# DEVELOPMENT OF WATER HARVESTING SYSTEM FOR SUSTAINABLE CROP PRODUCTION IN MICROWATERSHEDS

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2000

# DEVELOPMENT OF WATER HARVESTING SYSTEM FOR SUSTAINABLE CROP PRODUCTION IN MICROWATERSHEDS

By

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**A Thesis**

**submitted to the Faculty of Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the award of the degree of**

**DOCTOR OF PHILOSOPHY**

**in**

**AGRICULTURAL ENGINEERING**

**2000**

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# CERTIFICATE

This is to certify that the thesis entitled "**Development of water harvesting system for sustainable crop production in microwatersheds**", submitted to the Faculty of the Post Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Agricultural Engineering,** is a record of *bona fide* research work carried out by **Mr. Rajendra Kumar Sahu,** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received during the course of investigation has been duly acknowledged by him.

Place : New Delhi

Date : November 14, 2000

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# ACKNOWLEDGEMENTS

I take this privilage with immense pleasure to express my deep sense of gratitude and indebtedness to Dr. A. Singh, Professor, WST and Chairman, Dr. A.K. Bhattacharya, Project Coordinator, AICRP on agril. drainage and Co-Chairman, Water Technology Centre, IARI, New Delhi for their adept guidance, constructive criticisms, valuable suggestions and constant encouragements during the entire study period and finally going through the manuscript vividly. I owe my heartful thanks to Dr. (Smt.) A. Saksena, Dr. D.P. Handa, Senior Scientists, IASRI and Dr. R.P. Singh, Sr. Scientist, DMR, Pusa, New Delhi, for being in my advisory committee and rendering valuable suggestion as and when required.

I place record of my gratitude and indebtedness to Dr. O.P. Singhal and Dr. J.S. Panwar, present and Ex-Head, Division of Agricultural Engineering, respectively. I am also grateful to Dr. P. Chandra, Professor, Division of Agricultural Engineering for his encouragement and moral support.

I humbly express my deepest sense of gratitude and indebtedness to Dr. A. Alam, Dy. Director General (Engg.), ICAR, New Delhi and the then Vice Chancellor, IGAU, Raipur for granting me study leave, providing valuable suggestions, encouragements and moral support for successful completion of this assignment. I also express my heartfelt thanks to Dr. V.K. Patil, Vice Chancellor IGAU, Raipur for his generous help, moral support, useful suggestions and permission to extend study leave. Sincere thanks are also due to Dr. S.S. Baghel, Vice Chancellor, Central Agricultural University, Manipur for his moral support.

I gratefully acknowledge the financial support extended by IARI and UGC during the entire period of investigations. I am highly thankful to Director, IARI, Dean, P.G. School and their staff for providing facilities and support during the course of study. Special thanks are also due to Dr. I.M. Mishra, Shri J.S. Dhekale and Dr. Man Singh for their continued technical supports.

The encouragement and moral support extended by Dr. A.R. Pal, Dr. R.S. Tripathi, Dr. M.N. Shrivastava, Dr. K.C. Agrawal, Dr. A.S.R.A.S. Sastri, Shri S.B. Yadav (IGAU, Raipur) and Dr. R.B. Sharma (NDUAT, Faizabad), Dr. N.K. Tyagi, (CSSRI, Karnal) is duly acknowledged. The timely help and technical support extended by Dr. A.L. Rathore, Dr. K.K. Sahu, Shri J.L. Chaudhary, Shri Divakar Naidu, Shri H.C. Nanda, Dr. K.L. Nandeha, Dr. S.S. Sengar, Dr. H.K. Vardia, senior scientists of IGAU, staff of ZARS, Jagdalpur, IGAU, Raipur needs a record of my special appreciations. I express my sincere thanks to Mr. Narendra Kumar Sahu, Incharge, Computer Centre, Jabalpur for help in computer programming. Data provided by Deptt. of Land and Water Management, Deptt. of Agrometeorology, IGAU, Raipur are duly acknowledged.

The last moment help received from Dr. B.S. Thakur (IGAU, Raipur) and Dr. C.R. Satapathy (OUAT, Bhubaneswar), who kindly agreed to go through the manuscript, was really appreciable and moral booster. Thanks are also due to my collegues Mr. P.K. Sahu, Mr. P.K. Bora, Mr. R.C. Das, Mr. S. Ravichandran for their help in various ways.

Words and feelings will be insufficient to express my warmest regards/thanks as due to my parents, in-laws, wife - Purnima, son Sameer and daughter - Sonal for their silent, yet eloquent support during the study period.

Last but not least thanks are due to M/s. Ashok Computers for typing the manuscript.

Place : New Delhi

Date : November 14, 2000

**(RAJENDRA KUMAR SAHU)**

# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# LIST OF ABBREVIATIONS AND SYMBOLS

**Abbreviations**

| | | |
|---|---|---|
| AET | : | Actual evapotranspiration |
| AICRPAM | : | All Indian Coordinated Research Project on Agricultural Management |
| AMC | : | Antecedent Moisture Condition |
| B/C | : | Benefit-Cost ratio |
| CBIP | : | Central Board of Irrigation and Power |
| CF | : | Conservation factor, Conservation factor approach |
| CGWB | : | Central Ground Water Board |
| cm | : | Centimetre |
| CN | : | Curve number, Curve number method |
| CSE | : | Centre for Science and Environment |
| cu.m | : | Cubic metre |
| Deptt. | : | Department |
| d/s | : | Down stream |
| ET | : | Evapotranspiration |
| $ET_O$ | : | Reference crop evapotranspiration |
| FAO | : | Food and Agriculture Organization |
| $g\ l^{-1}$ | : | Gram per litre |
| GOI | : | Government of India |
| GOMP | : | Government of Madhya Pradesh |
| ha | : | Hectare |
| hp | : | Horse Power |
| hr | : | Hour |
| ICMR | : | Indian Council of Medical Research |
| i.e. | : | That is |
| IGAU | : | Indira Gandhi Agricultural University |
| IMD | : | India Meteorology Department |
| J-1, J-2 | : | Microwatersheds at Jagdalpur (Plateau) |
| JP-1, JP-2 | : | Ponds in microwatersheds 1 and 2 at Jagdalpur |
| kg | : | Kilogram |
| km | : | Kilometre |
| mm | : | [illegible] |

| | | |
|---|---|---|
| M.P. | : | Madhya Pradesh |
| msl | : | Mean sea level |
| NARP | : | National Agricultural Research Project |
| NBSS& LUP | : | National Bureau of Soil Survey and Land Use Planning |
| NGO | : | Non-government organization |
| PET | : | Potential evapotranspiration |
| R-1, R-2 | : | Microwatersheds at Raipur (plains) |
| RP-1, RP-2 | : | Ponds in microwatersheds 1 and 2 at Raipur |
| Rs | : | Rupees |
| SCS | : | Soil conservation service |
| SFR | : | Small farm reservoirs |
| SMW | : | Standard meteorological week |
| Sq.m. | : | Square metres |
| t/ha | : | Tonnes per hectare |
| USDA | : | United States Department of Agriculture |
| U/s | : | Upstream |
| viz. | : | Namely |
| viz. | : | Namely |
| WHP | : | Water harvesting potential |
| WUE | : | Water-use efficiency |
| ZARS | : | Zonal Agricultural Research Station |

**Symbols**

| | | |
|---|---|---|
| $\alpha$, $\beta$ | : | Parameters of Gamma distribution |
| > | : | Greater than |
| < | : | Less than |
| $^0$C | : | Degree celcious |
| % | : | Per cent |
| @ | : | At the rate of |
| $\geq$ | : | Greater than or equal to |
| $\leq$ | : | Less than or equal to |
| $R^2$ | : | Coefficient of determination |

CHAPTER I

# INTRODUCTION

Scarcity of water had been a critical limitation in adoption of modern technologies for increasing productivity of traditional rainfed rice growing areas of Chattisgarh. About 80 per cent cultivated area of the region is under rainfed farming. The principal crop, rice has very low productivity (1.2 t/ha) owing to the shortage of water at critical stages and water logging at initial stages of crop growth. The shortage of water results from uneven distribution of rains, significant gaps between rain events and field water losses. During monsoon the prolonged dryspell is a common feature which occurs twice or thrice in the same season. Their occurrences at the critical crop growth stages, becomes detrimental in realising the full potential of crop. It more often leads to temporary drought and subsequent crop failure over large area. This also causes temporary migration of farmers to the potential areas (Gupta and Prajapati, 1998).



It has been reported that about 50 per cent of the rainfall occurs in the form of high intensity rains (Pishroty, 1987). It results in flooding of cropped area. The generated runoff alongwith productive soil and nutrients flows from field to field as waste. This excess runoff amounts to about 30-42 and 40-55 per cent in plains and plateau areas of Chhattisgarh respectively (Pal *et al.,* 1994; Sahu, 1999).

Amongst several techniques of rainwater management, small ponds at community level were the most common technique followed by the ancient people. With the pace of development other options viz. large reservoirs, tubewells, diversions overshadowed the pond culture and virtually it became a dying wisdom (CSE, 1997). But the adverse impact of these new techniques in terms of water logging, salinity development and ground water depletion has forced the researchers and policy makers to look back into the traditional wisdom of pond culture and revive it with latest input of scientific techniques. In Chhattisgarh region, small ponds at farmers level are again becoming popular to alleviate drought and submergence. However, no design specifications are available for runoff water harvesting, storage structures, to support production system, particularly in those areas where ground water availability is either poor or its harnessing is difficult due to unfavourable geologic conditions (Plate 1).

A study is therefore, has been undertaken to investigate into the techno-economic feasibility of runoff harvesting, its storage and recycling for stabilizing biomass production, through improvement in existing rice based farming systems (Plate 2). The major objectives of the study are :

1. To select an appropriate runoff estimation model for water harvesting based on the analysis of the available hydrologic data.
2. To develop alternative designs of drainage system and farm ponds using the model output.
3. To evaluate optimal crop plan for different alternative designs to achieve maximum B/C ratio of the crop production.

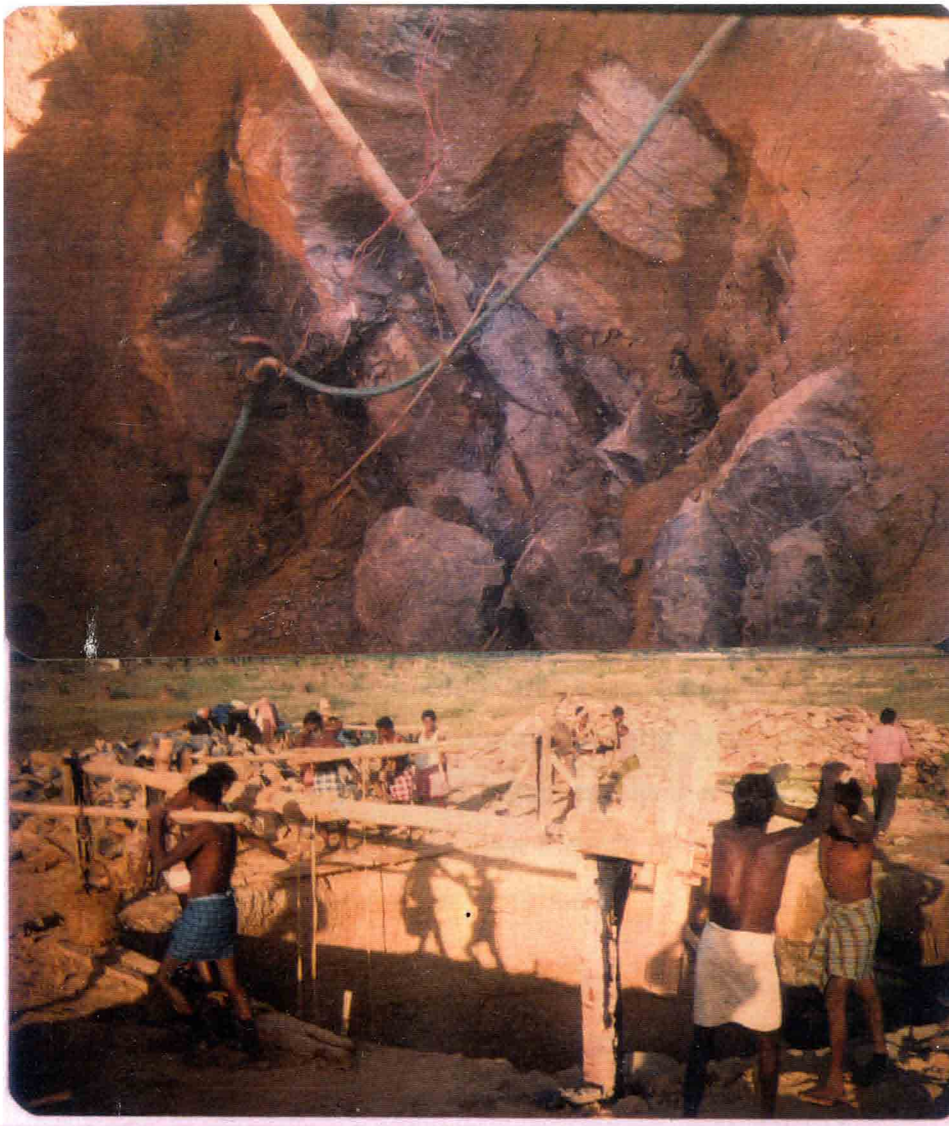


Plate 1. Absence of potential aquifers and presence of hard strata make ground water harnessing difficult.

Plate 2. Rainwater harvesting and recycling has a potential to save crop against drought

# CHAPTER II

# REVIEW OF LITERATURE

A major characteristic of Indian monsoon, mostly affecting rainfed agriculture is its temporal variability leading to unpredictable drought and floods. It is, therefore, necessary that agricultural planning, through efficient water management in rainfed areas, is taken up on scientific basis to harness available rainwater potential of the area, particularly for the benefit to small and marginal land holdings. In this chapter, a review of the previous work done, keeping in view today's most discussed issues, pertinent to the present study is summarised.

## 2.1 ECO-FRIENDLY TECHNOLOGY

The potential of rainwater harvesting through small farm reservoirs (SFR) to augment water supply to rainfed areas has been demonstrated by researchers (Sahu and Kadrekar, 1981; Das and Chowdhary, 1988; Bharadwaj and Singh, 1990), extensionsts and NGO's (Sinha, 1988; Varghese, 1990). Watershed is considered an ideal unit for managing water, vegetation and soil - the three vital and interdependent natural resources (Singh *et al.,* 1996). The other two major water management procedures viz. large reservoirs with canal networks and groundwater exploitation are proving hazardous besides being cost intensive. Water logging, high water table, salinity build up in canal command areas and declining of water table in tubewell command area are the cause of concern (Sarkar and Singh, 1997). To build large reservoirs or putting up tubewells are often inappropriate because these are either financially or geologically infeasible (Sharma *et al.,* 1982). However, despite of achieving full potential by these two approaches India would still be left with about its 45 per cent area to be managed by other methods of water supplies (Singh *et al.,* 1996). Traditional methods of pond culture provide solutions and show promise for their revival with modern skills and knowledge (CSE, 1997). Construction of a series of stop dams, tanks, diversions and SFRs utilizing watershed based water management concept is emerging as potential approach in developing local surface water resources for direct use and augmenting the recharge of ground water too. Developing water resources by impounding local surface runoff is perhaps the best option to improve water availability and to reduce environmental hazards. Such on-farm and community based measures in the catchments of major and medium irrigation reservoirs, increase their life by reducing its load (Dhawan, 1991; Sarkar and Bhattacharya, 1991). There is a need for comprehensive management and development of water resources on a microwatershed (MW) basis so that benefits of watershed development will not be restricted to farmers whose fields are in advantageous locations (Bortrall and John, 1991). Research on these storage systems has been conducted in Bangladesh, India, Indonesia and the Philippines to determine their value in conserving rainwater, improving land productivity and the impact on farmer income (Bhuiyan, 1994).

## 2.2 SUSTAINABILITY

A production system can be considered sustainable in long term only if outputs produced or lost can be balanced with inputs into the system (Lal, 1993). Lack of sustainability in traditional low input systems mostly has its roots in the inadequate control and/or supply of water for crop production. Judicious management of rainwater that improves local hydrology, reduces soil erosion and fertility loss from top soil and reduces runoff loses, contribute to sustainability of the production system (Pal and Bhuiyan, 1995). However, adoption of these new technologies need to be integrated with existing farming systems through interactive process of research and development (Singh, 1996; Sarkar and Singh, 1997) and it needs location specific studies in order to improve production and protection against degradation (Singh and Bhattacharya, 1998).

## 2.3 FARMER'S FIELD - A CONCEPTUAL MICROWATERSHED

Majority of land holdings in our country (78.2%) are of small and marginal category with average size of 1.43 and 0.39 ha respectively (GOI, 1998). A more or less similar land holding pattern exists in Philippines and Indonesia where SFRs are mostly individually owned and managed by farmers, thus organizational complexity inherent in conventional irrigation technologies is avoided. An individual farmer would find managing a SFR relatively simple and easy (Moya *et al.*, 1994). Farmer's field, if made hydrologically isolated and independent from the surrounding area on even a flat topography by bunding and trenching or by some other means, so that all incoming runoff from upstream (u/s) area is cutoff, it creates artificial microwatershed (MW). Within MW, all rainwater is either conserved and/or stored in SFR through surface drainage system and subsequently recycled for crop production. This symbolizes the judicious use of rainwater, where it falls and is significant in arresting soil and nutrient losses besides avoiding water logging (Pal and Bhuiyan, 1995; Sahu and Chandrakar, 1993).

## 2.4 RAINFALL VARIABILITY, DROUGHT RISK AND SUBMERGENCE

The influence of weather on yield of rice showed significant relationship with seasonal rainfall in the study area (AICRPAM, 1998).

Raipur district : $Y = 230.77 + 0.26\ X\ (R^2=0.288^{**})$

Bastar district : $Y = 360.55 + 0.33\ X\ (R^2 = 0.263^{**})$

** Significant at 1%, X is the rainfall, Y is the rice yield.

Erratic nature of rainfall occurrence - time, space and quantity often results in submergence and drought problems. Drought is one of the significant causes of year to year fluctuations in the rice production (Fukui, 1982). Enormous losses of rice production occur in Eastern India (Widawsky and O'Toole, 1990), as a result large scale migration of farmers take place (Gupta and Prajapati, 1998). Even with high concentration of rainfall events, rainfed rice in many areas and in most years suffers from in-season drought and consequent loss of yield. Another constraint farmers face is the variation in the timing of the onset and termination of monsoon. Such a situation gives farmers little choice but to adopt a very low risk, low input cropping system, which is directed to giving a stable rather than a high production. Water shortage prevents most farmers from growing an economic non-rice crop during post-monsoon season. Even a marginal improvement in the soil water status in this season can make a significant difference in cropping opportunity and/or yields (Bhuiyan and Zeigler, 1994).

## 2.5 ROLE OF SFR

The SFR system plays a crucial role in the alleviation of drought and submergence. Established on farm, this system is used to harvest surplus rainfall and runoff produced in the catchment area and in-situ rainfall, and store the water for subsequent use. SFRs or farm ponds have been in use in rural areas since ancient times. But today this time tested technology has acquired a new dimension because of the following reasons :

1. Modern farming technologies have opened up new opportunities for farmers, provided availability of water is ensured.
2. The pressure to produce more crops and a higher income from rainfed land is increasing.
3. Recent research results have shown that scientific management of water resources within MW using SFR as the centerpiece, is economically attractive and socially desirable.

## 2.6 ISSUES AND CHALLENGES

A major thrust is now underway in Indonesia and Philippines to adopt and adapt the SFR based farming system in a variety of field conditions with the objective of raising productivity and farmer income. But inspite of these recent advances, there is a lack of clear understanding of the range of physical, social, economic, institutional and environmental factors that favours successful adoption of the system, and allow sustainable benefits to be achieved from use of the concept. Some of the issues and challenges are :

1. Minimum data needed to design SFRs and to site them within MW or to identify areas potentially suited for SFRs.
2. Measures to reduce water losses, economically in SFRs.
3. Sustained availability of water in SFR, as affected by land use in the catchment area.
4. Fish and duck rearing in SFRs as optional activity during storage period, without sacrificing crop production.
5. Low cost, low head, water lifting device to lift water from SFRs for irrigation.
6. The effect of SFR on groundwater status in the long run.
7. Crop diversification selection of remunerative and water efficient crops.

Rainwater harvesting is undoubtedly a sound concept for rainfed areas. Its successful adoption by farmers depends on whether or not the relevant issues and challenges are properly addressed (Bhuiyan and Zeigler, 1994).

## 2.7 DESIGN OF WATER HARVESTING SYSTEM

Water harvesting for MW can be physically characterised by the presence of 4 components (1) well defined catchment (2) A suitable reservoir (3) Drainage system (4) Irrigation service area/ command area (Galang *et al.,* 1994). SFR based production system offers crop diversification and facilitates remunerative crop production including fish rearing and more intensive cropping (Pal and Bhuiyan, 1995; Sahu, 1996). The SFR technology is highly suitable to mildly rolling landscape with heavy soils where runoff collection and storage are convenient and where the lower fields can be irrigated by gravity flow. However, the technology can also be adopted in flat areas, using suitable and economic water lifting devices (Moya *et al.,* 1994). Land slope is an important determinant of reservoir suitability. Slopes higher than 2 per cent are required when constructing reservoirs with high storage ratio (Guerra *et al.,* 1988). Excavating type SFR can be constructed in varying toposequence. This is a common situation prevailing in farmer's field. It is generally constructed at the lowest area of MW where a higher water storage capacity per unit volume of earth work is achievable (Sahu, 1999). The ideal location of SFR is in the middle of MW so that a sizable amount of runoff collected in SFRs is used for irrigating lower areas by gravity flow (Radder *et al.,* 1995). Among various shapes, the circular SFRs have the highest storage capacity and have least circumferential length for a given surface area and side slopes (Radder *et al.,* 1995) and it results the minimum wetted perimeter for a given storage thereby reducing seepage losses and least cost of lining or other seepage control measures. However, circular shape is diadvantageous in agricultural operations, fish netting and quite often does not match with the existing field layout (Sahu, 1999).

The design of SFR consists of finding a suitable combination of water spread area and depth of storage at a permissible side slopes and a given storage volume. Krimgold equation (Krimgold and Harrold, 1944) was found to be appropriate for designing SFR capacity and size (Bhandarkar, 1985; Sahu and Chandrakar, 1993) using different water balance and hydrological parameters of a MW.

SFR sizing is a difficult process because of the scarcity of information on the stochastic nature of runoff yield and irrigation water requirement and storage losses. Historically, pond sizing has been done by guess work. Palmer *et al.* (1982) estimated the required amount of irrigation water by superimposing monthly rainfall (R) onto the average monthly potential evapotranspiration (PET) to form a PET-R diagram.

From this, the magnitude and duration of long term average deficiency and surplus during the crop's growing period was obtained. Paul and Tiwari (1994) followed the same principle using weekly PET-R values, with the assumption that tank catchment area is sufficient to fill the reservoir atleast once a month at 60 per cent rainfall probablility and 40 per cent storage loss due to evaporation, seepage and percolation.

## 2.8 WATER LOSSES AND ITS CONTROL

Water losses from SFR comprise of, seepage, percolation and evaporation losses. Seepage and percolation constitute major losses and may be as high as 18.56 lit/hr-sq. m. in newly dugout SFR in lateritic soils (Kale *et al.,* 1986). With the passage of time soil pores get choked and sealed off resulting in reduction of losses. Studies at Dehradun and Rajkot (Vijayalakshmi *et al.,* 1982) reveal that seepage from a newly dug SFR stabilizes to a very low rate in a period of 8 years due to silting. The annual change in seepage loss rates, Y (ha-cm) and age, in years after construction of SFR were fitted by an equation (Husenappa *et al.,* 1979).

$$Y = 262.2 \ / \ T^{0.2615} \qquad (r = 0.82) \qquad \text{..........} \ 2.1$$

A linear relationship exists between seepage rate S (lit/sq.m./day) and hydraulic head (m)

$$S = 8.541 \ H - 1.2067 \qquad (r = 0.991) \qquad \text{..........} \ 2.2$$

The seepage losses in SFRs were calculated at Kharagpur and Hazaribagh from the relationship (Paul and Tiwari, 1994; Rao, 1969).

$$S = 0.314H + 35.7 \ H^2 \qquad \text{..........} \ 2.3$$

where H is the storage depth in meters and S is the seepage loss.

Cluff (1977) has suggested compartmentalisation of SFR to reduce seepage and percolation losses by reducing wetted area but under Indian conditions it is not viable and cost effective (Verma, 1987). The study conducted at Jagdalpur indicated that seepage losses in light soils reduced from 71.3 per cent to 24.1 per cent by combination of several low cost treatments such as mixing of clay soil in SFR bed followed by trampling by animals and puddling and finally compacting manually by impact type hand compactor and roller. In another SFR in medium soils, compaction alone proved to be effective in controlling seepage losses. In this SFR seepage losses were reduced from 37.8 per cent to 15.2 per cent. To maintain low seepage rate, the SFR bed and side slopes are to be compacted and rolled every year before the onset of monsoon (Sahu, 1999). The treatment of puddling and trampling SFR bed by water buffalloes was found to be beneficial in checking seepage losses in SFRs at Raipur. The treatment of sodium carbonate alongwith puddling was found to be more effective than puddling and trampling. However, it was not cost effective and may cause harm for fish rearing in the SFR (Pal *et al.,* 1994).

An economical, efficient and durable evaporation retardant for SFR is yet to be found by research under varying agro-climatic regions and soil types. Until such time, to overcome the storage losses in SFRs, it is advisable to use the water by irrigating as soon as it is needed and storing the water in the soil profile for subsequent utilization by deep rooted perennial crops (Radder *et al.,* 1995). Paul and Tiwari (1994) estimated evaporation loss from open water surface of SFR from pan evaporation records and corrected using the coefficient (0.74). Khandelwal (1999) used this coefficient as 0.66 for estimating the evaporation from open water surface of SFRs at Rajkot in Gujrat.

## 2.9 RUNOFF ESTIMATION MODELS

Continuous watershed models offer the most reliable method of runoff estimation for even very short intervals. Many of these models for estimating watershed yield are described by Fleming (1975). Some of these kinds of models are Stanford watershed model (Crawford and Linsley, 1966), the Boughton model (Boughton, 1966), HEC runoff yield model (U.S. Army Corps of Engineers, 1968) and the USDAHL model

(Holtan and Lopez, 1971). These models require a large input data recorded continuously over a watershed, limiting their general applicability.

Pedersen *et al.* (1980) reported a model considering the watershed as a single linear reservoir and observed that the use of this model was restricted to small flashy watersheds having very small time of concentration. Helweg *et al.* (1982) presented the improvement of non linear rainfall-runoff model suggested by the Amorocho (1967). Multiple linear regression was used to solve the model coefficients from historical values. Mathematical model of the instantaneous unit hydrograph based on time-area histogram was developed (Vinod Kumar and Rastogi, 1989). The instantaneous unit hydrograph was used for generation of runoff hydrographs. The predicted runoff hydrographs were found to be in good agreement with the observed runoff hydrographs. Gupta and Solomon (1977) have developed a distributed model for predicting both runoff and sediment discharge. They used the square elements. Though the above discussed models reveals better accuracy in the prediction of runoff, their increased complexity, huge data requirements and time of computation are the major limitations for their use.

Naef (1981) concluded, while attempting to test such complicated models, that neither simple nor complex models are free from failures and found that simple models also perform satisfactorily in many cases. This was further supported by Mathur *et al.* (1992) by observing in their review that application of theories and models should be done on merit and the best suited methodology to the conditions and hydrologic data available in the watershed, particularly in developing countries like India.

The review of above models reveals that they are complicated and sophisticated in nature and predict the runoff rates even during small time intervals, less than a day, with resonable accuracy. However, in most of the cases, the continuous measurement of rainfall and soil moisture are needed as input which are usually not available. Hence some of the research workers have developed water yield models with total rainfall in a given period as input.

Various empirical formulae such as Inglis formula, Lacey's formula, Khosla's formula were developed for Indian catchments (Verma, 1987).

Singh (1987) developed different regression equations using the concept of cumulative rainfall, threshold rainfall, conservation factor and topography of the watershed to estimate runoff and soil loss from hill slope watersheds. It was observed that the water yield potential of hilly MWs varied from 0.10 to 0.72 ha-m/ha indicating the scope for construction of water storage structure. Bajpai (1999) also used conservation factor concept to assess the water yield potential of 6 MWs located in different agro-hydrological conditions.

Binnie was one of the first who studied the relationship of runoff to rainfall and expressed as a percentage of rainfall. His results were based on the observations on two rivers in Madhya Pradesh. The runoff percentage varied from 7 to 55 for annual rainfall variation from 250 to 1725 mm. The Binnie's percentages have been slightly adjusted to give a more regular curve (CGWB, 1994). Binnie's method of runoff estimation was used for designing farm ponds in heavy textured soils of Bhopal (Bhandarkar, 1985) and medium textured soils of Bastar (Sahu, 1996).

Using annual runoff coefficient is quite a crude method. This requires considerable judgement in selection of runoff coefficient which is considered to vary with annual rainfall, nature of soil and catchment slope. Burton (1965) recommended this method for the design of small storage and he suggested that runoff coefficients vary with average rainfall and soil type, but not with the slope of catchment.

Strange's method (CGWB, 1994) gives total monsoon rainfall and corresponding runoff in terms of the percentage of rainfall in the catchment area according to its nature i.e. good, bad or average. A good catchment has high slope, poor surface water retention and absorption and a bad catchment has high surface retention and absorption due to low gradient, heavy soil cover, vegetation etc. Average catchment has mixed characteristics.

The storm or daily rainfall-runoff relation that has had maximum application in water storage structure design is US Soil Conservation Service runoff curve number method developed by SCS, USDA (l1964). This method is based on the recharge capacity of the watershed. The recharge capacity is determined by antecedent moisture condition and by the physical characteristics of the watershed. The recharge capacity is empirically related to curve number which is a function of soil type, antecedent wetness, land use or cover, farming treatment and hydrologic condition. By selecting suitable curve number based on watershed conditions including antecedent wetness, the runoff can be calculated by using the equation :

$$Q = (P - Ia)^2 / (P-Ia+S) \quad \text{Where } P > Ia \qquad \text{........ 2.4}$$

$$Q = 0 \quad \text{When } P < Ia \qquad \text{........ 2.5}$$

The potential maximum retention, S, is determined by the equation

$$CN = 25400/ (254 + S) \qquad \text{........ 2.6}$$

where Q is the runoff, P is the rainfall, CN is the curve number and Ia is the initial abstraction.

In this method, the rainfall-runoff relationship is discrete and not continuous, implying step shift in curve number with corresponding change of antecedent rainfall index. Actually, curve number varies continuously with soil moisture and thus there should be many values instead of only three. Some modifications of this method were done for antecedent moisture using soil moisture accounting procedure (Williams and La Seur, 1976; Hawkins, 1978; Pathak *et al.,* 1989) but these modified methods are complicated requiring more data.

## 2.10 PROBABILISTIC ESTIMATES OF PARAMETERS

Rainfall, runoff, length of dryspell, crop ET are some of the important parameters, the estimates of these at various probabilities of exceedence are needed for design of storage structures, drainage system, planning irrigation to crops and subsequently economic analysis of the water harvesting system or its components. Ray *et al.* (1980) predicted expected rainfall amount of 50, 60 and 80 per cent probability of exceedence for Bhubaneshwar and concluded that the rainfall expected at 80 per cent probability of exceedence can be taken as minimum assured value for crop planning, Suresh *et al.* (1992) used Weibulls method of frequency analysis for predicting rainfall at 10, 50, 100 per cent probability levels at Pusa, Bihar. Verma and Sarma (1988) estimated the lowest assured weekly rainfall at different probability levels using incomplete Gamma distribution for Kandi region of Punjab. Gupta (1982) worked out the water requirement of rice at Karnal during continuous dryspell at 25 per cent probability of exceedence. Chaudhary (1998) analysed the occurrence of dry and wet spells using the concept of Markov chain modelling for upland and lowland situations of Bastar district of M.P. Gabriel and Neumann (1957) have shown that dry and wet spells follow a geometric distribution. They used Markov-chain model to the spell distribution and other properties of rainfall occurrence. The same procedure was adopted by Basu (1971) to study the daily rainfall at Calcutta and by Bhargava *et al.* (1973) to study the occurrence of rainfall in Raipur district. Later it was also applied by Sundararaj and Ramachandra (1975) to study the weather spells at Hebbal and by Singh and Bhandari (1998) in Himachal Pradesh.

## 2.11 DRAINAGE SYSTEM DESIGN

The SCS curve number method is also used to determine daily runoff from daily rainfall without any consideration of the size of watershed. The curve numbers developed by SCS, USDA (1964) were used in determining the surface drainage coefficients of agricultural land in the watersheds of the country (Gupta *et al.*,1971) for AMC III condition. Boughton and Stone (1985) studied the effect of conveyance losses due to increase in size of watershed on the value of curve number and reported modification for semi arid tropics. The curve number method was used for drainage system design at Bhopal (Bhandarkar and Nimje, 1990) and Jagdalpur (Sahu, 1999).

For surface drainage, the main requirement is of suitable outlet and the outlet design is dependent on the drainage coefficient which denotes the depth of water to be removed per day. Gupta *et al.* (1971) had worked out drainage coefficient for different parts of India. He considered crops, soil cover complex numbers, rainfall intensity for 2-5 years frequency for the duration equal to the period considered safe for the crops and conversion of this rainfall to the runoff depth. The time required for removal of excess water was taken as 6-8 hours for vegetable crops, 24 hours for general crops and 72 hours for rice crop. Drainage system was designed at Jagdalpur (Sahu, 1999) and Bhopal (Bhandarkar and Nimje, 1990) by considering 16 and 24 hours respectively as the excess water removal time from composite MWs.

## 2.12 RUNOFF POTENTIAL AND SEDIMENT TRAPPING

Runoff potential vary greatly from one region to other, even within same region-from one location to other and catchment size. It is estimated that between 20-35 per cent of the annual rainfall is available for harvesting in cultivated red soils of Karnataka (Hegde *et al.,* 1981). In Doon valley it is 16.5 per cent of monsoon rainfall (Sastry and Singh, 1993). The seasonal runoff coefficient for 2-3 ha MW at Luzon, Philippines was found to be 0.35 (Guerra *et al.,* 1988). In the sub mountain area of Maharashtra, the rainwater harvesting potential was found to be 23 per cent of monsoon rainfall (Chunale *et al.,* 1994) whereas at Bellary, Karnataka, it was worked out to 5000 cu.m/ha (Chittaranjan, 1981). The SFRs are very effective in controlling soil erosion and flooding. The long term sediment trapping efficiency ranges from 60-100 per cent (Dendi, 1974; Griffin, 1979; Dendi and Cooper, 1984). The overall nutrient trapping efficiency was 72 per cent for phosphorus and 82 per cent for nitrate nitrogen during the five years of study (Cooper and Knight, 1990). The average annual reduction in SFR's capacity due to siltation was found to be 1 per cent at Doon valley for the period of 18 years (Husenappa *et al.,* 1978).

## 2.13 VALIDATION OF MODEL

Validation of developed model can be done by comparing the model output with the observed data series. This comparison can be made by applying statistical tests. These tests of significance are done to know the extent of agreement between the observed and predicted hydrologic data series. However, some research workers have used non-parametric tests and correlation analysis for the same. Bhattacharya (1977) used Wilcoxon matched pairs signed ranks test for examining water table depths while the same test was applied for verifying the water levels in different wells (Selvarajan, 1990). Savabi *et al.* (1988) used least square analysis to correlate the measured water yield with the simulated water yield.

## 2.14 RUNOFF RECYCLING FOR CROP PRODUCTION

The prime objective of runoff recycling for crop production is to get maximum return per unit of water stored. The volume of water in SFR goes on reducing with time after monsoon and within monsoon if long dryspell exists. Hence the unit cost of water storage increases with time. Maximising yield per unit area through intensive irrigation is economically justified where water is readily available and irrigation cost is low. On the other hand, when water supplies become more limited or irrigation cost is high, the objective of irrigation shall be to maximise yields per unit of available water (Stegmen *et al.,* 1980). Supplement irrigations at critical crop growth stages is more productive.

These critical periods for various crops have been described by Hukkeri and Pandey (1977) and Rao (1991). Verma (1987) reviewed various work done in connection to application of stored water as supplemental irrigation and its benefits for different crops and concluded that extensive irrigation increased the water use efficiency (WUE) of crops.

## 2.15 OPTIMAL ALLOCATION OF WATER RESOURCES

Both linear and dynamic programming have been used by different research workers for optimal allocation of water resources to various competitive crop activities. A comprehensive study using simulation approach was conducted by Hall *et al.* (1968). They presented a dynamic programming model to estimate optimal usage of irrigation supplies, particularly in a season when there is insufficient water for meeting all the demands. The model included two state variables, i.e. the soil moisture content and the total amount of water available at the start of the season. Aron (1968) used dynamic programming to optimize the conservation and use of a ground water-surface water system. A study by Bargur (1972) offered a multi-sector planning and management approach to water resources. The model was based on general equilibrium analysis employing input-output models and linear programming technique. Heady *et al.* (1973) employed linear programming model to determine optimal water and land allocation and agricultural water needs of USA in the year 2000 A.D. Soni (1984) formulated two goal programming models with the main aim of optimal utilization of land and water in *rabi* season and efficient utilization of human resources in *Kharif* season. Varshney (1990) developed linear goal programming model within the conflicting goals of maximising the irrigated cropped area and the economic returns. The model was formulated for three crop seasons during a year, utilizing surface water and ground water conjunctively. Singh *et al.* (1997) developed multiple objective model of linear programming for optimal utilization of land and water considering various resource and requirement constraints. Land allocation was made under different crops in *rabi* season for the considered objectives of net benefit maximizing, production maximization and investment minimization.

## 2.16 CRITIQUE OF LITERATURE REVIEWED

The review on MW based runoff water harvesting reveal the following facts :

1. The traditional wisdom in rainfed water management have potential and if properly evaluated can provide dues for better adoption of new technologies.
2. Development of new technologies needs to be aim at improving farming systems and their integration demands interactive process of research and development.
3. MW based water harvesting is emerging as effective means of water management for rainfed agriculture.
4. Scientific management of water resources in MWs are economically attractive and viable, socially desirable and environment friendly.
5. Optimal crop plan based on optimal allocation of land and water resources and profits of production activity, ensures maximization of profits from SFR based farming.
6. Fish rearing, as an optional activity during storage period of water and without sacrificing crop production, can further strengthen economy of SFR based farming.
7. Crop diversification is possible in SFR based farming. Water efficient and remunerative crops, vegetables, fruits, tubers, oilseeds, pulses can be included in the crop plan, which can fulfil family's nutritional requirement.

# CHAPTER III

# STUDY AREA AND MICROWATERSHEDS

This chapter deals with the location, agroclimatic features, soils, crops, irrigation, production constraints, climatic water balance of study area and details of experimental microwatersheds investigated in the present study. The various data were collected from different sources and the relevant parameters were worked out during the course of investigation.

## 3.1 LOCATION

The study area lies in the Chhattisgarh state with three agro climatic zones viz. (i) Chhattisgarh plains (ii) Bastar plateau and (iii) Northern hills. In the present study, first two agroclimatic zones are covered. The study sites were in Raipur and Jagdalpur (Fig. 3.1) representing zone (i) and (ii) respectively.

One of the study site (21°16' latitude and 81°36' E longitude, 289.6 m above msl) is located at Labhandi farm IGAU in district Raipur. The other site, Jagdalpur (19°5' N latitude and 82° E longitude, 553, 35 m above msl) is located at Kumhrawand farm of IGAU in district Bastar. The first site is located in Kharoon river (a tributary of Mahanadi river) basin while the other site is located in Indravati river (a tributary of Godavari river) basin.

## 3.2 AGROCLIMATIC FEATURES

In general, the climate of the region is sub-humid with an average annual rainfall of about 1400 mm. However, there is considerable spatial variation of rainfall. The average rainfall over plains is 1422 mm and over plateau areas is 1538 mm with 64 and 73 average annual number of rainy days respectively. The stable rainfall period is higher in plateau

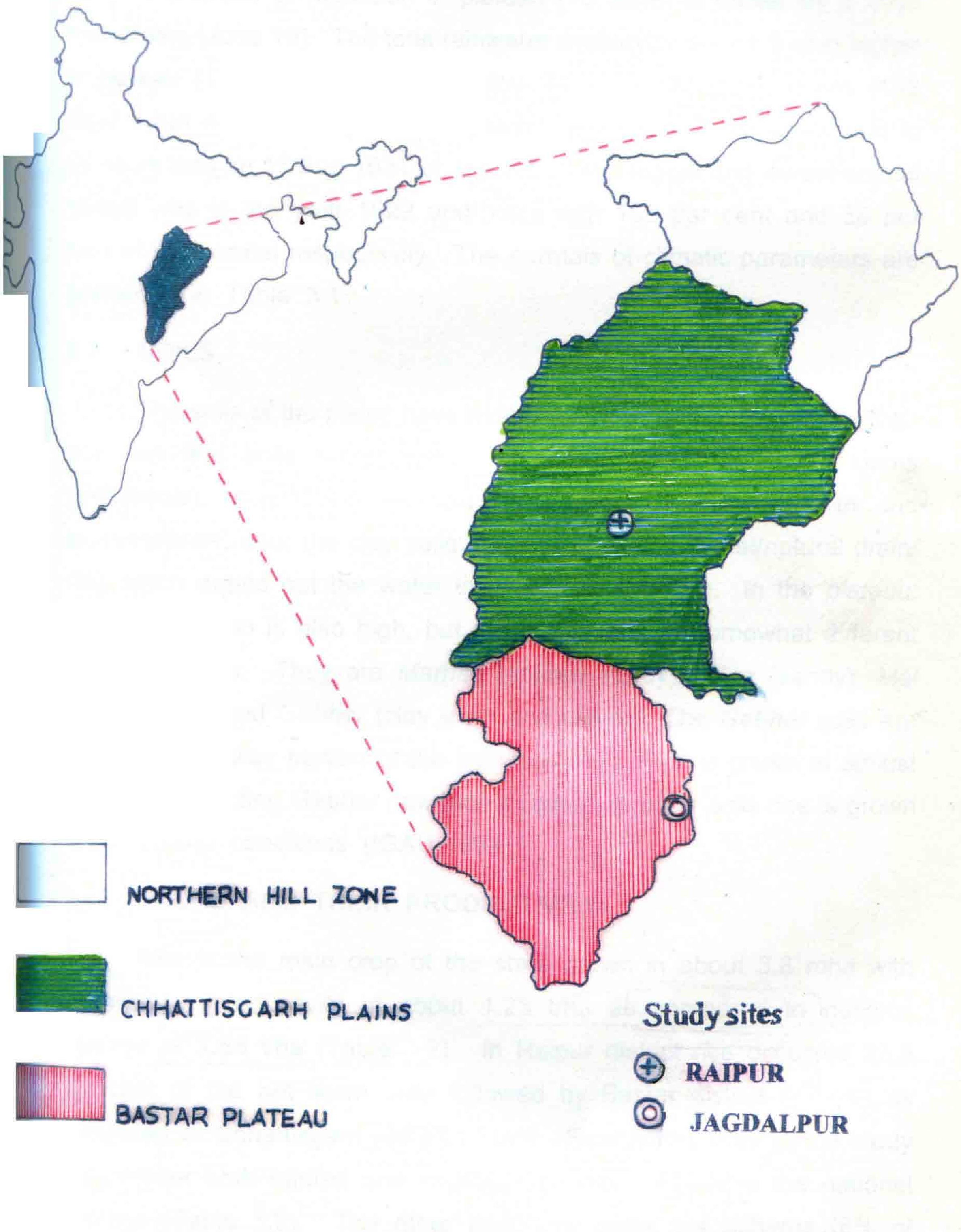



Fig. 3.1 Location of study sites in Chhattisgarh state with agroclimatic zones

areas as compared to plains. It is 84 days (22 Jun to 13 Sep.) at Raipur and 98 days (21 June to 26 Sep.) at Jagdalpur.

