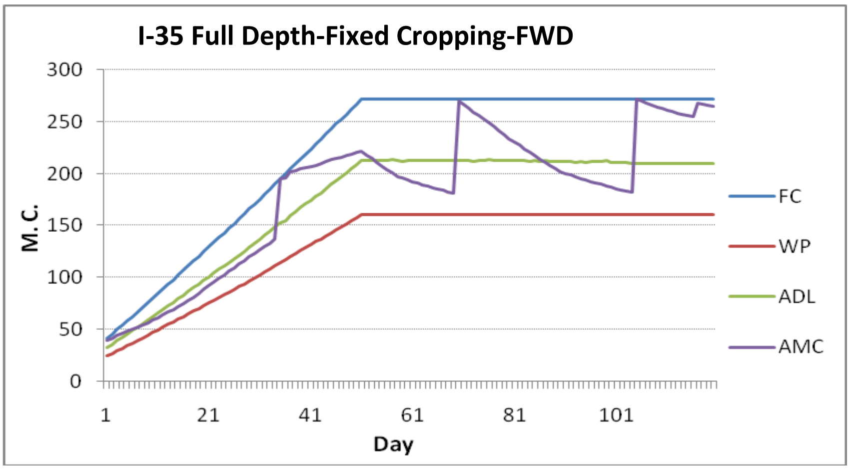


Figure 5.24 Variation of soil moisture in the root zone of wheat when irrigation interval is 35 days and irrigation is FDI for Soil 002

Table 5.29 Yield of wheat as influenced by the irrigation strategy for irrigation interval is 35 days and irrigation is FDI for Soil 002

Stage No.	Days since planting	Yield Response Factor	Crop ET (max)(mm)	Crop ET (actual)(mm)	Maximum Yield (Kg/ha)	Actual Yield (Kg/ha)
1	1-10	0	20.89	20.32		
2	11-25	0.2	42.59	19.58		
3	26-65	0.75	137.99	101.84		
4	66-80	0.75	54	44.85		
5	81-110	0.5	79.33	59.31		
6	111-120	0	10.89	10.89		
			345.7	256.8	3500	1548

5.3.5 Comparison of different irrigation intervals for wheat grown on Soil 002

The comparison of actual yield, water use efficiency, irrigation depth and application depth for different irrigation intervals of 14 days, 21 days, 28 days and 35 days for wheat grown on Soil 002 is given in Table 5.30, Figure 5.25 and Figure 5.26.

From the Table 5.30, Figure 5.25 and Figure 5.26 it is observed that the maximum actual yield is obtained for irrigation interval of 14 days i.e. 3498 Kg/ha, which is 99.93 % of the maximum yield. The application depth given is 405 mm (irrigation depth is 540 mm). But the water use efficiency is observed 6.48 Kg/ha-mm which is less than that attained in 21 days irrigation interval i.e. 7.08 Kg/ha-mm, the highest among all irrigation intervals considered.

The minimum actual yield i.e. 1548 Kg/ha is observed for 35 days irrigation interval, which is 44.22 % of the maximum yield. The depth of application is 296.25 mm (depth of irrigation 395 mm) which is 26.85 % less than that applied in 14 days irrigation interval. It is indicative that the moisture stress throughout the crop growth stages affects the yield as 35 days irrigation interval is more than that the required irrigation interval. The water use efficiency is also minimum in this case i.e. 3.92 Kg/ha-mm.

Table 5.30 Actual yield, Water use efficiency, irrigation depth and application depth for wheat grown on soil 002 for different irrigation interval under full depth irrigation

Figure No.	Irrigation Interval (days)	Maximum Yield (Kg/ha)	Actual yield (Kg/ha)	% Yield of the maximum yield	Application depth (mm)	Irrigation depth (mm)	WUE (Kg/ha-mm)
5.21	14	3500	3498	99.93	405	540	6.48
5.22	21	3500	3292	94.07	348.75	465	7.08
5.23	28	3500	2429	69.41	330	440	5.52
5.24	35	3500	1548	44.22	296.25	395	3.92

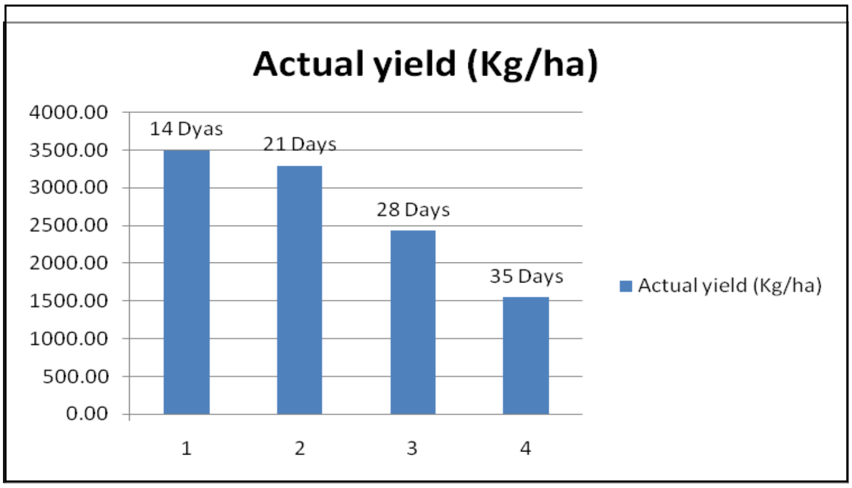


Figure 5.25 Actual yield of wheat grown on Soil 002 for different irrigation interval under full depth irrigation

From Figure 5.25 it is revealed that wheat grown on Soil 002 under FDI the actual yield decreases from 14 days to 35 days irrigation interval, while from Figure 5.26 the water use efficiency increases from 14 days to 21 days irrigation interval and further it decreases drastically for 28 days and 35 days irrigation interval.

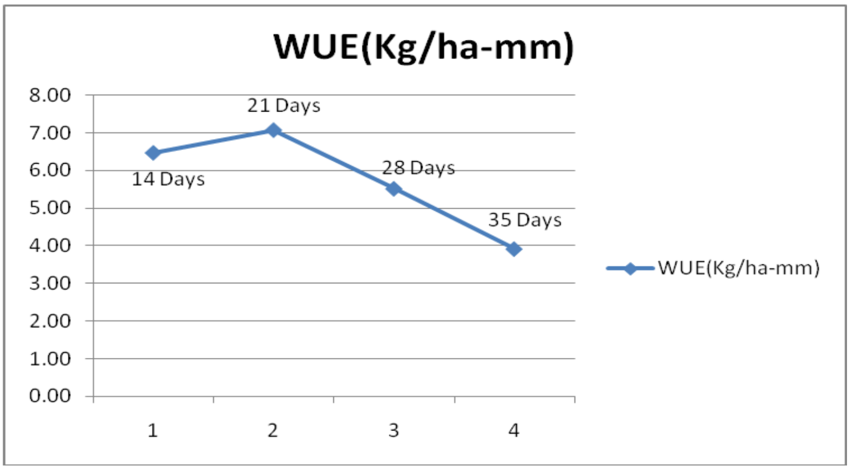


Figure 5.26 Water use efficiency for wheat grown on Soil 002 for different irrigation interval under full depth irrigation

5.4 The different irrigation Strategies for fixed cropping-Free water distribution (No equity) for 14 and 21 days irrigation interval

The analysis of different irrigation strategy as discussed in section 5.1.1 i.e. 1. FDI 2. FxDI and 3. Variable Depth Irrigation (VDI) are considered for wheat crop grown on Soil 002 with irrigation interval of 14 and 21 days. The 14 and 21 days of irrigation interval are selected as in section 5.2 to 5.6 it is revealed that irrigation interval 21 days is more than the required one to keep the available soil moisture above ADL in the root zone except during first and or second irrigation. Therefore for neatly comparison and to decide the policy the irrigation interval 14 and 21 days are selected. In this section the effect of 14 and 21 days of irrigation interval with different irrigation strategy on yield and water use is analysed and described.

5.4.1 Full depth irrigation strategy with 21 days irrigation interval for wheat grown on Soil 002

From Figure 5.27 it is seen that in FDI strategy with irrigation interval of 21 days the AMC in the root zone is above the ADL during the first irrigation but then after up to fourth irrigation the AMC is slightly drops during the period of successive irrigations. However, immediately after application of all irrigations it attains the FC. In general it is observed that the irrigation interval of 21 days is more than the required one to keep the sufficient moisture within the permissible limit. From Table 5.31 it is seen that this strategy attains 3292 kg/ha i.e. 94.06% of the maximum yield with water use efficiency of 7.08kg/ha-mm.

5.4.2 Full depth irrigation strategy with 14 days irrigation interval for wheat grown on Soil 002

From Figure 5.28 it is observed that in FDI strategy with irrigation interval of 14 days from the first irrigation to last irrigation the AMC in the root zone depth is above ADL and keeps the soil to FC during the entire period of crop. It results in very pleasant yield of 3498 kg/ha i.e. 99.93% of the maximum yield means almost equal to that of maximum yield. As shown in Table 5.31. However it requires more depth of application i.e. 405mm (depth of irrigation 540mm) which is 16% more than that of required in for 21 days of irrigation interval i.e. 348.75mm (depth of irrigation 465mm). From Table 5.31 and Figure 5.34 the water use efficiency is observed 6.48 kg/ha-mm.

5.4.3 Fixed depth irrigation strategy (70 mm depth of irrigation per application) with 21 days irrigation interval for wheat grown on Soil 002

From Figure 5.29 it is seen that in fix depth irrigation strategy with 70 mm depth of irrigation per application at 21days irrigation interval the AMC in the root zone of wheat, grown on Soil 002 is above ADL up to second irrigation and then after it drops drastically below the ADL. This creates unfavorable moisture contents condition in the root zone. Which results in yield of 2937 kg/ha which is about 84% of the maximum yield. Here the application depth is 315 mm (irrigation depth 420 mm). As shown in Table5.31 and Figure 5.34 the water use efficiency is observed 6.99Kg/ha-mm.

5.4.4 Fixed depth irrigation strategy (70 mm depth of irrigation per application) with 14 days irrigation interval for wheat grown on Soil 002

From Figure 5.30 in fix depth irrigation strategy with 70 mm depth of irrigation per application at 14 days irrigation interval the AMC in the root zone of wheat is above the ADL throughout the crop period and maintains the FC through out. This maintains favourable moisture content and results into the yield of 3498 kg/ha i.e. 99.93% of maximum yield. The depth of the application is 472.50 mm (irrigation depth 630mm) as shown in Table 5.31 and the water use efficiency is observed 5.55 kg/ha-mm. In this strategy it is clearly indicative that the AMC within the permissible limit throughout crop growth period resulted in almost equal to the maximum yield (i.e. 3500 kg/ha).

It is observed that in FxDI strategy with 70 mm depth of irrigation per application 21 days of irrigation interval is more than the required one which affects to maintain the AMC within the permissible limit which resulted in 16% less yield as compared to 14 days of irrigation interval. However 33% of water is saved in 21 days irrigation interval over 14 days of irrigation interval.

5.4.5 Variable depth irrigation strategy (dr1=1, dr2=1, dr3=1, dr4=1, dr5=1, dr6=0) with 21 days irrigation interval for wheat grown on Soil 002

From Figure 5.31 it is observed that while irrigating wheat crop grown on Soil 002 with 21 days irrigation interval with variable depths strategy (dr1=1, dr2=1, dr3=1, dr4=1, dr5=1, dr6=0), the AMC in the root zone up to second irrigation is above the allowable depletion level. Then after, it slightly falls down below the ADL just immediate before application of next irrigation. Otherwise in between the successive irrigations it helps to maintain the FC throughout the irrigation period. From Table 5.31 it is seen that the depth of application, depth of irrigation, yield and the water use efficiency are observed to be 296.25 mm, 395 mm, 3283 kg/ha and 8.31 kg/ha-mm respectively.

5.4.6 Variable depth irrigation strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.9, dr6=0.7, dr7=0.6, dr8=0.6, dr9=0) with 14 days irrigation interval for wheat grown on soil 002

From Figure 5.32 it is observed that for wheat crop grown on Soil 002, with VDI strategy (dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.9, dr6=0.7, dr7=0.6, dr8=0.6, dr9=0) at 14 days irrigation interval the AMC in the root zone is above the ADL and also throughout the entire irrigation period. It helps to maintain the soil moisture up to FC till fourth irrigation. Then after it slightly drops but it is above the ADL during the rest of the irrigation period. From Table 5.31 it is seen the depth of application, depth of irrigation, the yield and water use efficiency are observed to be 341.25 mm, 455 mm, 3498 kg/ha and 7.69 kg/ha-mm respectively.

It is revealed that about 13.18 % less water is given in variable depth strategy with 21 days irrigation interval over variable depth strategy with 14 days irrigation interval, while the comparative actual yield is reduced by just 6 %.

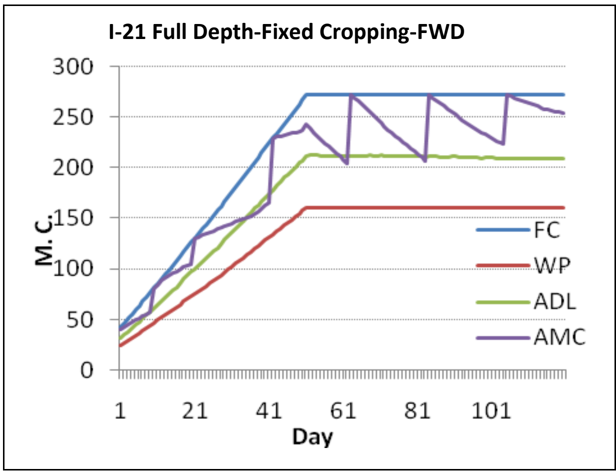


Figure 5.27 Variation of soil moisture in the root zone of wheat grown on soil 002 and FDI applied at irrigation interval of 21 days

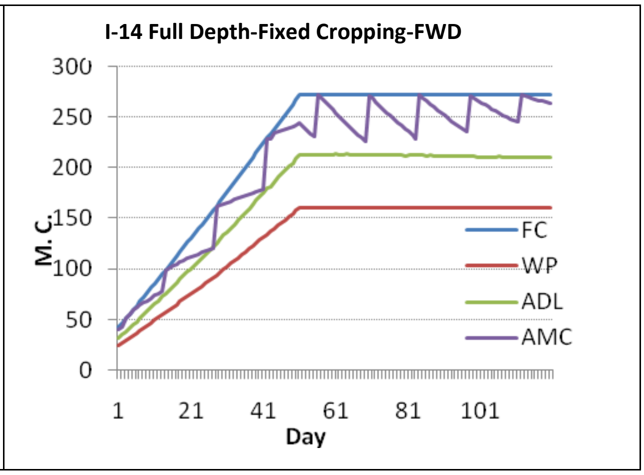


Figure 5.28 Variation of soil moisture in the root zone of wheat grown on soil 002 and FDI applied at irrigation interval of 14 days

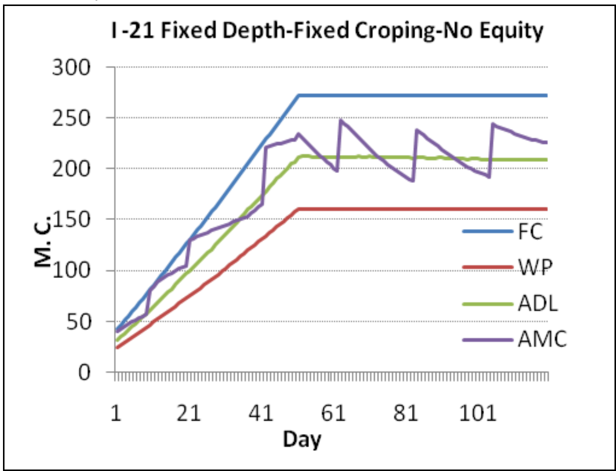


Figure 5.29 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 21 days

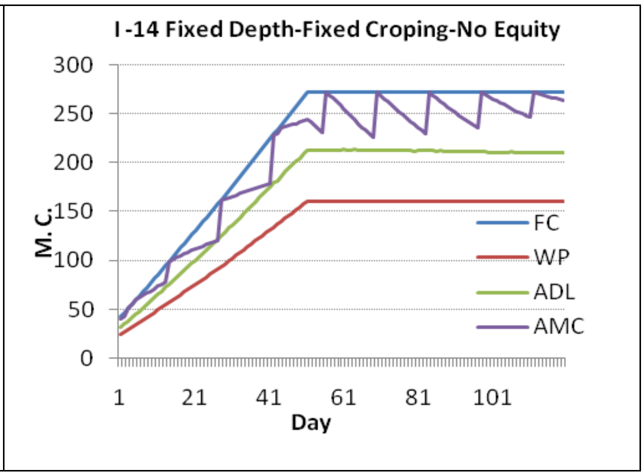


Figure 5.30 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 14 days

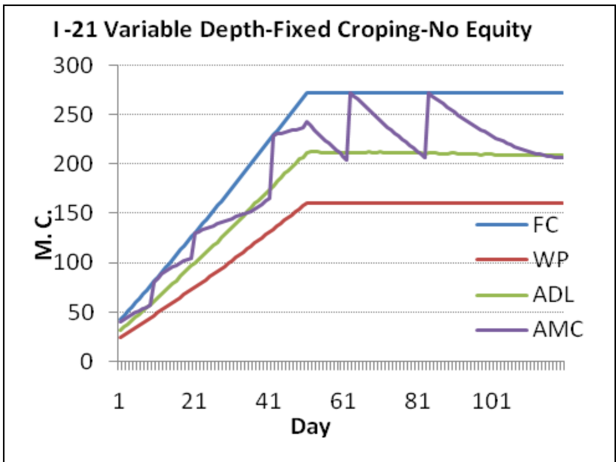


Figure 5.31 Variation of soil moisture in the root zone of wheat grown on soil 002 irrigation applied at irrigation interval of 21 days with Variable depth strategy(dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0)giving maximum yield

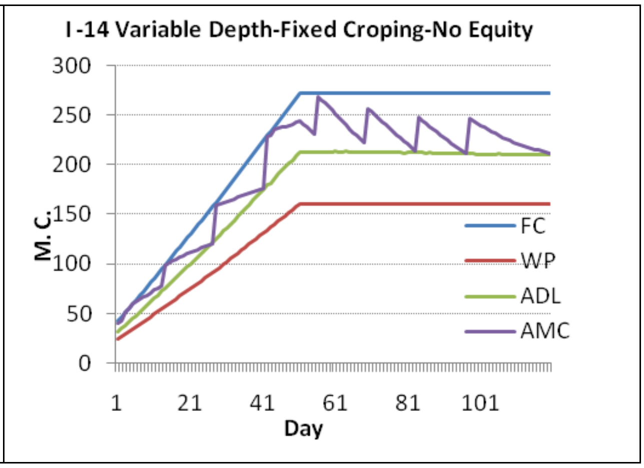


Figure 5.32 Variation of soil moisture in the root zone of wheat grown on soil 002 irrigation applied at irrigation interval of 14 days with Variable depth strategy(dr1=1.0, dr2=1.0, dr3=0.9, dr4=1.0, dr5=0.9, dr6=0.7, dr7=0.6, dr8=0.6, dr9=0) giving maximum yield

5.4.7 Comparison of different irrigation strategies for irrigation intervals of 14 days and 21 days

While comparing the different irrigation strategies (Full depth, Fixed depth and Variable depth) for 14 days irrigation interval, all three yields are the same actual yield i.e. 3498 kg/ha (Table 5.31 and Figure 5. 33). But the depths of irrigation are different. The variable depth strategy uses least irrigation water i.e. 455 mm and saves 15.74% and 27.77% water over full and FxDI strategies respectively. Comparing the different strategies (Full depth, Fixed depth and Variable depth) for 21 days irrigation interval, the FxDI strategy yields least, while both full depth and VDI strategies yields nearly same but about 10 % more than the FxDI strategy. However the maximum water use efficiency i.e. 8.31 Kg/ha-mm is observed in VDI strategy followed by full and FxDI strategies.

Table 5.31 Comparison of different irrigation strategies for wheat grown on soil 002 at irrigation intervals of 14 days and 21 days

Irrigation Strategy	Corresponding Parameters	Irrigation Interval (days)	
		14	21
Full depth irrigation	Figure No.	5.28	5.27
	Depth of application (mm)	405.00	348.75
	Depth of irrigation (mm)	540.00	465.00
	Yield (Kg/ha)	3498	3292
	WUE (Kg/ha-mm)	6.48	7.08
Fixed depth irrigation (70 mm per irrigation)	Figure No.	5.30	5.29
	Depth of application (mm)	472.50	315.00
	Depth of irrigation (mm)	630.00	420.00
	Yield (Kg/ha)	3498	2937
	WUE (Kg/ha-mm)	5.55	6.99
Variable depth irrigation giving maximum yield	Figure No.	5.32	5.31
	Depth of application (mm)	341.25	296.25
	Depth of irrigation (mm)	455.00	395.00
	Yield (Kg/ha)	3498	3283
	WUE (Kg/ha-mm)	7.69	8.31

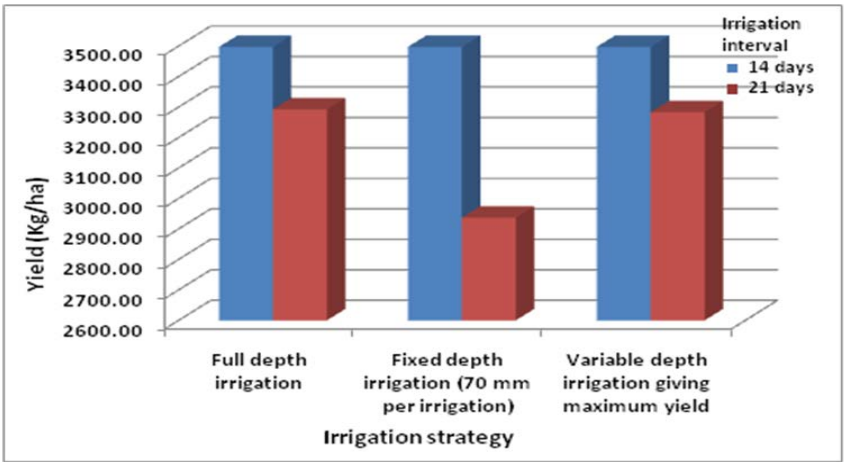


Figure 5.33 Comparison of yield for wheat grown on soil 002 for different irrigation strategies and irrigation interval of 14 and 21 days

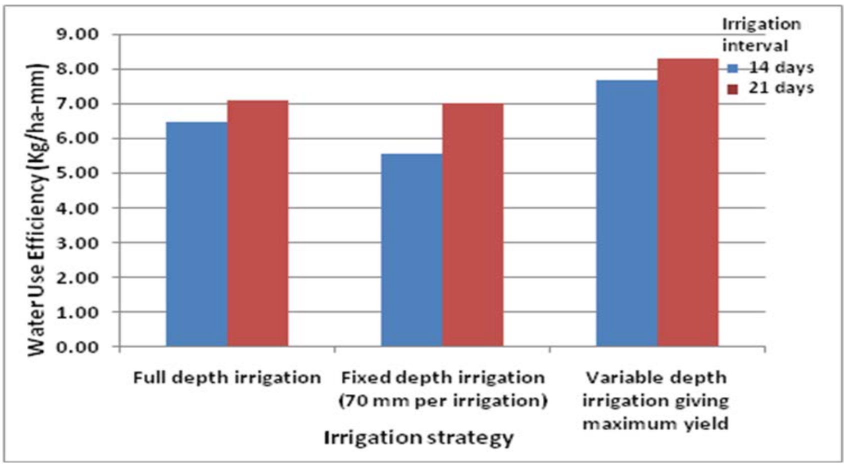


Figure 5.34 Comparison of Water Use Efficiency for wheat grown on soil 002 for different irrigation strategies and irrigation interval of 14 and 21 days

5.5 Effect of depth of irrigation

To analyse the effect of the depth of irrigation for wheat grown on Soil 002 with irrigation interval of 21 days, 10 different irrigation depths per application are considered under FxDI strategy. In this section the different irrigation depths per irrigation viz. 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm, 110 mm, 120 mm, 130 mm and 140 mm are considered. The comparative study of 10 different irrigation depths per application on yield and water use is described ahead.

It is seen from Figure 5.35 and 5.36 that soil moisture content in the root zone is above ADL upto only second irrigation by providing fixed irrigation depth of 50 mm and 60 mm per application at irrigation interval of 21 days for wheat grown on Soil 002. Thereafter for remaining irrigation period AMC drastically reduced below ADL in case of both irrigation depths. This results in attaining actual yield of 1806 Kg/ha & 2477 Kg/ha (Table 5.32) for respective depths.

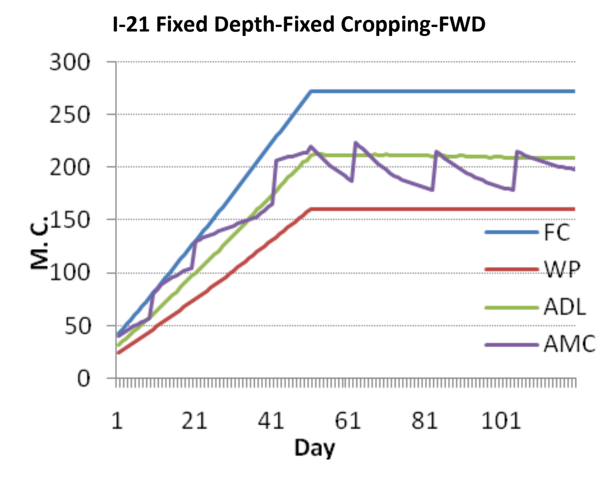


Figure 5.35 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 50 mm is applied at irrigation interval of 21 days

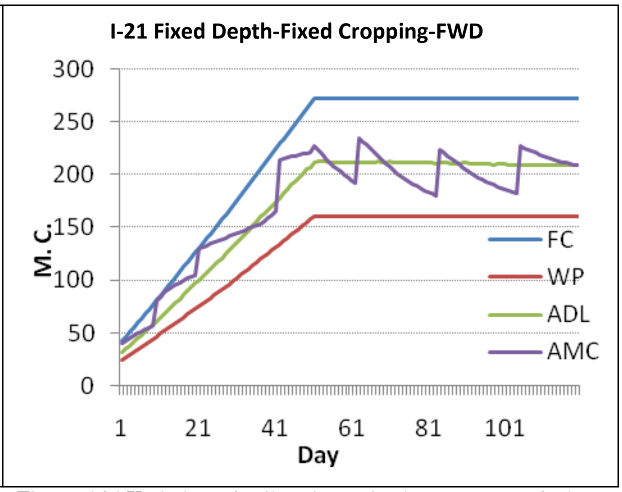


Figure 5.36 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 60 mm is applied at irrigation interval of 21 days

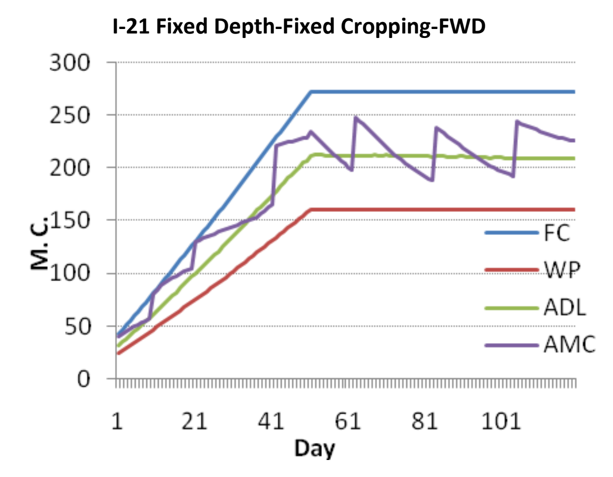


Figure 5.37Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 21 days

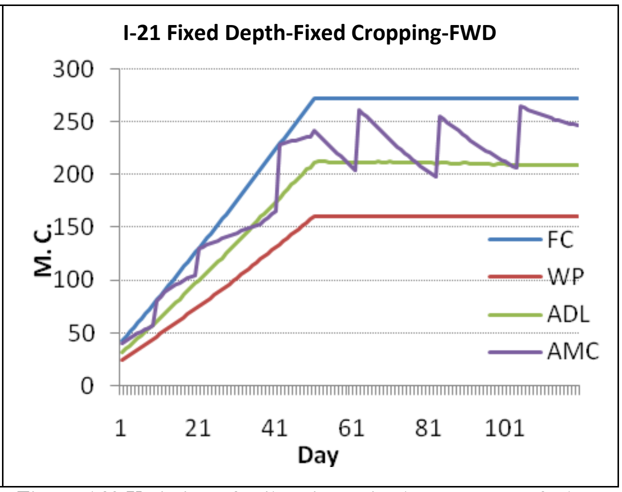


Figure 5.38 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 80 mm is applied at irrigation interval of 21 days

From Figure 5.37 and 5.38 it is revealed that the AMC is above ADL up to second irrigation with irrigation depth of 70 mm and 80 mm per application respectively. However, with 70 mm depth of irrigation per application the AMC in root zone drastically drops below AMC. While with 80 mm depth of irrigation per application the AMC slightly drops below ADL after second irrigation for entire irrigation period. In 70 mm depth of irrigation per application, the actual yield of 2937 Kg/ha which is 83.9 % of the maximum yield (3500 Kg) is attained. While it is

3229 Kg/ha in 80 mm depth of irrigation per application as shown in Table 5.33, which is 92.26 % of the maximum yield.

Table 5.32 Yield of wheat grown on Soil 002 with fixed depth of irrigation at irrigation interval of 21 days: depth of irrigation per irrigation = 50 mm and 60 mm

Stage No.	Days since planting	Yield Response Factor	Irrigation Depth=50 mm			Irrigation Depth=60 mm		
			Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha	Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51	1806	21.6	21.51	2477
2	11-25	0.2	41.31	41.31		41.31	41.31	
3	26-65	0.75	140.27	122.62		140.27	126.05	
4	66-80	0.75	49.11	32.64		49.11	41.11	
5	81-110	0.5	68.32	49.45		68.32	55.46	
6	111-120	0	9.9	8.67		9.9	9.89	
			330.52	276.2		330.52	295.34	

Table 5.33 Yield of wheat grown on Soil 002 with fixed depth of irrigation at irrigation interval of 21 days: depth of irrigation per irrigation = 70 mm and 80 mm

Stage No.	Days since planting	Yield Response Factor	Irrigation Depth=70 mm			Irrigation Depth=80 mm		
			Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)	Crop ET (max)(mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51	2937	21.6	21.51	3229
2	11-25	0.2	41.31	41.31		41.31	41.31	
3	26-65	0.75	140.27	128.17		140.27	129.59	
4	66-80	0.75	49.11	45.82		49.11	48.62	
5	81-110	0.5	68.32	62.05		68.32	66.57	
6	111-120	0	9.9	9.9		9.9	9.9	
			330.52	308.76		330.52	317.51	

From Figure 5.39, 5.40, 5.41, 5.42, 5.43 and 5.44 it is revealed that for depth of irrigation per application of 90 mm, 100 mm, 110 mm, 120 mm, 130 mm and 140 mm, the AMC in the root zone is above ADL up to second irrigation. The AMC in all above depths of irrigation per application touches the FC immediately after applying irrigation. However, the AMC drops below ADL before giving second and third irrigation.

Table 5.34 Yield of wheat grown on Soil 002 with fixed depth of irrigation at irrigation interval of 21 days: depth of irrigation per irrigation = 90 mm and 100 mm

Stage No.	Days since planting	Yield Response Factor	Irrigation Depth=90 mm			Irrigation Depth=100 mm		
			Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)	Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51	3283	21.6	21.51	3292
2	11-25	0.2	41.31	41.31		41.31	41.31	
3	26-65	0.75	140.27	129.59		140.27	129.59	
4	66-80	0.75	49.11	49.11		49.11	49.11	
5	81-110	0.5	68.32	67.66		68.32	68.02	
6	111-120	0	9.9	9.9		9.9	9.9	
			330.52	319.09		330.52	319.45	

Table 5.35 Yield of wheat grown on Soil 002 with fixed depth of irrigation at irrigation interval of 21 days: depth of irrigation per irrigation = 110 mm and 120 mm

Stage No.	Days since planting	Yield Response Factor	Irrigation Depth=110 mm			Irrigation Depth=120 mm		
			Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)	Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51	3292	21.6	21.51	3292
2	11-25	0.2	41.31	41.31		41.31	41.31	
3	26-65	0.75	140.27	129.59		140.27	129.59	
4	66-80	0.75	49.11	49.11		49.11	49.11	
5	81-110	0.5	68.32	68.02		68.32	68.02	
6	111-120	0	9.9	9.9		9.9	9.9	
			330.52	319.45		330.52	319.45	

From Table 5.34, 5.35 and 5.36 it is seen that depth of irrigation per application of 90 mm gives the actual yield of 3283 Kg/ha. For depth of irrigation per application of 100 mm, 110 mm, 120 mm, 130 mm and 140 mm the same actual yield is observed i.e. 3292 Kg/ha. It means that even after increasing the depth of irrigation per application beyond 90 mm it does not help in increasing actual yield as 90 mm depth of irrigation per application is sufficient to keep soil moisture content within limit of ADL for 21 days irrigation interval for wheat grown on soil 002, resulting in maximum yield of 3292 Kg/ha which is 94% of maximum yield (3500 Kg/ha).

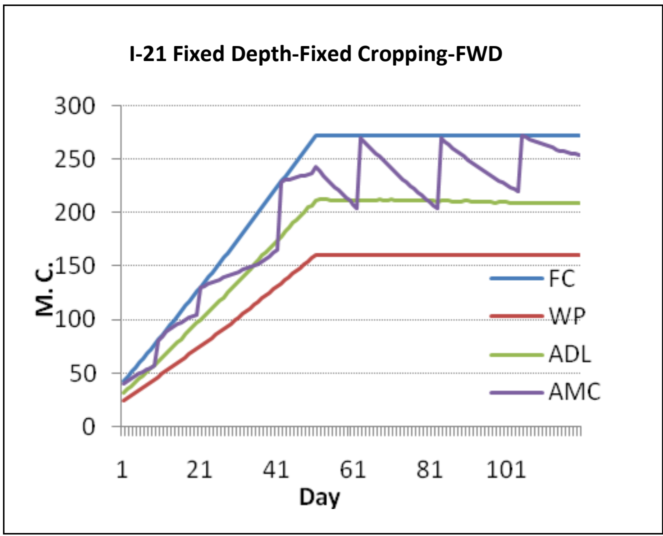


Figure 5.39 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 90 mm is applied at irrigation interval of 21 days

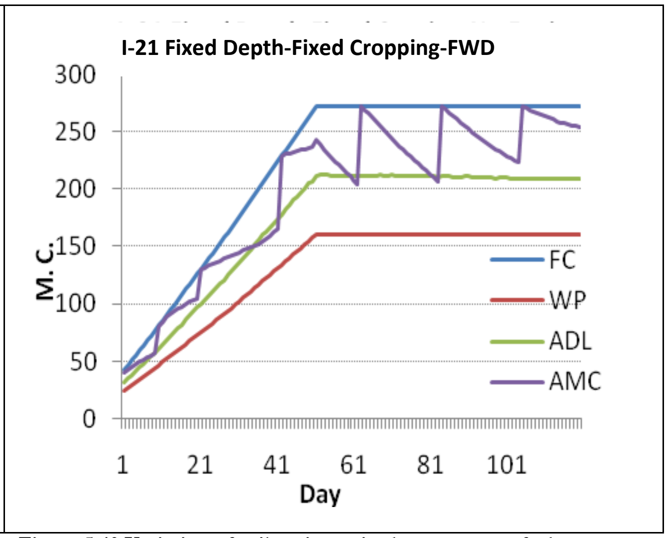


Figure 5.40 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 100 mm is applied at irrigation interval of 21 days

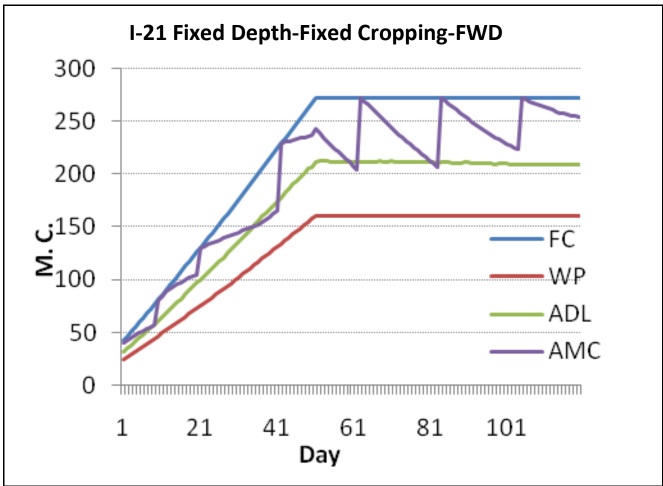


Figure 5.41 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 110 mm is applied at irrigation interval of 21 days

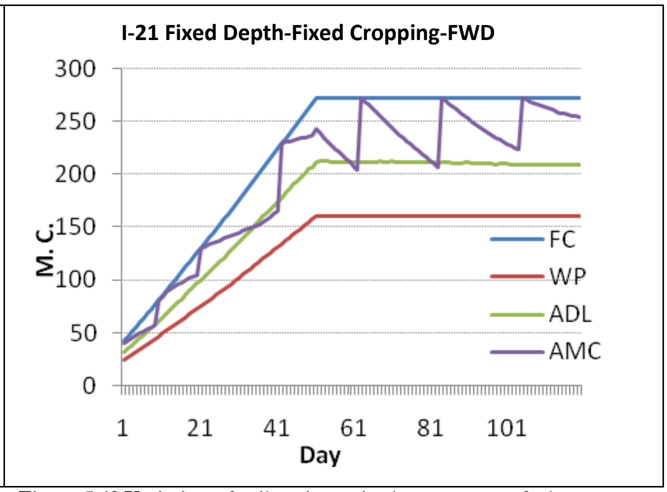


Figure 5.42 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 120 mm is applied at irrigation interval of 21 days

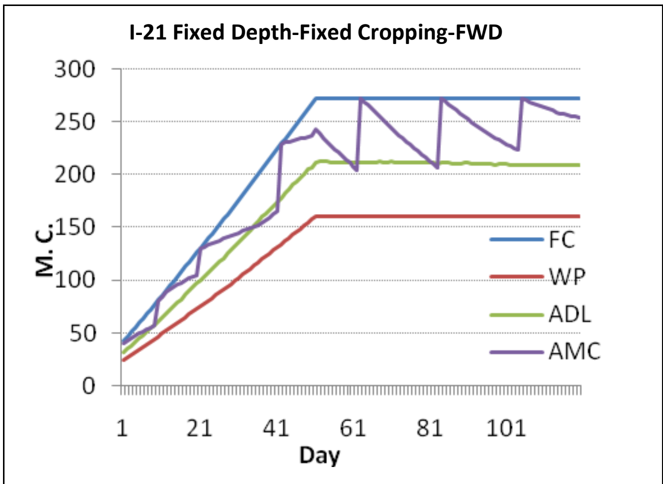


Figure 5.43 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 130 mm is applied at irrigation interval of 21 days

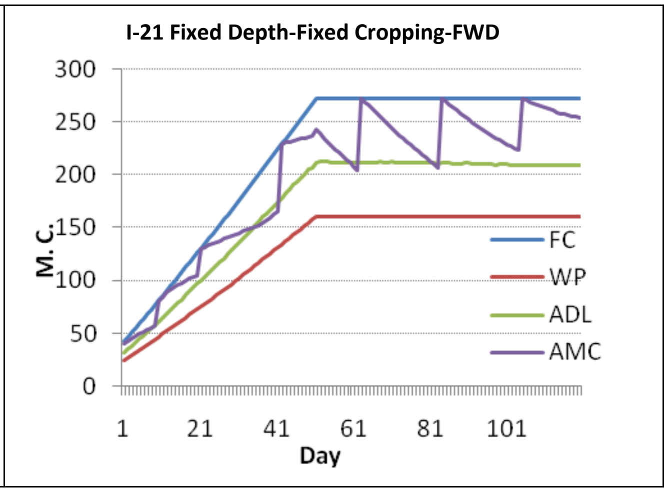


Figure 5.44 Variation of soil moisture in the root zone of wheat grown on soil 002 when fixed irrigation depth of 140 mm is applied at irrigation interval of 21 days

Table 5.36 Yield of wheat grown on Soil 002 with fixed depth of irrigation at irrigation interval of 21 days: depth of irrigation per irrigation = 130 mm and 140 mm

Stage No.	Days since planting	Yield Response Factor	Irrigation Depth=130 mm			Irrigation Depth=140 mm		
			Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)	Crop ET (max) (mm)	Crop ET (actual) (mm)	Actual Yield (Kg/ha)
1	1-10	0	21.6	21.51	3292	21.6	21.51	3292
2	11-25	0.2	41.31	41.31		41.31	41.31	
3	26-65	0.75	140.27	129.59		140.27	129.59	
4	66-80	0.75	49.11	49.11		49.11	49.11	
5	81-110	0.5	68.32	68.02		68.32	68.02	
6	111-120	0	9.9	9.9		9.9	9.9	
			330.52	319.45		330.52	319.45	

5.5.1 Comparison of different irrigation depths per irrigation:

Comparison of different irrigation depths applied per irrigation for wheat grown on soil 002 in FxDI strategies at irrigation interval of 21 days based on yield and water use efficiency is shown in Table 5.37.

Table 5.37 Comparison of different irrigation depths per irrigation for wheat grown on Soil 002 with FxDI strategy at irrigation interval of 21 days

Figure No.	Depth of irrigation per irrigation(mm)	Depth of irrigation (mm)	Yield (Kg/ha)	WUE (Kg/ha-mm)	% of maximum yield (3500 kg)
5.35	50	300	1806	6.02	51.60
5.36	60	360	2477	6.88	70.77
5.37	70	420	2937	6.99	83.90
5.38	80	480	3229	6.73	92.26
5.39	90	540	3283	6.08	93.80
5.40	100	600	3292	5.49	94.07
5.41	110	660	3292	4.99	94.07
5.42	120	720	3292	4.57	94.07
5.43	130	780	3292	4.22	94.07
5.44	140	840	3292	3.92	94.07

After applying incremental depth of 10 mm over 50 mm depth of irrigation per application the actual yield increases by 37 % (i.e. from 1806 to 2477 Kg/ha). From Table 5.37 it is seen that though there is increase of 10 mm over 50 mm depth of irrigation per application i.e. 60 mm, then also water use efficiency increases from 6 to 6.88 Kg/ha-mm. Not only that the % of maximum yield also increases by 19.17 % i.e. from 50.6 to 70.77 %.