The onset of monsoon in plateau (10 June) is earlier by 5 days than plains (June 15). The total rainwater availability period is also higher in plateau (171 days; May 22 to Nov. 7) as compared to plains (143 days : Jun 1 to Oct 21). The highest rainfall (203.2 mm) recorded in 24 hours was on 15 Aug 1931 at Jagdalpur. The highet and lowest annual rainfall was in the year 1929 and 1923 with 153 per cent and 56 per cent of the normal respectively. The normals of climatic parameters are presented in Table 3.1

## 3.3 SOILS

The soils of the plains have wide vairability. In almost every village one can find soils ranging from lateritic (Entisols) to sandy loams (Inceptisols), clay loam (Alfisol) and clayey (vertisols). In the toposequence, after the clay soils, there is always a rivulet/natural drain/ *nala* which drains out the water to rivers (IGAU-1994). In the *plateau*, the soil variation is also high, but the soil texture is somewhat different from the *plains*. They are *Marhan* (coarse sandy), *Tikra* (sandy), *Mal* (sandy loam) and *Gabhar* (clay loam and clayey). The *Gabhar* soils are found in the valley portion of the toposequence. Rice is grown in almost all soils. Excepting *Gabhar* (low land bunded), in other soils rice is grown under upland conditions (IGAU-1994).

## 3.4 CROPS AND THEIR PRODUCTIVITY

Rice is the main crop of the state grown in about 3.8 mha with an average productivity of about 1.23 t/ha as compared to national average of 1.88 t/ha (Table 3.2). In Raipur district rice occupies 93.5 per cent of the net sown area followed by Bastar district (77.7%) as compared to Chhattisgarh (30.3%) State. Rice productivity in the study area, under both rainfed and irrigated condition are below the national average (Table 3.2). The other important crops are lathyrus (6% of

**Table 3.1 Monthly normal (30 years) of meteorological parameters of the study area**

| Month | Rainfall (mm) | Max. temp. (°C) | Min. temp (°C) | RH (%) | wind speed (km/hr) | Sunshine (hours) | Evapo-* ration (mm) |
|---|---|---|---|---|---|---|---|
| | | | | RAIPUR | | | |
| Jan | 7.9 | 27.2 | 11.7 | 84 | 3.5 | 8.1 | 3.1 |
| Feb. | 16.1 | 30.5 | 14.1 | 74 | 4.4 | 9.2 | 4.8 |
| Mar | 23.5 | 35.2 | 17.9 | 59 | 5.4 | 9.1 | 7.1 |
| Apr | 15.1 | 39.9 | 22.9 | 47 | 7.4 | 9.4 | 10.3 |
| May | 21.3 | 41.9 | 26.1 | 43 | 8.7 | 9.0 | 12.5 |
| June | 203.7 | 37.3 | 26.2 | 69 | 11.5 | 5.2 | 9.0 |
| July | 354.4 | 31.1 | 24.3 | 88 | 11.1 | 3.5 | 4.7 |
| Aug. | 332.5 | 29.9 | 23.9 | 90 | 10.3 | 3.4 | 3.5 |
| Sep | 225.6 | 31.0 | 24.0 | 90 | 6.6 | 5.9 | 3.7 |
| Oct | 57.6 | 31.3 | 21.1 | 88 | 3.6 | 8.1 | 3.7 |
| Nov. | 9.1 | 29.3 | 14.7 | 86 | 3.3 | 8.9 | 3.4 |
| Dec. | 2.6 | 26.1 | 10.7 | 82 | 3.2 | 9.0 | 3.0 |
| **Total/Av** | **1269.4** | **32.6** | **19.9** | **75** | **6.6** | **7.3** | **5.8** |
| | | | | JAGDALPUR | | | |
| Jan | 9.9 | 28.5 | 11.0 | 73 | 2.8 | 8.1 | 3.0 |
| Feb. | 22.6 | 31.0 | 14.3 | 66 | 3.9 | 9.3 | 4.1 |
| Mar | 14.0 | 34.7 | 18.4 | 54 | 4.5 | 9.2 | 5.7 |
| Apr. | 49.5 | 36.9 | 22.2 | 54 | 5.7 | 8.5 | 6.2 |
| May | 60.5 | 38.3 | 24.6 | 53 | 6.6 | 8.2 | 6.4 |
| June | 232.7 | 33.5 | 23.9 | 71 | 7.2 | 7.9 | 5.2 |
| Jul | 384.6 | 28.1 | 22.2 | 86 | 9.1 | 3.2 | 2.5 |
| Aug | 391.4 | 28.4 | 22.2 | 86 | 7.8 | 2.4 | 2.3 |
| Sep. | 261.4 | 29.5 | 22.3 | 85 | 5.6 | 3.4 | 2.9 |
| Oct | 110.0 | 29.5 | 19.9 | 80 | 3.7 | 6.1 | 3.2 |
| Nov. | 30.0 | 28.1 | 14.7 | 76 | 3.0 | 7.1 | 3.1 |
| Dec. | 3.8 | 27.4 | 11.3 | 76 | 2.5 | 7.6 | 2.8 |
| **Total/Av.** | **1570.4** | **31.2** | **18.9** | **72** | **5.2** | **6.7** | **3.0** |

* Average of 15 and 22 years at Jagdalpur and Raipur respectively.

cropped area in Raipur) and minor millets (15.6% of cropped area in Bastar), beides smaller area under soybean, pigeonpea, vegetables, fruits and tuber crops. Cropping intensity is low (129% in Bastar district and 112% in Raipur district) due to lack of irrigation facilities for a second crop.

## 3.5 IRRIGATION

About 22.3 per cent of croped area in Chattisgarh is irrigated (Table 3.2) which is dependent on accumulation of rainwater in reservoirs and in the event of early withdrawal of monsoon, the water is used to give life saving irrigation to crops. The availability of irrigation, depends on adequacy of rains. The uncertainty on availability of water at the time of sowing forces the farmers to go for broadcast *biasi* system in preference to transplanting even in irrigated area (IGAU-1994). The irrigation system in the region is designed to avert famine rather than for productive agriculture. The percentage coverage of rice under irrigation at Raipur (47.5) is comparable to the national figure (49.8) while in Bastar this is extremely low (3.1). Among the different sources of irrigation, canal and tank irrigation are dominant at Raipur and Bastar respectively (Table 3.2).

## 3.6 PRODUCTION CONSTRAINTS

Among the physical factors, rainfall is the most important one as the onset of monsoon at the initial stage, break in monsoon during crop growth stage and withdrawal of monsoon at the terminal stage determine the productivity of rice in this region. Even the 22 per cent area under irrigation is also dependent upon the rainfall intensity and distribution in the catchment area, which determines the runoff for both medium and minor irrigation projects.

Farmers in this region generaly grow long duration (145 days) photosensitive tall rice varieties. These varieties flower by mid-October and mature by mid-Novembr, while monsoon ususally withdraws by

**Table 3.2 Agricultural characteristics of the study area in comparison to the state and country (1997-98)**

| Agricultural characteristics | Raipur* district | Bastar* district | Chhattisgarh* State | National** |
|---|---|---|---|---|
| **LAND HOLDINGS** | | | | |
| (i) Marginal (<1 ha) As % of total | | | | |
| No. | 55.9 | 28.3 | 51.3 | 59.4 |
| Area | 16.5 | 4.3 | 12.4 | 15.1 |
| Average size, ha | 0.45 | 0.47 | 0.43 | 0.39 |
| (ii) Small (1-2 ha) As % of total | | | | |
| No. | 21.6 | 22.4 | 21.0 | 18.8 |
| Area | 20.3 | 10.8 | 16.9 | 17.4 |
| Average size, ha | 1.43 | 1.49 | 1.44 | 1.43 |
| (iii) Average size of all holdings, ha | 1.50 | 3.10 | 1.79 | 1.57 |
| **IRRIGATION** | | | | |
| Cropped area covered by (%) | | | | |
| Canals | 37.4 | 0.8 | 16.9 | 11.6 |
| Tanks | 2.7 | 1.0 | 1.4 | 2.1 |
| Wells | 1.9 | 0.3 | 1.0 | 6.3 |
| Others | 4.0 | 0.7 | 3.0 | 10.6 |
| Total | 46.0 | 2.8 | 22.3 | 30.6 |
| **RICE** | | | | |
| (i) As % of cropped area | 93.5 | 77.7 | 80.3 | 30.3 |
| (ii) Irrigation coverage of rice area, (%) | 47.5 | 3.1 | 28.1 | 49.8 |
| (iii) Rice yield - t/ha | | | | |
| Rainfed | 1.17 | 0.77 | 0.93 | 1.25 |
| Irrigated | 1.88 | 1.90 | 1.58 | 2.64 |
| Average | 1.30 | 1.10 | 1.23 | 1.88 |
| **CROPPING INTENSITY %** | **129** | **112** | **124** | **132** |

** Government of India (1998)
* Government of Madhya Pradesh (1998)

mid-september. Thus terminal drought (at flowering and grain filling) is a recurring feature in this region and the success of the rice crop under rainfed conditions depends upon the October rainfall, occurring due to cyclonic activity.

Increased population pressure has forced farmers to extend rice cultivation in marginal and sub marignal lands (shallow depth and high percolation rate) where frequent moisture stresses during crop growth result in poor yield.

## 3.7 CLIMATIC WATER BALANCE

The climatic water balance for the study area was worked out and is shown in Fig. 3.2. Monthly water surplus was estimated by climatic water balance computations using Thornthwaite's book keeping procedure. Soil moisture reaches field capacity often in the month of June itself in most of the case and thereafter the actual ET becomes equal to PET. Under such a scenario, in high rainfall areas, the surplus rainwater is lost either through runoff or percolation, depending on the terrain. The details are discussed in Chapter VI. The water availability periods, based on humid and moist periods (humid period : R>PET, moist period : PET>R>PET/2, where R is the rainfall) were worked out. Growing season soil moisture was worked out based on soil moisture at field capacity. Availability of water for post-rice crop was worked out based on average plant available residual soil moisture. The resutls are presented in Chapter VI.

## 3.8 EXPERIMENTAL MICROWATERSHEDS

The details of the experimental microwatersheds investigated for the present study are given below :

### 3.8.1 Agro-ecological Region

Four microwatersheds were taken up for detailed investigation, two each at Raipur and Jagdalpur. Table 3.3 depicts the agroecological

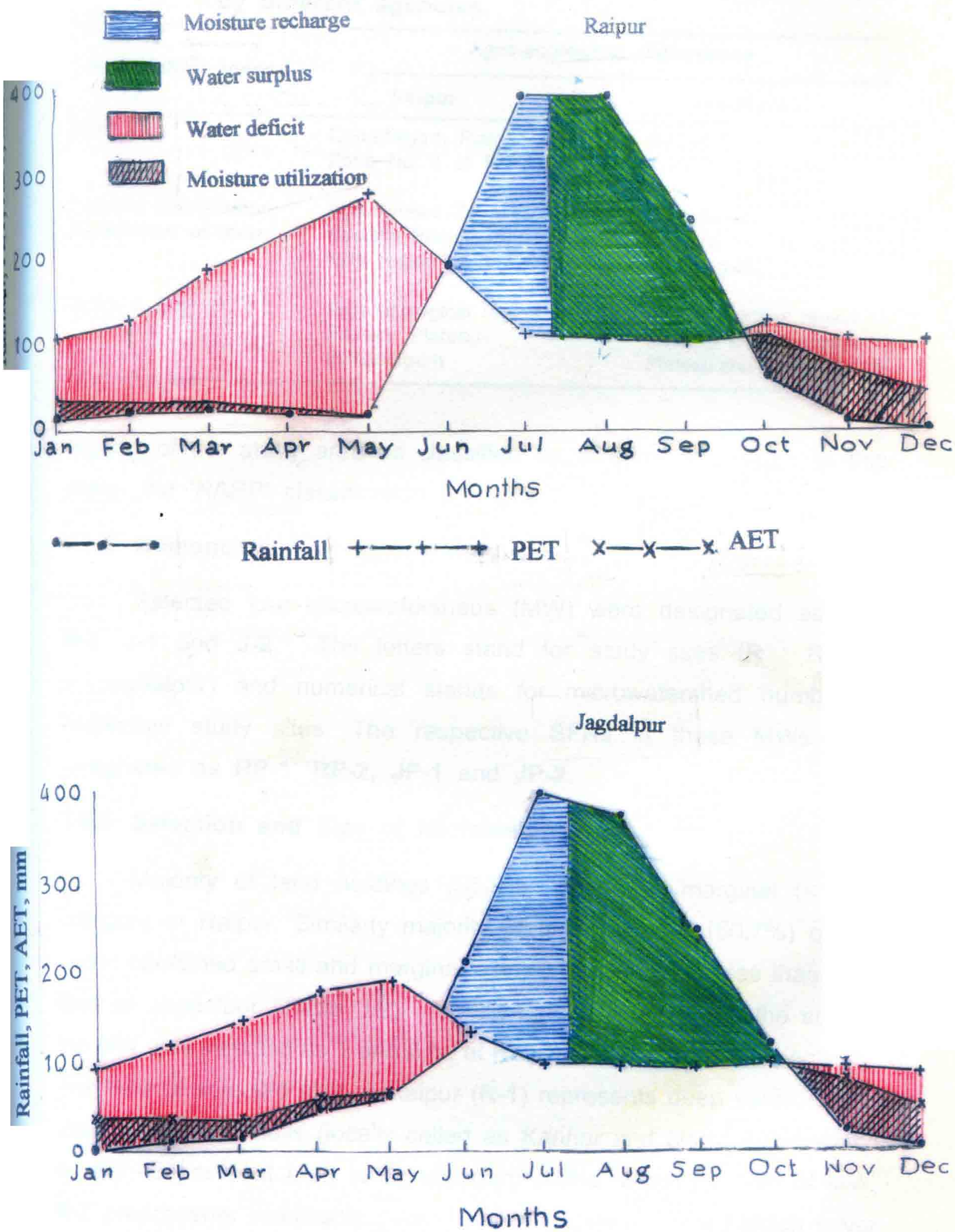



Fig. 3.2 Climatic water balance of study sites

Table 3.3 **Agro-ecological regions of the study area as classified by different agencies.**

| Classification agency | Agro-ecological region/zone | |
|---|---|---|
| | Raipur | Jagdalpur |
| NARP | Chhattisgarh Plains<br>Zone No. 1 of M.P. | Bastar Plateau<br>Zone No. 2 of M.P. |
| Planning Commission<br>Government of India | Agroclimatic Zone 7<br>Eastern Plateau &<br>Hills region | Agroclimatic Zone 7<br>Eastern Plateau &<br>Hills region |
| NBSS & LUP | Agro-ecological region 11<br>Eastern Plateau-<br>Chhattisgarh | Agro-ecological region 12<br>Eastern Chhotanagpur<br>Plateau and Eastern Ghats |

regions of the study area as classified by different agencies. In this study, the 'NARP' classification of regions was adopted.

### 3.8.2 Nomenclature of Microwatersheds

Selected four microwatersheds (MW) were designated as **R-1, R-2**, **J-1** and **J-2**. The letters stand for study sites (**R** : Raipur; **J** :Jagdalpur) and numerical stands for microwatershed number at respective study sites. The respective SFRs in these MWs were designated as **RP-1, RP-2, JP-1** and **JP-2**.

### 3.8.3 Selection and Size of Microwatersheds

Majority of land holdings (55.9%) belong to marginal (<1 ha) category at Raipur. Similarly majority of land holdings (50.7%) comes under combined small and marginal category possessing less than 2 ha land at Jagdalpur (Table 3.2). Considering land holdings, the size of the MW was selected as 1 and 2 ha at Raipur and Jagdalpur respectively. The field of selected MW at Raipur (**R-1**) represents deep vertisols and associated vertic soils (locally called as *Kanhar* and *Dorsa* soils) which covers 45 per cent area in Chhattisgarh plains, while the field of MW, **R-2** prepresents inceptisols (locally called as *Matasi* soils) which cover about 40 per cent area in the Chhattishgarh plains region.

Bunded rice fields were considered as MW. These artificially made MW were isolated hydrologically (as far as surface runoff is concerned) and independent from upstream (by bunding and cutoff drain) and surrounding area (by bunding). No outside runoff entered into experimental MW. It was tried that all the runoff in MW be either conserved or stored, in ponds. However, excess runoff, if any, was allowed to drain out safely.

### 3.8.4 Soils

Detailed field and laboratory investigatioins were carried out to find various soil physical and chemical properties (Table 3.4 and 3.5). Cumulative infiltration was determined under two conditions viz. barren land and ploughed land at Jagdalpur. Similarly basic infiltration rate of different pond strata was determined. In order to see the long term effect of SFR based intensive farming on infiltration, the infiltration study was further conducted in the year 2000. The soils of MWs have special problems viz. hardening, crusting, loss of water and nutrients, acidity, poor aggregation and low water retentivity, resulting in restricted root growth. In general, the MW area falls under the land capability class IIs and irrigability class 2.

### 3.8.5 Topography

During 1999-2000, topographic survey, of MWs **R-1** and **R-2**, was conducted. The topographic map of these MWs are shown in Fig. 3.3 and 3.4. The topographic map of **J-1** and **J-2** were available in the MWs (Sahu, 1996) and are shown in Fig. 3.5 and 3.6. All the MWs were more or less rectangular in shape with general slope varying between 0.4 to 1.05 per cent. The general slope is from South to north **(J-1, J-2)**, north to south **(R-1)** and east to west **(R-2)**. There are cross slopes of 0.08 **(J-1)** and 0.20 **(J-2)** from west to east, 0.15 per cent from east to west **(R-1)**, 0.05 per cent from south to north **(R-2)**. In MW **J-1** and **J-2**, SFR lies on the lowet part such that its drainage contributing area of 1.75 ha lies in the u/s side. Such SFRs have topographical

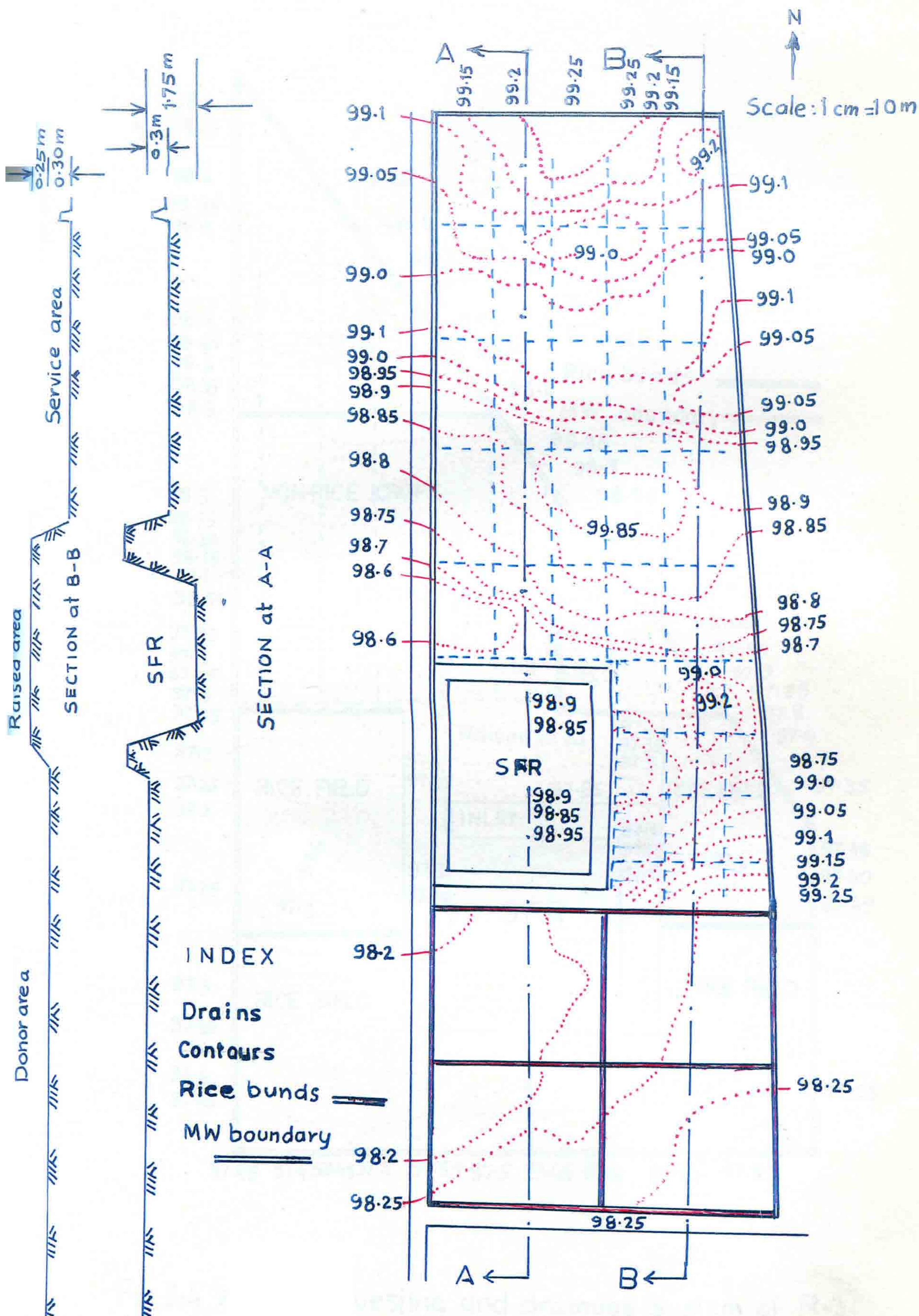



Fig 3.3 Water harvesting and drainage system of R-1

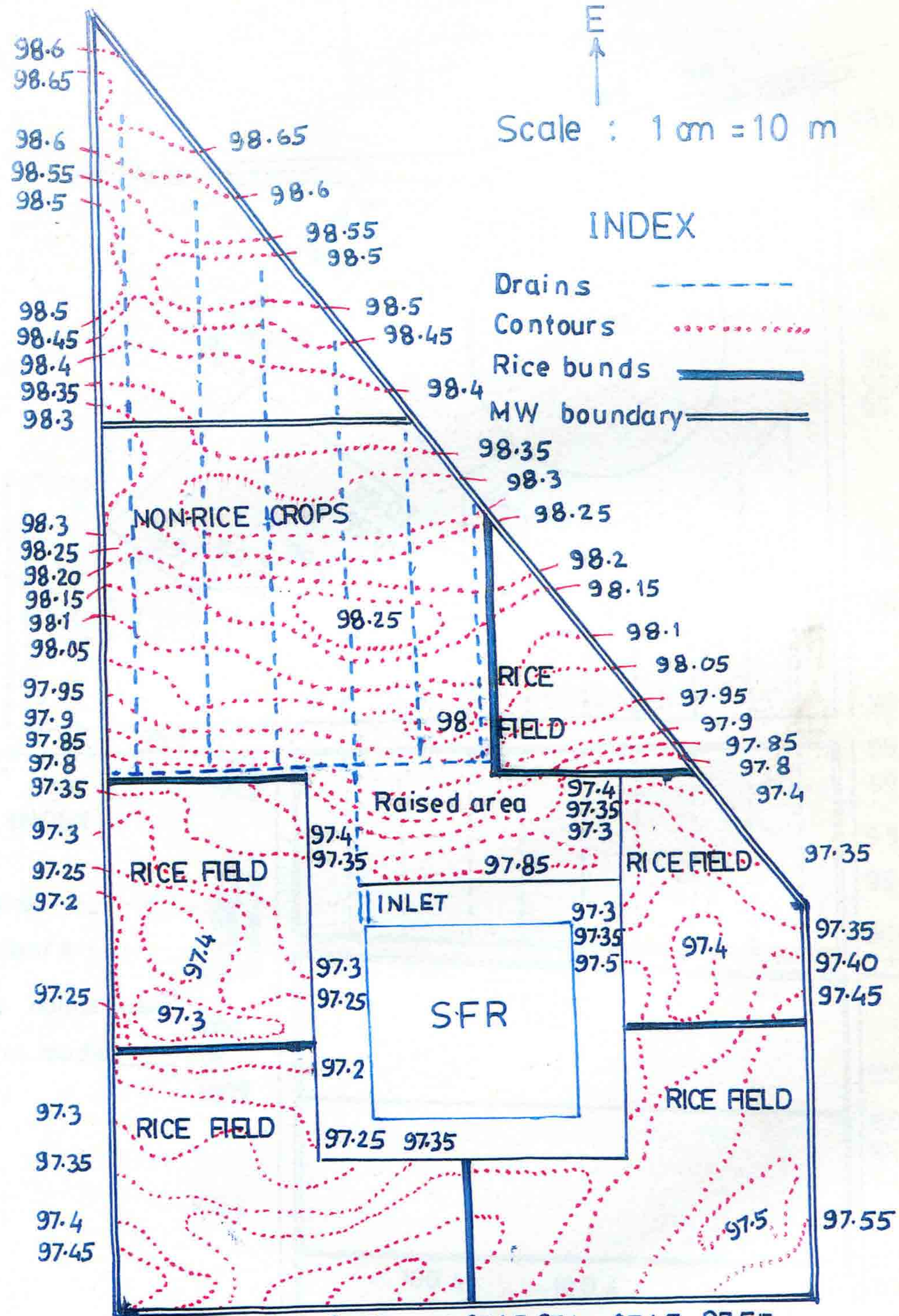



Fig 3.4 Water harvesting and drainage system of R-2

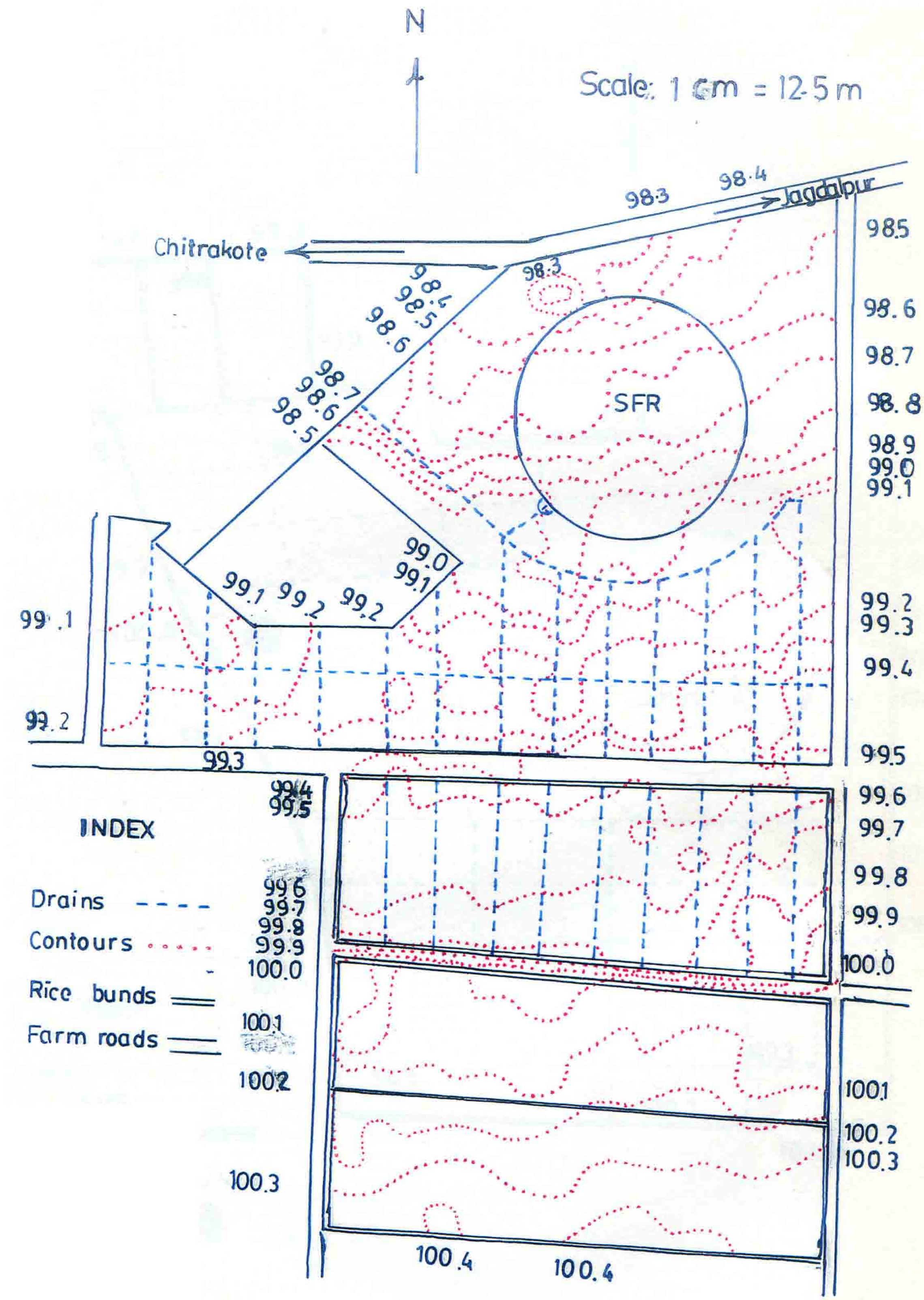



Fig 3.5 Water harvesting and drainage system of J-1

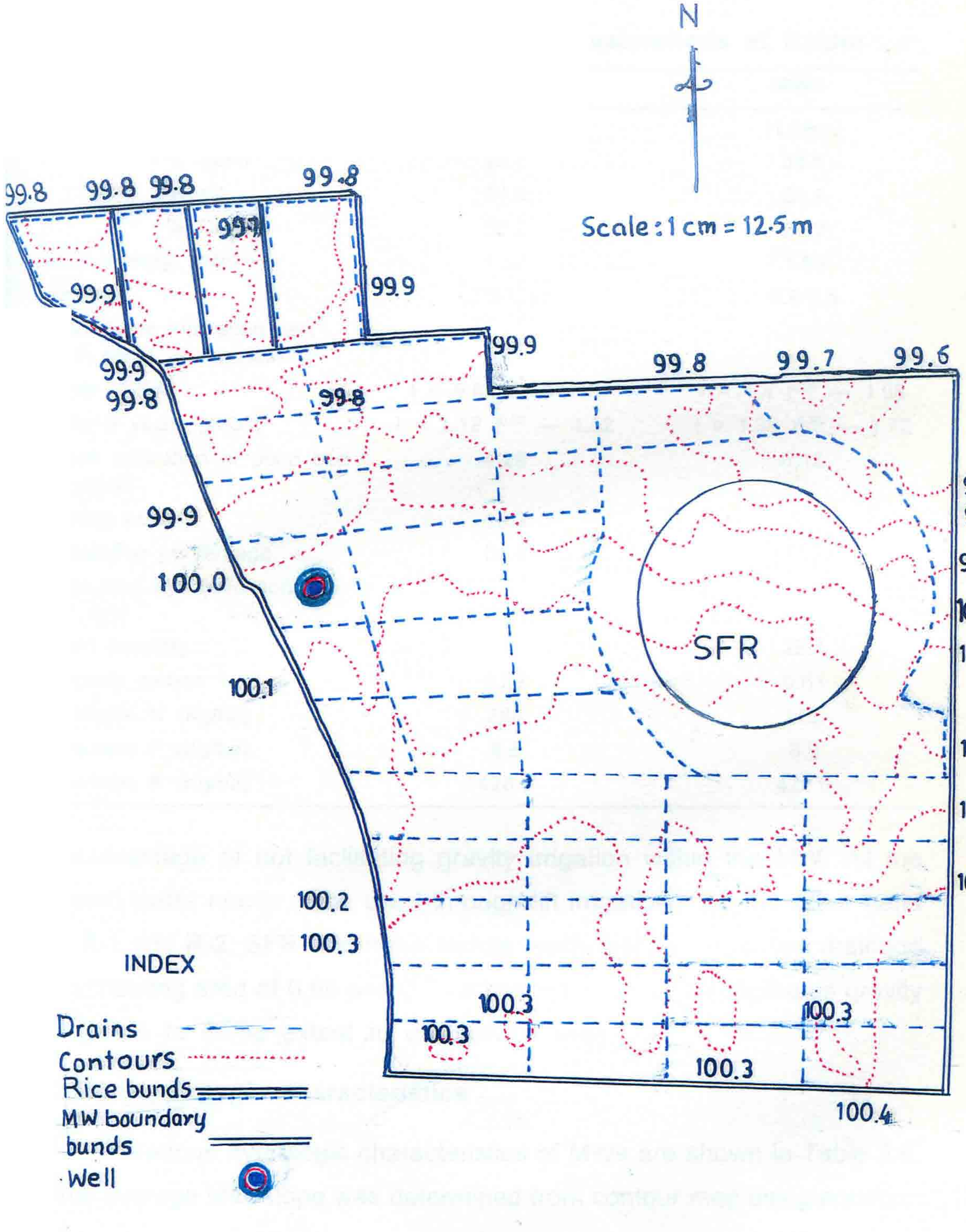



Fig. 3·6 Water harvesting and drainage system of J-2

**Table 3.4 Soil characteristics of microwatersheds at Raipur**

| Soil Characteristics | MW1 | MW2 |
|---|---|---|
| Texture | Clayey | Loam |
| % Sand | 25.2 | 38.6 |
| % silt | 24.6 | 35.4 |
| % Clay | 50.2 | 25.0 |
| Bulk density, $g/cm^3$ | 1.52 | 1.55 |
| Soil pH | 7.3-6.8 | 6.8-6.6 |
| Cumulative infiltration rate (I in cm, t in minutes) | | |
| Initial (1994) | $I = 9.8\ t^{0.31} — 1.43$ | $I = 1.4\ t^{0.28} — 1.68$ |
| After 6 years (2000) | $I = 1.12\ t^{0.36} — 1.52$ | $I = 1.39\ t^{0.36} — 1.72$ |
| Basic infiltration of pond bed (cm/day) | 4.29 | 5.13 |
| Wilting point | 13.3 | 5.6 |
| Saturation percentage | 54.4 | 47.8 |
| Saturated hydraulic conductivity (m day) | 0.62 | 0.65 |
| Field capacity | 39.9 | 28.7 |
| Organic carbon % | 0.62 | 0.51 |
| Available N (Kg/ha) | 288 | 252 |
| Available P (Kg/ha) | 8.8 | 8.0 |
| Available K (Kg/ha) | 428.0 | 422.6 |

disadvantage of not facilitating gravity irrigation within the MW. All the stored water needs to be used through lift irrigation. On the other hand in **R-1** and **R-2**, SFR lies in the middle, such that its respective drainage contributing area of 0.66 and 0.7 ha lies in the u/s and it facilitates gravity irrigation to some extent to d/s service area.

### 3.8.6 Hydrologic characteristics

Various hydrologic characteristics of MWs are shown in Table 3.6. The average MW slope was determined from contour map using equation 3.1.

$$X_2 = MN/A \qquad ..... 3.1$$

Where M is the total length of contour within the MW in meter
N is the contour interval in meters
A is the size of the MW in square meters.

**Table 3.5 Soil Characteristics of microwatersheds at Jagdalpur**

| Soil Characteristics | MW1 | MW2 |
|---|---|---|
| Texture | Clayey | Loam |
| % Sand | 30.83 | 35.16 |
| % Silt | 39.40 | 38.44 |
| % Clay | 29.70 | 26.40 |
| Bulk density, gm/cm$^3$ | 1.58 | 1.57 |
| Soil pH | 5.6-6.0 | 5.8-6.3 |
| Cumulative infiltration rate (I in cm, t in minutes) | | |
| Initial (1990) | | |
| Barren Land | $I = 1.16\ t^{0.20} - 1.03$ | $I = 0.56\ t^{0.37} - 0.30$ |
| Ploughed land | $I = 1.52\ t^{0.40} - 0.61$ | $I = 5.40\ t^{0.20} - 4.08$ |
| After 2 years (1992) | | |
| Barren land | $I = 1.01\ t^{0.35} - 0.82$ | $I = 0.84\ t^{0.35} - 0.69$ |
| Ploughed land | $I = 1.43\ t^{0.43} - 0.96$ | $I = 3.49\ t^{0.25} - 1.65$ |
| After 10 years (2000) | | |
| Barren land | $I = 0.98\ t^{0.42} - 0.48$ | $I = 1.02\ t^{0.42} - 0.76$ |
| Ploughed land | $I = 1.34\ t^{0.48} - 1.24$ | $I = 1.15\ t^{0.51} - 1.18$ |
| Basic infiltration rate (cm/day of pond Strata) | | |
| 0 - 50 cm | 3.82 | 3.68 |
| 50 - 100 cm | 3.68 | 3.12 |
| 100 - 150 cm | 5.12 | 4.08 |
| 150 - 200 cm | 5.31 | 4.12 |
| 200 - 250 cm | 6.15 | 3.88 |
| 250 - 300 cm | 6.42 | 4.03 |
| Drainable porosity, % | 26.60 | 27.90 |
| Saturation percent | 40.40 | 40.50 |
| Saturated hydraulic conductivity (m/day) | 0.69 | 0.63 |
| Field capacity % | 37.50 | 36.8 |
| Organic carbon, % | 0.56 | 0.40 |
| Available N (kg/ha) | 270 | 256 |
| Available P (kg/ha) | 12.7 | 13.4 |
| Available K (Kg/ha) | 424 | 314 |

## Table 3.6 Hydrologic characteristics of microwatersheds

| Parameters | Microwatersheds | | | |
|---|---|---|---|---|
| | R-1 | R-2 | J-1 | J-2 |
| Area, ha | 1.05 | 1.04 | 2.0 | 2.0 |
| Land Slope, (%) | 0.4 | 0.62 | 1.05 | 0.4 |
| Soil type | Vertisol Clayey to clay loam | Inceptisol Clay-loam, Underlain by Impermeable hard strata | Alfisol, Clay-loam, acidic, crusting and hardening | Alfisol clay - loam, loam acidic, crusting and hardening |
| Infiltration (mm/ hr) | Very low 1.86 | Very low 2.28 | Very low 2.12 | Very low 2.22 |
| Land use | April, May : Poor Fallow Remaining months : straight row crops | April, May : Poor fallow Remaining months : straight row crops | April, May : Poor fallow Remaining months: straight row crops | April May : Poor falow. Remaining month : straight row crops |
| Soil conservation Measures | Partily bunded, well laid out drainage system. Water harvesting pond | partly bunded, General drainage Water harvesting Pond | Partly bunded, well laid out drainage system. Water harvesting pond | Partly bunded, well laid out drainage system. Water harvesting pond |
| Major Crops | Monsoon : Rice, soybean, groundnut, pigeonpea Post Monsoon : gram, mustard, vegetables | Monsoon : Rice, soybean (small area), pigeon pea (long duration, extended to post-monsoon season). Post monsoon : Gram, mustard, vegetbales | Monsoon : Rice, Pigeon pea (short duration), groundnut, soybean, tapioca, intercrops, Post monsoon : pigeon pea (ratoon), gram, mustard, vegetables | Monsoon : Rice, pigeon-pea (short duration), groundnut, soybean, vegetables. Post monsoon ; Pigeon pea (ratoon) mustard, gram, vegetables |
| Monsoon rainfall | | | | |
| June | 185.3 | 185.3 | 256.7 | 256.7 |
| July | 306.4 | 306.4 | 346.8 | 346.8 |
| August | 335.1 | 335.1 | 354.7 | 354.7 |
| September | 180.5 | 180.5 | 194.3 | 194.3 |
| October | 46.6 | 46.6 | 81.7 | 81.7 |
| Total | 1053.8 | 1053.8 | 124.2 | 1234.2 |
| Hydrologic soil group | D* | D* | D* | D* |

* High runoff potential

### 3.8.7 Hydrological Behaviour of Microwatersheds

Daily record of gauged runoff of all the MWs for the period of 6 years (**J-1, J-2**: 1988-1993), 7 years (**R-1** : 1990-1996) and 5 years (**R-2** : 1992-1996) were collected from previous research (Pal *et al.,* 1996 and Sahu, 1999). It was planned to record one more year recent data of runoff in experimental MWs. Accordingly in 1999, the mosoon runoff data were recorded at Raipur (**R-1, R-2**) for both the MWs. The same was not possible at Jagdalpur, another study site, due to leasing of ponds and laying out of underground pipelines for irrigation, in the MWs. However, daily accretion and loss of water in SFRs were recorded.

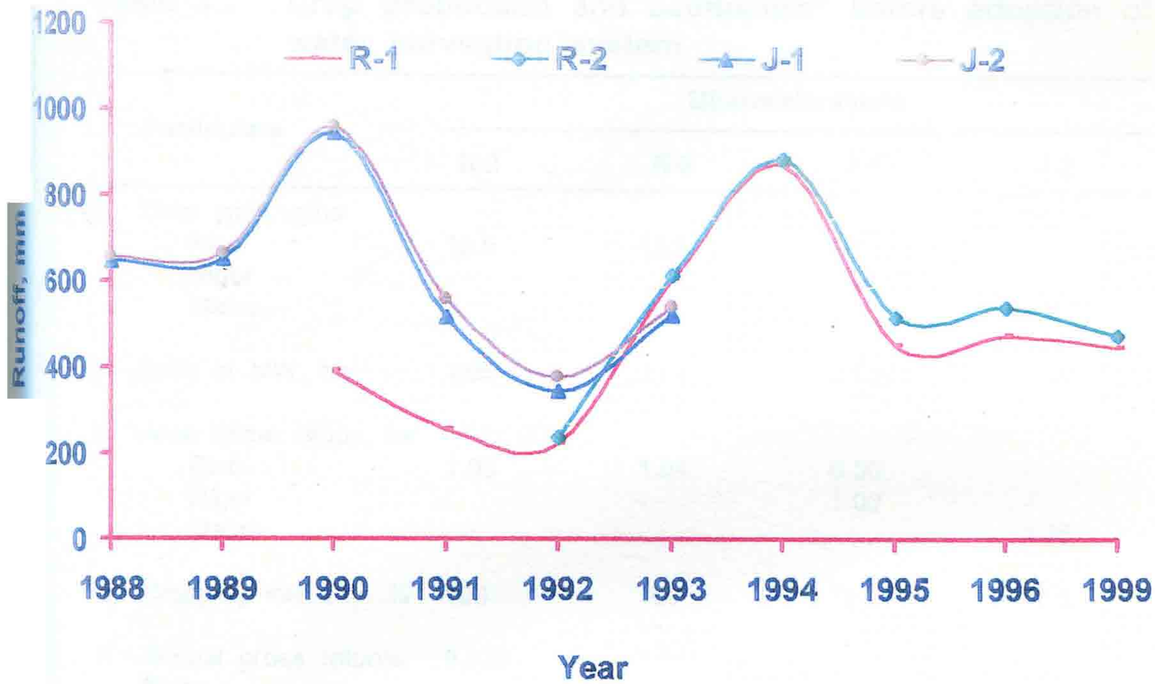
In this way, a total of 8 years (**R-1**) and 6 years (**R-2, J-1, J-2**) data of daily runoff were used in the present investigation (Fig. 3.7).

### 3.8.8 Production Situations

Crop production scenario in MWs before adoption of water harvesting system was quite disappointing. In **R-1** and **R-2** with comparatively fertile soil, rice was grown during monsoon season, no second crop was taken during post-monsoon season due to deficient soil moisture. However some farmers in similar soils grew *lathyrus* (broadcast in rice field one month before harvest), utilising residual soil moisture. Since no economical yields are expected, it is used as fodder for their animals. The monsoon rice yield was poor with 15.5 and 13.5 q/ha grain. The cropping intensity, thus, only 100 per cent in the monocropped rice system. With the data available from IGAU, Raipur, the economics of crop production was worked out for **R-1** and **R-2** at the current price levels (1999-2000) of inputs, power, labour and wholesale rate of produce (Table 3.7).