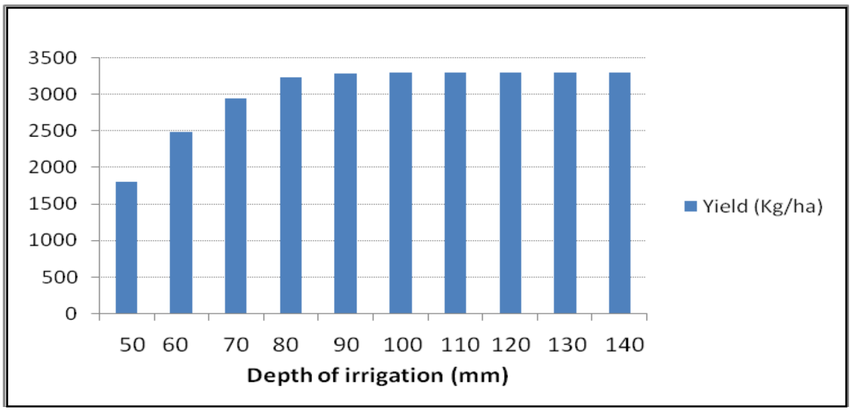


Figure 5.45 Yield of wheat grown on soil 002 under FxDI strategy at irrigation interval of 21 days for different irrigation depths per irrigation

From Table 5.37 and Figure 5.45 it is revealed that after applying 90 mm depth of irrigation per application to wheat grown on soil 002 at irrigation interval of 21 days, the actual yield attained is about 94 % of the maximum yield. The same yield is obtained for depth of irrigation per application of 100 mm to 140 mm. Therefore, there is no further improvement in the yield after applying more water per irrigation beyond 90 mm depth of irrigation per application at 21 days irrigation interval for wheat grown on soil 002. The least yield is observed in 50 mm depth of irrigation per application which is about 52 % of the maximum yield.

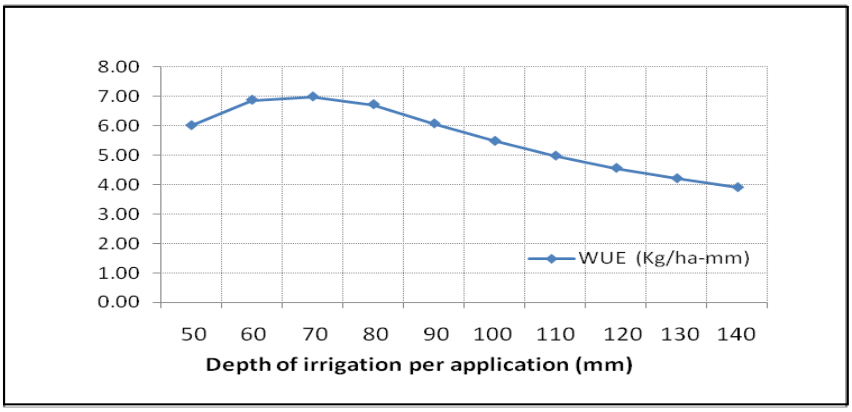


Figure 5.46 Water Use Efficiency for wheat grown on soil 002 under FxDI strategy at irrigation interval of 21 days for different irrigation depths per irrigation

From Figure 5.46 it is revealed that the water use efficiency goes on increasing as the depth of irrigation increases from 50 mm to 70 mm and attains the maximum water use efficiency of 9.99 Kg/ha-mm at 70 mm depth of irrigation per application. Thereafter, the water use efficiency goes on decreasing even by increasing the depth of irrigation per application beyond 70 mm, as there is little improvement in the yield from 70 mm to 90 mm depth of irrigation per application. However, there is absolutely no improvement in the actual yield from 90 to 140 mm depth of irrigation per application.

5.6 Response of different crops to different irrigation strategies and different irrigation intervals

Three different irrigation strategies and different irrigation intervals are described in section 5.1.1 and 5.1.2. In this section how different crops respond to the different irrigation strategies (Full depth, Fixed depth and Variable depth irrigation strategy) is described. Three different crops viz. Sunflower (*Kharif* season), Gram (*Rabi* season) and Cabbage (Summer season) are considered to be grown on Soil 002 and with two irrigation intervals viz. 14 days and 21 days. The irrigation depth of 70 mm per irrigation is considered for the FxDI strategy. While in case of VDI strategy, among the 10 optimum efficient irrigation programs, the one which gives the maximum yield is considered. The effect of different irrigation strategies on wheat grown on Soil 002 with 14 days and 21 days irrigation interval is already discussed in the section 5.4.7.

5.6.1 Response of Sunflower to different irrigation strategies

5.6.1.1 Full depth irrigation strategy for Sunflower

When FDI is applied to sunflower grown on Soil 002 at irrigation interval of 14 days it is observed from Figure 5.47 that AMC in the root zone of sunflower grown on Soil 002 with an irrigation interval of 14 days is above the ADL and attains almost the FC from first to fourth irrigations. Then after it drops and goes below the ADL upto seventh irrigation. From seventh irrigation onwards it increases and observed to be above ADL for rest of the irrigation period. Here, From Table 5.38 the irrigation depth, actual yield and water use efficiency are 630 mm, 1243 kg/ha and 1.97 kg/ha-mm respectively. However, for FDI at irrigation interval of 21 days, the AMC found to be sufficient and above ADL upto second irrigation (Figure 5.48). During third and fourth irrigation the AMC drops and goes below the ADL. After applying fifth irrigation the AMC increases above ADL for rest of the period. The actual yield and water use efficiency are found to be 505 mm, 795 kg/ha and 1.57 kg/ha-mm respectively (Table 5.38).

5.6.1.2 Fixed depth irrigation strategy for Sunflower

In case of 14 days irrigation interval the FxDI strategy with 70 mm depth of irrigation per application the irrigation depth, actual yield and water use efficiency are observed to be 630 mm, 1097 kg/ha and 1.74 kg/ha-mm respectively (Table 5.38). From Figure 5.49, the AMC slightly reduces and touches to ADL upto second irrigation. For rest of the period it maintains above ADL and close to FC. For 21 days irrigation interval the FxDI strategy with 70 mm depth of irrigation per application the irrigation depth, actual yield and water use efficiency are found to be 420 mm, 379 kg/ha and 0.90 kg/ha-mm respectively (Table 5.38).From Figure 5.50, it is seen that the AMC is sufficient and just above ADL upto fourth irrigation and for rest of the entire crop growth period AMC is observed to be in very erratic manner, which hampers the actual yield drastically.

5.6.1.3 Variable depth irrigation strategy for Sunflower

VDI strategies for sunflower giving maximum yield for 14 days irrigation interval is (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) and for 21 days irrigation interval is (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0).

For 14 days irrigation interval the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) the irrigation depth, actual yield and water use efficiency are observed to be 500 mm, 1243 kg/ha and 2.49 kg/ha-mm respectively (Table 5.38). From Figure 5.51 it is found that the AMC is absolutely above ADL and closer to FC up to fifth irrigation, which creates congenial condition during the critical crop growth stages. It results in better yield, though the AMC decreases below ADL in between subsequent irrigations. For 21 days irrigation interval the VDI strategy (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0) the irrigation depth, actual yield and water use efficiency are found to be 435 mm, 795 kg/ha and 1.83 kg/ha-mm respectively (Table 5.38). The AMC is above ADL upto third irrigation (Figure 5.52). After third and before fourth irrigation (during critical growth stages) AMC drops slightly below ADL and the actual yield gets affected.

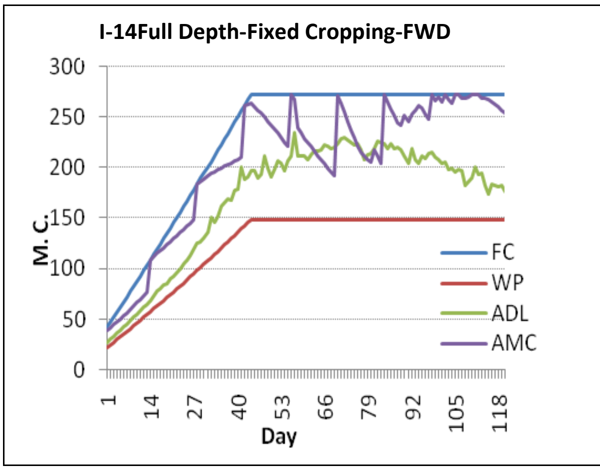


Figure 5.47 Variation of soil moisture in the root zone of sunflower grown on soil 002 when FDI is applied at irrigation interval of 14 days

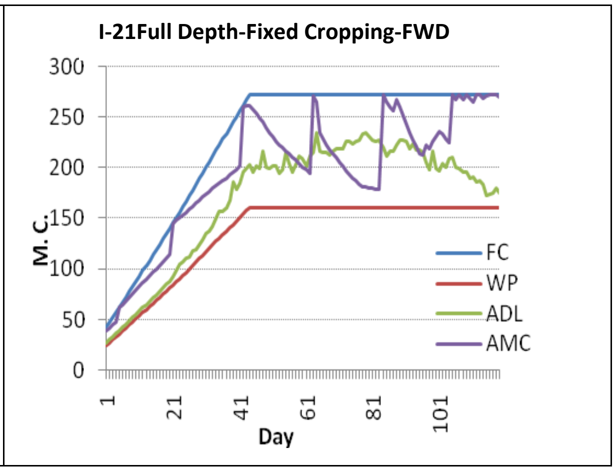


Figure 5.48 Variation of soil moisture in the root zone of sunflower grown on soil 002 when FDI is applied at irrigation interval of 21 days

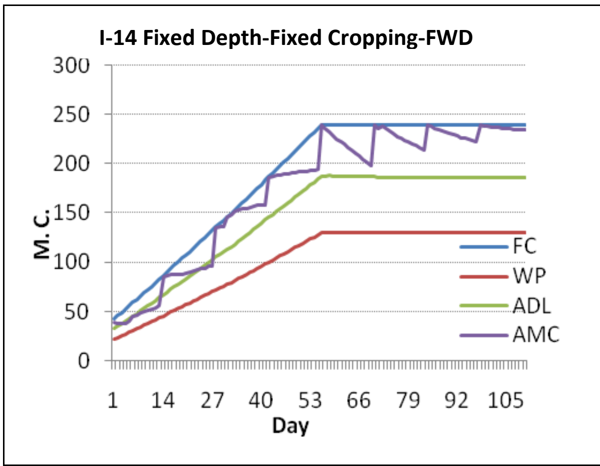


Figure 5.49 Variation of soil moisture in the root zone of sunflower grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 14 days

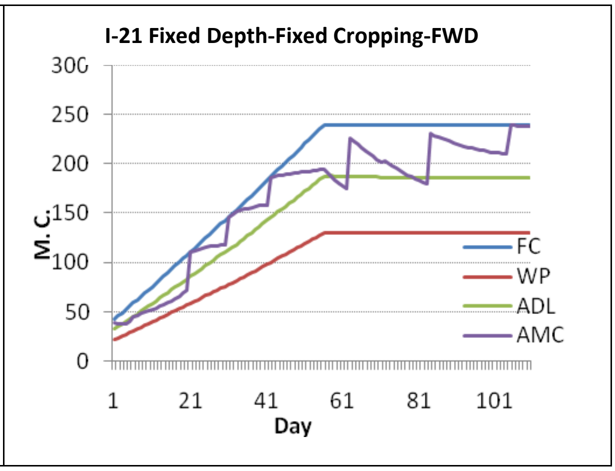


Figure 5.50 Variation of soil moisture in the root zone of sunflower grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 21 days

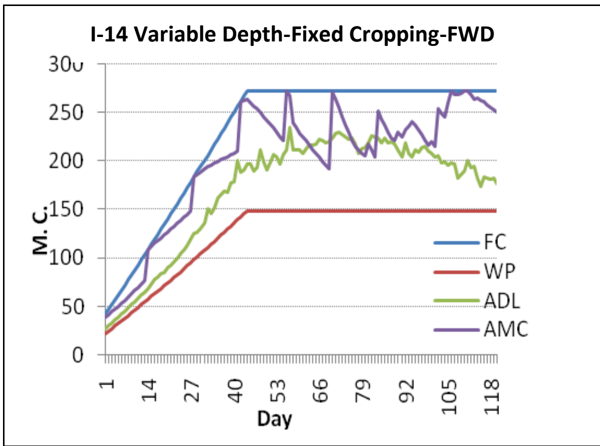


Figure 5.51 Variation of soil moisture in the root zone of sunflower grown on soil 002 when VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) is applied at irrigation interval of 14 days

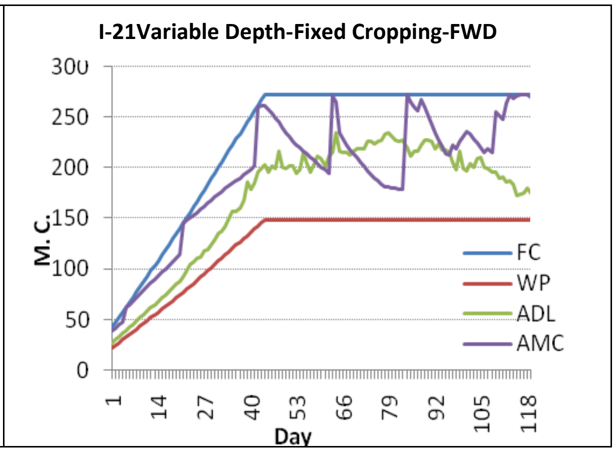


Figure 5.52 Variation of soil moisture in the root zone of sunflower grown on soil 002 when VDI (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0) is applied at irrigation interval of 21 days

5.6.1.4 Comparison of different irrigation strategies for sunflower

Comparison of different irrigation strategies for sunflower grown on Soil 002 is given in Table 5.38. Among the different irrigation strategies the same highest actual yield i.e. 1243 kg/ha is achieved in FDI strategy and VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) at irrigation interval of 14 days, which is about 83% of the maximum yield (i.e. 1500 kg/ha). But the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) saves 15.87 % water than FDI strategy and achieves more water use efficiency (i.e. 2.49 kg/ha-mm as compared to 1.97 kg/ha-mm). However, when we compare all irrigation strategies for 14 and 21 days irrigation intervals, it is observed that 21 days interval is too long for sunflower grown on Soil 002 and yields poorly i.e. only 25.26 % of maximum yield for FxDI strategy with 70 mm depth of irrigation per application and 53% of maximum yield for both full depth and variable depth strategy.

5.6.2 Response of Gram to different irrigation strategies

5.6.2.1 Full depth irrigation strategy for Gram

When FDI is applied to gram grown on Soil 002 at irrigation interval of 14 days, irrigation depth, actual yield and water use efficiency are observed to be 445 mm, 2493 kg/ha and 5.6 kg/ha-mm respectively (Table 5.38). From Figure 5.53 it is revealed that the AMC is slightly less upto second irrigation. From third irrigation onward the AMC is completely above allowable depletion level.

From Figure 5.54 for irrigation interval of 21 days the AMC drops below the ADL in between first and second irrigation and in between third and fourth irrigation and afterward it is within the permissible limit. The irrigation depth, actual yield and water use efficiency are found to be 380 mm, 2451 kg/ha and 6.45 kg/ha-mm respectively (Table 5.38).

5.6.2.2 Fixed depth irrigation strategy for Gram

For 14 days irrigation interval the FxDI strategy with 70 mm depth of irrigation per application from Figure 5.55 the AMC in the root zone is almost above ADL throughout the crop growth period. The irrigation depth, actual yield and water use efficiency are found to be 560 mm, 2493 kg/ha and 4.45 kg/ha-mm respectively (Table 5.38).

For 21 days irrigation interval from Figure 5.56 the AMC is below the ADL in between first and second irrigation and in between fourth and fifth irrigation otherwise the AMC is above ADL.

The irrigation depth, actual yield and water use efficiency are 420 mm, 2440 kg/ha and 5.81 kg/ha-mm respectively (Table 5.38).

5.6.2.3 Variable depth irrigation strategy for Gram

VDI strategies for gram giving maximum yield for 14 days irrigation interval is (dr1=0.7, dr2=1.0, dr3=0.9, dr4=1.0, dr5=1.0, dr6=0.9, dr7=0.0, dr8=0.0) and for 21 days irrigation interval is (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0).

For 14 days irrigation interval the VDI strategy (dr1=0.7, dr2=1.0, dr3=0.9, dr4=1.0, dr5=1.0, dr6=0.9, dr7=0.0, dr8=0.0) from Figure 5.57, it is observed that the AMC is above the ADL throughout the crop growth period which results in achieving the highest water use efficiency. From Table 5.38 it is seen that the irrigation depth, actual yield and water use efficiency are 315 mm, 2493 kg/ha and 7.91 kg/ha-mm respectively. For 21 days irrigation interval the VDI strategy (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0) from Figure 5.58 it is revealed that the AMC drops below the ADL after first and fourth irrigation and above ADL for rest of irrigations. From Table 5.38 the irrigation depth, actual yield and water use efficiency are observed to be 255 mm, 2451 kg/ha and 9.61 kg/ha-mm respectively.

5.6.2.4 Comparison of different irrigation strategies for Gram

From Table 5.38 it is observed that for gram grown on Soil 002 for all 3 different irrigation strategies the same yield is attained i.e. 2493 kg/ha (almost equal to maximum yield i.e. 2500 kg) at 14 days irrigation interval and about 2450 kg/ha (98 % of maximum yield) at 21 days irrigation interval. However, the highest water use efficiency of 9.61 kg/ha-mm is achieved with VDI strategy (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0) at irrigation interval of 21 days, followed by 7.91 kg/ha-mm with VDI strategy (dr1=0.7, dr2=1.0, dr3=0.9, dr4=1.0, dr5=1.0, dr6=0.9, dr7=0.0, dr8=0.0) at irrigation interval of 14 days.

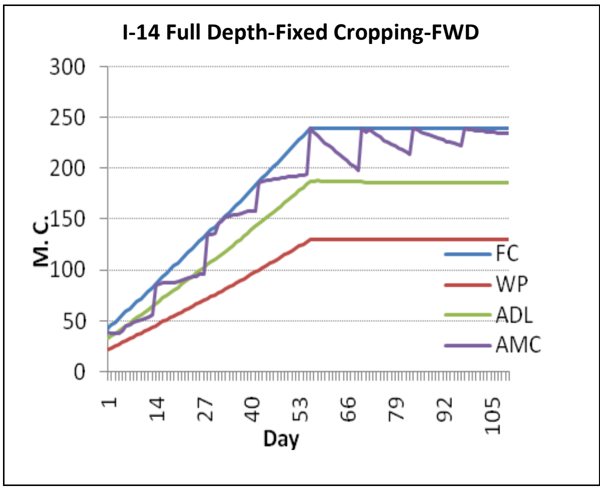


Figure 5.53 Variation of soil moisture in the root zone of gram grown on soil 002 when FDI is applied at irrigation interval of 14 days

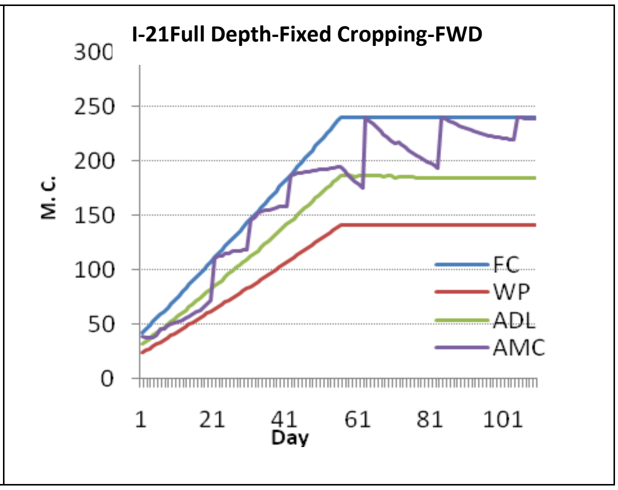


Figure 5.54 Variation of soil moisture in the root zone of gram grown on soil 002 when FDI is applied at irrigation interval of 21 days

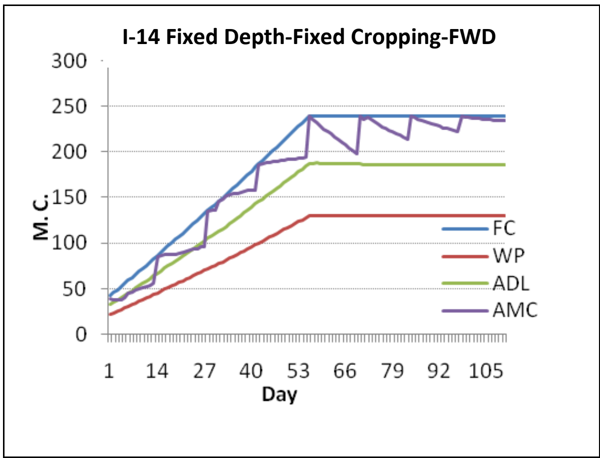


Figure 5.55 Variation of soil moisture in the root zone of gram grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 14 days

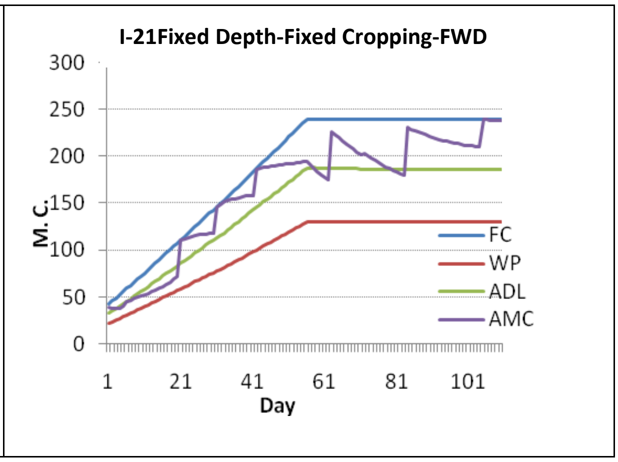


Figure 5.56 Variation of soil moisture in the root zone of gram grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 21 days

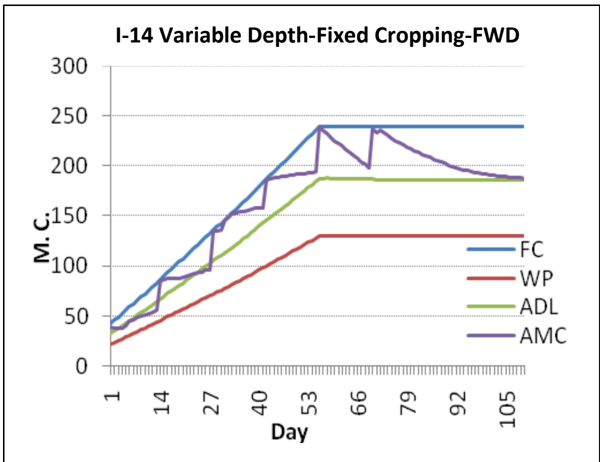


Figure 5.57 Variation of soil moisture in the root zone of gram grown on soil 002 when VDI (dr1=0.7, dr2=1.0, dr3=0.9, dr4=1.0, dr5=1.0, dr6=0.9, dr7=0.0, dr8=0.0) is applied at irrigation interval of 14 days

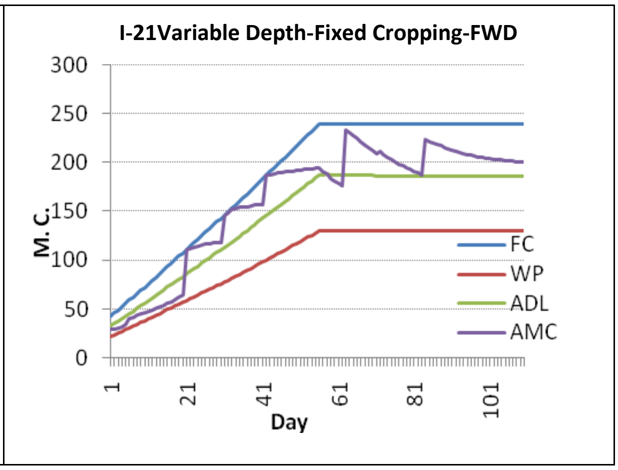


Figure 5.58 Variation of soil moisture in the root zone of gram grown on soil 002 when VDI (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0). is applied at irrigation interval of 21 days

5.6.3 Response of Cabbage to different irrigation strategies

5.6.3.1 Full depth irrigation strategy for Cabbage

When FDI is applied to cabbage grown on Soil 002 at irrigation interval of 14 days from Figure 5.59 it is seen that immediately after first irrigation the AMC drops below the ADL. However, for all subsequent irrigations it is above ADL. From Table 5.38 the observed irrigation depth, actual yield and water use efficiency are 330 mm, 24659.4 kg/ha and 74.72 kg/ha-mm respectively. From Figure 5.60 it is revealed that for irrigation interval of 21 days the AMC is maintained above ADL during all irrigations. The irrigation depth, actual yield and water use efficiency are found to be 260 mm, 24838.2 kg/ha and 95.53 kg/ha-mm respectively (Table 5.38).

5.6.3.2 Fixed depth irrigation strategy for Cabbage

From Figure 5.61 for 14 days irrigation interval the FxDI strategy with 70 mm depth of irrigation per application it is seen that the AMC slightly drops below ADL. Then after it is above ADL and close to FC, creates favaourable soil moisture condition for crop growth and yield. The irrigation depth, actual yield and water use efficiency are 420 mm, 24659.4 kg/ha and 587.12 kg/ha-mm respectively (Table 5.38). For 21 days irrigation interval it is observed that the AMC is maintained above ADL for entire crop growth period (Figure 5.62). From Table 5.38 it is seen that the irrigation depth, actual yield and water use efficiency are 280 mm, 24838.2 kg/ha and 88.7 kg/ha-mm respectively.

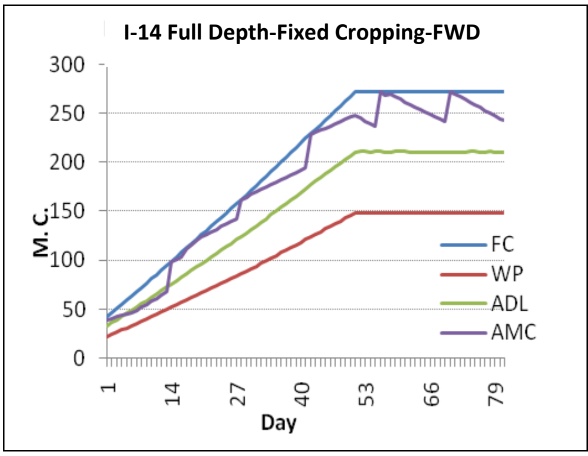


Figure 5.59 Variation of soil moisture in the root zone of cabbage grown on soil 002 when FDI is applied at irrigation interval of 14 days

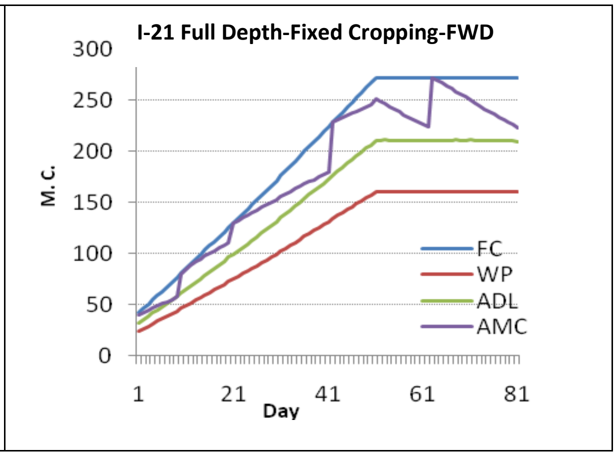


Figure 5.60 Variation of soil moisture in the root zone of cabbage grown on soil 002 when FDI is applied at irrigation interval of 21 days

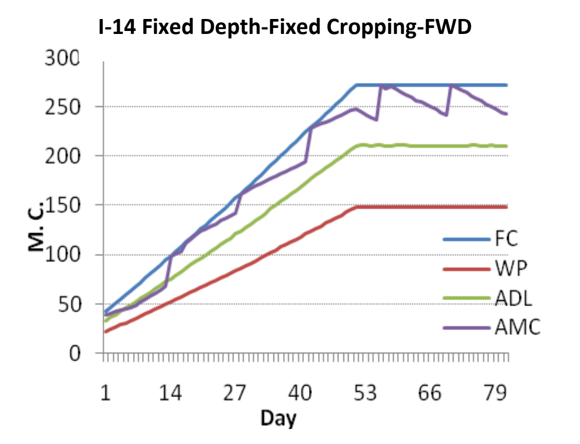


Figure 5.61 Variation of soil moisture in the root zone of cabbage grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 14 days

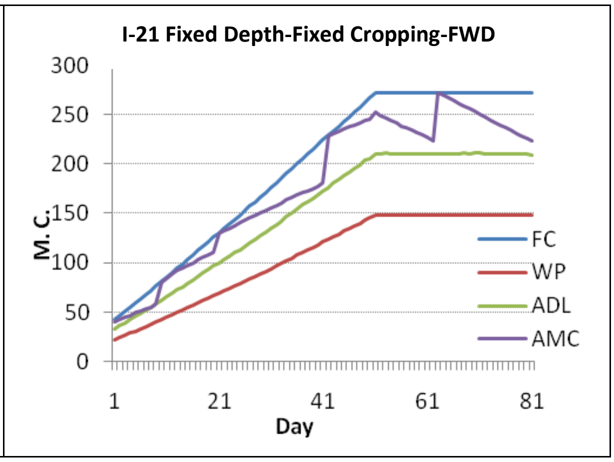


Figure 5.62 Variation of soil moisture in the root zone of cabbage grown on soil 002 when fixed irrigation depth of 70 mm is applied at irrigation interval of 21 days

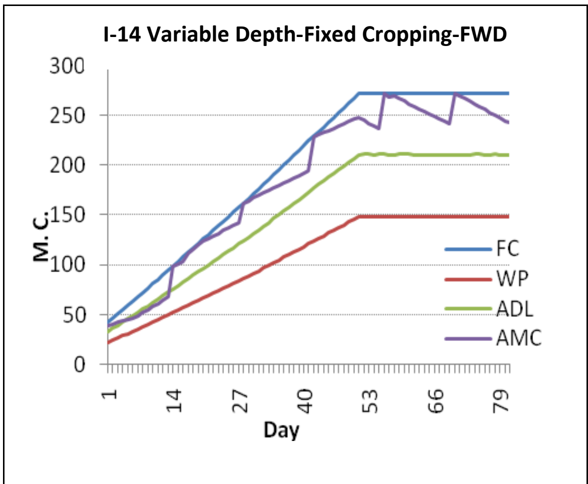


Figure 5.63 Variation of soil moisture in the root zone of cabbage grown on soil 002 when VDI (dr1=0.6, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0) is applied at irrigation interval of 14 days

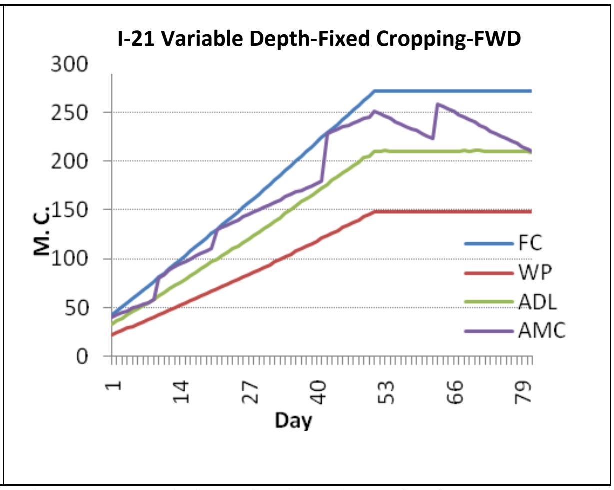


Figure 5.64 Variation of soil moisture in the root zone of cabbage grown on soil 002 when VDI (dr1=0.6, dr2=1.0, dr3=1.0, dr4=0.7) is applied at irrigation interval of 21 days

5.6.3.3 VDI strategy for Cabbage

VDI strategies for cabbage giving maximum yield for 14 days irrigation interval is (dr1=0.6, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0) and for 21 days irrigation interval is (dr1=0.6, dr2=1.0, dr3=1.0, dr4=0.7).

From Figure 5.63 when irrigation is applied at 14 days irrigation interval the VDI strategy (dr1=0.6, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0) it is observed that the AMC drops slightly below the ADL after first irrigation. After that for the entire irrigation period it is above ADL and touches to the FC at every subsequent irrigations. The irrigation depth, actual yield and water use efficiency are 300 mm, 24659.4 kg/ha and 82.19 kg/ha-mm respectively (Table 5.38). For 21 days irrigation interval the VDI strategy (dr1=0.6, dr2=1.0, dr3=1.0, dr4=0.7) the AMC is below ADL after first irrigation and in between fourth and fifth irrigations. For rest of the irrigations it is above ADL (Figure 5.64). From Table 5.38 the irrigation depth, actual yield and water use efficiency are 210 mm, 24838.2 kg/ha and 118.27 kg/ha-mm respectively.

5.6.3.4 Comparison of different irrigation strategies for Cabbage

From Table 5.38 for cabbage grown on Soil 002 the different strategies (Full depth, Fixed depth and VDI) responds same at irrigation interval of 14 days and 21 days in terms of actual yield i.e. 24659.4 kg/ha (98.63% of maximum yield) and 24838.2 kg/ha (99.35% of maximum yield) respectively. However, the maximum water use efficiency of 118.27 kg/ha-mm is achieved with VDI strategy (dr1=0.6, dr2=1.0, dr3=1.0, dr4=0.7) at 21 days irrigation interval, followed by 95.53 kg/ha-mm with FDI at 21 days irrigation interval.

Table 5.38 Comparison of different irrigation strategies for Sunflower, Gram and Cabbage grown on Soil 002 at irrigation intervals of 14 days and 21 days

Crop		Sunflower		Gram		Cabbage	
Irrigation Strategy	Corresponding Parameters	Irrigation Interval (days)		Irrigation Interval (days)		Irrigation Interval (days)	
		14	21	14	21	14	21
Full depth irrigation	Figure No.	5.47	5.48	5.53	5.54	5.59	5.60
	Depth of irrigation (mm)	630.00	505.00	445	380	330	260
	Yield (Kg/ha)	1243	795	2493	2451	24659.4	24838.2
	WUE (Kg/ha-mm)	1.97	1.57	5.60	6.45	74.72	95.53
Fixed depth irrigation (70 mm per irrigation)	Figure No.	5.49	5.50	5.55	5.56	5.61	5.62
	Depth of irrigation (mm)	630.00	420	560	420	420	280
	Yield (Kg/ha)	1097	379	2493	2440	24659.4	24838.2
	WUE (Kg/ha-mm)	1.74	0.90	4.45	5.81	58.71	88.70
Variable depth irrigation giving maximum yield	Figure No.	5.51	5.52	5.57	5.58	5.63	5.64
	Depth of irrigation (mm)	500.00	435.00	315	255	300	210
	Yield (Kg/ha)	1243	795	2493	2451	24659.4	24838.2
	WUE (Kg/ha-mm)	2.49	1.83	7.91	9.61	82.19	118.27

5.7 Cropping Pattern produced by AWAM under Free-Cropping Distribution

AWAM model allocates land and water resources optimally to different crops grown on different soils in different allocation units, with the help of the irrigation programmes obtained for different Crop-Soil-Region units from Phases 1, 2 and 3 of AWAM. e.g. for irrigation strategy of "Optimized fixed depth irrigation- II= 35 days in Rabi season and 28 days in Summer season- Equitable distribution of water and free cropping distribution" at Location-1 the AWAM model allocated the area for only two crops among the 9 crops under consideration i.e. 45.75% area for groundnut and 54.25% area for cabbage. However considering entire Mula Right Bank Canal command area AWAM allocated 24% area for Groundnut and 76% area for cabbage. Accordingly AWAM allocated location wise the area for different crops for different irrigation strategies. Some of the Cropping Patterns produce by AWAM under Free Cropping for different irrigation strategies are presented in APPENDIX-D1. In practice, market factors would probably limit the scope to expand the areas of these crops without a significant reduction in prices and benefits.

5.8 Conclusions

In this chapter the results are presented sequentially as described in section 5.1.6.

5.8.1 Response of irrigation strategies in different soils

The response of different irrigation strategies to the water use and actual yield in different soils is discussed for single wheat crop for irrigation interval of 21 days.

It is seen from Tables 5.7, 5.13, 5.19 and 5.25 that comparing the different irrigation strategies for wheat grown on Soil 001 to Soil 004 for irrigation interval of 21 days, the variable depth of irrigation (VDI) (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0.7) strategy gives almost same yield as of the fixed depth of irrigation (80 mm) and full depth of irrigation that to with higher water use efficiency and with less irrigation depth. The application of water according to variable depth of irrigation (VDI) strategy is operationally and management point of view not convenient. However FxDI is convenient to manage in the field.

5.8.2. Effect of irrigation interval on yield and water use

To analyse the impact of irrigation interval on yield and water use a single crop i.e. wheat is grown on soil 002 with full depth of irrigation and different irrigation interval viz. 14 days, 21 days, 28 days and 35 days are considered.

It is seen from Table 5.30 that the irrigation interval of 14 days gives maximum yield and close/equal to maximum yield with highest irrigation depth and water use efficiency (WUE) than 28 and 35 days of irrigation interval but lower water use efficiency (WUE) than 21 days of irrigation interval.

5.8.3 Comparison of different irrigation strategies for fixed cropping, FWD for 14 and 21 days of irrigation interval when wheat crop grown on Soil 002

The 14 and 21 days of irrigation interval are selected as discussed in section 5.2 to 5.6. It is revealed that, the irrigation interval of 21 days is more than the required one to keep the available soil moisture above ADL in the root zone. Therefore for neatly comparison and to decide policy, the irrigation interval of 14 and 21 days are selected. Therefore the effect of 14 and 21 days of irrigation interval with different irrigation strategy (when wheat grown on Soil 002) on yield and water use is analysed and described.

It is revealed from Table 5.31 that, the yield obtained in FDI, FxDI and VDI for 14 days of irrigation interval are almost equal, however WUE is found to be higher in VDI. The yield obtained in FDI and VDI with 21 days of irrigation interval are almost equal however WUE is observed to be higher in VDI.

5.8.4 Comparison of different irrigation depth per irrigation

From Table 5.37 it is revealed that with incremental depth of irrigation by 10 mm over 50 mm per irrigation the yield are goes on increasing up to 100 mm and then after from 100 mm to 140 mm depth of irrigation per irrigation it attains the same yield as obtained in 100 mm depth of irrigation. However the WUE is goes on increasing from 50 mm to 70 mm only and then after it declines from 80 mm to 140 mm.

5.8.5 Comparison of different strategies for Sunflower, Gram and Cabbage grown on Soil 002 at irrigation interval of 14 and 21 days

From Table 5.38 it is revealed that the WUE is observed to be maximum in VDI than FDI and FxDi in respect of all irrigation strategies and for irrigation interval of 14 and 21 days when Sunflower, Gram and Cabbage are grown on Soil 002. The yield obtained also same and equal in all the irrigation strategies for 14 and 21 days for irrigation interval except in FxDI for 21 days of irrigation interval. The results presented and discussed in this Chapter 5 are built on for the analysis and discussion in Chapter 6.

6. RESULTS AND DISCUSSION (FINAL PERFORMANCE OF THE MULA IRRIGATION SCHEME) (III)

AWAM model was run for the Mula Irrigation Project to maximise the net benefits under each irrigation strategy. AWAM model is described in Chapter 3. The data that was used for running the model is described in Chapter 5. The performance results in terms of productivity, equity, adequacy and excess were obtained for different irrigation intervals, irrigation strategies and cropping distributions. These include:

Irrigation amount: 1. Full depth irrigation (FDI); 2. Fixed depth irrigation (FxDI) and 3. Variable Depth Irrigation (VDI)

Irrigation frequency: Different combinations of irrigation interval (14, 21, 28, 35 days) in *Rabi* season and Summer season.

Water distribution: 1. Free water distribution (FWD); 2. Equitable distribution of seasonal water allocation based on CCA of AU (EDSW) is the annual equity and 3. Equitable distribution of intra-seasonal water based on CCA of AU (EDIW) is the intra-seasonal equity.

Cropping distribution: 1.Free cropping distribution; 2.Fixed cropping distribution

These results are described in this Chapter.

6.1 Area and water productivity

The area that can be irrigated and net benefits estimated for different irrigation amounts(fixed depth, full depth and variable depth) for different irrigation intervals and for free water distribution are presented in Tables 6.1 and 6.2 for free cropping and fixed cropping respectively. Where two irrigation intervals are given (e.g. 21-14) the first applies to the rabi season and the second to the summer season. Similarly the results for annual equity are presented in Tables 6.3 and 6.4 and for intra-seasonal equity (EDIW) in Tables 6.5 and 6.6. From Table 6.4 and 6.6 it is revealed that for fix cropping the results for annual equity are similar to EDIW. However from Table 6.3 and 6.5 for free cropping the annual equity and EDIW are not found to be similar.

From Table 6.1 it is revealed that for free cropping and free water distribution (FWD), with fixed depth irrigation strategy as we proceed from irrigation interval of 14 days to 35 days; the volume of irrigation increases from 76824 ha-m to 84026 ha-m and area to be irrigated increases from 65960 ha to 123560 ha. While the net benefits are increased from Rs. 5031380000 for 14 days irrigation interval to Rs. 8856100000 for 35-28 days of irrigation interval and then after it is decreased i.e. Rs. 8818210000 for 35 days irrigation interval. In case of full and variable depth of irrigation the same trend is observed.