In MWs **J-1** and **J-2** with poor and degraded soils, the crop production scenario was still worse, except some portion of **J-1** where rice was grown. Rice yield in **J-1** was 16.7 q/ha. The oil seed crop niger was grown in major portion at the last phase of monsoon season

a. Seasonal Runoff




b. Monthly Runoff

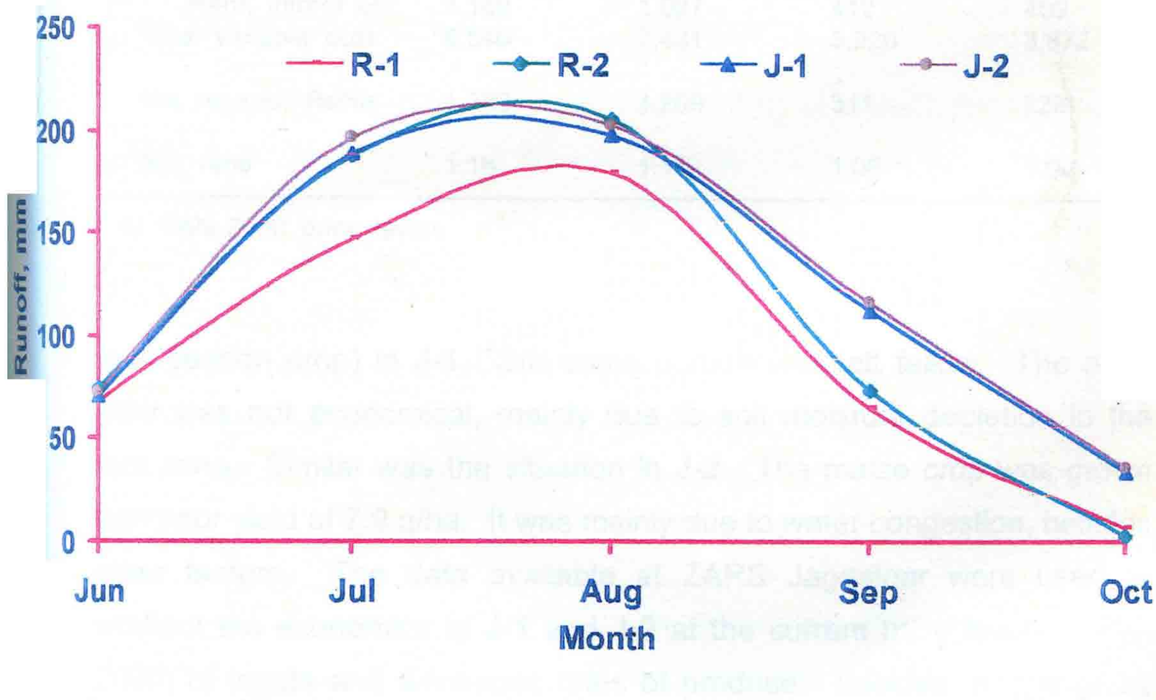



Fig 3.7 Observed runoff in microwatersheds

**Table 3.7 Crop production and economics* before adoption of water harvesting system**

| Particulars | Microwatersheds | | | |
|---|---|---|---|---|
| | **R-1** | **R-2** | **J-1** | **J-2** |
| 1. Crop yield, q/ha | | | | |
| Rice | 15.5 | 13.5 | 16.7 | - |
| Niger | - | - | 1.8 | - |
| Maize | - | - | - | 7.9 |
| 2. Area of MW, ha | 1.05 | 1.04 | 2.00 | 2.00 |
| 3. Area under crops, ha | | | | |
| Rice | 1.05 | 1.04 | 0.50 | - |
| Niger | - | - | 1.00 | - |
| Maize | - | - | - | 1.25 |
| 4. Cropping intensity, % | 100 | 100 | 75 | 62.5 |
| 5. Annual gross returns Rs/ha | 9,920 | 8,640 | 4,231 | 4,098 |
| 6. Variable cost, Rs/ha | | | | |
| Labour and Power | 5,886 | 4,904 | 3,090 | 2,798 |
| Material inputs | 1,486 | 1,500 | 419 | 665 |
| Rent, interet etc. | 1,169 | 1,027 | 412 | 409 |
| Total variable cost | 8,540 | 7,431 | 3,920 | 3,872 |
| 7. Net returns, Rs/ha | 1,380 | 1,209 | 311 | 226 |
| 8. B/C ratio | 1.16 | 1.16 | 1.08 | 1.06 |

* At 1999-2000 price levels

(mid season crop) in **J-1**. Still some portion was left fallow. The niger yield was not economical, mainly due to soil moisture depletion in the root zone. Similar was the situation in **J-2**. The maize crop was grown with poor yield of 7.9 q/ha. It was mainly due to water congestion, besides other factors. The data available at ZARS Jagdalpur were used to workout the economics of **J-1** and **J-2** at the current price levels (1999-2000) of inputs and wholesale rates of produce. Besides annual gross returns, total variable cost and net returns, the B/C ratios of all the MWs with rate of returns of various inputs were worked out and is presented in Table 3.7

CHAPTER IV

# THEORETICAL CONSIDERATIONS

Since time immemorial water harvesting has been a practice to meet water demand in drought prone areas. Agricultural development, particularly during the past few decades, witnessed clear demarcation in terms of rainfed and irrigated agriculture. The success of rainfed agriculture centres around water harvesting to meet water demands for irrigation and drought mitigation. In this area, assessment of water availability in terms of runoff in the micro water sheds (MWs) is essential for designing appropriate water storage structures. There are several methods of runoff estimation and four of them were examined with a view to select the most appropriate one for use in this study.

## 4.1 CONSERVATION FACTOR APPROACH (CF)

The concept of conservation factor (CF) of a watershed was first used by Singh (1987) and later by Bajpai (1999) for the assessment of runoff. In this method, monthly/monsoon, season/annual, rainfall, land use, conservation measures, soil type and slope of the watershed are the input parameters. Potential of watershed, in producing runoff and soil loss, is related to a discrete number called 'conservation factor' (CF). The CF is a function of land use, conservation measures and soil type in the watershed. It is a dimensionless number.

### 4.1.1 The Concept of CF

Besides rainfall, the other major factors which govern the runoff from a MW are land use, conservation measures and soil type. These factors have their individual potential of affecting the runoff producing process. These factors are listed in descending order of their runoff retarding potential and numerical values are assigned to these factors considering their relative influence such that the more influencing factors in retention of rainfall get higher value. Areas under different land uses from A1 to An, conservation measures C1 to Cn and soil type from NS1 to NSn are combined into single weighted number through equation 4.1.

$$CF = \frac{A1\ (NL1 + NC1+NS1)+............+An(NLn+NCn+NSn)}{A} \quad .....4.1$$

where A1..........An : area under assigned to land uses

NL1..........NLn : numbers assigned to land uses

NC1..........NCn : numbers assigned different conservation measures

NS1..........NSn : numbers assigned different soil types.

In this way CF shows the relative strength of watershed to runoff retardation potential. Larger the CF, lesser the runoff and smaller the CF, higher the runoff.

### 4.1.2 Development of Runoff Models

Runoff models were developed for monthly monsoon and annual runoff estimation using water yield producing factor and observing water yields as inputs. The water yield producing factor is defined as

$$X = (X_1 * X_2) / CF \quad ........... 4.2$$

where X is the water yield producing factor,

$X_1$ is the rainfall, mm.

CF is the conservation factor.

$X_2$ is the land slope in per cent.

## 4.2 CURVE NUMBER TECHNIQUE (CN)

USDA-SCS curve number method is one of the most widely used methods for runoff estimation from small watersheds (Pathak *et al.,* 1989). The CN is simple and provides reasonable accurate results under certain conditions (Williams and La seur, 1976). Its biggest advantage is that it requires few inputs which are generally available. Original CN was developed for individual rainfall events, however, researchers are using now daily rainfall values with appropriate changes. Besides rainfall, it requires land use hydrological soil group and antecedent moisture condition (AMC) of watershed as input. In this method, the potential maximum retention storage of watershed is related to a discrete number (CN) which is a function of land use, different land treatments, AMC of watershed and soil type. CN is dimensionless and its value varies from 0 to 100. However, this method has following major drawbacks (Williams and La seur, 1976; Hawkins, 1978) :

(i) The model does not take into consideration the effects of surface roughness. It provides soil profile water retention on the basis of soil type only.

(ii) Because a discrete rather than a continuous relationship between CN and soil moisture content is used in the original model, small changes in water content sometimes result in sudden shifts in CN which then give unrealistic quantum jumps in the calculated runoff.

(iii) Accurate selection of CN is very difficult. Since upto 23 mm rainfall, runoff is more sensitive to CN than to rainfall. Any inaccuracy in CN, therefore, may lead to unrealistic runoff, estimation.

(iv) There is no consideration of slope and area of watershed.

### 4.2.1 Development of New Criteria for AMC in *Plateau* Areas

Despite the above drawbacks, CN may apply suitably in *plains* (Raipur) but may not give desirable results in *plateau* (Jagdalpur) areas of Chhattisgarh where slope is a dominating feature affecting runoff. In an artificial MW separated hydrologically from u/s slopy area grown with paddy with cutoff drains and bunds (Fig 4.1) the sub surface flow continues to as usual and changes moisture regimes. This enhanced moisture regimes can not be described by the existing AMC's limits.

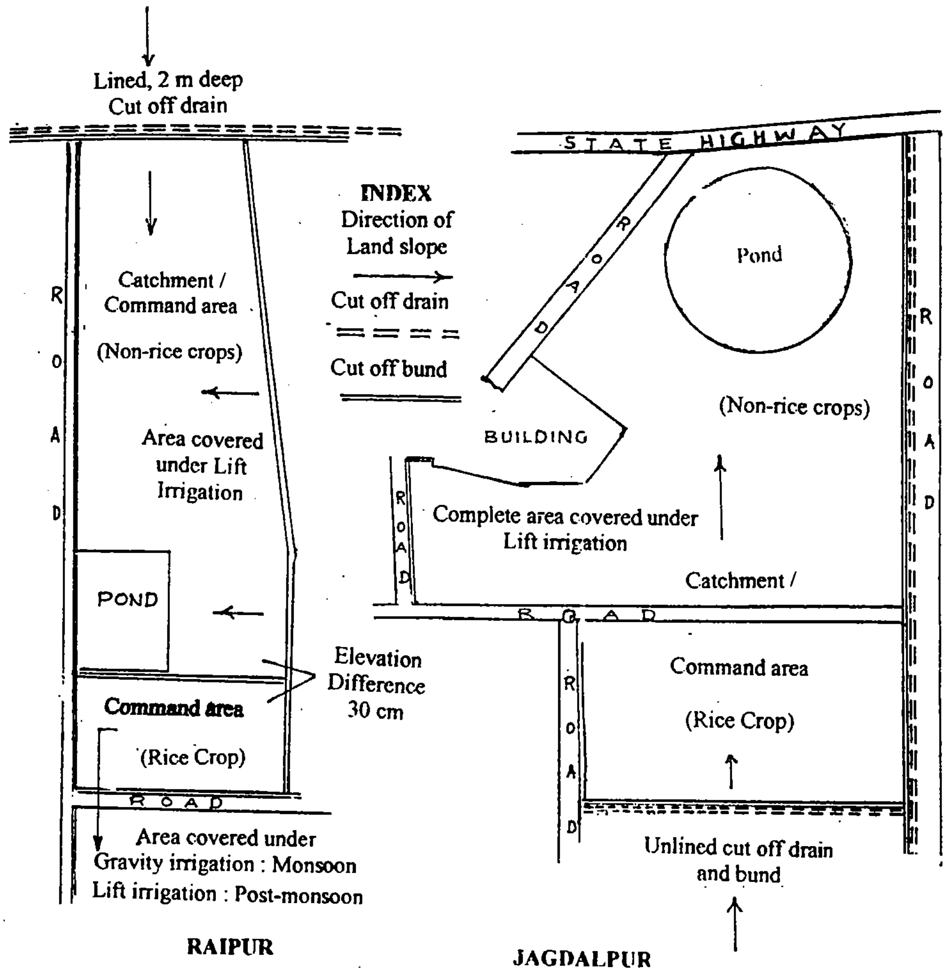



Fig. 4.1 Schematic representation of catchment, pond, command area in microwatersheds

Therefore, it is necessary to modify the existing limits (previous 5 days sum of rainfall) of AMCs. In order to simulate moisture coditions in *plateau* area corresponding to AMC I, AMC II and AMC III (as per the existing criteria and assumed to be applicable in *plains*, new criteria was developed for *plateau* areas, the steps followed were :

(i) Past 6 years moisture depletion/addition data of crop root zone at Raipur (*plains*) and Jagdalpur (*plateau*) were studied with regard to sum of previous 5 days rainfall.

(ii) Range of moisture regimes at *plains* were determined for different sum of previous 5 days rainfall (viz <36 mm, 36-53 mm, > 53 mm).

(iii) Ranges of moisture regimes in *plateau* area were determined for different sums of previous 5 days rainfall (viz <10 mm, <14 mm, <18 mm, <22 mm).

(iv) The range of moisture regimes as determined in (ii) were compared with those determined in (iii).

(v) The most appropriate value of the sum of previous 5 days rainfall in *plateau* as determined in (iii) was selected against which the ranges of moisture regimes were closely matching to those as determined in step (ii).

The above procedure was repeated for different growing seasons, dormant seasons, monsoon seasons and non-monsoon seasons. Thus the above procedure was aimed at arriving appropriate criteria of AMC in *plateau* area that had equivalent moisture status to that under plains corresponding to different AMC groups so that the same procedure could be applied in *plateau* areas for runoff estimation. The new criteria developed for *plateau* and the existing criteria adopted for *plains* is presented in Table 4.1.

Table 4.1 **Existing and modified criteria of AMC**

| AMC | Existing Criteria (Raipur) | | Modified Criteria (Jagdalpur) | |
|---|---|---|---|---|
| | Growing season (Jun to Mar)* | Dormant season (Apr and May) | Monsoon season (Jun to Oct) | Non-monsoon season (Nov to May) |
| 1 | <36 mm | <12 mm | <10 mm | <10 mm |
| 2 | 36-53 mm | 12-28 mm | Escaped | 10-18 mm |
| 3 | >53 mm | >28 mm | >10 mm | >18 mm |

* Months are divided on the basis of crop cover-poor, fair, good as reflected by growth stages in the region.

Comparing of runoff using existing and modified criteria and subsequent verification/validation of developed model will be presented in chapters V and VI

### 4.2.2 Estimation of Direct Runoff from Rainfall

The data generally available in India are the amounts of rainfall measured by non-recording raingauges and for such data, rainfall-runoff relation was developed given by the following formula (CGWB-1994).

$$Q = (P - Ia)^2 / P - Ia + S) \quad \text{.......... 4.3}$$

where Q is the runoff in mm.

P is the rainfall in mm.

S is the potential maximum retention in mm.

Ia is the initial abstraction during the period between the beginning of the rainfall and runoff in equivalent depth over the catchment in mm.

**Condition of the Region** for black soils, (AMC III) :

$$Ia = 0.1S \quad \text{....... 4.4}$$

This equation can be used with the assumption that the cracks which are typical of these soils when dry have been filled. Therefore, the equation can be used where AMC would fall into groups II and

III. The same equation can be used for AMC I, if summer ploughing is done in the field and mixed with previous crop residues. Also uniformly under all AMC conditions, equation 4.4 can be used where the soils are of hydrologic soil group 'D' with problems of acidity, soil hardening and crusting. To show this relationship graphically, S values are transformed into curve numbers (CN) by the following equation.

$$CN = 25400 / (254 + S) \qquad \text{..........4.5}$$

Using the above equations 4.3 to 4.5, the equation developed is

$$Q = (P - 0.1\ S)^2 / (P + 0.9S) \qquad \text{..........4.6}$$

## 4.3 DEVELOPMENT OF PROGRAMME FOR RUNOFF ESTIMATION BY CN

A computer programme was developed (Appendix II) for runoff estimation by CN as described in section 4.3, using the programming language $C^{++}$. It contains three separate sub programmes for (i) Raipur - MW 1 (ii) Raipur-MW 2 and (iii) Jagdalpur. Various subroutines involved in this programme corresponds to various steps described in Fig 4.2 for runoff estimation. Two separate programmes are required for MW 1 and MW 2 of Raipur because of different durations of crop grown with changed crop cover conditions in different months. The programme has been made user's friendly. It is required to enter date (1.....28/29....30/31), month (1.....12), and rainfall (mm) each time. It directly estimate runoff after calculating sum of previous 5 days rainfall, delineating crop cover, assigning CN-II, AMC, converting CN-II to new CN as per AMC, calculating S and finally runoff from rice, non-rice and its weighted value. The flow of informations in these computations is shown in the flow chart, Fig 4.2. A sample calculation of this programme was tested and it very well matched with those calculated by conditional statements (Appendix I) using MS Excel 5.0.

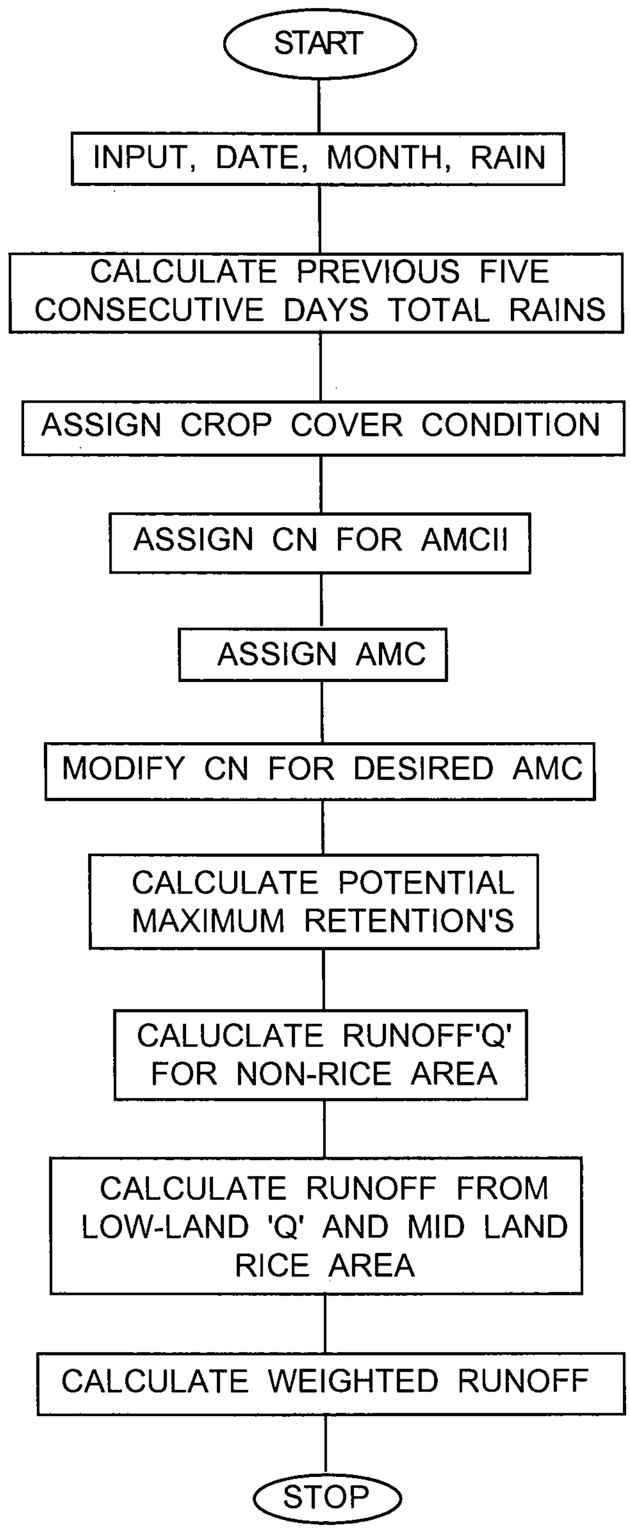



**Figure 4.2**

**Flow chart for estimation of runoff by curve number technique**

## 4.4 STRANGE'S METHOD

Strange's method as described in section 2.9, can be used to estimate monsoon runoff in terms of the percentage of monsoon rainfall by considering nature of the catchment as good, bad or average. Strange's method can be applied considering the catchment as 'good', if managed well with drainage system and SFR.

## 4.5 BINNIE'S METHOD

The readymade table prepared by Captain Garret and later slightly adjusted by Deptt. of irrigation, Govt. of Maharashtra (CGWB, 1994) can be used to estimate annual runoff as percentage of annual rainfall. In order to estimate monsson runoff using corresponding rainfall, the Binnie's percentages are to be increased by 1.0 to 4.0 per cent, according to the observed series of monsoon and annual rainfall and runoff. This is based on the report of Betwa Command Area (CGWB, 1981) and adopted by the Minor Irrigation Deptt., Govt. of M.P.

## 4.6 RAINFALL ANALYSIS BY MARKOV CHAIN MODEL

For effective growth of rice crop, a minimum weekly rainfall amount of 50 mm is considered (Chaudhary, 1998). This is because of the fact that on daily basis 3-4 mm of percolation loss and 3-4 mm of ET loss take place. In early crop stages, percolation losses are found to be high as compared to later growth stages. On the contrary, the ET requirement is less at early stages and increased in later growth stages. This amounts to 7 mm of water loss per day or approximately to 50 mm of water loss every week.

### 4.6.1 Criteria of Dry Week and Wet Week

A week receiving equal to or more than 50 mm rainfall is considered as a wet week. Similarly, a week receiving less than 50 mm rainfall is considered as dry week.

### 4.6.2 Initial and Conditional Probabilities

Based on the historic data of weekly rainfall and following the above mentioned criteria of dry week and wet week, the initial probabilities can be calculated as:

$$P\ (D) = F(D)\ /\ n \quad \text{and} \quad P(W)\ /\ n \qquad \text{..........4.7}$$

where P(D) is the probability of occurrence of a dry week.
P(W) is the probability of occurrence of a wet week.
F(D) is the frequency of occurrence of a dry week.
F(W) is the frequency of occurrence of a wet week.
n is the number of years.

This conditional probabilities can be calculated as :

$$P(D/D) = F(D/D)\ /\ \{\ F(D/D) + F(W/D)\} = F(D/D)\ /\ F(D) \qquad \text{....4.8}$$

$$P(D/W) = F(W/W)\ /\{\ F(W/W) + F(D/W)\} = F(W/W)\ /\ F(W) \qquad \text{....4.9}$$

$$P(D/W) = F(D/W)\ /\ F(W) = 1 - P(W/W) \qquad \text{....4.10}$$

$$P(W/D) = 1 - P(D/D) \qquad \text{....4.11}$$

where P(D/D) is the probability of occurrence of a dry week provided the preceding week was a dry week.

P(D/W) is the probability of occurrence of a dry week provided the preceding week was a wet week.

P(W/W) is the probability of occurrence of a wet week provided the preceding week was a wet week.

P(W/D) is the probability of occurence of a wet week provided the preceding week was a dry week.

This first letter in the conditional probability is indicating the present week and the second letter is indicating the past week.

### 4.6.3 Probability of Consecutive Wet Weeks and Dry Weeks

Probability of wet run and dry run of two weeks and three weeks can be calculated as:

$$P(2W) = P(W)*P(W/W)_2 \quad ...4.12$$

$$P(2D) = P(D)*P(D/D)_2 \quad ...4.13$$

$$P(3W) = P(2W) * P(W/W)_3 = P(W) * P(W/W)_2 * P(W/W)_3 \quad ...4.14$$

$$P(3D) = P(2D) * P(D/D)_3 = P(D) * P(D/D)_2 * P(D/D)_3 \quad ...4.15$$

where $P(2W)$ is the probability of two consecutive wet weeks.
$P(3W)$ is the probability of three consecutive wet weeks.
$P(2D)$ is the probability of two consecutive dry weeks.
$P(3D)$ is the probability of three consecutive dry weeks.
$P(W)$ is the initial wet probability.
$P(D)$ is the initial dry probability.
$P(W/W)_2$ is the conditional wet probability of second week (next week)
$P(W/W)_3$ is the conditional wet probability of third week (second next week)
$P(D/D)_2$ is the conditional dry probability of second week (next week)
$P(D/D)_3$ is the conditional dry probability of third week (second next week)

## 4.7 DESIGN OF SFR (FARM POND)

The water from dugout SFR is lost mainly through evaporation and seepage. An economical, efficient and durable evaporation retardant for SFR is yet to be found by research. Until such time, to overcome the storage loss of SFR, it is advisable to use the water immediately by irrigating and storing the water in the soil profile or subsequent utilization by deep rooted perennial crops. Seepage loss can be minimised by reducing the wetted or seepage area. However, the volume of stored water per unit wetted area increase with increase in the depth of water in SFR. Hence, there is a need to optimise the dimension to obtain the desired seepage reduction and to minimise the cost of SFR lining.

### 4.7.1 SFR Storage Optimization

The generalized form of equation for different derived parameters of trapezoidal section SFR are as follows :

**4.7.1.1 Rectangular SFR :** Plan and section is shown in Fig. 4.3.

(a) Average cross sectional area, $Aav = \frac{XY + (X+2DZ+Y+2DZ)}{2}$ ...4.16

b) Wetted area, $Aw = XY+2D*(1+Z^2)^{1/2} * (X+2DZ+Y)$ ...4.17

c) Storage volume, $V = [XY+(X+2DZ) * (Y+2DZ)] * D/2$ ...4.18

Where X,Y = Length of the two adjacent sides of the SFR

D = Depth of the SFR

Z = Side slope (Horizontal : Vertical : : Z:1)

Now expressing $Y = CX$ or, $Y/X = C$

Equations 4.16, 4.17, 4.18 are transformed to equations 4.19, 4.20 and 4.21 respectively.

$$Aav = [CX^2+(X+2DZ) (CX+2DZ)] / 2 \quad .....4.19$$

$$AW = CX^2 + 2D (1+Z^2)^{1/2} * (X + 2DZ+CX) \quad .....4.20$$

$$Y = [CX^2 + (X+2DSZ)* (CX +2DZ)] D/2 \quad .....4.21$$

Converting equation 4.21 to quadratic form and solving for X

$$X = [-DZ(1+C) + \sqrt{\{DZ(1+C)\}^2 - 4C(2D^2Z^2-V/D)} ] / 2C \quad ....4.22$$

Theoretically, for a particular storage volume, the surface area of the SFR is the least when the depth is increased to a point where the bottom surface area becomes zero. For this condition we get :

By putting X = 0 and Y = 0 in equations 4.21, 4.19 and 4.20.

$$D = (V/2Z)^{1/3} \quad .....4.23$$

$$Aav = V/D = 2D^2Z^2 \quad .....4.24$$

$$Aw = 4D^2 Z \sqrt{1+Z^2} \quad .....4.25$$

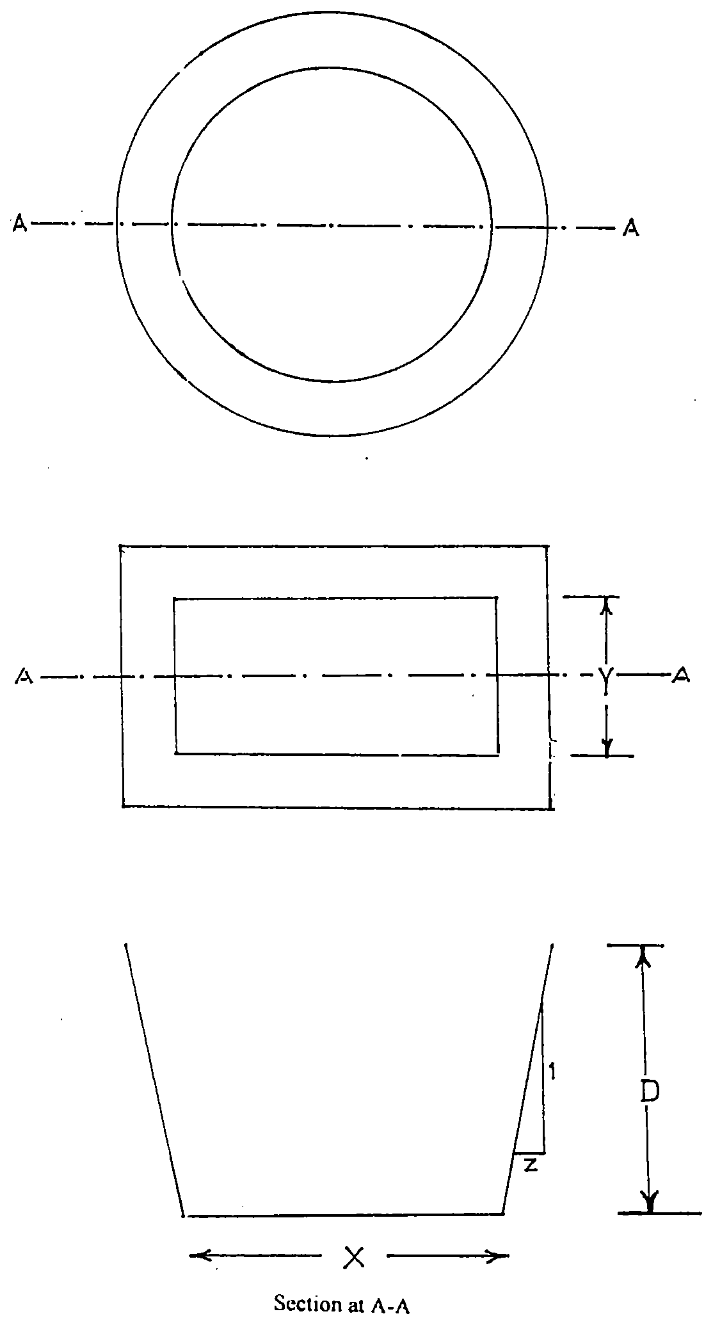



Fig. 4.3 Schematic representation of plan and section of circular and rectangular farm ponds

Thus using equations 4.23 to 4.25 optimum dimensions of a SFR for a particular storage volume can be arrived at. Equation 4.22 can be used to determine the other adjacent side Y.

#### 4.7.1.2 Circular SFR

Let X be the diameter of SFR bottom

D be the depth of SFR

Z side slope (Horizontal : Vertical : : Z : 1)

$$Aav = \pi/8 * [X^2 + (X-2DZ)^2] \qquad ...4.26$$

$$Aw = \pi D(X+DZ) * (1+Z^2)^{1/2} \qquad ...4.27$$

$$V = \pi D/8 [X^2 + (X+2DZ)^2] \qquad ...4.28$$

Converting equation 4.28 to quadratic form and solving for X :

$$X = -DZ + (-D^2Z^2 + 4V/D)^{1/2} \qquad ...4.29$$

Theoretically, for a particularly storage volume, the surface area of the SFR is the least when the depth is increased to a point where the bottom surface area becomes zero. For this condition we get :

By putting X = 0 in equation 4.28, 4.26 and 4.27.

$$D = (2V/\pi Z^2)^{1/3} \qquad ...4.30$$

$$Aav = \pi D^2Z^2/2 \qquad ...4.31$$

$$Aw = \pi D^2 Z(1+Z^2)^{1/2} \qquad ...4.32$$

Thus using equations 4.30 to 4.32, optimum dimensions of a SFR for a particular storage volume can be arrived at.

### 4.7.2 Shape and Depth of SFR

For soils having mild to moderate sloping topography, excavated SFR are more suitable. These are of 3 types according to their shape: (i) Square (ii) Rectangular and (iii) Circular. Among these, the circular SFRs have the geometrical advantage that they have the highest storage capacity and have least circumferential length for a given surface area and side slopes (Radder *et al.*, 1995), and thereby minimizing the seepage loss (Sahu, 1999). However, their curved shape is disadvantageous in as much as a substantial area is normally lost for agricultural operations (Radder *et al.,* 1995). Large areas of shallow water should be avoided due to excessive evaporation losses and the growth of noxious aquatic plants. The depth of SFR more than 3.0 m is not conducive for fish growth (FAO, 1998). The depth of soil and presence of hard strata and *murum* (semi weathered material) in the lower strata restricts the SFR depth. Therefore, optimum depth as calculated by equations 4.4 and 4.1 is subjected to above practical considerations for finally deciding the depth of SFR.

### 4.7.3 Mean Surface Area of SFR

For small, relatively shallow reservoirs for a given period of time, for which the surface area of the SFR is practically constant, the relationship between the various hydrologic factors and the dimensions of the SFR can be worked out as follows :

$$RA/a + P - (S + U/a + E) = d + W/a \qquad ...4.33$$

From this relationship mean surface area of SFR can be worked out as follows :

$$a = (RA - W + U) / (S - P + d + E) \qquad ...4.34$$

Where A is the size of contributing drainage area, ha

R is the total runoff from the contributing drainage area per ha during the period under consideration, ha-m

a is the mean surface area of SFR for a given depth, ha

P is the precipitation falling on SFR during the period, irrespective of whether or not it produces surface runoff from the drainage area, m

E is the evaporation from the surface of the reservoir during the period under consideration, m

U is the amount of water used during the period, ha-m.

d is the average depth of water in SFR during the given period, m

S is the seepage loss during the given period, m.

W is the amount of water in excess of the capacity of SFR which is wasted over the spillway, m.

Another factor not included in the above expression, is the loss of reservoir capacity due to silting, which must be considered especially when the drainage area is cultivated. Once the mean surface area of SFR is known, its dimensions can be fixed/determined as per its shape by following relationship after using equations 4.19, 4.24, 4.26 and 4.31.

Rectangular SFR : $a = (XY+dz(X+Y+2dZ)]*10^{-4}$ ...4.35

Circular SFR : $a = (\pi/4(X^2+2XdZ+2d^2Z^2)]*10^{-4}$ ...4.36

Where X, Y, d are the dimensions and Z is the side slopes (H:V ::Z:1) of SFR.

The minimum drainage area required to fill a reservoir with a given depth 'd' and a corresponding mean surface area 'a' within a reasonable time after completion (1-2 years) is expressed as follows :

$$A = (d - P - E + U/a) * a/R \quad ...4.37$$

Where P, E and R are amounts for the reasonable period (1-2 years) that can be expected to be equalled or exceeded 50 per cent or 80 per cent of the time.

The minimum drainage area required to maintain a dependable supply in a reservoir with a depth d and a corresponding mean surface area 'a' after the reservoir was once filled is expressed as follows :

$$A = (E + U/a - P - d) * a/R \quad ...4.38$$

With these relationships, curves or tables can be prepared for a given hydrologic region showing the minimum drainage areas needed to fill and maintain required supplies of water in reservoirs with various depths and corresponding mean surface areas.

For a given mean surface area of reservoir, greater depth will provide more storage and less water will be wasted over the spillway when rainfall and runoff are less than ET plus water utilized during a given period, there will be no waste and during droughts the storage in a deep reservoir will supply water for longer periods than a shallower reservoir.

To provide a dependable supply in a small reservoir, the depth of usable water at no time be less than the difference between the total demand and the total supply during the critical period. This condition can be expressed as follows :

$$d \geq (E + U/a) - (RA/a + P) \qquad \text{...4.39}$$

For critical periods, when no runoff can be expected the minimum allowable mean surface area of SFR with a given depth is expressed as follows :

$$a \geq U/ (P + d - E) \qquad \text{...4.40}$$

The purpose of SFR, the topographic and geologic characteristics of the site, the hydrologic factors as well as economic and legal factors and health hazards all enter into the planning procedure for an adequate impounding SFR. The hydrologic considerations involved are basic and common to all uses (crop production, fish rearing, duck rearing etc.) and conditions (facility of gravity and lift irrigation).

## 4.8 SEEPAGE LOSS ESTIMATION FROM SFR

The water balance approach can be followed for a precise estimation of seepage losses by assessing the input and output components. The analysis in terms of depth is made as follows :

Initial depth of water is SFR = di

Final depth of water in SFR = df

**Input to SFR** : (i) Rainfall = R; (ii) Runoff = Ro

**Output from SFR** : Abstraction and losses :

Evaporation = E (Coefficient * Open pan evaporation)
Water use = Wu
Seepage = S

Applying the principle of conservation of mass

$$df = di + R + Ro - (E + Wu + S) \quad ...4.41$$

$$\text{or, } S = [(di+R+Ro) - (E + Wu)] - df \quad ...4.42$$

Thus the seepage and evaporation losses can be estimated using above expressions.

## 4.9 DESIGN OF SURFACE DRAINAGE SYSTEM

As an important component of rainwater management in crop production, to mitigate waterlogging in the microwatershed, particularly during high intensity storms, it is of utmost importance to design an appropriate drainage system with SFR as its outlet. The main drain leading to inlet of SFR can be provided with silt trap at its d/s end to reduce the silt load of drainage effluent before it enters into SFR. Utmost care is required to design drainage system for those areas which were recently converted into non-rice area from the traditional rice fields as a result of crop diversification taking place in this region. Also those non rice areas surrounding by u/s rice fields. Such fields require intensive drainage at closer spacing, particularly in vertisols. *Kharif* crops such as soybean, pigeon pea, groundnut and vegetables have a good drainage requirement. Time required for removal of excess water is 6-8 hours for vegetables, 24 hours for general crop and 72 hours for rice crop, (Gupta *et al.*, 1971). This excess water removal time was considered 16 hours for drainage system design at Jagdalpur (Sahu, 1999). The CN can be used (Equation 4.3) for estimation of runoff volume to be disposed through the surface drainage system. Rainfall intensity for 2-5 years recurrence interval can be taken for the duration equal to the period considered safe for the crops to be grown and conversion of this rainfall to the runoff depth. For the seasonal drainage system, which is collapsed during tillage operations and needs to be reinstalled after this operation every year, a smaller recurrence interval of 1.25, 1.33, 1.66 and 2 years can be taken. Previously at Jagdalpur the drainage system was designed by taking 5 years recurrence interval (Sahu, 1999).

## 4.10 CROP AREA ALLOCATION MODEL

The crop area allocation model uses the linear progrmming technique to choose the crops and the area to be allocated to each crop for maximising returns. The first step is to identify suitable crops for the area using a suitable selection procedure (Pal *et al.,* 1996). This model uses the following information

(i) Water requirement for crop maintenance

(ii) Net income from each crop per unit of area based on current prices of production inputs and produce

(iii) Production constraint e.g. limited water in SFR and available cultivated area.

Two components of seasonal water supply are the amount of water in the SFR to be used during monsoon season and during the year. Similarly two components of available cultivated area are : (i) during the monsoon and (ii) during the year. Rice, vegetables, mustard, gram at Raipur and rice, soybean, vegetables, mustard, gram, fruits, tubers at Jagdalpur were found suitable for the study area in earlier research (Pal *et al.,* 1996; Sahu, 1996). It was established that most farmers want to grow some rice for their own consumption. The model can be run for different combinations of limiting situations such as imposing a minimum area for rice and other crops and limited water supply conditions.

The crop area allocation process for these different situations was formulated as follows :

$$\text{Maximize} : Z = \sum_{i=1}^{t} C_i X_i \qquad \text{..... 4.43}$$

Subject to

i) $\sum_{i=1}^{m} W_i X_i \leq W_m$ (Monsoon water utilization)

ii) $\sum_{i=1}^{t} W X_i = W_t$ (Total water availability)

iii) $\sum_{i=1}^{m} X_i = X$ (Monsoon cropped area)

iv) $\sum_{i=1}^{t} X_i = 2X$ (Annual cropped area)

v) $X_r \geq PX$ (rice area as a fraction of monsoon area)

vi) $X_o \geq 0.05\ X$ (oil seed area)

vii) $X_p \geq 0.05\ X$ (pulse area)

viii) $X_v \geq 0.10\ X$ (vegetable area)

ix) $X_f \geq 0.05\ X$ (fruit area: **J-1**, **J-2**)

x) $X_t \geq 0.05\ X$ (tuber area: **J-1**, **J-2**)

xi) $X_i \geq 0$

Where $Z$ = maximum net return from all the crops. Rs.

$C_i$ = net return from $i^{th}$ crop, Rs/ha.

$X_i$ = area under $i^{th}$ crop, ha

$m$ = number of monsoon crops

$t$ = total number of crops

$W_i$ = irrigation requirement of $i^{th}$ crop in $m^3$/ha

$W_m$ = monsoon season water utilization $m^3$

$W_t$ = annual water availability, $m^3$

$X_r$ = area under rice crop, ha

$P$ = fraction of rice area to the total monsoon area.

$X_o$ = sum of the area under oilseed crops, ha.

$X_p$ = sum of the area under pulse crops, ha.

$X_v$ = sum of the area under vegetable crops, ha.

$X_f$ = area under fruit crop (ha) (only in **J-1** and **J-2**)

$X_t$ = area under tuber crop (ha) (only in **J-1** and **J-2**).

It was established from nutritional survey conducted by ICMR and quoted in NARP status Report (1995) that besides rice, farmers should grow at least 5% of cropped area, each under oilseed and pulse crops. In tribal areas of Bastar it was reported that in addition to above, tubers and fruits each should also be grown at least in 5% of the cropped area. This report further recommended that in order to get regular income, the vegetables be grown in at least 10% of the cropped area.

## CHAPTER V

# MATERIALS AND METHODS

The literature reviewed and the problems identified in the study area, as given in the previous chapters, reveals that planning and design of efficient rainwater management through SFR water harvesting systems in a rainfed area requires systematic analysis of different types of information. There are rainfall, runoff, evaporation, crop evapotranspiration, dry spells, topography, crops to be grown, soil characteristics and irrigation requirement at various critical crop growth stages, besides the socio-economic conditions and infra-structural facilities of farmers. To study the feasibility of runoff collection in SFRs and its utilization for supplemental irrigation to rainfed crops in the monsoon season and subsequent use for establishment of post-monsoon crops, estimation of runoff, proper design of SFR and drainage system and computations of costs and benefits of the whole system are required.

## 5.1 RUNOFF ESTIMATION

Several runoff estimation models are in use. Most of them are quite complex in nature and require a large number of parameters in their use. Some of them are too simple and empirical in nature that their use is often questionable. Selection of an appropriate model for runoff estimation in this study was attempted, while selecting four of them for comparison which are popularly in use or are emerging as new techniques (Table 5.1). Consideration in selecting these models was based on the availability of data base in Indian condition.

The monsoon runoff was estimated for 4 microwatersheds (R-1, R-2, J-1, J-2), two each at Raipur and Jagdalpur, using the selected models. Hydrologic characteristics of each microwatershed (MW) have

**Table 5.1 Models and techniques of runoff estimation for evaluation**

| | Methods | Inputs required | Out put delivered | Reference |
|---|---|---|---|---|
| 1. | Curve number technique | Daily rainfall, crop cover, soil characteristics land use, antecedent moisture conditions etc. | Daily runoff | Bhattacharya - 1999<br>Ramana Rao - 1994<br>Gupta *et al.* - 1971<br>SCS-USDA - 1964 |
| 2. | Conservation factor approach | Monthly/monoon/annual rainfall, soil consrvation measurs, soil type, land slope etc. | Monthly runoff | Singh - 1987<br>Bajpai - 1999 |
| 3. | Strange's table | MW characteristics, good*, bad** average*** Stranges table monsoon rainfall | Monsoon runoff | CGWB - 1994<br>Shivanappan - 1992 |
| 4. | Binnie's percentage | Annual rainfall, Binie's table | Annual runoff | CGWB - 1994<br>Bhandarkar - 1985 |

* MW with high slope, poor surface retention and absorption.

** MW with high surface water retention and absorption due to low gradient, heavy soil cover.

*** MW with mixed characteristics

been presented in Table 3.6 and the hydrologic behaviour of these microwatersheds has been depicted in Fig. 3.7. Daily rainfall of past 31 (Raipur) and 30 (Jagdalpur) years were collected from the meteorological observatory of IGAU Raipur and the local unit of IMD. Monthly runoff was worked out only by two methods viz. curve number technique and conservation factor approach, as the other methods estimate only monsoon or annual runoff; weekly and daily runoff estimation was possible only by 'curve number technique'.

### 5.1.1 Curve Number Technique (CN)

Daily runoff was estimated by curve number technique available for Indian conditions (Gupta *et al.,* 1970, 1971; Datta, 1986). In order to perform rigorous calculations, two types of computer programmes were developed : (i) Programme in MS Excel version 5.0 (Appendix I) and

(ii) Programme in $C^{++}$ (Appendix II). The steps followed in daily runoff estimation were as follows (Appendix I) using conditional statements :

**(i) Daily rainfall (mm) :** Listed in column C alongwith date (column B) and month (column A) of Appendix I.

**(ii) Sum of previous 5 days rainfall** : Worked out in column D of Appendix I.

**(iii) Land uses** : Three land uses were considered : fallow, straight row crops and paddy. Month wise delineation was made as per the land use in the region i.e. in the months of April, May land remained fallow, straight row crops were grown during two seasons viz. monsoon; Jun-Oct, and post-monsoon; Nov-Mar. Paddy is grown in limited area only during monsoon season.

**(iv) Hydrologic soil group** : All the microwatersheds were put under group D due to low infiltration and heavy soil texture (Table 3.6).

**(v) Crop cover** : Monthwise delineation of 3 crop cover conditions was made based on the land coverage of less than 50; 50-75 and greater than 75 per cent. These conditions were respectively poor, fair and good, (Table 5.2) which approximately coincides with aforesaid months, in the two cropping seasons. In MW, R-2 different monthly sequence of crop cover condition was taken, as compared to the rest of the microwatersheds because the late duration pigeon pea covered both the crop seasons.

**(vi) Initial abstraction (Ia)** : It was taken as 0.1S uniformly for all the antecedent moisture conditions due to high runoff producing characteristics and well laid out drainage system.