Table 6.1 Area irrigated and net benefit estimated for free cropping and free water distribution (FWD)

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	65960	76824	5031380000	43435	53703	2839020000	78740	55622	5655080000
2	21-14	83358	72023	7174610000	56063	58947	4063260000	72920	48877	7141360000
3	21	87821	72023	7170000000	62554	64883	4074250000	79833	56909	7152530000
4	28-21	94886	79225	7205690000	67015	66938	4708030000	114535	63463	7377310000
5	28	100138	76824	7200690000	62642	58607	4696290000	100138	76824	7200690000
6	35-28	117452	84026	8856100000	69730	72102	4945350000	112851	72793	8946920000
7	35	123560	84026	8818210000	75513	73332	4905240000	118634	75224	8906800000

Table 6.2 Area irrigated and net benefit estimated for fixed cropping and free water distribution (FWD)

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	50546	69969	1015770000	39573	51212	784356000	66351	59173	1311620000
2	21-14	71318	85206	1376130000	47709	57220	953383000	66832	58756	1335420000
3	21	71280	71988	1366270000	47709	54204	946580000	79048	57792	1483490000
4	28-21	86647	83430	1509360000	60110	69958	1146320000	85093	62617	1539790000
5	28	85860	70959	1477140000	59794	66852	1127930000	85860	70959	1477140000
6	35-28	102882	75765	1647310000	61106	65746	1099300000	87996	65599	1532260000
7	35	104155	75169	1629770000	61106	62457	1079850000	88123	65147	1509123000

From Table 6.2 for fixed cropping and free water distribution (FWD) with fixed depth of irrigation, no particular trend is found between area under irrigation and depth but the net benefits are found to be increased from 14 days to 35-28 days irrigation interval. The same trend is observed for all the rest of the strategies with full and variable depth of irrigation (Table 6.3, 6.4, 6.4, 6.5 and 6.6). However, for fixed cropping and free water distribution (FWD) (Table 6.2) in case of full and variable depth of irrigation the maximum net benefits are obtained with an irrigation interval 28-21 days for 69958 ha-m and 62617 ha-m volume of irrigation water respectively.

Table 6.3 Area irrigated and net benefit estimated for free cropping and annual equity

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	63298	76824	5019440000	40693	53630	2828180000	77382	55698	5647900000
2	21-14	81415	72023	7159210000	53719	58423	4050650000	71729	48693	7110890000
3	21	85744	72023	7154560000	60226	64925	4064510000	78734	56007	7123280000
4	28-21	94061	79218	7195620000	65920	67248	4690590000	77098	33297	7198490000
5	28	99593	76824	7189470000	62134	59180	4680440000	99593	76824	7189470000
6	35-28	117474	84026	8844960000	64576	64871	4922390000	78052	27089	6896580000
7	35	122871	82110	8804040000	59434	51921	4871640000	77645	27089	6877410000

From Table 6.3 it is revealed that for free cropping and annual equity in case of full depth of irrigation maximum net benefits are obtained with an irrigation interval of 35-28 days with 64871 ha-m volume of irrigation water while for variable depth of irrigation maximum net benefits are obtained with an irrigation interval of 28-21 days and with 33297 ha-m volume of irrigation water.

Table 6.4 Area irrigated and net benefit estimated for fixed cropping and annual equity

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	49033	69058	973163000	35655	50955	710889000	57813	50800	994890000
2	21-14	70804	80181	1342490000	44971	57210	886009000	62134	53596	1417555000
3	21	70463	68702	1326200000	40475	48507	789305000	65134	41177	1497899000
4	28-21	85492	73406	1461460000	38381	45368	710298000	67123	43052	1413745000
5	28	83897	67459	1424720000	34114	38343	621650000	64755	42647	1459436000
6	35-28	99115	69153	1570790000	31302	33567	548390000	59991	39510	1313678000
7	35	99099	64185	1554500000	30534	31059	525003000	58750	38187	1219871000

From Table 6.4 it is revealed that for fixed cropping and annual equity in case of full depth of irrigation maximum net benefits are obtained with an irrigation interval of 21-14 days with 57210 ha-m volume of irrigation water while for variable depth of irrigation maximum net benefits are obtained for an irrigation interval of 21 days and with 41177 ha-m volume of irrigation water.

Table 6.5 Area irrigated and net benefit estimated for free cropping and intra-seasonal equity

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	61821	76824	4714010000	25492	17314	877357000	31283	27488	3245767000
2	21-14	80339	72023	6918040000	29123	21198	1176542000	36165	31195	4398631000
3	21	84838	72023	6913650000	29991	24040	1192789000	36756	31705	4473892000
4	28-21	94784	79225	7009530000	30391	26967	1321830000	78719	23971	4494830000
5	28	100226	76824	7003880000	29558	25972	1344210000	100226	76824	7003880000
6	35-28	114534	84026	8565480000	37397	25773	2193530000	42187	16931	4268910000
7	35	121194	84026	8527280000	37397	25773	2193530000	42187	16931	4268910000

From Table 6.5 it is revealed that for free cropping and intra-seasonal equity with full depth of irrigation, maximum net benefits are obtained for an irrigation interval of 35-28 days with 25773 ha-m volume of irrigation water while for variable depth of irrigation maximum net benefits are obtained for an irrigation interval of 28 days and with 76824 ha-m volume of irrigation water.

Table 6.6 Area irrigated and net benefit estimated for fixed cropping and intra-seasonal equity

Sr. No.	Irrigation interval (days)	Fixed depth			Full depth			Variable depth		
		Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)	Area (ha)	Total Water Required (ha-m)	Net benefits (Rs)
1	14	47705	73343	952684000	26723	18171	111234000	48712	42803	1012345000
2	21-14	69851	77952	1327840000	29187	21245	423456000	70053	60427	1397865000
3	21	69851	66101	1316420000	32545	26088	523456000	70186	60359	1412345000
4	28-21	84172	68919	1439670000	39823	32527	563768000	86167	61238	1445678000
5	28	83578	60513	1402520000	40123	35151	401123000	83578	60513	1402520000
6	35-28	102263	62764	1478860000	38767	35964	377865000	73823	52466	1279876000
7	35	102263	59252	1468090000	37878	37230	354767000	70536	50129	1214555000

From Table 6.6 it is observed that for fixed cropping and intra-seasonal equity in case of full and variable depth of irrigation maximum net benefits are obtained with an irrigation interval of 28-21 days with 32527 ha-m and 61238 ha-m volume of irrigation water respectively.

Variation of Net benefits for different strategies for fixed depth, full depth and variable depth is plotted in Figure 6.1, 6.2 and 6.3 respectively. From Figure 6.1 it is observed that in respect of fix depth of irrigation the net benefits increases with increase in irrigation interval but only up to 35-28 days of irrigation interval for all the cases i.e. for free cropping and free water distribution (FWD), fixed cropping and free water distribution (FWD), free cropping and annual equity, fixed cropping and annual equity, free cropping and intra-seasonal equity and fixed cropping and intra-seasonal equity. While From Figure 6.2 and 6.3 for full and variable depth the maximum net benefits obtained with the optimum irrigation interval and season in which crops are grown.

Area and net benefit productivity values are estimated from the area irrigated and net benefit estimated for different management scenarios by following formulae.

Area productivity = area irrigated for a particular management strategy/maximum area irrigated

Benefit productivity= Net benefits estimated for a particular management strategy/maximum net benefits.

The maximum area irrigated is found in Table 6.1 as 123560 ha. The maximum net benefit is found in Table 6.1 as Rs. 894692000.

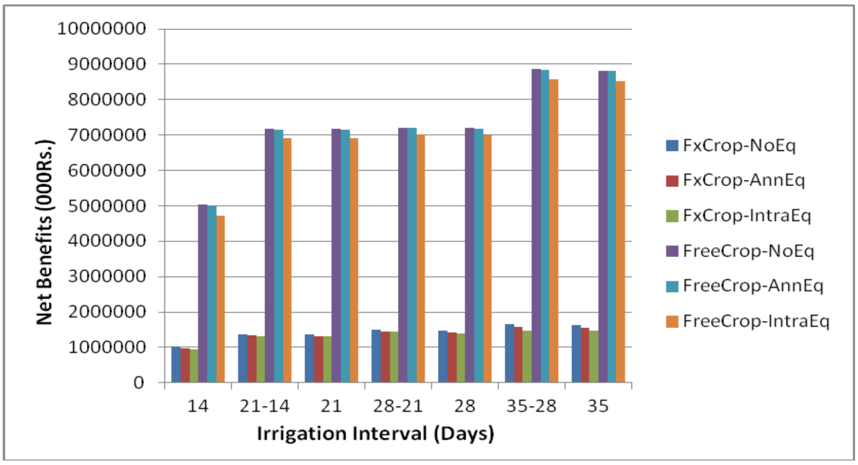


Figure 6.1 Variation of Net benefits for different strategies for Fixed Depth

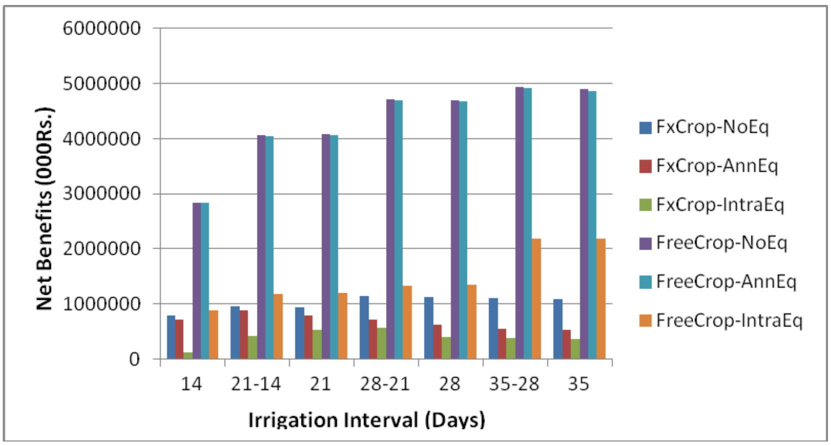


Figure 6.2 Variation of Net benefits for different strategies for Full Depth

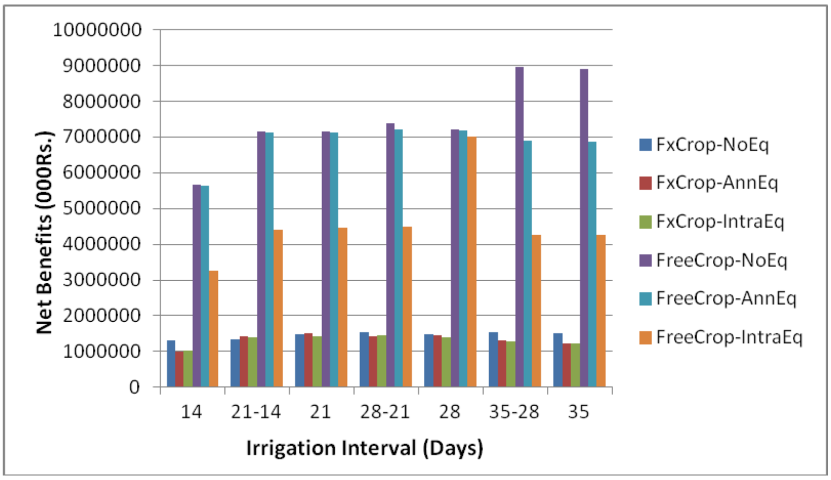


Figure 6.3 Variation of Net benefits for different strategies for Variable Depth

Area and net benefit productivity for different management scenarios are presented in Tables 6.7 to 6.12.

Table 6.7 Area and Net Benefit productivity for free cropping and free water distribution (FWD)

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.53	0.56	0.35	0.32	0.64	0.63
2	21-14	0.67	0.80	0.45	0.45	0.59	0.80
3	21	0.71	0.80	0.51	0.46	0.65	0.80
4	28-21	0.77	0.81	0.54	0.53	0.93	0.82
5	28	0.81	0.80	0.51	0.52	0.81	0.80
6	35-28	0.95	0.99	0.56	0.55	0.91	1.00
7	35	1.00	0.99	0.61	0.55	0.96	1.00

The area and benefit productivity increased with the irrigation interval for all the three irrigation strategies. The increases in values of the productivities are almost twice from the lowest irrigation interval of 14 days to the highest irrigation interval of 35 days. This is due to the fact that both the cropping and water distribution strategies are free. As AWAM provides the optimised allocation plans, it tends to select crops that are less sensitive to water stress and in that process productivity values increase with the increased irrigation interval. The productivity values are more for VDI followed by FxDI and FDI. Similar results are obtained by Smout and Gorantiwar (2005a). This is due to the fact that in case of VDI, the depths are adjusted for optimisation of area and net benefits. In case of FxDI, the fixed depth that provides the highest values of net benefits is selected by the AWAM, resulting in deficit irrigation for some instances. However in case of FDI as always the full depth is applied, the net benefits per unit area are though higher, but as less area is irrigated for the given amount of water available, the productivity values are the lowest. Balasubramaniam et. al. (1996), Sarma and Rao (1997) and Evans et.al. (2003) have reported the similar findings from their studies.

Balasubramaniam et. al. revealed that excess water utilisation caused under utilisation of the resources. Sarma and Rao reported that by use of performance indicators i.e. water supply, requirement ratio, irrigation intensity, crop production and cropping pattern increased the irrigated area, irrigation intensity which resulted in 100% crop production. Evans et. al. revealed that productivity is found to be largely dependent upon farmers proximity to water source, where upstream farmers were lacking the incentives to use water efficiently and the downstream have no incentive to use water efficiently and water resources and equity should be transfer to lower zone.

Table 6.8 Area and Net Benefit productivity for fixed cropping and free water distribution (FWD)

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.41	0.11	0.32	0.09	0.54	0.15
2	21-14	0.58	0.15	0.39	0.11	0.54	0.15
3	21	0.58	0.15	0.39	0.11	0.64	0.17
4	28-21	0.70	0.17	0.49	0.13	0.69	0.17
5	28	0.69	0.17	0.48	0.13	0.69	0.17
6	35-28	0.83	0.18	0.49	0.12	0.71	0.17
7	35	0.84	0.18	0.49	0.12	0.71	0.17

In case of fixed cropping distribution, the productivity values in general increase with the irrigation interval, but the increase is not pronounced as compared to the free cropping distribution. This is due to the fact that the crops are pre-decided with their proportions in fixed cropping distribution and the programme is not free to select the crops that provide the maximum benefits. The slight increase in productivity is due to the fact that the prolonged irrigation interval offers the deficit irrigation and it results in to bringing more area under irrigation. As in case of free cropping distribution, the productivity values are more in case of VDI, followed by FxDI and FDI.

When the free and fixed cropping distributions are compared for free water distribution (Tables 6.7 and 6.8), the productivity values area more for free cropping distribution as compared to fixed cropping distribution as in case of free cropping distribution the optimisation model in

AWAM is free to select the crops that provide more benefits per unit of water used. Smout and Gorantiwar (2005a) have also revealed the same results and stated that the monetary productivity (net benefits and productivity (area irrigated) are higher for the free cropping distribution than that for the fixed cropping distribution.

Table 6.9 Area and Net Benefit productivity for free cropping and annual equity

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.51	0.56	0.33	0.32	0.63	0.63
2	21-14	0.66	0.80	0.43	0.45	0.58	0.79
3	21	0.69	0.80	0.49	0.45	0.64	0.80
4	28-21	0.76	0.80	0.53	0.52	0.62	0.80
5	28	0.81	0.80	0.50	0.52	0.81	0.80
6	35-28	0.95	0.99	0.52	0.55	0.63	0.77
7	35	0.99	0.98	0.48	0.54	0.63	0.77

In case of free cropping distribution with equitable distribution on seasonal basis, the productivity values increase with the irrigation interval for FxDI and FDI (as observed with free water distribution). However for VDI, these values increase with the irrigation interval of 28 days and then decreases. This could be due to the fact that the allocation of water to less productive units (which is inherent in equitable distribution of water) results in marked decrease in yield at higher irrigation interval due to the more stress. In general VDI is having more productivity followed by FxDI and FDI (as observed with free water distribution). When the free cropping distribution for free water distribution is compared with free cropping distribution for equitable water distribution on seasonal basis, the productivity values are less in case of equitable water distribution for the obvious reason that in case of equitable water distribution, the water tends to be allocated to the less productive units (units with unfavourable soils and units that are at the tail end of the distribution system). Levite and Sally (2002) has also reported the similar results.

Table 6.10 Area and Net Benefit productivity for fixed cropping and annual equity

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.40	0.11	0.29	0.08	0.47	0.11
2	21-14	0.57	0.15	0.36	0.10	0.50	0.16
3	21	0.57	0.15	0.33	0.09	0.53	0.17
4	28-21	0.69	0.16	0.31	0.08	0.54	0.16
5	28	0.68	0.16	0.28	0.07	0.52	0.16
6	35-28	0.80	0.18	0.25	0.06	0.49	0.15
7	35	0.80	0.17	0.25	0.06	0.48	0.14

In case of fixed cropping distribution with equitable distribution on seasonal basis, the productivity values increase with the irrigation interval for FxDI (as observed with free water distribution). However for FDI and VDI, these values increase with the irrigation interval of 28 days and then decreases. In general VDI is having more productivity followed by FxDI and FDI (as observed with free water distribution). When the fixed cropping distribution for free water distribution is compared with fixed cropping distribution for equitable water distribution on seasonal basis, the productivity values are less in case of equitable water distribution These are similar to the results for free cropping discussed above.

Table 6.11 Area and Net Benefit productivity for free cropping and intra-seasonal equity

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.50	0.53	0.21	0.10	0.25	0.36
2	21-14	0.65	0.77	0.24	0.13	0.29	0.49
3	21	0.69	0.77	0.24	0.13	0.30	0.50
4	28-21	0.77	0.78	0.25	0.15	0.64	0.50
5	28	0.81	0.78	0.24	0.15	0.81	0.78
6	35-28	0.93	0.96	0.30	0.25	0.34	0.48
7	35	0.98	0.95	0.30	0.25	0.34	0.48

Almost similar results are obtained for free cropping distribution and intra-seasonal water distribution as in case of for free cropping distribution and seasonal water distribution. The productivity values are less in case of intra-seasonal distribution of water compared with the seasonal distribution of water for the reasons that in case of intra-seasonal distribution of water irrespective of crop growth stages, the water is distributed equitably and in case of seasonal distribution of water, water is distributed equitable seasonally and seasonal allocation of water is then optimally distributed over the crops season of the specified crop.

Table 6.12 Area and Net Benefit productivity for fixed cropping and intra-seasonal equity

Sr. No.	Irrigation interval (days)	Fixed depth		Full depth		Variable depth	
		Area	Net benefits	Area	Net benefits	Area	Net benefits
1	14	0.39	0.11	0.22	0.01	0.39	0.11
2	21-14	0.57	0.15	0.24	0.05	0.57	0.16
3	21	0.57	0.15	0.26	0.06	0.57	0.16
4	28-21	0.68	0.16	0.32	0.06	0.70	0.16
5	28	0.68	0.16	0.32	0.04	0.68	0.16
6	35-28	0.83	0.17	0.31	0.04	0.60	0.14
7	35	0.83	0.16	0.31	0.04	0.57	0.14

The trend of free cropping distribution with equitable intra- seasonal distribution of water; and fixed cropping distribution with equitable intra- seasonal distribution of water is similar. However, as discussed above the productivity values are less in case of intra-seasonal distribution compared to seasonal distribution.

6.2 Equity and Adequacy

Equity and adequacy values were computed for different irrigation strategies and cropping distributions, as described in Chapter 5.

Equities are estimated as Equity 1 (area distribution), Equity 2 (water distribution to the farmer, taking account of conveyance and distribution efficiencies), Equity 3 (water distribution to the tertiary/watercourse, taking account of conveyance efficiency), Equity 4 (water distribution ignoring efficiency) and Equity 5 (benefits obtained). Equity and adequacy values were calculated as set out in Chapter 3 section 3.2.2.2 and 3.2.2.3. The Equity and Adequacy results for different irrigation strategies are presented in Tables 6.13 to 6.30. Makin et.al. (1991) have worked on the performance assessment for two seasons at scheme level (*Kraseio* Project) using different indicators, namely: actual versus targeted supply, equity, reliability and adequacy measures. They have observed that with an introduced computerized irrigation scheduling the accuracy of information about areas greatly improved, more realistic targets were set and the numbers of complaints from farmer groups about inadequate supplies were decreased. They have also reported that with an introduction of computerised irrigation scheduling less no. of complaints regarding inadequate supplies were received and also less no. of complaints from tail reach farmers in respect of inadequacy were received.

Table 6.13 Equity and adequacy for free cropping and free water distribution (FWD) - Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.358	0.360	0.384	0.261	0.464	0.715
2	21-14	0.388	0.342	0.364	0.254	0.519	0.716
3	21	0.332	0.220	0.238	0.181	0.517	0.747
4	28-21	0.288	0.071	0.078	0.080	0.417	0.742
5	28	0.282	0.080	0.092	0.096	0.420	0.760
6	35-28	0.429	0.124	0.142	0.146	0.693	0.702
7	35	0.429	0.133	0.153	0.174	0.701	0.706

Table 6.14 Equity and adequacy for free cropping and free water distribution (FWD) - Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.36	0.4	0.43	0.29	0.3	1
2	21-14	0.47	0.5	0.52	0.39	0.4	1
3	21	0.39	0.4	0.42	0.31	0.4	1
4	28-21	0.4	0.3	0.32	0.27	0.4	1
5	28	0.34	0.1	0.15	0.15	0.4	1
6	35-28	0.38	0.2	0.18	0.18	0.5	1
7	35	0.38	0.2	0.19	0.21	0.5	1

Table 6.15 Equity and adequacy for free cropping and free water distribution (FWD) - Variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.52	0.4	0.43	0.34	0.5	0.751
2	21-14	0.4	0.4	0.42	0.32	0.5	0.746
3	21	0.45	0.5	0.46	0.38	0.5	0.685
4	28-21	0.47	0.2	0.24	0.18	0.5	0.556
5	28	0.28	0.1	0.09	0.1	0.4	0.760
6	35-28	0.46	0.1	0.16	0.16	0.7	0.664
7	35	0.46	0.1	0.16	0.18	0.7	0.678

Table 6.16 Equity and adequacy for fixed cropping and free water distribution (FWD) - Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.55	0.5	0.53	0.52	0.5	0.778
2	21-14	0.66	0.4	0.42	0.62	0.6	0.771
3	21	0.57	0.3	0.38	0.55	0.5	0.762
4	28-21	0.64	0.3	0.39	0.61	0.5	0.695
5	28	0.65	0.3	0.37	0.56	0.5	0.642
6	35-28	0.9	0.4	0.48	0.74	0.7	0.617
7	35	0.91	0.4	0.47	0.75	0.7	0.636

Table 6.17 Equity and adequacy for fixed cropping and free water distribution (FWD)- Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.46	0.5	0.61	0.45	0.4	1
2	21-14	0.51	0.4	0.5	0.48	0.4	1
3	21	0.51	0.4	0.47	0.45	0.4	1
4	28-21	0.44	0.3	0.31	0.41	0.4	1
5	28	0.46	0.3	0.3	0.4	0.4	1
6	35-28	0.68	0.3	0.37	0.51	0.5	1
7	35	0.68	0.3	0.37	0.5	0.5	1

Table 6.18 Equity and adequacy for fixed cropping and free water distribution (FWD)- Variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.53	0.4	0.41	0.47	0.5	0.689
2	21-14	0.51	0.4	0.38	0.49	0.5	0.688
3	21	0.58	0.3	0.36	0.44	0.5	0.600
4	28-21	0.63	0.3	0.35	0.5	0.5	0.604
5	28	0.65	0.3	0.37	0.56	0.5	0.642
6	35-28	0.67	0.3	0.35	0.58	0.5	0.633
7	35	0.69	0.3	0.33	0.58	0.5	0.631

Table 6.19 Equity and adequacy for free cropping and annual equity- Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.55	1	0.78	0.52	0.5	0.710
2	21-14	0.6	1	0.78	0.52	0.5	0.716
3	21	0.61	1	0.78	0.52	0.6	0.746
4	28-21	0.58	1	0.78	0.52	0.4	0.740
5	28	0.61	1	0.78	0.52	0.5	0.757
6	35-28	0.65	1	0.78	0.52	0.7	0.700
7	35	0.64	1	0.78	0.52	0.7	0.700

Table 6.20 Equity and adequacy for free cropping and annual equity- Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.43	1	0.78	0.52	0.3	1
2	21-14	0.52	1	0.78	0.52	0.4	1
3	21	0.46	1	0.78	0.52	0.4	1
4	28-21	0.48	1	0.78	0.52	0.4	1
5	28	0.46	1	0.78	0.52	0.4	1
6	35-28	0.48	1	0.78	0.52	0.5	1
7	35	0.47	1	0.78	0.52	0.5	1

Table 6.21 Equity and adequacy for free cropping and annual equity- variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.63	1	0.78	0.52	0.5	0.670
2	21-14	0.61	1	0.78	0.52	0.6	0.679
3	21	0.57	1	0.78	0.52	0.6	0.728
4	28-21	0.68	1	0.78	0.52	0.5	0.594
5	28	0.61	1	0.78	0.52	0.5	0.757
6	35-28	0.78	1	0.78	0.52	0.5	0.464
7	35	0.89	1	0.78	0.52	0.5	0.467

Table 6.22 Equity and adequacy for fixed cropping and annual equity- Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.45	1	0.78	0.52	0.4	0.762
2	21-14	0.72	1	0.78	0.52	0.6	0.751
3	21	0.69	1	0.78	0.52	0.5	0.746
4	28-21	0.81	1	0.78	0.52	0.5	0.663
5	28	0.84	1	0.78	0.52	0.5	0.635
6	35-28	0.96	1	0.78	0.52	0.7	0.599
7	35	0.97	1	0.78	0.52	0.7	0.594

Table 6.23 Equity and adequacy for fixed cropping and annual equity- Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.47	1	0.78	0.52	0.5	1
2	21-14	0.48	1	0.78	0.52	0.5	1
3	21	0.44	1	0.78	0.52	0.5	1
4	28-21	0.43	1	0.78	0.52	0.5	1
5	28	0.41	1	0.78	0.52	0.5	1
6	35-28	0.4	1	0.78	0.52	0.5	1
7	35	0.4	1	0.78	0.52	0.5	1

Table 6.24 Equity and adequacy for fixed cropping and annual equity- variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.47	1	0.78	0.52	0.5	0.762
2	21-14	0.82	1	0.78	0.52	0.5	0.751
3	21	0.71	1	0.78	0.52	0.5	0.746
4	28-21	0.85	1	0.78	0.52	0.5	0.663
5	28	0.87	1	0.78	0.52	0.5	0.635
6	35-28	0.98	1	0.78	0.52	0.5	0.599
7	35	0.99	1	0.78	0.52	0.5	0.600

Table 6.25 Equity and adequacy for free cropping and intra-seasonal equity- Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.53	1	0.78	0.52	0.5	0.707
2	21-14	0.60	1	0.78	0.52	0.5	0.719
3	21	0.60	1	0.78	0.52	0.5	0.75
4	28-21	0.74	1	0.78	0.52	0.5	0.739
5	28	0.71	1	0.78	0.52	0.5	0.756
6	35-28	0.78	1	0.78	0.52	0.7	0.713
7	35	0.98	1	0.78	0.52	0.7	0.536

Table 6.26 Equity and adequacy for free cropping and intra-seasonal equity- Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.44	1	0.78	0.52	0.5	1
2	21-14	0.45	1	0.78	0.52	0.5	1
3	21	0.44	1	0.78	0.52	0.5	1
4	28-21	0.44	1	0.78	0.52	0.5	1
5	28	0.45	1	0.78	0.52	0.5	1
6	35-28	0.44	1	0.78	0.52	0.5	1
7	35	0.44	1	0.78	0.52	0.5	1

Table 6.27 Equity and adequacy for free cropping and intra-seasonal equity- variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.82	1	0.78	0.52	0.5	0.727
2	21-14	0.80	1	0.78	0.52	0.5	0.82
3	21	0.79	1	0.78	0.52	0.5	0.665
4	28-21	0.78	1	0.78	0.52	0.4	0.359
5	28	0.71	1	0.78	0.52	0.5	0.756
6	35-28	0.48	1	0.78	0.52	0.5	0.553
7	35	0.48	1	0.78	0.52	0.5	0.553

Table 6.28 Equity and adequacy for fixed cropping and intra-seasonal equity- Fixed depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.52	1	0.78	0.52	0.5	0.760
2	21-14	0.62	1	0.78	0.52	0.5	0.750
3	21	0.62	1	0.78	0.52	0.5	0.739
4	28-21	0.77	1	0.78	0.52	0.5	0.649
5	28	0.81	1	0.78	0.52	0.6	0.586
6	35-28	0.98	1	0.78	0.52	0.7	0.538
7	35	0.98	1	0.78	0.52	0.7	0.536

Table 6.29 Equity and adequacy for fixed cropping and intra-seasonal equity- Full depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.42	1	0.78	0.52	0.6	1
2	21-14	0.51	1	0.78	0.52	0.6	1
3	21	0.53	1	0.78	0.52	0.6	1
4	28-21	0.58	1	0.78	0.52	0.6	1
5	28	0.61	1	0.78	0.52	0.6	1
6	35-28	0.68	1	0.78	0.52	0.6	1
7	35	0.68	1	0.78	0.52	0.6	1

Table 6.30 Equity and adequacy for fixed cropping and intra-seasonal equity- Variable depth

Sr. No.	Irrigation interval (days)	Equity					Adequacy
		1	2	3	4	5	
1	14	0.61	1	0.78	0.52	0.6	0.887
2	21-14	0.72	1	0.78	0.52	0.6	0.892
3	21	0.72	1	0.78	0.52	0.6	0.775
4	28-21	0.80	1	0.78	0.52	0.6	0.598
5	28	0.81	1	0.78	0.52	0.6	0.586
6	35-28	0.98	1	0.78	0.52	0.6	0.555
7	35	0.98	1	0.78	0.52	0.6	0.532

From the Equity and Adequacy values obtained (Table 6.13 to 6.30), the graphs representing variation of Equity and Adequacy for different irrigation strategies for fixed, full and variable depth are plotted.

Figures 6.4, 6.5 and 6.6 show the variation of Equity for different irrigation strategies for fixed, full and variable depth respectively.

It is observed from Figure 6.4, 6.5 and 6.6 that the maximum Equity is achieved in case of annual and intra-seasonal equity water distribution in both fixed and free cropping distribution for all irrigation intervals.

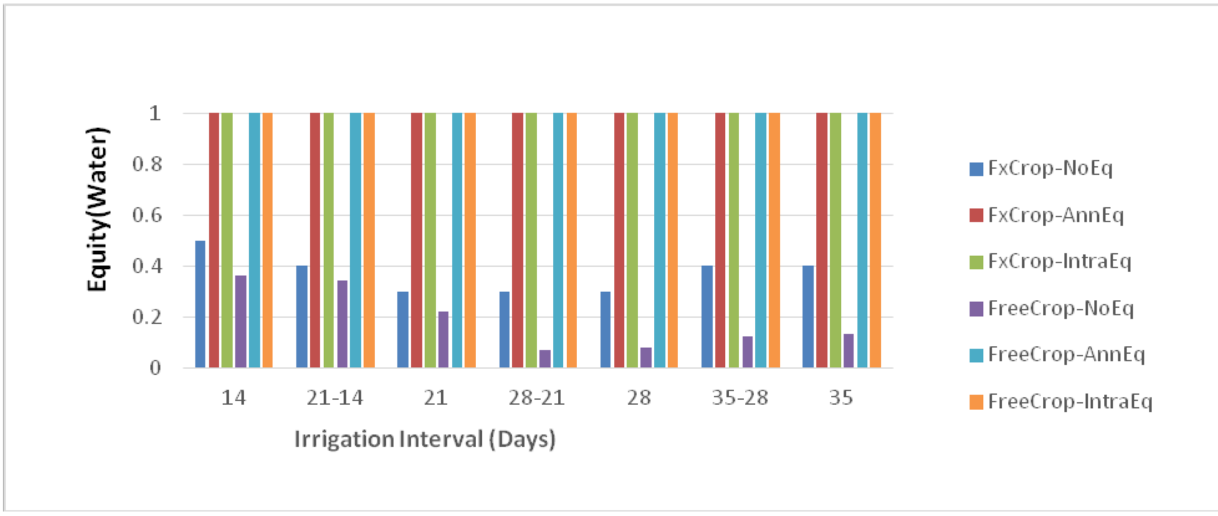


Figure 6.4 Variation of Equity for different irrigation strategies for Fixed Depth

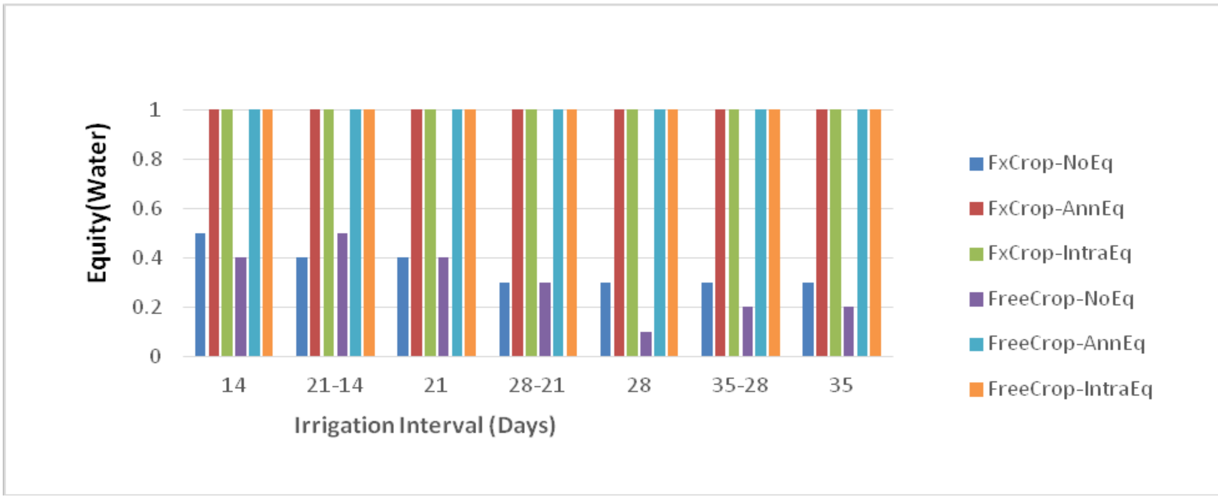


Figure 6.5 Variation of Equity for different irrigation strategies for Full Depth

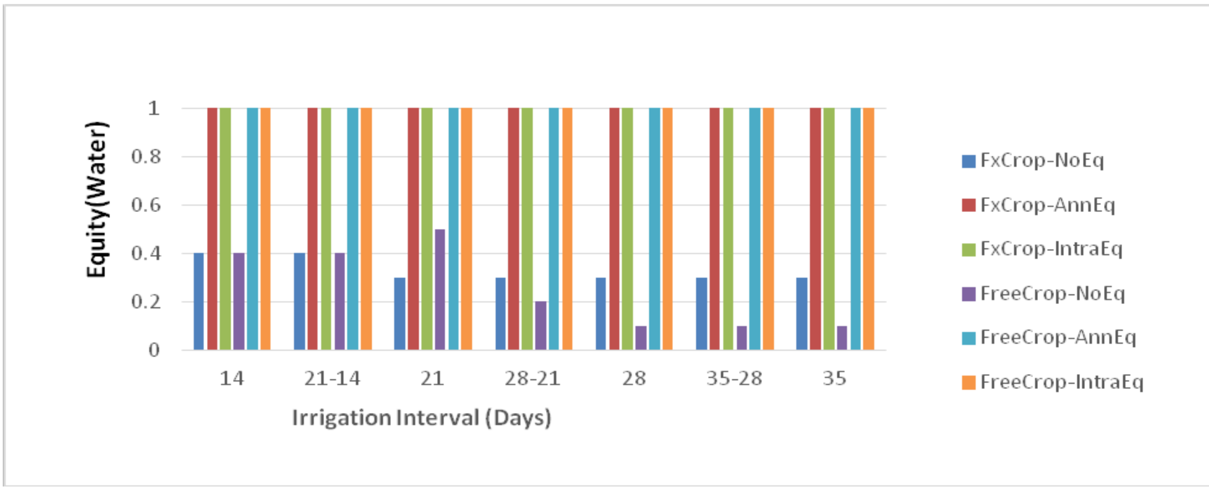


Figure 6.6 Variation of Equity for different irrigation strategies for Variable Depth

The equity values are as expected more or unity for equitable water distribution compared to free water distribution. Jahromi et.al. (2000) and Evans et. al. (2003) have obtained the similar results. While for free water distribution, equity values are more in case of Full depth of irrigation compared to Fixed and Variable depth approach. Also for the free water distribution the equity values are more in case Fixed cropping distribution compare to Free cropping distribution. In case of Fixed depth approach, fixed depth is allocated; however in case of Full depth and Variable depth approaches, the depth varies as per the crop and soil characteristics

Figure 6.7, 6.8 and 6.9 shows the variation of Adequacy for different irrigation strategies for fixed, full depth and variable depth respectively.

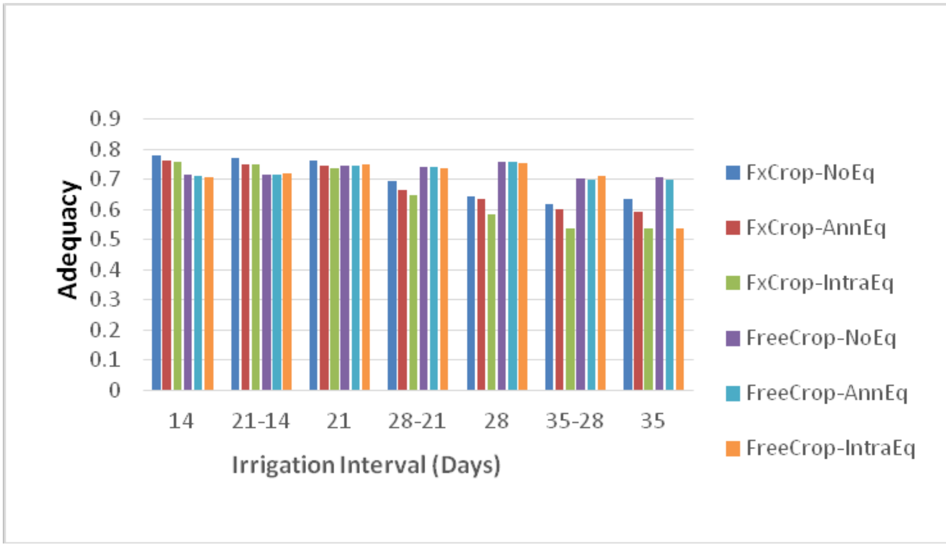


Figure 6.7 Variation of Adequacy for different irrigation strategies for Fixed Depth

From Figure 6.7 it is observed that for Fixed Depth of irrigation the highest adequacy (0.8) is obtained at 21 and 28 days irrigation interval with free cropping and intra-seasonal equity while least adequacy was found in case of 35 days irrigation interval with free cropping and intra-seasonal equity. For free cropping highest adequacy is found at irrigation interval of 28 days in terms of equity of water distribution. While in case of fixed cropping Adequacy goes on decreasing with increase in irrigation interval. From Figure 6.8 for Full Depth of irrigation Adequacy was found to be maximum i.e.1 irrespective of the strategy in terms of cropping, irrigation interval and equity of water distribution. The similar results are obtained by Smout and Gorantiwar (2005a) and they stated that adequacy and excess are constant for full irrigation. It is observed from Figure 6.9 that in case of Variable Depth of irrigation the maximum Adequacy is attained for irrigation strategy with fixed cropping and intra-seasonal equity at irrigation interval of 21-14 days. While, Adequacy is least for free cropping and intra-seasonal equity at irrigation interval of 28-21 days.

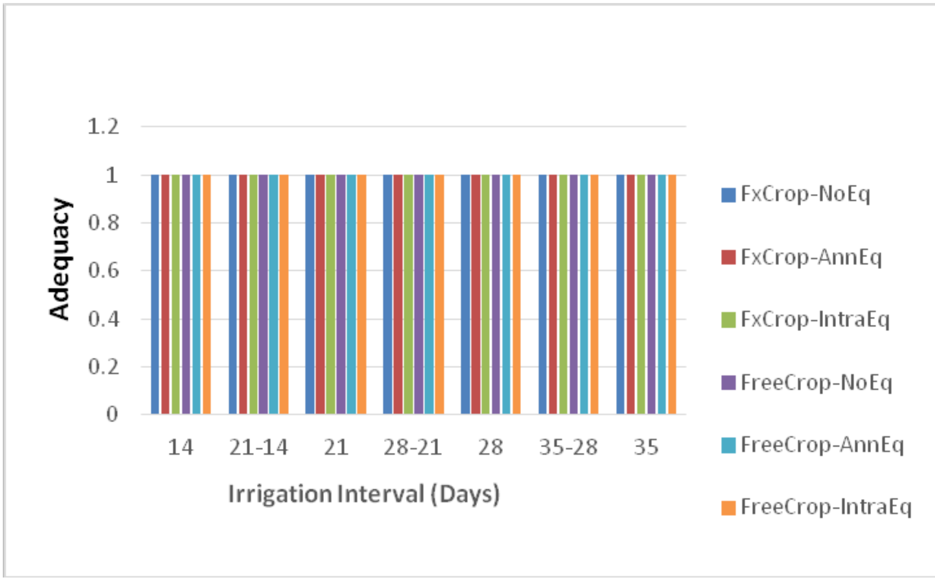


Figure 6.8 Variation of Adequacy for different irrigation strategies for Full Depth

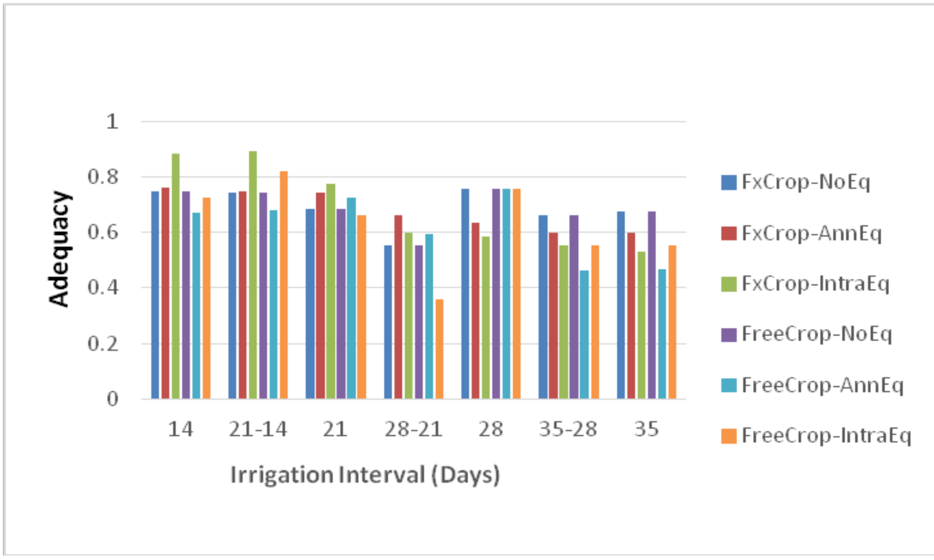


Figure 6.9 Variation of Adequacy for different irrigation strategies for Variable Depth

In general, the adequacy values are more in full depth of irrigation followed by variable depth irrigation and fixed depth irrigation. Smout and Gorantiwar (2005a) have also reported that the adequacy is maximum i.e. 1 in full depth of irrigation. In case of full depth of irrigation, the water is applied to fill the root zone of crop to field capacity; however in case of variable depth, it is not necessary all the time. It depends on the net benefit optimisation. In case of fixed depth irrigation, the fixed depth that is applied may not be the one that is required to fill the root zone to the field capacity.

The above results on productivity, equity and adequacy show that these performance measures are sensitive to crop, soil, climate, irrigation interval, irrigation depth strategies, free and fixed cropping distribution, free and equitable water distribution and relative location of different units in the command area of the irrigation scheme. Hence it is very difficult to arrive on the particular management scenario unless those are analysed properly. It is also necessary to obtain the allocation plans for optimising the performance measures rather than obtaining the allocation plans for pre specified strategies. Thus in case of heterogeneous irrigation scheme, it is necessary to integrate all these parameters together (as described in this section) and obtain the performance indices and then further integrate different performance indices to select the particular irrigation strategy (as described in the next section). Levite and Sally (2002) and Smout and Gorantiwar (2005a) are having the similar opinion from their studies which are in close agreement.

6.3 Final Performance Index (FPI)

As described in Chapter IV, section 4.4 the average weights of different performance measures (monetary productivity, equity in water distribution and adequacy) obtained from farmers for different reaches are presented in Table 6.31.

Table 6.31 The average weights of different performance measures (monetary productivity, equity in water distribution and adequacy)

Reach	Performance objectives		
	Productivity	Equity	Adequacy
Head	0.57	0.07	0.36
Middle	0.35	0.17	0.48
Tail	0.06	0.70	0.24
Mean	0.33	0.31	0.36

The FPI was then computed by using the approach described and developed by Gorantiwar and Smout (2010) for head, middle and tail reach farmers using the weights obtained from AHP by compromise programming presented above and following the procedure described in chapter 3, section 3.2.2. The balancing factor of 1 was considered for this purpose. The Table 6.32 presents highest and lowest FPIs with corresponding irrigation strategy obtained from the perspective of head, middle and tail reach farmers. Santhi and Pundarikanthan (2000) have also considered assigned weights less than 1.00. The values of final performance index as obtained for all different irrigation strategies considered in the study are given in APPENDIX– D.

Table 6.32 Comparison of Highest and Lowest FPIs with corresponding irrigation strategy obtained

FPI and corresponding irrigation strategy	**Reach**		
	Head	**Middle**	**Tail**
Highest FPI			
Value	0.83	0.84	0.97
Irrigation strategy	Optimized fixed depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution	Full depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution	Full depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution
Lowest FPI			
Value	0.24	0.28	0.19
Irrigation strategy	Optimised variable depth irrigation II= 21 days Free water distribution Fixed cropping distribution	Optimised variable depth irrigation II= 21 days Free water distribution Fixed cropping distribution	Optimized fixed depth irrigation II= 28 days in Rabi season and 21 days in Summer season Free water distribution Free cropping distribution

From Table 6.32, it is interesting to note that the strategies that best met the farmers' preferences (highest FPI), were same for middle reach and tail reach farmers however it is different for head reach. It is also interesting to note that the preferences of the head, middle and tail reach farmers, irrespective of their relative location in irrigation scheme, were best met by strategies which include the equitable distribution of water. For middle and tail reach farmers, full depth irrigation would give the highest FPI, while for head reach farmers optimised fixed depth would be best. It is also seen that for head and middle reach farmers a strategy with fixed cropping distribution and free water distribution would be worst for meeting the preferences of head and middle reach farmers while for tail reach farmers a strategy with free water and free cropping distribution would be worst. Gaur et. al. (2008) have similar findings during their study.

Table 6.32, also shows that the highest FPIs are substantially higher (>2x) than the lowest FPIs at each location.

Implications of employing the irrigation strategies

The strategy with higher final performance index (FPI) needs to be chosen for the land and water allocation and operation of the irrigation scheme. It could be possible that the irrigation strategy associated with the highest FPI could be different for different reaches as the relative preferences of the farmers to different performance measures may vary. That was found in this study and also it was observed that the irrigation strategy associated with the maximum FPI is similar for middle and tail reach farmers and different for head reach farmers. These are given below.

Head reach farmers	Middle reach farmers	Tail reach farmers
Optimized fixed depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution	Full depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution	Full depth irrigation II= 35 days in Rabi season and 28 days in Summer season Equitable distribution of seasonal water Free cropping distribution

The irrigation strategy is the combination of four different parameters namely; irrigation depth, irrigation interval, distribution of water and cropping distribution. If the irrigation strategies for head, middle and tail reach farmers are same on the basis of irrigation depth and cropping distribution and differ on the basis of distribution of water and irrigation interval, then it is difficult to employ the irrigation strategies based on FPI (which are different for different reaches) for whole of the command area of irrigation scheme, due to the difficulties of delivering water at different irrigation interval in different parts of the command area of the irrigation scheme and allocation of different proportion of water to different farmers in the scheme. However on the other hand if the irrigation strategies for head, middle and tail reach farmers are same on the basis of distribution of water and irrigation interval and differ on the basis of irrigation depth and cropping distribution, there may not be any problems associated with the implementation of the irrigation strategies, though these are different for different reaches; as the crops that different farmers grow and the depth that different farmers apply do not interfere with distribution of water and operation of the irrigation scheme.

In this particular case, the irrigation strategies for head, middle and tail reaches are same on the basis of irrigation interval, cropping distribution and water distribution and differ on the basis of irrigation depth only. Therefore there should not be any difficulty in implementing the irrigation strategies that are obtained on the basis of FPI.

It is to state that this may not be the situation always. Therefore there is a necessity of developing the procedure that will integrate the FPIs of head, middle and tail reaches and come out with the single FPI for whole of the irrigation scheme so that the irrigation strategy will be same for all the reaches of the command area or canal. Assuming that farmers throughout the whole command area have the same importance, the weights for each performance objective can be averaged, for the whole command area, as shown in Table 6.31. The FPI values for different irrigation strategies using mean weights to performance measures are computed and presented in APPENDIX-D3. From APPENDIX-D3 the first four irrigation strategies on the basis of highest FPI values are observed to be –

1. Full depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer (FPI = 0.85)
2. Full depth irrigation with free cropping and annual equity at irrigation interval of 35 days (FPI = 0.85)
3. Full depth irrigation with free cropping and annual equity at irrigation interval of 28 days (FPI = 0.84)
4. Fixed depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer (FPI = 0.83)

However, considering the highest FPI values the first three irrigation strategies with full depth of irrigation are difficult to implement in field as stated in Chapter 5 earlier. Therefore, the option to suggest the optimum and feasible irrigation strategy to implement for entire irrigation scheme based on mean weights of performance measures is 'Fixed depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer'.

6.3.1 Existing Irrigation Strategy in MRBC

To compare the obtained best irrigation strategy based on FPI with existing irrigation strategy (Level-1) in MRBC, one year actual field data of MRBC at Level-1 i.e. for Year 2006-07 was collected and presented in Table 6.33 and APPENDIX-D2.

In the current scenario of MRBC scheme, when the canal is in operation, farmers actually irrigate their fields when and while they observe that the crops are in need of water to avoid water stress to crops, which is similar to full depth irrigation in AWAM. Regarding cropping pattern, farmers choose different crops to cultivate as per their own need and to get high price in the market as per their own judgment. At present, there is no any restriction in the existing set up to the farmers for depth of irrigation to be applied, distribution of water and crop distribution

(Farmers are free to choose the crops. For year 2006-07 there were 12 crops grown over the entire command area of MRBC). Farmers also make use of groundwater to supplement the irrigation water they receive from the canal system. This conjunctive use is outside the scope of this thesis and therefore a direct comparison cannot be made between the optimal solution from the model and the existing irrigation strategy.

Table 6.33 Actual Canal Operation Schedule for year 2006-07 (Data from Record of Maharashtra State Irrigation Department)

Canal Rotation No.	Start Date	End date	Total days of Canal operation	Total Volume of Water utilized (million cubic meter)
1	04-12-2006	17-12-2006	14	71.50
2	03-03-2007	04-04-2007	33	168.53
3	22-04-2007	29-05-2007	38	194.10

6.4 Sensitivity Analysis

6.4.1 Sensitivity of AWAM to reservoir volume

Sensitivity of AWAM model to initial reservoir volume is studied by Gorantiwar and Smout (2005b) for "Nazare Medium Irrigation Scheme" in Maharashtra State of India. Therefore that analysis is not done for the 'Mula Irrigation Scheme' under study to avoid the repetitive work. Gorantiwar and Smout have observed that, the rainfall variability during rainy months influences the reservoir storage volume. They have obtained the results for the various known initial reservoir storage volumes in terms of water available in the reservoir at the start of the planning period. For the purpose they have chosen the percentages from 100 to 10% at an interval of 10%.

Using AWAM to get the maximum total net benefits they have considered different initial reservoir storage volumes, cropping distributions and irrigation depth approaches for different sets of irrigation intervals. They found that the feasible solutions could not be obtained with initial reservoir volumes of 10, 20 and 30% of maximum reservoir storage. This was due to the commitment to allow water for other uses throughout the planning period. They have concluded that the irrigation is possible only when the reservoir is 40 % full or above, if other requirements are to be fulfilled. Further they found that the total net benefits increase linearly with the initial reservoir volume of 100% to 40% which is shown in the figure 6.10.

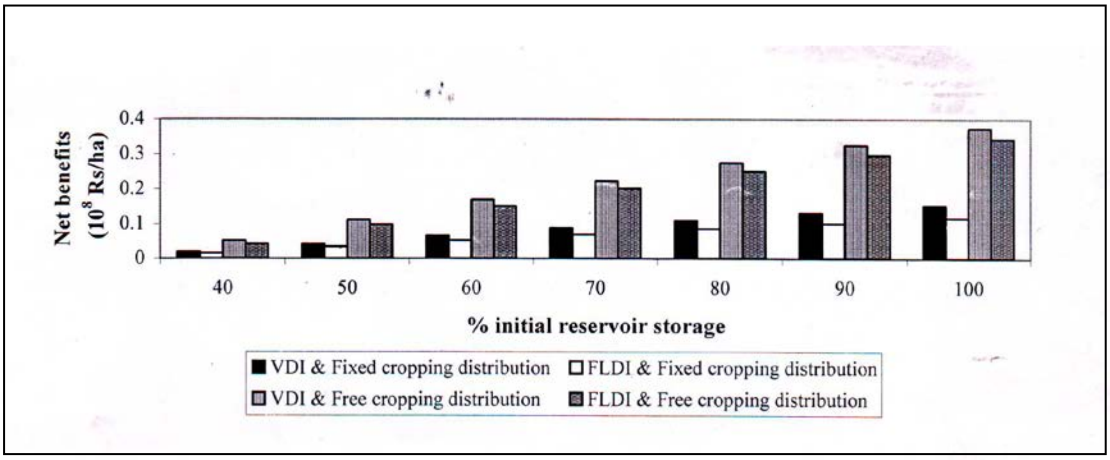


Figure 6.10 Variation of Net Benefits over the scheme for different % initial reservoir storage

From figure 6.10 it is revealed for 100% to 40% initial reservoir volume, that the maximum net benefits are obtained in VDI and Free cropping distribution followed by FLDI(Full depth of irrigation) and Free cropping distribution and least benefits are obtained in FLDI(Full depth of irrigation) and fixed cropping distribution.

From this figure it is also observed that when the initial reservoir volume i.e. 100% is reduced by 10% then the net benefits are reduced by 12.50%, 16.67%, 10.00%, 11.11% for VDI and Fixed cropping distribution, FLDI(Full depth of irrigation) and Fixed cropping distribution, VDI and free cropping distribution, FLDI(Full depth of irrigation) and free cropping distribution respectively.

6.4.2 Sensitivity of optimal solution by changes in weights

For the sensitivity analysis of optimal solution four different cases 1. Productivity = 0.33, Equity = 0.33 and Adequacy = 0.33 2. Productivity = 0.50, Equity = 0.25 and Adequacy = 0.25 3. Productivity = 0.25, Equity = 0.50 and Adequacy = 0.25 and 4. Productivity = 0.25, Equity = 0.25 and Adequacy = 0.50 of weights to different performance measures are considered and accordingly FPI values for different 126 irrigation strategies are computed and are presented in Appendix-D4 (1 to 4)

A. FPI with Productivity = 0.33, Equity = 0.33 and Adequacy = 0.33

If the weights given in Table 6.31 are considered same for three performance measures i.e. productivity, equity and adequacy the sensitivity of the results to the weights can be determined. Computed the FPI with the weight of 0.33 for productivity, equity and adequacy and presented in Appendix-D4. From Appendix-D4 it is observed that even after changes in weights of productivity, equity and adequacy and keeping the same weight of 0.33 for these three performance measures, the irrigation strategies with maximum FPIs values for the whole of the command area are observed to be:

1. Irrigation Interval-35-28 days, Full Depth, Free Cropping and Annual Equity (FPI = 0.84)
2. Irrigation Interval-35 days, Full Depth, Free Cropping and Annual Equity (FPI = 0.84)
3. Irrigation Interval-35-28 days, Fix Depth, Free Cropping and Annual Equity (FPI = 0.83).

These are the same strategies as determined in section 6.3 using weights determined by AHP. Therefore after changes in the weights the FPI values changes merely but the obtained strategy remains same.

B. FPI with Productivity = 0.50, Equity = 0.25 and Adequacy = 0.25

When the weights for different performance measures are considered to be 0.50 for Productivity, 0.25 for Equity and 0.25 for Adequacy, the FPI values are computed for different irrigation strategies, and presented in Appendix-D4. From Appendix-D4 the irrigation strategies with maximum FPIs values for the whole of the command area are observed to be:

1. Irrigation Interval-35-28 days, Fixed Depth, Free Cropping, Annual Equity (FPI =0.88)
2. Irrigation Interval-35 days, Fixed Depth, Free Cropping, Annual Equity (FPI = 0.87)
3. Irrigation Interval-35-28 days, Fixed Depth, Free Cropping, Intraseasonal Equity (FPI = 0.87)

C. FPI with Productivity = 0.25, Equity = 0.50 and Adequacy = 0.25

Here the weights for different performance measures are considered to be 0.25 for Productivity, 0.50 for Equity and 0.25 for Adequacy, and FPI values for different irrigation strategies are computed. From Appendix-D4 the irrigation strategies with maximum FPIs values for the whole of the command area are observed to be:

1. Irrigation Interval-35-28 days, Full Depth, Free Cropping, Annual Equity (FPI = 0.89)
2. Irrigation Interval-35 days, Full Depth, Free Cropping, Annual Equity (FPI = 0.88)
3. Irrigation Interval-35-28 days, Fixed Depth, Free Cropping, Annual Equity (FPI = 0.88)

D. FPI with Productivity = 0.25, Equity = 0.25 and Adequacy = 0.50

Considering the weights for different performance measures as 0.25 for Productivity, 0.25 for Equity and 0.50 for Adequacy, the FPI values for different irrigation strategies are computed and presented in Appendix-D4. The irrigation strategies with maximum FPIs values for the whole of the command area are observed to be:

1. Irrigation Interval-35-28 days, Full Depth, Free Cropping, Annual Equity (FPI = 0.89)
2. Irrigation Interval-35 days, Full Depth, Free Cropping, Annual Equity (FPI = 0.88)
3. Irrigation Interval-28 days, Full Depth, Free Cropping, Annual Equity (FPI = 0.88)

Table 6.34 Comparison among the best irrigation strategies based on FPI values for different weights to performance measures

Sr. No.	Weights to performance measures	Irrigation Strategy with Highest FPI	FPI value
1	Productivity = 0.33, Equity = 0.33 and Adequacy = 0.33	II-35-28, Full Depth, Free Cropping and Annual Equity	0.84
2	Productivity = 0.50, Equity = 0.25 and Adequacy = 0.25	II-35-28, Fixed Depth, Free Cropping and Annual Equity	0.88
3	Productivity = 0.25, Equity = 0.50 and Adequacy = 0.25	II-35-28, Full Depth, Free Cropping and Annual Equity	0.89
4	Productivity = 0.25, Equity = 0.25 and Adequacy = 0.50	II-35-28, Full Depth, Free Cropping and Annual Equity	0.89

Comparison among the best irrigation water strategies based on FPI values for different weights to performance measures is presented in Table 6.34. It is observed that irrespective of the weights given to the different performance measures the irrigation interval of 35 days in winter and 28 days in summer, Free cropping pattern and Seasonal equity are best to be applied so has to obtain best overall performance of irrigation scheme. While Fixed depth is found to be best for: Productivity = 0.50, Equity = 0.25 and Adequacy = 0.25 and for rest of the three cases of different weights given to the performance measures Full depth is observed to be best. Therefore after changes in the weights the FPI values changes merely but the obtained strategy remains same.

The fertilizer response is not considered in AWAM. Considering the number of assumptions to develop the AWAM model, it was assumed that farmers follow standard practices so that yield is a function of crop water use only, ignoring any variations in seed variety, fertiliser application, weed control, etc. It was assumed that the farmer shall apply the fertilizer as per the recommendations of Universities for different type of soils and the availability of N and P in the soil to get the required productivity.

It was also assumed for this study that the water table is too deep to enter into the root zone due to groundwater rise. If there are certain problems, particularly at Head reach regarding high ground water table and/or salinity, the farmer shall adopt the appropriate technology evolved by Universities to the particular problem. However, to get acquainted with the remedies, the farmers / stakeholders / water-users should be properly trained while recommending the suggested irrigation strategy in this study to improve the overall performance of irrigation scheme. The integrated approach is required to synchronise the combine efforts of University Researchers, Irrigation Managers and Water-users to tackle the problems occurring in Command area of irrigation scheme.

7. CONCLUSIONS

7.1 Introduction

This Chapter presents the conclusions of the research.

7.1.1 Performance of Irrigation Water Management

Benchmarking is a continuous process of measuring one's performance and practices against the best competitors and is a sequential exercise of learning from other's experience. Performance of irrigation water management can be viewed as the important step of benchmarking. Comparative performance indicators make it possible to see how well irrigated agriculture is performing at the subsystem, system, basin or national scale.

The interrelationships amongst the different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency) and behaviour of the different performance measures in irrigation schemes facilitates planning and management of scarce water resources in irrigation scheme and further to enhance the performance of the irrigation water management of the irrigation scheme. Different stakeholders may have different views on the performance measures as Policy makers and planners, Irrigation managers, Researchers, Donor agencies, governments and NGOs. The comparative performance indicators enable policy makers and planners to know how productive their use of water and land for agriculture is.

7.1.2 Hypothesis and Objectives

The four hypotheses were made for Mula irrigation schemes in Maharashtra under rotational water supply in the proposed study based on the experiences of previous researchers. These are: 1. The different irrigation water management performance measures conflict with each other. 2. For the different stakeholder the relative importance of the performance measures is different and varies between locations within the irrigation scheme (i.e. head, middle and tail reach). 3. The optimum allocation policies for different performance measures can be obtained by evaluating different irrigation strategies. 4. It is possible to obtain the suitable policy by identifying the tradeoff amongst different performance measures.

Proposed study was conducted for ***Mula* irrigation scheme** keeping in view four objectives:

1. To study the relative importance of performance measures to farmers (water users) in different locations in an irrigation scheme (Mula Irrigation Scheme in Maharashtra, India).
2. To study the performance of irrigation water management in irrigation schemes in terms of

different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency).

3. To provide the guidelines for improving the performance of irrigation water management in irrigation schemes.
4. To test a technique for obtaining the suitable optimal policy based on the relative preferences of the farmers to different performance measures in allocation process.

7.2 Methodology adopted for the research study

7.2.1 Selection of irrigation schemes and data collection

Mula Irrigation Scheme in Ahmednagar District of Maharashtra State was identified after verifying that most of the needed data was available. The Mula Project with dam (gross storage capacity=767 Mcum and a live storage capacity=609 Mcum) has a planned capacity to irrigate 80,810 ha in 149 drought prone villages in Ahmednagar district through two main canals, the MLBC and the MRBC and their branch canals serving an area of 10,100 ha and 70,710 ha respectively. The command area of the MRBC is divided into 5 sub-divisions known as Rahuri, Newasa, Ghodegaon, Kukana and Amarapur. For the study purpose the Rahuri sub-division was considered as head reach, Newasa and Ghodegaon as middle reach and Kukana and Amarapur as tail reach of the project. In Mula system 61 Water Users' Associations (WUAs) have been registered so far and about 56 have started functioning and about 14 WUAs were in the process of getting their registration.

7.2.2 Performance Assessment of Irrigation Water Management: The performance of different irrigation schemes is assessed with the help of Area and Water Allocation Model (AWAM) (Gorantiwar 1995 and Gorantiwar and Smout 2005a) and framework for assessment developed at Loughborough University (Smout and Gorantiwar 2005b). The six performance indicators viz. productivity, equity, adequacy Reliability, Flexibility and Sustainability were identified as the important one for obtaining the information on the relative preference from the farmers and first three were considered for obtaining the allocation plans.

7.2.3 Computation of the performance measures: In this study allocative performance measures - i.e. productivity and equity - and scheduling performance measures - adequacy - were determined. AWAM model was used to compute the values of these performance measures. The reservoir is assumed to be full at the end of rainy season i.e. on 15 of October which is also the start of irrigation year. The inflow into the reservoir after rainy season until the end of summer season is considered as negligible as there is insignificant rainfall during this period. The

AWAM model followed following steps for each set of irrigation interval over the irrigation season. 1. Firstly, the several irrigation strategies were generated for the optimum allocation of water that needs estimates of the output obtained from several possible ways of irrigating the crop for each CSR unit and for a given set of irrigation intervals. 2. Further for each irrigation generated strategy the number of irrigation programmes consisting the information on yield/benefits and irrigation requirement (depth) per irrigation were prepared using two sub-models viz. SWAB and CRYB. 3. From the number of irrigation programmes so obtained, a specified number of optimal and efficient irrigation programmes, according to certain criteria for each CSR unit were selected. 4. Finally, these selected optimal and efficient irrigation programmes were used to allocate land and water resources optimally to different crops grown on different soils in different allocation units.

7.2.4 Relative preference of performance measures: Further, Analytic Hierarchy Process (AHP) was used to assign weights of different performance measures by determining the farmers' relative preference of different performance measures. In AHP, the considered performance measures were set up in the form of hierarchy. The pair wise comparisons for performance measures was carried out by allowing the stakeholders (Farmers at different locations in the irrigation scheme in this case) to compare two performance measures as a pair (for example productivity and equity) for all combinations. Each pair wise comparison was assigned a numerical value (as per the judgment scale presented in Table 3.2) to the pair corresponding to the relative importance between the two performance measures. Based on pair wise comparison, the judgment matrix was prepared and priority vector was computed for performance measures. Further consistency of pair wise judgments was assessed. Finally, relative weights/ranks**:** for the satisfactory value of CR of the judgment matrix (less than 10%), the priority vector values were assigned as relative weights of factors. In case of non consistent results pair wise comparison was repeated.

Analytical hierarchical process (AHP): AHP was used to obtain the relative preference of different performance measures and weights of different performance measures at each level. AHP involved obtaining the preference and intensity of preference of one performance measure compared to another performance measure from farmers at different locations.

7.2.5 Multicriteria decision making for finding out the overall performance:

The different performance indicators were combined into a final overall performance indicator (FPI) of irrigation management in an irrigation scheme from the farmers' perspective using the concept provided by Smout and Gorantiwar (2010).

The values of the indicators and weights were obtained from the simulation-optimization modeling (AWAM model) and analytical hierarchical process (AHP) respectively. The multi level problem was arranged in hierarchal way (Figure 3.8) and compromise programming was used at each level.

7.2.6 Analysis of Performance Results:

The performance results were obtained for different management scenarios (for example on the irrigation interval) and irrigation strategies (for example full, fixed or variable depth of irrigation). The results were obtained at scheme level, main canal (right bank) level, secondary and tertiary levels. The AHP results were analysed to determine whether different performance measures (Productivity, Equity and Adequacy) conflict with each other. As detailed in Section 7.7.1 below, it is revealed from the pair wise comparison of productivity, equity and adequacy by the farmers that 'Productivity and Equity' and 'Adequacy and Equity' conflict with each other for Head, Middle and Tail reaches.

7.2.7 Trade-off Analysis amongst Performance Indicators

The relative importance of different performance measures is different to different stakeholders in irrigation scheme. The views of farmers at different locations were investigated and the relative preferences were obtained from them with the formulated questionnaire. The responses are analysed by using analytical hierarchical process and multicriteria decision making process and integrated with the performance results.

7.2.8 Conclusions on the Methodology

The methodology is appropriate and worked well. However the methodology can be improved by involving different stake holders e.g. irrigation managers, policymakers academicians and researchers.

7.3. Results of AHP

The software in M.S. Excel ®was used to analyze the pair wise comparison to obtain the weights.

At **level-2 (**the canals/direct outlets (D.O.) on the canals at level-1 are considered as level 2) on an average flexibility and reliability were found to be more important followed by productivity sustainability, adequacy and equity. It was observed that the productivity is more important in head reach whereas in middle and tail reaches, other performance measures are important. Head reach farmers gave more importance to productivity while they are least concerned about equity. However, in tail reach equity is the most important. Middle reach farmers also indicated the preference to equity compared to productivity. Adequacy and reliability are more important in middle and tail reaches compared to head reach. While in case of Sustainability head reach farmers showed more importance to sustainability compared to middle and tail reaches. At level-1 (the canals originating from reservoir are considered as level-1) the weights of different performance measures for productivity, equity and flexibility were found to be consistent except for at one location.

7.4 Evaluation of different irrigation strategies using AWAM model

Different irrigation strategies based on 1. Irrigation amount (FDI, FxDI and VDI), 2. Irrigation frequency (14 days, 21 days, 28 days and 35 days), 3.Water distribution (FWD, EDSW and EDIW) and 4. Cropping distribution (Free cropping distribution and Fixed cropping distribution) were evaluated using AWAM model. The response of different criteria such as soil, irrigation interval, irrigation strategy, irrigation depth, crops to performance measure, i.e. productivity (in terms of the actual yield and the irrigation water use i.e. water use efficiency) were analysed.

7.4.1 Response of different irrigation strategies in different Soils

The response of different irrigation strategies (FDI, FxDi and VDI) on actual yield and water use for wheat grown on different Soils (001, 002, 003 and 004) was studied.

When the different irrigation strategies for wheat grown on soil 001 for irrigation interval of 21 days were compared it was observed that FxDI strategy provides (80 mm per irrigation) less moisture stress and hence it results in estimation of higher crop yield. The said FxDI strategy provided the maximum actual yield (1884 Kg/ha) amongst all the tested irrigation strategies; which is about 54 % of the maximum yield (3500 Kg/ha). Hence it was concluded that the irrigation interval of 21 days exceeds the threshold for the water stress. The FDI strategy with a total irrigation depth of 380 mm and VDI (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0) both give similar estimated wheat yield (1864 Kg/ha) which is about 53 % of maximum yield.

However, the VDI (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=0.7, dr6=0) attains the maximum WUE (6.21 Kg/ha-mm) amongst all irrigation strategies considered.

For Soil 002, when amongst all different irrigation strategies for wheat grown on Soil 002 for irrigation interval of 21 days, FDI strategy provided maximum actual yield (3292 Kg/ha) followed by VDI(dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0) i.e. 3283 Kg/ha. However for wheat grown on Soil 002, the maximum WUE was found in VDI (dr1=1.0, dr2=1, dr3=0.9, dr4=1.0, dr5=0.5, dr6=0) i.e. 8.91 Kg/ha-mm, followed by VDI (dr1=1.0, dr2=1, dr3=1.0, dr4=1.0, dr5=1.0, dr6=0) i.e. 8.31 Kg/ha-mm, followed by FDI i.e. 7.08 Kg/ha-mm.

When the different irrigation strategies for wheat grown on Soil 003 for irrigation interval of 21 days are compared the maximum actual yield is obtained in FDI strategy i.e. 3497 Kg/ha with application depth of 386.25 mm (irrigation depth 515 mm). In this strategy the actual yield is almost equal to the maximum yield (3500 Kg/ha). In the FxDI strategy the actual yield obtained is 3494.7 Kg/ha with total application depth of 360 mm (irrigation depth 480 mm) which is also almost equal to the maximum yield. But in FxDI strategy 6.7% water is saved. The VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.9, dr5=0.5, dr6=0.0) estimated the yield 3475 Kg/ha which is near to those estimated by fix(480 mm) and FDI(515mm); but required 17.70 and 23.30 % less water compared to fixed and FDI strategy respectively.

For wheat grown on Soil 004 with irrigation interval of 21 days, the FDI with application depth of 390 mm (irrigation depth 520 mm) which provides no moisture stress at all throughout the crop growth period results in maximum wheat yield (3500 Kg/ha) which is also highest among all strategies considered. The FxDI (80 mm per irrigation) also results in almost same yield (3498 Kg/ha) but saves 7.69% water than that applied in FDI. However, VDI (dr1=1.0, dr2=1.0, dr3=1.0, dr4=0.7, dr5=0.4, dr6=0.0) results in 97% of maximum yield i.e. 3403 Kg/ha with about 27 % and 21% water saved that of that applied in FDI strategy and FxDI (80 mm per irrigation) irrigation strategy.

Thus as is seen for wheat grown on all considered soils, the variable irrigation depth strategy may provide better performance of irrigation scheme in terms of productivity. It is noted though that the application of water according to the variable irrigation depth strategy is operationally and management point of view is not convenient but results in higher irrigation water use efficiency.

7.4.2 Effect of irrigation interval on yield and water use

The impact of different irrigation intervals on yield and water use was analyzed for a single crop i.e. wheat grown on Soil 002 with FDI. Here four different irrigation intervals viz. 14 days, 21 days, 28 days and 35 days were considered.

When the response of wheat grown on Soil 002 with FDI was compared in terms of the actual yield for different irrigation intervals of 14 days, 21 days, 28 days and 35 days; it is observed that the irrigation interval of 14 days results in to maximum actual yield obtained i.e. 3498 Kg/ha, which almost equals to the maximum yield (i.e. 3500 Kg/ha) with WUE of 6.48 Kg/ha-mm. While the irrigation interval of 21 days gives the actual yield of 3292 Kg/ha which is 94 % of the maximum yield. However, it gives the maximum WUE i.e. 7.1 Kg/ha-mm.

7.4.3 The different irrigation Strategies for fixed cropping- for 14 and 21 days irrigation interval

The different irrigation strategies i.e. 1.FDI, 2.FxDI, and 3. VDI were considered for wheat crop grown on Soil 002 with irrigation interval of 14 and 21 days and their response in terms of the actual yield and the WUE was compared. In 14 days irrigation interval, all three irrigation strategies (i.e. FDI, FxDI and VDI) yield the same actual yield i.e. 3498 Kg/ha. However, the VDI strategy consumes the least water (i.e. Depth of irrigation =455mm) with highest WUE of 7.69 Kg/ha-mm.

When the three different irrigation strategies are compared for 21 days irrigation interval, it is observed that the FxDI strategy yields least, while both FDI and VDI strategies yields nearly same but about 10 % more than the FxDI strategy. However the maximum water use efficiency i.e. 8.31 Kg/ha-mm is observed in VDI strategy.

7.4.4 Effect of depth of irrigation

The different irrigation depths applied per irrigation for wheat grown Soil 002 with irrigation interval of 21 days, were compared in terms of the actual yield and WUE. For that 10 different irrigation depths per application were considered under FxDI strategy viz. 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm, 110 mm, 120 mm, 130 mm and 140 mm.

With an incremental depth of 10 mm over 50 mm depth of irrigation per application the actual yield increases by 37 % (i.e. from 1806 to 2477 Kg/ha) and the WUE increases from 6 to 6.88 Kg/ha-mm. It is observed that, after applying 90 mm depth of irrigation per application to wheat grown on soil 002 at irrigation interval of 21 days, the actual yield attained is about 94 % of the maximum yield. Further increasing the depth of application per irrigation beyond 90 mm the same actual yield of 3292 Kg/ha is obtained however, the WUE obviously goes on decreasing. The least yield is observed in 50 mm depth of irrigation per application which is about 52 % of the maximum yield (3500 Kg/ha).

7.4.5 Response of different crops to different irrigation strategies and different irrigation intervals

The three different irrigation strategies (FDI, FxDI and VDI) with irrigation interval of 14 days and 21 days were considered for three different crops namely viz. Sunflower (*Kharif* season), Gram (*Rabi* season) and Cabbage (Summer season) grown on Soil 002 and compared in terms of the actual yield and the WUE.

For Sunflower, among the different irrigation strategies the same highest actual yield i.e. 1243 kg/ha was achieved in FDI strategy and VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) at irrigation interval of 14 days, which is about 83% of the maximum yield (i.e. 1500 kg/ha). But the VDI strategy (dr1=1.0, dr2=1.0, dr3=1.0, dr4=1.0, dr5=1.0, dr6=1.0, dr7=0.7, dr8=0.0, dr9=0.0) saves 15.87 % water than FDI strategy and achieves higher water use efficiency (i.e. 2.49 kg/ha-mm as compared to 1.97 kg/ha-mm). Comparing the three different irrigation strategies for 14 and 21 days irrigation intervals, it was observed that 21 days interval proves to be too long for sunflower grown on Soil 002 and yields poorly i.e. only 25.26 % of maximum yield for FxDI strategy with 70 mm depth of irrigation per application and 53% of maximum yield for both full depth and variable depth strategy.

When the gram is grown on Soil 002 for all 3 different irrigation strategies, it was revealed that the same yield is attained i.e. 2493 kg/ha (almost equal to maximum yield i.e. 2500 kg) at 14 days irrigation interval and about 2450 kg/ha (98 % of maximum yield) at 21 days irrigation interval. However, the highest water use efficiency of 9.61 kg/ha-mm is achieved with VDI strategy (dr1=0.0, dr2=0.9, dr3=1.0, dr4=0.9, dr5=0.7, dr6=0.0) at irrigation interval of 21 days, followed by 7.91 kg/ha-mm with VDI strategy (dr1=0.7, dr2=1.0, dr3=0.9, dr4=1.0, dr5=1.0, dr6=0.9, dr7=0.0, dr8=0.0) at irrigation interval of 14 days.

When the cabbage is grown on Soil 002 the different strategies (Full depth, Fixed depth and VDI) responds same at irrigation interval of 14 days and 21 days in terms of actual yield i.e. 24659.4 kg/ha (98.63% of maximum yield) and 24838.2 kg/ha (99.35% of maximum yield) respectively. However, the maximum water use efficiency of 118.27 kg/ha-mm is achieved with VDI strategy (dr1=0.6, dr2=1.0, dr3=1.0, dr4=0.7) at 21 days irrigation interval, followed by 95.53 kg/ha-mm with FDI at 21 days irrigation interval.

The responses of different irrigation strategies (Fixed, Full and Variable depth) and cropping distribution (free and fixed) to the water use and actual yield in different soils were obtained and discussed. The complete analysis showed that the different irrigation strategies (in terms of amount and interval) had the marked influence on crop yield and net benefits. Different cropping distributions (fixed and free) and water distribution (free and equitable) also influenced the crop production and net benefits. In general as expected free cropping and water distributions resulted in more benefits compared to the fixed distributions.

7.4.6 Conclusions - AWAM Model

7.4.6.1 Response of different irrigation strategies in different Soils

The response of different irrigation strategies (FDI, FxDI and VDI) on actual yield and water use for wheat grown on different Soils (001, 002, 003 and 004) for irrigation interval of 21 days was studied.

7.4.6.2 Effect of irrigation interval on yield and water use

The impact of different irrigation intervals on yield and water use was analyzed for a single crop i.e. wheat grown on Soil 002 with FDI. Here four different irrigation intervals viz. 14 days, 21 days, 28 days and 35 days were considered.

It is observed that the irrigation interval of 14 days results in to maximum actual yield obtained which is almost equals to the maximum yield with second highest WUE followed by the irrigation interval of 21 days with the maximum WUE.

7.4.6.3 The different irrigation Strategies for fixed cropping- for 14 and 21 days irrigation interval

In 14 days irrigation interval, all three irrigation strategies (i.e. FDI, FxDI and VDI) yield the same actual yield However, the VDI strategy consumes the least water (i.e. Depth of irrigation) with highest WUE.

When the three different irrigation strategies are compared for 21 days irrigation interval, it is observed that the FxDI strategy yields least, while both FDI and VDI strategies yields nearly same. However the maximum water use efficiency is observed in VDI strategy.

7.4.6.4 Effect of depth of irrigation

The different irrigation depths applied per irrigation for wheat grown Soil 002 with irrigation interval of 21 days, were compared in terms of the actual yield and WUE.

With an incremental depth of 10 mm over 50 mm depth of irrigation per application the actual yield increases and the WUE also increases up to certain extent. Further increasing the depth of application per irrigation beyond 90 mm the same actual yield is obtained however, the WUE obviously goes on decreasing. The least yield is observed in 50 mm depth of irrigation per application.

7.4.6.5 Response of different crops to different irrigation strategies and different irrigation intervals

The three different irrigation strategies (FDI, FxDI and VDI) with irrigation interval of 14 days and 21 days were considered for three different crops namely viz. Sunflower (*Kharif* season), Gram (*Rabi* season) and Cabbage (Summer season) grown on Soil 002 and compared in terms of the actual yield and the WUE.

This analysis showed that the different irrigation strategies proposed in AWAM model have the marked influence on crop production, net benefits and water use efficiency and hence can influence the performance of the irrigation scheme. This has provided the basis for considering different irrigation strategies for further analysis.

7.5 Overall performance of the Mula Irrigation Scheme

The performance measures viz. productivity, equity, adequacy and excess for suggested irrigation strategies were obtained with the help of AWAM model. The values of the performance measures and importance given by different stakeholders were used for obtaining the suitable optimum policy.

7.5.1 Area and water productivity

The area and benefit productivity were estimated from area that can be irrigated and net benefits estimated for different irrigation strategies (fixed depth, full depth and variable depth) for different irrigation intervals and for water distribution for free cropping and fixed cropping obtained from AWAM model.

The area and benefit productivity increased with the irrigation interval for all the three irrigation strategies free and fixed cropping distributions and free water distribution (no equity). In case of free and fixed cropping distributions with equitable water distribution on seasonal basis, the productivity values increase with the irrigation interval for FxDI and FDI (as observed with free water distribution). However for VDI, these productivity values increase up to the irrigation interval of 28 days and then decreases. Almost similar results are obtained for free cropping distribution and intra-seasonal water distribution as in case of for free cropping distribution and seasonal water distribution (Annual Equity). In general productivity values are higher in fixed depth irrigation followed by variable depth and then full depth. The productivity values are higher in case of free cropping distribution compared to fixed cropping distribution. The equitable water distribution resulted in lower productivity compared to free water distribution.

7.5.2 Equity

Equity values were computed for different management scenarios (irrigation intervals). Equities are estimated as Equity 1 (area distribution), Equity 2 (water distribution with conveyance and distribution efficiencies), Equity 3 (water distribution with conveyance efficiency), Equity 4 (water distribution without efficiency) and Equity 5 (benefits obtained).

No specific trend of equity with the irrigation interval was found. Equity values are higher in case of fixed depth of irrigation compared to full depth. The equity values are higher in case of fixed cropping distribution compared to free cropping. The equity values are as expected higher or unity for equitable water distribution compared to free water distribution.

7.5.3 Adequacy

The adequacy values are higher in full depth of irrigation followed by variable depth irrigation and fixed depth irrigation

7.5.4 Final Performance Index (FPI)

The average weights of different performance measures (monetary productivity, equity in water distribution and adequacy) were obtained for farmers from different reaches from the weights obtained from AHP analysis.

The FPI was computed for head, middle and tail reach farmers using the weights obtained from AHP by compromise programming. The balancing factor of 1 was considered for this purpose.

It is interesting to note that the strategies that best met the farmers' preferences (highest FPI), were same for middle reach and tail reach farmers however it is different for head reach. It is also interesting to note that the preferences of the head, middle and tail reach farmers, irrespective of their relative location in irrigation scheme, were best met by strategies which include the equitable distribution of water. For middle and tail reach farmers, full depth irrigation would give the highest FPI, while for head reach farmers optimised fixed depth would be best. It is also seen that for head and middle reach farmers a strategy with fixed cropping distribution and free water distribution would be worst for meeting the preferences of head and middle reach farmers while for tail reach farmers a strategy with free water and free cropping distribution would be worst.

7.6 Sensitivity Analysis

7.6.1 Sensitivity of AWAM to reservoir volume

Sensitivity of AWAM model to initial reservoir volume is studied by Gorantiwar and Smout (2005b) for "Nazare Medium Irrigation Scheme" in Maharashtra State of India. Further they have stated that the total net benefits increase linearly with the reservoir capacity. From the study of Gorantiwar and Smout it is also observed that when the initial reservoir volume i.e. 100% is reduced by 10% then the net benefits are reduced by 12.50%, 16.67%, 10.00%, 11.11% for VDI and Fixed cropping distribution, FLDI (Full depth of irrigation) and Fixed cropping distribution, VDI and free cropping distribution, FLDI (Full depth of irrigation) and free cropping distribution respectively. Thus the net benefits of these best irrigation strategies (at Head, Middle and Tail) as previously determined, are highly sensitive to the reduction in the available reservoir water volume.