**(vii) AMC** : The sum of previous 5 days rainfall was adopted for designating AMC of the MWs. The usual limit of previous 5 days total rainfall, however, was modified for MWs, **J-1** and **J-2,** of *plateau* area due to high slopes which is discussed in section 4.2.1. The existing criteria was used for MWs, **R-1** and **R-2** of *plains* area while modified criteria (Table 4.1) was used for MWs, **J-1** and **J-2** lying in *plateau* area.

**(viii) Curve number for AMC-II** : After deciding the AMC, Ia (=0.1S) and soil group (D) the CN for AMC-II were selected using standard tables (GOI, 1972) for a given land use and crop cover condition (Table 5.2). These curve numbers were assigned with the help of conditional statement (column F, Appendix I).

**Table 5.2 Monthwise delineation of crop cover conditions and curve numbers for AMC II**

| Land use | Crop cover condition | MWs, J-1, J-2, R-1 | | MW, R-2 | CN II for AMC II |
|---|---|---|---|---|---|
| | | Monsoon crops | Post-monsoon cropd | Monsoon crop extended to post monsoon season | |
| Straight row crops | Poor | Jun, July | Nov., Dec. | June to Aug | 91 |
| Straight row crops | Fair | Aug. | Jan | Sept. to Nov. | 90 |
| Straight row crops | Good | Sept. Oct. | Feb. March | Dec. to March | 89 |
| Fallow | P-F | - | April, May | April, May | 94 |
| Paddy | - | Jun to Oct. | - | Jun to Oct. | 95 |

**(ix) Conversion of CN for AMC II to CN-for given AMC** : With the help of standard tables and conditional statement (Appendix I) the previously assigned for AMC II were converted into new curve number (CN-AMC) for the given AMC on daily basis.

**(x) Potential maximum retention "S"** : It was worked out by equation 5.1 after knowing the new curve number (CN) :

$$S = [1000/CN) - 10] \quad 25.4 \qquad \text{....5.1}$$

**(xi) Surface runoff "Q" from non-rice area** : It was calculated by equation 5.2, after putting the values of "P" - direct rainfall and "S" - the maximum potential retention

$$Q = (P - 0.1\ S) / (P + 0.9\ S) \qquad .....5.2$$

**(xii) Runoff from rice area** : The CN value was taken as 95 (GOI, 1972) for estimating runoff by using equations 5.1 and 5.2. The runoff was estimated after allowing 50 mm retention in bunded rice fields, in case the rainfall exceeded 50 mm. Also upto 140 mm of initial rains (in the month of June mostly), runoff from rice fields was not allowed to be drained and as such runoff is treated as nil. This was in accordance to local practice for conserving rains for rice crop.

**(a) Runoff from low land-rice** : Runoff from low land-rice was estimated according to the procedure described above, treating no runoff for rains less than 2 mm or 0.1 S, whichever, is greater (Appendix I, column K).

**(b) Runoff from upland-rice** : Runoff from upland-rice was estimated according to the procedure described above treating no runoff for rains less than 25 mm or 0.1 S, whichever, is greater (Appendix I, column L).

### 5.1.2 Conservation Factor Approach (CF)

The hydrologic data available for the MWs (**R-1, R-2, J-1, J-2**) with different land uses and conservation measures were analysed and evaluated for their hydrologic response using the concept of conservation factor through regression approach (Singh, 1987 and Bajpai, 1999). Steps followed in runoff estimation were :

(i) Conservation factor was worked out by using equation 4.1.

(ii) The water yield producing factor was worked out by equation 4.2 for different periods i.e. monthly - seasonal and annual.

(iii) The average watershed slope was worked out by equation 3.1.

(iv) Regression models were developed between water yield producing factors and observed water yield of 8 years (**R-1**) and 6 years

**(R-2, J-1, J-2)**. These runoff regression models were developed using the "curve fit" software.

(v) Coefficient of determination $R^2$ was worked out and used to examine how the variation in observed water yields is accounted for by the variation in water yield producing factors.

(vi) These regression models, developed for monthly, seasonal and annual runoff estimation, were used for the data series of 30 and 31 years at Jagdalpur and Raipur respectively.

### 5.1.3 Binnie's Method

The ready made tables prepared by Captain Garret and later slightly adjusted by the Deptt. of irrigation, Govt. of Maharashtra (CGWB - 1994) was used to estimate monsoon runoff for both the places. This table gives the values of annual runoff in terms of percentage of rainfall. In order to determine monsoon runoff using corresponding rainfall, the Binnie's percentages were increased by 1.0 to 4.0 according to the observed series of monsoon and annual rainfall and runoff. This was based on the report of Betwa Command Area (CGWB - 1981) and adopted by the Minor Irrigation Deptt., Govt. of M.P.

### 5.1.4 Strange's Method

Strange's method was applied considering catchment as "good" as they were managed well with good drainage system and farm pond. The monsoon runoff were directly worked out by using appropriate percentages from the tables (Sivanappan - 1992).

## 5.2 VALIDATION OF RUNOFF MODELS

Hydrologic model in simple term is a set of mathematical equations describing hydrologic processes in a given watershed. It is necessary to test the accuracy of prediction of these models to decide upon its applicability and use. Validation is the process by which the observed and predicted series are tested for their statistical agreement over different locations at all times.

In the present context of model development, it was proposed to test the applicability of the model using the following steps :

(i) Comparison between the observed and predicted runoff at two different locations (MWs) in the same agroclimatic zone, to verify the correctness of the chosen criteria. For Chattisgarh plains the existing criteria of AMC was used while in Baster plateau agroclimatic zone modified criteria of AMC was used for runoff estimation (Table 4.1) by curve number method.

(ii) Comparison between the observed and predicted runoff estimated by using existing criteria and modified criteria of AMC at two different locations of Bastar plateau agroclimatic zone in order to adjudge the correctness of the modified criteria over existing criteria of AMC for runoff estimation.

(iii) If verification is satisfactory, test of validation of the model without changing logic for all other sites in the same agroclimatic zone.

(iv) If the tests at different sites are successful, the validity of the model is accepted.

It is necessary to assess the success of a model by using an appropriate statistical test. Such tests can be done by using parametric or non-parametric statistical procedures.

The statistical parameters used for comparison were (i) average (ii) CV in per cent (iii) Per cent deviation of estimated runoff with observed runoff (iv) Paired t-test.

(v) Mean of the difference of estimated runoff with observed runoff. Eight years gauged data of R-1 and 6 years gauged data of R-2, J-1 and J-2 were used for comparison. Two types of comparisons of observed and estimated runoff were made :

(a) Comparison between observed and estimated runoff. The runoff was estimated by 4 methods viz. curve number technique (Raipur - using existing method, Jagdalpur-using modified method), conservation factor approach, Strange's method, Binnie's method.

(b) (i) Comparison between observed and estimated runoff by CN technique (using existing criteria) for J-1 and J-2.

(ii) Comparison between observed and estimated runoff by CN technique (using modified criteria) for J-1 and J-2.

(iii) Comparison between estimated runoff for J-1 and J-2 using existing and modified criteria.

### 5.2.1 Paired t - test

Paired t - test (Parametric test) was performed to see if there was any significant difference between the means of observed runoff and the runoff estimated by four methods. Comparison were made on monsoon (June to October) runoffs. In this test, the null hypothesis (Ho) and alternate hypothesis ($H_1$) were as follows :

$H_0$ : Observed and estimated runoff are from the same population.

$H_1$ : Observed and estimated runoff are from different populations.

't' : values for (n-1) degrees of freedom were calculated by equation 4.6

$$t = \frac{|\bar{d}|}{\sqrt{S_d^2/n}} \sim t_{n-1} \qquad \text{....5.3}$$

Where $\bar{d}$ is the mean of the difference of the estimated runoff with the observed runoff = $\frac{\Sigma di}{n}$ where n is the number of years of runoff being compared.

$S_d^2$ is the variance of the difference of the estimated runoff with observed runoff = $\Sigma\ (di - d)^2$

These calculated "t" values were compared with the table "t" values for (n - 1) degrees of freedom at 0.05 and 0.001 significance level. The range of per cent deviation of estimated runoff with observed runoff was also worked out to assess the best method which gives results closest to the observed ones in estimating runoff.

## 5.3 COMPARISON OF RUNOFF

### 5.3.1 Between Pairs of Runoff Estimation Methods

Here again paired t-test was applied in a similar manner as described earlier for comparing the runoff estimated by different pairs of methods. Six pairs out of four methods were formed viz. CN. x Strange; CN x Binnie; CN x CF; Strange x Binnie; Strange x CF and Binnie x CF. Mean of difference and 't' values for runoff estimated by the methods (in pairs) under comparison were worked out. Calculated 't' values were compared with table 't' values at 5% and 1% level of significance to see whether the runoff estimated by two methods (under comparison) is statistically indifferent or the runoff estimated by two methods is significantly different.

### 5.3.2 Rice and Non-rice Areas

Runoff from rice areas under two conditions viz. low land and upland were compared with runoff from non-rice areas by applying the paired t - test to examine whether any significant differences in the means of runoff existed or statistically they belonged to the same population.

## 5.4 RAINFALL AND RUNOFF ANALYSIS

### 5.4.1 Fitting Probability Distributions

Long term fortinightly data (30 years for Jagdalpur and 31 years for Raipur) of monsoon rainfall and runoff estimated by CN were used to fit in appropriate probability distribution to draw inference on probable future behaviour of such events. The steps followed were :

(i) Frequency curve of the data was drawn by adopting a suitable class interval.

(ii) These were compared with the frequency curves of known probability distribution.

(iii) Maximum likelyhood estimates of the parameters of the chosen distribution were calculated.

(iv) The probability density functions were used to predict the frequencies of the various class intervals.

(v) Chi-square test was performed to test the goodness of fit between the observed and the estimated frequencies.

(vi) If there was no significant differences between the two, the density function was used to predict the magnitude associated with various probabilities of exceedence.

### 5.4.2 Normal Distribution

The function NORMDIST (MS Excel 5.0) was used. It returns the normal cumulative distribution function. The equation used for the normal probability density function was

$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \quad \text{... 5.4}$$

Where $x$ = variable for which the distribution is required.

$\mu$ = arithmatic mean of the distribution

$\sigma$ = standard deviation of the distribution

The probability (area under pdf curve) was obtained by multiplying the value on pdf curve of each class with class interval. The resultant when multiplied by the number of years of data, gave expected frequency.

### 5.4.3 Chi-Square Test of Goodness of Fit

The hypothesis to be tested was

$H_o$ : The data fit to normal distribution.

$H_1$ : The data did not fit to normal distribution.

Test statistic Chi square was calculated as :

$$\chi^2_{cal} = (O_i - E_i)^2 / E_i \quad \text{....5.5}$$

Where $O_i$ is the observed and $E_i$ is the expected frequencies. All Chi square calculated values were summed up to yield the test statistic $\chi^2_{cal}$. Test statistic $\chi^2_{tab}$ = $\chi^2_{\alpha,(K-1)}$ was seen from statistical tables at $\alpha$ level of significance and k-1 degrees of freedom. If $\chi^2_{cal} < \chi^2_{tab}$, the $H_o$ was accepted, and concluded that was $\alpha$% confidence that the data fit to a normal distribution. On the contrary if $\chi^2_{cal} > \chi^2_{tab}$, $H_o$ was rejected and the conclusion was that the data did not fit to normal distribution.

### 5.4.4 Expected Amount at Different Probabilities of Exceedence

After applying Chi square test - in case $H_o$ was accepted, the equation 4.7 was used to estimate the expected amount of rainfall / runoff at different probabilities of exceedence. The expected amount of rainfall/ runoff were worked out at fortnightly, seasonal and annual time intervals.

### 5.4.5 Exponential Distribution

The function EXPONDIST (MS Excel 5.0) was used. It returned the probability density function as :

$$f(X;\lambda) = \lambda e^{-lx} \qquad \ldots 5.6$$

Where X = value of the function

$\lambda$ = parameter of the distribution.

The probabilities on the pdf curve for each class were determined. The Chi square test of goodness of fit was applied as described under section 4.8.3. The expected amount of rainfall / runoff at fortnightly intervals were worked out using equation 4.9.

### 5.4.6 Gamma Distribution

The function GAMMADIST (MS Excel 5.0) was used to estimate the value on pdf curve for each classes. This function was used to study rainfall / runoff that had a skewed distribution. The probability density function for the Gamma distribution is

$$f(x\,;\,\alpha,\beta) = \frac{1}{\beta^{\alpha}\sqrt{(\alpha)}} X^{\alpha-1}\, e^{x/\beta} \qquad ....5.7$$

Where $\alpha$, $\beta$ = parameters of distribution

X = variable for which distribution is required.

The values on the pdf curve for each class values were determined using equation 4.10. Chi square test (as given in section 5.4.3) was applied and expected rainfall / runoff at different probabilities of exceedence were determined using equation 5.7.

## 5.5 PROBABILITY ANALYSIS OF DRY WEEKS

Past 30-31 years rainfall data were used for analysis considering 5 rainy months (Jun to Oct). Various crop growth stages/month/season covered under the study were :

Stage 1 Sowing / transplanting (27 + 28 SMW)

Stage 2 Flowering (37 + 38 SMW)

Stage 3 September (1 - 30 days)

Stage 4 Reproductive phase (37 to 40 SMW)

Stage 5 Monsoon season (23 to 42 SMW)

### 5.5.1 Criteria of Selecting Dry Day

Apart from the rainless day, a day was designated as a dry day, if the rainfall was less than 7.5 mm because at least 7.5 mm rainfall is necessary to make the upper soil crust moist. The two consecutive days on which rainfall occurred were considered dry only when the sum of the 2 days rainfall was less than 10 mm, if it was more, both the days were assumed to be wet though the rainfall may be less than 7.5 mm on any day (Gupta, 1972).

### 5.5.2 Fitting Probability Distributions

Following the procedure of section 5.4.1 frequency curves of number of continuous dry days in various periods were drawn and compared with curves of known probability distribution. After selecting the distribution (here Gamma distribution), its parameters ($\alpha$, $\beta$) were determined. By using equation 4.10 frequencies of various class intervals were determined. After applying Chi square test of goodness of fit (section 5.4.3) and if there was no significant difference between observed and estimated frequencies, the magnitude of continuous dry weeks at various probabilities of exceedence were worked out. Average number of dry days and rainfall at various growth stages / monsoon season / months were also worked out.

### 5.5.3 Computation of Drought Level

Monthly and yearly drought levels were worked out (as proposed by Sharma *et al.,* 1979) as :

**Drought month** : Any month receiving rainfall less than 50% of the average monthly rainfall.

**Drought year** : Any year receiving rainfall less than or equal to (X - SD) in which X is the mean and SD is the standard deviation of the annual rainfall.

## 5.6 EVAPOTRANSPIRATION (ET) OF CROPS

ET of rice crop was determined by lysimeters at Raipur (IGAU - 1994) and by drum culture technique at Jagdalpur (Sahu - 1993) for the period of 14 and 6 years respectively. ET of non-rice crops were determined by soil moisture depletion studies. Reference crop ET (using past 20 years meteorological data) were determined by modified Penman method as proposed by Doorenbos and Pruitt (1984). Crop coefficients were developed for each crop using the relationship (Doorenbos *et al.,* 1993).

$$ET\ crop = K_c * ET_o \qquad .....5.8$$

Where $K_c$ = crop coefficient

$ET_o$ = reference crop ET

### 5.6.1 Reference Crop Evapotranspiration ($ET_o$)

$ET_o$ was worked out at fortnightly interval, starting from (1+2) SMW and ending in (51+52) SMW using meteorological parameters and modified Penman method as described above. This exercise was extended over 20 years for each period thus 20 values for each period were obtained.

### 5.6.2 Probability Distribution of $ET_o$

Following the procedure described under sections 5.4.1 to 5.4.3, good fit to normal distribution was obtained for each period. The expected amount of $ET_o$ at different probabilities of exceedence was worked out as per the procedure described in section 5.4.4

### 5.6.3 Average Fortnightly Evaporation

The fortnightly evaporation as measured from open pan evaporimeter (USDA) was averaged over 22 and 15 years for Raipur and Jagdalpur respectively.

### 5.6.4 ET of Rice Crop

ET of rice (medium duration) was determined by lysimeters and averaged over 14 years (IGAU - 1994) at Raipur. ET of rice (early duration) was determined by drum culture technique (Sahu - 1993) and averaged over 6 years at Jagdalpur. $ET_o$, as worked out at 50% probability, and the ET values, as determined above, were correlated by equation 4.20 to obtain fortnightly and seasonal crop coefficient. Why $ET_o$ was considered at 50% probability is discussed in Chapter VI. ET of rice during nursery stage was determined by soil moisture depletion studies right from sowing upto transplanting stage. Subsequently it was measured by lysimeters at Raipur and drum culture technique at Jagdalpur. The various crop growth stages coinciding with different fortnightly intervals were also identified.

### 5.6.5 ET of Non-Rice Crops

A series of non-rice crops were covered under the study starting from cash crops (soybean, gram, mustard), vegetables (radish, okra), tuber crops (sweet potato, tapioca), fruits (banana, papaya), mixed crops (tapioca with groundnut).

ET of non-rice crops were determined by soil moisture depletion studies using the equation as

$$ET_j = \sum_{i=1}^{n} Q_{ij} \qquad ...5.9$$

Where $ET_j$ = crop ET requirement in mm in the $j^{th}$ period

$Q_{ij}$ = quantity of moisture depleted (mm) during the $j^{th}$ time interval from $i^{th}$ layer

**Case (A)** *No irrigation was applied*

$Q_j$ was calculated from the change in soil water content in successive samples from the relation as:

$$Q_j = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} A_i D_i \qquad 5.10$$

Where $M_{1i}$ = soil moisture (%) at first sampling in $i^{th}$ layer

$M_{2i}$ = soil moisture (%) at second sampling in the $i^{th}$ layer.

$A_i$ = bulk density of soil in the $i^{th}$ layer, $g/cm^3$.

$D_i$ = depth of $i^{th}$ layer of soil root zone, mm

n = No. of soil layers sampled in the root zone depth D.

**Case (B)** *Irrigation was applied*

$$Q_j = \sum_{i=1}^{n} \frac{M_{fci} - M_{bi}}{100} A_i D_i \qquad ..... 5.11$$

where $M_{fci}$ = field capacity moisture content in the $i^{th}$ layer (%)

$M_{bi}$ = moisture content before irrigation in the $i^{th}$ layer (%)

Other terms remain same as in equation 4.22.

The short term ET as determined above were summed over crop growth period to result in total ET of crop.

### 5.6.6 Crop Growth Stages

ET crop and its crop coefficient were also worked out by delineating growth stages as defined by FAO - 1984, FAO - 1993 viz. 1. Initial stage 2 Crop development stage, 3. Mid season stage 4. Late season stage.

Based on above method, ET-crop was determined for monsoon crops (Rice, soybean, Okra, radish, Soybean) and postmonsoon crops (Radish, mustard, gram). ET of long duration crops, covering monsoon and post-monsoon season (tapioca, papaya, banana), were also worked out.

## 5.7 DESIGN OF SMALL FARM RESERVOIRS

Designs of SFRs were attempted considering rainfall and runoff at different probabilities of exceedence, irrigation requirement, seepage, evaporation and excess runoff, if any, above SFR capacity, to be disposed off. The mean surface area of 3 forms of SFR's was worked out using equation 4.34. This exercise was performed for all the four MWs, R-1, R-2, J-1 and J-2. The capacity of SFRs were decided while considering the above parameters for the monsoon season and the year as a whole (monsoon and post-monsoon season taken together). The different criteria and input parameters used for SFR's design are briefly described in Table 5.3. The input parameters; rainfall, runoff and

**Table 5.3 The input parameters and criteria used for the designs of SFRs.**

| Input parameters | Criteria used | Remarks |
|---|---|---|
| Rainfall runoff | Four levels of probability of exceedence viz. 50, 60, 75, 80 per cent | Same for RP-1 and RP-2<br>Same for JP-1 and JP-2 |
| Evaporation | 0.66 times the pan evaporation (USWB) | -do- |
| Average depth of water | Observed depths, averaged over the years in SFRs during monsoon and during the year | Same for JP-1 and JP-2<br>Different for RP-1 and RP-2 |
| Seepage loss | Observed depths 1.7, 1.0, 1.96 m during monsoon and 1.8, 1.1 and 2.28 m during the year in RP-1, RP-2 and JP-1/JP-2 respectively. | -do- |
| Drainage area | 0.66, 0.37, 1.75 ha for RP-1, RP-2 and JP-1/JP-2 | Depending on location of SFR in MW. |
| **Water demand** | | |
| (i) Monsoon | Rice crop 2 irrigation each 5 m in R-1<br>1 irrigation 4 cm in R-2<br>2 irrigation 10 cm in J-1/J-2<br>Non rice crops 2 irrigation 5 cm in J-1/J-2<br>No irrigation in R-1 and R-2<br>vegetables 4 irrigations each 7.5cm in R-1 J-1/J-2<br>4 irrigation each 5 cm in R-2 | Depending on location of rice area with respect to SFR and soil type, ET requirement and moisture replenishment in root zone. |
| (ii) Post-monsoon | Vegetables 2 irrigations each 7.5 cm in R-1<br>6 irrigations, each 10 cm in J-1/J-2 | Depending on ET, soil type, moisture depletion in the root zone. |
| | Others 1 irrigation, 4.9 cm in R-1 | For establishment of crop. |
| | 1 irrigation, 7.3 cm pigeon pea in R-2 | Monsoon sown late mature |
| | 1 irrigations, 5 cm each in R-2 | Gram and mustard |
| | 2 irrigations, 7.5 cm each in J-1/J-2 | Gram and mustard |
| Mean water area | Considering monsoon and post-monsoon seasons | Uniform for all SFR's |
| Depth of SFR | 1.8; 1.65 and 3 m in RP-1, RP-2, JP-1/JP-2 respectively. | Depending on geology of site |
| Rain catch area | Maximum inside area of SFR at the top of side bunds | Contributing direct rainfall |
| Freeboard | Not considered | Taken care by side bunds |
| Side slope | 1:1 (H : V) | Observed to be safe |
| Excess runoff to be diposed | To store 100% runoff in SFR | Assumed to be zero |
| Total water gains | Direct rainfall, runoff in all SFRs additional seepage contribution in JP-1/JP-2 | |
| Seepage contribution | Measured in nearby lined pit (except seepage face in u/s side 20 m x 20 m x 3 m | JP-1/JP-2 only |
| Total water loss from SFR | Evaporation + seepage + irrigation | Irrigation too considered as loss for water budgeting. |

evaporation for different locations (JP-1 and JP-2; RP-1 and RP-2) in the same agroclimatic zone were almost same.

The runoff model output (Section 5.4.4) for expected amount of rainfall and runoff at various probabilities of exceedence were used in working out mean water surface area of SFR's. The seepage losses in SFR's were worked out by the water balance approach (section 4.8), after assessing the input and output components of SFRs daily. The observed mean depth of water in SFR's during monsoon season was 1.35, 1.20, 2.70 and during the year was 1.08, 0.89, 1.42 in SFR's, RP-1, RP-2 and JP-1/JP-2 respectively.

The depth of SFR was decided considering the geology of sub-strata at Raipur whereas at Jagdalpur besides geology, the considerations were given for fish rearing - for which 3 m depth was considered appropriate (FAO, 1998). The optimum depth was worked out using equations 4.23 and 4.30 for Raipur and Jagdalpur respectively.

For assessing the water demand, no supplemental irrigation was considered for non-rice crops grown at Raipur for the crops of soybean and pigeonpea because in the later part of crop growth when dry spell is expected, drains were used as tiny reservoirs by blocking them at about 10 m intervals which served for recharging the soil profile as moisture conservation technique. Supplemental irrigation were provided to only rice crop grown d/s of SFR at Raipur through gravity irrigation. Irrigation demand of crops were worked out considering the soil type, ET requirement (sections 5.6.4 and 5.6.5), crop growth stages and the actual moisture replenishment needed in the crop root zone. Moderate dry spell is expected at late maturity stage at Jagdalpur. Considering the location (u/s of SFR) of upland rice and percolation losses from rice fields, higher irrigation requirement of 10 cm was considered for rice crop whereas the same for non-rice area was considered as 15 cm (Table 5.3). the details of water demand in microwatershed was worked out considering both monsoon and postmonsoon season (Table 5.4).

Table 5.4 **Estimation of water use (U) of SFRs**

| MW | Crops | Monsoon | | | | Post-monsoon | | | | Total ha-m |
|---|---|---|---|---|---|---|---|---|---|---|
| | | No. of irrigation | Depth cm | Area ha | Water use ha-m | No. of irrigation | Depth cm | Area ha | Water use ha-m | |
| R-1 | Rice | 1 | 5 | 0.30 | 0.015 | - | - | - | - | 0.015 |
| | Non-rice | - | - | - | - | 1 | 4.9 | 0.80 | 0.039 | 0.039 |
| | Vegetables | 4 | 7.5 | 0.05 | 0.015 | 2 | 7.5 | 0.06 | 0.009 | 0.024 |
| | Total | - | | 0.35 | 0.030 | - | - | 0.86 | 0.048 | 0.078 |
| R-2 | Rice | 1 | 4 | 0.58 | 0.023 | - | - | - | - | 0.023 |
| | Non-rice | - | - | - | - | 1 | 7.3* | 0.55 | 0.036 | 0.036 |
| | Vegetables | 4 | 4 | 0.03 | 0.006 | 2 | 7.5 | 0.06 | 0.009 | 0.015 |
| | Total | - | - | 0.61 | 0.029 | 0 | 0 | 0.51 | 0.045 | 0.074 |
| J-1&J-2 | Rice | 2 | 10 | 0.50 | 0.100 | - | - | - | - | 0.100 |
| | Non-rice | 2 | 5 | 0.60 | 0.060 | 2 | 7.5 | 0.74 | 0.111 | 0.171 |
| | Vegetables | 4 | 7.5 | 0.10 | 0.030 | 6 | 10.0 | 0.60 | 0.240 | 0.270 |
| | Total | | | 1.20 | 0.190 | - | - | 1.34 | 0.351 | 0.541 |

It included (i) Pigeon pea grown in 0.37 ha with water use of 0.027 ha-m at 7.3 cm irrigation.
(ii) Gram and mustard grown in 0.18 ha with water use of 0.009 of ha-m at 5.0 cm irrigation

In the Post-monsoon season, one come up irrigation of 4.9 and 5.0 cm was considered in view of the good amount of residual moisture available in **R-1** and **R-2,** respectively. This was required to establish crops like gram and mustard. In the other microwatersheds due to less availability of residual moisture, two irrigations were considered for non-vegetable crops. Taking into account the length of growing period of crops, besides other soil moisture parameters and critical crop growth stages, 2 and 4 irrigations were considered for MWs (R-1, R-2) at Raipur and MWs (J-1, J-2) at Jagdalpur respectively. The number and depth of irrigations, area covered and water use during monsoon, post-monsoon season and the total of the two seasons were worked out. In this way the water use (u) in equation 4.34 was determined for subsequent calculations of mean area 'a' of SFRs.

The capacity of SFR's were determined, after working out mean water area 'a' for the different alternative design at different probabilities of exceedence. The detailed dimensions of SFR were worked out by considering the mean water area for different alternative designs for 3 regular shapes of SFR.

## 5.8 CONSTRUCTIONAL DETAILS OF SFRs

A circular shape of SFR was preferred at Jagdalpur (JP-1, JP-2) (Plate 3) as it gives the minimum wetted perimeter for a given volume of storage, thereby minimising the seepage loss. On the other hand rectangular shape was selected at Raipur (RP-1, RP-2) (Plate 4) to make conformity with existing bunds/field roads. With side slopes (1:1), the SFR was an inverted frustum of a cone with top diameter of 56 m, bottom diameter of 50 m and depth of 3 m, for the design runoff arrived against 80% probability of exceedence. The storage volume at full water level of this SFR worked out to be 6640 $m^3$. The SFR for MWs J-1 and J-2 were constructed with dozers down to a depth of 2.0 m. Excavation beyond this depth was done manually. The SFR's at Raipur (R-1, R-2) were constructed completely with dozers as per the design

Plate 3. Circular SFR in J-1 and J-2 at Jagdalpur

Plate 4. Rectangular SFR in R-1 and R-2 at Raipur

specifications arrived against 80% probability of exceedence. To facilitate the inflow of surface runoff, 30 cm diameter hume pipe inlet was provided with suitable stilling tank and antiseep collar arrangements (Plate 5). The SFRs were not provided with an outflow structure. Excess water was diverted into a diversion drain. This excess water was stored in rice fields, d/s to SFRs, at Raipur (Plate 6).

### 5.9 WATER BALANCE OF SFRs

The surface runoff flowing into the SFR was measured by automatic stage level recorder as well as by observing the accretion in the SFR water levels after rainfalls. The evaporation from open water surface of SFR was estimated by multiplying a factor of 0.66 (Khandelwal, 1999) to the daily open pan evaporation data recorded in USWB class A open pan evaporimeter. Daily rainfall data was recorded by Symon's non-automatic rain-gauge. Meteorological parameters were also obtained from the IGAU observatory located within 0.5 Km from the study site. Automatic weather station was installed at the study sites with data logger to monitor water levels in SFR (Plate 6). Daily water budgeting of SFR was carried out in order to partition various hydrological parameters viz. rainfall, runoff, evaporation, seepage losses, irrigation etc. Evaporation and seepage losses were estimated by equations 4.41 and 4.42. As mentioned earlier, the SFR's did not have any outflow arrangement of its own because these were designed to conserve all of the rainwater in excess to crop requirement. Excess water if any, a part of it was pumped into the SFRs after closing its inlet (Jagdalpur) or stored in rice fields, d/s to SFR (Raipur). Incoming water, if any, was diverted into a diversion drain close to the inlet which, for water budgeting purpose, was cosidered as outflow from SFR. At certain times, an increase in pond water level was observed (**JP-2, JP-2**) even if there was no rain or direct runoff flowing into the SFR. Such inflow was treated as contribution of seepage from the u/s areas. Parallel measurements were also taken from 20 m x 20 m x 3 m pit in nearby area. It was lined

Plate 5. SFR in J-1 showing main drain, silt trap and inlet

Plate 6. Rice grown, D/s of SFR benefited by its seepage, gravity irrigation and unaccomodable runoff, in the foreground automatic weather station is seen

at all sides except u/s seepage face. The sediment concentration in the runoff was determined by analysis of the samples of runoff water taken periodically.

## 5.10 DESIGN OF DRAINAGE SYSTEM

Time required for removal of excess water is 6-8 hours for vegetable crops, 24 hours for general crops, 72 hours for rice crop (Gupta *et al.,* 1971). In experimental MWs, **R-1** and **R-2** rice was not grown in the drainage contributing area but in MWs, **J-1** and **J-2** rice was grown in uplands. Vegetables were grown in smaller raised area / uplands required less intensive drainage. Considering all these factors and the area covered under these crops, a weighted value of the time to remove excess water was taken as 16 hours. The annual maximum value of runoff were selected from the estimated values of daily runoff by CN technique (5.1.1). Daily maximum runoff data of 31 years (**R-1, R-2**) and 30 years (**J-1, J-2**) were arranged in descending order of magnitudes and the recurrence interval in years was computed by the Weibull's formula. Next, the magnitudes of runoff were plotted against the corresponding recurrence intervals and the magnitude corresponding to 1.25, 1.33, 1.66, 2 and 5 years recurrence intervals were interpolated from the plotted graphs. Thus, the recurrence intervals selected were 1.24, 1.33, 1.66, 2 and 5 years for working out the alternative designs of drainage system. Annual maximum values of daily runoff expected at above 5 levels of recurrence intervals were worked out. This was converted into discharge by considering 16 hours as the excess removal time (Sahu 1999). Using this as the design drainage coefficient and adopting Manning's equation for the hydraulic design (with n = 0.04, side slope Z = 1 : 1, s = 0.001 m/m), the channel flow depth was determined, including a freeboard of 0.2 times the flow depth for trapezoidal section.

Looking to the good drainage requirements of the Kharif crops and high runoff potential of soils in the MWs, a close spacing of 10 m and 7 m between the adjacent drains was adopted at Jagdalpur and

Raipur respectively. The kharif crops included soybean, groundnut, pigeon pea and small proportion of area under vegetables and tuber crops. All these drains led to a collector and then to main drain which ultimately led to the inlet of S.F.R. Before entering the water into SFR, silt traps were placed to collect coarser particles of silt load of the runoff. The layout of the drainage system for all the microwatersheds are shown in Figures 3.3 to 3.6; Plates 7 and 8.

## 5.11 RUNOFF SEDIMENT LOAD

The sediment concentration in runoff was determined by analysis of the samples of runoff water at fortnightly interval for a period of 3 years in the microwatersheds. With the runoff calculated at various levels of probability of exceedence, the sediment deposition for the same were worked out. Thereafter the resulting capacity reduction was estimated. The sedimentation in SFR takes place due to sediment inflow with runoff and also due to erosion of the SFR sides and banks. The later two components are difficult to measure. Hence to find the capacity loss due to sedimentation, capacity survey was conducted after first, second and third years of study in the dry season. Assuming the third year sedimentation value as the stabilised sedimentation rate and accounting for the higher sedimentation in the initial years, the capacity reduction of SFR's were calculated for 10, 15, 30 and 40 years of life respectively.

## 5.12 FISH PRODUCTION

Fish rering in the small water bodies is a common practice in the region. Rish fingerlings were raised (enhancement of fish seeds from 1-2 cm size to 15-20 cm within a period of 45-60 days) in the SFRs of **R-1** and **R-2**. Fish rearing in SFRs **J-1** was carried out with pig dung (**J-1**) and cowdung including dairy washings (**J-2**) as a base feed (Plate 9). The common ration of oilcakes, rice straw and others were supplied to fishes, of **J-1** and **J-2**. Fish variety ratio in these SFRs were : Rohu 15 : Mrigal 70 : Grass Carp 15. At the start of monsoon season

Plate 7. SFR's inlet, main drain and silt trap along with post-monsoon crops in J-2

Plate 8. SFR based farming alongwith drainage system

liming [$CaO$ and $Ca(OH)_2$)] was done to disinfect the SFR bottom @ 1 t/ha of water area. Intake waters were screened to prevent predators from entering the culture ponds, as per the normal procedures (FAO, 1998).

## 5.13 IRRIGATION REQUIREMENT

Irrigation requirement of crops were worked out by considering soil texture, critical crop growth stage, ET requirement, excepted length of dry spell and soil water replenishment needed as worked out in previous sections. The water requirement of rice was worked out by considering its location d/s (**R-1, R-2**) or u/s (**J-1, J-2**) of SFR besides above factor (Plate 10). Considerations were given to water requirement of rice from output obtained by Markov-chain modelling of rainfall and dry spell. Monsoon vegetables (Okra followed by radish) were supplied two irrigations, one each to okra and radish. Fruits (Papaya + soybean) in **J-1** were provided four irrigations, two irrigations (1000 $m^3$/ha) in monsoon season and two irrigation (200 $m^3$ha) in post monsoon season (Plate 11). Soybean was harvestred in monsoon season, therefore, post-monsoon irrigation pertains to only papaya, supplied in the basins. Fruits (Banana + green chillis) in **J-2** were provided four irrigations, two irrigations each in monsoon (1000 $m^3$/ha) and post-monsoon (1400 $m^3$/ ha) season (Plate 12). Tubers (Tapioca grown with groundnut) in **J-1** were provided two irrigations (750 $m^3$/ha each) (Plate 13), while in **J-2** only one irrigation was provided to tuber (sweet potato) crop (Plate 14). In **J-1** while groundnut was harvested in monsoon season, tapioca was extended to some portion of post-monsoon season because of longer duration. Soybean and groundnuts were grown with SFR water in **J-1** (Plate 15). Vegetables were also grown in both the seasons with SFR water (Plate 16 and 17), irrigation requirements is shown in Table 6.38 and 6.39. Besides above crops, intercropping of pigeon pea and groundnut (Plate 18) and gram and mustard (Plate 19) were also irrigated by SFRs.

Plate 9. Dairy effluent (washings) directed in the SFR to serve as fish feed and seepage retardant

Plate 10. Rice, U/s of SFR in J-1, is seen with pigeonpea grown on rice bunds

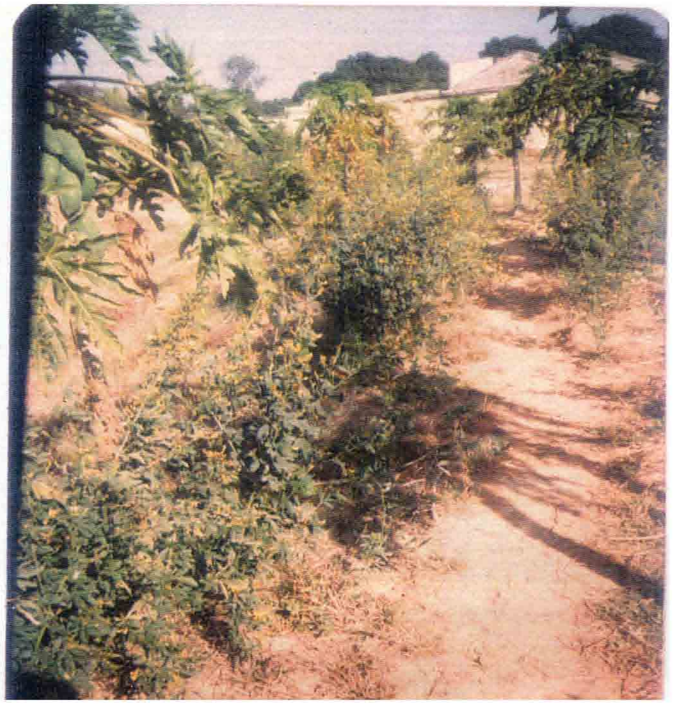


Plate 11. Papaya grown in J-1 with SFR water

Plate 12. Banana grown in J-2 with SFR water.

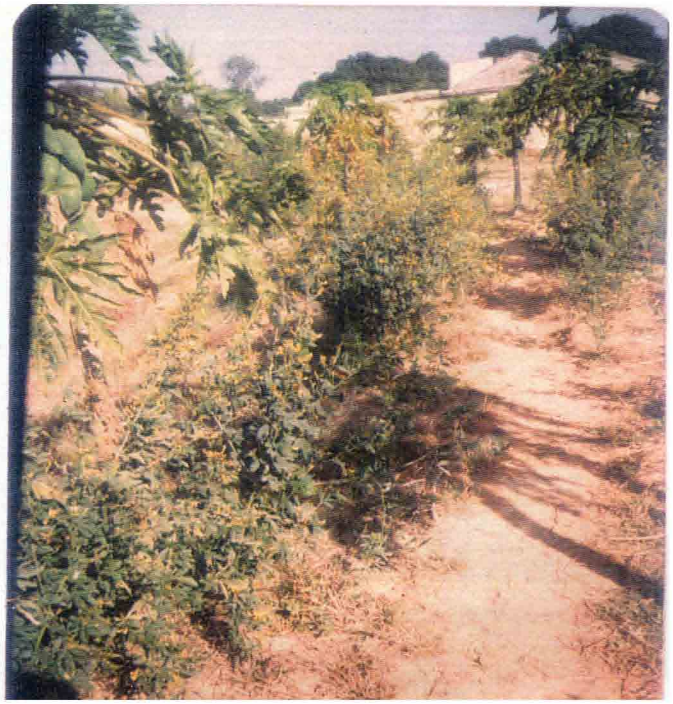


Plate 11. Papaya grown in J-1 with SFR water

Plate 12. Banana grown in J-2 with SFR water.

Plate 13. Tuber crop (Tapioca) grown in J-1

Plate 14. Tuber (Sweet potato) grown in SFR embankment and soybean is seen below in J-2


Plate 15. Soybean grown on embankment and groundnut is seen below in J-1

Plate 16. Vegetables grown in J-1 with SFR water

Plate 17. Vegetables grown in J-2 with SFR water

Plate 18. Intercropping of pigeonpea and groundnut (1:3) grown in J-1 with SFR water

Plate 19. Mustard and gram with one irrigation from SFR

Single phase 2 H.P. monoblock electric pumpset with discharge of 21.6 $m^3/hr$ was used to lift water from SFR. In **R-1** and **R-2**, gravity system with no extra pumping cost was adopted to irrigate downstream rice fields. A portable low cost sprinkler with 4 sprinkler heads fitted in GI pipes and run by power tiller operated pump (3HP) was used to irrigated post-monsoon crops in **R-1** and **R-2** with a discharge of 21.6 $m^3/hr$.

## 5.14 ALLOCATION OF SFR WATER TO CROPS

It may be recalled from section 5.7 that corresponding to different probabilities of exceedences of rainfall and runoff, different SFR designs were arrived at. Each design ensures a certain volume of water available for distribution to different crop activities for irrigation and also for fish rearing. The linear programming approach was adopted to different crop activities (type and area under the crop) with the objective of maximizing the net returns from the crop production and fish rearing activities. While applying linear programming approach it was assumed that the input and output relationship are linear within the limited water resources as input. The details regarding the crop activities, area under the crop, the constraints etc. are discussed in detail in Section 6.18 under Chapter VI - Results and Discussion.

## CHAPTER VI

# RESULTS AND DISCUSSION

### 6.1 AGRO-ECOLOGICAL REGION

The study site at Raipur comes under agro-ecological region 11 J3 C3. This region is described as Eastern Plateau (Chhattisgarh), hot sub humid eco-region with red and yellow soils and growing periods vary from 150 - 180 days. The other site at Jagdalpur comes under agro-ecological region 12 J2 C3 (4). This region is described as Eastern (Chhotanagpur) plateau and Eastern ghats, hot, sub-humid eco-region with red and lateritic soils, growing periods vary from 150 - 200 days (NBSS & LUP - 1992).

### 6.2 CLIMATIC WATER BALANCE

Detailed analysis of the water availability indicated that the humid periods, which is important for rice cultivation varies from 115 days (Raipur) to 137 days (Jagdalpur). The total combined duration of humid and moist periods are considered suitable for rice cultivation right from sowing operations to crop maturity. Thus the rice growing season of the study areas vary from 171 days at Jagdalpur to 142 days at Raipur (World Bank, 1995).

Climatic water balance helps in partitioning the rainfall in relation to the PET demand of the atmosphere, into the soil moisture accumulation, actual ET, water deficit and water surplus. The annual PET was higher than the annual rainfall at one of the study site (Raipur) while it was lower at the other (Jagdalpur) with higher annual water deficit at the former as compared to later (Table 6.1). Annual water surplus was also lower at Raipur as compared to Jadalpur. Soil moisture

**Table 6.1 Climatic water balance of study sites**

| Particulars | | | Raipur | Jagdalpur |
|---|---|---|---|---|
| **Annual** | | | | |
| 1. | Annual rainfall (mm) | | 1260.4 | 1534.1 |
| 2. | Annual PET (mm) | | 1762.0 | 1422.2 |
| 3. | Annual AET (mm) | | 909.7 | 869.6 |
| 4. | Annual water surplus (mm) | | 525.6 | 632.6 |
| 5. | Annual water deficit (mm) | | 896.8 | 525.9 |
| 6. | Beginning of soil moisture recharge | | 10 June | 3 June |
| 7. | End of soil moisture recharge and beginning of water surplus | | 21 July | 18 July |
| 8. | End of water surplus and beginning of soil moisture use and water deficit | | 27 Sept. | 15 Oct. |
| 9. | Humid periods (days) | | 115 | 137 |
| 10. | (Humid + Moist) periods - rice growing season (days) | | 142 | 171 |
| **Growing season (Monsoon)** | | | | |
| 1. | Rainfall (mm) | | 1202.0 | 1366.0 |
| 2. | PET (mm) | | 569.0 | 466.0 |
| 3. | Soil storage (mm) | MW1 | 370.0 | 370.0 |
| | | MW2 | 350.0 | 350.0 |
| 4. | Runoff and percolation losses (mm) | MW1 | 263.0 | 530.0 |
| | | MW2 | 284.0 | 586.0 |
| 5. | Loss to rainfall (%) | MW1 | 21.9 | 38.8 |
| | | MW2 | 23.6 | 42.9 |
| 6. | Loss per day (mm) | MW1 | 1.9 | 3.8 |
| | | MW2 | 2.0 | 4.2 |
| 7. | Available water for post-rice crop (mm) | Soil | 168.0 | 168.0 |
| | | Rainfall | 8.0 | 14.0 |
| | | Total | 176.0 | 182.0 |

recharge process begins one weak earlier at Jadalpur and ends 3 days earlier as compared to Raipur (Fig 3.2).

Growing season water balance at the two study sites (Table 6.1) indicate for ample rainwater availability during rice growing period directly from rains. At the same time, the excess water in the form of losses and soil storage are also substantially higher at Jagdalpur (586 - 530 mm) as compared to Raipur (284 - 263 mm). Thus, the available rainfall can meet the complete water requirement of rice, if all the available rain water can be stored in the field. Some of losses are unavoidable due to higher percolation rates and erratic distribution of rains. If the excess runoff water is stored in the dug out farm ponds at each farmer's field, it is possible to check flooding and avoid drought risk in monsoon season as well as establishing second crop.

## 6.3 ESTIMATION OF SURFACE RUNOFF

The surface runoff estimated by the four runoff estimation models are presented and discussed in this section.

### 6.3.1 Conservation Factor Approach (CF)

Conservation factors for the experimental watersheds were worked out as described in section 4.1 and selecting the numerical values for the input parameters as given by Bajpai (1999). These values are presented in Table 6.2. The high value of CF in J-1 as compared to J-2 showed its relative low runoff potential due to better conservation measures adopted. The regression models were developed for annual, monsoon and monthly runoff estimation (Table 6.3) showed highly significant correlation between CF and runoff at both the study sites, $R^2$ value being more than 0.8259.

Summary of the monthly and monsoon runoff is presented in Table 6.2 indicating higher variability of monsoon runoff at Raipur as compared to Jagdalpur. Similar trend followed for monthly runoff, therefore, it can

**Table 6.2 Conservation factors for the microwatersheds**

| Particulars | Raipur | | Jagdalpur | |
|---|---|---|---|---|
| | R-1 | R-2 | J-1 | J-2 |
| Land use | 30 | 30 | 30 | 30 |
| Soil conservation measures | 15 | 15 | 25 | 15 |
| Soil type | 10 | 10 | 10 | 10 |
| Conservation factor (CF) | 55 | 55 | 65 | 45 |

be concluded that CF method gave better estimation of runoff in *plateau* as compared to *plains.*

### 6.3.2 Curve Number Method (CN)

The runoff estimated by this method at two different microwatersheds in each of the two agroclimatic zones are presented in Table 6.4. The coefficient of variation of estimated monsoon runoff was found to be very close to that of monsoon rainfall indicating the stability in runoff estimation except in MW, R-2 where the pigeon pea growth is very sensitive to high intensity storms and consequent drainage problem affecting runoff. The monthly runoff showed higher variability than seasonal runoff. June, the starting month of monsoon showed higher variability of runoff than rest of the months particularly in R-1 and R-2 when compared to rainfall variability.

### 6.3.3 Strange's Method

Table 6.4 gives the seasonal runoff values estimated by Strange's method. It is associated with higher degree of variability as compared to the variability of seasonal rainfall. These results indicate the instability of the method in runoff estimation at microlevel. However due to expeditious estimation with the help of ready made tables, this method find place in the minor irrigation / P.W.D. works for comparatively larger areas (GOMP, 1996).

**Table 6.3 Regression models for estimation of runoff using conservation factor approach**

| MW | Period | Regression model | $R^2$ |
|---|---|---|---|
| R-1 | Annual | $Y = X/(0.062 - 0.002X)$ | 0.9204 |
| | Monsoon | $Y = 6.1229\ X^2 + 9.6931\ X - 8.4083$ | 0.9740 |
| | June | $Y = 32.4712\ X^2 - 14.8274\ X + 15.1007$ | 0.9898 |
| | July | $Y = 26.6136\ X^2 - 20.5568\ X + 27.5757$ | 0.9777 |
| | August | $Y = 823.3271 - (2436.1590/X) + 1937.3758/X^2$ | 0.8808 |
| | September | $Y = 50.7845\ X\ (1.6316/X)$ | 0.9151 |
| | October | $Y = 30.1154\ X^2 - 8.3738\ X + 1.9254$ | 0.9878 |
| R-2 | Annual | $Y = 70.6486\ X = 398.0234$ | 0.9842 |
| | Monsoon | $Y = 70.6976\ X - 349.1522$ | 0.9795 |
| | June | $Y = 85.5010\ X - 130.4032 + (61.4463/X)$ | 0.9882 |
| | July | $Y = 1291.602 * (0.0004)^{(1/X)}$ | 0.9677 |
| | August | $Y = 1059.7493 - (5333.3766/X) + (7287/X^2)$ | 0.9571 |
| | September | $Y = 46.6651\ X - 24.0607$ | 0.8951 |
| | October | $Y = 12.84\ X^2 - 5.1404\ X + 2.1282$ | 0.8259 |
| J-1 | Annual | $Y = 2490.1558-(55486.3335/X)+(360316.7677/X^2)$ | 0.9974 |
| | Monsoon | $Y = 32.9781\ X$ | 0.9563 |
| | June | $Y = 422.2634/\exp\ (5.7005/X)$ | 0.9987 |
| | July | $Y = 1/(0.0112 - 0.001\ X)$ | 0.9196 |
| | August | $Y = 38.3314\ X$ | 0.9723 |
| | September | $Y = X\ /\ (0.0359 - 0.0015\ X)$ | 0.9977 |
| | October | $Y = 28.5262\ X$ | 0.9882 |
| J-2 | Annual | $Y = 68.5820\ X - 104.1256$ | 0.9909 |
| | Monsoon | $Y = 60.6489\ X$ | 0.9684 |
| | June | $Y = 255.1534 * (0.0752)^{(1/X)} * (X)\hat{}\ 0.3731$ | 0.9992 |
| | July | $Y = 1\ /\ (0.0101 - 0.0016\ X)$ | 0.9767 |
| | August | $Y = 70.8951\ X$ | 0.9777 |
| | September | $Y = X/\ (0.0176 - 0.0007\ X)$ | 0.9997 |
| | October | $Y = 53.9264$ | 0.9834 |

**Table 6.4** **Surface runoff estimated by different methods (Data base : Raipur 31 years, Jagdalpur 30 years)**

(mm)

| Particulars | | June | | July | | August | | September | | October | | Monsoon | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | CV(%) | Mean | CV(%) | Mean | CV(%) | Mean | CV(%) | Mean | CV(%) | Mean | CV(%) |
| **RAIPUR** | | | | | | | | | | | | | |
| Rainfall | | 185.3 | 65.9 | 306.4 | 40.5 | 335.1 | 31.7 | 180.5 | 68.9 | 46.6 | 103.2 | 1053.8 | 23.6 |
| Curve No. | R-1 | 82.0 | 125.6 | 148.2 | 71.0 | 160.0 | 53.0 | 69.2 | 137.4 | 6.0 | 157.5 | 465.5 | 21.4 |
| | R-2 | 82.4 | 125.1 | 148.2 | 71.0 | 168.1 | 51.6 | 72.6 | 133.7 | 6.7 | 155.1 | 478.1 | 39.0 |
| Strange | | - | - | - | - | - | - | - | - | - | - | 446.2 | 51.3 |
| Binnie | | - | - | - | - | - | - | - | - | - | - | 446.6 | 44.8 |
| Cons. factor | R-1 | 78.9 | 133.1 | 134.9 | 73.1 | 171.1 | 44.6 | 53.0 | 61.1 | 5.9 | 157.5 | 444.9 | 44.0 |
| (CF) | R-2 | 89.0 | 113.4 | 141.1 | 80.2 | 211.0 | 43.3 | 71.2 | 91.3 | 6.4 | 154.4 | 490.7 | 40.4 |
| **JAGDALPUR** | | | | | | | | | | | | | |
| Rainfall | | 256.7 | 47.1 | 346.8 | 25.5 | 354.7 | 39.0 | 194.3 | 39.8 | 81.7 | 86.6 | 1234.2 | 21.3 |
| Curve No. | J-1 | 131.7 | 70.6 | 204.2 | 32.2 | 212.4 | 48.2 | 96.6 | 50.4 | 33.4 | 120.7 | 678.2 | 26.8 |
| | J-2 | 149.0 | 66.7 | 218.6 | 33.6 | 227.6 | 50.1 | 99.2 | 54.1 | 33.0 | 130.5 | 727.3 | 27.3 |
| Strange | | - | - | - | - | - | - | - | - | - | - | 617.3 | 45.8 |
| Binnie | | - | - | - | - | - | - | - | - | - | - | 644.0 | 39.1 |
| Cons. factor | J-1 | 100.0 | 60.1 | 190.6 | 26.1 | 219.7 | 39.0 | 103.5 | 47.6 | 37.6 | 86.6 | 667.7 | 21.4 |
| (CF) | J-2 | 109.2 | 65.6 | 205.1 | 24.8 | 223.6 | 39.0 | 106.7 | 43.4 | 39.2 | 86.6 | 647.7 | 21.4 |

### 6.3.4 Binnie's Method

This method also estimates only seasonal runoff. The average estimated runoff was 42.4 and 52.2 per cent of rainfall in *plateau* and *plains* with CV of 44.8 and 39.1 per cent respectively (Table 6.4). Though the CV of runoff was high in comparison to rainfall, this variation was less pronounced than the Strange's method. Therefore it can be said that Binnie's method is more stable than Strange's method for runoff estimation. Binnie's method too is quite popular in use due to ease in computation.

## 6.4 VALIDATION OF RUNOFF MODELS

Table 6.5 shows comparison between observed and estimated runoff during monsoon season (June to Oct.) by four methods

**Average :** The average estimated runoff by CN in J-1, J-2, R-1 and R-2 were quite close to the observed runoff which accounted for 46.0, 48.4, 54.0 and 58.3 per cent of rainfall respectively. The average runoff was almost same as observed by CF. The Strange's and Binnie's method estimates runoff lower than the observed values (Tables 6.5 and 6.6).

**Per cent deviation from observed runoff :** Estimated runoff deviated within narrow range from observed values in CN and CF but the range was large in case of Strange's than Binnie's method.

**Mean of the difference with observed runoff :** It was of low order in case of CN and CF whereas in case of Binnie's and Strange's method the range was large and negative indicating underestimation of runoff.

**Coefficient of variation :** The CV of estimated runoff was quite close to the observed runoff in case of CN and CF indicating the stability in runoff estimation whereas in other two methods it was large showing the instability in runoff estimation.

**Paired t - test :** This test indicated that there were no significant differences in the means of estimated and observed runoff in all the MWs

**Table 6.5 Comparison between observed and estimated runoff during the monsoon period.**

| MW | Particulars | Rainfall (mm) | Observed runoff (mm) | Estimated runoff (mm) by different methods: Curve number | Strange | Binnie | Conservation factor |
|---|---|---|---|---|---|---|---|
| R-1 | Average | 1060.2 | 475.8 | 487.7 | 453.8 | 464.6 | 465.3 |
| | CV (%) | 25.8 | 45.9 | 46.9 | 57.7 | 48.5 | 46.8 |
| | % deviation from observed | - | - | +2.5 | -4.6 | -2.3 | -2.2 |
| | Mean of the difference with observed | - | - | +11.8 | -22.1 | -11.2 | -10.5 |
| | Paired t-test ($t_{7, 0.05}$) | - | - | 0.727 | 1.015 | 2.220 | 1.723 |
| R-2 | Average | 1105.9 | 544.6 | 534.9 | 492.8 | 503.5 | 547.1 |
| | CV (%) | 24.3 | 38.4 | 43.1 | 53.4 | 43.7 | 37.6 |
| | % deviation from observed | - | - | -1.8 | -9.5 | -7.5 | +0.5 |
| | Mean of the difference with observed | - | - | -9.7 | -51.8 | -41.1 | +2.6 |
| | Paired t-test ($t_{5, 0.05}$) | - | - | 0.484 | 1.564 | 2.600* | 0.208 |
| J-1 | Average | 1138.8 | 604.4 | 614.8 | 542.5 | 564.0 | 618.2 |
| | CV (%) | 30.4 | 33.4 | 35.8 | 66.8 | 55.0 | 30.2 |
| | % deviation from observed | - | - | +1.7 | -10.2 | -6.7 | +2.3 |
| | Mean of the difference with observed | - | - | +10.5 | -61.9 | -40.3 | +13.8 |
| | Paired t-test ($t_{5, 0.05}$) | - | - | 0.503 | 0.867 | 0.777 | 0.980 |
| J-2 | Average | 1138.8 | 625.2 | 663.6 | 542.5 | 546.0 | 625.6 |
| | CV (%) | 30.4 | 30.9 | 37.3 | 66.8 | 55.0 | 30.2 |
| | % deviation from observed | - | - | +6.1 | -13.2 | -12.7 | +0.1 |
| | Mean of the difference with observed | - | - | +38.3 | -82.7 | -61.2 | +0.4 |
| | Paired t-test ($t_{5, 0.05}$) | - | - | 1.175 | 1.119 | 1.141 | 0.0.29 |

* Significant at 5%

except Binnie's method that too in one MW, R-2 where the means of the differences in estimated and observed runoff were significant at 5% level of significance.

Performance evaluation of runoff estimation models is presented in Table 6.6.

**Table 6.6 Performance evaluation of selected runoff estimation techniques**

| Runoff techniques | Average | Per cent deviation from observed | Mean of the difference | Paired t-test |
|---|---|---|---|---|
| Curve number technique | Quite close to the observed runoff | -1.8 to +6.1 | -9.7 to +11.8 | Non-significant |
| Conservation factor approach | Almost same as observed | -2.2 to +2.3 | -10.5 +13.8 | Non-significant |
| Strange's method | Lower than observed runoff | -13.2 to -4.6 | -82.7 -22.1 | Non-significant |
| Binnie's method | Lower than observed runoff | -12.7 to -2.3 | -61.2 -11.2 | Non-significant |

### 6.4.1 Justification and Performance of New Criteria for AMC Limit In plateau

Past 6 years moisture data in crop root zone indicated that the subsurface flow used to enhance the moisture regimes to such an extent that the existing limits of the sum of past 5 days rainfall for AMCs cannot be used as such. It needed to be modified, accordingly new criteria of describing AMC's were developed (Section 4.2.1). Use of existing criteria resulted in underestimation of runoff by 23.4 per cent. It can be seen by comparing the observed and estimated runoff by CN method using modified and existing criteria of AMC (Table 6.7). In the process of development of new criteria, it was observed that in most of the cases, almost same moisture regime existed when the previous 5 days sum of rainfall were less than 10 mm in plateau, as that existed when the

**Table 6.7 Comparison of observed and estimated runoff by curve number method using modified and existing criteria of AMC**

| MW | Average run-off | Criteria | Jun. | Jul. | Aug. | Sept. | Oct. | Mon-soon |
|---|---|---|---|---|---|---|---|---|
| J-1 | **Average** | | | | | | | |
| | (i) Observed | | 70.7 | 189.1 | 198.4 | 112.1 | 34.2 | 604.4 |
| | (ii) Estimated | EM# | 57.0 | 166.3 | 134.4 | 77.9 | 27.3 | 462.9 |
| | (iii) Estimated | MM | 79.2 | 189.4 | 198.7 | 112.9 | 34.7 | 614.8 |
| | **CV%** | | | | | | | |
| | i) Observed | | 71.4 | 27.0 | 51.0 | 44.9 | 136.1 | 33.4 |
| | ii) Estimated | EM | 62.7 | 36.2 | 71.4 | 61.0 | 177.7 | 43.2 |
| | iii) Estimated | MM | 58.6 | 29.9 | 50.6 | 52.5 | 147.1 | 35.8 |
| | **% dev. from observed** | | | | | | | |
| | i) Estimated | EM | -19.4 | -12.0 | -32.2 | -30.5 | -20.1 | -23.4 |
| | ii) Estimated | MM | +12.1 | +0.1 | +0.2 | +0.7 | +1.5 | +1.7 |
| | **Paired t-test : $t_{5,\ 0.05}$)** | | | | | | | |
| | i) Obs. Vs. Est. | EM | 4.30** | 2.25 | 6.24** | 6.03** | 2.87* | 14.20** |
| | ii) Obs. Vs. Est. | MM | 2.08 | 0.04 | 0.05 | 0.11 | 0.13 | 0.50 |
| J-1 | **Average** | | | | | | | |
| | (i) Observed | | 72.8 | 197.3 | 202.9 | 115.9 | 36.3 | 625.2 |
| | (ii) Estimated | EM | 66.4 | 168.3 | 135.4 | 73.5 | 25.4 | 468.9 |
| | (iii) Estimated | MM | 79.8 | 215.4 | 212.8 | 116.4 | 39.2 | 663.6 |
| | **CV%** | | | | | | | |
| | i) Observed | | 70.1 | 24.0 | 49.4 | 44.5 | 131.6 | 30.9 |
| | ii) Estimated | EM | 74.0 | 36.9 | 85.1 | 68.9 | 193.7 | 47.5 |
| | iii) Estimated | MM | 63.5 | 23.4 | 54.7 | 52.1 | 151.1 | 37.3 |
| | **% dev. from observed** | | | | | | | |
| | i) Estimated | EM | -8.9 | -14.7 | -33.3 | -36.6 | -30.0 | -25.0 |
| | ii) Estimated | MM | +9.6 | +9.2 | +4.9 | +0.4 | +8.0 | +6.1 |
| | **Paired t-test : ($t_{5,\ 0.05}$)** | | | | | | | |
| | i) Obs. Vs. Est. | EM | 1.52 | 2.61* | 5.71** | 6.18** | 2.97* | 8.75** |
| | ii) Obs. Vs. Est. | MM | 1.37 | 2.35 | 1.01 | 0.05 | 0.49 | 1.17 |

* Significant at 5%
** Significant at 1%
#EM existing method
MM modified method

previous 5 days sum of rainfall were less than 36 mm in plains (AMC I). Similarly the equivalent moisture regime existed in plateau area, for the previous 5 days sum of rainfall exceeding 9.9 mm as that existed in plains when previous 5 days sum of rainfall were more than 53 mm (AMC III). The AMC II condition is escaped or of very short duration in platea. On the same pattern, the criteria of AMC for plateau during post-monsoon season were developed. It may be noted that unlike in plains (dormant and growing season), uniform criteria was evolved for non-monsoon months irrespective of dormant season because of occurrence of rainfall, in the months of April and May by local cyclonic activity.

The performance evaluation of this new criterion of deciding AMC over the existing criteria is presented in Table 6.7. The performance was adjudged by 4 parameters viz. average, CV (%), per cent deviation from observed runoff, and finally by paired t-test. This was done for monthly as well as seasonal runoff for two locations (J-1, J-2) of plateau. The results are summarised below :

(i) The existing criteria of AMC under estimates runoff by 23.4 per cent in J-1 and 25 per cent in J-2, where as the modified criteria estimates runoff quite close to the observed ones with difference of +1.7 per cent in J-1 and +6.1 per cent in J-2.

(ii) The seasonal as well as monthly variability in runoff estimation associated with existing AMC criteria was higher as comapred to those associated with modified AMC criteria and observed values.

(iii) Paired t-test indicated that the estimated runoff using existing AMC criteria was significantly different than that of observed runoff in most of the cases, seasonal as well as monthly values. On the other hand, no significant differences existed between observed runoff and those estimated by using the modified AMC criteria.

These results demonstrated that the existing criteria of AMC in runoff estimation by CN resulted in underestimation of runoff and the developed new criterion of AMC estimated runoff quite close to the observed runoff in plateau areas of Chhattisgarh.

### 6.5 COMPARISON BETWEEN RUNOFF ESTIMATED BY PAIRS OF METHODS

Comparative performance of the 4 runoff estimation methods was evaluated by comparing the runoff estimated by two methods. It was done by forming 6 different pairs (Table 6.8). For this purpose long term historical and short term recent data were used as shown in this table. Two parameters were used for comparison (i) mean of the difference and (ii) paired t-test - t values at appropriate level of significance. The results are summarised below :

(i) As seen in Tables 6.5 and 6.6, CF and CN estimate runoff close to the observed runoff. Paired t - test applied for this pair (Table 6.8) further confirmed that there were no significant difference in the means of the runoff estimted by two methods.

(ii) Comparison of runoff estimated by CF and Strange's method revealed significant differences using long term data in some of the MWs (R-2, J-2) while in remaining the difference in runoff were insignificant. Similarly short term data also show insignificant differences in the runoff estimated by two methods. Similar trend was observed in the runoff estimated by CF and Binnie's method.

(iii) The comparison of runoff estimated by CN and Strange's method shows significant difference while using long term data and insignificant difference while using short term data. Similar trend can be seen while comparing CN and Binnie's method.

(iv) Insignificant differences existed between the runoff estimated by Binnie's and Strange's methods.

From the above results some salient features emerged regarding comparative performance of methods.

(i) CF and CN were at par in all the MWs.

**Table 6.8 Paired comparison of seasonal runoff estimated by different methods over long and short term data**

| MW Parameters | | Pair of methods for comparison | | | | | |
|---|---|---|---|---|---|---|---|
| | | CF vs. CN | CF vs. Strange | CF vs. Binnie | CN vs. Strange | CN vs. Binnie | Binnie vs. Strrange |
| | M.D. 31+ | -20.7 | -1.4 | -1.7 | +19.3 | +19.3 | +0.3 |
| | 8+ | -22.4 | +11.5 | +0.7 | +33.9 | +23.0 | +10.9 |
| R-1 | | | | | | | |
| | $t_{30,\ 0.05}$ | 2.219 | 0.225 | 1.003 | 1.531 | 1.962 | 0.060 |
| | $t_{7,\ 0.05}$ | 1.204 | 0.542 | 0.178 | 2.162 | 1.272 | 0.533 |
| | M.D. 31+ | +12.6 | +44.5 | +44.1 | +31.9 | +31.5 | +0.3 |
| | 6+ | +12.3 | +54.3 | +43.7 | +42.1 | +31.4 | +10.7 |
| R-2 | | | | | | | |
| | $t_{30,\ 0.05}$ | 1.210 | 5.501** | 11.330** | 2.610** | 3.341** | 0.060 |
| | $t_{7,\ 0.05}$ | 0.539 | 1.734 | 4.852** | 2.220 | 1.436 | 0.413 |
| | M.D. 30+ | -11.5 | 48.8 | 22.7 | +60.3 | +34.1 | +26.1 |
| | 6+ | -145.3 | -73.0 | -148.7 | +72.3 | -3.4 | +75.7 |
| J-1 | | | | | | | |
| | $t_{29,\ 0.05}$ | 1.234 | 1.825 | 0.921 | 2.884** | 1.702 | 1.495 |
| | $t_{5,\ 0.05}$ | 0.810 | 0.315 | 0.891 | 1.209 | 0.204 | 1.023 |
| | M.D. 30+ | -52.7 | +56.8 | +30.7 | +109.5 | +83.4 | +26.1 |
| | 6+ | -37.9 | +83.1 | +61.6 | +121.0 | +99.5 | +21.5 |
| J-1 | | | | | | | |
| | $t_{29,\ 0.05}$ | 4.597* | 2.147* | 1.254 | 6.007** | 4.324** | 1.495 |
| | $t_{5,\ 0.05}$ | 1.411 | 1.136 | 1.108 | 2.466 | 2.536 | 0.553 |

M.D. Mean of the difference

\+ Number of years of data used for comparison

* Significant at 5%

** Significant at 1%

(ii) Binnie's and Strange's methods were also at par in all the MWs.

(iii) CF and CN were superior over other two methods.

## 6.6 SELECTION OF RUNOFF MODEL

Based on the above results and discussion regarding performance of four runoff models. Their merits and demerits are summarised in Table 6.9. In the light of above merits and demerits and the requirement, the following ranking can be made in descending order

CN > CF > Binnie's method > Strange's method. Based on the above merits, demerits, ranking and the physical requirement in use, the CN is selected.

## 6.7 COMPARISON OF RUNOFF FROM RICE, NON-RICE, MID-LAND RICE AND LOW-LAND RICE AREAS

As described earlier, farmers of the region are now coming forward to grow non-rice cash crops viz. soybean, vegetables, pigeon pea, groundnut, etc. not only for economical gain but also under compulsion of frequent drought. In view of these emerging crop diversification, it is imperative to compare runoff from rice and non-rice areas to assess the additional water harvesting potential available due to such activity. Similarly due to dietary habit, affinity to rice and increased population pressure, farmers are opting to grow or extend rice cultivation in sub-marginal lands, consequently reducing their runoff potential. It is, therefore, necessary to assess the reduction in runoff water harvesting potential from such areas.

### 6.7.1 Rice Vs Non-rice Areas

The CN method distinguishes runoff from rice and non-rice areas. The runoff estimated by this method is shown in Tables 6.10 and 6.11.

**Raipur** : The seasonal runoff from non-rice area (R-1) was found to be higher by 19.5 and 75.8 per cent from low land and mid land rice area

**Table 6.9 Merits and demerits of selected runoff methods**

| Methods | Merits | Demerits |
|---|---|---|
| Conservation factor | 1. Estimation is close to the observed values<br>2. Less assumptions and easy to work out procedure<br>3. Slope of watershed is considered so works equally good in plains and plateau areas | 1. Regression models need to be developed for each period under consideration<br>2. Daily, weekly or fortnightly estimation of runoff is quite difficult as $R^2$ values are not obtained in acceptable range |
| Curve number | 1. With ready made charts and tables, it is easy to work out runoff<br>2. Takes care of periodical variations of crop, soil moisture etc. so better representing ground realities at micro level<br>3. Runoff can be worked out stormwise and later clubbed to any desired period<br>4. Runoff from paddy fields can be estimated which is impossible in other methods | 1. Slope has no consideration in this method unless suitably amended<br>2. Errors are likely to occur in proper selection of curve numbers<br>3. Accurate estimation requires programming to avoid tedious calculations |
| Strange's and Binnie's | 1. Less number of input variables required<br>2. Easy to workout procedures<br>3. Locally adopted in the region | 1. Periodical variations of crops, soil moisture etc. are not taken care of<br>2. Short period (say weeky, fortnightly or monthly) estimation is quite impossible |

***Table 6.10*** **Estimated runoff by CN for (i) Rice and non-rice areas (ii) Low land and mid land rice areas**

**(Runoff in mm)**

| Particulars | June | | July | | August | | September | | October | | Monsoon | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | CV% | Mean | CV% | Mean | CV% | Mean | CV% | Mean | CV% | Mean | CV% |
| **RAIPUR** | | | | | | | | | | | | |
| Rice-low land | 31.1 | 167.7 | 127.1 | 43.2 | 139.5 | 41.0 | 71.9 | 79.6 | 20.0 | 122.8 | 389.7 | 28.9 |
| Rice-mid land | 24.1 | 193.9 | 84.8 | 69.4 | 98.0 | 55.7 | 46.4 | 116.0 | 11.4 | 158.4 | 264.8 | 36.5 |
| Non rice R-1 | 82.1 | 125.6 | 148.2 | 71.0 | 160.0 | 53.0 | 69.2 | 137.4 | 6.0 | 157.5 | 465.6 | 39.5 |
| Non rice R-2 | 82.4 | 125.1 | 148.2 | 71.0 | 168.1 | 51.6 | 72.6 | 133.7 | 6.7 | 155.1 | 478.1 | 39.0 |
| % huigher in low lands | 29.0 | — | 49.9 | — | 42.3 | — | 55.0 | — | 75.4 | — | 47.3 | — |
| JAGDALPUR | | | | | | | | | | | | |
| Rice-Low land | 59.1 | 104.9 | 49.4 | 32.9 | 154.9 | 47.7 | 86.8 | 39.8 | 34.7 | 92.0 | 484.9 | 27.7 |
| Rice - Mid land | 47.1 | 123.5 | 96.5 | 46.0 | 96.8 | 68.9 | 43.3 | 64.6 | 20.2 | 140.8 | 304.0 | 36.1 |
| Non rice | 148.9 | 63.6 | 224.5 | 34.7 | 236.5 | 51.2 | 92.9 | 50.3 | 27.6 | 133.7 | 730.5 | 23.9 |
| % higher in low lands | 25.5 | — | 54.8 | — | 60.0 | — | 100.5 | — | 71.8 | — | 59.5 | — |

**Table 6.11 Comparison of runoff from rice areas and non rice areas in Chattisgarh**

| | Cropped area | Parameters | Runoff (mm) | |
|---|---|---|---|---|
| | | | Raipur | Jagdalpur |
| 1. | Low land rice areas | a) Average | 389.7 | 491.7 |
| | | b) CV (%) | 28.9 | 27.0 |
| 2. | Mid land rice areas | a) Average | 264.8 | 340.8 |
| | | b) CV (%) | 36.5 | 33.5 |
| 3. | Non-rice areas | a) Average | 465.6 | 730.5 |
| | | b) CV (%) | 39.5 | 23.9 |
| 4. | Paired t-Test | | | |
| i) | Low land rice Vs. Non rice | a) mean of the difference | -75.9 | -238.8 |
| | | b) Paired t-test | 3.5** | 10.2** |
| ii) | Mid land rice Vs. Non-rice | a) Mean of the difference | -200.7 | -389.8 |
| | | b) Paired t-test | 9.3** | 15.7** |
| iii) | Low land rice Vs. mid land rice | a) Mean of the difference | +124.8 | +151.0 |
| | | b) Paired t-test | 18.2** | 17.0** |

respectively. These values for non-rice area (R-2) were 22.7 and 80.6 per cent.

**Jagdalpur :** The runoff from non-rice area was found to be higher by 50.6 and 140.3 per cent from low land and mid land rice areas respectively.

The variability of monsoon runoff from low land rice is comparatively less, 28.9 per cent, as compared to non-rice area, 39.5 per cent, at Raipur. Paired t - test indicated that there exists significant differences in the runoff produced by rice and non-rice areas at Raipur and Jagdalpur.

The runoff pattern from rice and non-rice areas as analysed above can be used to explore two possibilities

(i) If midland rice is replaced by non-rice crops, the water harvesting potential can be enhanced by 200.8 and 389.7 mm at Raipur and Jagdalpur respectively.

(ii) If 20 per cent of mid land rice area (based on the assumption that the farmer opt to construct farm pond in 10 per cent of farm area, the dug out soil spread in 20 per cent surrounding area to have better drained area for growing vegetables, soybean, groundnut etc.) the water harvesting potential can further be enhanced by 15.2 - 15.7 mm at Raipur and 77.9 mm at Jagdalpur.

By adding the above figures for mid land and low land overall availability of runoff water harvesting potential can be enhanced by 216 mm at Raipur and 467.6 mm at Jagdalpur just by replacing rice with non-rice crops. This quantity is sufficient to grow second post-monsoon crop, if stored/conserved. The existing monocropped area can be benefitted by intensive farming, employment generation, assured water supply to cope up with frequent in-season drought and subsequent migration.

### 6.7.2 Low-land vs. Mid-land Rice Areas

The runoff estimated by CN was found to be higher in low land as compared to mid land (Table 6.11) due to higher percolation losses in the later and topographic advantage in the former. The mean monsoon total runoff was found to be 47.3 and 59.8 per cent higher at Raipur and Jagdalpur respectively with monthly figures ranged from 29-75.4 per cent at Raipur and 25.5 to 100.5 per cent at Jagdalpur (Table 6.10).

## 6.8 RAINFALL, RUNOFF DISTRIBUTION

### 6.8.1 Type of Rainfall Distributions

Tables 6.12 and 6.13 shows type of rainfall distributions fitted to different periods of monsoon season at Raipur and Jagdalpur respectively. In general, normal distributions were good fit to periods where variability of rainfall was comparatively less. In periods with high variability or low amount of rainfall, either exponential (in most of the cases) or Gamma distribution (in one case) fitted well to rainfall data. Annual as well as

| Period | SMW | Mean rainfall (mm) | CV (%) | Probability density function | Distribution |
|---|---|---|---|---|---|
| Annual | 1-52 | 1160.7 | 21.4 | $f\,(X, 1160.7,\ 247.9) = \frac{1}{621.5} e^{-\left[\frac{(X-1160.7)^2}{122948.5}\right]}$ | Normal |
| Monsoon | 22-43 | 1055.5 | 23.8 | $f\,(X, 1055.5,\ 250.7) = \frac{1}{628.5} e^{-\left[\frac{(X-1055.5)^2}{125721.0}\right]}$ | Normal |
| May 21 - Jun 3 | 21+22 | 10.1 | 163.9 | $f\,(X,\ 0.09873) = 0.09873\ e^{-0.09873X}$ | Exponential |
| Jun 4 - 17 | 23+24 | 54.6 | 134.8 | $f\,(X,\ 0.0183) = 0.0183\ e^{-0.0183X}$ | Exponential |
| Jun 18 - Jul 1 | 25+26 | 139.8 | 68.0 | $f\,(X,\ 0.007153) = 0.007153\ e^{-0.007153X}$ | Exponential |
| Jul 2 - 15 | 27+28 | 149.7 | 70.3 | $f\,(X,\ 0.006681) = 0.006681\ e^{-0.006681X}$ | Exponential |
| Jul 16 - 29 | 29+30 | 125.9 | 51.8 | $f\,(X\ 125.9,\ 65.2) = \frac{1}{163.4} e^{-\left[\frac{(X-125.9)^2}{8501.3}\right]}$ | Normal |
| Jul 30 - Aug.12 | 31+32 | 161.6 | 58.5 | $f\,(X, 161.6,\ 94.6) = \frac{1}{237.1} e^{-\left[\frac{(X-161.6)^2}{17887.0}\right]}$ | Normal |
| Aug. 13 - 26 | 33+34 | 141.7 | 50.4 | $f\,(X, 141.7,\ 71.5) = \frac{1}{179.2} e^{-\left[\frac{(X-141.7)^2}{10218.8}\right]}$ | Normal |
| Aug. 27 - Sept.9 | 35+36 | 117.5 | 53.0 | $f\,(X, 117.5,\ 62.3) = \frac{1}{156.1} e^{-\left[\frac{(X-117.5)^2}{7760.1}\right]}$ | Normal |
| Sept 10 - 23 | 37+38 | 90.1 | 125.4 | $f\,(X,\ 0.011103) = 0.011103\ e^{-0.011103X}$ | Exponential |
| Sept 24 - Oct.7 | 39+40 | 41.5 | 82.9 | $f\,(X,\ 0.024063) = 0.024063\ e^{-0.024063X}$ | Exponential |

**Table 6.13** ***Type of Rainfall distribution*, good fit to different periods at Jagdalpur**

| Period | SMW | Mean rainfall (mm) | CV (%) | Probability density function | Distribution |
|---|---|---|---|---|---|
| Annual | 1-52 | 1425.1 | 20.9 | $f\ (X, 1425.1,\ 297.4) = \frac{1}{745.4}\ e^{-\left[\frac{(X-1425.1)^2}{176845.9}\right]}$ | Normal |
| Monsoon | 22-43 | 1247.7 | 21.2 | $f\ (X, 1247.7,\ 264.5) = \frac{1}{662.9}\ e^{-\left[\frac{(X-1247.7)^2}{139888.8}\right]}$ | Normal |
| May 21-Jun 3 | 21-22 | 32.4 | 88.6 | $f\ (X, 1.2723,\ 25.5) = \frac{1}{61.6\ \ 1.2723}\ X^{0.2723}\ e^{X/25.5}$ | Gamma |
| Jun 4-17 | 23+24 | 100.5 | 76.8 | $f\ (X,\ 0.009946) = 0.009946\ e^{-0.009946X}$ | Exponential |
| Jun 18 - Jul 1 | 25+26 | 160.2 | 64.5 | $f\ (X\ 160.2,\ 103.3) = \frac{1}{258.86}\ e^{-\left[\frac{(X-160.2)^2}{21329.4}\right]}$ | Normal |
| Jul 2 - 15 | 27+28 | 151.2 | 51.8 | $f\ (X,\ 151.2,\ 78.34) = \frac{1}{196.37}\ e^{-\left[\frac{(X-151.2)^2}{12274.3}\right]}$ | Normal |
| Jul 16-29 | 29+30 | 166.3 | 56.5 | $f\ (X\ 166.3,\ 93.96) = \frac{1}{235.52}\ e^{-\left[\frac{(X-166.3)^2}{17697.0}\right]}$ | Normal |
| Jul 30 - Aug.12 | 31+32 | 159.6 | 42.6 | $f\ (X, 159.6,\ 68.02) = \frac{1}{170.5}\ e^{-\left[\frac{(X-159.6)^2}{9253.4}\right]}$ | Normal |

*(Contd.)*

| Period | SMW | Mean rainfall mm | CV % | Probability density function | Distribution |
|---|---|---|---|---|---|
| Aug. 13-26 | 33+34 | 157.0 | 62.2 | $f\ (X, 157.0,\ 97.73) = \frac{1}{245.0}\ e^{-\left[\frac{(X-157.0)^2}{19102.3}\right]}$ | Normal |
| Aug. 27-Sept.9 | 35+36 | 131.7 | 48.4 | $f\ (X, 131.7,\ 63.75) = \frac{1}{159.8}\ e^{-\left[\frac{(X-131.7)^2}{8128.1}\right]}$ | Normal |
| Sept 10-23 | 37+38 | 92.6 | 53.1 | $f\ (X,\ 92.6,\ 49.32) = \frac{1}{232.1}\ e^{-\left[\frac{(X-92.6)^2}{17149.5}\right]}$ | Normal |
| Sept 24-Oct.7 | 39+40 | 63.5 | 90.8 | $f\ (X,\ 0.017351) = 0.0.17351\ e^{-0.017351X}$ | Exponential |
| Oct. 8 - 21 | 41+42 | 32.3 | 102.1 | $f\ (X,\ 0.030915) = 0.030915\ e^{-0.030915X}$ | Exponential |

monsoon rainfalls (CV : 20.9-23.8 per cent) at both study sites followed normal distribution. At the start and end of monsoon season (CV : 68 - 163.9 per cent) when variability of rains was of higher degree, the exponential distribution was good fit at both the study sites except in (23 + 24) SMW at Jagdalpur where Gamma distribution fitted well. Rainfall for more fortnights in Jagdalpur followed normal distribution than that at Raipur.

### 6.8.2 Type of Runoff Distributions

Type of runoff distributions fitted to different periods of monsoon season at Raipur and Jagdalpur are given in Tables 6.14 and 6.15. Monsoon as well as post-monsoon runoff were described by normal distributions at both the places (CV : 26.2-40.5). Fortnightly runoff (except July 30 - August 12, CV 54.4 per cent and Aug 27 - Sep 9, CV 61.7 per cent at Jagdalpur) followed exponential distribution with higher variability (CV : 64.7 - 251.6 per cent). A comparison of variability in runoff for corresponding periods at both the places indicated higher values at Raipur as compared to Jagdalpur.

### 6.8.3 Expected Rainfall at Different Probabilities of Exceedence

Tables 6.16 and 6.17 show the expected rainfall at different probabilities of exceedence. The annual rainfall expected at 90 per cent probability is 843 mm and 1044.1 mm at Raipur and Jagdalpur respectively which is quite below their respective drought levels (912.8 and 1127.7 mm) as defined in section 5.5.3. The rainfall amount predicted at 75 per cent probability of exceedence can be taken as minimum assured value and for crop planning that amount of rainfall should be available during the particular period (Ray *et al.,* 1980). The results indicated rainfall above the drought level is assured in Jagdalpur for more numbers of fortnights as compared to Raipur. Crop growth stage wise rainfall availability is given below :

**Table 6.14 Type of runoff distribution, good fit to different periods at Raipur**

| Period | SMW | Mean rainfall (mm) | CV (%) | Probability density function | Distribution |
|---|---|---|---|---|---|
| Annual | 1-52 | 479.3 | 38.7 | $f(X, 479.3, 185.4) = \frac{1}{464.8} e^{-\left[\frac{(X-479.3)^2}{68767.5}\right]}$ | Normal |
| Monsoon | 22-43 | 463.4 | 40.5 | $f(X, 463.4, 178.6) = \frac{1}{470.2} e^{-\left[\frac{(X-463.4)^2}{70359.6}\right]}$ | Normal |
| Jun 4-17 | 23+24 | 21.4 | 251.6 | $f(X, 0.046832) = 0.046823\ e^{-0.046823X}$ | Exponential |
| Jun 18 - Jul 1 | 25+26 | 68.4 | 117.3 | $f(X, 0.014611) = 0.014611\ e^{-0.014611X}$ | Exponential |
| Jul 2 - 15 | 27+28 | 76.0 | 113.7 | $f(X, 0.01316) = 0.01316\ e^{-0.01316X}$ | Exponential |
| Jul 16 - 29 | 29+30 | 55.5 | 96.9 | $f(X, 0.018013) = 0.018013\ e^{-0.018013X}$ | Exponential |
| Jul 30 - Aug.12 | 31+32 | 79.4 | 95.2 | $f(X, 0.012587) = 0.012587\ e^{-0.012587X}$ | Exponential |
| Aug 13 - 26 | 33+34 | 67.7 | 81.7 | $f(X, 0.014776) = 0.014776\ e^{-0.014776X}$ | Exponential |
| Aug 27-Sept.9 | 35+36 | 43.2 | 102.5 | $f(X, 0.023138) = 0.023138\ e^{-0.023138X}$ | Exponential |
| Sept 10-23 | 37+38 | 39.7 | 231.1 | $f(X, 0.02518) = 0.02518\ e^{-0.02518X}$ | Exponential |
| Sept 24-Oct.7 | 39+40 | 8.5 | 141.2 | $f(X, 0.118082) = 0.118082\ e^{-0.118082X}$ | Exponential |

**Table 6.15** ***Type of runoff distribution,*** **good fit to different periods at Jagdalpur**

| Period | SMW | Mean rainfall (mm) | CV (%) | Probability density function | Distribution |
|---|---|---|---|---|---|
| Annual | 1-52 | 741.5 | 27.6 | $f\ (X,741.5,\ 204.4)= \frac{1}{512.25}\ e^{-\left[\frac{(X-741.5)^2}{122948.5}\right]}$ | Normal |
| Monsoon | 22-43 | 683.0 | 26.2 | $f\ (X,683.0,\ 179.3)= \frac{1}{449.43}\ e^{-\left[\frac{(X-683.0)^2}{125721.0}\right]}$ | Normal |
| May 21 - Jun 3 | 21+22 | 12.0 | 147.9 | $f\ (X,\ 0.083025) = 0.083025\ e^{-0.083025X}$ | Exponential |
| Jun 4 - 17 | 23+24 | 44.8 | 119.2 | $f\ (X,\ 0.02232) = 0.02232\ e^{-0.02232X}$ | Exponential |
| Jun 18 - Jul 1 | 25+26 | 92.5 | 84.7 | $f\ (X,\ 0.010813) = 0.010813\ e^{-0.010813X}$ | Exponential |
| Jul 2 - 15 | 27+28 | 86.6 | 64.7 | $f\ (X,\ 0.011545) = 0.011545\ e^{-0.011545X}$ | Exponential |
| Jul 16 - 29 | 29+30 | 99.4 | 69.9 | $f\ (X\ 0.010055) = 0.010055\ e^{-0.010055X}$ | Exponential |
| Jul 30 - Aug.12 | 31+32 | 93.4 | 54.4 | $f\ (X,93.4,\ 50.77)\ \frac{1}{127.25}\ e^{-\left[\frac{(X-93.4)^2}{5154.64}\right]}$ | Normal |
| Aug. 13 - 26 | 33+34 | 95.7 | 78.5 | $f\ (X,0.010145) = 0.010145\ e^{-0.010145X}$ | Exponential |
| Aug. 27 - Sept.9 | 35+36 | 70.6 | 61.7 | $f\ (X,70.62,\ 43.6)\ \frac{1}{109.27}\ e^{-\left[\frac{(X-70.62)^2}{3800.77}\right]}$ | Normal |
| Sept 10 - 23 | 37+38 | 45.5 | 67.7 | $f\ (X,\ 0..021962) = 0.021962\ e^{-0.021962X}$ | Exponential |
| Sept 24 - Oct.7 | 39+40 | 28.7 | 114.2 | $f\ (X,\ 0.034886) = 0.034886\ e^{-0.034886X}$ | Exponential |
| Oct 8 - 21 | 41+42 | 12.4 | 150.1 | $f\ (X,\ 0.080539) = 0.080539\ e^{-0.080539X}$ | Exponential |

**Table 6.16 Expected rainfall amount at different probabilities of exceedence at Raipur**

| Period | SMW | Rainfall (mm) at probabilities of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 25 | 50 | 60 | 75 | 80 | 90 |
| Annual | 1-52 | 1328.0 | 1160.7 | 1097.9 | 993.5 | 952.1 | 843.0 |
| Monsoon | 22-43 | 1224.6 | 1055.5 | 992.0 | 886.4 | 844.5 | 734.2 |
| May 21-Jun 3 | 21+22 | 14.0 | 7.0 | 5.2 | 2.9 | 2.3 | 1.1 |
| Jun 4-17 | 23+24 | 75.7 | 37.9 | 27.9 | 15.7 | 12.2 | 5.8 |
| Jun 18-Jul 1 | 25+26 | 193.8 | 96.9 | 71.4 | 40.2 | 31.2 | 14.7 |
| Jul 2-15 | 27+28 | 207.4 | 103.8 | 74.5 | 43.1 | 33.4 | 15.8 |
| Jul 16-29 | 29+30 | 169.9 | 125.9 | 109.4 | 87.3 | 71.0 | 42.3 |
| Jul 30-Aug. 12 | 31+32 | 225.3 | 161.1 | 137.6 | 97.8 | 82.0 | 40.4 |
| Aug 13-26 | 33+34 | 189.9 | 141.7 | 123.6 | 93.5 | 81.6 | 50.1 |
| Aug 27-Sept. 9 | 35+36 | 159.6 | 117.6 | 101.8 | 75.5 | 65.1 | 37.8 |
| Sept 10-23 | 37+38 | 124.9 | 62.4 | 46.0 | 25.9 | 20.1 | 9.5 |
| Sept 24-Oct. 7 | 39+40 | 57.6 | 28.8 | 21.2 | 12.0 | 9.3 | 4.4 |

**Table 6.17 Expected rainfall amount at different probabilities of exceedence at Jagdalpur**

| Period | SMW | Rainfall (mm) at probabilities of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 25 | 50 | 60 | 75 | 80 | 90 |
| Annual | 1-52 | 1630.3 | 1425.1 | 1349.8 | 1224.5 | 1174.9 | 1044.1 |
| Monsoon | 22-43 | 1432.0 | 1247.7 | 1180.7 | 1169.3 | 1025.1 | 908.8 |
| May 21-Jun 3 | 21+22 | 44.8 | 24.5 | 18.8 | 11.6 | 9.4 | 5.1 |
| Jun 4-17 | 23+24 | 139.4 | 69.7 | 51.4 | 28.9 | 22.4 | 10.6 |
| Jun 18-Jul 1 | 25+26 | 229.8 | 160.2 | 134.0 | 90.5 | 73.3 | 27.8 |
| Jul 2-15 | 27+28 | 204.1 | 151.2 | 131.4 | 98.4 | 85.3 | 50.8 |
| Jul 16-29 | 29+30 | 229.7 | 166.3 | 142.5 | 102.9 | 87.2 | 45.9 |
| Jul 30-Aug. 12 | 31+32 | 205.5 | 159.6 | 142.4 | 113.7 | 102.3 | 72.4 |
| Aug 13-26 | 33+34 | 223.0 | 157.0 | 132.3 | 91.1 | 74.8 | 31.8 |
| Aug 27-Sept. 9 | 35+36 | 174.7 | 131.7 | 115.6 | 88.7 | 78.1 | 50.0 |
| Sept 10-23 | 37+38 | 126.2 | 92.8 | 80.4 | 59.5 | 51.3 | 29.6 |
| Sept 24-Oct. 7 | 39+40 | 79.9 | 39.9 | 29.5 | 16.6 | 12.9 | 6.1 |
| Oct. 8-21 | 41+42 | 43.5 | 21.9 | 16.2 | 9.1 | 7.1 | 3.4 |

**Nursery stage** : The ET of rice is much less than the availability of rains at 75 per cent assured probability of exceedence (17.4 mm - ETrice; 55.9 mm - rain) as can be seen from Tables 6.16 and 6.28. The probability of being a wet week is higher as that of a dry week (Table 6.20). However the probability of two consecutive wet weeks is low (Table 6.22).