7.6.2 Sensitivity of optimal solution by changes in weights

To check whether the optimal policy is changed by changes in weights, given in Table 4.6 therefore for the sensitivity analysis of optimal solution four different cases of weights to different performance measures are considered: FPI values for different 126 irrigation strategies are computed for each case, giving highest values as listed below.

1. Productivity = 0.33, Equity = 0.33 and Adequacy = 0.33 (highest FPI = 0.84)
2. Productivity = 0.50, Equity = 0.25 and Adequacy = 0.25 (highest FPI = 0.88)
3. Productivity = 0.25, Equity = 0.50 and Adequacy = 0.25 (highest FPI = 0.89) and
4. Productivity = 0.25, Equity = 0.25 and Adequacy = 0.50 (highest FPI = 0.89)

While comparing the best irrigation strategies based on FPI values for different weights to performance measures it is revealed that irrespective of the weights given to the different performance measures the irrigation interval of 35 days in winter and 28 days in summer, Free cropping pattern and Seasonal equity are best to be applied so as to obtain best overall performance of irrigation scheme.

7.7 Conclusions

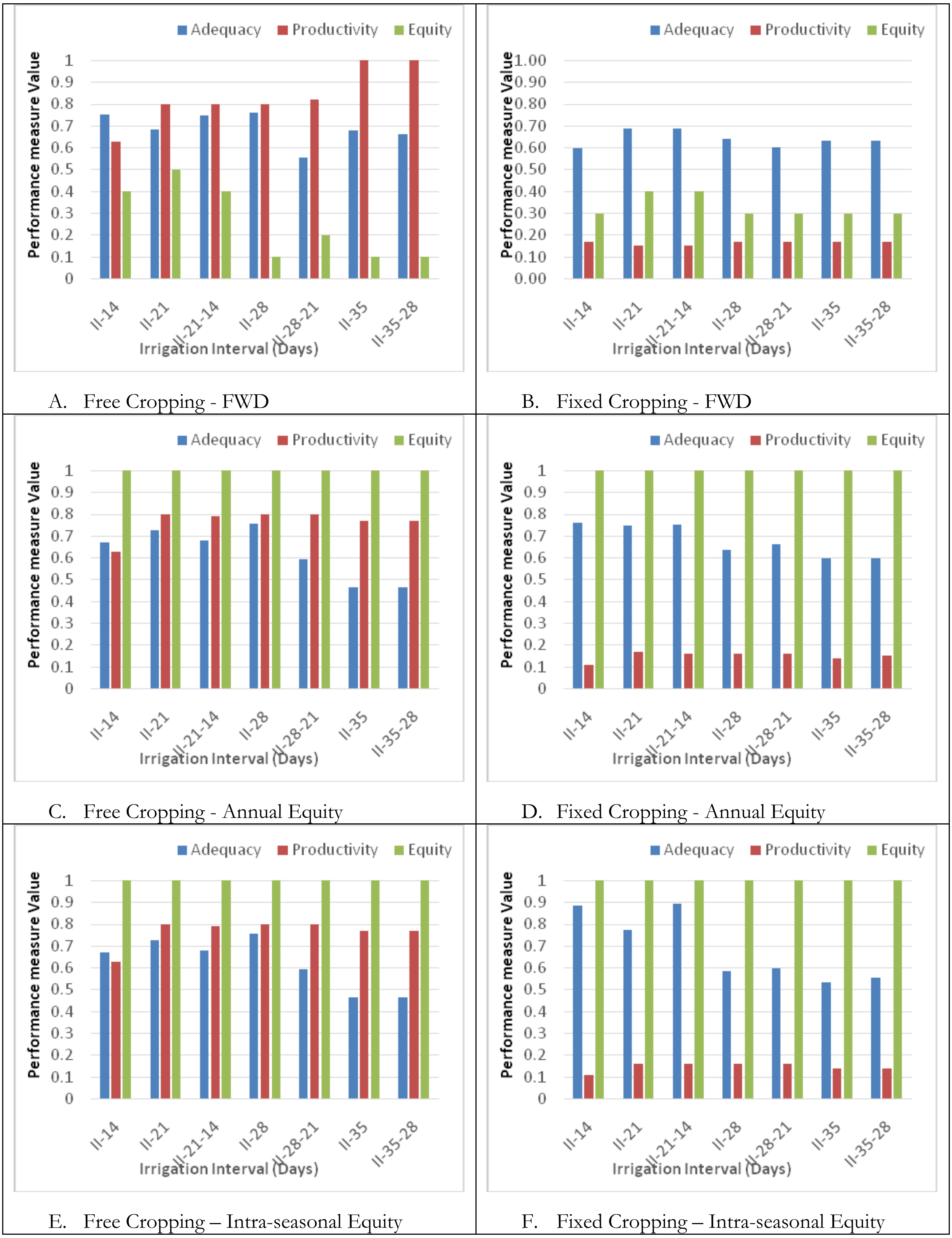
7.7.1 Hypothesis 1: The different performance measures of irrigation water management in the irrigation scheme (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency) conflict with each other.

In this study out of seven performance measures viz. productivity, equity, adequacy, reliability, flexibility and sustainability, three performance measures namely productivity, equity and adequacy were investigated to know whether they conflict with each other. Several irrigation strategies derived from the combination of irrigation amount (full depth irrigation, fixed depth irrigation and variable depth irrigation), irrigation frequency (different combinations of irrigation interval (14, 21 28, 35 days) in Rabi season and Summer season, water distribution (free water distribution, equitable distribution of seasonal water allocation and equitable distribution of intra-seasonal water and cropping distribution: (free cropping distribution and fixed cropping distribution were used for this purpose. The productivity, equity and adequacy values of typical cases are described below.

Variation of Productivity, Equity and Adequacy for Variable Depth of irrigation approach for Free and Fixed Cropping at different irrigation intervals is presented in Figure 7.1.

From Figure 7.1 (i.e. from A to F), it is observed that productivity and equity are conflicting to each other for both free and fixed cropping distribution with free distribution of water (no equity), annual equity and intra-seasonal equity at all irrigation intervals.

The adequacy and equity also observed to be conflicting with each other for both free and fixed cropping distribution with free water distribution, annual equity and intra-seasonal equity at all irrigation intervals.



A. Free Cropping - FWD

B. Fixed Cropping - FWD

C. Free Cropping - Annual Equity

D. Fixed Cropping - Annual Equity

E. Free Cropping – Intra-seasonal Equity

F. Fixed Cropping – Intra-seasonal Equity

Figure 7.1 Variation of Productivity, Equity and Adequacy for Variable Depth irrigation strategies

The AHP results were analysed to determine whether different performance measures (Productivity, Equity and Adequacy) conflict with each other. This revealed from the pair wise comparison of productivity, equity and adequacy by the farmers that 'Productivity and Equity' and 'Adequacy and Equity' conflict with each other for Head, Middle and Tail reaches.

7.7.2 Hypothesis 2: The relative importance of different performance measures varies between locations within the irrigation scheme i.e. head, middle and tail reach.

Analytic Hierarchy Process (AHP) was used to compute the weights or importance of different performance measures by determining the relative preference of different performance measures in different reaches i.e. head, middle and tail. Variation of different performance measures in head, middle and tail reaches of Mula Right Bank Canal is shown in Figure 7.2.

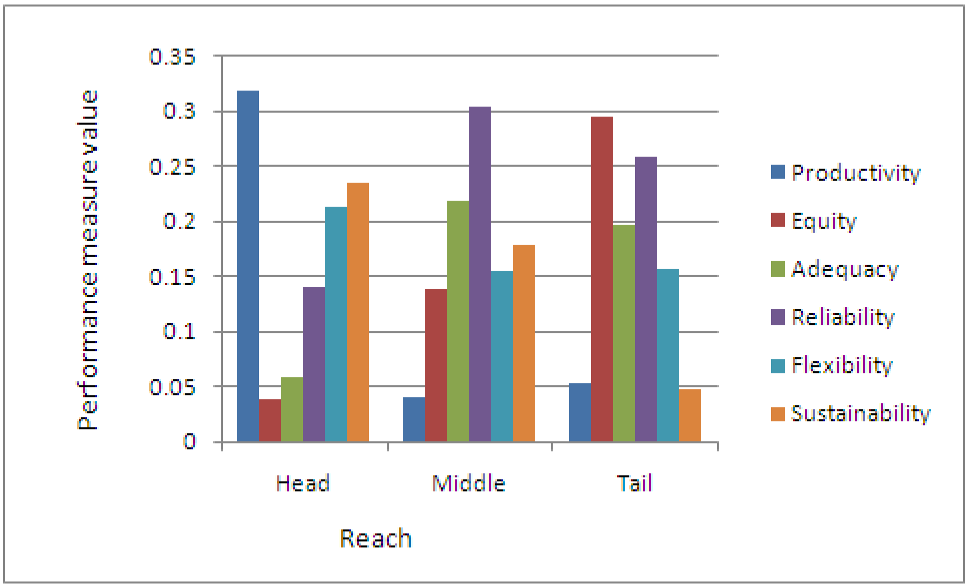


Figure 7.2 Variation of different performance measures in head, middle and tail reaches of Mula Right Bank Canal.

It is observed that the productivity is more important in head reach whereas in middle and tail reaches, other performance measures are important. Head reach farmers gave more importance to productivity while they are least concerned about water equity. However, in tail reach equity is the most important. Middle reach farmers also indicated the preference to equity compared to productivity. Adequacy and reliability are more important in middle and tail reaches compared to head reach. While in case of Groundwater (Rise) Sustainability head reach farmers showed more importance to sustainability compared to middle and tail reaches.

Thus the hypothesis that "The relative importance of different performance measures varies between locations within the irrigation scheme i.e. head, middle and tail reach" holds valid.

7.7.3 Hypothesis 3: The optimum allocation policies (i.e. the model allocates land and water resources optimally to different crops grown on different soils in different allocation units, with the help of irrigation programmes obtained for different Crop-Soil-Region) for different performance measures can be obtained by evaluating different irrigation strategies (i.e. the existing irrigation schedule specified for the particular Crop-Soil-Region (CSR) unit is the irrigation strategy for that CSR unit).

The optimum allocation policies are generally obtained for maximization of productivity and other performance measures such as equity and adequacy are obtained for this optimum plan. However in this study the optimum allocation policies were obtained for the maximization of productivity (free water distribution and optimized variable depth irrigation), maximization of equity (equitable water distribution) and maximization of adequacy (full depth irrigation) for the command area of Right Bank Canal of Mula Irrigation Scheme that consists of 43 allocation units at first level with varying soils and crops. The derived allocation policies provided water to be allocated to different crops grown in different allocation units during different irrigation period and at different levels in irrigation scheme. The examples of optimum area and water allocation policies for maximization of productivity, maximization of equity and maximization of adequacy for typical irrigation strategies are provided in Tables 7.1(A) and (B), 7.2 (A) and (B) and 7.3 (A) and (B), respectively.

Thus it is seen that the optimum allocation policies for different performance measures can be obtained by evaluating different irrigation strategies with the help of AWAM model which was hypothesized in this study.

Table 7.1 (A) Maximum productivity: Irrigated areas and volumes for Free cropping, free water, variable depth, 35-28 days interval

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Area (ha)	51	62	1020	76	276	946	1650	95	400	130	136	102	58	32	200
Water (ha-m)	6	11	232	14	33	522	520	18	94	24	25	24	11	6	38
Location	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Area (ha)	1794	3446	116	666	110	137	274	125	923	9598	196	202	275	5090	276
Water (ha-m)	395	2360	57	164	67	64	128	63	530	6850	101	105	141	2643	146
Location	31	32	33	34	35	36	37	38	39	40	41	42	43	**Total**	
Area (ha)	485	430	144	144	3363	260	1173	280	838	31316	29315	16643	0	112850	
Water (ha-m)	253	222	74	74	2671	150	779	165	572	26618	17433	8390	0	72793	

Table 7.1(B) Maximum productivity – Irrigation wise water allocated (ha-m) for Free cropping, free water, variable depth 35-28 days irrigation interval

Irrigation No.	**Location No.**																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	3	4	77	5	17	51	173	6	31	8	8	8	4	2	13	198	360	6	55	8	6	13
2	0	4	77	5	0	36	173	6	31	8	8	8	4	2	13	0	308	4	55	5	5	9
3	3	4	77	5	17	36	173	6	31	8	8	8	4	2	13	198	257	4	55	5	5	9
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	374	11	0	13	12	24
6	0	0	0	0	0	47	0	0	0	0	0	0	0	0	0	0	187	6	0	7	6	11
7	0	0	0	0	0	106	0	0	0	0	0	0	0	0	0	0	374	11	0	13	13	26
8	0	0	0	0	0	109	0	0	0	0	0	0	0	0	0	0	374	11	0	13	13	26
9	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0	125	4	0	4	4	9
Total	6	12	231	15	34	520	519	18	93	24	24	24	12	6	39	396	2359	57	165	68	64	127

Irrigation No.	**Location No.**																					
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
1	7	79	1040	11	12	16	308	16	30	28	9	9	354	17	115	18	83	3520	2400	2880	0	
2	4	47	893	7	7	10	181	10	18	16	5	5	377	10	67	11	49	3810	2600	3120	0	
3	4	47	744	7	7	10	181	10	18	16	5	5	292	10	67	11	49	2930	4270	2400	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	12	93	1090	20	21	28	515	29	49	42	14	14	430	30	138	32	102	4270	2130	0	0	
6	6	47	544	10	10	14	257	14	24	21	7	7	215	15	69	16	51	2130	1070	0	0	
7	12	93	1090	20	21	28	515	29	49	42	14	14	430	30	138	32	102	4270	2130	0	0	
8	12	93	1090	20	21	28	515	29	49	42	14	14	430	30	138	32	102	4270	2130	0	0	
9	4	31	363	7	7	9	172	10	16	14	5	5	143	10	46	11	34	1420	710	0	0	
Total	61	530	6854	102	106	143	2644	147	253	221	73	73	2671	152	778	163	572	26620	17440	8400	0	

Table 7.2(A) Maximum equity: Irrigated areas and volumes for Free cropping, intra-seasonal equitable, variable depth 35-28 days irrigation interval

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Area (ha)	51	62	793	74	269	455	924	91	301	124	129	77	54	30	185
Water	9	11	180	13	49	84	291	17	71	23	24	18	10	6	35
Location	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Area (ha)	959	1146	49	476	38	70	140	51	359	3063	79	81	112	2065	108
Water	317	410	10	118	10	12	25	11	98	1139	17	18	25	462	24
Location	31	32	33	34	35	36	37	38	39	40	41	42	43	**Total**	
Area (ha)	197	179	60	60	955	94	394	99	274	8301	9579	6325	3256	42187	
Water	44	41	14	14	398	23	123	25	87	3723	4451	2939	1513	16931	

Table 7.2 (B) Maximum equity: Irrigation wise water allotted (ha-m) for Free cropping, intra-seasonal equitable, variable depth 35-28 days irrigation Interval

Irrigation No.	**Location no**																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	3	4	60	4	16	28	97	6	24	8	8	6	3	2	12	106	137	3	39	3	4	8
2	3	4	60	4	16	28	97	6	24	8	8	6	3	2	12	106	137	3	39	3	4	8
3	3	4	60	4	16	28	97	6	24	8	8	6	3	2	12	106	137	3	39	3	4	8
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	9	12	180	12	48	84	291	18	72	24	24	18	9	6	36	318	411	9	117	9	12	24
Irrigation No.	**Location no**																				
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
1	4	33	380	6	6	8	154	8	15	14	5	5	133	8	41	8	29	1240	1480	980	504	
2	4	33	380	6	6	8	154	8	15	14	5	5	133	8	41	8	29	1240	1480	980	504	
3	4	33	380	6	6	8	154	8	15	14	5	5	133	8	41	8	29	1240	1480	980	504	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total	12	99	1140	18	18	24	462	24	45	42	15	15	399	24	123	24	87	3720	4440	2940	1512	

Table 7.3(A) Maximum adequacy: Irrigated areas and volumes for Free cropping, free water, full irrigation, 21 days irrigation interval

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Area (ha)	51	122	1638	136	276	946	1377	185	638	250	256	174	116	64	381
Water (ha-m)	13	55	891	61	70	682	796	87	358	119	121	99	56	32	185
Location	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Area (ha)	1311	2517	108	1070	96	121	240	113	826	7031	180	183	241	4471	259
Water (ha-m)	852	2524	67	633	74	70	140	71	630	7336	117	118	154	2888	173
Location	31	32	33	34	35	36	37	38	39	40	41	42	43	**Total**	
Area (ha)	426	380	127	127	2474	251	1054	261	753	22873	8450	0	0	62554	
Water (ha-m)	277	248	83	83	2896	185	924	193	676	28771	11076	0	0	64883	

Table 7.3 (B) Maximum adequacy: Irrigation wise water allotted (ha-m) for Free cropping, free water, full irrigation, 21 days irrigation interval

Irrigation No.	Location no																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	4	6	117	7	20	84	193	9	46	13	14	13	6	3	20	0	281	9	83	10	10	20
3	3	4	80	5	17	36	159	6	33	8	8	8	4	2	13	173	281	4	56	5	5	10
4	3	4	92	5	17	44	169	7	37	10	10	10	4	2	15	144	209	5	65	5	5	11
5	3	5	106	6	17	51	193	8	43	11	12	11	5	3	18	144	232	5	76	6	6	13
6	0	0	6	0	0	0	36	0	3	0	0	0	0	0	0	173	102	0	4	1	0	1
7	0	0	8	0	0	0	46	0	4	0	0	0	0	0	0	217	137	0	5	1	1	1
8	0	6	75	6	0	99	0	9	30	12	12	9	6	3	18	0	281	10	53	10	9	18
9	0	4	47	4	0	36	0	6	19	7	7	6	4	2	11	0	94	3	33	3	3	7
10	0	6	84	7	0	69	0	10	33	13	13	10	7	4	21	0	187	7	60	7	6	13
11	0	8	108	8	0	95	0	13	43	17	17	13	8	5	26	0	253	9	77	9	9	17
12	0	9	117	9	0	109	0	14	46	19	19	14	9	5	29	0	281	10	83	10	10	20
13	0	4	51	4	0	58	0	6	20	8	8	6	4	2	13	0	187	7	37	7	5	11
Total	13	56	891	61	71	681	796	88	357	118	120	100	57	31	184	851	2525	69	632	74	69	142

Irrigation No.	Location no																				
	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	10	70	816	16	17	21	386	23	37	32	11	11	322	24	104	26	76	3200	1030	0	0	
3	4	70	816	7	7	11	210	10	21	20	7	7	322	10	102	11	73	3200	1380	0	0	
4	5	52	607	8	8	11	213	12	21	19	6	6	239	12	76	13	55	2380	910	0	0	
5	6	58	675	9	10	13	245	13	24	21	7	7	266	14	85	15	62	2650	996	0	0	
6	0	26	298	0	0	2	30	0	3	4	2	2	117	0	36	0	26	1170	590	0	0	
7	0	34	397	0	0	2	41	0	4	6	2	2	157	0	49	0	34	1560	787	0	0	
8	10	70	816	17	17	21	386	25	37	32	11	11	322	28	104	28	76	3200	1180	0	0	
9	3	23	272	6	6	7	129	8	12	11	4	4	107	9	35	9	25	1070	393	0	0	
10	7	47	544	11	11	14	257	17	24	21	7	7	215	18	69	19	51	2130	786	0	0	
11	9	63	735	15	15	19	347	23	33	29	10	10	290	25	93	25	69	2880	1060	0	0	
12	10	70	816	17	17	21	386	25	37	32	11	11	322	28	104	28	76	3200	1180	0	0	
13	7	47	544	11	11	14	257	17	24	21	7	7	215	18	69	19	51	2130	786	0	0	
Total	71	630	7336	117	119	156	2887	173	277	248	85	85	2894	186	926	193	674	28770	11078	0	0	

7.7.4 Hypothesis 4: It is possible to obtain the suitable policy by identifying the tradeoff amongst different performance measures.

The relative importance of different performance measures is different to farmers in different reaches of the irrigation schemes. These responses were analysed by using analytical hierarchical process and multicriteria decision making process and integrated with the performance results to perform trade-off analysis and obtain the final performance index (FPI). The FPIs were computed for head, middle and tail reach farmers using the weights obtained from AHP by compromise programming.

It is interesting to note that the strategies that best met the farmers' preferences (highest FPI), were same for middle reach and tail reach farmers however it is different for head reach. It is also interesting to note that the preferences of the head, middle and tail reach farmers, irrespective of their relative location in irrigation scheme, were best met by strategies which include the equitable distribution of water. For middle and tail reach farmers, full depth irrigation would give the highest FPI, while for head reach farmers optimised fixed depth would be best. It is also seen that for head and middle reach farmers a strategy with fixed cropping distribution and free water distribution would be worst for meeting the preferences of head and middle reach farmers while for tail reach farmers a strategy with free water and free cropping distribution would be worst.

Thus the suitable policies were obtained by considering three important performance measures i.e. productivity, equity and adequacy, though these policies were not same for all the reaches of the irrigation scheme. Considering the different depth of irrigations (FxDI, VDI and FDI) the VDI and FDI are practically difficult to execute due to the data required for their calculation and operational point of view of irrigation canal and to improve the overall performance of the irrigation scheme in terms of productivity and net benefits. Therefore the suggested optimum and feasible irrigation strategy to implement for entire irrigation scheme is 'Fixed depth irrigation with free cropping and annual equity at irrigation interval of 35 days in winter and 28 days in summer'.

7.7.5 Conclusions based on the research analysis of Mula irrigation scheme, Maharashtra

- Different irrigation strategies (fixed depth, full depth and variable depth) have different benefits and characteristics.

- The fixed depth irrigation strategy offers more convenience in management as compared to full depth and variable depth; as it avoids complex operation to deliver different irrigation depths and collection of extensive data for calculating these depths (Climatological parameters, soil parameters, crop characteristics, losses in distribution and conveyance system not being considered to determine the crop water requirement). However this strategy has shown to be less productive compared to other strategies.

- Preferences amongst the different performance indicators vary for different farmers in different locations i.e. at head reach, middle reach and tail reach of the command area.

- Productivity values are higher in fixed depth irrigation followed by variable depth and then full depth. The productivity values are higher in case of free cropping distribution compared to fixed cropping distribution. The equitable water distribution resulted in less values productivity compared to free water distribution.

- Equity values are higher in case of fixed depth of irrigation compared to full depth. The equity values are higher in case of fixed cropping distribution compared to free cropping. The equity values are as expected higher or unity for equitable water distribution compared to free water distribution

- The adequacy values are higher in full depth of irrigation followed by variable depth irrigation and fixed depth irrigation

- Considering the final performance index (FPI) of the Mula Irrigation Scheme it is to conclude that the strategies that best met the farmers' preferences (highest FPI), were same for middle and tail reach farmers, however it is different for head reach. It is also concluded that the preferences of the head, middle and tail reach farmers, irrespective of their relative location in irrigation scheme, were best met by strategies which include the equitable distribution of water. For middle and tail reach farmers, full depth irrigation would give the highest FPI, while for head reach farmers optimised fixed depth would be best. It is also seen that for head and middle reach farmers a strategy with fixed cropping distribution and free water distribution would be worst for meeting the preferences of head and middle reach farmers while for tail reach farmers a strategy with free water and free cropping distribution (adopted at scheme level) would be worst.

- To fulfil the objective 4 the methodology as described in Chapter 3 was tested successfully to obtain suitable optimal policy based on relative preferences of farmers to different performance measures in allocation process i.e. interrelation of AHP and AWAM.

- In case of FxDI an increase in the depth of application results in actual yield increasing upto certain depth, beyond which it become stagnant and further increase in depth of application does not influence to improve the actual yield.

7.8 Limitations of the Research and Suggestions for Further Research

- In India there are two type of irrigation scheme i.e. storage and river runoff type scheme. The methodology used in this thesis can be applied to storage type irrigation schemes in semi arid tropics, where water availability is a major constraint.

- Most of the data is collected from the record books maintained by Water Resource department. Therefore availability of data, data recording, data collections and response of farmers may be sources of errors.

- In this study the reservoir is considered to be full at the end of rainy season. Further research should be done using AWAM to find out the optimal policy when the reservoir is partially full.

- The AHP and MCA methodology should be used to find out the relative preferences to performance by different stake holders e.g. irrigation managers, agriculture officials and farmers of the irrigation scheme.

8. BIBLIOGRAPHY

Abernethy, C.L. 1986. Performance Measurement in Canal Water management: A Discussion. ODI-IIMI Irrigation Management Network Paper 86/2d, pp. 25.

Akkuzu, E., H. B. Unal and B.S. Karatas. 2007. Determination of adequacy and equity of water delivery in irrigation systems: A case of the Gediz Basin. Journal of Applied Science. 7(4): 607-611.

Allen, R. G., L. S. Periera, D. Raes and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing Crop Requirements. Irrigation and Drainage Paper No. 56. FAO, Rome, Italy.

Anonymous. 1990. Soil Physical Conditions and Crop Production. Ministry of Agriculture, fisheries and food technology bulletin, 29.

Anonymous. 2006. Scheme for cost of cultivation studies. Department of Agricultural Economics, M.P.K.V., Rahuri (Govt. of Maharashtra).

Anonymous. 2007. Krishidarshni published by Mahatma Phule Krishi Vidyapeeth Rahuri.

Arora V. K. and Gajri P. R. 1998. Evaluation of a crop growth-water balance model for analysing wheat responses to climate- and water-limited environments. Field Corps Research, 59

Balasubramaniam C., Somasundaram M. V. and Pundarikanthan N. V. 1996. LP analysis in a tank irrigation system for near real representation and optimal allocation of area. Irrigation and Drainage Systems, 10.

Bastiaanssen W.G.M. and M.G. Bos. 1999. Irrigation performance indicators based on remotely sensed data: A review of literature. Irrigation and Drainage Systems 13: 291–311.

Bazzani G. M. 2005. An integrated decision support system for irrigation and water policy design: DSIRR. Environmental Modelling & Software 20

Bender M. J., and Simonovic S. P. 2000. A fuzzy compromise approach to water resource systems planning under uncertainty. Fuzzy Sets and Systems, 115.

Berbel j. and Rodriguez-Ocana A. 1998. Theory and Methodology An MCDM approach to production analysis: An application to irrigated farms in Southern Spain. European Journal of Operational Research, 107.

Bergez J. E., Garcia F. and Lapasse L. 2004. A hierarchical partitioning method for optimizing irrigation strategies. Agricultural Systems, 80.

Bhutta M. N. and Velde Edward J. V. D.1992. Equity of water distribution along secondary canals in Punjab, Pakistan. Irrigation and Drainage Systems, 6.

Bos M. G., Murray-Rust D. H., Merrey D. J., Johnson H. G., and Snellen W. B. 1994. Methodologies for assessing performance of irrigation and drainage management. Irrigation and Drainage Systems, 7.

Bos M. G. 1997. Performance indicators for irrigation and drainage. Irrigation and Drainage Systems, 11.

Burt C. M., Clemmens A. J., Strelkoff T. S, Solomon K. H., Bliesner R. D, Hardy L. A., T. A. Howell and Eisenhauer Dean E. 1997. Irrigation Performance Measures: Efficiency and Uniformity. Journal of Irrigation and Drainage Engineering 123:6 (November 1, 1997), pp. 423-442.

Burt, C. M. and S. W. Styles. 1999. Modern Water Control and Management Practices in Irrigation. Impact on Performance. Water Reports - 19. Food and Agriculture Organization of the United Nations. ISSN 1020-1203. ISBN 92-5-104282-9. 224 p.

Burt, C. M. 2001. Rapid Appraisal Process (RAP) and Benchmarking Explanation and Tools ITRC Report No. R 01-008. pp 1-50.

Bustos R., Marre M. and Chambouleyron J. 2001. Performance of water users' associations in the Lower Tunuyan area, Argentina. Irrigation and Drainage Systems 15: 235–246.

Cai X. 2006. Water stress, water transfer and social equity in Northern China: Implications for policy reforms. Human Development Report Office, Occasional Paper 37. Washington DC.

Chambers, R. 1988. Managing Canal Irrigation: Practical Analysis from South Asia. Cambridge University Press, Cambridge, UK.

Chaturvedi M.C. 2005. Management of India's waters and the challenge to academics. Journal of water resources society, 25(1).

Clemmens, A.J. and M.G. Bos. 1990. Statistical methods for irrigation system water delivery performance evaluation. Irrigation and Drainage Systems 4: 345-365.

Clemmens A. J and D. J. Molden. 2007. Water uses and productivity of irrigation systems. Irrigation Science. 25:247–261.

Dechmi F., Playan E., Faci J.M., and Tejero M. 2003. Analysis of an irrigation district in northeastern Spain- I. Characterisation and water use assessment. Agricultural Water Management, 61. 75–92.

Dechmi F., Playan E., Faci J.M., Tejero M. and Bercero A. 2003. Analysis of an irrigation district in northeastern Spain- II. Irrigation evaluation, simulation and scheduling. Agricultural Water Management, 61. 93–109.

Doorenbos, D. W. and A. H. Kassam. 1979. Yield Response to Water. FAO Irrigation and Drainage Paper 33, Food and Agricultural Organization of United Nations, Roam, Italy.

Doorenbos, D. W. and W. O. Pruitt. 1984. Guidelines for Predicting crop water Requirements. FAO Irrigation and Drainage paper 24, Food and Agriculture Organization of United Nations, Rome, Italy.

Doorenbos, J. and W.O. Pruitt. 1977. Crop Water Requirements. FAO Irrigation and Drainage Division of ASCE Paper 24, Food and Agriculture Organization of the United Nations, Rome.

Droogers. P. and Bastiaanssen W. 1999. Irrigationperformance using hydrological and remotesensing modelling. Journal of Irrigation and Drainage Engineering 128.

Droogers P., Kite G. and Rust H. M. 2000. Use of simulation models to evaluate irrigation performance including water productivity, risk and system analyses. Irrigation Science 19.

Evans, E. M., Lee, D. R., Boisvert, R. N., Blanca, A., Steenhuis, T. S., Prano, M., and Poats, S. V. 2003. Achieving efficiency and equity in irrigation management: An optimization model of the El Angel watershed, Carchi, Ecuador. Agriculture Water Management, 77. (2003) 1–22.

Fereres, E., W.O. Pruitt, J.A. Beutel, D.W. Hemderson, E. Holzapfel, H. Schulbach, and K. Uriu. 1981. Evapotranspiration and drip irrigation scheduling, En: Drip Irrigation Management, Fereres E. Tech. Ed., Division of Agricultural Sciences, University of California: 8-13.

Gaur A, Biggs T. W., Gumma M. K., Parthasaradhi G. and Turral H. 2008. Water Scarcity Effects on Equitable Water Distribution and Land Use in a Major Irrigation Project—Case Study in India. Journal of Irrigation and drainage engineering. ASCE. (0733-9437) 134:1-26.

Giupponi C., Eiselt B. and P. F. Ghetti. 1999. A multicriteria approach for mapping risks of agricultural pollution for water resources: The Venice Lagoon atershed case study. Journal of Environmental Management 56.

Godfrey, S. 2006. Microbiological Risk Assessment and Management of Shallow Groundwater Sources in Lichinga Mozambique. Ph. D. thesis submitted to Loughbough University, Loughborough, UK

Godswill, Makombe, Johannes M. M. and Ranjan K. 1998. An analysis of the water management performance of small holder irrigation schemes in Zimbabwe. Irrigation and Drainage Systems, 12.

Gomez-Limon J.A., Berbel J. 2000. Multicriteria analysis of derived water demand functions: a Spanish case study. Agricultural Systems, 63.

Gorantiwar, S. D. 1995. A model for Planning and Operation of Heterogeneous Irrigation Scheme in Semi-arid Regions under Rotational Water Supply. An Unpublished Ph. D. thesis submitted to Loughborough University and Technology, Loughborough, UK.

Gorantiwar S. D. and Smout I.K. 2005(a). Performance assessment of irrigation water management of heterogeneous irrigation schemes: 1. A framework for evaluation: Irrigation and Drainage Systems (2005) 19: 1–36.

Gorantiwar S. D. and Smout I.K. 2005(b). A multilevel approach for optimizing land and water resources and irrigation deliveries for tertiary units in large irrigation schemes. II: Application. Journal of Irrigation and Drainage Engineering, 131:3(264).

Gorantiwar S. D., and Smout I. K. 2010. Multicriteria Decision Making (Composite Programming) for Integrated Water Resources Management in an Irrigation Scheme. In 3rd International Perspective on Current & Future State of Water Resources & the Environment (pp. 10). Chennai: EWRI-ASCE.

Gorantiwar, S. D., Smout I. K., and Vairavamoorthy K. 2006. Performance-Based Optimization of Land and Water Resources within Irrigation Schemes. I: Method. Journal of Irrigation and Drainage Engineering, 132:4(332).

Gulati H. S. and Murty V. V. N. (1997). A model for optimal allocation of canal water based on crop production functions. Agric. Water Management, 2.

Hales A. L. and Burton M. A. 1999. Using the IRMOS model for diagnostic analysis and performance enhancement of the Rio Cobre Irrigation Scheme, Jamaica. Agricultural Water Management, 45.

Hanks, R. J. 1974. Model for predicting plant yield as influenced by water use. Argon. J., 66.

Hargreaves, G. H. and Z. A. Samani. 1985. Reference Crop Evapotranspiration. Applied Engg. in Agriculture, ASAE 1 (2), 96-99.

Ines V. M. and Droogers P. 2002. Inverse modeling to quantify irrigation system characteristics and operational management. Irrigation and Drainage Systems, 16.

Isidoro D., Quilez D., and Aragues R. 2004. Water balance and irrigation performance analysis: La Violada irrigation district (Spain) as a case study. Agricultural Water Management, 64.

Jahromi S. S. and Feyen J. 2001. Spatial and temporal variability performance of the water delivery in irrigation schemes. Irrigation and Drainage Systems, 15.

Jahromi S. S., Depeweg H. and Feyen J. 2000.Water delivery performance in the Doroodzan Irrigation Scheme, Iran. Irrigation and Drainage Systems 14: 207–222, 2000.

Jensen M. E. 1968. Water consumption by agricultural plants. In Water Defecit and Plant Growth: Plant Water Consumption and Response (volume II), London, UK.

Kalu, I. L., Paudyal, G. N., and Gupta, A. D. 1995. Equity and efficiency issues in irrigation water distribution. Agriculture Water Management, 28.

Karami E. 2006. Appropriateness of farmers' adoption of irrigation methods: The application of the AHP model. Agricultural Systems, 87.

Kassam, A. H. and D.W. Doorenbos. 1986. Yield Response to water. FAO Irrigation and Drainage paper 33, Food and Agriculture Organization of United Nations, Rome, Italy.

Latif M. and J. A. Tariq. 2009. Performance assessment of irrigation management transfer from government-managed to farmer-managed irrigation system: A case study. Irrigation and Drainage. 58: 275–286.

Lecina S., Playan E., Isidoro D., Dechmi F., Causape J. and Faci J. M. 2005. Irrigation evaluation and simulation at the Irrigation District V of Bardenas (Spain). Agricultural Water Management, 73.

Levite H. and Sally H. 2002. Linkages between productivity and equitable allocation of water. Physics and Chemistry of the Earth, 27.

Liu D. and Stewart T. J. 2004. Object-oriented decision support system modelling for multicriteria decision making in natural resource management. Computers & Operations Research, 31.

Mahmoud M. R., and Garcia. L. A. 2000. Comparison of different multicriteria evaluation methods for the Red Bluff diversion dam. Environmental Modelling & Software, 15.

Makadho Jahannes. 1996. Irrigation timeliness indicators and application in smallholder irrigation systems in Zimbabwe. Irrigation and Drainage Systems, 10.

Makin I. W., Goldsmith H. and SkutSch J.C. 1991. Ongoing performance assessment- a case study of Kraseio Project, Thailand. Irrigation and Drainage Systems, 5:31-42.

Malano and Burton (2001) Guidelines for Benching Performance in the irrigation and drainage sector, IPTRID Secretariat Food and Agriculture Organization of the United Nations Rome, 2001.

Mandavia, A.B., (1998). Modernization of irrigation system operational management by way of canal automation in India. Modernisation of irrigation system operations: proceedings of the 5th ITIS network international meeting, Aurangabad, 28-30 October 1998 the Food and Agriculture Organisation of the United Nations, Regional Office for Asia and the Pacific, Maliwan Mansion, 39 Phra Athit Road Bangkok 10200, Thailand.

Marchi B. D., Funtowicz S. O., Cascio S. L. and Munda G. 2000. Combining participative and institutional approaches with multicriteria evaluation. An empirical study for water issues in Troina, Sicily. Ecological Economics, 34.

McCarthy C. 2005. Productivity performance in developing countries, Country Case Studies, South Africa.

Michael, A. M. 1978. Irrigation Theory and Practices. Vikas Publishing House Pvt. Ltd., New Delhi.

Molden, D.J. and Gates, T.K. 1990. Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering. 116 (6), 804–823.

Mujumdar P. P. and Teegavarapu R. 1998. A short-term reservoir operation model for multicrop irrigation. Hydrological Sciences- Journal-des Sciences Hydrologiques, 43.

Murray-Rust D. H. and M. Svendsen. 2001. Performance of locally managed irrigation in Turkey: Gediz case study: Irrigation and Drainage Systems, 15.

Ngo L. L. 2006. Optimising reservoir operation- A case study of the Hoa Binh reservoir, Vietnam. An unpublished Ph. D. Thesis submitted to Institute of Environment & Resources, Technical University of Denmark.

Ngigi S. N., Savenije H. H.G., Thome J. N., Rockstrom J., Penning de Vries F.W.T. 2005. Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. Agricultural Water Management, 73.

Nys E. D., Gab P. L., Raes D. and Ana E. 2007. WaDI (water delivery for irrigation): A simulation tool to address strategic interaction of water demand and supply in irrigation schemes. Agricultural Water Management, 2513.

Olubode-Awosola , O.O., E. O. Idowu, H. and D. Van Schalkwyk. 2006. Assessing irrigation projects performance for sustainable irrigation policy reform. Irrigation and Drainage Systems. 20:303-315.

Onta P.R., Loof R.,and Banskota M. 1995. Performance based irrigation planning under water shortage.Irrigation and Drainage Systems. 9:2(143-162).

Parsinejad M., Yazdani M. R. and Ebrahimin H. 2009. Field and regional scale evaluation of irrigation efficiency in paddy fields case study – Guilan, Iran. Irrigation and Drainage. 58: 147–156.

Palmer J. D., Albert J., Clemmens, Dedrick A. R., Replogle J. A. and Clyma W. 1991. Delivery system performance case study: Wellton-Mohawk irrigation and drainage district, USA. Irrigation and Drainage Systems, 5.

Perry C. 2005. Irrigation reliability and the productivity of water: A proposed methodology using evapotranspiration mapping. Irrigation and Drainage Systems (2005) 19: 211–221.

Planning Commission, Government of India. 1998. 9th Five Year Plan. Government of India, Planning Commission, Yojana Bhavan, New Delhi.

Plantey J. and B. Molle. 2003. Performance assessment in the management of "Canal de Provence", France. Irrigation and Drainage Systems. 17: 263–284.

Plusquellec, H.L., McPhail, K. & Polti, C. 1990. Review of irrigation system performance with respect to initial objectives. Irrigation and Drainage Systems 4: 313–327.

Prasad A. S., Umamahesh N. V., ViswanathG. K. 2006. Optimal Irrigation Planning under Water Scarcity. Journal of Irrigation and Drainage Engineering 132:3 (228-237).

Prasad K. C. Koppen B. V. and Kenneth Strzepek. 2006. Equity and productivity assessments in the Olifants River basin, South Africa. Natural Resources Forum, 30:63-75.

Prathapar S. A., Meyer W. S. and J. C. Madden. 1997. SWAGMAN Options: A Hierarchical Multicriteria Framework to Identify Profitable Land Uses that Minimize Water Table Rise and Salinization. Applied Mathematics and Computation, 83.

Purkey, D.R. and W.W. Wallender. 1994. A review of irrigation performance assessment in California. Irrigation and Drainage Systems 8: 233-249.

Raj P. A. and Kumar D. N. 1998. Ranking multi-criterion river basin planning alternatives using fuzzy numbers. Fuzzy Sets and Systems, 100.

Raju K. S. and Pillai C. R. S. 1999. Multicriterion decision making in performance evaluation of an irrigation system. European Journal of Operational Research, 112.

Ray, S.S., V.K. Dadhwal and R.R. Navalgund. 2002. Performance evaluation of an irrigation command area using remote sensing: a case study of Mahi command, Gujarat, India. Agricultural Water Management 56: 81–91.

Renault D. 1999. Offtake sensitivity, operation effectiveness, and performance of irrigation system: Journal of Irrigation and Drainage Engineering**,** 125.

Robinson P. B. 2002. All for some: water inequity in Zambia and Zimbabwe. Physics and Chemistry of the Earth, 27.

Roost N. 2002. Improving Irrigation Water Use Efficiency, Productivity and Equity- Simulation Experiments in the Downstream Yellow River Basin. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Saaty, T. L. 1977. A scaling method for priorities in a hierarchical structure. Journal of Mathematical Psychology, 15: 234-281.

Saaty, T. L. 1994. How to make a decision: The Analytic Hierarchy Process. Interfaces, 24(6): 19-43.

Salman A.Z., Al-Karablieh E.K. and Fisher F.M. 2001. An inter-seasonal agricultural water allocation system (SAWAS). Agricultural Systems, 68.

Santhi C., Pundarikanthan N.V. 2000. A new planning model for canal scheduling of rotational irrigation. Agricultural Water Management, 43.

Santhi C.and Pundarikanthan N. V. 2000. A new planning model for canal scheduling of rotational irrigation. Agricultural Water Management 43: 327-343.

Sarma P. B. S. and Rao V. V. 1997. Evaluation of an irrigation water management scheme- a case study .Agricultural Water Management, 32.

Singh A. K., Jas Pal Singh and Rashmi Singh. 1998. Optimum utilization of resources for crop production –a case study. Journal of water resources society, 18 (4).