**Seedling stage** : This stage coincided with (27+28) and (25 to 28) SMW at Raipur and Jagdalpur respectively (direct seeded). Rice at Raipur may experience drought at this stage as chances of rainfall exceeding its requirement (74.4 mm) are only 60 per cent (Table 6.16). On the otherhand the rainwater availability at Jagdalpur (at 75 per cent probability of exceedence 188.9 mm) was much higher than its requirement of 120.7 mm (Tables 6.17 and 6.28). Initial probabilities (Table 6.20) shows higher probability of being a wet week.

**Reproductive stage** : This is the most sensitive stage of rice crop with regard to water availability. It extends from 35-40 and 33-38 SMW with 234.7 and 208 mm ET requirement at Raipur and Jagdalpur respectively (Table 6.28). Rice crop at this stage may experience severe drought at Raipur as the water availability (113.4 mm at 75% probability of exceedence) is short of its requirement at this stage. The crop may not experience water shortage, as its availability (239.3 mm) is more than its requirement, at Jagdalpur.

Similar interpretations for non-rice crops revealed that in general, the rainwater availability was sufficient at 75 per cent probability of exceedence at Jagdalpur while it fell short of respective ET requirement at reproductive stage at Raipur.

### 6.8.4 Expected Runoff at Different Probabilities of Exceedence

Runoff at 75 per cent dependability is used in design of small and big reservoirs (CBIP - 1994, Irrigation deptt-Govt. of M.P. - 1996). The runoff at this probability of exceedence was worked out to be 336.9

**Table 6.18 Expected runoff amount at different probabilities of exceedence at Raipur**

| Period | SMW | Runoff (mm) at probabilities of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 25 | 50 | 60 | 75 | 80 | 90 |
| Annual | 1-52 | 604.4 | 479.3 | 432.3 | 354.2 | 323.2 | 241.7 |
| Monsoon | 22-43 | 509.9 | 463.4 | 415.9 | 336.9 | 305.6 | 223.1 |
| Jun 4-17 | 23+24 | 29.6 | 14.8 | 10.9 | 6.1 | 4.8 | 2.3 |
| Jun 18-Jul 1 | 25+26 | 94.9 | 47.4 | 35.0 | 19.7 | 15.3 | 7.2 |
| Jul 2-15 | 27+28 | 105.4 | 52.7 | 38.8 | 21.9 | 17.1 | 8.0 |
| Jul 16-29 | 29+30 | 77.0 | 38.5 | 28.4 | 16.0 | 12.4 | 5.9 |
| Jul 30-Aug. 12 | 31+32 | 110.2 | 55.1 | 40.6 | 22.9 | 17.7 | 8.4 |
| Aug 13-26 | 33+34 | 93.8 | 46.9 | 34.6 | 19.5 | 15.1 | 7.1 |
| Aug 27-Sept. 9 | 35+36 | 59.9 | 30.0 | 22.1 | 12.4 | 9.6 | 4.6 |
| Sept 10-23 | 37+38 | 55.1 | 27.5 | 20.3 | 11.4 | 8.9 | 4.2 |
| Sept 24-Oct. 7 | 39+40 | 11.7 | 5.9 | 4.3 | 2.4 | 1.9 | 0.9 |

**Table 6.19 Expected runoff amount at different probabilities of exceedence at Jagdalpur**

| Period | SMW | Runoff (mm) at probabilities of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 25 | 50 | 60 | 75 | 80 | 90 |
| Annual | 1-52 | 879.4 | 741.5 | 689.7 | 603.7 | 569.5 | 479.6 |
| Monsoon | 22-43 | 803.9 | 783.0 | 637.6 | 562.1 | 532.1 | 453.3 |
| May 21-Jun 3 | 21+22 | 16.7 | 8.4 | 6.2 | 3.5 | 2.7 | 1.3 |
| Jun 4-17 | 23+24 | 62.1 | 31.1 | 22.9 | 12.9 | 10.0 | 4.7 |
| Jun 18-Jul 1 | 25+26 | 128.2 | 64.1 | 47.2 | 26.6 | 20.6 | 9.8 |
| Jul 2-15 | 27+28 | 120.1 | 60.1 | 44.2 | 24.9 | 19.4 | 9.1 |
| Jul 16-29 | 29+30 | 137.9 | 69.0 | 50.8 | 28.6 | 22.2 | 10.5 |
| Jul 30-Aug. 12 | 31+32 | 127.6 | 93.4 | 80.5 | 59.2 | 59.6 | 28.3 |
| Aug 13-26 | 33+34 | 132.7 | 66.3 | 48.9 | 27.5 | 21.4 | 10.1 |
| Aug 27-Sept. 9 | 35+36 | 100.0 | 70.6 | 59.6 | 41.2 | 33.9 | 14.7 |
| Sept 10-23 | 37+38 | 63.1 | 41.7 | 23.2 | 13.1 | 10.2 | 4.8 |
| Sept 24-Oct. 7 | 39+40 | 39.7 | 19.9 | 14.6 | 8.2 | 6.4 | 3.0 |
| Oct. 8 - 21 | 41+42 | 17.2 | 8.6 | 6.3 | 3.6 | 2.8 | 1.3 |

mm and 562.1 mm for Raipur and Jagdalpur respectively (Tables 6.18 and 6.19). Runoff availability at reproductive stage of rice crop is expected to be only 26.2 mm at Raipur as compared to 81.8 mm at Jagdalpur. Thus runoff in combination with rainfall received at this stage cannot fulfil ET requirement of rice at Raipur whereas rainfall received at 75 per cent dependability alone can fulfil ET requirement of rice at Jagdalpur. It may be concluded that stored runoff in ponds can be utilised to save rice crop at Raipur at the reproductive stage whereas additional runoff available at this stage could be stored for establishing second post-monsoon crop at Jagdalpur.

## 6.9 RAINFALL AND DRY SPELL ANALYSIS BY MARKOV CHAIN

The crop planning in the region can be planned in such a way that vegetative growth and development period of rice crop must fall during the period when probability of occurrence of a wet week is greater than 50 per cent. It is, therefore, necessary that sowing of the rice crop must take place 3 weeks prior to the occurrence of a week with P (W) > 50% as the seedling stage in rice crop is normally taken as of 3 weeks duration followed by vegetative growth and development period of the crop. The crop should enter into its maturity phase when P (D) becomes 0.75, as longer wet spells during the reproductive stage of the rice crop will result in sterility and reduced yield. It means reproductive stage of the rice must end by the week till P (D) reaches 0.75. The reproductive stages and maturity stages of the rice crop are considered of 4 weeks and 3 weeks duration respectively.

The initial (55-71%) and conditional wet probability (0.57-0.76) was the highest from 25 to 33 SMW at Raipur. Similarly the initial (53-70%) wet probability was the highest from 24-36 SMW and conditional wet probability (52-74%) was the highest from 24-34 SMW at Jagdalpur (Table 6.21). The probabilities of getting two and three consecutive wet weeks during this period indicates the continuous and heavy rainfall. Hence, to harvest runoff, storage tanks may be used for recycling during deficit

Table 6.20 Initial probabilities of dry and wet weeks* during monsoon season at the study sites

| SMW | Raipur | | Jagdalpur | |
|---|---|---|---|---|
| | P(W) | P(D) | P(W) | P(D) |
| 22 | 0.00 | 1.00 | 0.13 | 0.87 |
| 23 | 0.06 | 0.94 | 0.27 | 0.73 |
| 24 | 0.23 | 0.77 | 0.57 | 0.43 |
| 25 | 0.55 | 0.45 | 0.53 | 0.47 |
| 26 | 0.58 | 0.42 | 0.63 | 0.37 |
| 27 | 0.55 | 0.45 | 0.57 | 0.43 |
| 28 | 0.65 | 0.35 | 0.63 | 0.37 |
| 29 | 0.61 | 0.39 | 0.63 | 0.37 |
| 30 | 0.55 | 0.45 | 0.67 | 0.33 |
| 31 | 0.65 | 0.35 | 0.67 | 0.33 |
| 32 | 0.58 | 0.42 | 0.70 | 0.30 |
| 33 | 0.71 | 0.29 | 0.63 | 0.37 |
| 34 | 0.42 | 0.58 | 0.57 | 0.43 |
| 35 | 0.52 | 0.48 | 0.57 | 0.43 |
| 36 | 0.45 | 0.55 | 0.43 | 0.57 |
| 37 | 0.35 | 0.65 | 0.27 | 0.73 |
| 38 | 0.19 | 0.81 | 0.20 | 0.80 |
| 39 | 0.19 | 0.81 | 0.23 | 0.77 |
| 40 | 0.16 | 0.84 | 0.07 | 0.93 |
| 41 | 0.03 | 0.97 | 0.03 | 0.97 |
| 42 | 0.03 | 0.97 | 0.07 | 0.93 |
| 43 | 0.03 | 0.97 | 0.10 | 0.90 |

* Dry week - rainfall < 50 mm

Wet week - rainfall $\geq$ 50 mm

**Table 6.21 Conditional probabilities of dry and wet weeks**

| SMW | Raipur | | | | Jagdalpur | | | |
|---|---|---|---|---|---|---|---|---|
| | P(W/W) | P(D/W) | P(D/D) | P(W/D) | P(W/W) | P(D/W) | P(D/D) | P(W/D) |
| 22 | 0.00 | 1.00 | 0.86 | 0.14 | 0.00 | 1.00 | 1.00 | 0.00 |
| 23 | 0.25 | 0.75 | 0.73 | 0.27 | 0.00 | 0.00 | 0.94 | 0.06 |
| 24 | 0.75 | 0.25 | 0.50 | 0.50 | 1.00 | 0.00 | 0.83 | 0.17 |
| 25 | 0.53 | 0.47 | 0.46 | 0.54 | 0.57 | 0.53 | 0.46 | 0.54 |
| 26 | 0.56 | 0.44 | 0.29 | 0.71 | 0.65 | 0.35 | 0.50 | 0.50 |
| 27 | 0.63 | 0.37 | 0.55 | 0.45 | 0.61 | 0.39 | 0.54 | 0.46 |
| 28 | 0.53 | 0.47 | 0.23 | 0.77 | 0.76 | 0.24 | 0.50 | 0.50 |
| 29 | 0.68 | 0.32 | 0.45 | 0.55 | 0.60 | 0.40 | 0.36 | 0.64 |
| 30 | 0.74 | 0-.26 | 0.45 | 0.55 | 0.63 | 0.37 | 0.58 | 0.42 |
| 31 | 0.60 | 0.40 | 0.20 | 0.80 | 0.71 | 0.29 | 0.43 | 0.57 |
| 32 | 0.65 | 0.35 | 0.20 | 0.80 | 0.70 | 0.30 | 0.64 | 0.36 |
| 33 | 0.52 | 0.48 | 0.11 | 0.89 | 0.67 | 0.33 | 0.23 | 0.77 |
| 34 | 0.58 | 0.42 | 0.45 | 0.55 | 0.45 | 0.55 | 0.67 | 0.33 |
| 35 | 0.47 | 0.53 | 0.31 | 0.69 | 0.54 | 0.46 | 0.50 | 0.50 |
| 36 | 0.65 | 0.35 | 0.54 | 0.46 | 0.44 | 0.56 | 0.53 | 0.47 |
| 37 | 0.41 | 0.59 | 0.54 | 0.46 | 0.29 | 0.71 | 0.59 | 0.41 |
| 38 | 0.23 | 0.77 | 0.71 | 0.29 | 0.18 | 0.82 | 0.80 | 0.20 |
| 39 | 0.38 | 0.62 | 0.86 | 0.14 | 0.50 | 0.50 | 0.88 | 0.12 |
| 40 | 0.33 | 0.67 | 0.79 | 0.21 | 0.17 | 0.83 | 0.84 | 0.16 |
| 41 | 0.14 | 0.86 | 0.96 | 0.04 | 0.20 | 0.80 | 1.00 | 0.00 |
| 42 | 0.00 | 1.00 | 0.96 | 0.04 | 0.00 | 1.00 | 0.97 | 0.03 |
| 43 | 0.00 | 1.00 | 0.93 | 0.07 | 0.00 | 1.00 | 0.97 | 0.03 |

Table 6.22 Probability of dry and wet runs of two and three weeks

| SMW | Raipur | | | | Jagdalpur | | | |
|---|---|---|---|---|---|---|---|---|
| | P(2W) | P(3W) | P(2D) | P(3D) | P(2W) | P(3W) | P(2D) | P(3D) |
| 22 | 0.00 | 0.00 | 0.94 | 0.77 | 0.03 | 0.02 | 0.63 | 0.32 |
| 23 | 0.06 | 0.04 | 0.77 | 0.35 | 0.20 | 0.11 | 0.37 | 0.17 |
| 24 | 0.13 | 0.08 | 0.35 | 0.18 | 0.30 | 0.17 | 0.20 | 0.06 |
| 25 | 0.35 | 0.22 | 0.23 | 0.12 | 0.30 | 0.19 | 0.13 | 0.07 |
| 26 | 0.35 | 0.27 | 0.23 | 0.11 | 0.40 | 0.21 | 0.20 | 0.05 |
| 27 | 0.42 | 0.25 | 0.23 | 0.08 | 0.30 | 0.21 | 0.10 | 0.05 |
| 28 | 0.39 | 0.24 | 0.13 | 0.08 | 0.43 | 0.32 | 0.17 | 0.08 |
| 29 | 0.39 | 0.27 | 0.23 | 0.10 | 0.47 | 0.28 | 0.17 | 0.03 |
| 30 | 0.39 | 0.27 | 0.19 | 0.12 | 0.40 | 0.26 | 0.07 | 0.01 |
| 31 | 0.45 | 0.30 | 0.23 | 0.05 | 0.43 | 0.23 | 0.07 | 0.01 |
| 32 | 0.39 | 0.18 | 0.10 | 0.06 | 0.37 | 0.21 | 0.03 | 0.02 |
| 33 | 0.32 | 0.17 | 0.19 | 0.10 | 0.37 | 0.17 | 0.17 | 0.05 |
| 34 | 0.23 | 0.10 | 0.29 | 0.15 | 0.27 | 0.17 | 0.13 | 0.07 |
| 35 | 0.23 | 0.06 | 0.26 | 0.15 | 0.37 | 0.15 | 0.23 | 0.13 |
| 36 | 0.13 | 0.02 | 0.32 | 0.265 | 0.23 | 0.05 | 0.23 | 0.16 |
| 37 | 0.06 | 0.03 | 0.52 | 0.45 | 0.10 | 0.04 | 0.40 | 0.35 |
| 38 | 0.10 | 0.02 | 0.71 | 0.60 | 0.10 | 0.03 | 0.63 | 0.50 |
| 39 | 0.03 | 0.01 | 0.68 | 0.68 | 0.07 | 0.01 | 0.63 | 0.61 |
| 40 | 0.03 | 0.00 | 0.84 | 0.81 | 0.03 | 0.00 | 0.73 | 0.71 |
| 41 | 0.00 | 0.00 | 0.94 | 0.90 | 0.00 | 0.01 | 0.90 | 0.84 |
| 42 | 0.00 | 0.00 | 0.94 | 0.94 | 0.07 | 0.01 | 0.90 | 0.80 |
| 43 | 0.00 | 0.00 | 0.97 | 0.94 | 0.07 | 0.01 | 0.83 | 0.83 |

period. The wet probability linearly decreases with the increasing dry probability (Table 6.22).

The initial dry probability is more than 55% at both the stations during reproductive stage indicating the immense need of supplemental irrigations to different crops, particularly rice crop. It ranges from 55-81% at Raipur and 57-80% at Jagdalpur. Similarly conditional dry probabilities at reproductive stage varies from 53-88% and 54-86% at Raipur and Jagdalpur respectively (Table 6.21).

## 6.10 PROBABILITY ANALYSIS OF DRY DAYS

Gamma distribution was found to be good fit to the number of dry days occurring during monsoon season at both the places (Table 6.23). Observed probability of dry days was determined by Weibull's methods and expected continuous dry days at various crop growth stages at different probability of exceedence was estimated using Gamma distribution. Reproductive phase was found to be most vulnerable for dry spell. The expected continuous dry days at 25% probability of exceedence were found to be highest (17.4 at Raipur and 14.1 at Jagdalpur) among all other stages of crop growth. The longest continuous dry spell throughout the monsoon was found to be 23 days at Jagdalpur and 26.5 days at Raipur at 25% probability of exceedence, whereas the respective figures at 75% probability of exceedence were 12.1 (Jagdalpur) and 16.0 (Raipur). To be on the safer side, the 25% probability of exceedence may be used for planning water resources in analysis of dry days (Gupta, 1982). The observed probability as calculated by Weibull's method are quite close to that estimated by Gamma distributions at both the places. It was found that dry spell exceeding 7 days (Sahu - 1993 and Pal *et al.,* 1994) during flowering or complete reproductive phase is detrimental to rice productivity. If this criteria is adopted, the reproductive phase of Raipur (9.3 days at 75% probability of exceedence, 17.4 days at 25% probability of exceedence) requires supplemental irrigation. Similarly at 25% probability of exceedence (14.1 days)

**Table 6.23 Computed and observed probability of occurrence of dry spells during various periods/growth stages (in days)**

| Place | Periods/ growth stages | SMW days | Parameters of distribution | Expected lengthof dry spell≥ at probability of exceedence 25% | 40% | 50% | 60% | 75% | 80% |
|---|---|---|---|---|---|---|---|---|---|
| Jagdalpur | Transplanting | 27+28 | $\alpha$=3.075 | 5.8 | 4.6 | 4.0 | 3.4 | 2.6 | 2.3 |
| | | | $\beta$=1.442 | (6.0) | (4.9) | (4.3) | (3.7) | (2.8) | (2.5) |
| | Flowering | 37+38 | $\alpha$=5.725 | 8.9 | 7.5 | 6.8 | 6.0 | 5.0 | 4.6 |
| | | | $\beta$=1.252 | (8.2) | (6.7) | (5.8) | (4.9) | (3.7) | (3.2) |
| | Reproductive phase | 37to40 | $\alpha$=3.808 | 14.1 | 11.5 | 10.1 | 8.8 | 6.9 | 6.2 |
| | | | $\beta$=2.897 | (13.8) | (10.0) | (8.6) | (7.7) | (6.7) | (6.5) |
| | September | 1-30 | $\alpha$=4.988 | 13.3 | 11.1 | 9.9 | 8.8 | 7.1 | 6.6 |
| | | | $\beta$=2.124 | (11.3) | (9.4) | (8.3) | (7.3) | (5.9) | (5.4) |
| | Monsoon season | 23to42 | $\alpha$=4.710 | 23.0 | 19.1 | 17.0 | 15.0 | 12.1 | 11.1 |
| | | | $\beta$=3.872 | (22.7) | (18.2) | (16.0) | (14.3) | (12.1) | (11.5) |
| Raipur | Transplanting | 27+28 | $\alpha$=2.730 | 6.7 | 5.2 | 4.5 | 3.8 | 2.8 | 2.5 |
| | | | $\beta$=1.855 | (6.8) | (5.2) | (4.4) | (3.8) | (3.0 | (2.8) |
| | Flowering | 37+38 | $\alpha$=5.833 | 9.8 | 8.3 | 7.5 | 6.7 | 5.6 | 5.1 |
| | | | $\beta$=1.360 | (10.9) | (9.2) | (8.0) | (6.9) | (5.2) | (4.7) |
| | Reproductive phase | 37to40 | $\alpha$=4.918 | 17.4 | 14.5 | 12.9 | 11.4 | 9.3 | 8.5 |
| | | | $\beta$=2.814 | (17.9) | (13.8) | (11.9) | (10.5) | (8.9) | (8.5) |
| | September | 1-30 | $\alpha$=5.049 | 15.0 | 12.5 | 11.2 | 9.9 | 8.1 | 7.4 |
| | | | $\beta$=2.370 | (16.6) | (13.3) | (11.3) | (9.6) | (7.4) | (6.7) |
| | Monsoon season | 23to42 | $\alpha$=7.380 | 26.5 | 22.8 | 20.8 | 18.9 | 16.0 | 14.9 |
| | | | $\beta$=2.951 | (26.0) | (21.7) | (19.7) | (18.0) | (15.9) | (15.3) |

NB : Figures in brackets represent observed length of dry spell as calculated by weibull's method reproductive phase of rice at Jagdalpur also requires supplemental irrigation to save rice crop - if full potential of the crop is to be realised.

The average number of dry days during monsoon season as observed at Raipur are slightly high (88.1) as compared to Jagdalpur (78.2) (Table 6.24). Reproductive phase including flowering stage experienced highest number of dry days at Raipur (21.8) as compared to Jagdalpur (18.4).

**Table 6.24 Average number of dry days and rainfall (mm) during crop growing season**

| Particulars | Dry days | | Rainfall | |
|---|---|---|---|---|
| | Raipur | Jagdalpur | Raipur | Jagdalpur |
| June (from 4) | 18.2 | 16.2 | 183.2 | 249.2 |
| July | 15.4 | 14.3 | 306.4 | 346.4 |
| August | 15.2 | 13.6 | 335.2 | 354.7 |
| September | 20.6 | 17.9 | 180.4 | 194.3 |
| October (till 21) | 18.6 | 16.5 | 34.5 | 68.3 |
| Total | 88.1 | 78.2 | 1040.9 | 1214.4 |
| Transplanting (27+28 SMW) | 6.8 | 6.7 | 149.7 | 151.2 |
| Reproductive phase (37 to 40 SMW) | 21.3 | 18.4 | 131.6 | 159.8 |
| Flowering (37 + 38 SMW) | 9.6 | 7.9 | 90.1 | 92.9 |

## 6.11 EVAPOTRANSPIRATION (ET) OF CROPS

### 6.11.1 Reference Crop Evapotranspiration ($ET_o$)

Reference crop evapotranspiration (ETo) as calculated by modified Penman method at different probability levels and obtained by normal distribution is shown in tables 6.25 and 6.26. The normal distribution was found to good fit the ETo for all the fortnightly intervals of the year. Average fortnightly amount of evaporation (daily as well as total) for the

**Table 6.25 Reference crop evapotranspiration $ET_o$ by modified-penman method at different probability levels - Raipur**

| SMW | $ET_o$ (mm/day) at probability of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|
| | 20 | 40 | 50 | 60 | 75 | 80 |
| 1+2 | 3.61 | 3.43 | 3.35 | 3.27 | 3.14 | 3.09 |
| 3+4 | 3.95 | 3.73 | 3.63 | 3.53 | 3.37 | 3.31 |
| 5+6 | 5.20 | 4.88 | 4.74 | 4.60 | 4.36 | 4.27 |
| 7+8 | 5.32 | 5.10 | 5.00 | 4.91 | 4.75 | 4.69 |
| 9+10 | 6.43 | 6.08 | 5.93 | 5.78 | 5.53 | 5.43 |
| 11+12 | 7.24 | 6.98 | 6.86 | 6.75 | 6.56 | 6.49 |
| 13+14 | 8.06 | 7.77 | 7.64 | 7.51 | 7.29 | 7.21 |
| 15+16 | 9.72 | 9.26 | 9.06 | 8.87 | 8.54 | 8.41 |
| 17+18 | 10.42 | 9.96 | 9.76 | 9.56 | 9.23 | 9.10 |
| 19+20 | 11.34 | 10.49 | 10.12 | 9.75 | 9.14 | 8.90 |
| 21+22 | 10.73 | 10.2 | 10.00 | 9.78 | 7.41 | 9.27 |
| 23+24 | 9.89 | 9.12 | 8.79 | 8.46 | 7.91 | 7.69 |
| 25+26 | 6.24 | 5.71 | 5.49 | 5.26 | 4.88 | 4.73 |
| 27+28 | 5.67 | 5.20 | 5.00 | 4.80 | 4.46 | 4.33 |
| 29+30 | 4.96 | 4.62 | 4.47 | 4.32 | 4.07 | 3.97 |
| 31+32 | 4.55 | 4.30 | 4.19 | 4.09 | 3.91 | 3.84 |
| 33+34 | 4.70 | 4.39 | 4.25 | 4.12 | 3.90 | 3.81 |
| 35+36 | 4.16 | 3.92 | 3.81 | 3.71 | 3.54 | 3.47 |
| 37+38 | 5.09 | 4.75 | 4.60 | 4.46 | 4.21 | 4.11 |
| 39+40 | 5.15 | 4.95 | 4.87 | 4.78 | 4.64 | 4.59 |
| 41+42 | 5.01 | 4.81 | 4.72 | 4.63 | 4.49 | 4.43 |
| 43+44 | 4.85 | 4.60 | 4.50 | 4.39 | 4.22 | 4.15 |
| 45+46 | 4.06 | 3.90 | 3.84 | 3.77 | 3.65 | 3.61 |
| 47+48 | 3.92 | 3.77 | 3.70 | 3.63 | 3.53 | 3.48 |
| 49+50 | 3.66 | 3.47 | 3.38 | 3.29 | 3.15 | 3.09 |
| 51+52 | 3.53 | 3.28 | 3.17 | 3.06 | 2.88 | 2.81 |

Table 6.26 Reference crop evapotranspiration $ET_0$ by modified-penman method at different probability levels - Jagdalpur

| SMW | $ET_0$ (mm/day) at probability of exceedence (%) | | | | | |
|---|---|---|---|---|---|---|
| | 20 | 40 | 50 | 60 | 75 | 80 |
| 1+2 | 3.79 | 3.58 | 3.49 | 3.39 | 3.24 | 3.18 |
| 3+4 | 4.14 | 3.95 | 3.87 | 3.79 | 3.66 | 3.61 |
| 5+6 | 5.10 | 4.84 | 4.72 | 4.61 | 4.41 | 4.34 |
| 7+8 | 5.69 | 5.41 | 5.29 | 5.17 | 4.97 | 4.89 |
| 9+10 | 6.66 | 6.29 | 6.13 | 5.97 | 5.71 | 5.61 |
| 11+12 | 7.85 | 7.26 | 7.01 | 6.76 | 6.34 | 6.17 |
| 13+14 | 8.28 | 7.80 | 8.59 | 7.38 | 7.03 | 6.89 |
| 15+16 | 9.21 | 8.52 | 8.22 | 7.92 | 7.43 | 7.23 |
| 17+18 | 9.27 | 8.49 | 8.16 | 7.83 | 7.28 | 7.06 |
| 19+20 | 9.98 | 8.94 | 8.50 | 8.05 | 7.31 | 7.01 |
| 21+22 | 10.32 | 9.24 | 8.77 | 8.31 | 7.53 | 7.23 |
| 23+24 | 8.61 | 7.75 | 7.39 | 7.02 | 6.41 | 6.17 |
| 25+26 | 5.78 | 5.15 | 4.88 | 4.61 | 4.16 | 3.99 |
| 27+28 | 4.64 | 4.34 | 4.22 | 4.09 | 3.88 | 3.79 |
| 29+30 | 4.28 | 4.04 | 3.94 | 3.83 | 3.66 | 3.59 |
| 31+32 | 3.99 | 3.75 | 3.65 | 3.54 | 3.37 | 3.30 |
| 33+34 | 4.30 | 4.02 | 3.91 | 3.79 | 3.59 | 3.52 |
| 35+36 | 4.22 | 4.00 | 3.91 | 3.82 | 3.66 | 3.60 |
| 37+38 | 4.81 | 4.49 | 4.35 | 4.21 | 3.98 | 3.89 |
| 39+40 | 5.71 | 5.15 | 4.90 | 4.66 | 4.26 | 4.10 |
| 41+42 | 5.00 | 4.68 | 4.54 | 4.41 | 4.18 | 4.09 |
| 43+44 | 4.66 | 4.36 | 4.23 | 4.10 | 3.88 | 3.80 |
| 45+46 | 4.10 | 3.94 | 3.87 | 3.80 | 3.66 | 3.64 |
| 47+48 | 4.29 | 3.97 | 3.84 | 3.70 | 3.48 | 3.39 |
| 49+50 | 3.85 | 3.55 | 3.43 | 3.30 | 3.09 | 3.01 |
| 51+52 | 4.19 | 3.85 | 3.71 | 3.56 | 3.32 | 3.22 |

available periods at study site is shown in Table 6.27. Evaporation in most of the fortnights were found to be higher at Raipur as compared to Jagdalpur. Consequently, the same trend is reflected in ETo at respective study sites.

Senapati *et al.* (1996) used ETo at 20% probability level as calculated by Weibull's method. If we take this probability level ET of rice will be overestimated (by 8.9% at Raipur and 11.3% at Jagdalpur) as compared to long term measured values of ET by lysimeters and drum culture technique at Raipur and Jagdalpur. ET of rice as worked out by ETo at 50% probability level was very close to the observed/ measured ET values at both study sites therefore 50% probability value was considered appropriate for working out ET.

### 6.11.2 ET of Rice Crop

ET of mid duration rice variety at Raipur was found to be 647.3 mm as compared to 528.3 mm of early duration rice at Jagdalpur (Table 6.28). It is seen that crop coefficient was low in the beginning i.e. from sowing to tillering period and then slowly increased and attained a maximum value of 1.50 (Raipur) and 1.37 (Jagdalpur) in the $13^{th}$ (Raipur) and $10^{th}$ (Jagdalpur) week when flowering took place. The trend of values is in conformity with trend given by Doorenbos and Pruit (1975), Shih *et al.*, (1982) and Sahu *et al.* (1990) as per different stages of crop growth. The early duration rice variety had three fold advantages in utilizing pond stored harvested water.

(i) Fields get ready for subsequent crops earlier, to utilise residual moisture.

(ii) Reduced ET requirement which enhanced the availability of pond water for subsequent crop.

(iii) Reduced intensity of dry spells at reproductive phase :

Table 6.27 Average fortnightly amount of evaporation (mm)

Data base : Raipur - 22 years (1978-1999)
Jagdalpur - 15 years (1985-1999)

(mm)

| Period | S.M.W. | Raipur | | Jagdalpur | |
|---|---|---|---|---|---|
| | | Total | Daily | Total | Daily |
| Monsoon | 22-43 | 753.5 | 4.89 | 506.2 | 3.29 |
| May 21-Jun 3 | 21+22 | 182.3 | 13.02 | 107.9 | 7.71 |
| Jun 4 - 17 | 23+24 | 153.4 | 10.95 | 86.8 | 6.20 |
| Jun 18-Jul 1 | 25+26 | 85.2 | 6.09 | 49.1 | 3.51 |
| Jul 2 - 15 | 27+28 | 62.0 | 4.43 | 36.7 | 2.62 |
| Jul 16 - 29 | 29+30 | 52.3 | 3.74 | 32.2 | 2.30 |
| Jul 30-Aug 12 | 31+32 | 46.7 | 3.34 | 29.7 | 2.12 |
| Aug 13 - 26 | 33+34 | 48.4 | 3.46 | 32.0 | 2.29 |
| Aug 27-Sep 9 | 35+36 | 48.3 | 3.45 | 35.3 | 2.52 |
| Sep. 10 - 23 | 37+38 | 48.3 | 3.45 | 41.7 | 2.98 |
| Sep 24-Oct. 7 | 39+40 | 50.6 | 3.61 | 44.7 | 3.19 |
| Oct. 8 - 21 | 41+42 | 51.6 | 3.69 | 44.5 | 3.18 |
| Post-monsoon | 44-12 | 581.8 | 3.96 | 546.0 | 3.71 |
| Oct. 22-Nov. 4 | 43+44 | 47.4 | 3.39 | 45.5 | 3.25 |
| Nov 5 - 18 | 45+46 | 44.0 | 3.15 | 44.7 | 3.19 |
| Nov 19-Dec 2 | 47+48 | 43.4 | 3.10 | 42.1 | 3.01 |
| Dec 3 - 16 | 49+50 | 36.8 | 2.63 | 39.1 | 2.79 |
| Dec 17 - 31 | 51+52 | 37.8 | 2.52 | 40.7 | 2.72 |
| Jan 1 - 14 | 1+2 | 39.5 | 2.82 | 37.4 | 2.67 |
| Jan 15 - 28 | 3+4 | 43.5 | 3.11 | 45.6 | 3.26 |
| Jan 29-Feb 11 | 5+6 | 57.2 | 4.09 | 51.0 | 3.64 |
| Feb 12 - 25 | 7+8 | 70.7 | 5.05 | 63.2 | 4.51 |
| Feb 26-Mar 11 | 9+10 | 85.3 | 6.09 | 74.3 | 5.30 |
| Mar 12-25 | 11+12 | 100.6 | 7.19 | 85.9 | 6.13 |

**Table 6.28 Crop coefficient, $ET_0$ and $ET_{rice}$ at study sites**

**(mm)**

| Crop growth stage | SMW | Crop coefficient | Daily $ET_0$ | Daily $ET_{rice}$ | Total* $ET_{rice}$ | Remarks |
|---|---|---|---|---|---|---|
| Nursery | 23-26 | | | | 17.39 | RAIPUR |
| Seedling | 27-28 | 1.06 | 5.00 | 5.31 | 74.40 | Medium |
| Vegetative | 29-30 | 1.17 | 4.47 | 5.23 | 73.25 | duration |
| Vegetative | 31-32 | 1.19 | 4.19 | 5.01 | 70.10 | variety |
| Vegetative | 33-34 | 1.42 | 4.25 | 6.05 | 84.70 | 140 days |
| Reproductive | 35-36 | 1.50 | 3.81 | 5.73 | 80.18 | transplanted |
| Reproductive | 37-38 | 1.22 | 4.60 | 5.62 | 78.73 | condition |
| Reproductive | 39-40 | 1.11 | 4.87 | 5.41 | 75.80 | |
| Maturity | 41-42 | 1.02 | 4.72 | 4.82 | 67.54 | |
| Maturity | 43 | 0.80 | 4.50 | 3.60 | 25.21 | |
| AV / Total | | 1.17 | 4.49 | 5.20 | 647.30 | |
| Seedling | 25-26 | 0.91 | 4.88 | 4.46 | 62.40 | JAGDALPUR |
| Seedling | 27-28 | 0.99 | 4.22 | 4.16 | 58.29 | Early |
| Vegetative | 29-30 | 1.17 | 3.94 | 4.61 | 64.54 | duration |
| Vegetative | 31.32 | 1.36 | 3.65 | 4.96 | 69.41 | variety |
| Reproductive | 33-34 | 1.37 | 3.91 | 5.36 | 75.09 | (112 days) |
| Reproductive | 35-36 | 1.25 | 3.91 | 4.90 | 68.91 | Direct sown |
| Reproductive | 37-38 | 1.06 | 4.35 | 4.63 | 67.76 | condition |
| Maturity | 39-40 | 0.95 | 4.90 | 4.66 | 65.16 | |
| AV / Total | | 1.13 | 4.22 | 4.72 | 528.16 | |

* IGAU - 1994 for Raipur
Sahu - 1993 for Jagdalpur

Direct sowing of early duration rice variety comes at reproductive phase about 14 days earlier therefore the intensity of dry spells could be reduced, as can be seen in Table 6.23, the expected number of dry days at 25% probability of exceedence could be reduced from 17.4 to 9.8, and the expected number of dry days at 75% probability of exceedence could be reduced from 8.5 to 5.1 at Raipur.

### 6.11.3 ET of Non-rice Crops

The greatest advantage of growing non-rice crop is its reduced ET requirement and increased profit per unit of water used. ET requirement of non-rice crops is presented in Tables 6.29 to 6.31. The ET requirement of non-rice crops varied from 132.5 - 490.7 mm as compared to 647.3 mm required for rice, grown in the monsoon season at Raipur (Tables 6.28 and 6.29). Similarly ET requirement of non-rice crops varied from 89.0 - 275.2 mm as compared to 528.3 mm required for rice, grown in the monsoon season at Jagdalpur (Tables 6,28 and 6.30).

ET requirement of monsoon crops extended to post-monsoon season is presented in Table 6.31. The monsoon season portion of ET of these crops varied from 331.4 - 425.2 mm which is less than the ET of rice. However, the full season ET requirement was quite high and varied from 755.6 mm in papaya + soybean to 979.7 mm in banana + green chillis. Banana grown with green chillis had the highest ET requirement (full season ET 979.7 mm) but its monsoon season portion of ET (383.4 mm) was quite less than rice (528.3 mm). Radish was found to be one of the prospective vegetable crops, had short duration maturity and low ET requirement besides highest net profit per unit water used. ET requirement of post-monsoon crops are presented in Table 6.30. It varied from 89.0 - 275.2 mm.

**Table 6.29 Evapotranspiration requirement of monsoon crops (Modified Penman method)**

**(mm)**

| SMW | Raipur | | Jagdalpur | | | |
|---|---|---|---|---|---|---|
| | **Okra** | **Radish** | **Okra** | **Radish** | **Soybean** | **Sweet potato** |
| 25+26 | 30.0 | - | 26.6 | - | 21.2 | 27.3 |
| 27+28 | 52.0 | - | 43.9 | - | 39.1 | 23.6 |
| 29+30 | 48.2 | - | 42.5 | - | 39.7 | 39.7 |
| 31+32 | 53.7 | - | 46.8 | - | 48.1 | 36.8 |
| 33+34 | 55.9 | - | 51.5 | - | 56.4 | 39.4 |
| 35+36 | 49.6 | - | 50.9 | - | 47.6 | 52.0 |
| 37+38 | 59.3 | - | 56.0 | - | 43.2 | 57.9 |
| 39+40 | 8.6 | - | 8.1 | - | 6.3 | 65.2 |
| 41+42 | - | 33.1 | - | 31.3 | - | 60.4 |
| 43+44 | - | 51.8 | - | 52.1 | - | 46.2 |
| 45+46 | - | 51.0 | - | 49.0 | - | 42.3 |
| Initial Development | 31.9 | 8.8 | 28.3 | 8.4 | 23.8 | 51.0 |
| Crop Development | 104.7 | 37.1 | 90.3 | 35.9 | 86.7 | 115.9 |
| Mid Season | 128.3 | 61.6 | 118.4 | 61.0 | 122.2 | 235.4 |
| late Season | 92.3 | 28.3 | 89.3 | 27.2 | 68.9 | 88.5 |
| Total | 357.2 | 135.9 | 326.3 | 132.5 | 301.6 | 490.7 |

**Table 6.30 Evapotranspiration requirement of post-monsoon crops (Modified Penman method)**

**(mm)**

| SMW | Raipur | | | Jagdalpur | | |
|---|---|---|---|---|---|---|
| | Gram | Mustard | Radish | Gram | Mustard | Radish |
| 41+42 | - | - | - | 20.1 | 13.1 | - |
| 43+44 | 21.4 | 13.6 | - | 24.9 | 28.7 | - |
| 45+46 | 24.7 | 30.6 | - | 31.2 | 33.6 | - |
| 47+48 | 30.0 | 33.3 | 31.2 | 36.0 | 49.0 | 13.0 |
| 49+50 | 35.5 | 47.2 | 39.8 | 47.8 | 47.5 | 37.5 |
| 51+52 | 40.8 | 46.9 | 18.1 | 45.0 | 51.4 | 43.2 |
| 1+2 | 43.2 | 43.9 | - | 33.6 | 31.3 | - |
| 3+4 | 31.5 | 30.1 | - | 21.2 | 20.6 | - |
| 5+6 | 21.2 | 19.3 | - | - | - | - |
| Initial development | 30.6 | 30.2 | 7.2 | 29.3 | 28.6 | 7.5 |
| Crop development | 59.4 | 54.2 | 26.4 | 60.8 | 53.9 | 25.3 |
| Mid season | 129.1 | 151.0 | 42.7 | 139.7 | 161.5 | 45.9 |
| Late season | 29.4 | 29.5 | 12.7 | 29.8 | 31.2 | 14.8 |
| Total | 248.4 | 264.8 | 89.0 | 259.7 | 275.2 | 93.5 |

Table 6.31 **Evapotranspiration requirement of Monsoon crops extended over to post monsoon season (Modified Penman method) at Jagdalpur**

(mm)

| SMW | Tapioca+ Groundnut | Papaya + Soybean | Banana + Green chilli |
|---|---|---|---|
| 23+24 | - | 33.1 | 41.4 |
| 25+26 | 27.3 | 21.9 | 27.3 |
| 27+28 | 23.6 | 18.9 | 23.6 |
| 29+30 | 24.6 | 37.5 | 22.1 |
| 31+32 | 36.8 | 34.8 | 36.8 |
| 33+34 | 39.4 | 37.2 | 39.4 |
| 35+36 | 39.4 | 37.2 | 39.4 |
| 37+38 | 43.8 | 41.4 | 43.9 |
| 39+40 | 49.4 | 65.2 | 43.4 |
| 41+42 | 47.1 | 60.4 | 66.1 |
| 43+44 | 60.4 | 56.3 | 61.6 |
| 45+46 | 55.3 | 51.5 | 56.4 |
| 47+48 | 54.8 | 51.1 | 55.9 |
| 49+50 | 49.0 | 45.6 | 49.9 |
| 51+52 | 53.0 | 38.4 | 54.0 |
| 1+2 | 49.8 | 36.2 | 46.4 |
| 3+4 | 52.8 | 40.1 | 51.5 |
| 5+6 | 56.8 | 48.9 | 62.8 |
| 7+8 | 63.7 | - | 70.4 |
| 9+10 | 42.2 | - | 81.5 |
| Initial develoment | 69.9 | 73.9 | 114.4 |
| Crop development | 257.0 | 188.1 | 208.9 |
| Mid season | 366.4 | 330.0 | 343.9 |
| Late season | 176.0 | - | 312.6 |
| Total | 869.9 | 755.6 | 979.7 |

## 6.12 ALTERNATIVE DESIGNS OF SFR

The alternative designs of SFR for MWs, R-1, R-2, J-1 & J-2 as worked out at different probabilities of exceedence of rainfall and runoff for both growing seasons with relevant hydrological parameters thereof, are presented in Table 6.32.

**Table 6.32 Alternative designs of SFR's at different probability of exceedence of rainfall and runoff**

| MW | Probability % | Rain m | Run-off m | Drainage area,ha | Evapo. m | Seepage m | Av. depth m | Water use ha-m | Water area ha |
|---|---|---|---|---|---|---|---|---|---|
| R-1 | 50 | 1.161 | 0.479 | 0.66 | 0.464 | 1.80 | 1.08 | 0.078 | 0.190 |
| (1.05 ha) | 60 | 1.100 | 0.432 | | | | | | 0.157 |
| | 75 | 0.994 | 0.354 | | | | | | 0.110 |
| | 80 | 0.952 | 0.323 | | | | | | 0.092 |
| R-2 | 50 | 1.161 | 0.47 | 0.37 | 0.486 | 1.10 | 0.89 | 0.074 | 0.301 |
| (1.04 ha) | 60 | 1.098 | 0.432 | | | | | | 0.212 |
| | 75 | 0.994 | 0.354 | | | | | | 0.112 |
| | 80 | 0.952 | 0.323 | | | | | | 0.083 |
| J-1 & J-2 | 50 | 1.425 | 0.742 | 1.75 | 0.457 | 2.28 | 1.42 | 0.540 | 0.417 |
| (1.75 ha) | 60 | 1.350 | 0.690 | | | | | | 0.352 |
| | 75 | 1.225 | 0.604 | | | | | | 0.256 |
| | 80 | 1.175 | 0.570 | | | | | | 0.221 |

General trend, common to all microwatersheds are as follows :

(i) With the increase in probability of exceedence of expected rainfall and runoff, the designed water area of SFR reduces.

(ii) At 80% probability of exceedence (expected rainfall and runoff) the water surface area of SFR remains constant irrespective of the seasons (i.e. whether the relevant parameters are considered only for monsoon season or for seasons).

(iii) At 80% probability of exceedence as reference the water surface area at other probabilities compares as :

| Probability of exceedence of rainfall (%) | SFR water surface area at probability of column I / SFR water surface area at 80 % probability |
|---|---|
| 50 | 1.45 to 3.63 |
| 60 | 1.31 to 2.56 |
| 75 | 1.12 to 1.35 |

With decreased probability of exceedence of rainfall and runoff larger water surface area of SFR is required.

### 6.12.1 Size of SFR for Fixed Water-use

Based on the hydrologic parameters observed during monsoon and post-monsoon season taken together and for uniform water use of 780 cu. m. in MW, R-1, the mean water areas of SFR, RP-1 were worked out as 924, 1095, 1573 and 1898 sq. m. at probabilities exceedence of 80, 75, 60 and 50% respectively. These figures for SFR, R-2 were 826, 1118, 2116 and 3010 sq. m. considering uniform water use of 740 cu m. The corresponding figures for Jagdalpur SFR's (JP-1 and JP-2) were 2208, 2558, 3522 and 4167 sq. m. for uniform water use of 5400 cu m. (Table 6.32).

Irrigable water amount was quantified, keeping the fixed design area of SFR's at 80 per cent probability of exceedence of rainfall and runoff. The irrigable quantum of water was 780, 740 and 5400 cu m. at 80 per cent probability of exceedence in RP-1, RP-2 and JP-1/ JP-2, respectively.

### 6.12.2 Dimensions of SFR

Dimensions of SFR's for alternative designs and shapes were worked out (Table 6.33). Three different shapes and 4 probability levels were used for alternative designs of SFR. For the same capacity, depth and mean water surface of SFR, circular shape required less space than other two shapes considered. However, their curved shape is

## Table 6.33 Dimensions of SFR for alternative designs and shapes

| SFR identify | Probability of exceedence % | Design dimensions*, m | | | Maximum water area sq.m | | | Rain catch area sq. m | | | Depth at inlet level | Capacity at inlet level | Percentage area under SFR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rectangular | Square | Circular | Rectan- | Square | Circular | Rectan- | Square | Circular | | | |
| RP-1 | 80 | 30.00 x 27.16 | 28.55 | 32.46 | 1033.5 | 1033.6 | 1021.3 | 1098.9 | 1098.0 | 1078.7 | 21.80 | 1663.5 | 10.3-10.5 |
| | 75 | 35.50 x 27.87 | 31.25 | 35.50 | 1214.7 | 1214.5 | 1200.7 | 1285.8 | 1285.2 | 1262.9 | 1.80 | 1972.7 | 12.0-12.2 |
| | 60 | 40.00 x 35.76 | 37.82 | 42.92 | 1716.1 | 1715.6 | 1699.7 | 1800.1 | 1799.5 | 1773.5 | 1.80 | 2831.7 | 16.9-17.1 |
| | 50 | 60 x 28.86 | 41.73 | 47.33 | 2064.5 | 2054.8 | 2037.2 | 2161.5 | 2146.5 | 2118.0 | 1.80 | 3416.7 | 20.2-20.6 |
| RP-2 | 80 | 30.00 x 24.37 | 27.05 | 30.74 | 921.4 | 921.1 | 910.1 | 983.4 | 982.8 | 964.3 | 1.65 | 1363.3 | 9.3-9.5 |
| | 75 | 35.00 x 28.78 | 31.75 | 36.05 | 1228.7 | 1228.5 | 1216.1 | 1300.0 | 1299.6 | 1278.7 | 1.65 | 1845.1 | 12.3-12.5 |
| | 60 | 50.00 x 39.27 | 44.32 | 50.23 | 2269.0 | 2267.7 | 2250.5 | 2365.9 | 2363.9 | 2335.4 | 1.65 | 3491.5 | 22.5-22.7 |
| | 50 | 60 x 47.13 | 53.19 | 60.24 | 3192.2 | 3191.1 | 3170.9 | 3306.9 | 3305.1 | 3271.5 | 1.65 | 4966.8 | 31.5-31.8 |
| JP-1 & JP-2 | 80 | 60.00 x 31.91 | 43.90 | 49.94 | 2502.1 | 2490.0 | 2457.7 | 2713.9 | 2693.6 | 2636.6 | 3.00 | 6625.2 | 13.2-13.6 |
| | 75 | 60.00 x 37.46 | 47.49 | 54.00 | 2868.4 | 2861.2 | 2827.4 | 3091.3 | 3079.1 | 3019.1 | 3.00 | 7675.0 | 15.1-15.5 |
| | 60 | 60.00 x 52.77 | 56.27 | 63.90 | 3878.8 | 3877.6 | 3837.5 | 4132.4 | 4130.6 | 4060.2 | 3.00 | 10566.6 | 20.3-20.7 |
| | 50 | 70.00 x 53.96 | 61.48 | 69.78 | 4557.0 | 4553.6 | 4510.2 | 4832.9 | 4827.5 | 4751.4 | 3.00 | 12501.0 | 23.8-24.2 |

* At SFR bed level (bottom)

disadvantageous in as much as a substantial area is normally lost for agricultural operations. Hence either square or rectangular SFR's are preferred. The space required by square shaped SFR was found to be slightly less than rectangular shaped SFR.

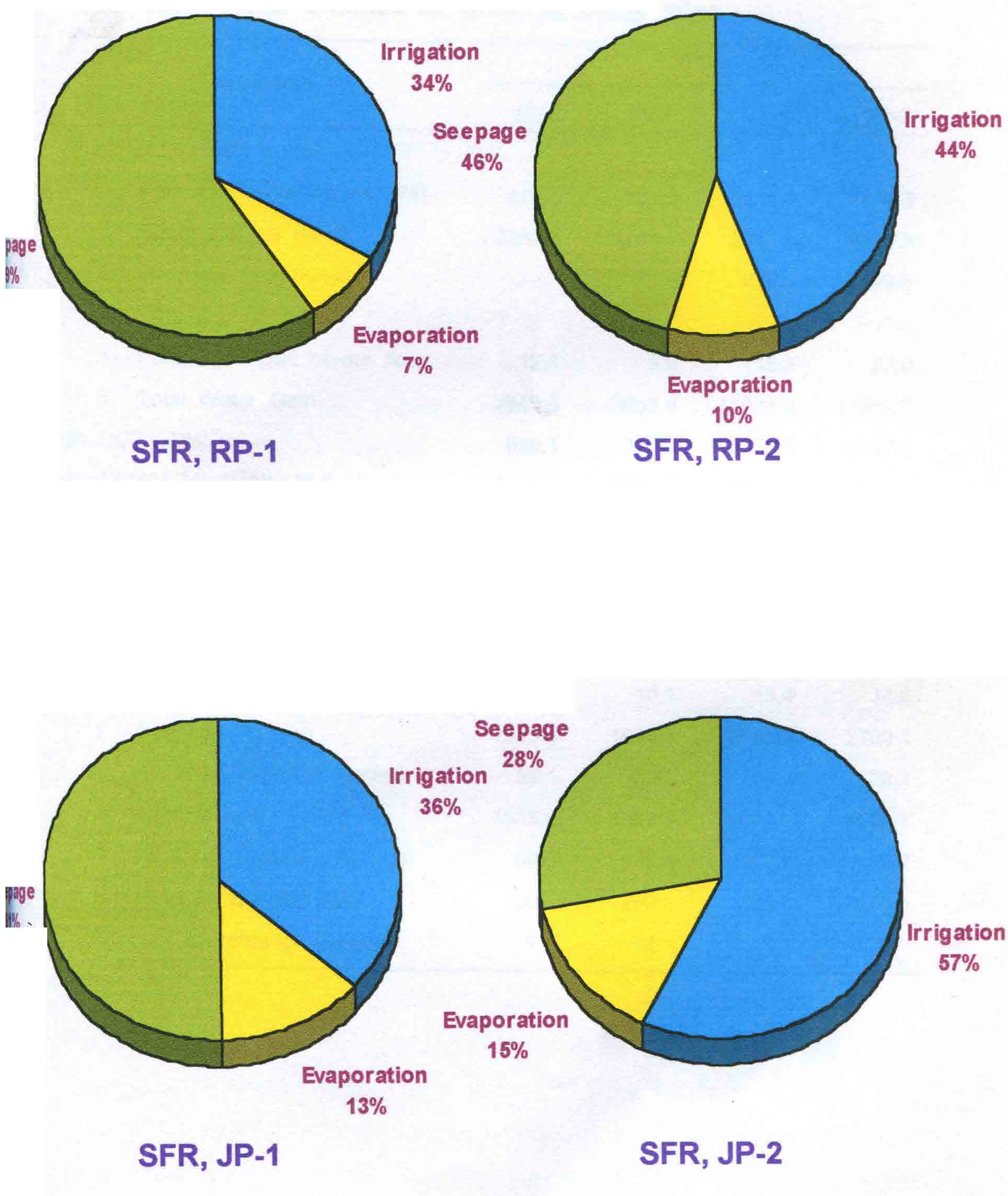
Rain catch area of SFR is the total area, including the space occupied by peripheral bunds of SFR, upto its top level, that contributes direct rainfall. It is a measure of the area occupied by SFR excluding bunds. By taking this into account, the percentage area under SFR's were worked out to be 10.3-10.5% (R-1), 9.3-9.5% (R-2), 13.2-13.6% (J-1 and J-2) at 80% probability of exceedence. This percentage increases with decrease in probability of exceedence (Table 5.33).

## 6.13 WATER BALANCE OF SFR

The water balance of SFRs at study sites as a percentage of available storage is depicted in Fig. 6.1.

### 6.13.1 Water Gain

Total water gain in SFR consisted of direct rain falling in the SFR, direct runoff and inter flow and a small portion of the diverted outflow pumped into the SFR due to its inability to flow in by gravity. Total water gained in the SFR's averaged over 3 to 7 years (Table 6.34) were 2915.8, 2633.8, 11624.9, 11951.2 $m^3$ in RP-1, RP-2, JP-1 and JP-2 respectively. The share of direct rain, runoff and interflow (only in JP-1 and JP-2) was 20.2 to 33.4, 66.2 to 77.6 per cent, 4.4 and 5.8 per cent respectively. Outflow pumped into SFR constituted less than 1 per cent. During the relatively dry year of 1992-93, water stored in SFR's was augmented by diverting a part of the outflow by pumping it into the SFR's. The outflow pumped were 356, 81, 85 and 38.6 cu.m. in SFR's JP-1, JP-2, RP-1 and RP-2 respectively. The outflow which could not be harnessed were 12.6 to 21.6 per cent of the total water gain.




6.1 : Water balance of SFRs as percentage of available storage

**Table 6.34 Water balance of SFRs at study sites**

| Particulars | SFR's | | | |
|---|---|---|---|---|
| | **RP-1** | **RP-2** | **JP-1** | **JP-2** |
| (A) WATER GAIN, cu.m | | | | |
| 1. Rain directly falling on SFR | 640.2 | 880.5 | 2414.3 | 2414.3 |
| 2. Direct surface runoff | 2263.5 | 1743.7 | 8412.9 | 8986.3 |
| 3. Seepage contribution (Sub surface runoff) | - | - | 678.9 | 523.6 |
| 4 Pumping a part of out flow | 12.1 | 9.6 | 118.8 | 27.0 |
| 5. Total Water Gain | 2915.8 | 2633.8 | 11624.9 | 11951.2 |
| (B) OUTFLOW, cu.m | 630.1 | 332.6 | 2358.2 | 2327.8 |
| (C) STORAGE AVAILABLE cu. m | 2285.7 | 2301.2 | 9266.7 | 9623.4 |
| (D) IRRIGATION cu.m | 765.9 | 1021.7 | 3362.6 | 5513.3 |
| As % of storage available | 33.5 | 44.4 | 36.3 | 57.3 |
| (E) LOSSES, cu.m. | | | | |
| 1. Evaporation | 169.3 | 233.1 | 1238.8 | 1400.7 |
| as % of available storage | 7.4 | 10.1 | 13.4 | 14.6 |
| 2. Seepage | 1350.5 | 1046.4 | 4665.3 | 2709.4 |
| As % of available storage | 59.1 | 45.5 | 50.3 | 28.1 |
| 3. Total losses | 1519.8 | 1287.6 | 5904.1 | 4110.1 |
| As % of available storage | 66.5 | 55.6 | 63.7 | 42.7 |
| (F) STORAGE PERIOD, days | 180 | 200 | 250 | 270 |
| Number of years of average | 7 | 4 | 3 | 3 |

### 6.13.2 Irrigation

The amount of water utilised for irrigation was 33.5, 44.4, 36.3, 57.3 per cent of available storage in SFR's RP-1, RP-2, JP-1, JP-2 respectively. This constituted 33.5, 44.4, 36.3 and 57.3 per cent of available storages in respective SFR's. The percentage of irrigation to monsoon crops constituted 39.2, 3.1, 59.0 and 23.2 in SFR's, RP-1, RP-2, JP-1 and JP-2 respectively. The low utilisation during monsoon was due to reduced percolation losses in rice fields (underlain by impervious strata) in MW, R-2. On the contrary in MW, J-1, increased percolation losses from cropped area and higher area under rice was responsible for higher water utilisation during monsoon season. Low utilisation during monsoon season (R-2) helped in carrying over relatively larger quantities of stored water for irrigation in the post-monsoon season. During the first year of construction of SFR, the utilisation of irrigation water was very poor due to higher seepage losses, thereafter it improved due to reduced losses. Therefore, losses from SFR's are crucial in determining its success as reflected in amount of irrigation, it can provide to crop. Normally no shortage of water for supplemental irrigations to monsoon crops was experienced in order to realise full potential of crops grown. However, judicious use even in the monsoon season helped in carrying over large amount of water for use in the post-monsoon season.

### 6.13.3 Losses

The losses from SFR's consisted of evaporation from open water surface and seepage from sides. An economical, efficient and durable evaporation retardant for farm ponds is yet to be found by research under varying agro-climatic regions and soil types (Radder *et al.,* 1995). Until such time, to overcome the storage loss of water in farm ponds, it is advisable to use the water immediately by irrigating and storing the water in the soil profile for subsequent utilization by deep rooted perennial crops. The evaporation losses constituted 7.4, 10.1, 13.4 and 14.6 per cent of available storage averaged over 3 to 7 years in SFR's RP-1, RP-2, JP-1 and JP-2 respectively. The seepage losses during this period in respective SFR's were 59.1, 45.5, 50.3 and 28.1 per cent of available storages. Total losses from the respective SFR's, thus worked out to be 66.5, 55.6, 63.7 and 42.7 per cent of available storage. Higher infiltration rates in substrata was a major factor responsible for higher losses in SFR's RP-1 and JP-1.

### 6.13.4 Storage Period

The storage periods of water in SFR's averaged over 3 to 7 years were found to be 180, 200, 250, 270 days in the SFR's RP-1, RP-2, JP-1 and JP-2 respectively.

## 6.14 RATING CURVES OF SFRs

The capacity survey of reservoirs was done in order to develop rating curves of water spread area and storage volumes as functions of reservoir storage depths.

### 6.14.1 Depth-Capacity Relationship

The depth-capacity relationship of SFRs were developed using the capacity survey informations of SFRs, which are as follows :

SFR in R-1 : $Y = 4.17 + 0.01 X^2$ ($R^2 = 1.000$)

SFR in R-2 : $Y = 5.24 + 0.01 X^2$ ($R^2 = 1.000$)

SFR in J-1 : $Y = 1.3143 * 0.9987^x X^{1.551}$ ($R^2 = 0.999$)

SFR in J-2 : $Y = 4.2031 * 2.7283^{1/x} X^{1.2888}$ ($R^2 = 0.999$)

Where X = Depth of SFR in cm.

Y = Capacity of SFR in $m^3$

This relationship is also shown in Fig. 6.2

### 6.14.2 Depth-Waterspread Area Relationship

The depth-water spread area relationship of SFRs were developed using the capacity survey informations, which are as follows :

SFR in R-1 : $Y = 414.15 + 2.03 X$; ($R^2 = 1.000$)

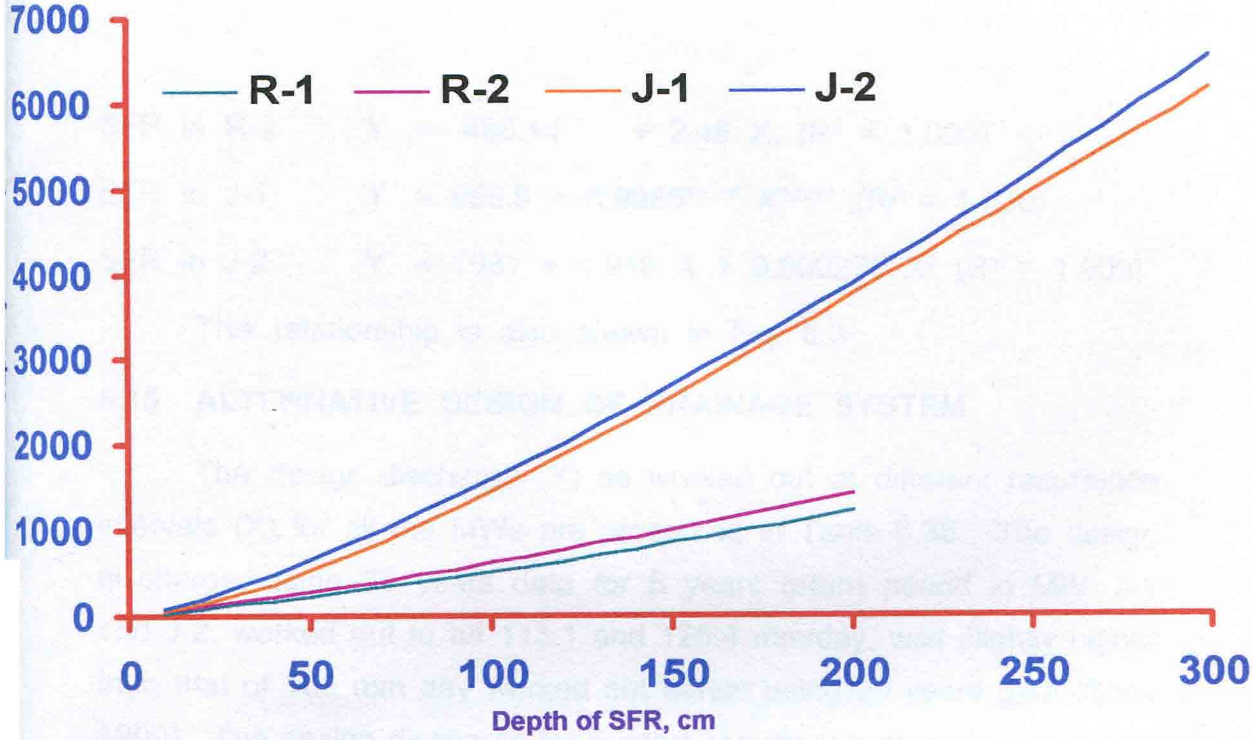



**Fig 6.2 : Rating curves of SFRs : Depth - Volume relationship**

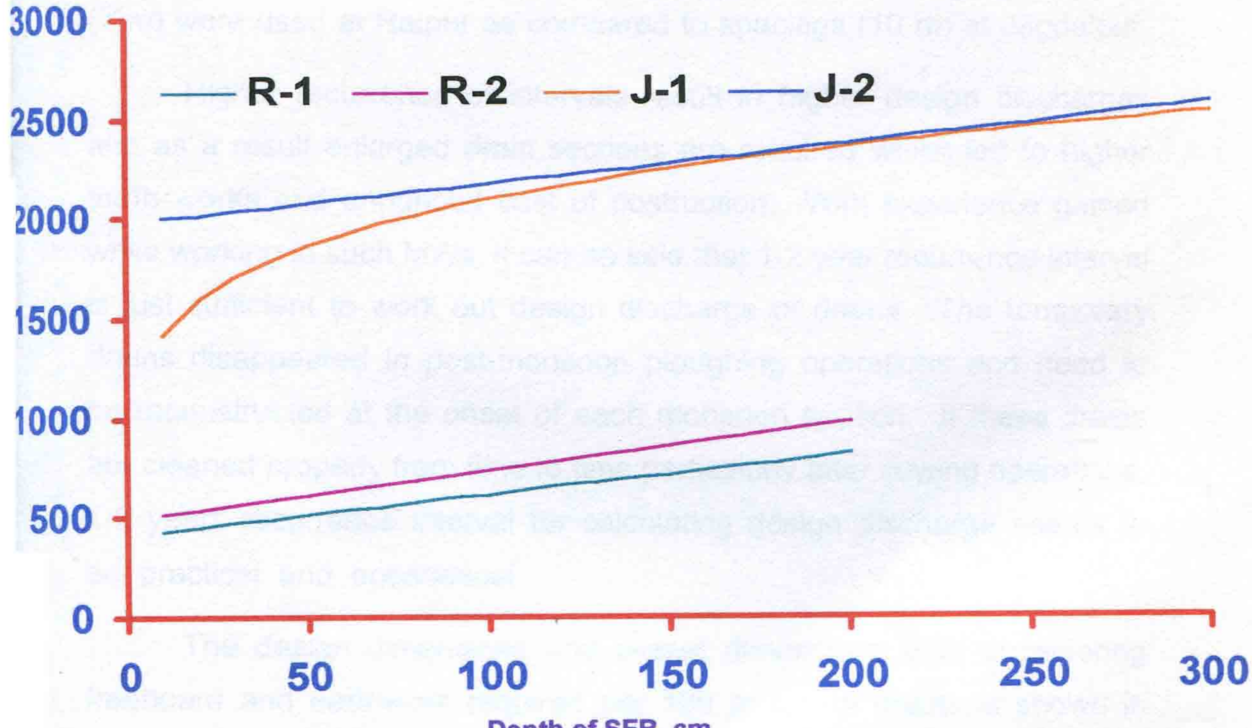



**Fig 6.3 : Rating curves of SFRs : Depth - Water spread relationship**

SFR in R-2 : $Y = 486.14 + 2.46 X$; ($R^2 = 1.000$)

SFR in J-1 : $Y = 955.9 + 0.9986^{1/x} * X^{0.1707}$ .($R^2 = 1.000$)

SFR in J-2 : $Y = 1981 + 1.916 X + 0.000275 X^2$ ($R^2 = 1.000$)

This relationship is also shown in Fig. 6.3

## 6.15 ALTERNATIVE DESIGN OF DRAINAGE SYSTEM

The design discharge (Y) as worked out at different recurrence intervals (X) for all the MWs are presented in Table 6.35. The design discharge, using 30 years data for 5 years return period in MW, J-1 and J-2, worked out to be 113.1 and 125.4 mm/day, was slightly higher than that of 103 mm day worked out earlier using 20 years data (Sahu 1999). The design discharge for 5 years recurrence interval was worked out to be 142.8 mm and 136.2 mm per day in MW, R-1 and R-2 at Raipur which is 26.2 and 8.6 per cent higher than the corresponding MWs at Jagdalpur. Due to higher design discharge and heavy texture of soil coupled with higher intensity of rains, closer spacings of drains (7 m) were used at Raipur as compared to spacings (10 m) at Jagdalpur.

Higher recurrence of intervals result in higher design discharges and as a result enlarged drain sections are required which led to higher earth works and enhanced cost of costruction. With experience gained while working in such MWs, it can be said that 1-2 year recurrence interval is just sufficient to work out design discharge of drains. The temporary drains disappeared in post-monsoon ploughing operations and need to be reconstructed at the onset of each monsoon season. If these drains are cleaned properly from time to time particularly after sowing operations, 1-2 years recurrence interval for calculating design discharge seems to be practical and economical.

The design dimensions and overall dimensions after considering freeboard and earthwork required per 100 m run of drains is shown in Table 6.35. It can be seen that earth work and thereby cost of construction of drains at 5 years recurrence interval is higher by 92.7,

## Table 6.35 Capacity and dimensions of drains for alternative designs

| MW | R.I. years | Design discharge | | Design dimensions of drains (m) | | | | | Area of flow ($m^2$) | Wetted perimeter (m) | Hydraulic radius (m) | Velocity ($m\ s^{-1}$) | Actual discharge ($m^3\ sec^{-1}$) | Earth work required per 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ($mm\ day^{-1}$) | ($m^3\ sec^{-1}$) | d | f | D | t | T | | | | | | |
| R-1 | 1.25 | 57.6 | 0.0066 | 0.18 | 0.04 | 0.22 | 0.36 | 0.43 | 0.03 | 0.51 | 0.06 | 0.22 | 0.0071 | 4.67 |
| | 1.33 | 61.4 | 0.0070 | 0.19 | 0.04 | 0.23 | 0.38 | 0.46 | 0.04 | 0.54 | 0.07 | 0.23 | 0.0082 | 5.20 |
| | 1.66 | 76.5 | 0.0088 | 0.20 | 0.04 | 0.24 | 0.40 | 0.48 | 0.04 | 0.57 | 0.07 | 0.23 | 0.0094 | 5.76 |
| | 2 | 89.5 | 0.0103 | 0.21 | 0.04 | 0.25 | 0.42 | 0.50 | 0.04 | 0.59 | 0.07 | 0.24 | 0.0107 | 6.35 |
| | 5 | 142.8 | 0.0164 | 0.25 | 0.05 | 0.30 | 0.50 | 0.60 | 0.06 | 0.71 | 0.09 | 0.27 | 0.0170 | 9.00 |
| R-2 | 1.25 | 59.0 | 0.0038 | 0.14 | 0.03 | 0.17 | 0.28 | 0.34 | 0.02 | 0.40 | 0.05 | 0.21 | 0.0042 | 2.82 |
| | 1.33 | 65.0 | 0.0042 | 0.15 | 0.03 | 0.18 | 0.30 | 0.36 | 0.02 | 0.42 | 0.05 | 0.22 | 0.0050 | 3.24 |
| | 1.66 | 83.2 | 0.0053 | 0.16 | 0.03 | 0.19 | 0.32 | 0.38 | 0.03 | 0.45 | 0.06 | 0.23 | 0.0060 | 3.69 |
| | 2 | 95.5 | 0.0061 | 0.17 | 0.03 | 0.20 | 0.34 | 0.41 | 0.03 | 0.48 | 0.06 | 0.24 | 0.0070 | 4.16 |
| | 5 | 136.2 | 0.0087 | 0.19 | 0.04 | 0.233 | 0.38 | 0.46 | 0.04 | 0.54 | 0.07 | 0.26 | 0.0094 | 5.20 |
| J-1 | 1.25 | 55.8 | 0.0170 | 0.24 | 0.05 | 0.29 | 0.48 | 0.58 | 0.06 | 0.68 | 0.08 | 0.31 | 0.0176 | 8.29 |
| | 1.33 | 57.2 | 0.0174 | 0.24 | 0.05 | 0.29 | 0.48 | 0.58 | 0.06 | 0.68 | 0.08 | 0.31 | 0.0176 | 8.29 |
| | 1.66 | 62.6 | 0.0190 | 0.25 | 0.05 | 0.30 | 0.50 | 0.60 | 0.06 | 0.71 | 0.09 | 0.31 | 0.0196 | 9.00 |
| | 2 | 68.0 | 0.0207 | 0.26 | 0.05 | 0.31 | 0.52 | 0.62 | 0.07 | 0.74 | 0.09 | 0.32 | 0.0218 | 9.73 |
| | 5 | 113.1 | 0.0344 | 0.31 | 0.06 | 0.37 | 0.62 | 0.74 | 0.10 | 0.88 | 0.11 | 0.36 | 0.0348 | 13.84 |
| J-2 | 1.25 | 63.8 | 0.0194 | 0.27 | 0.05 | 0.32 | 0.54 | 0.65 | 0.07 | 0.76 | 0.10 | 0.29 | 0.0209 | 10.50 |
| | 1.33 | 65.3 | 0.0198 | 0.27 | 0.05 | 0.32 | 0.54 | 0.65 | 0.07 | 0.76 | 0.10 | 0.29 | 0.0209 | 10.50 |
| | 1.66 | 71.1 | 0.0216 | 0.28 | 0.06 | 0-.34 | 0.56 | 0.67 | 0.08 | 0.79 | 0.10 | 0.29 | 0.0230 | 11.29 |
| | 2 | 76.9 | 0.0234 | 0.29 | 0.06 | 0.35 | 0.58 | 0.70 | 0.08 | 0.82 | 0.10 | 0.30 | 0.0252 | 12.11 |
| | 5 | 125.4 | 0.0381 | 0.34 | 0.07 | 0.41 | 0.68 | 0.82 | 0.12 | 0.96 | 0.12 | 0.33 | 0.0386 | 16.65 |

94.4, 66.9 and 58.6 per cent as compared to using 1.25 years recurrence interval in MW's R-1, R-2, J-1 and J-2 respectively.

## 6.16 CAPACITY REDUCTION OF SFR DUE TO SEDIMENTATION

The average sediment concentration in the first three years of JP-1 was highest (13.5 g $l^{-1}$) followed by JP-2 (10.8 g $l^{-1}$), RP-1 (10.6 g $l^{-1}$) and RP-2 (8.9 g $l^{-1}$). The three years average annual sediment deposition in the SFR, JP-1 was 126.4 t causing a capacity reduction of 80 $m^3$. The corresponding values for the SFR, JP-2 were 110.3 t and 69.9 $m^3$ respectively. Considering the third year's stabilised sedimentation rate, the total sediment deposition and resulting capacity reduction including the erosion of sides and bunds of SFR were worked out (Table 6.36) using capacity survey of SFR's during dry season. The annual capacity of SFR's was highest in the SFR's designed at 50 per cent probability of exceedence of runoff and lowest at 80 per cent probability level in all the microwatersheds. The SFR's RP-1. JP-1 and JP-2 had higher per cent capcity reduction as compared to SFR RP-2, because of comparatively higher drainage contributing area and higher runoff collection in SFR.

A remarkable decline in the sediment outflow was observed in microwatersheds with passage of time. During the first year it was several times (4 to 5) higher than the stabilised sediment outflow rate as observed in third year. Assuming the third year sedimentation value as the stabilised sedimentation rate and accounting for the higher sedimentation in the initial years, it was calculated that 5, 10 and 15 per cent capacity reduction of the SFR's will occur in about 15, 30 and 40 years respectively.

## 6.17 PRODUCTION ACTIVITY AFTER ADOPTION OF WATER HARVESTING SYSTEM

With the development of water resources and drainage system in the MWs various water efficient and remunerative crops besides

**Table 6.36 Capacity reduction of SFR's due to sedimentation (Annual values)**

| SFR | Probability of exceedence (%) | Annual Runoff sediment in SFR | | | Erosion of sides and bund | Total capacity reduction ($m^3$) | % of capacity |
|---|---|---|---|---|---|---|---|
| | | Concentration (g $l^{-1}$) | Weight (tonnes) | Capacity ($m^3$) | | | |
| RP-1 | 50 | 3.6 | 11.39 | 7.49 | 0.42 | 7.91 | 0.48 |
| | 60 | 3.6 | 10.27 | 6.76 | 0.42 | 7.18 | 0.43 |
| | 75 | 3.6 | 8.42 | 5.54 | 0.42 | 5.96 | 0.36 |
| | 60 | 3.6 | 7.68 | 5.05 | 0.42 | 5.47 | 0.33 |
| RP-2 | 50 | 3.4 | 6.03 | 3.89 | 0.32 | 4.21 | 0.31 |
| | 60 | 3.4 | 5.44 | 3.51 | 0.32 | 3.83 | 0.28 |
| | 75 | 3.4 | 4.46 | 2.87 | 0.32 | 3.19 | 0.23 |
| | 80 | 3.4 | 4.07 | 2.62 | 0.32 | 2.94 | 0.22 |
| JP-1 | 50 | 3.5 | 45.42 | 28.74 | 2.48 | 31.22 | 0.47 |
| | 60 | 3.5 | 42.24 | 26.74 | 2.48 | 29.22 | 0.44 |
| | 75 | 3.5 | 36.98 | 23.40 | 2.48 | 25.88 | 0.39 |
| | 80 | 3.5 | 34.88 | 22.08 | 2.48 | 24.56 | 0.37 |
| JP-2 | 50 | 3.1 | 40.23 | 25.62 | 1.76 | 27.38 | 0.41 |
| | 60 | 3.1 | 37.42 | 23.83 | 1.76 | 25.59 | 0.39 |
| | 75 | 3.1 | 32.75 | 20.86 | 1.76 | 22.62 | 0.34 |
| | 80 | 3.1 | 30.90 | 19.68 | 1.76 | 21.44 | 0.32 |

traditional crops (rice, tubers) were grown. To make judicious use of available land and water resources, the crop area allocation process using linear programming technique was adopted. It is detailed in section 6.18. In this process, the available cultivated land, water availability in SFR, and net profit were taken into account.

### 6.17.1 Land and Water Availability in Microwatersheds

The land and water availability in MWs were assessed under various alternative designs of SFR and drainage system, using these designs, the area under field bunds, drains SFR and its bunds were worked out in order to arrive at the area available for cultivation in both the seasons. Similarly by water balance approach as described in preceding sections, the availability of water in SFR during monsoon and post-monsoon seasons were worked out (Table 3.37).

### 6.17.2 Crop Production

The basic crop production data of the MWs available at Z.A.R.S. Jagdalpur and Deptt. of Land and Water management IGAU, Raipur were used to workout the strategic crop plan for MWs in order to achieve maximum B/C ratio under different alternative designs of SFR and drainage system. The crops and their yields are shown in Table 6.38 and 6.39. The yields are averaged over 6, 4, 3, 3 years in MWs R-1, R-2, J-2 and J-2 respectively. Rice and vegetables were grown in monsoon season, whereas gram, mustard vegetables were grown during post-monsoon season in MWs R-1 and R-2. Soybean in addition to rice vegetables were grown during monsoon season, whereas during post-monsoon season, in addition to gram mustard and vegetables, fruits and tubers were also grown in MWs J-1 and J-2.

The vegetables during monsoon season include Okra (var. Parbhani Kranti) followed by radish (Pusa Chetki) where radish alone grown in post-monsoon season. Fruit in J-1 was papaya (var. Honeydeu) grown with soybean (Gaurav JS 72-44) in the interspace of papaya. Fruit

## Table 6.37 Land and water features of the microwatersheds

### (A) FIXED FEATURES

| MW | Total area (ha) | Field bunds (ha) | Drains ha | SRF water (m³) used during | | |
|---|---|---|---|---|---|---|
| | | | | Monsoon season | Post-monsoon season | Total |
| R-1 | 1.05 | 0.02 | 0.03 | 300 | 480 | 780 |
| R-2 | 1.04 | 0.02 | 0.03 | 290 | 450 | 740 |
| J-1 | 2.00 | 0.04 | 0.06 | 1900 | 3500 | 5400 |
| J-2 | 2.00 | 0.04 | 0.06 | 1900 | 2500 | 5400 |

### (B) VARIABLE FEATURES

| MW | Features | Probability of exceedence of runoff (%) | | | |
|---|---|---|---|---|---|
| | | 80 | 75 | 60 | 50 |
| R-1 | SFR and its bunds, ha | 0.13 | 0.15 | 0.21 | 0.26 |
| | Land for cultivation, ha | 0.87 | 0.85 | 0.79 | 0.74 |
| R-2 | SFR and its bunds, ha | 0.12 | 0.15 | 0.35 | 0.46 |
| | Land for cultivation, ha | 0.7 | 0.84 | 0.64 | 0.53 |
| J-1 | SFR and its bunds, ha | 0.29 | 0.32 | 0.42 | 0.48 |
| | Land for cultivation, ha | 1.61 | 1.58 | 1.48 | 1.42 |
| J-2 | SFR and its bunds, ha | 0.29 | 0.32 | 0.42 | 0.48 |
| | Land for cultivation, ha | 1.61 | 1.58 | 1.48 | 1.42 |

**Table 6.38 Crop yield, irrigation requirement and economics[1] after adoption of water harvesting system in R-1 and R-2**

| Crops | | No. of Irrigation | Irrigation requirement ($m^3$/ha) | Yield (q/ha) | Gross returns (Rs./ha) | Total cost (Rs./ha) | Net returns (Rs./ha) |
|---|---|---|---|---|---|---|---|
| | | | | **Microwatershed R-1** | | | |
| Rice | M | 1 | 500 | 44.8 | 26,432 | 14,287 | 12,145 |
| Vegetables[2] | M | R | - | 151.7 | 59,430 | 19,208 | 40,222 |
| Mustard | PM | 1 | 490 | 8.8 | 14,960 | 6,166 | 8,794 |
| Gram | PM | 1 | 490 | 13.1 | 16,768 | 6,610 | 10,158 |
| Vegetables[3] | PM | 2 | 1500 | 235.0 | 70,500 | 10,540 | 59,960 |
| Vegetables[3] | PM | 1 | 750 | 162.0 | 48,600 | 9,820 | 38,780 |
| Fish | M | - | - | - | 73,178 | 39,578 | 53,600 |
| | | | | **Microwatershed R-2** | | | |
| Rice | M | 1 | 400 | 38.6 | 22,774 | 14,187 | 8,587 |
| Vegetables[2] | M | R | - | 172.4 | 66,270 | 20,828 | 45,442 |
| Mustard | PM | 1 | 500 | 3.9 | 6,630 | 4,489 | 2,141 |
| Gram | PM | 1 | 500 | 5.4 | 6,912 | 5,666 | 1,246 |
| Vegetables[3] | PM | 2 | 1500 | 240.2 | 72,060 | 12,100 | 59,960 |
| Vegetables[3] | PM | 1 | 750 | 168.2 | 50,460 | 11,320 | 39,140 |
| Fish | M | - | - | - | 73,178 | 39,578 | 53,600 |

1 At 1999-2000 price level

2. Okra followed by radish in monsoon season. Okra yield was 92.8 q/ha in R-1 and 97.0 in R-2 while radish yield was 58.9 q/ha in R-1 and 75.4 q/ha in R-2.

3. Radish in post-monsoon season

R Rainfed crop

M Monsoon season crop

PM Post-monsoon season crop

**Table 6.39 Crop productivity, irrigation requirement and economics[1] in MW, J-1 and J-2 after adoption of water harvesting system**

| Crops | | No. of Irrigation | Irrigation requirement ($m^3$/ha) | Yield (q/ha) | Gross returns (Rs./ha) | Total cost (Rs./ha) | Net returns (Rs./ha) |
|---|---|---|---|---|---|---|---|
| **Microwatershed R-1** | | | | | | | |
| Rice | M | 2 | 2000 | 33.6 | 19,824 | 11,651 | 8,173 |
| Vegetables[2] | M | R | - | 143.9 | 55,215 | 19,508 | 35,707 |
| Mustard | PM | 2 | 1500 | 7.9 | 13,430 | 5,019 | 8,411 |
| Gram | PM | 2 | 1500 | 11.6 | 19,720 | 6,630 | 13,090 |
| Vegetables[2] | M | 2 | 1500 | 180.6 | 68,100 | 20,908 | 47,192 |
| Vegetables | Pm | 2 | 2000 | 148.5 | 44,550 | 10,680 | 33,870 |
| Fruits[4] | M+PM | 4 | 1000+2000 | 50.9 | 33,881 | 14,140 | 19,741 |
| Tubers[5] | M+Pm | 2 | 7850+750 | 85.2 | 45,776 | 9,778 | 35,509 |
| Fish rearing | | - | - | 6.36 | 25,425 | 6,849 | 18,575 |
| **Microwatershed J-2** | | | | | | | |
| Rice | M | 2 | 2000 | 32.2 | 19,057 | 11.601 | 7,456 |
| Soybean | M | 2 | 1000 | 22.5 | 28,125 | 11,168 | 16,957 |
| Vegetables[2] | M | R | 0 | 138.1 | 53,025 | 19,898 | 33,127 |
| Gram | PM | 2 | 1500 | 10.4 | 17,680 | 6,630 | 11.050 |
| Vegetables[2] | M | 2 | 1500 | 165.9 | 62.685 | 20,728 | 41,957 |
| Vegetables[3] | Pm | 2 | 2000 | 142.2 | 42,660 | 10,560 | 32,100 |
| Fruits[6] | M+Pm | 4 | 1000+1400 | 96.1 | 63,070 | 20,749 | 42,321 |
| Tubers[7] | m | 1 | 750 | 87.9 | 35,160 | 7,538 | 27,245 |
| Fish rearing | | - | - | 10.3 | 41,195 | 10,644 | 30,551 |

1. At 1999-2000 price levels
2. Okra followed by radish m monsoon season. Okra yield was 80.3 and 92.8 q/ha in J-1 and 77.3 and 86.1 q/ha in J-2 while radish yield was 63.6 and 87.8 q/ha in J-1 and 60.8 and 79.8 q/ha in J-2 under rainfed and irrigated conditions respectively
3. Radish in post-monsoon season
4. Soybean was additionally grown in between the space of papaya. Payapa Yield : 22.7 q/ha, Soybean yield : 28.3 q/ha
5. Groundnut was additionally grown on ridges of tapioca crop. Groundnut yield : 17.2 q/ha, Tapioca yield : 68.4 q/ha
6. Green chilli was additionally gorwn in between the space of Banana, Banana yield : 28.0 q/ha, Green chilli yield : 68.1 q/ha
7. Tuber crop was sweet potato.

R Rainfed crop

M Monsoon season crop

PM Post monsoon season crop

in J-2 was banana (Basarai dwarf) grown with green chilli (var. Japani Laungi) in the interspace of banana. It was grown on SFR bund in J-1 and at the toe of SFR bund to be benefitted by its seepage, in J-2. Tubers in J-1 included tapioca (var. F. Pend.) alongwith groundnut (var. ICGS-11) on its ridges. Tubers in J-2 included pure crop of sweet potato (var Kalmegh, B.K.S.) grown on outer side of SFR bund, in order to take advantage of increased porosity of newly dugout soil and to protect outer bund from soil erosion.

Rice crop (var. Mahamaya, IR-36) was grown in the service area (d/s of SFR), benefitted with SFR seepage in R-1 and R-2 whereas it was grown in the catchment area (u/s of SFR) in J-1 and J-2 (var. MW-10). Gram (var. JG-74) and mustard (var. Varuna) were also grown in post-monsoon season.

The average yield as obtained over the years, is depicted in Tables 6.38 and 6.39.