Small, L.E. and Svendsen, M. 1990. A framework for assessing irrigation performance. Irrigation and Drainage Systems 4: 283–312.

Small L.E. and Rimal A. 1996. Effects of alternative water distribution rules on irrigation systems performance: A simulation analysis. Irrigation and Drainage System, 10.

Smout, I. K. and Gorantiwar, S. D. 2005(a). Performance assessment of irrigation water management of heterogeneous irrigation schemes: 2. a case study. Irrigation and Drainage Systems, 19:1(37-60).

Smout, I. K. and Gorantiwar, S. D. 2005(b). A multilevel approach for optimizing land and water resources and irrigation deliveries for tertiary units in large irrigation schemes. I: Method. Journal of Irrigation and Drainage Engineering, 131:3(254).

Smout, I. K. and Gorantiwar, S. D. 2006. Productivity and Equity of different irrigation schedules under limited water supply. Journal of Irrigation and Drainage Engineering, 132:4(349).

Smout I. K., Gorantiwar, S. D., and Vairavamoorthy K. 2006. Performance-Based Optimization of Land and Water Resources within Irrigation Schemes. II: Application. Journal of Irrigation and Drainage Engineering. 132:4(341).

Smout, I.K. and Gorantiwar, S.D. 2009. AWAM: a model for optimal land and water resources allocation. In EWRI-ASCE, An International Perspective on Environmental and Water Resources, Bangkok.

Stewart, J. I., R. M. Hagan and W. O. Pruitt. 1976. Production functions and predicted irrigation program for principle crops required for water resources planning and increased water use efficiency. Final Report, U.S. Dept. of Interior, Bureau of Reclamation, Washington, D. C., US.

Suresh K. R. and Mujumdar P. P. 2004. A fuzzy risk approach for performance evaluation of an irrigation reservoir system. Agricultural Water Management, 69.

Syme G. J., Nancarrow B. E. and McCreddin J. A. 1999. Defining the components of fairness in the allocation of water to environmental and human uses. Journal of Environmental Management, 57.

Unal H. B., Asik S., Avci M., Yasar S., and Akkuzu E. 2004. Performance of water delivery system at tertiary canal level: A case study of the Menemen Left Bank Irrigation System, Gendiz Basin, Turkey. Agricultural Water Management, 65.

Unami K., Kawachi T. and Yangyuoru M. 2005. Optimal water management in small-scale tank irrigation systems. Energy, 30.

Uphoff, N. 1988. Improving performance of irrigation bureaucracies: Suggestions for systematic analysis and agency reorientation. Irrigation Studies Group Working Paper, Cornell University, Ithaca, NY, USA.

Vairavamoorthy, K., Gorantiwar S. D., Yan J., Galgale H. M., Mansoor M. A. M. and Mohan S. 2006. Water Safety Plans: Risk Assessment for Contaminant Intrusion into Water Distribution Systems. Water Engineering and Development Centre, Loughborough University, UK.

Vandersypen K., Bengaly K., Keita A. C. T., Sidibe S., Raes D. and Jamin J. Y. 2006. Irrigation performance at tertiary level in the rice schemes of the Office du Niger (Mali): Adequate water delivery through over-supply. Agricultural Water Management, 83.

Vedula, S., and Mujumdar P. P. 1992. Optimal reservoir operation for irrigation of multiple crops. Water Resources Research, 28(1).

Verma H.N. 2002. Optimizing water resource in high rainfall regions. Journal of water management, 10 (1&2).

Yercan, M., F. Dorsan and M.A. Ul. 2004. Comparative analysis of performance criteria in irrigation schemes: a case study of Gediz river basin in Turkey. Agricultural Water Management. 66: 259–266.

APPENDIX – A

The performance measures along with their different attributes suggested by different researchers.

Reference	Type of irrigation system	Performance measures	Assessment method	Spatial level	Temporal level	Data collected (Type and Source)	Model type/ sol. technique	Lessons for this research	Name of River basin/ country	Type of irrigation methods
Clemmens and Bos. (1990)	Canal irrigation, Rotational water supply	Equity , Adequacy and Reliability	Broken down the overall performance of an irrigation water delivery system into two components viz. the delivery schedule and operations	Distribution system	Irrigation season	Past evaluation delivery performance	Statistical methods/approach	The appropriate statistics to use depend on the type of project being studied and the key water management. Problems. Statistical relations have been defined to mathematically describe adequacy, equity and reliability based on such ratios		Surface, pressurized
Plusquellec et. al. (1990).	Canal irrgation system	Water availability, Water Use Efficiency, Equity of water distribution, Cropping Intensity and Crop Yields, and Project Economic Rates	computational method	Irrigation project	Irrigation season	field and office data		There is a need for more realistic assumptions in the adoption of design standards, especially irrigation efficiency which affect the cropping intensity, the overall productivity of the project and its economic viability.	Irrigation Projects in 6 different countries.1.Daukkala - Morocco 2.Sinaloa, Yaqui and Panuco-Mexico 3.Upper Pampanga-Phillipines 4. Lam Pao - Thiland	Gravity and Sprinkler irrigation systems.

		of Return.							5.Coello and RUT -Colombia 6.Gezira-Sudan	
Molden and Gates(1990)	Canal irrgation system	Adequacy, Efficiency, Dependability, and equity	An approach to cross-system comparison is to compare outputs and impacts of irrigated agriculture. "External" indicators are used to relate outputs from a system derived from the inputs into that system. Standardized Gross Value of Production (SGVP)	Field, distribution system	Year	The available data with the Irrigation department regarding climate, command, crop finance etc	Standardized Gross Value of Production (SGVP)	Adequacy assesses whether the requirement has been met by the amount of water delivered. Efficiency is a measure for the excess of water delivered in comparison with the requirements. Dependability expresses the degree of temporal variability of irrigation delivery compared to requirements. Equity is a measure for the spatial uniformity of water deliveries and shows the fairness of water delivery across delivery points.	Colombo, Sri Lanka: International Water Management Institute, Upali Amerasinghe, Muda System in Malaysia; Carlos Garcés-Restrepo and Charlotte de Fraiture, Colombia; Paul van of wegen (IHE), Morocco; Wim H. Kloezen, Carlos Garcés-Restrepo, and Sam Johnson, Mexico; Chris Perry, Egypt; Hilmy Sally, Burkina Faso; R. Sakthivadivel, India; M. Samad and Douglas Vermillion, Sri Lanka; Zaigham Habib, Pakistan; Charles Abernethy and Kurt	Surface

									Lonsway, Niger; and David Molden, Turkey.	
Small and Svendsen (1990)	Canal irrgation system	Process measures, Impact measures and output measures	A framework for conceptualizing irrigation performance	Distribution system	Irrigation season		Goal Model, natural system model	A framework presented for conceptualizing irrigation performance. Categorized performance according to their purposes, with significant differences among those that monitor operational performance, those that facilitate interventions to improve performance, and those that promote accountability within an operating agency. Impact measures of performance pertain to the effects that the system's outputs induce in its larger environment.		
Bos et. al. (1994)	Canal systems for agricultural production	Physical, economic and social sustainability, water supply performance (conveyance indicators, maintenance indicators, utility of water supplied,	A framework for irrigation managers that can be used in assessing performance of irrigation	Distribution system	Year		A framework	The framework developed by the Authors provides a basis for understanding the roles, strengths and limitations of the many different approaches to assessing irrigation system performance.		

		and equity), agricultural productivity (area indicators and production indicators) and economic, social and environmental performance (economic viability, social viability and environmental sustainability and drainage).								
Purkey and Wallender(1994)	Canal irrigation	Irrigated area performance, Fee collection performance, Conveyance efficiency, distribution efficiency, Efficiency of Infrastructure, Total financial viability, Application efficiency and Distribution uniformity.	A survey of irrigation performance assessment with irrigation managers	irrigation system	season and year	Review	Formal survey methodology. A guided discussion.	This paper has provided a useful overview of some innovative irrigation performance assessment approaches employed by irrigation professionals.	California	Surface
Bos (1997)	canal	40 multidisciplinary	Provided the detailed	irrigation and	week, month,	Field and collected	Research Program on	The indicators are to be recommended for use in		Surface

	irrigation	performance indicators related to water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economic and management.	methodology for assessing these performance indicators and also proposed to measure and collect the field data and analyze the data to know these measures.	drainage system level	season, year	data	Irrigation Performanc e (RPIP).	irrigation and drainage performance assessment		
Burt et. al.(1997)		Irrigation efficiency, Irrigation consumptive use coefficient, irrigation sagacity, distribution uniformity, application efficiency, adequacy and potential application efficiency	Water balance studies	Spatial (field, farm, scheme, basin) and temporal intervals (irrigation event, season etc)	one irrigation interval	Review		Accurately determination and quantifying water-balance omponents is not easy to do in a hydrologic system, regardless of scale (e.g., field or basin).		Surface, sprinkler, border and drip
Bastiaanssen and Bos.(1999)S	Canal	Adequacy (crop water stress index, relative water supply, water deficit index	Remote sensing determinants such as actual evapotranspir	Irrigation scheme	Year	Review		Aspects of adequacy, productivity, equity, reliability and sustainability in irrigation management can be computed from		Surface

		evaporative fraction and soil moisture); equity (water application per unit area, CV of evapotranspiration, CV of evaporative fraction, CV of depleted fraction); reliability (temporal variation of the evaporative fraction); productivity (actual evapotranspiration over water applied, yield over water applied, yield over evapotranspiration); sustainability (irrigation intensity, water-logging, salinity of top soil).	ation, soil water content and crop growth that reflect the overall water utilization at a range of scales, up to field level					remotely sensed data. satellite measurements can help in surveying the conditions of irrigated land in a consistent and objective manner		
Hales and Burton (1999)	Canal irrigation system	Total volume allocated, total effective rainfall, Relative water	Optimal water allocation policy	Irrigation scheme	Seasonal	Field data	IRMOS	The process shows how the use of modelling to identify performance shortfalls followed by	The Rio Cobre Irrigation Scheme, Jamaica,	Surface

		supply, Supply:demand ratios, Relative yield, Relative profitability, Specific yield, conveyance efficiency.						management (rather than infrastructural) interventions can be a valid way forward to improving scheme performance.		
Bustos et. al. (2001)	Canal, Rotational water supply	Management performance of Water User Associations was evaluated in terms of : knowledge to identify water users; knowledge to meet users' needs; knowledge to control water distribution; and knowledge to determine the irrigation water rate.	on basis of 85-question questionnaire and related interviews	Field, distribution system	Irrigation season	Data collection was done by means of 89-item questionnaire, interviewing 19 inspectors of Users' Associations (UA's). The questionnaire was organized around : Distribution of water, identification of user needs,management and control,social factors		The balance between technology and the related management and technical skills should receive full attention	Lower Tunuyan area, Argentina,	Surface
Malano and Burton	Describing the	1.Service delivery performance in	computation	irrigation	season,	Field and collected		The indicators provided by Malano and Burton,		

(2001)	guidelines for benchmarking performance in the irrigation and drainage sector	terms of (a) the adequacy with which the organization manages the operation of the irrigation delivery system to satisfy the water required by users (system operation), and (b) the efficiency with which the organization uses resources to provide this service (financial performance). 2. Productive efficiency: Measures the efficiency with which irrigated agriculture uses water resources in the production of crops and fibre. 3. Environmental performance: Measures the impacts of irrigated agriculture on land and water	al method	scheme	year	data		however do not include the performance indicators related to equity and adequacy which are very important in the assessment of performance of irrigation scheme.			

		resources.								
Ray et. al. (2002)	Canal irrigation	Adequacy (based on relative water supply), equity (based on NDVI), agricultural productivity (cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land and productivity of water)	Multi-temporal remote sensing (RS) data-based crop inventory, generation of vegetation spectral index profiles and crop evapotranspiration estimation were carried out	distributaries, Head to tail	Rabi season	Indian Remote Sensing Satellite (IRS)-1C Linear Imaging and Self Scanning-III (LISS-III) and Wide Field Sensor (WiFS) data.	Using Indian Remote Sensing Satellite (IRS)-1CLinear Imaging and Self Scanning-III (LISS-III) and Wide Field Sensor (WiFS) data.	The integration of RS data and GIS tools to regularly compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system.	Mahi command, Gujarat, India	Surface
Plantey and Molle (2003)	Canals and pressurised pipes of the public and private company	Water balance performance, Conveyance and distribution efficiency ratios,Water delivery performance, Environment performance assessment,Commercial performance, Cost-effectiveness of performance	Water balance performance assessment	irrigation sceme	year	Files of contracts, complaints reports, specific enquiries		They have also presented the detailed description of different indicators along with definitions and formulae.	Societé du Canal de Provence, France	

		assessment								
Perry (2005)	canal irrigation	Reliability of irrigation, Productivity of water	Remote sensing, management effectiveness which is a ratio of (irrigation delivery + effective rainfall) and (evapotranspiration + seepage and deep percolation). Measurements for these variables at various points in irrigation scheme and at regular intervals provide an indication of whether water availability exceeds or fall short of demand.	irrigation system	seasonal	Review		Better understanding of the extent to which complex irrigation schedules, Insights into whether erratic inflows into dams are better released as lower volumes at higher reliability – saving unexpected peaks for later use as reliable, controlled supplies in a subsequent season. designed to meet precise needs of water sensitive crops should be pursued at the cost of potential degradation in reliability		

Yercan et. al. (2004)	irrigation scheme	1. Physical performance criteria, 2. Economic performance criteria	Selected irrigation schemes in Gediz river basin were examined and assessed for their physical and economic performance criteria according to the situation of before and after management transfer process 1. the rate of irrigation (RI) = irrigated land (ha)/˙Irrigable land (ha) and sustainability of irrigated land = irrigated land (ha)/initial irrigated land	Basin, four main reservoirs and four regulators are used for irrigation diversions	Summer irrigation period	Office data and field data. Official reports of Turkish Republic State Hydraulic Works and audited annual reports of WUAs.		Irrigation management transfer from Govt to users is recommended as the greater participation of farmers in the management of irrigation systems which resulted in doubling of irrigation fee collection rates and a shifting of operation and maintenance expenditures from the public to the users.	"Demirköprü" reservoir, Gediz river basin, Turkey.	Surface

			(ha). 2. the effectiveness of fee collection (EFC) = collected fee/total fee and financial self-sufficiency (FSS) = annual fee revenue/total annual expenditures.							
Gorantiwar and Smout (2005)	Heterogeneous irrigation schemes, Canal Irrigation ,Rotational water supply	Productivity and Equity, Adequacy, Reliability, Flexibility, Sustainability and efficiency	A framework for the performance assessment of irrigation water management in heterogeneous irrigation schemes, based on earlier studies made in this direction. Framework consists of three phases	Scheme	Irrigation season	Review	Simulation model	The conceptual framework for performance measurement has been extended in this paper for the qualitative and quantitative evaluation of performance during every phase of irrigation water management, The methodologies to estimate these measures explained in this paper provide the irrigation authorities with The information on the performance of irrigation water management in the scheme, their anagement capability, the response of		surface

			of irrigation water management namely planning, operation and evaluation for assessment of performance for which two types of allocative measures (productivity and equity) and five types of scheduling measures (adequacy, reliability, flexibility, sustainability and efficiency) are proposed.					the irrigation water management to variations in climatological, physical and management aspects and insight to improve the performance during different phases of irrigation water management.		
Olubode-Awosola et. al. (2006)	Canal	Socio-economic and financial performances	Performance indices based on the indicators	basin level	Irrigation season		Perrformance indices based on the	Proposed performance indices based on the indicators proposed by Bos (1997).	Ogun-Oshun River Basin and Rural Development	Surface

			proposed by Bos (1997) fee collection index as the ratio of irrigated fees collected and irrigation fees due, user's stake index as the ratio of number of active project farmers and total number of project farmers, relative water cost index as the ratio of irrigation cost per ha and total production cost per ha, relative irrigation profit index as the ratio of irrigated cropping profit per ha rain – fed cropping				indicators proposed by Bos (1997)			Authority in Nigeria	

			profit per ha, financial self − sufficiency index as the ratio of actual income to total recurrent expenditure on irrigation related services and financial self − sufficiency index as the ratio of actual income to total recurrent expenditure on irrigation related services.							
Akkuzu et. al.(2007)	Canal irrigation	Adequacy and equity irrigation ratio (actual irrigated area/projected irrigation area), water use ratio (actual water		Irrigation Scheme	Annual, Seasonal and Monthly	Data from General Diroctorate of State Hydraulic Works(DSI), Actual flow records,	Four performanc e measures based on the remote sensing techniques	The authors elaborated in detail how to estimate the NDVI values with the help of remote sensing data for the determination of performance measures.	Gediz Basin Irrigation System, Turkey	Surface

		use/target water use), average Normalized Difference Vegetation Index ($NDVI_{ave}$) and coefficient of variation of NDVI for equity in water delivery				Images from NOAA-16/AVHRR				
Clemmens and Molden (2007)	calal irrigation	Annual relative water supply (RWS), which is the ratio of total water supply and crop water requirement; and Annual relative irrigation water supply (RIS) which is the ratio of irrigation water supply to crop irrigation water requirement.	A quantitative approach for estimating the impact of internal performance indicators on water productivity	Field	Irrigation season	RAP process		Suggested that crop-scale irrigation uniformity can be examined at a project scale by understanding how field, farm and project irrigation systems contribute to nonuniformity.		surface
Latif and Tariq.(2009)	canal irrigation	Relative water supply (the ratio of total water supply to total water demand at field level), water delivery capacity (canal capacity to	computational method	Field	Intraseasonal	Field data, office records, conducting interviews		The discharge measurement training and formation of hydraulic committees at distributaries to measure and monitor discharge at intakes and critical points. Similarly, training of	Maira Branch Canal of the Upper Swat Canal (USC) System in Pakistan.	surface

		deliver water at the system head to the peak consumptive use demand), delivery performance ratio (the ratio of the actual discharge and design or authorized discharge) and reliability (ability of a system to deliver design irrigation supplies in a given time span).						farmers in soil–water–plant relationships may be helpful in increasing their understanding on scientific bases of farm irrigation methods to reduce excessive and intensive irrigation water application.			

APPENDIX - A1

The details of different performance measures used by the researchers/managers.

Reference	Type of irrigation system	Performance measures	Assessment method	Spatial level	Temporal level	Data collected (Type and Source)	Model type /sol. Technique	Lessons for this research	Name of River basin/ country	Type of irrigation methods	Values of the performance measures
Isidoro and Aragues (2004)	District irrigation	Water use and returns		District		water diverted for irrigation, which includes the irrigation ditches operational losses; precipitation; direct water releases of the Monegros Canal into the drainage system; surface runoff and groundwater inflows from outside the study area; municipal and industrial wastewaters; canal seepage, surface drainage outflow, evapo-transpiration in the whole surface of the study area and deep percolation and groundwater outflows from the system.	Scenario I,II,III	The average annual water outputs (80.9 hm^3 or 2260 mm) were 23% higher than the inputs (65.5 hm^3 or 1830 mm).	Ebro River Basin, La Violada irrigation District (Spain)	Surface	Annual water outputs =80.9 hm3
Makin et. al. (1991)	Canal irrigation , Rotational water supply	Actual versus targeted supply, alongwith Equity, Reliability	Computer based irrigation scheduling	Irrigation project	Two seasons	Office record	Computer assessment system	The computer assisted irrigation scheduling to a 20,000 ha small holder rice and	Kraseio Project, Suphanburi, Thailand.	Surface canal irrigation with pumping scheme	The dam release had a reliability index of 65% against advised target flow. Effective command area

		and Adequacy						sugarcane irrigation project in Thailand provided an opportunity for continuous performance assessment.			incresed by 20 % of nominal area.
Palmer et. al. (1991)	Canal irrigation system	Performance of water delivery system in terms of Timeliness, Adequacy in terms of Flow Rate and duration	Examining water order reports and bills, and conducting a diagnostic analysis of the water delivery and onfarm irrigation systems through interviews.	Bellow scheme level	seasonal	Data were obtained through monitoring of lateral canals, examining water order reports and bills, and conducting a diagnostic analysis of the water delivery and onfarm irrigation systems through interviews.		The canal system which was designed to be operated under upstream control, was found to be operated under a complex mixture of manual upstream and downstream control that resembled dynamic regulation	Wellton-Mohawak Irrigation District(WMIDD), Southwestern Arizona	Surface	The mean value for flow rate adequacy was 0.96. The average duration adequacy was found to be 0.98.The annual conveyance-distribution efficiency= 90%. The overall district project Water Use Efficiency > 60%.
Bhutta and Velde (1992)	Warabandi Canal irrigation system	Equity of water distribution in terms of	Examining and sudies of Canal operational data from	Distributory Level		Data from Punjab Irrigation Department. Flow conditions for three distributaries and of selected outlets served by each were measured daily		The field observations showed that discharge variation at	Chenab Canal system, Punjab Province,	Perrenial canal Surface irrigation	The DPR for Mananwala Distributary outlets in the head and middle

		DPR(delivery performance ratio)	the office records			throughout 1988, and data were converted to discharges.		the head of distributaries greatly exceeded the original design criteria. Evaluation of field data also showed that better operational procedures at the distributary level could substantially improve water supply conditions in the tail reaches.	Pakistan. (3 distributaries :Mananwala and Lagar Distributaries in the head reach of the Gugera Branch Canal and Pir Mahal Distributary at the very tail of this Branch)		reach was 223%, for tail outlets was 50% of their sanctioned discharges. The DPR value Lagar distributary ranged from 150% to 8% of design discharge. The DPR for Pir Mahal Distributary outlets varied between 272% and 18% of design discharge.
Mujumdar and Vedula (1992)	Canal irrigation	Reliability, resiliency and productivity index	Stochastic dynamic programming (SDP)	Sceme	Irriagtion season	Office record	Stochastic dynamic programming (SDP).	Three different optimal operating policies are derived, having increasing mathematical complexity, using stochastic	Malaprabha Reservior Project, Krishna River Basin, Karnataka, India	Surface	When initial moisture content (ϴo) at Field Capacity for policy I, II, and III the reliability index were found to be 0.63, 0.95 and 0.99 respectively, the resiliency values

								dynamic programming (SDP). Two of the three policies, policy II and Policy III, incorporate a detailed soil moisture dynamics model as an integral part of SDP. Policy III considers, in addition, an optimal allocation of water among the irrigated crops when there is competition of water			were 0.45, 0.96 and 0.95 respectively . For lower value of Ɵo both policy II and III had reliability index values as 0.87 and 0.89 respectively and resiliency index values as 0.68 and 0.22 respectively.
Kalu and Gupta (1995)	Canal irrigation , Rotation al water supply	Equity and efficiency	Optimizatio n model , simulation model	Irrigati on water distrib ution policy			Optimizatio n model ,Simulation model	A multi-objective analysis was carried out to select a compromise solution. This methodology		Surface	

								was applied to select a water distribution policy			
Makadho (1996)	Canal irrigation system	timeliness indicators	The methodology they followed in the study differentiated between timely irrigation deliveries which meet Crop Water Requirements (CWR) and surplus water supplies due to poor timeliness which could not be used by the crop, hence denoting wastage.	Irrigation schemes	Irrigation season			The Results indicated that applying measures of timeliness helped to assess water management practices across scheme types.	Smallholder irrigation systems in Zimbabwe	surface	
Small and Rimal (1996)	Canal irrigation system	Economic efficiency and equity	Simulation analysis	irrigation system	Season		Simulation models	Economic efficiency and equity among all farmers	Irrigation systems in Asia.	Surface	

								within the command area of the irrigation system are largely complementary strategies at the lower levels of water shortage, but with increasing shortage, significant trade-offs develops.				
Balasubramaniam et. al. (1996)	Aralikottai tank system		near real time analysis through LP modeling	system	Year	The analysis was conducted separately for a drought year (1988) and a surplus year (1990) with the available five year data from 1988 to 1992.	LP model	the existing status of irrigation can be improved to obtain the maximum benefits from the tank command area based on the quantification done.				
Sarma and Rao (1997)	Canal irrigation system, Rotation	Water supply-requirement ratio	Integrated Water Management Scheme	Distributary	Single season	Based on the availability of field data,		Equitable rotational distribution of irrigation	Nagarjuna Sagar Right Canal (NSRC)	Surface		

	al water supply	and other indices such as irrigation intensity, crop productivity and cropping pattern	(IWMS)					water, has a definite impact on water utilisation in the command area which resulted insteadily increased irrigated area.	irrigation project in Andhra Pradesh, India,		
Arora and Gajri (1998)		Water balance aspects	Probability distribution analysis	field	Season	Field data	Water balance model (WBM)and crop growth simulator (SUCROS)	Supplemental irrigation and higher soil water retentivity increases mean grain yield and reduces the effects of annual rainfall variability		Surface	
Godswill et. al. (1998)	Canal irrigation system	Match desired with actual water supply	Theil measure of accuracy of forecasts	Field	Season	Field data		The farmer managed system performed better than the government system in matching supply and	Zimbabwe.	Surface	

								demand.			
Hales and Burton (1999)	Canal irrigation system	Total volume allocated, total effective rainfall, Relative water supply, Supply: demand ratios, Relative yield, Relative profitability, Specific yield, conveyance efficiency.	Optimal water allocation policy	Irrigation scheme	Seasonal	Field data	IRMOS	Any measures for improvement in the specific yield (without changing the cropping pattern) would involve making more water available to the crops at certain times during the season.	Rio Cobre Irrigation Scheme, Jamaica.	Surface	Relative water supply for optimal and actual allocation was 1.08 and 1.19 respectively. The relative yield was 25% more for the optimal over the actual allocation. The specific yield increased by some 45% over the actual allocation. Unsatisfied demand ration for optimal and actual allocation were 0.30 and 0.38 respectively
Raju and Pillai (1999)	Canal irrigation	on farm development works, adequacy of water, supply of inputs, conjunctive use of	Multi-criterion decision making ;Taguchi experimental design technique	Distributary	Year	Office data and field data	Stochastic extension of PROMETHEE-2 (STOPROM-2) ;MAUT	The proposed methodology can serve as a model to choose the best one for formulating guide lines for improving the	Sri Ram Sagar Project, a major irrigation project in India	Surface	The weightages of the criteria, on-farm development works, adequacy of water, supply of inputs, conjunctive use of water

		water resources, productivity, farmers' participation, economic impact and social impact					method.	efficiency and performance of similar other distributaries.			resources, productivity, farmers' participation, economic impact and social impact for expert 1 were 0.0826, 0.12, 0.0477, 0.0823, 0.1783, 0.0478, 0.2788, 0.1625 and values for expert 2 were 0.0449, 0.0435, 0.1001, 0.0671, 0.2088, 0.1509, 0.2091, 0.1756.
Renault (1999)	Canal irrigation system	Adequacy and efficiency, and equity (coefficient of variation and Theil information index).	Analytical system indicators and numerical hydraulic simulations and Sensitivity,			field and office data		These global system indicators can be used to define the precision level required to achieve a given performance, to estimate actual performance from recorded precision at	Three different irrigation systems in Sri Lanka and Pakistan	Surface	

								regulators, and to diminish the system sensitivity, improving the performance for a given precision.			
Syme et. al. (1999)	Canal irrigation	Justice, equity and fairness	Balancing the needs of multiple users and uses in water allocation		season	Office and field data		It was evident that the public could make relatively complex judgements which used dimensions that go beyond the scope of traditional social psychological definitions of equity and procedural justice.	Australia	Surface	

Jahromi et. al. (2001)	Irrigation canals and their tertiary outlets	Reliability, equity and Ability(Adequacy), Actual overall efficiency	Delivery performance ratio to assess the water delivery performance in an irrigation district	head, middle and tail end	Irrigation season	Field data and office data. Monthly water balance components and real time climatic data processed using the CROPWAT program	Actual overall efficiency	The results from the Doroodzan Irrigation System revealed that the system could not deliver water according to the real crop water requirements.	Doroodzan Irrigation System in Iran	Surface	Equity at tertiary level =0.16. Reliability at tertiary level=0.08. Ability(Adequacy) at teriary level=1
Santhi and Pundarikan-than (2000)	Rotational water supply	Equity, adequacy, timeliness and locational or convenience of operation;	Planning model for canal scheduling of rotational irrigation based on multi-criteria approach	Distributary canal.	Irrigation season	Office record	Planning model	The releases were found to be more than the demand in the beginning of the season and less than the demand at the end of the season (critical period), which might considerably affect the crop production in the case of conventional scheduling.	Left bank main canal of the Sathanur Irrigation Project in the State of Tamil Nadu in India.	Surface	The Modified inter-quartile ratios, a measure of equity computed were 1.19 (model) and 1.76 (manual), which indicated that inequity in water distribution can be reduced from 76% in the conventional scheduling to 19% in the present model. Adequacy in the form of supply

											to demand ratio can be improved upto 0.95±1.05 from present value of 0.85±5.90.
Bustos et.al. (2001)	Canal Rotational water supply	Management performance of Water User Associations was evaluated in terms of knowledge to identify water users; knowledge to meet users' needs; knowledge to control water distribution; and knowledge to determine the	Basis of an 85-question questionnaire and related interviews.			Data collection was done by means of 89-item questionnaire, interviewing 19 inspectors of Users' Associations (UA's). The questionnaire was organized around : Distribution of water, identification of user needs,management and control,social factors		The system facilitates management supervision by the users themselves and makes it possible to correct the UA's management system deficiencies. The lack of access to new information technology and to training in flow measurement affects an inspector's performance.	Lower Tunuyan area, Argentina,	Surface	

		irrigation water rate.									
Murray-Rust and Svendsen (2001)	Canal irrigation system	Yields and water productivity		Field	Irrigation season	Office record		During the first four years after management transfer there has been a continued improvement in irrigation performance. While the area cropped using surface water has only marginally improved, yields and water productivity have shown significant increases		surface	
Ines and Droogers (2002)	Canal irrigation	Irrigation system characteristics and operational management	Inverse modelling,	minor level	Irrigation season	Remotely sensed (RS) data and observable data	Genetic Algorithm loaded stochastic physically based soil-water-atmosphere-plant	Good agreement with the inventoried data such as soil hydraulic properties, sowing dates, groundwater	The BataMinor (an offtake from the Sirsa Branch) of the Bhakra Irrigation System at	surface	

							model (SWAP) was developed.	depths, irrigation practices and water quality. The derived data could be used to predict the state of the system at any time in the cropping season, which can be used to evaluate operational management strategies.	Kaithal, Haryana, India.		
Levite and Sally(2002)	Canal irrigation , Rotational water supply	Productivity and equitable allocation of water, sustainability	Computation of the implications of water reallocations on water use and productivity at the basin level with a special focus on opportunities for revitalizing	Olifants river basin	Irrigation season	Office record		The economics is undoubtedly playing a major role in the allocation of water rights. There is needs to take cognizance of the notion of equity in the sharing of water at every	Olifants river basin, South Africa	Surface	

			and expanding small holder irrigation systems.					stage.			
Ray et. al. (2002)	Canal irigation	Adequacy (AI), equity (EI) and water use efficiency (WUE)	Multi-temporal remote sensing (RS) data-based crop inventory, generation of vegetation spectral index profiles and crop evapotranspiration estimation	distributaries, Head to tail	Rabi season	Indian Remote Sensing Satellite (IRS)-1C Linear Imaging and Self Scanning-III (LISS-III) and Wide Field Sensor (WiFS) data.		The performance evaluation has shown the discrepancies and relative ranking of the distributaries vis-a-vis crop water requirements. The water applied is also not equitably distributed, the head getting more than the tail end.	Mahi command, Gujarat, India	Surface	The agricultural productivity in terms of efficiency of water to produce crop growth ranged from 0.3 to 2.0/m3.Equity for two different distributories was found to be decresing from Zone I to Zone III as : Distributory 1: from 57.9% to 40.5%; Distributory 2: from 56.6% to 41.4% .Adequacy in terms of Relative water supply for various distributories ranged from 0.58 to 3.54.

Roost (2002)	Canal irrigation system	Irrigation water use efficiency, productivity and equity	A new irrigation model, OASIS (Options Analysis in Surface Irrigation Systems), which was developed to conceptualize and test irrigation interventions in a medium to large-scale irrigation system.	Basin	Irrigation season		OASIS (Options Analysis in Surface Irrigation Systems)	OASIS integrates recycling and captures all the main factors of the water balance, including non-process depletion from fallow lands and non-crop vegetation. The model allows proper quantification of water use efficiency, productivity and equity under actual or hypothetical conditions of land use, infrastructure and water management	Bojili Irrigation District (BID), China's lower Yellow River basin	Surface	Simulation output following the equitable principle resulted an increase in productivity of available water to 5.01 Yuan/m3 from actual value of 4.93 Yuan/m^3

Dechmi et. al. (2003)		On-farm water use (WU) and net irrigation requirements (NIR). seasonal irrigation performance index (SIPI),	Statistical analysis. The analysis of irrigation WU during three irrigation seasons (dry, average and humid) was used to characterise the performance of relatively modern irrigation systems in the LQD	cadastral plot	Three rrigation season	field data, district records on WU and farmers' interviews records of irrigation practices for three different irrigation seasons		The high cost of irrigation water in relation to crop revenues, the technical deficiencies of the irrigation systems, and the limitations imposed by climate and soils appeared to be major causes of local water management problems.	Loma de Quinto irrigation district (LQD), located in Zaragoza (Spain).	Sprinkler	The district average SIPI (computed in all plots) was 155, 95 and 131 for the years 1989, 1995 and 1997, respectively. The average inter-annual SIPI amounted to 127%. The average WU was 477, 995 and 585 mm, for the 1989, 1995 and 1997 years, respectively
Evans et. al. (2003)	Canal irrigation system	Efficiency in land and water use and equity in income distribution	A comprehensive, crop-livestock mathematical programming model to maximize aggregate gross margin from agricultural production in the El	Lower and upper level	Irrigation season	Office record	Crop-livestock mathematical programming model	Achieving efficiency in resource use and equity in income distribution requires a significant transfer of water resources to the lower zone, largely accomplished	El Angel watershed, located in Ecuador's Sierra region	Surface	

			Angel watershed, constraints being the limited supplies of land, labor and water					through a shift to lower irrigation intensity crop activities upstream.			
Plantey and Molle (2003)	Network of canals and pressurised pipes	Water balance indicators, water delivery performance indicators, maintenance indicators, environmental indicators, commercial indicators and financial indicators.	Computational	irrigation sceme	year	Files of contracts, complaints reports, specific enquiries		The overall efficiency of Canal de Provence conveyance system appears to remain equal or greater than 95% (with 2 or 3% standard deviation), and close to 85% when considering the conveyance plus distribution systems. On the average for 10 years, the *rate of recovery* of	Societé du Canal de Provence, France		Conveyance efficency> 95% (with 2 or 3% standard deviation). The rate of recovery of water charges is 99.75%.

								water charges is 99.75%.			
Unal et. al. (2004)	Tertiary canal level	Adequacy, efficiency, dependability and equity	Using measured water deliveries and calculated crop water requirements.	head/ middle /tail	6-month irrigation seasons			The analysis of results of the spatial and temporal dimensions of the performance indicators showed that factors causing this problem resulted from the part from management, and physical structure.	Menemen Left Bank Irrigation System, Gediz Basin, Turkey	Surface	Equity for year 1999 and 2000 are 0.67 and 0.74 respectively. Adequacy for year 1999 and 2000 are 0.53 and 0.57 respectively. Efficiency for year 1999 and 2000 are 0.83 and 0.84 respectively. Dependability for year 1999 and 2000 are 0.81 and 0.73 respectively
Yercan et. al. (2004)	Irrigation schemes	Rate of irrigation (RI) ,sustainability of irrigated land ,effectiveness of fee collection (EFC) ,financial	Comparative analysis of performance criteria before and after irrigation management	Scheme	Year	Office data and field data. Official reports of Turkish Republic State Hydraulic Works and audited annual reports of WUAs.		Irrigation management transfer from Govt to users is recommended as the greater participation of farmers in the management of irrigation	Gediz river basin in Turkey.	Surface	With the management transfer Rate of irrigation (RI) increased by 51 to 57%.

		self-sufficiency (FSS)						systems which resulted in doubling of irrigation fee collection rates and a shifting of operation and maintenance expenditures from the public to the users.			
Vandersypen et. al. (2006)	Canal irrigation	Adequacy, Dependability and equity	Interventions implemented and current water management practices	Ttertiary level		Field data		The solution lies in increased irrigation efficiency which will also help to solve the recurrent drainage problems that trouble the harvest in the rice schemes of the Office du Niger.	Office du Niger (Mali)	Surface	Adequacy=0.96 and 0.92 for year 1995 for 2004 respectively. Dependability= 0.78 and 0.71 or year 1995 and 2004 respectively. Equity=0.63 and 0.54 or year 1995 and 2004 respectively.

Clemmens and Molden (2007)	Canal Irrigation	Annual relative water supply (RWS), which is the ratio of total water supply and crop water requirement; and annual relative irrigation water supply (RIS) which is the ratio of irrigation water supply to crop irrigation water requirement.	A quantitative approach for estimating the impact of internal performance indicators on water productivity	Field	Irrigation season	RAP process		The primary indicators used to determine the suitability of the water supply for agricultural production is the annual relative water supply (RWS). According to authors, for examining the adequacy of the irrigation water supply, the annual relative irrigation water supply (RIS) can be used.		Surface	
Gaur et. al. (2008)	Canal irrigation	Spatial equity and land use	Computational approach	head, middle, and tail	Irrigation event 8-10days	Canal release data combined with census statistics moderate resolution imaging spectrometer (MODIS)		The findings of this study suggested that equitable allocations could be	left main canal command of Nagarjuna Sagar ,India	Surface	

								achieved by improving the water distribution efficiency of the canal network during normal years and by crop diversification and introduction of alternative water sources during water shortage years			
Latif and Tariq (2009)	Canal irrigation	Relative water supply , water delivery capacity, delivery performance ratio and reliability	computational method	Field,distribution system	Intraseasonal period, irriagtion period	Field data, office records, conducting interviews		The discharge measurement training and formation of hydraulic committees at distributaries to measure and monitor discharge at intakes and critical points. Similarly, training of farmers in soil–water–	Maira Branch Canal of the Upper Swat Canal (USC) System in Pakistan.	Surface	Water delivery capacity = 0.85, average Delivery performance ratio = 0.78 to 0.83 during the summer and itis 0.63 to 0.73 during winter months.

								plant relationships may be helpful in increasing their understanding on scientific bases of farm irrigation methods to reduce excessive and intensive irrigation water application.			
Parsinejad et. al. (2009)	Canal irrigation	Application water efficiency	Field measurements of water inflow and outflow, deep percolation and calculation of evapotranspiration and water balance	field	Seasonal	Field data	Computation and field data analysis	The performance measures under study related to productivity, equity and water supply need to be measured or addressed simultaneously. The performance measures were	Sefidrood irrigation and drainage network, Guilan Province, Iran	Surface	

								addressed mostly at the scheme level.			
Akkuzu et. al. (2007)	Canal irrigation	Adequacy and equity irrigation ratio (actual irrigated area/projected irrigation area), water use ratio (actual water use/target water use), average Normalized Difference Vegetation Index ($NDVI_{ave}$) and coefficient of variation of NDVI for equity in water delivery		Irrigation Scheme	Annual, Seasonal and Monthly	Data from General Directorate of State Hydraulic Works(DSI), Actual flow records, Images from NOAA-16/AVHRR	Four performance measures based on the remote sensing techniques	The authors elaborated in detail how to estimate the NDVI values with the help of remote sensing data for the determination of performance measures.	Gediz Basin Irrigation System, Turkey	Surface	Adequacy in the form of Irrigation Ratio was 77% and 76% for year 2004 and 2005 respectively. Adequacy in the form of $NDVI_{AVE}$ was 0.32 to 0.42 and 0.26 to 0.42 for year 2004 and 2005 respectively. Equity in the form of $CV(NDVI_{AVE})$ ranged from 0.14 to 0.23 and 0.14 to 0.30 for year 2004 and 2005 respectively.

APPENDIX - A2

The values of different performance measures estimated for different irrigation schemes.

Name of Irrigation scheme	Productivity	Equity	Adequacy	Efficiency	Reliability	Other
Gediz Basin Irrigation System, Turkey	Not Reported	Equity in the form of CV($NDVI_{AVE}$) ranged from 0.14 to 0.23 and 0.14 to 0.30 for year 2004 and 2005 respectively.	Adequacy in the form of Irrigation Ratio was 77% and 76% for year 2004 and 2005 respectively. Adequacy in the form of NDVIAVE was 0.32 to 0.42 and 0.26 to 0.42 for year 2004 and 2005 respectively.	Not Reported	Not Reported	Not Reported
Ebro River Basin, La Violada irrigation District (Spain)	Not Reported	Not Reported	Not Reported	Distribution efficiency of System = 83%. and on farm consumptive use coefficient = 61%	Not Reported	Not Reported
Rio Cobre Irrigation Scheme, Jamaica.	Not Reported	Not Reported	Not Reported	Not reported	Not Reported	Relative water supply for optimal and actual allocation was 1.08 and 1.19 respectively. The relative yield was 25% more for the optimal over the actual allocation. The specific yield increased by some 45% over the actual allocation. Unsatisfied demand ration for optimal and actual allocation were 0.30 and 0.38 respectively

Doroodzan Irrigation System, Iran	Not Reported	Equity at tertiary level =0.16	Ability(Adequacy) at teriary level=1	Not Reported	Reliability at tertiary level=0.08	Not Reported
Sathanur Irrigation Project , Tamil Nadu, India.	Not Reported	The Modified inter-quartile ratios, a measure of equity computed were 1.19 (model) and 1.76 (manual), which indicated that inequity in water distribution can be reduced from 76% in the conventional scheduling to 19% in the present model.	Adequacy in the form of supply to demand ratio can be improved upto 0.95±1.05 from present value of 0.85±5.90.	Not Reported	Not Reported	Not Reported
Societé du Canal de Provence, France	Not Reported	Not Reported	Not Reported	Conveyance efficiency = 95%	Not Reported	Not Reported
Mahi River command, Gujarat, India	The agricultural productivity in terms of efficiency of water to produce crop growth ranged from 0.3 to 2.0/m^3	Equity for two different distributories was found to be decresing from Zone I to Zone III as : Distributory 1: from 57.9% to 40.5%; Distributory 2: from 56.6% to 41.4%	Adequacy in terms of Relative water supply for various distributories ranged from 0.58 to 3.54.	Not Reported	Not Reported	Not Reported

Bojili Irrigation District (BID), Yellow River basin, China	With the used model the productivity of available water is increased to 5.01 Yuan/m3 from actual value of 4.93 Yuan/m^3	Not Reported	Not Reported	Not Reported	Not Reported	Not Reported
Loma de Quinto irrigation district (LQD), Zaragoza, Spain	Not Reported	Not Reported	Not Reported	Not Reported	Not Reported	The district average inter-annual SIPI (seasonal irrigation performance index) (computed in all plots) was 155, 95 and 131 for the years 1989, 1995 and 1997, respectively. The average inter-annual SIPI amounted to 127%. The average WU was 477, 995 and 585 mm, for the 1989, 1995 and 1997 Years respectively.
Menemen Left Bank Irrigation System, Gediz Basin, Turkey (Unal et al 2004)	Not Reported	Equity for year 1999 and 2000 are 0.67 and 0.74 respectively	Adequacy for year 1999 and 2000 are 0.53 and 0.57 respectively	Efficiency for year 1999 and 2000 are 0.83 and 0.84 respectively	Not Reported	Dependability for year 1999 and 2000 are 0.81 and 0.73 respectively
Gediz river basin, Turkey (Yercan et al 2004)	Not Reported	Not Reported	Not Reported	Not Reported	Not Reported	With the management transfer Rate of irrigation (RI) increased by 51 to 57%.

Maira Branch Canal , Upper Swat Canal System, Pakistan	Not Reported	Not Reported	Not Reported	Not Reported	Water delivery capacity = 0.85, average Delivery performance ratio = 0.78 to 0.83 during the summer and itis 0.63 to 0.73 during winter months.	Not Reported
Wellton-Mohawak Irrigation District(WMIDD), Southwestern Arizona	Not reported	Not reported	The mean value for flow rate adequacy was 0.96 . The average duration adequacy was found to be 0.98.	The annual conveyance-distribution efficiency= 90%. The overall district project Water Use Efficiency > 60%.	Not reported	Not reported
Chenab Canal system, Punjab Province, Pakistan.	Equity in terms of DPR for Mananwala Distributary outlets in the head and middle reach was 223%, for tail outlets was 50%; For Lagar distributary ranged from 150% to 8%, for Pir Mahal Distributary outlets varied between 272% and 18%.	Not reported	Not reported	Not reported	Not reported	Not reported

Malaprabha Reservior Project, Krishna River Basin, Karnataka, India	Not reported	Not reported	Not reported	Not reported	When initial moisture content (ϴo) at Field Capacity the reliability index for policy I, II, and III were found to be 0.63, 0.95 and 0.99 respectively. For lower value of ϴo both policy II and III had reliability index values as 0.87 and 0.89 respectively.	When initial moisture content (ϴo) at Field Capacity the resiliency values were 0.45, 0.96 and 0.95. For lower value of ϴo both policy II and III the resiliency index values were 0.68 and 0.22 respectively.
Sri Ram Sagar Project, Andhra Pradesh, India.	Expert 1= 0.1783 Expert 2= o.2088	Not Reported	Expert 1= 0.12 Expert 2= o.1	Not Reported	Not Reported	The weightages of the criteria, on-farm development works, supply of inputs, conjunctive use of water resources, farmers' participation, economic impact and social impact for expert 1 were 0.0826, 0.12, 0.0823, 0.0478, 0.2788, 0.1625 and values for expert 2 were 0.0449, 0.0435, 0.0671, 0.1509, 0.2091, 0.1756.

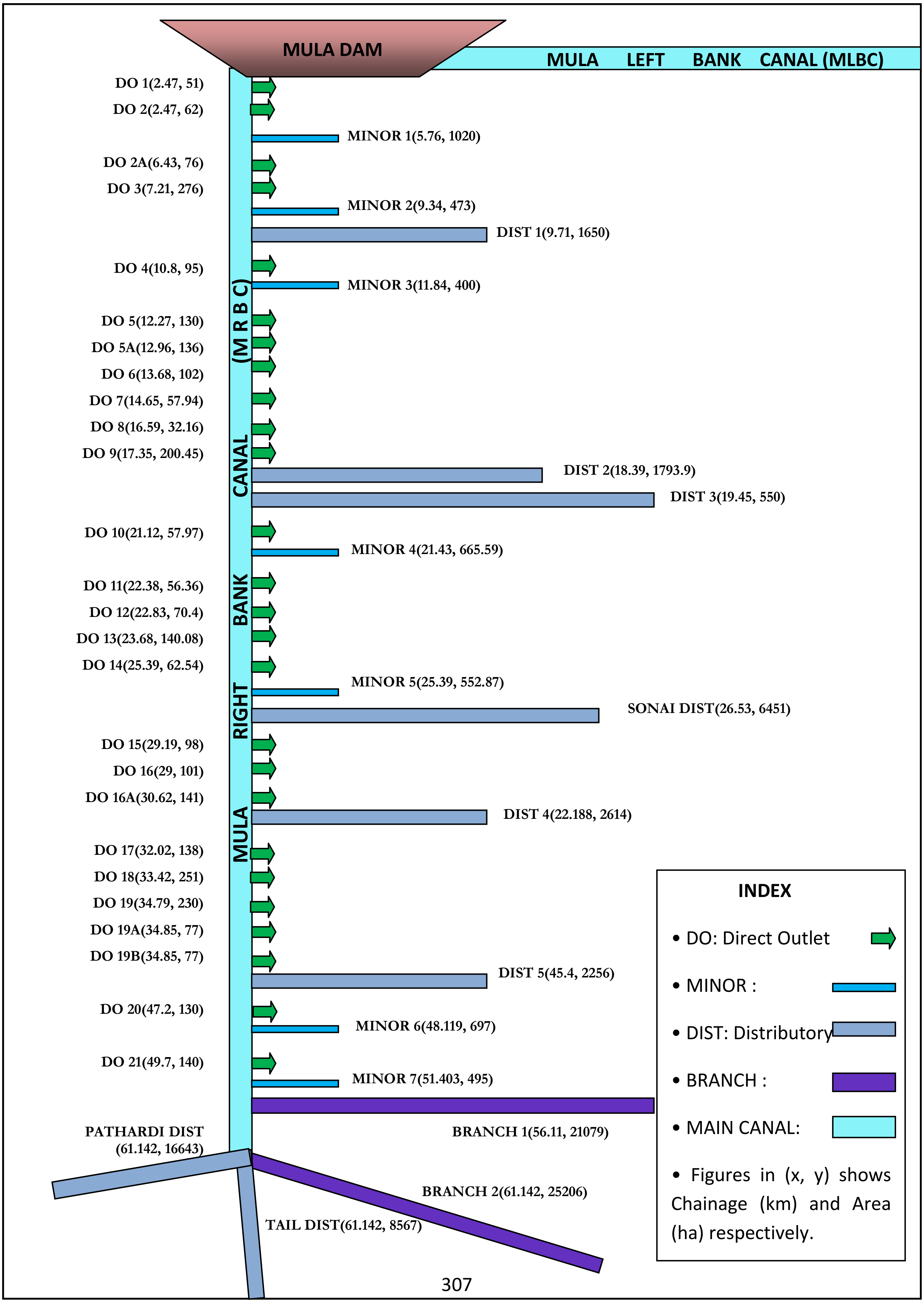
APPENDIX B

Details about the outlets, distributories and minors in Mula Right Bank Canal (LEVEL 1)

SR. NO.	Level 1			DO	MINOR	DIST	BRANCH
1	DO 1			DO 1			
2	DO 2			DO 2			
3	MINOR 1				MINOR 1		
4	DO 2A			DO 2A			
5	DO 3			DO 3			
6	MINOR 2				MINOR 2		
7	DIST 1					DIST 1	
8	DO 4			DO 4			
9	MINOR 3				MINOR 3		
10	DO 5			DO 5			
11	DO 5A			DO 5A			
12	DO 6			DO 6			
13	DO 7			DO 7			
14	DO 8			DO 8			
15	DO 9			DO 9			
16	DIST 2					DIST 2	
17	DIST 3					DIST 3	
18	DO 10			DO 10			
19	MINOR 4				MINOR 4		
20	DO 11			DO 11			
21	DO 12			DO 12			
22	DO 13			DO 13			
23	DO 14			DO 14			
24	MINOR 5				MINOR 5		
25	SONAI DIST					SONAI DIST	
26	DO 15			DO 15			
27	DO 16			DO 16			
28	DO 16A			DO 16A			
29	DIST 4					DIST 4	
30	DO 17			DO 17			
31	DO 18			DO 18			
32	DO 19			DO 19			
33	DO 19A			DO 19A			
34	DO 19B			DO 19B			
35	DIST 5					DIST 5	
36	DO 20			DO 20			
37	MINOR 6				MINOR 6		
38	DO 21			DO 21			
39	MINOR 7				MINOR 7		
40	BRANCH 1						BRANCH 1
41	BRANCH 2						BRANCH 2
42	PATHARDI DIST					PATHARDI DIST	
43	TAIL DIST					TAIL DIST	
TOTAL	43			26	7	8	2

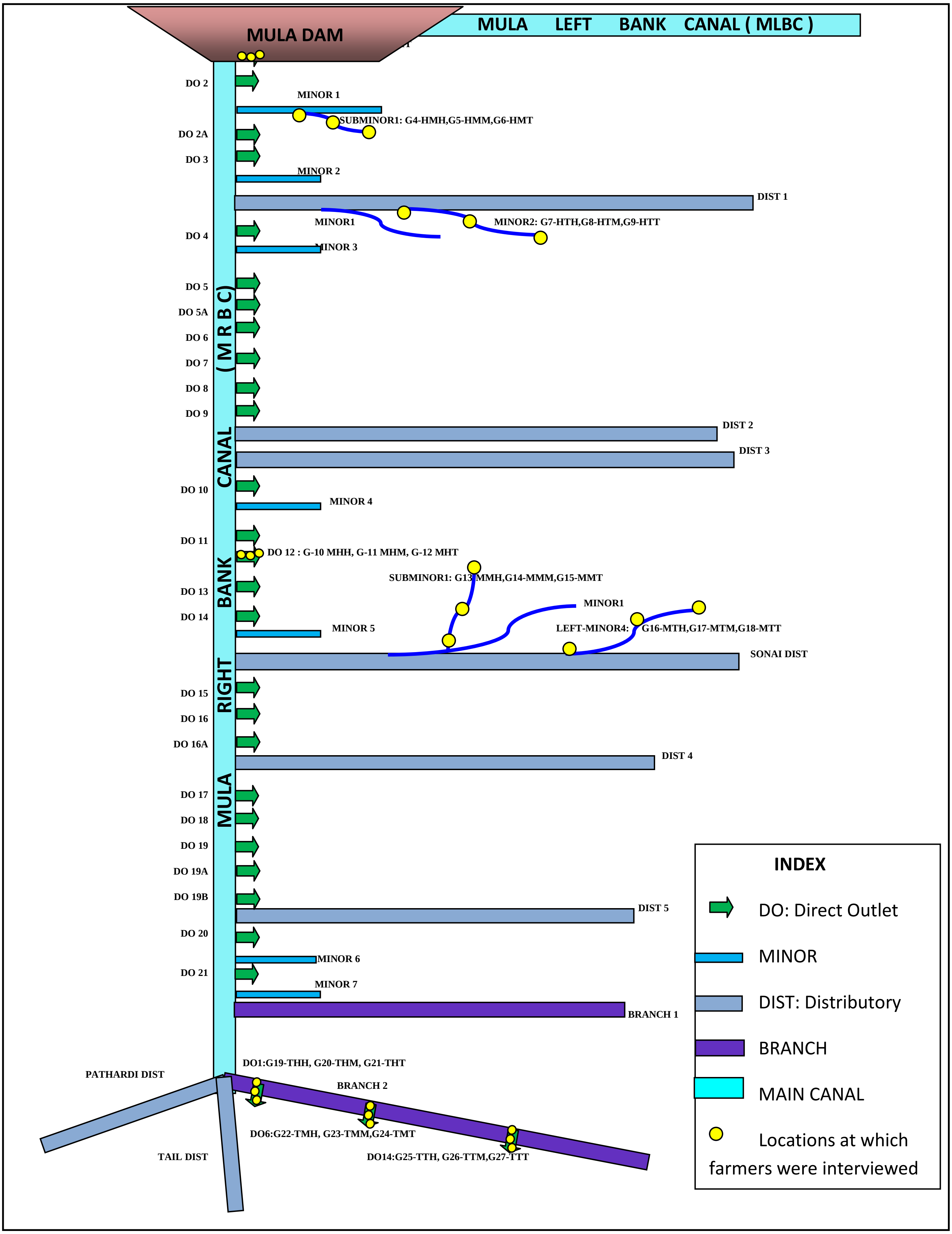
APPENDIX B1

Schematic layout of outlets, minors, distributaries and Branch canals in Mula Right Bank Canal (MRBC): LEVEL 1



APPENDIX B2

Schematic layout of Mula Right Bank Canal (MRBC) network showing the locations where 27 groups of farmers were interviewed to know their preferences of performance measures



APPENDIX - C

Questionnaire for using AHP to assign weights to different performance measures and their attributes

Purpose of the Questionnaire

The purpose of the questionnaire is to know the relative preference of different stakeholders in irrigation scheme to different performance measures (productivity, equity, adequacy, reliability, flexibility, sustainability and efficiency) in different parts of the irrigation scheme

Preamble

This questionnaire is the part of Ph D studies. The response to this questionnaire will be analysed and used to know the performance of the irrigation scheme; finding out the possible causes of the low performance (if any) and suggesting the alternative irrigation strategies to improve the performance of the irrigation scheme

Irrigation Scheme: Mula Irrigation Project, District: Ahmednagar, Maharashtra, India

Parts of irrigation scheme: Head, middle and tail portions of the main canals/chosen distributaries, minors and outlets

Stakeholders: Farmers in the respective part of the irrigation scheme, irrigation authorities and policy makers

Performance measures: productivity, equity, adequacy, reliability, flexibility and sustainability and their attributes as given below

The main performance measures are the factors at level-2 and their attributes are the factors at level-1 in the respective groups of performance measures i.e. factors at level-2. The hierarchy of these measures is shown in accompanying figure

Instructions

The purpose of the questionnaire of this kind is to generate the weights for factors of each group at each level by using the technique called as Analytical Hierarchical Process (AHP). This method needs the degree of preference of one factor over another factor in a specific group. Therefore there is a need to carry out comparisons for each two factors at one time.

The weights for factors of each of 6 groups at level 2 and their attributes at level 1 will be obtained.

The questionnaire consists of two columns for each comparison. The respondent is required to tick the choice of preference in the **column 1** and tick the degree of preference in the **column 2** of each comparison.

For example in case of questionnaire-1, to compare the two performance measures of *productivity* and *equity* in *performance* group, if respondent feels *productivity* is more contributory factor for *performance* than that of *equity*, respondent should tick '*productivity*' in the **column-1** of the table and then go to column-2. If respondent thinks that '*productivity*' is 'strongly contributory' over the '*equity*' for *performance*, then 'strongly preferred' should be ticked in the **column-2** of the table. In this way the respondent is required to complete all the pair-wise comparisons for each group. At the beginning of questionnaire there are notes describing each factor that contributes to the final output i.e. performance.

Questionnaire-1

Performance Assessment

Name of Interviewee: --

Address: --

Profession: --

Experience -- *(Years)*

Date: ------------------ / ------------------ / ------------------

Time: --

Notes:

Productivity: **The productivity is related to output from the system in response to the input added to the system. The principle output of the scheme is the crop produce or its economic equivalence and the area irrigated. The inputs of interest in irrigation are land, water and finance. It will be calculated as the ratio of actual output to the targeted output.**

Equity: **Equity refers to the distribution of input resources in the irrigation scheme (area and water) or the resulting output (crop production or net benefits) among the users (farmers, outlet) in a fair manner which is prescribed in the objectives of the irrigation scheme in the form of social welfare. Equity will be calculated as the ratio of input/output allocated to input/output desired. Inputs may be water or area; and output may be crop production or net benefits.**

Adequacy: **Adequacy deals with water supply to the crop relative to its demand. It will be calculated as the ratio of the water allocated or supply from all the sources (irrigation, effective rainfall, capillary water, etc.) and the demand due to all the processes (consumptive use, losses, land preparation, leaching for draining accumulated chemicals or salts, other special needs, etc.) over a specific time period for a specific crop grown in a specific area.**

Reliability: **This refers to the ability of the water delivery system and the schedule to meet the scheduled demand of the crop. It will be calculated as the ratio of the water delivered from all the sources (irrigation, effective rainfall, capillary water, etc.) and the demand due to all the processes (consumptive use, losses, land preparation, leaching for draining accumulated chemicals or salts, other special needs, etc.) over a specific time period for a specific crop grown in a specific area.**

Flexibility: **This refers to the ability of the water delivery schedule of the allocation plan to recover from any changes caused in the schedule." This needs consideration during planning of the irrigation water management. The schedules based on a management strategy of full or over irrigation are normally more flexible than those based on deficit irrigation.**

***Sustainability*: Sustainability is the performance measure related to upgrading, maintaining, and degrading the environment in the irrigation scheme. The sustainability is the most difficult factor to encompass and refers to the issue of leaching, drainage and salinisation which if not attended to properly, may shorten the system's life.**

1. Productivity – Equity

Column-1	Column-2	
❑ Productivity ❑ Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

2. Productivity – Adequacy

Column-1	Column-2	
❑ Productivity ❑ Adequacy	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

3. Productivity – Reliability

Column-1	Column-2	
❑ Productivity ❑ Reliability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

4. Productivity – Flexibility

Column-1	Column-2	
❑ Productivity ❑ Flexibility	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

5. **Productivity – Sustainability**

Column-1	Column-2	
❑ Productivity ❑ Sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

6. **Equity – Adequacy**

Column-1	Column-2	
❑ Equity ❑ Adequacy	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

7. **Equity – Reliability**

Column-1	Column-2	
❑ Equity ❑ Reliability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

8. **Equity – Flexibility**

Column-1	Column-2	
❑ Equity ❑ Flexibility	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

9. Equity - Sustainability

Column-1	Column-2	
❑ Equity ❑ Sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

10. Adequacy – Reliability

Column-1	Column-2	
❑ Adequacy ❑ Reliability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

11. Adequacy – Flexibility

Column-1	Column-2	
❑ Adequacy ❑ Flexibility	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

12. Adequacy – Sustainability

Column-1	Column-2	
❑ Adequacy ❑ Sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

13. Reliability – Flexibility

Column-1	Column-2	
❑ Reliability ❑ Flexibility	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

14. Reliability – Sustainability

Column-1	Column-2	
❑ Reliability ❑ Sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

15. Flexibility – Sustainability

Column-1	Column-2	
❑ Flexibility ❑ Sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Productivity Group

Net benefits per unit area productivity: This indicator denotes the productivity based on net benefits per unit area. This is the ratio of net benefits per unit area obtained to the targeted (maximum possible) net benefits per unit area.

Crop production per unit area productivity: This indicator denotes the productivity based on crop production per unit area. This is the ratio of crop production per unit area obtained to the targeted crop production (maximum possible) per unit area.

Net benefits per unit used water productivity: This indicator denotes the productivity based on net benefits per unit of water utilised. This is the ratio of net benefits obtained per unit of water utilised to the targeted net benefits (maximum possible) per unit water of utilised.

Crop production per unit used water productivity: This indicator denotes the productivity based on crop production per unit of water utilised. This is the ratio of crop production obtained per unit of water utilised to the targeted crop production (maximum possible) per unit of water utilised.

Irrigated area per unit of culturable command area productivity: This indicator denotes the productivity based on the area irrigated per unit culturable command area. This is the ratio of area irrigated to the culturable command area.

1 Net benefits per unit area productivity – Crop production per unit area productivity

Column-1	Column-2	
❑ Net benefits per unit area productivity ❑ Crop production per unit area productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

2 Net benefits per unit area productivity – Net benefits per unit used water productivity

Column-1	Column-2	
❑ Net benefits per unit area productivity ❑ Net benefits per unit used water productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

3 Net benefits per unit area productivity – Crop production per unit used water productivity

Column-1	Column-2	
❑ Net benefits per unit area productivity ❑ Crop production per unit used water productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

4 Net benefits per unit area productivity – Irrigated area per unit of culturable command area productivity

Column-1	Column-2	
❑ Net benefits per unit area productivity ❑ Irrigated area per unit of culturable command area productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

5 **Crop production per unit area productivity – Net benefits per unit used water productivity**

Column-1	Column-2	
❑ Crop production per unit area productivity ❑ Net benefits per unit used water productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

6 **Crop production per unit area productivity – Crop production per unit used water productivity**

Column-1	Column-2	
❑ Crop production per unit area productivity ❑ Crop production per unit used water productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

7 **Crop production per unit area productivity – Irrigated area per unit of culturable command area productivity**

Column-1	Column-2	
❑ Crop production per unit area productivity ❑ Irrigated area per unit of culturable command area productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

8 Net benefits per unit used water productivity – Crop production per unit used water productivity

Column-1	Column-2	
❑ Net benefits per unit used water productivity ❑ Crop production per unit used water productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

9 Net benefits per unit used water productivity – Irrigated area per unit of culturable command area productivity

Column-1	Column-2	
❑ Net benefits per unit used water productivity ❑ Irrigated area per unit of culturable command area productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

10 Crop production per unit used water productivity – Irrigated area per unit of culturable command area productivity

Column-1	Column-2	
❑ Crop production per unit used water productivity ❑ Irrigated area per unit of culturable command area productivity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Equity Group

Notes:

Area Equity: Area Equity refers to the equitable distribution of area to be irrigated among the users (farmers, outlet) i.e. proportional to the culturable command area.

Water Equity: Water equity refers to the equitable distribution of water available in the irrigation project i.e. water allocation proportional to the culturable command area.

Crop production equity: This equity refers to distribution of area and water in such a way that it offers the equitable distribution of crop production i.e. proportional to the culturable command area.

Benefit equity: This equity refers to distribution of area and water in such a way that it offers the equitable distribution of net benefits i.e. proportional to the culturable command area.

1. Area Equity – Water Equity

Column-1	Column-2	
❑ Area Equity ❑ Water Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

2. Area Equity – Crop Production Equity

Column-1	Column-2	
❑ Area Equity ❑ Crop Production Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

3 Area Equity – Benefit Equity

Column-1	Column-2	
❑ Area Equity ❑ Benefit Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

4. Water Equity – Crop Production Equity

Column-1	Column-2	
❑ Water Equity ❑ Crop Production Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

5 Water Equity – Benefit Equity

Column-1	Column-2	
❑ Water Equity ❑ Benefit Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

6 Crop Production Equity – Benefit Equity

Column-1	Column-2	
❑ Crop Production Equity ❑ Benefit Equity	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Adequacy Group

Notes:
Seasonal Adequacy: Seasonal adequacy refers to the adequate water supply over the entire crop season **Intra seasonal Adequacy: This adequacy refers to the adequate water supply over the individual irrigation period**

1. **Seasonal Adequacy – Intra seasonal Adequacy**

Column-1	Column-2	
❑ Seasonal Adequacy ❑ Intra seasonal Adequacy	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Reliability Group

Notes:
Seasonal Reliability: Seasonal reliability refers to the reliable water supply over the entire crop season **Intra seasonal Adequacy: This adequacy refers to the reliable water supply over the individual irrigation period**

1. **Seasonal Reliability – Intra seasonal Reliability**

Column-1	Column-2	
❑ Seasonal Reliability ❑ Intra seasonal Reliability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Flexibility Group

Notes:

Flexibility in irrigation amount: This refers to the ability of the water delivery schedule of the allocation plan to recover from the deficient application of irrigation water

Flexibility in irrigation frequency: This refers to the ability of the water delivery schedule of the allocation plan to recover from the delaying of irrigation

1. **Flexibility in irrigation amount – Flexibility in irrigation frequency**

Column-1	Column-2	
❑ Seasonal Reliability ❑ Intra seasonal Reliability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

Level -1 – Sustainability Group

Notes:

Crop occupancy sustainability: This refers to the area irrigated over the years compared to the area originally irrigable. It is proposed to use average crop occupancy ratio as the indicator. This is the ratio of area irrigated during a season to the area originally irrigable

Irrigated area sustainability: This refers to the percentage change in irrigated area over the period of years of concern

Groundwater (rise) sustainability: This refers to the rise in groundwater table over the period of years. If the management strategy chosen brings the groundwater table in to the root zone of the crop, the chosen strategy is not sustainable. It is proposed to use the number of years after groundwater starts reaching into the soil root zone, as the indicator

Groundwater (fall) sustainability: This refers to the drop in groundwater table over the years. If the chosen management strategy is causing the farmers in the area to overdraw groundwater over the years, the level may drop below the safe level specified for pumping. It is proposed to use number of years after the groundwater starts falling below the safe level, as the indicator

Problematic area sustainability: This refers to the change in problematic area (saline, alkaline and saline alkaline) within the culturable command area of the irrigation scheme over the period of concern. It is proposed to use the number of years after the soils in the culturable command area start becoming problematic as the indicator.

1. **Crop occupancy sustainability – Irrigated area sustainability**

Column-1	Column-2	
❑ Crop occupancy sustainability ❑ Irrigated area sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

2. **Crop occupancy sustainability – Groundwater (rise) sustainability**

Column-1	Column-2	
❑ Crop occupancy sustainability ❑ Groundwater (rise) sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

3. **Crop occupancy sustainability – Groundwater (fall) sustainability**

Column-1	Column-2	
❑ Crop occupancy sustainability ❑ Groundwater (fall) sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

4. **Crop occupancy sustainability – Problematic area sustainability**

Column-1	Column-2	
❑ Crop occupancy sustainability ❑ Problematic area sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

5. **Irrigated area sustainability – Groundwater (rise) sustainability**

Column-1	Column-2	
❑ Irrigated area sustainability ❑ Groundwater (rise) sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

6. **Irrigated area sustainability – Groundwater (fall) sustainability**

Column-1	Column-2	
❑ Irrigated area sustainability ❑ Groundwater (fall) sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

7. **Irrigated area sustainability – Problematic area sustainability**

Column-1	Column-2	
❑ Irrigated area sustainability ❑ Problematic area sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

8. **Groundwater (rise) sustainability – Groundwater (fall) sustainability**

Column-1	Column-2	
❑ Groundwater (rise) sustainability ❑ Groundwater (fall) sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

9. Groundwater (rise) sustainability – Problematic area sustainability

Column-1	Column-2	
❑ Groundwater (rise) sustainability ❑ Problematic area sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

10. Groundwater (fall) sustainability – Problematic area sustainability

Column-1	Column-2	
❑ Groundwater (fall) sustainability ❑ Problematic area sustainability	❑ Equally preferred ❑ Moderately preferred ❑ Strongly preferred	❑ Very strongly preferred ❑ Extremely preferred
Reasons for preference if any		

APPENDIX C-1 (MH1) HHH

Name of the project		Main canal		Branch canal		Distributory		Minor
		Water course		Head/Middle/Tail				

Assessing the relative preference of different performance measures of irrigation scheme at different levels using AHP

Level 2 — Performance Group

	Productivity	Equity	Adequacy	Reliability	Flexibility	Sustainability	Geometric Mean	Priority Vector	Eigen Value
Productivity	1	5	5	3	1	1	2.05	0.27	1.02
Equity	0.2	1	1	0.2	0.3333333	0.3333333	0.41	0.05	0.97
Adequacy	0.2	1	1	0.2	0.2	0.2	0.34	0.05	1.01
Reliability	0.333333333	5	5	1	3	1	1.71	0.23	1.31
Flexibility	1	3	5	0.333333333	1	0.3333333	1.09	0.15	1.24
Sustainability	1	3	5	1	3	1	1.89	0.25	0.97
Add Columns	3.733333333	18	22	5.733333333	8.533333333	3.866666667	7.49	1.00	6.53
								Consistency Index	0.106
								Consistency Ratio	0.085

Pairwise comparison is consistent

Level 1 — Group-1 — Productivity Group

	Net benefits per unit area productivity	Crop production per unit area productivity	Net benefits per unit used water productivity	Crop production per unit used water productivity	Irrigated area per unit of culturable command area	Geometric Mean	Priority Vector	Eigen Value
Net benefits per unit area	1	1	3	1	3	1.55	0.29	1.05
Crop production per unit area	1	1	1	0.3333333	3	1.00	0.19	1.17
Net benefits per unit used water productivity	0.333333333	1	1	3	1	1.00	0.19	1.17
Crop production per unit used water productivity	1	3	0.333333333	1	5	1.38	0.26	1.41
Irrigated area per unit of	0.333333333	0.333333333	1	0.2	1	0.47	0.09	1.12
Add	3.666666667	6.333333333	6.333333333	5.533333333	13	5.40	1.00	5.94
							Consistency Index	0.235
							Consistency Ratio	0.210

Pairwise comparison is not consistent

Level 1	Group-2		Equity Group				
	Area Equity	Water Equity	Crop production equity	Benefit equity	Geometric Mean	Priority Vector	Eigen Value
Area Equity	1	1	1	3	1.32	0.32	1.06
Water Equity	1	1	1	0.2	0.67	0.16	1.30
Crop production equity	1	1	1	1	1.00	0.24	0.97
Benefit equity	0.333333333	5	1	1	1.14	0.28	1.43
Add Columns	3.333333333	8	4	5.2	4.12	1.00	4.77
						Consistency Index	0.256
						Consistency Ratio	0.284
		Pairwise comparison is not consistent					

Level 1	Group-3		Adequacy Group		
	Seasonal Adequacy	Intra seasonal	Geometric Mean	Priority Vector	Eigen Value
Seasonal Adequacy	1	1	1.00	0.50	1.00
Intra seasonal	1	1	1.00	0.50	1.00
Add	2	2	2.00	1.00	2.00
				Consistency Index	0.000
				Consistency Ratio	0.000
		Pairwise compariosn is consistent			

Level 1	Group-4		Reliability Group		
	Seasonal Reliability	Intra seasonal	Geometric Mean	Priority Vector	Eigen Value
Seasonal Reliability	1	0.3333333	0.58	0.25	1.00
Intra seasonal	3	1	1.73	0.75	1.00
Add	4	1.333333333	2.31	1.00	2.00
				Consistency Index	0.000
				Consistency Ratio	0.000
		Pairwise compariosn is consistent			

Level 1	Group-5		Flexibility Group		
	Flexibility in irrigation amount	**Flexibility in irrigation frequency**	**Geometric Mean**	**Priority Vector**	**Eigen Value**
Flexibility in irrigation amount	1	0.2	0.45	0.17	1.00
Flexibility in irrigation frequency	5	1	2.24	0.83	1.00
Add Columns	6	1.2	2.68	1.00	2.00
				Consistency Index	0.000
				Consistency Ratio	0.000
		Pairwise compariosn is consistent			

Level 1	Group-6		Sustainability					
	Crop occupancy sustainability	**Irrigated area sustainability**	**Groundwater (rise) sustainability**	**Groundwater (fall) sustainability**	**Problematic area sustainability**	**Geometric Mean**	**Priority Vector**	**Eigen Value**
Crop occupancy sustainabilit	1	1	1	5	1	1.38	0.24	0.99
Irrigated area sustainabilit	1	1	1	5	0.3333333	1.11	0.19	1.17
Groundwater (rise) sustainabilit	1	1	1	5	1	1.38	0.24	0.99
Groundwater (fall) sustainabilit	0.2	0.2	0.2	1	0.2	0.28	0.05	0.99
Problematic area sustainabilit	1	3	1	5	1	1.72	0.29	1.04
Add Columns	4.2	6.2	4.2	21	3.533333333	5.86	1.00	5.17
							Consistency Index	0.043
							Consistency Ratio	0.039
		Pairwise compariosn is consistent						

AHP Weights to different performance measures

Level-2	Group-0	Performance	Productivi	0.27
			Equity	0.05
			Adequacy	0.05
			Reliability	0.23
			Flexibility	0.15
			Sustainab	0.25

Pairwise compariosn is consistent

Level-1	Group-1	Productivity	Net benefits per unit	0.29
			Crop production per unit area	0.19
			Net benefits per unit used water	0.19
			Crop production per unit used water productivit	0.26
			Irrigated area per unit of culturable command area	0.09

Pairwise comparison is not consistent

A	B	C	D	E	F	G	H
Level-1	Group-2	Equity	Area	0.32	Pairwise comparison is not consistent		
			Water	0.16			
			Crop production equity	0.24			
			Benefit equity	0.28			
Level-1	Group-3	Adequacy	Seasonal Adequacy	0.50	Pairwise compariosn is consistent		
			Intra seasonal Adequacy	0.50			
Level-1	Group-4	Reliability	Seasonal Reliability	0.25	Pairwise compariosn is consistent		
			Intra seasonal Reliability	0.75			
Level-1	Group-5	Flexibility	Flexibility in irrigation	0.17	Pairwise compariosn is consistent		
			Flexibility in irrigation	0.83			
Level-1	Group-6	Sustainability	Crop occupancy sustainabil	0.24	Pairwise compariosn is consistent		
			Irrigated area	0.19			
			Groundwater (rise) sustainabil	0.24			
			Groundwater (fall) sustainabil	0.05			
			Problematic area sustainabil	0.29			

APPENDIX – D

Final Performance Index Values obtained for Different Irrigation Strategies

Sr. No.	STRATEGY	Head	Middle	Tail
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.61	0.76	0.96
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.48	0.68	0.95
3	II-14, FULL DEPTH FREE CROPPING FWD	0.56	0.65	0.51
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.47	0.67	0.94
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.43	0.65	0.94
6	II-14, FULL DEPTH FX CROPPING FWD	0.44	0.59	0.57
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.58	0.63	0.86
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.56	0.61	0.86
9	II-14, FX DEPTH FREE CROPPING FWD	0.54	0.51	0.38
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.35	0.51	0.86
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.35	0.51	0.86
12	II-14, FX DEPTH FX CROPPING FWD	0.33	0.43	0.49
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.60	0.62	0.85
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.48	0.57	0.86
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.60	0.57	0.43
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.35	0.51	0.86
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.42	0.60	0.90
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.29	0.36	0.38
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.68	0.81	0.96
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.50	0.69	0.95
21	II-21, FULL DEPTH FREE CROPPING FWD	0.64	0.70	0.52
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.48	0.68	0.94
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46	0.67	0.94
24	II-21, FULL DEPTH FX CROPPING FWD	0.44	0.58	0.49
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.74	0.74	0.89
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73	0.73	0.89
27	II-21, FX DEPTH FREE CROPPING FWD	0.68	0.60	0.31
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.37	0.51	0.85
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.36	0.50	0.85
30	II-21, FX DEPTH FX CROPPING FWD	0.32	0.39	0.33
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.73	0.73	0.89
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.52	0.57	0.84
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.67	0.60	0.49
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.38	0.52	0.85
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.39	0.53	0.86
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.24	0.28	0.27
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.68	0.81	0.96
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.50	0.69	0.95
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.65	0.71	0.59
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.48	0.68	0.95

Sr. No.	STRATEGY	Head	Middle	Tail
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.45	0.66	0.94
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.44	0.58	0.49
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.73	0.72	0.88
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71	0.71	0.88
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.68	0.60	0.39
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.37	0.51	0.86
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.37	0.51	0.85
48	II-21-14, FX DEPTH FX CROPPING FWD	0.34	0.42	0.41
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.70	0.69	0.87
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.61	0.68	0.90
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.70	0.63	0.44
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.38	0.52	0.86
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46	0.62	0.91
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.29	0.36	0.38
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.72	0.83	0.96
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.51	0.70	0.95
57	II-28, FULL DEPTH FREE CROPPING FWD	0.66	0.67	0.29
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.46	0.67	0.94
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.45	0.66	0.94
60	II-28, FULL DEPTH FX CROPPING FWD	0.45	0.56	0.42
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.75	0.75	0.90
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74	0.74	0.90
63	II-28, FX DEPTH FREE CROPPING FWD	0.68	0.58	0.20
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.31	0.43	0.81
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.37	0.51	0.85
66	II-28, FX DEPTH FX CROPPING FWD	0.27	0.31	0.29
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.75	0.75	0.90
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74	0.74	0.90
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.68	0.58	0.22
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.31	0.43	0.81
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.28	0.39	0.79
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.27	0.31	0.29
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.68	0.81	0.96
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.51	0.70	0.95
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.68	0.71	0.44
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.47	0.67	0.94
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46	0.67	0.94
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.45	0.56	0.42
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.74	0.73	0.89
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73	0.73	0.89
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.68	0.57	0.19
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.33	0.45	0.82
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.32	0.44	0.82

Sr. No.	STRATEGY	Head	Middle	Tail
84	II-28-21, FX DEPTH FX CROPPING FWD	0.30	0.35	0.31
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.66	0.63	0.84
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.35	0.34	0.73
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.59	0.46	0.22
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.33	0.45	0.82
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.29	0.40	0.80
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.25	0.27	0.27
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.74	0.83	0.96
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.57	0.73	0.95
93	II-35, FULL DEPTH FREE CROPPING FWD	0.68	0.69	0.37
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.46	0.67	0.94
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.45	0.66	0.94
96	II-35, FULL DEPTH FX CROPPING FWD	0.44	0.56	0.42
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.82	0.77	0.89
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71	0.63	0.82
99	II-35, FX DEPTH FREE CROPPING FWD	0.76	0.62	0.24
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.29	0.40	0.80
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.26	0.36	0.78
102	II-35, FX DEPTH FX CROPPING FWD	0.28	0.33	0.36
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.57	0.52	0.79
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.45	0.48	0.80
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.75	0.59	0.20
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.28	0.40	0.80
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.24	0.35	0.77
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.26	0.30	0.28
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.74	0.84	0.97
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.57	0.73	0.95
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.68	0.69	0.37
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.46	0.67	0.94
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.45	0.66	0.94
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.44	0.56	0.42
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.83	0.77	0.89
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.82	0.77	0.89
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.76	0.61	0.23
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.30	0.41	0.80
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.26	0.36	0.78
120	II-35-28, FX DEPTH FX CROPPING FWD	0.27	0.31	0.35
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.57	0.52	0.79
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.45	0.48	0.80
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.74	0.58	0.20
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.29	0.40	0.80
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.25	0.36	0.78
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.26	0.30	0.28

APPENDIX-D1

1. **Area allocated (ha) to different Crops under Free Cropping- Free Water distribution (No Equity) at 21 days irrigation interval with Full Depth Approach**

Location No.	Area allocated (ha)								
	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.00	51.00
2	0.00	0.00	0.00	0.00	60.20	0.00	0.00	62.00	122.20
3	0.00	0.00	0.00	0.00	618.20	0.00	54.10	965.90	1638.20
4	0.00	0.00	0.00	0.00	60.20	0.00	0.00	76.00	136.20
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	276.00	276.00
6	0.00	0.00	0.00	0.00	473.00	0.00	0.00	473.00	946.00
7	0.00	0.00	0.00	0.00	0.00	0.00	229.40	1147.20	1376.60
8	0.00	0.00	0.00	0.00	90.20	0.00	0.00	95.00	185.20
9	0.00	0.00	0.00	0.00	237.80	0.00	28.50	371.50	637.80
10	0.00	0.00	0.00	0.00	120.30	0.00	0.00	130.00	250.30
11	0.00	0.00	0.00	0.00	120.30	0.00	0.00	136.00	256.30
12	0.00	0.00	0.00	0.00	72.20	0.00	0.00	102.00	174.20
13	0.00	0.00	0.00	0.00	57.90	0.00	0.00	57.90	115.80
14	0.00	0.00	0.00	0.00	32.20	0.00	0.00	32.20	64.40
15	0.00	0.00	0.00	0.00	180.40	0.00	0.00	200.50	380.90
16	0.00	0.00	0.00	0.00	0.00	0.00	1311.20	0.00	1311.20
17	0.00	0.00	0.00	0.00	845.00	0.00	616.10	1056.20	2517.30
18	0.00	0.00	0.00	0.00	50.10	0.00	0.00	58.00	108.10
19	0.00	0.00	0.00	0.00	404.20	0.00	34.00	631.60	1069.80
20	0.00	0.00	0.00	0.00	40.10	0.00	6.20	50.10	96.40
21	0.00	0.00	0.00	0.00	50.10	0.00	5.00	65.40	120.50
22	0.00	0.00	0.00	0.00	100.30	0.00	9.30	130.80	240.40
23	0.00	0.00	0.00	0.00	50.10	0.00	0.00	62.50	112.60
24	0.00	0.00	0.00	0.00	277.40	0.00	202.20	346.70	826.30
25	0.00	0.00	0.00	0.00	2360.10	0.00	1720.90	2950.10	7031.10
26	0.00	0.00	0.00	0.00	82.40	0.00	0.00	98.00	180.40
27	0.00	0.00	0.00	0.00	82.40	0.00	0.00	101.00	183.40
28	0.00	0.00	0.00	0.00	100.30	0.00	15.70	125.30	241.30
29	0.00	0.00	0.00	0.00	1856.80	0.00	293.10	2320.90	4470.80
30	0.00	0.00	0.00	0.00	120.50	0.00	0.00	138.00	258.50
31	0.00	0.00	0.00	0.00	175.40	0.00	31.70	219.30	426.40
32	0.00	0.00	0.00	0.00	150.30	0.00	42.10	187.90	380.30
33	0.00	0.00	0.00	0.00	50.10	0.00	14.30	62.70	127.10
34	0.00	0.00	0.00	0.00	50.10	0.00	14.30	62.70	127.10
35	0.00	0.00	0.00	0.00	830.40	0.00	605.50	1038.00	2473.90
36	0.00	0.00	0.00	0.00	120.50	0.00	0.00	130.00	250.50
37	0.00	0.00	0.00	0.00	356.60	0.00	251.20	445.80	1053.60
38	0.00	0.00	0.00	0.00	120.50	0.00	0.00	140.00	260.50
39	0.00	0.00	0.00	0.00	257.60	0.00	173.00	322.00	752.60
40	0.00	0.00	0.00	0.00	7677.60	0.00	5598.30	9597.00	22872.90
41	0.00	0.00	0.00	0.00	2728.90	0.00	2732.60	2988.00	8449.50
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	0.00	21060.70	0.00	13988.70	27504.20	62553.60

2. **Area allocated (ha) to different Crops under Free Cropping- Free Water distribution (No Equity) at 21 days irrigation interval with Fixed Depth Approach**

Location No.	Area allocated (ha)								
	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.00	51.00
2	0.00	0.00	0.00	0.00	62.00	0.00	0.00	62.00	124.00
3	0.00	0.00	0.00	0.00	702.50	0.00	0.00	1020.00	1722.50
4	0.00	0.00	0.00	0.00	68.40	0.00	0.00	76.00	144.40
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	473.00	0.00	0.00	473.00	946.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1650.00	1650.00
8	0.00	0.00	0.00	0.00	95.00	0.00	0.00	95.00	190.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	400.00	400.00
10	0.00	0.00	0.00	0.00	130.00	0.00	0.00	130.00	260.00
11	0.00	0.00	0.00	0.00	136.00	0.00	0.00	136.00	272.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	102.00	102.00
13	0.00	0.00	0.00	0.00	57.90	0.00	0.00	57.90	115.80
14	0.00	0.00	0.00	0.00	32.20	0.00	0.00	32.20	64.40
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	200.50	0.00	0.00	200.50	401.00
17	0.00	0.00	0.00	0.00	1267.50	0.00	0.00	2319.00	3586.50
18	0.00	0.00	0.00	0.00	58.00	0.00	0.00	58.00	116.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	665.60	665.60
20	0.00	0.00	0.00	0.00	56.40	0.00	0.00	56.40	112.80
21	0.00	0.00	0.00	0.00	70.40	0.00	0.00	70.40	140.80
22	0.00	0.00	0.00	0.00	180.40	0.00	0.00	140.10	280.20
23	0.00	0.00	0.00	0.00	62.50	0.00	0.00	62.50	125.00
24	0.00	0.00	0.00	0.00	416.00	0.00	0.00	552.90	968.90
25	0.00	0.00	0.00	0.00	3540.10	0.00	0.00	6451.00	9991.10
26	0.00	0.00	0.00	0.00	98.00	0.00	0.00	98.00	196.00
27	0.00	0.00	0.00	0.00	101.00	0.00	0.00	101.00	202.00
28	0.00	0.00	0.00	0.00	141.00	0.00	0.00	101.00	242.00
29	0.00	0.00	0.00	0.00	2614.00	0.00	0.00	2614.00	5228.00
30	0.00	0.00	0.00	0.00	138.00	0.00	0.00	138.00	276.00
31	0.00	0.00	0.00	0.00	251.00	0.00	0.00	251.00	502.00
32	0.00	0.00	0.00	0.00	225.50	0.00	0.00	230.00	455.50
33	0.00	0.00	0.00	0.00	75.20	0.00	0.00	77.00	152.20
34	0.00	0.00	0.00	0.00	75.20	0.00	0.00	77.00	152.20
35	0.00	0.00	0.00	0.00	1245.60	0.00	0.00	2256.00	3501.60
36	0.00	0.00	0.00	0.00	130.00	0.00	0.00	130.00	260.00
37	0.00	0.00	0.00	0.00	535.00	0.00	0.00	697.00	1232.00
38	0.00	0.00	0.00	0.00	140.00	0.00	0.00	140.00	280.00
39	0.00	0.00	0.00	0.00	386.30	0.00	0.00	495.00	881.30
40	0.00	0.00	0.00	0.00	11516.40	0.00	0.00	21079.00	32595.40
41	0.00	0.00	0.00	0.00	4766.70	0.00	0.00	14427.80	19194.50
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	0.00	30047.70	0.00	0.00	57773.30	87821.00

3. **Area allocated (ha) to different Crops under Free Cropping- Free Water distribution (No Equity) at 21 days irrigation interval with Variable Depth Approach**

Location No.	Area allocated (ha)								
	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.00	51.00
2	0.00	0.00	0.00	0.00	62.00	0.00	0.00	62.00	124.00
3	0.00	0.00	0.00	0.00	671.90	0.00	0.00	1020.00	1691.90
4	0.00	0.00	0.00	0.00	65.40	0.00	0.00	76.00	141.40
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	473.00	0.00	0.00	473.00	946.00
7	0.00	0.00	0.00	0.00	798.10	0.00	0.00	1650.00	2448.10
8	0.00	0.00	0.00	0.00	95.00	0.00	0.00	95.00	190.00
9	0.00	0.00	0.00	0.00	130.00	0.00	0.00	130.00	260.00
10	0.00	0.00	0.00	0.00	82.90	0.00	0.00	41.90	124.80
11	0.00	0.00	0.00	0.00	130.80	0.00	0.00	136.00	266.80
12	0.00	0.00	0.00	0.00	78.40	0.00	0.00	102.00	180.40
13	0.00	0.00	0.00	0.00	57.90	0.00	0.00	57.90	115.80
14	0.00	0.00	0.00	0.00	32.20	0.00	0.00	32.20	64.40
15	0.00	0.00	0.00	0.00	196.10	0.00	0.00	200.50	396.60
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	845.00	0.00	0.00	2319.00	3164.00
18	0.00	0.00	0.00	0.00	50.10	0.00	0.00	58.00	108.10
19	0.00	0.00	0.00	0.00	539.40	0.00	0.00	665.60	1205.00
20	0.00	0.00	0.00	0.00	40.10	0.00	0.00	56.40	96.50
21	0.00	0.00	0.00	0.00	55.70	0.00	0.00	70.40	126.10
22	0.00	0.00	0.00	0.00	111.40	0.00	0.00	140.10	251.50
23	0.00	0.00	0.00	0.00	50.10	0.00	0.00	62.50	112.60
24	0.00	0.00	0.00	0.00	277.40	0.00	0.00	552.90	830.30
25	0.00	0.00	0.00	0.00	2460.10	0.00	0.00	6451.00	8911.10
26	0.00	0.00	0.00	0.00	82.40	0.00	0.00	98.00	180.40
27	0.00	0.00	0.00	0.00	82.40	0.00	0.00	101.00	183.40
28	0.00	0.00	0.00	0.00	140.00	0.00	0.00	141.00	281.00
29	0.00	0.00	0.00	0.00	1956.80	0.00	0.00	2614.00	4570.80
30	0.00	0.00	0.00	0.00	114.50	0.00	0.00	138.00	252.50
31	0.00	0.00	0.00	0.00	175.40	0.00	0.00	251.00	426.40
32	0.00	0.00	0.00	0.00	150.30	0.00	0.00	230.00	380.30
33	0.00	0.00	0.00	0.00	50.10	0.00	0.00	77.00	127.10
34	0.00	0.00	0.00	0.00	50.10	0.00	0.00	77.00	127.10
35	0.00	0.00	0.00	0.00	830.40	0.00	0.00	2256.00	3086.40
36	0.00	0.00	0.00	0.00	120.50	0.00	0.00	130.00	250.50
37	0.00	0.00	0.00	0.00	356.60	0.00	0.00	697.00	1053.60
38	0.00	0.00	0.00	0.00	120.50	0.00	0.00	140.00	260.50
39	0.00	0.00	0.00	0.00	257.60	0.00	0.00	495.00	752.60
40	0.00	0.00	0.00	0.00	7777.60	0.00	0.00	21079.00	28856.60
41	0.00	0.00	0.00	0.00	2809.60	0.00	0.00	14427.80	17237.40
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.00	0.00	0.00	0.00	22377.80	0.00	0.00	57455.20	79833.00

4. **Area allocated (ha) to different Crops under Free Cropping- Equitable Distribution of Water at 35-28 days irrigation interval with Fixed Depth Approach**

Location No.	Area allocated (ha)									
	Gram	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0	0	0	0	0	43	0	0	51	94
2	0	0	0	0	0	57	0	0	62	119
3	0	0	0	0	0	673	0	0	1020	1693
4	0	0	0	0	0	68	0	0	76	144
5	0	0	0	0	0	227	0	0	276	503
6	0	0	0	0	0	283	0	0	473	756
7	0	0	0	0	0	678	0	0	1650	2328
8	0	0	0	0	0	82	0	0	95	177
9	0	0	0	0	0	253	0	0	400	653
10	0	0	0	0	0	112	0	0	130	242
11	0	0	0	0	0	116	0	0	136	252
12	0	0	0	0	0	65	0	0	102	167
13	0	0	0	0	0	49	0	0	58	107
14	0	0	0	0	0	27	0	0	32	59
15	0	0	0	0	0	166	0	0	200	366
16	0	0	0	0	0	937	0	0	388	1325
17	0	0	0	0	0	714	0	0	2319	3033
18	0	0	0	0	0	41	0	0	58	99
19	0	0	0	0	0	391	0	0	666	1057
20	0	0	0	0	0	29	0	0	56	85
21	0	0	0	0	0	49	0	0	70	119
22	0	0	0	0	0	97	0	0	140	237
23	0	0	0	0	0	43	0	0	63	106
24	0	0	0	0	0	269	0	0	553	822
25	0	0	0	0	0	1844	0	0	6451	8295
26	0	0	0	0	0	65	0	0	98	163
27	0	0	0	0	0	67	0	0	101	168
28	0	0	0	0	0	92	0	0	141	233
29	0	0	0	0	0	1690	0	0	2614	4304
30	0	0	0	0	0	89	0	0	138	227
31	0	0	0	0	0	161	0	0	251	412
32	0	0	0	0	0	145	0	0	230	375
33	0	0	0	0	0	49	0	0	77	126
34	0	0	0	0	0	49	0	0	77	126
35	0	0	0	0	0	608	0	0	2256	2864
36	0	0	0	0	0	74	0	0	130	204
37	0	0	0	0	0	271	0	0	697	968
38	0	0	0	0	0	77	0	0	140	217
39	0	0	0	0	0	186	0	0	495	681
40	0	0	0	0	0	4977	0	0	21079	26056
41	0	0	0	0	0	5555	0	0	25206	30761
42	0	0	0	0	0	3668	0	0	16643	20311
43	0	0	0	0	0	2982	0	0	3462	6444
Total	0	0	0	0	0	28118	0	0	89360	117478

5. **Area allocated (ha) to different Crops under Free Cropping- Free Water Distribution (No Equity) at 35-28 days irrigation interval with Fixed Depth Approach**

Location No.	Area allocated (ha)									
	Gram	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0	0	0	0	0	0	0	0	51	51
2	0	0	0	0	0	0	0	0	62	62
3	0	0	0	0	0	0	0	0	1020	1020
4	0	0	0	0	0	0	0	0	76	76
5	0	0	0	0	0	0	0	0	276	276
6	0	0	0	0	0	473	0	0	473	946
7	0	0	0	0	0	0	0	0	1650	1650
8	0	0	0	0	0	0	0	0	95	95
9	0	0	0	0	0	0	0	0	400	400
10	0	0	0	0	0	0	0	0	130	130
11	0	0	0	0	0	0	0	0	136	136
12	0	0	0	0	0	0	0	0	102	102
13	0	0	0	0	0	0	0	0	58	58
14	0	0	0	0	0	0	0	0	32	32
15	0	0	0	0	0	0	0	0	200	200
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	1207	0	0	2319	3526
18	0	0	0	0	0	58	0	0	58	116
19	0	0	0	0	0	0	0	0	666	666
20	0	0	0	0	0	56	0	0	56	112
21	0	0	0	0	0	70	0	0	70	140
22	0	0	0	0	0	140	0	0	140	280
23	0	0	0	0	0	63	0	0	63	126
24	0	0	0	0	0	396	0	0	553	949
25	0	0	0	0	0	3372	0	0	6451	9823
26	0	0	0	0	0	98	0	0	98	196
27	0	0	0	0	0	101	0	0	101	202
28	0	0	0	0	0	141	0	0	141	282
29	0	0	0	0	0	2614	0	0	2614	5228
30	0	0	0	0	0	138	0	0	138	276
31	0	0	0	0	0	251	0	0	251	502
32	0	0	0	0	0	215	0	0	230	445
33	0	0	0	0	0	72	0	0	77	149
34	0	0	0	0	0	72	0	0	77	149
35	0	0	0	0	0	1186	0	0	2256	3442
36	0	0	0	0	0	130	0	0	130	260
37	0	0	0	0	0	509	0	0	697	1206
38	0	0	0	0	0	140	0	0	140	280
39	0	0	0	0	0	368	0	0	495	863
40	0	0	0	0	0	10968	0	0	21079	32047
41	0	0	0	0	0	5345	0	0	25206	30551
42	0	0	0	0	0	0	0	0	16643	16643
43	0	0	0	0	0	0	0	0	3759	3759
Total	0	0	0	0	0	28200	0	0	89300	117500

6. Area allocated (ha) to different Crops under Fixed Cropping- Free Water Distribution (No Equity) at 21 days irrigation interval with Fixed Depth Approach

Location No.	Area allocated (ha)									
	Gram	Sorghum	Onion	Wheat	Sunflower	Groundnut	Maize	Maize-fodder	Cabbage	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	4.60	10.80	11.60	19.40	7.70	7.70	3.10	4.60	7.70	77.20
3	76.50	178.50	191.20	318.80	127.50	127.50	51.00	76.50	127.50	1275.
4	5.70	13.30	14.20	23.80	9.50	9.50	3.80	5.70	9.50	95.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	35.50	82.80	88.70	147.80	59.10	59.10	23.70	35.50	59.10	591.3
7	123.80	288.80	309.40	515.60	206.20	206.20	82.50	123.80	206.20	2062.
8	7.10	16.60	17.80	29.70	11.90	11.90	4.80	7.10	11.90	118.80
9	30.00	70.00	75.00	125.00	50.00	50.00	20.00	30.00	50.00	500.0
10	9.80	22.80	24.40	40.60	16.20	16.30	6.50	9.80	16.30	162.7
11	10.20	23.80	25.50	42.50	17.00	17.00	6.80	10.20	17.00	170.0
12	7.60	17.90	19.10	31.90	12.80	12.80	5.10	7.70	12.80	127.7
13	4.30	10.10	10.90	18.10	7.20	7.20	2.90	4.30	7.20	72.20
14	2.40	5.60	6.00	10.10	4.00	4.00	1.60	2.40	4.00	40.10
15	15.00	35.10	37.60	62.60	25.10	25.10	10.00	15.00	25.10	250.6
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	173.90	405.80	434.80	724.70	289.90	289.90	116.00	173.90	289.90	2898.
18	4.30	10.10	10.90	18.10	7.20	7.20	2.90	4.30	7.20	72.20
19	49.90	116.50	124.80	208.00	83.20	83.20	33.30	49.90	83.20	832.0
20	4.20	9.90	10.60	17.60	7.00	7.00	2.80	4.20	7.00	70.30
21	5.30	12.30	13.20	22.00	8.80	8.80	3.50	5.30	8.80	88.00
22	10.50	24.50	26.30	43.80	17.50	17.50	7.00	10.50	17.50	175.10
23	4.70	10.90	11.70	19.50	7.80	7.80	3.10	4.70	7.80	78.00
24	41.50	96.80	103.70	172.80	69.10	69.10	27.60	41.50	69.10	691.2
25	483.80	1128.90	1209.60	2015.90	806.40	806.40	322.6	483.80	806.40	8063.
26	7.30	17.20	18.40	30.60	12.20	12.20	4.90	7.30	12.20	122.3
27	7.60	17.70	18.90	31.60	12.60	12.60	5.00	7.60	12.60	126.2
28	10.60	24.70	26.40	44.10	17.60	17.60	7.10	10.60	17.60	176.3
29	196.00	457.50	490.10	816.90	326.80	326.80	130.7	196.00	326.70	3267.
30	10.30	24.20	25.90	43.10	17.20	17.20	6.90	10.30	17.20	172.3
31	18.80	43.90	47.10	78.40	31.40	31.40	12.60	18.80	31.40	313.8
32	17.20	40.30	43.10	71.90	28.70	28.70	11.50	17.20	28.70	287.3
33	5.80	13.50	14.40	24.10	9.60	9.60	3.90	5.80	9.60	96.30
34	5.80	13.50	14.40	24.10	9.60	9.60	3.90	5.80	9.60	96.30
35	169.20	394.80	423.00	705.00	282.00	282.00	112.80	169.20	282.00	2820.
36	9.80	22.70	24.40	40.60	16.20	16.30	6.50	9.80	16.30	162.6
37	52.30	122.00	130.70	217.80	87.10	87.10	34.80	52.30	87.10	871.2
38	10.50	24.50	26.20	43.70	17.50	17.50	7.00	10.50	17.50	174.9
39	37.10	86.60	92.80	154.70	61.90	61.90	24.80	37.10	61.90	618.8
40	1580.9	3688.80	3952.30	6587.20	2634.90	2634.90	1054.	1580.90	2634.90	26348
41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	384.20	896.50	960.50	1600.90	640.30	640.30	256.1	384.20	640.30	6403.
43	642.50	1499.20	1606.30	2677.20	1070.90	1070.90	428.4	642.50	1070.90	10708
Total	4276.5	9979.40	10691.9	17820.2	7127.60	7127.80	2851.	4276.60	7127.70	71279

APPENDIX – D2

1. Allocation Unit wise Total Command Area, Capacity, Actual Total Irrigated Area for MRBC (2006-07) at Level-1

Location No.	Location Name	Chainage (Km)	Capacity (Cusec)	Total Command Area (ha)	Total Irrigated Area (ha)
1	DO 1	2	0.65	51	51
2	DO 2	2.47	0.75	62	62
3	MINOR 1	5.76	20.14	1020	669.4
4	DO 2A	6.43	0.5	76.00	67
5	DO 3	7.21	3.4	276.00	56.2
6	MINOR 2	9.34	8.9	473.00	56.1
7	DIST 1	9.71	26.16	1650.00	1400.92
8	DO 4	10.8	1.65	95.00	24.4
9	MINOR 3	11.84	8.85	400.00	196.8
10	DO 5	12.27	1.99	130.00	30.5
11	DO 5A	12.96	1.45	136.00	56.2
12	DO 6	13.68	1.12	102.00	2.8
13	DO 7	14.65	1	57.94	54.6
14	DO 8	16.59	1.08	32.16	1.6
15	DO 9	17.35	2.9	200.45	27
16	DIST 2	18.39	30	1793.90	1089.2
17	DIST 3	19.45	89	2319.00	636.2
18	DO 10	21.12	2.09	57.97	2
19	MINOR 4	21.43	8	665.59	69.6
20	DO 11	22.38	1.94	56.36	0.8
21	DO 12	22.83	1.06	70.4	11.6
22	DO 13	23.68	1.2	140.08	1.4

Location No.	Location Name	Chainage (Km)	Capacity (Cusec)	Total Command Area (ha)	Total Irrigated Area (ha)
23	DO 14	25.39	1.2	62.54	4.6
24	MINOR 5	25.6	12.5	552.87	103.36
25	SONAI DIST	26.53	95.5	6451	2734.55
26	DO 15	29.19	1.65	98.00	210.8
27	DO 16	29.50	1.65	101.00	210.8
28	DO 16A	30.62	1.2	141.00	210.8
29	DIST 4	31.00	37.93	2614.00	1406.75
30	DO 17	32.02	1.2	138.00	145.8
31	DO 18	33.42	3.25	251.00	145.8
32	DO 19	34.79	3.25	230.00	145.8
33	DO 19A	34.85	0.5	77.00	145.8
34	DO 19B	35.00	0.5	77.00	145.8
35	DIST 5	45.40	33.71	2256.00	1357.4
36	DO 20	47.20	1.2	130.00	38.7
37	MINOR 6	48.12	11.06	697.00	147.3
38	DO 21	49.70	1.2	140.00	58.2
39	MINOR 7	51.40	8.12	495.00	229.3
40	BRANCH 1	56.11	325	21079.00	6339.2
41	BRANCH 2	61.42	451	25206.00	6602
42	PATHARDI DIST	61.14	267	16643.00	6365.7
43	TAIL DIST	61.142	110	8567	6486.4

2. Allocation Unit wise Actual Crops grown and its Area for MRBC (2006-07) at Level-1

Level 1 Location No.	Location Name	Distribution of Crop and its Area (ha)											
		Sugarcane	Wheat	Cotton	Groundnut	Oilseed	Maize	Fodder	Other	Fruit	Vegetable	Gram	Bajra
1	DO 1	5	4.5	0	0	0	8	0	33.5	0	0	0	0
2	DO 2	2.2	5.4	4	0	0	7.6	0	42.8	0	0	0	0
3	MINOR 1	144	270	12	12	0	26	0	115.6	60.6	29.2	0	0
4	DO 2A	3.5	4.5	0	0	0	7	0	52	0	0	0	0
5	DO 3	7.4	40	0	0	0	0.3	0	8.5	0	0	0	0
6	MINOR 2	31.1	21.6	0	0	0	1	0	2.4	0	0	0	0
7	DIST 1	681.47	185.85	2.9	0	0	29.5	500	1.2	0	0	0	0
8	DO 4	12	9.5	0	0	0	2.9	0	0	0	0	0	0
9	MINOR 3	51.6	43.8	0	0	0	1.2	100	0.2	0	0	0	0
10	DO 5	10	7.5	0	0	0	10	3	0	0	0	0	0
11	DO 5A	2.2	4.5	0	0	0	6.7	0	42.8	0	0	0	0
12	DO 6	0	1.6	0	0	0	0	1.2	0	0	0	0	0
13	DO 7	38.9	15.7	0	0	0	0	0	0	0	0	0	0
14	DO 8	0.4	1.2	0	0	0	0	0	0	0	0	0	0
15	DO 9	1	2	0	0	0	0	24	0	0	0	0	0
16	DIST 2	730.2	198.3	0	5	0	15.9	139.8	0	0	0	0	0
17	DIST 3	582.2	4.5	0	0	0	0	6.7	42.8	0	0	0	0
18	DO 10	1.6	0	0	0.2	0	0	0.2	0	0	0	0	0
19	MINOR 4	41	26	0	0	0	0	2.6	0	0	0	0	0
20	DO 11	0	0.8	0	0	0	0	0	0	0	0	0	0
21	DO 12	0	0.8	0	0	0	0.8	10	0	0	0	0	0
22	DO 13	1.4	0	0	0	0	0	0	0	0	0	0	0

Level 1 Location No.	Location Name	Distribution of Crop and its Area (ha)											
		Sugarcane	Wheat	Cotton	Groundnut	Oilseed	Maize	Fodder	Other	Fruit	Vegetable	Gram	Bajra
23	DO 14	2.6	0	0	0	0	1	1	0	0	0	0	0
24	MINOR 5	62.4	37.56	0	2	0	0	1.4	0	0	0	0	0
25	SONAI DIST	1574.95	591.9	0	0	32.3	16.9	444.8	0	0	0	73.7	0
26	DO 15	95.6	66.7	0	0	0	0	1.2	0	0	0	47.3	0
27	DO 16	95.6	66.7	0	0	0	0	1.2	0	0	0	47.3	0
28	DO 16A	95.6	66.7	0	0	0	0	1.2	0	0	0	47.3	0
29	DIST 4	263.4	397.7	0	0	0	1.4	508.8	0	0	0	0	235.45
30	DO 17	53.7	57.8	0	14.2	0	5.9	0	0	0	0	14.2	0
31	DO 18	53.7	57.8	0	14.2	0	5.9	0	0	0	0	14.2	0
32	DO 19	53.7	57.8	0	14.2	0	5.9	0	0	0	0	14.2	0
33	DO 19A	53.7	57.8	0	14.2	0	5.9	0	0	0	0	14.2	0
34	DO 19B	53.7	57.8	0	14.2	0	5.9	0	0	0	0	14.2	0
35	DIST 5	831	406.2	0	5.4	8.8	0	0	0	0	0	106	0
36	DO 20	15	22	0	0	0	0.2	1.5	0	0	0	0	0
37	MINOR 6	55.6	85.8	0	0	0	0.2	0	0	0	0	5.7	0
38	DO 21	44	10	0	4	0.2	0	0	0	0	0	0	0
39	MINOR 7	123.35	30.85	0	14.2	0	2.4	12.5	46	0	0	0	0
40	BRANCH 1	1150	2815	0	423	0	10.2	1476	465	0	0	0	0
41	BRANCH 2	2323.65	1375.5	0	542.15	0	7.75	1307.15	558	0	0	487.8	0
42	PATHARDI DIST	3232.9	603.2	18.2	1115	167	289.7	452	0	0	0	0	487.7
43	TAIL DIST	2528.8	1538	133	540	20	348	301	252.6	0	0	540	285

3. Crop wise Maximum Yield (Kg/ha) and Actual Yield (Kg/ha) and Price (Rs.) for year 2006-07

Source	Sugarcane	Wheat	Cotton	Groundnut	Oil Seed	Maize	Fodder	Other	Fruit	Vegetable	Gram	Bajra
Actual yield kg/ha (Directorate of Economics and Statistics, Government of Maharashtra, 2008)	84000	1520	1486	1527	930	3500	40000	20000	4000	20000	707	729
Max Yield Kg/ha (From the Records of State Agricultural University)	100000	3500	2000	2500	1500	5000	50000	40000	8000	30000	2500	1600
Price Rs/ Kg (As per MSP declared by GOI 2006-07)	2.5	9	25	12	12	10	9	2	20	4	8	7

4. Actual Canal Operation in MRBC in Year 2006-07 (Data from Record of Maharashtra State Irrigation Department)

Initial Reservoir Volume = 598.27 million cubic meter

Actual water used = 434.13 million cubic meter

Canal Rotation No.	Start Date	End date	Total days of Canal operation	Total Volume of Water utilized (million cubic meter)
1	04-12-2006	17-12-2006	14	71.50
2	03-03-2007	04-04-2007	33	168.53
3	22-04-2007	29-05-2007	38	194.10
		Total	85	434.13

APPENDIX – D3

Final Performance Index Values for different irrigation strategies using mean weights to performance measures

Sr.	Irrigation Strategy	FPI
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.77
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.70
3	II-14, FULL DEPTH FREE CROPPING FWD	0.57
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.67
6	II-14, FULL DEPTH FX CROPPING FWD	0.53
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.69
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.68
9	II-14, FX DEPTH FREE CROPPING FWD	0.48
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.57
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.57
12	II-14, FX DEPTH FX CROPPING FWD	0.41
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.69
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.63
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.54
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.57
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.64
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.34
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.82
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71
21	II-21, FULL DEPTH FREE CROPPING FWD	0.62
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.70
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.69
24	II-21, FULL DEPTH FX CROPPING FWD	0.50
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.79
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
27	II-21, FX DEPTH FREE CROPPING FWD	0.53
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.57
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.57
30	II-21, FX DEPTH FX CROPPING FWD	0.35
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.78
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.65
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.59
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.58
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.59
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.27

Sr.	Irrigation Strategy	FPI
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.82
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.65
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.70
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.50
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.77
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.55
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.58
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.58
48	II-21-14, FX DEPTH FX CROPPING FWD	0.39
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.75
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.59
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.58
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.66
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.34
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.84
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.72
57	II-28, FULL DEPTH FREE CROPPING FWD	0.54
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
60	II-28, FULL DEPTH FX CROPPING FWD	0.48
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.80
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
63	II-28, FX DEPTH FREE CROPPING FWD	0.49
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.52
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.57
66	II-28, FX DEPTH FX CROPPING FWD	0.29
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.80
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.50
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.52
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.49
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.29
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.82
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.72
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.61

Sr.	Irrigation Strategy	FPI
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.69
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.48
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.79
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.48
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.53
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.52
84	II-28-21, FX DEPTH FX CROPPING FWD	0.32
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.71
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.47
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.42
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.53
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.49
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.27
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.85
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.75
93	II-35, FULL DEPTH FREE CROPPING FWD	0.58
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
96	II-35, FULL DEPTH FX CROPPING FWD	0.47
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.82
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.72
99	II-35, FX DEPTH FREE CROPPING FWD	0.54
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.50
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46
102	II-35, FX DEPTH FX CROPPING FWD	0.32
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.62
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.58
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.52
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.49
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.45
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.28
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.85
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.75
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.58
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.47
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.83

Sr.	Irrigation Strategy	FPI
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.83
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.54
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.50
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46
120	II-35-28, FX DEPTH FX CROPPING FWD	0.31
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.62
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.58
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.51
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.49
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.28

Appendix-D4

1. FPI values for different irrigation strategies with equal weights to different performance parameters (Productivity=0.33, Equity=0.33, Adequacy=0.33)

Sr. No.	Irrigation Strategy	FPI
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.76
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.69
3	II-14, FULL DEPTH FREE CROPPING FWD	0.55
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.68
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.66
6	II-14, FULL DEPTH FX CROPPING FWD	0.51
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.69
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.68
9	II-14, FX DEPTH FREE CROPPING FWD	0.47
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.57
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.57
12	II-14, FX DEPTH FX CROPPING FWD	0.40
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.70
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.64
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.53
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.57
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.64
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.33
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.81
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.70
21	II-21, FULL DEPTH FREE CROPPING FWD	0.60
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
24	II-21, FULL DEPTH FX CROPPING FWD	0.48
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.79
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
27	II-21, FX DEPTH FREE CROPPING FWD	0.52
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.58
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.57
30	II-21, FX DEPTH FX CROPPING FWD	0.34
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.78
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.65
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.58
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.58
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.59

Sr. No.	Irrigation Strategy	FPI
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.26
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.81
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.70
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.63
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.69
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.67
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.48
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.78
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.54
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.58
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.58
48	II-21-14, FX DEPTH FX CROPPING FWD	0.38
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.75
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.58
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.58
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.65
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.33
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.83
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71
57	II-28, FULL DEPTH FREE CROPPING FWD	0.51
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.68
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.67
60	II-28, FULL DEPTH FX CROPPING FWD	0.45
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.80
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
63	II-28, FX DEPTH FREE CROPPING FWD	0.47
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.52
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.58
66	II-28, FX DEPTH FX CROPPING FWD	0.28
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.80
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.48
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.52
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.50
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.28
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.81
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.71

Sr. No.	Irrigation Strategy	FPI
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.58
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.68
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.45
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.79
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.46
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.54
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.53
84	II-28-21, FX DEPTH FX CROPPING FWD	0.31
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.71
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.49
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.42
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.54
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.50
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.26
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.84
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74
93	II-35, FULL DEPTH FREE CROPPING FWD	0.56
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.68
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.67
96	II-35, FULL DEPTH FX CROPPING FWD	0.45
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.83
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73
99	II-35, FX DEPTH FREE CROPPING FWD	0.53
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.50
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
102	II-35, FX DEPTH FX CROPPING FWD	0.32
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.64
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.59
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.50
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.50
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.27
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.84
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.56
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.68
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.67

Sr. No.	Irrigation Strategy	FPI
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.45
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.83
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.83
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.52
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.51
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.48
120	II-35-28, FX DEPTH FX CROPPING FWD	0.31
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.64
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.59
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.50
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.50
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.28

2. FPI values for different irrigation strategies with different weights to different performance parameters (Productivity=0.50, Equity=0.25, Adequacy=0.25)

Sr. No.	Irrigation Strategy	FPI
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.66
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.55
3	II-14, FULL DEPTH FREE CROPPING FWD	0.50
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.54
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.50
6	II-14, FULL DEPTH FX CROPPING FWD	0.41
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.66
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.65
9	II-14, FX DEPTH FREE CROPPING FWD	0.49
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.46
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46
12	II-14, FX DEPTH FX CROPPING FWD	0.33
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.68
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.57
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.55
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.46
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.51
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.29
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.72
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.56
21	II-21, FULL DEPTH FREE CROPPING FWD	0.57

Sr. No.	Irrigation Strategy	FPI
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.54
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.53
24	II-21, FULL DEPTH FX CROPPING FWD	0.39
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.80
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
27	II-21, FX DEPTH FREE CROPPING FWD	0.59
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.47
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
30	II-21, FX DEPTH FX CROPPING FWD	0.29
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.79
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.62
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.64
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.48
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.49
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.24
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.72
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.56
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.59
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.55
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.52
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.39
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.79
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.61
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.47
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
48	II-21-14, FX DEPTH FX CROPPING FWD	0.32
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.77
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.67
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.64
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.48
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.53
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.29
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.76
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.57
57	II-28, FULL DEPTH FREE CROPPING FWD	0.52
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.53
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.52
60	II-28, FULL DEPTH FX CROPPING FWD	0.37

Sr. No.	Irrigation Strategy	FPI
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.80
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
63	II-28, FX DEPTH FREE CROPPING FWD	0.56
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.43
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
66	II-28, FX DEPTH FX CROPPING FWD	0.25
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.80
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.56
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.43
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.41
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.25
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.72
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.57
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.57
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.54
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.53
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.37
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.80
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.55
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.44
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.44
84	II-28-21, FX DEPTH FX CROPPING FWD	0.27
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.74
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.50
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.52
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.44
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.42
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.24
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.77
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.62
93	II-35, FULL DEPTH FREE CROPPING FWD	0.56
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.53
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.52
96	II-35, FULL DEPTH FX CROPPING FWD	0.37
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.87
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
99	II-35, FX DEPTH FREE CROPPING FWD	0.65

Sr. No.	Irrigation Strategy	FPI
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.42
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.39
102	II-35, FX DEPTH FX CROPPING FWD	0.28
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.68
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.56
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.63
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.41
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.38
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.25
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.77
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.62
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.56
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.53
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.52
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.37
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.88
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.87
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.64
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.43
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.40
120	II-35-28, FX DEPTH FX CROPPING FWD	0.28
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.67
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.56
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.63
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.41
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.39
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.25

3. FPI values for different irrigation strategies with different weights to different performance parameters (Productivity=0.25, Equity=0.50, Adequacy=0.25)

Sr. No.	Irrigation Strategy	FPI
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.83
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
3	II-14, FULL DEPTH FREE CROPPING FWD	0.51
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.75
6	II-14, FULL DEPTH FX CROPPING FWD	0.50
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.78

Sr. No.	Irrigation Strategy	FPI
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
9	II-14, FX DEPTH FREE CROPPING FWD	0.43
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.68
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
12	II-14, FX DEPTH FX CROPPING FWD	0.42
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.78
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.49
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.68
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.73
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.34
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
21	II-21, FULL DEPTH FREE CROPPING FWD	0.54
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
24	II-21, FULL DEPTH FX CROPPING FWD	0.45
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.85
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.84
27	II-21, FX DEPTH FREE CROPPING FWD	0.43
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.69
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.68
30	II-21, FX DEPTH FX CROPPING FWD	0.32
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.84
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.56
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.69
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.70
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.26
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.59
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.45
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.84
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.83
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.48
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.69

Sr. No.	Irrigation Strategy	FPI
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.69
48	II-21-14, FX DEPTH FX CROPPING FWD	0.37
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.82
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.80
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.53
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.69
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.75
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.34
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.88
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
57	II-28, FULL DEPTH FREE CROPPING FWD	0.39
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
60	II-28, FULL DEPTH FX CROPPING FWD	0.40
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.85
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.85
63	II-28, FX DEPTH FREE CROPPING FWD	0.36
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.65
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.69
66	II-28, FX DEPTH FX CROPPING FWD	0.27
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.85
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.85
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.37
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.65
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.63
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.27
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.50
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.40
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.85
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.84
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.35
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.66
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.65
84	II-28-21, FX DEPTH FX CROPPING FWD	0.29
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.79

Sr. No.	Irrigation Strategy	FPI
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.62
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.35
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.66
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.63
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.26
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.88
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.81
93	II-35, FULL DEPTH FREE CROPPING FWD	0.46
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.76
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
96	II-35, FULL DEPTH FX CROPPING FWD	0.40
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.88
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.81
99	II-35, FX DEPTH FREE CROPPING FWD	0.42
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.63
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.61
102	II-35, FX DEPTH FX CROPPING FWD	0.33
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.73
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.69
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.39
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.63
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.60
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.27
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.89
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.81
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.46
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.76
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.40
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.88
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.88
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.41
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.64
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.61
120	II-35-28, FX DEPTH FX CROPPING FWD	0.32
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.73
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.69
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.38
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.63

Sr. No.	Irrigation Strategy	FPI
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.61
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.27

4. FPI values for different irrigation strategies with differnt weights to different performance parameters (Productivity=0.25, Equity=0.25, Adequacy=0.50)

Sr. No.	Irrigation Strategy	FPI
1	II-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.83
2	II-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
3	II-14, FULL DEPTH FREE CROPPING FWD	0.67
4	II-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
5	II-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.75
6	II-14, FULL DEPTH FX CROPPING FWD	0.64
7	II-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.66
8	II-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.65
9	II-14, FX DEPTH FREE CROPPING FWD	0.49
10	II-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.59
11	II-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.59
12	II-14, FX DEPTH FX CROPPING FWD	0.47
13	II-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.65
14	II-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.63
15	II-14, VARIABLE DEPTH FREE CROPPING FWD	0.55
16	II-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.59
17	II-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.69
18	II-14, VARIABLE DEPTH FX CROPPING FWD	0.38
19	II-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
20	II-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
21	II-21, FULL DEPTH FREE CROPPING FWD	0.70
22	II-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
23	II-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
24	II-21, FULL DEPTH FX CROPPING FWD	0.61
25	II-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.75
26	II-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.75
27	II-21, FX DEPTH FREE CROPPING FWD	0.54
28	II-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.59
29	II-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.58
30	II-21, FX DEPTH FX CROPPING FWD	0.41
31	II-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.74
32	II-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.61

Sr. No.	Irrigation Strategy	FPI
33	II-21, VARIABLE DEPTH FREE CROPPING FWD	0.57
34	II-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.59
35	II-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.61
36	II-21, VARIABLE DEPTH FX CROPPING FWD	0.29
37	II-21-14, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
38	II-21-14, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.78
39	II-21-14, FULL DEPTH FREE CROPPING FWD	0.73
40	II-21-14, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
41	II-21-14, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
42	II-21-14, FULL DEPTH FX CROPPING FWD	0.61
43	II-21-14, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.73
44	II-21-14, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.72
45	II-21-14, FX DEPTH FREE CROPPING FWD	0.55
46	II-21-14, FX DEPTH FX CROPPING ANNUAL EQUITY	0.59
47	II-21-14, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.59
48	II-21-14, FX DEPTH FX CROPPING FWD	0.45
49	II-21-14, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.70
50	II-21-14, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.73
51	II-21-14, VARIABLE DEPTH FREE CROPPING FWD	0.59
52	II-21-14, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.59
53	II-21-14, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.70
54	II-21-14, VARIABLE DEPTH FX CROPPING FWD	0.38
55	II-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.88
56	II-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
57	II-28, FULL DEPTH FREE CROPPING FWD	0.64
58	II-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
59	II-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
60	II-28, FULL DEPTH FX CROPPING FWD	0.59
61	II-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.76
62	II-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.75
63	II-28, FX DEPTH FREE CROPPING FWD	0.51
64	II-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.50
65	II-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.58
66	II-28, FX DEPTH FX CROPPING FWD	0.32
67	II-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.76
68	II-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.75
69	II-28, VARIABLE DEPTH FREE CROPPING FWD	0.52
70	II-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.50
71	II-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.46

Sr. No.	Irrigation Strategy	FPI
72	II-28, VARIABLE DEPTH FX CROPPING FWD	0.32
73	II-28-21, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.86
74	II-28-21, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.79
75	II-28-21, FULL DEPTH FREE CROPPING FWD	0.69
76	II-28-21, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.77
77	II-28-21, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
78	II-28-21, FULL DEPTH FX CROPPING FWD	0.59
79	II-28-21, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.75
80	II-28-21, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.74
81	II-28-21, FX DEPTH FREE CROPPING FWD	0.50
82	II-28-21, FX DEPTH FX CROPPING ANNUAL EQUITY	0.53
83	II-28-21, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.51
84	II-28-21, FX DEPTH FX CROPPING FWD	0.36
85	II-28-21, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.63
86	II-28-21, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.37
87	II-28-21, VARIABLE DEPTH FREE CROPPING FWD	0.39
88	II-28-21, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.53
89	II-28-21, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.47
90	II-28-21, VARIABLE DEPTH FX CROPPING FWD	0.29
91	II-35, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.88
92	II-35, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.81
93	II-35, FULL DEPTH FREE CROPPING FWD	0.67
94	II-35, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.76
95	II-35, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
96	II-35, FULL DEPTH FX CROPPING FWD	0.59
97	II-35, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.76
98	II-35, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.63
99	II-35, FX DEPTH FREE CROPPING FWD	0.53
100	II-35, FX DEPTH FX CROPPING ANNUAL EQUITY	0.47
101	II-35, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.43
102	II-35, FX DEPTH FX CROPPING FWD	0.35
103	II-35, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.53
104	II-35, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.52
105	II-35, VARIABLE DEPTH FREE CROPPING FWD	0.51
106	II-35, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.47
107	II-35, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.42
108	II-35, VARIABLE DEPTH FX CROPPING FWD	0.31
109	II-35-28, FULL DEPTH FREE CROPPING ANNUAL EQUITY	0.89
110	II-35-28, FULL DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.81

Sr. No.	Irrigation Strategy	FPI
111	II-35-28, FULL DEPTH FREE CROPPING FWD	0.67
112	II-35-28, FULL DEPTH FX CROPPING ANNUAL EQUITY	0.76
113	II-35-28, FULL DEPTH FX CROPPING INTRASEASONAL EQUITY	0.76
114	II-35-28, FULL DEPTH FX CROPPING FWD	0.59
115	II-35-28, FX DEPTH FREE CROPPING ANNUAL EQUITY	0.76
116	II-35-28, FX DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.77
117	II-35-28, FX DEPTH FREE CROPPING FWD	0.53
118	II-35-28, FX DEPTH FX CROPPING ANNUAL EQUITY	0.48
119	II-35-28, FX DEPTH FX CROPPING INTRASEASONAL EQUITY	0.43
120	II-35-28, FX DEPTH FX CROPPING FWD	0.33
121	II-35-28, VARIABLE DEPTH FREE CROPPING ANNUAL EQUITY	0.52
122	II-35-28, VARIABLE DEPTH FREE CROPPING INTRASEASONAL EQUITY	0.52
123	II-35-28, VARIABLE DEPTH FREE CROPPING FWD	0.50
124	II-35-28, VARIABLE DEPTH FX CROPPING ANNUAL EQUITY	0.47
125	II-35-28, VARIABLE DEPTH FX CROPPING INTRASEASONAL EQUITY	0.44
126	II-35-28, VARIABLE DEPTH FX CROPPING FWD	0.32