### 6.17.3 Economics of Production Activities

Economics of various production activities inclouding fish rearing in SFRs were worked out based on the current prices of inputs, labour, power and wholesale rates of produce. The various economic parameters viz. gross returns, total variable cost and net returns are presented in Tables 6.38 and 6.39. It excluded interest on investment and rental value of land as the same were included in computing the overal,l economics of the MWs. The overall economics will be dealt in succeeding sections after finalizing the optimal crop plans for various alternative designs wherein the B/C ratios were also worked out.

## 6.18 OPTIMAL CROP PLAN

Based on the information available on (i) crop and fish production viz. irrigation requirement and net profit per ha (Tables 6.38 and 6.39) (ii) availability of land and water for cultivation during monsoon and post monsoon seasons, the crop area and water allocation process for these different situations was formulated.

### 6.18.1 Formulation of Optimal Crop Plan

The crop area allocation process was formulated by linear programming model. The steps followed were :

**Objective Function** : Objective function was to maximise net profit from different crops under consideration.

**Constraints *(A) Essential Constraints*** : (i) Monsoon season water utiliztion (ii) total water availability (iii) monsoon cropped area (iv) total cropped area

***(B) Optional Constraint*** : Optinal constraints were those restricting crop area to certain fixed value. These constraints were either governed by the local peoples affinity to the crop, family requirement or nutritional requirement as suggested by ICMR and quoted by NARP status reports (1995). Considering all these facts the optional constraints were framed out as follows : (in terms of per cent total cultivated area).

v) Rice area constraint : It varied from 0 to 30% in different optimal plants as described in succeeding paragram.

vi) Oil seed area constraint : it was not less than 5%

vii) Pulses area constraint : It was not less than 5%

viii) Vegetables area constraint : It was not less than 10%

ix) Fruit area constraint : Only in J-1 and J-2 it was not less than 5%

x) Tuber area constraint : Only in J-1 and J-2. It was not less than 5%

xi) Non negative constraint : Area under any crop was equal to or greater than zero.

Considering all above constraints, using linear programming technique, the crop area-water allocation model was formulated as given in section 4.10 (Chapter IV)

### 6.18.2 Optimal Crop Planning for Different Cases

Based on the different per cent of minimum acceptable rice area, optimal allocation of land-water resource crop plans were formulated. The socio-economic survey revealed the following fact regarding minimum acceptable rice area to the farmers of the region.

(i) 30 per cent at Raipur and 25 per cent at Jagdalpur - Farmers having great affinity to rice (about 26 per cent farmers)

(ii) 20 per cent at Raipur and 15 per cent at Jagdalpur - farmers having moderate affinity to rice (about 62 per cent farmers)

(iii) Farmer's having no affinity to any crop - (Enterprising farmer's about 12 per cent).

Based on the basic information regarding minimum acceptable rice area as given above, three different crop-area and water allocation plans were formulated as detailed below :

Case I In this restriction on rice area was placed. The minimum rice area was not less than 30 per cent at Raipur (R-1 and R-2) and 25 per cent at Jagdalpur (J-1 and J-2).

Case II The minimum acceptable rice area was not less than 20 per cent at Raipur (R-1 and R-2) and 15 per cent (J-1 and J-2)

Case III No imposed conditions regarding area under any crop, i.e. no affinity to any crop.

In this way the value of P under Case I was considered as 0.30 (R-1, R-2) and 0.25 (J-1, J-2). These figures for case II were 0.20 (R-1 and R-2) and 0.15 (J-1, J-2).

The crop area and water allocation plan as formulated by linear programming model under three different cases and four alternative designs of SFR and drainage system for four MWs were solved by using software package LP-88-version 7.03. (Tables 6.40 and 6.41).

## 6.19 ECONOMICS OF PRODUCTION ACTIVITIES UNDER OPTIMAL CROP PLANNING

Economics of production activities in MWs (R-1, R-2, J-2, J-2) under three optimal crop plans (for case I, case II and case III) with four alternative designs of SFR (at 80 per cent, 75 per cent, 60 per cent, 50 per cent probabilities of exceedence of rainfall runoff) were worked out at current price levels (1999-2000) of inputs and wholesale rates of produce. The cost of cultivation, gross returns and net profit under different plans are whosn in Appendices VI to X. Besides economics, area water requirement for irrigation and net profit for individual crops and area covered by them are presented in Appendices XI and XII for case I. Similarly these were worked out for other plans also. In these appendices besides crop production, economics of fish production was also included to determine overall economics of production activities in MWs.

## 6.20 OVERALL ECONOMICS OF MICROWATERSHEDS

Overall economics of MWs were determined by considering the cost of SFR, drainage system irrigation cost including running cost of pump, interest on investment (@ 10 per cent per annum), depreciation, maintenance (@ 2 per cent per annum) rental value of land etc. These were worked out at current price levels (1999-2000). The fixed cost per annum of SFR (depreciation) was worked out by assuming its life as 20 and 40 years, in R-1, R-2 and J-1, J-2 respectively, based on silt deposition data in these SFRs. From these, the annual cost of SFR, irrigation and drainage were worked out. These figures were added to annual cost of production activities in microwatershed to give the overall

**Table 6.40 Optimal crop plan for R-1 and R-2**

**(Area in ha.)**

| Design | Crops | R-1 | | | R-2 | | |
|---|---|---|---|---|---|---|---|
| | | Case I atleast 30% rice area | Case II atleast 20% rice area | Case III | Case I atleast 30% rice area | Case II atleast 20% rice area | Case III |
| 80% | Rice 1 M | 0.2610 | 0.174 | - | 0.261 | 0.174 | - |
| | Vegetables PM | 0.690 | 0.696 | 0.87 | 0.690 | 0.696 | 0.87 |
| | Mustard 1PM | 0.0435 | 0.0435 | - | 0.0435 | 0.0435 | - |
| | Gram 1PM | 0.0435 | 0.0435 | - | 0.0435 | 0.0435 | - |
| | Vegetables 2PM | 0.0262 | 0.0842 | 0.17 | 0.0065 | 0.0529 | 0.1167 |
| | Vegetables 1PM | 0.7568 | 0.6988 | 0.70 | 0.7765 | 0.7301 | 0.7533 |
| | **Net Profit Rs.** | **59,408** | **63,079** | **72,332** | **60,884** | **65,016** | **76,015** |
| 75% | Rice 1 M | 0.2550 | 1.1700 | - | 0.2520 | 0.1680 | - |
| | Vegetables PM | 0.5850 | 0.6800 | 0.85 | 0.5880 | 0.6720 | 0.84 |
| | Mustard 1PM | 0.0425 | 0.0425 | - | 0.0420 | 0.0320 | - |
| | Gram 1PM | 0.0425 | 0.0425 | - | 0.0420 | 0.0320 | - |
| | Vegetables 2PM | 0.4950 | 0.1061 | 0.19 | 0.0403 | 00784 | 0.1467 |
| | Vegetables 1PM | 0.7155 | 0.6589 | 0.66 | 0.7157 | 0.6976 | 0.6933 |
| | **Net Profit Rs.** | **58,549** | **62,136** | **71,175** | **58,456** | **64,093** | **74,102** |
| 60% | Rice 1 M | 0.2370 | 0.1580 | - | 0.1920 | 0.1280 | - |
| | Vegetables PM | 0.5530 | 0.6320 | 0.79 | 0.4480 | 0.5120 | 0.64 |
| | Mustard 1PM | 0.0395 | 0.0395 | - | 0.0320 | 0.0320 | - |
| | Gram 1PM | 0.0395 | 0.0395 | - | 0.0320 | 0.0320 | - |
| | Vegetables 2PM | 0.1194 | 0.1721 | 0.25 | 0.2656 | 0.2997 | 0.3467 |
| | Vegetables 1PM | 0.5916 | 0.5290 | 0.54 | 0.3104 | 0.2763 | 0.2933 |
| | **Net Profit Rs.** | **55,971** | **59,304** | **67,707** | **50,190** | **53,259** | **61,350** |
| 50% | Rice 1 M | 0.2220 | 0.148 | - | 0.1590 | 0.1060 | - |
| | Vegetables PM | 0.5180 | 0.592 | 0.74 | 0.3710 | 0.4240 | 0.53 |
| | Mustard 1PM | 0.0370 | 0.037 | - | 0.0265 | 0.0265 | - |
| | Gram 1PM | 0.0370 | 0.037 | - | 0.0265 | 0.0265 | - |
| | Vegetables 2PM | 0.1777 | 0.2270 | 0.30 | 0.0395 | 0.4178 | 0.4567 |
| | Vegetables 1PM | 0.4884 | 0.4390 | 0.44 | 0.0875 | 0.0592 | 0.0733 |
| | **Net Profit Rs.** | **53,823** | **56,945** | **64,815** | **45,094** | **47,636** | **54,336** |

Numericals followed by crops indicate number of irrigations

RM : Rainfed crop grown in monsoon season

M : Crop grown during Monsoon season

PM : Crop grown during post-monsoon season

## Table 6.41 Optimal crop plan for J-1 and J-2

(Area in ha.)

| Design | Crops | J-1 | | | J-2 | | |
|---|---|---|---|---|---|---|---|
| | | Case I atleast 30% rice area | Case II atleast 20% rice area | Case III | Case I atleast 30% rice area | Case II atleast 20% rice area | Case III |
| 80% | Rice 2M | 0.4025 | 0.2415 | - | 0.4025 | 0.2410 | - |
| | Soybean 2M | - | - | - | 0.0805 | 0.0805 | - |
| | Mustard 2PM | 0.0805 | 0.0805 | - | - | - | - |
| | Gram 2PM | 0.0805 | 0.0805 | - | 0.0805 | 0.0805 | - |
| | Vegetables 2PM | 1.2880 | 1.280 | 1.6100 | 1.4490 | 1.4490 | 1.61 |
| | Tubers 1PM | 0.0805 | 0.0805 | - | 0.0805 | 0.0805 | - |
| | Fruits 4M+PM | 0.0805 | 0.0805 | - | 0.0805 | 0.0805 | - |
| | Vegetables 2M | 0.6361 | 0.8508 | 1.2667 | 0.5824 | 0.7575 | 1.2667 |
| | Vegetables RM | 0.414 | 0.3568 | - | 0.3836 | 0.2895 | - |
| | **Net Profit Rs.** | **97,765** | **1,01,215** | **1,26,257** | **94,512** | **99,730** | **1,16,200** |
| 75% | Rice 2M | 0.3965 | 0.2370 | - | 0.3950 | 0.2370 | - |
| | Soybean 2M | - | - | - | 0.0790 | 0.0790 | - |
| | Mustard 2PM | 0.0790 | 0.0790 | - | - | - | - |
| | Gram 2PM | 0.0790 | 0.0790 | - | 0.0790 | 0.0790 | - |
| | Vegetables 2PM | 1.2624 | 1.2624 | 1.58 | 1.4220 | 1.4220 | 1.58 |
| | Tubers 1PM | 0.0790 | 0.0790 | - | 0.0790 | 0.0790 | - |
| | Fruits 4M+PM | 0.0790 | 0.0790 | - | 0.0790 | 0.0790 | - |
| | Vegetables 2M | 0.6478 | 0.8585 | 1.2667 | 0.5952 | 0.8058 | 1.2667 |
| | Vegetables RM | 0.3792 | 0.3265 | - | 0.3528 | 0.3002 | - |
| | **Net Profit Rs.** | **96,215** | **1,02,985** | **1,24,479** | **92,959** | **98,876** | **1,14,243** |
| 60% | Rice 2M | 0.3700 | 0.2220 | - | - | 0.3700 | 0.2220 |
| | Soybean 2M | - | - | - | 0.0740 | 0.0740 | - |
| | Mustard 2PM | 0.0740 | 0.0740 | - | - | - | - |
| | Gram 2PM | 0.0740 | 0.0740 | - | 0.0740 | 0.0740 | - |
| | Vegetables 2PM | 1.1840 | 1.1840 | 1.48 | 1.3320 | 1.3320 | |
| | Tubers 1PM | 0.0740 | 0.0740 | - | 0.0740 | 0.0740 | - |
| | Fruits 4M+PM | 0.0740 | 0.0740 | - | 0.0740 | 0.0740 | - |
| | Vegetables 2M | 0.6870 | 0.8843 | 1.2667 | 0.6377 | 0.8350 | 1.2667 |
| | Vegetables RM | 0.2750 | 0.2257 | - | 0.2503 | 0.2010 | 0.2133 |
| | **Net Profit Rs.** | **91,046** | **97,387** | **1,17,522** | **87,784** | **93,325** | **1,07,721** |
| 50% | Rice 2M | 0.3550 | 0.2130 | - | 0.3550 | 0.2130 | - |
| | Soybean 2M | - | - | - | 0.0710 | 0.0710 | - |
| | Mustard 2PM | 0.0710 | 0.710 | - | - | - | - |
| | Gram 2PM | 0.0710 | 0.710 | - | 0.0710 | 0.710 | - |
| | Vegetables 2PM | 1.1360 | - | 1.42 | 1.2780 | 1.2780 | - |
| | Tubers 1PM | 0.0710 | 0.710 | - | 0.0710 | 0.710 | - |
| | Fruits 4M+PM | 0.0710 | 0.710 | - | 0.0710 | 0.710 | - |
| | Vegetables 2M | 0.7105 | 0.710 | 1.2667 | 0.6632 | 0.8525 | 1.2667 |
| | Vegetables RM | 0.2125 | 0.1652 | - | 00.1888 | 0.1415 | 0.1533 |
| | **Net Profit Rs.** | **87,945** | **94,029** | **1,13,347** | **84,678** | **89,995** | **1,03,807** |

Numericals followed by crops indicate number of irrigations

RM : Rainfed crop grown in monsoon season

M : Crop grown during Monsoon season

PM : Crop grown during post-monsoon season earlier determined (Appendices VI to X). In the next step B/C ratio of all the microwatersheds under different plans and designs were worked out and are shown in Tables 6.42 and 6.43 for case I only. similar procedure was adopted for other plans also.

**Intangible benefits** : Attempts were made to assess the intangible benefit as resulted from development of water harvesting system. Intangible benefits included social gains (employment generation), national gains (increased crop yields and intensity of cropping, improved eco-system), value additiona (increased value of land) and agricultural environmental gains (improved ground water status) were quantified. Due to absence of standardized methods, these gains could not be transformed into monetary values and thus unable to be included in cost-benefit analysis of microwatersheds.

Finally table 6.44 presents the summary of comparative economics including B/C ratio of MWs having water harvesting based production system under various optimal crop plans - choosen to suit different category of farmers (not land holding wise) with different alternaive designs of SFR and drainage system.

## 6.21 IMPROVEMENT IN PRODUCTION SITUATIONS

Alleviation of drought and submergence through water harvesting system brought revolutionary changes in the production scenario of microwatersheds. These were the two major constraints of production. Previously crops were grown during monsoon season only with cropping intensity either 100 (R-2, R-2) or less than that (J-1, J-2) as shown in Table 3.7 but after adoption of water harvesting system intensive cropping programme was implemented in both the seasons as a result cropping intensity increased to 200% (Table 6.39, 6.39). Intensive cropping programme was formulated based on logical proportion of grain crops (rice-the traditional crop), pulses (gram), oilseeds (soybean and mustard) and fruit (papaya, banana), tubers (tapioca, sweet potato) to fulfil family's nutritional requirement as per the recommendation of ICMR and

**Table 6.42 Cost benefit analysis of MWs R-1 and R-2 under Case I**

| Particulars | Probability of exceedence of rainfall and runoff (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | R-1 | | | | R-2 | | | |
| | 80 | 75 | 60 | 50 | 80 | 75 | 60 | 50 |
| **(A) S.F.R.** | | | | | | | | |
| i) Capital investment | 20,213 | 23,951 | 34,418 | 41,530 | 16,471 | 22,295 | 42,195 | 60,029 |
| ii) Fixed cost p.a. | 1,011 | 1,198 | 1,721 | 2,077 | 824 | 1,115 | 2,110 | 3,001 |
| iii) Average interest | 1,011 | 1,198 | 1,721 | 2,077 | 824 | 1,115 | 2,110 | 3,001 |
| iv) Maintenance @ 2% | 404 | 479 | 688 | 831 | 329 | 446 | 844 | 1,201 |
| Anual total cost of SFR | 2,426 | 2,874 | 4,130 | 4,984 | 1,997 | 2,675 | 5,063 | 7,203 |
| Drainage cost (p.a.) | 596 | 664 | 736 | 812 | 487 | 559 | 636 | 718 |
| **(B) IRRIGATION** | | | | | | | | |
| i) Capital Investment | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 |
| ii) Fixed cost p.a. | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| iii) Average interest | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| iv) Maintenance @ 2% | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| v) Annual running cost | 209 | 274 | 428 | 537 | 198 | 238 | 339 | 399 |
| Annual total cost of irrigation | 1,909 | 1,974 | 2,138 | 2,237 | 1,898 | 1,938 | 2,039 | 2,099 |
| Annual cost of SFR, irrigation and drainage | 4,931 | 5,513 | 7,004 | 8,032 | 4,362 | 5,173 | 7,738 | 10,021 |
| **(C) PRODUCTION SYSTEM** | | | | | | | | |
| i) Annual return | 91,149 | 90.494 | 89,874 | 88,726 | 93,860 | 93,074 | 91,250 | 90,320 |
| ii) Annual production | 28,044 | 27,912 | 28,309 | 28,179 | 29,655 | 29,587 | 30,981 | 31,787 |
| iii) Rental value of land and interest | 3,502 | 3,496 | 3,515 | 3,563 | 3,559 | 3,559 | 3,629 | 3,669 |
| Total cost | 36,447 | 36,920 | 38,829 | 39,720 | 37,580 | 38,319 | 42,348 | 45,477 |
| **(D) B/C Ratio** | 2.50 | 2.45 | 2.31 | 2.23 | 2.50 | 2.43 | 2.15 | 1.99 |
| **(E) INTANGIBLE BENEFIT** | | | | | | | | |
| I) Employment generation | | | | | | | | |
| a)initially, man days | 362 | 424 | 599 | 717 | 300 | 422 | 728 | 1025 |
| b)Anually, man days | 252 (98) | 262 (98) | 274 (98) | 280 (98) | 236 (98) | 252 (98) | 259 (98) | 268 (98) |
| ii) Increased cropping intensity (per cent) | 200 (100) | 200 (100) | 200 (100) | 200 (100) | 200 (100) | 200 (100) | 200 (100) | 200 (100) |
| iii) % increase in rice yield by seepage of | 21.3 | 21.3 | 21.3 | 21.3 | 17.3 | 17.3 | 17.3 | 17.3 |
| iv) Increased value of land Rs./ha | 48,000 (28,000) | 48,000 (28,000) | 48,000 (28,000) | 48,000 (28,000) | 42,000 (20,000) | 42,000 (20,000) | 42,000 (20,000) | 42,000 (20,000) |

Figures in parenthesis indicates corresponding values without

Table 6.43 Cost benefit analysis of MWs J-1 and J-2 under Case I

| Particulars | Probability of exceedence of rainfall and runoff (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | J-1 | | | | J-2 | | | |
| | 80 | 75 | 60 | 50 | 80 | 75 | 60 | 50 |
| **(A) S.F.R.** | | | | | | | | |
| i) Capital investment | 82,633 | 95,740 | 131851 | 156010 | 82633 | 95740 | 131851 | 156010 |
| ii) Fixed cost p.a. | 2,066 | 2,394 | 3,296 | 3,900 | 2,066 | 2,394 | 3,296 | 3,900 |
| iii) Average interest | 4,132 | 4,787 | 6,593 | 7,801 | 4,132 | 4,787 | 6,593 | 7,801 |
| iv) Maintenance @ 2% | 1,653 | 1,915 | 2,637 | 3,120 | 1.653 | 1,915 | 2,637 | 3,120 |
| Annual total cost of SFR | 7,850 | 9,095 | 12,526 | 14,821 | 7,850 | 9,095 | 12,526 | 14,821 |
| Annual drainage cost | 1,553 | 1,553 | 1,685 | 1,822 | 1,342 | 1,342 | 1,443 | 1,548 |
| **(B) IRRIGATION** | | | | | | | | |
| i) Capital Investment | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 | 10,000 |
| ii) Fixed cost p.a. | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| iii) Average interest | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| iv) Maintenance @ 2% | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| v) Annual running cost | 1,447 | 1,637 | 2,114 | 2,402 | 1,447 | 1,637 | 2,114 | 2,402 |
| Annual total cost of irrigation | 3,147 | 3,357 | 3,814 | 4,102 | 3,147 | 3,357 | 3,814 | 4,102 |
| Annual cost of SFR, irrigation and drainage | 12,550 | 13,985 | 18,025 | 20,745 | 12,339 | 13,774 | 17,783 | 20,471 |
| **(C) PRODUCTION SYSTEM** | | | | | | | | |
| i) Gross returns | 146775 | 144971 | 139297 | 139944 | 148226 | 146709 | 142197 | 139573 |
| ii) Total Cost | 44,326 | 43,702 | 41,714 | 40,534 | 46,047 | 45,471 | 43,693 | 42,647 |
| iii) Rental value of land and interest cost | 5,216 | 5,185 | 5,086 | 5,027 | 5,302 | 5,274 | 5,185 | 5,132 |
| Total cost | 62,093 | 62,872 | 64,824 | 66,306 | 63,688 | 64,518 | 66,660 | 68,250 |
| **(D) B/C Ratio** | 2.36 | 2.31 | 2.15 | 2.05 | 2.33 | 2.27 | 2.13 | 2.05 |
| **(E) INTANGIBLE BENEFIT** | | | | | | | | |
| I) Employment generation | | | | | | | | |
| a)initially, man days | 1442 | 1681 | 2303 | 2725 | 1452 | 1708 | 2350 | 2792 |
| b)Anually, man days | 423 | 428 | 430 | 420 | 403 | 400 | 390 | 372 |
| | (98) | (75) | (98) | (98) | (87) | (87) | (87) | (87) |
| ii) Increased cropping intensity (per cent) | 220 ((75) | 220 (75) | 220 (75) | 220 (75) | 200 (62.5) | 200 (62.5) | 200 (62.5) | 200 (62.5) |
| iii) % increase in rice yield | 38,000 (24,000) | 38,000 (24,000) | 38,000 (24,000) | 38,000 (24,000) | 46,000 (22,000) | 46,000 (22,000) | 46,000 (22,000) | 46,000 (22,000) |
| iv) Ground water | | | | | | | | |
| a) increase in water table, m | 0.8-1.0 | 0.8-1.0 | 0.8-1.0 | 0.8-1.0 | 0.6-1.2 | 0.6-1.2 | 0.6-1.2 | 0.6-1.2 |
| b) % increase in recuperation race of wells | 15.3-33.6 | 15.3-33.6 | 15.3-33.6 | 15.3-33.6 | 12.0-42 | 12.0-42 | 12.0-42 | 12.0-42 |

3 category of choices of farmers regarding rice area. This crop diversification was possible only after adopting water harvesting system as compared to subsistence farming before adoption. This is depicted through 3 optimal crop plans. Case I was meant for those farmers which follow the norms prescribed by ICMR regarding minimum area under pulses, oilseeds, tubers, fruits but wanted to grow vegetables in substantial area to get cyclic income in good amount over a fairly large period of time. It may be noted that in the region, women's participation in crop production activities was very high (70-80 per cent) particularly in tribal belt as compared to the man's participation. Their man's counterpart, if received income from produce at a time, spent it within short period mainly in alcoholic drinks. Also case I is meant for those farmers who wanted to stick up with rice cultivation in substantial area (not less than 30 per cent at Raipur and 25 per cent at Jagdalpur).

Case II is similar to case I but it is meant to those farmers who have moderate affinity to rice but not less than 20 per cent at Raipur and 15 per cent at Jagdalpur of the total cropped area in monsoon season.

Case III have no imposed conditions restricting area under any of the crop. This is meant for those farmers who wish to increase net profit of the production activity. However, this probably may not be sustainable production activity. As described in succeeding sections such production activity (selecting only fewer higher profit giving crop) may create imbalances in the production of other crops which he did not grow besides not fulfilling his family requirements.

As a resutl of crop diversification it was possible to include more remunerative and water efficient crops in the cropping programme, keeping considerations of family and nutritional needs. As resulted from assured water supply and enhanced ground water status, favourable agro-eco system was created for production activities. SFR's in J-1 and J-2 caused ground water recharge, it resulted in 15.3-33.6 per cent increase in water yield of shallow dugwells J-1 and 12.9-42 per cent in J-2 due to rise in water tabl,e. This made possible to pump out 521 and 480 cu.m. of ground water from these wells in J-1 and J-2 and was used for crop production (Sahu, 1999). Thus the seepage losses from SFR's within specified limit, is tolerable to some extent as it enriched ground water status which could be beneficially explored by way of conjunctive use of surface SFR's stored water and ground water though shallow dug wells.

Rice productivity in microwatersheds after adoption of water harvesting system increased by 189, 186, 101 per cent in R-1, R-2 and J-1 respectively. Similarly oilseed yield in J-1 increased by 339% (Tables 3.7, 6.38, 6.39). With the SFR as the centerpiece, the cropping intensity increased by 100 (R-1, R-2) 167 (J-1) and 220 (J-2) per cent. With one irrigation, the rice yields were increased by 35.9, 37.0, 45.9, 58.2 per cent in J-1, J-2, R-1 and R-2 respectively over rainfed crop. With two irrigations the rice yield in J-1 and J-2 increased by 52.7 and 49.5 per cent over rainfed rice. The higher percentage increase in rice yield in response to one irrigation in R-1, R-2 as compared to J-1 and J-2 was owing to the benefits of rice by SFR seepage. This can lead to conclude that rice area, as far as possible be located below (d/s) the SFR.

Vegetables (Okra followed by radish) consistently gave higher yields in monsoon season under rainfed conditions. The combined yields of Okra + radish were found to be 151.7, 172.4, 143.9, 138.1 q/ha in R-1, R-2, J-1, J-2 respectively. With two irrigations one irrigation to each crop, their yields increased by 34.9, 53.5, 45.7 and 37.9% in respective microwatersheds. With irrigations, two irrigations to each crop, these figures were 34.9, 53.5, 45.7 and 37.3 per cent.

Vegetables (Okra only) also performed well in post-monsoon season with yields of 162, 168.2, 106.8 and 112 q/ha with only one irrigation in R-1, R-2, J-1 and J-2 respectively. With two irrigations their percent increase in yield over one irrigation were 45.1, 42.8, 39.0 and 29.6 in R-2, R-2, J-1 and J-2 respectively.

Gram and mustard performed badly in all the microwatersheds except R-1. Poor yields were mostly due to acidic nature of soils (pH 5.8 - 6.9) in these microwatersheds. These soils required lime application to amend its pH for good growh of these crops. Soybean in J-2 performed better with yield of 22.5 q/ha and it replaced mustard in the optimal crop plans.

### 6.21.1 Fish Production in SFR

Fish production in SFR supplemented crop production in MWs besides utilizing water area for remunerative production activity. Fish is liked by the local tribal population and constituted an important sources of protein in their diet. Due to less water depths in SFRs of R-1 and R-2 (1.8 - 1.65 m) and consequent less water storage periods (180-200 days), instead of fish rearing, fish fingerlings were raised in these SFRs. It consisted of fish seed size enhancement (from 2-3 to 15-22 cm). However, successful raising of fingerlings has number of requirements (i) Farmers have to be trained (ii) the fields must be accessible and (iii) fingerlings must be packed in a way that ensures a supply of oxygen during transport (Pal *et al.,* 1994). Some enterprising farmers as visualised in PLAN III are likely to be benefitted from this farm production component.

High water levels (2-3 m) are not only needed to prevent lethal water temperatures but at the same time reduce growth of benthic algae (i.e. sunlight cannot reach the SFR bottom). In take waters should also be screened to prevent predators from entering the culture ponds. In view of the low pH in soil, therefore, liming was required to disinfect pond bottom to kill possible pathogens and predators (FAO, 1996). Fish catch in SFR of J-2 was higher (10.3 q/ha) as compared to SFR of J-1. The difference in yield was due to the difference in basic feed.

The dairy washings and cowdung were used in the J-2 and pig dung was used in J-1.

## 6.22 PRODUCTION ECONOMICS AND OPTIMAL CROP PLAN

Three optimal crop plans as worked out for each MWs and alternative designs are presented in Table 6.40 and 6.41. Case I was maximum rice area resulted in lowest net profit in all the microwatersheds and in all the designs selected. The net profit in Case II and Case III increased with decrease in rice area. Case III with no rice area resulted in highest net profit in all the cases. However, this plan has a drawback of only considering vegetables in the optimal plan. Grains, pulses, oilseeds, vegetables were totally excluded. Small and marginal farmers who used to fulfil family requirement from own fields will find this plan unacceptable, though for some enterprising farmers, who are interested in getting highest net profit, with higher capital investment capacity, this plan will be quite alright. However, from the point of view of sustainable crop production, in case I and case II, were found to be realistic as they contain good proportion of grains, pulses, vegetables, oilseeds, fruits tubers to fulfil the nutritional requirement of family. Among the Case I and Case II the later gives highest net profit and it seems better in comparison to former. The reason is 20% area under rice is more than fulfilling the family's nutritional requirement. Reducing net profit by increasing rice area, over and above the family's requirement is not justified.

Similar to different optimal crop plans, alternative designs of SFR and drainage system had marked influence on resulted net profit under each plan in each microwatershed. Design of SFR and drainage system at 80 per cent probability of exceedence of rainfall and runoff, resulted in highest net profit under all the three optimal crop plans. On contrary, design at 50 per cent probability resulted in lowest net profit.

In this way we see the highest net profit achievable is in Case of exceedence. As this is not an appropriate crop production system in area where rice is the main diet of people, the next highest net profit was obtained in case II with the SFR and drainage system designed at 80 per cent probability of exceedence. Therefore, it can be considered an appropriate crop production system as it contains logical proportions of various crops flfilling family's nutritional requirement. The details of this plan are as under :

| | | | |
|---|---|---|---|
| (i) | SFR constructed | : | 12.5% gross area (R-1, R-2), 14.5% gross area (J-1, J-2) |
| (ii) | Rice area | : | 20% in R-1, R-2 and 15% in J-1, J-2 |
| (iii) | Soybean area | : | 5% in J-2 |
| (iv) | Rainfed vegetable area | : | 59% in R-1, R-2, 22% in J-1, 18% in J-2. |
| (v) | Monsoon vegetable area with two supplemental irrigations one each to okra and radish | : | 53% in J-1 and 47% in J-2 |
| (vi) | Tubers pure (sweert potato) | : | 10% in J-2 |
| (vii) | Tubers (grown additionally | : | 5% in J-1 |
| (viii) | Fruits (papaya with soybean grown in the interspace) | : | 5% in J-1 |
| (ix) | Fruits (Banana with green chillis in the interspace | : | 5% in J-2 |
| (x) | Post-monsoon vegetables (radish) with one irrigation | : | 80% in R-1, 84% in R-2 |
| (xi) | Post-monsoon vegetables (radish) with two irrigations | : | 10% in R-1, 6% in R-2 80% in J-1, 90% in J-2 |
| (xii) | Mustard and gram, each | : | 6% in R-1, R-2, J-1, J-2 (only gram) |
| (xiii) | Fish rearing | : | R-1, R-2, J-1, J-2 |

(xiv) Total net profit : Rs. 63079 in R-1, Rs. 65016 in R-2, Rs. 1,01,215 in J-1, Rs. 99,730 in J-2.

## 6.23 OVERALL ECONOMICS OF WATER HARVESTING BASED CROP PRODUCTION IN MICROWATERSHEDS

Results of overall economics of microwatersheds is presented in Tables 6.42 and 6.43. It revealed that optimal crop plan under case III resulted in highest net profit and so also the highest B/C ratio, followed by Case II and Case II. The highest annual net profit was worked out to be Rs. 1,01,132 (J-1) in microwatershed of Jagdalpur and Rs. 71,333 (J-1) in MWs of Raipur. The B/C ratio for these microwatersheds were worked out to be 2.60 and 2.78 respectively. the highest net profit and consequently higher B/C ratios in these microwatersheds is attributed due to higher yield and net returns from vegetables exclusively grown under plan III. As mentioned earlier the sustainable crop production was found under case II with realistic proportions of grains, vegetables tubers, fruits, pulses and oilseeds. Under optimal crop plan case II also, the highest net profit and so also the B/C ratio were obtained in microwatersheds J-1 at Jagdalpur and R-2 at Raipur. The highest net profit in these MWs were Rs 91,507 and Rs. 60,422 and B/C ratios were 2.44 and 2.58 respectively.

All the above mentioned figures of net profit and B/C ratios pertains to design of SFR at 80 per cent probability of exceedence of rainfall and runoff. Highest net profit and B/C ratios were obtained at above design levelsof SFR and drainage system.

Fish rearing was quite beneficial to enhance net profit of the overall production system of MWs. Its share in overall net profit of MWs was 6.33, 5.56, 5.08 and 8.51% in R-1, R-2, J-1 and J-2. The maximum share was in J-2 where dairy washings and cowdung were used as basic feed to fishes. It follows the mixed farming concept with interaction among man-animal water-crop. The output of one production activity

Table 6.44 Comparative economics (Rs.) of water harvesting based crop production system under Optimal Crop Plans in microwatersheds

| Alt. designs | Case I | | | Case II | | | Case III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gross | Total | B/C | Gross | Total | B/C | Gross | Total | B/C |
| **R-1** | | | | | | | | | |
| 80% | 91149 | 36477 | 2.50 | 95290 | 36970 | 2.58 | 105759 | 38248 | 2.77 |
| 75% | 90494 | 36920 | 2.45 | 94538 | 37402 | 2.53 | 104768 | 38651 | 2.71 |
| 60% | 89874 | 38829 | 2.31 | 93639 | 39278 | 2.38 | 103259 | 40.437 | 2.55 |
| 50% | 88726 | 39720 | 2.23 | 92243 | 40138 | 2.30 | 101148 | 41225 | 2.45 |
| **R-2** | | | | | | | | | |
| 80% | 93860 | 37580 | 2.50 | 98646 | 38224 | 2.58 | 111393 | 40060 | 2.78 |
| 75% | 93074 | 38319 | 2.43 | 98425 | 39067 | 2.52 | 110002 | 40714 | 2.70 |
| 60% | 91250 | 42348 | 2.16 | 94771 | 42822 | 2.21 | 101121 | 44173 | 2.29 |
| 50% | 90320 | 45447 | 1.99 | 93226 | 45870 | 2.03 | 101002 | 46988 | 2.15 |
| **J-1** | | | | | | | | | |
| 80% | 146775 | 62093 | 2.36 | 155245 | 63739 | 2.44 | 164342 | 63210 | 2.60 |
| 75% | 144971 | 62872 | 2.31 | 153278 | 64486 | 2.38 | 163514 | 64452 | 2.54 |
| 60% | 139297 | 64824 | 2.15 | 147077 | 66335 | 2.22 | 161092 | 67946 | 2.37 |
| 50% | 135944 | 66306 | 2.05 | 92817 | 55017 | 1.69 | 159691 | 70353 | 2.27 |
| **J-2** | | | | | | | | | |
| 80% | 148226 | 63688 | 2.33 | 153996 | 64203 | 2.40 | 158378 | 63553 | 2.49 |
| 75% | 146709 | 64518 | 2.27 | 154110 | 66078 | 2.33 | 157926 | 64879 | 2.43 |
| 60% | 142197 | 66660 | 2.13 | 149131 | 68122 | 2.19 | 105131 | 56720 | 1.85 |
| 50% | 139573 | 68250 | 2.05 | 144970 | 69158 | 2.10 | 104009 | 58713 | 1.77 |

could be used as input of other production activity, and the system could be made self sustained. It was also found that in SFR where cowdung slurry was used, the seepage losses were quite less as compared to other SFR.

## 6.24 CONCLUSIONS

Rainfed rice culture and drought problem with subsequent migration of farm labours frequently go hand in hand for most of the areas of Chhattisgarh. A great variation in the onset and termination of monsoon, its occurrence give farmers a little choice but to adopt a very low-risk, low-input cropping system, which is directed to giving a stable rather than a high production. Water shortage prevents farmers from growing an economic non-rice crop during post-rice season. Even a marginal improvement in the soil-water status in this season can make a significant difference in cropping opportunity and/or yields.

The above results indicated that a sustainable crop production programme such as optimal crop plan II with available land and water resources within a microwatershed could be formulated, using SFR as centerpiece, which is economically attractive and socially desirable. The role played by SFR and drainage system to alleviate drought and submergence cannot be denied. The salient findings based on the results obtained above can be summarized as below :

1. Among various alternative designs of SFR and drainage system, the one at 80 per cent probability of exceedence gave the highest B/C ratio (2.33 - 2.78) in different microwatersheds.
2. Among the three optimal crop plans tried, optimal crop plan case II (with rice area not less than 20 per cent at Raipur and 15 per cent at Jagdalpur) was found to be sustainable crop production system with B/C varying between 2.40 to 2.58 in different microwatersheds under the design mentioned in S.No. 1 above.
3. Fish rearing inside SFR substantially contribute (5.08 to 8.51 per cent share of total net profit) to strengthen economy of microwatershed and justify the land utilized for SFR construction.

# CHAPTER VII

# SUMMARY AND CONCLUSION

The Chhattisgarh state (erstwhile Chhattisgarh region of Madhya Pradesh) is inhabited mostly by tribal population with agriculture as their main vocation. Under the prevalent rainfed condition, the agricultural productivity is poor. Apparently, there appears to be a good scope of harnessing rainwater through water harvesting technology for irrigating the crops. Adequate research informations are not available on the technical and economic feasibility of adopting this technology on a large scale. With this background, a study on "Development of water harvesting system for sustainable crop production in microwatersheds", was taken up. The study comprised rainfall analysis and estimation of runoff, design of water harvesting structures and drainage system; estimation of crop water requirement and crop performance as a result of irrigation using the water stored in ponds. The fish rearing in pods was introduced to enhance the overall productivity of the production system. Considering water allocation to different crop production activity, optimal crop-area and water allocation model for maximising net return from the command area was attempted. The study was carried out in four microwatersheds (MWs). Two of the MWs measuring 1 ha each were in Chhattisgarh plains and the remaining two, measuring 2 ha each, were located in Bastar plateau agroclimatic zone of the Chattisgarh state.

Four runoff estimation models viz. curve number method (CN), conservation factor approach (CF), Binnies and Strange's method, were compared for selecting the most appropriate one, using the data of MWs. In case of plateau microwatersheds, modifications were needed in the existing criteria of deciding antecedent moisture condition (AMC), and a new criteria was developed.

Rainfall, dryspell and runoff analysis, using past 30-31 years data, were undertaken and appropriate probability distributions were fitted. Expected values of rainfall, runoff and dryspell length were determined at 80, 75, 60 and 50 % probability of exceedence. Keeping in view the weekly water requirement of rice, the rainfall and dryspell analysis was also undertaken by Markov-chain model. In this analysis initial and conditional probabilities, probability of consecutive wet weeks and dry weeks were worked out.

Evapotranspiration (ET) of rice crop, as determined by weighing type lysimeter in plains and drum culture technique in plateau were used in this study. ET of non-rice crops were determined by soil moisture depletion/addition studies available in the area. Crop coefficients were developed for the two zones, after working out reference crop evapotranspiration by Modified Penman method using past 20 years meteorological data.

Using the model outputs as obtained above, alternative desins of small farm reservoirs were attempted at 4 levels of probability of exceedence of rainfall and runoff viz. 80, 75, 60 and 50 per cent. The expected amount of rainfall and runoff at above probabilities of exceedence and various hydrological parameters were used in working out the mean water surface area of small farm reservoirs (SFRs). The seepage losses in SFRs were worked out by the water balance approach. The optimum depth of SFRs for circular and rectangular shapes were worked out by using reservoir storage optimization. The water demand of crops were estimated by the soil textured, ET and expected length of dryspells at critical crop growth stages, soil water replenishment needed in the crop root zone and location of crop area in reference to SFR (in case of rice).

Water balance approach was adopted based on daily water budgeting of SFR, in order to partition various hydrological components viz. rainfall, runoff, evaporation, seepage losses, irrigation etc. Seepage contribution to SFR were estimated by taking measurements in a 20 m x 24 m x 3 m pit in nearby area, which was lined all sides except the seepage face. Further, in order to develop rating curves of storage volumes and water spread area as functions of reservoir storage depth, the capacity survey of SFR's were conducted.

The alternative designs of surface drainage systems were undertaken at four levels of recurrence interval, after analysing daily maximum runoff to be disposed off, viz. 1.25, 1.33, 1.66 and 2 years. Looking to the good drainage need of monsoon crops, and considering 16 hours as the excess water removal time, a close spacing of 7 and 10 m was adopted in plains and plateau areas. Sediment concentration of runoff were also recorded at fortnightly intervals. Assuming the third year sedimentation value as the stabilized sedimentation rate, and accounting for the higher sedimentation in the initial years, per cent capacity reduction and active life of SFRs were worked out.

Besides crop production, remunerative enterprise of pisciculture was also incorporated in SFRs, which included addition of cow dung and pig dung to serve as fish feed and seepage retardant. In MWs, crops like rice, pulses, oilseeds, fruits and tubers were grown and its performance utilizing SFR water were evaluated. As a result of increased ground water recharge, the conjunctive use of surface water (SFR) and ground water (shallow dug wells) were also attempted, for crop production in MWs. The economics of crop and fish production were worked out.

Crop-area and water allocation model were formulated using linear programming. It was assumed that under the limited availability of water, the input and output relationship was linear. The optimal crop plans were worked out using above model under three different cases as established by socio-economic survey of the region :

CASE 1 : When rice area is limited to atleast 25-30 % of the cropped area (for farmers having strong affinity to rice)

CASE 2 : When rice area is limited to least 15-20% of the cropped area (for farmers having moderate affinity to rice)

CASE 3 : No restriction on any of the crop (Progressive farmers).

In case 1 and case 2 restrictions were also placed on the area of oilseeds, pulses, tubers, fruits (each atleast 5 % of the cropped area) and vegetables (at least 10% of cropped area). Besides, availability of cultivated land and water in SFR were the obvious restrictions, in all cases.

The overall economics of SFR based farming in all the MWs were worked out for four alternative designs of SFR, each under optical crop plans for three different cases (group of farmers), taking into account the investments incurred in installation and maintenance of SFR and drainage system.

Based on the present research findings, the following conclusions are drawn :

1. Curve number method was found superior over other methods for runoff estimation because of its ability to calculate runoff for shortest period (daily).

2. The water harvesting potential (WHP) of composite MW (with rice coverage 25-30%) were found to be higher (617-727 mm) in plateau than that under plains (445-491 mm).

3. Annual as well as monsoon rainfalls followed normal distribution. In periods with high variability or low amount of rainfall, either exponential or Gamma distribution fitted well to rainfall data.

4. The annual as well as seasonal runoffs followed normal distribution whereas fortnightly runoffs were found to follow exponential form.

5. Gamma distribution was found to be good fit to the dry spell length, the longest one was found to be 23 and 27 days at 25 per cent, 12 and 16 days at 75 per cent probability of exceedence in plateau and plains, respectively. It was coinciding with the reproduction stages of most crops, needed irrigation from SFR. The Markov-chain modelling also showed the occurrence of wet periods between 25-36 SMWs when WHP is the highest. This analysis further revealed the occurrence of dry periods after 36 SMW (initial and conditional dry probabilities higher than 55%), showed immense needs of water for the crops from SFR.

6. Among various alternative designs of SFR and drainage system, the one at 80 per cent probability of exceedence of rainfall and runoff resulted in highest B/C ratio (2.33-2.78). Under this design area required for SFR was worked out to be 10 and 13.5 per cent of MW area in plains and plateau areas of Chhattisgarh.

7. The overall B/C ratio of MWs was found to be highest (2.49-2.78) when there was no restriction to choice of crops and its area (Progressive farmers).

8. Being a rice growing tract, where rice coverage was atleast 15-20 per cent (farmers with moderate rice affinity), the B/C ratio was found slightly to reduce (2.40-2.58) but it was still higher than the case with atleast 25-30 per cent rice coverage (farmers with strong rice affinity). In this case B/C ratio was found to be lowest (2.33-2.50).

9. Fish rearing inside SFR alone substantially contributed (5.1-8.5 per cent of net profit) to the overall economy of MWs including the compensation of foregone crops under SFR.

10. Economic analysis based on crop yields, net profits (at 1999-2000 price levels), the optimal crop plans, showed that there could be remarkable change in the economic scenario of MW under SFR based farming. The analysis revealed that B/C ratio could be enhanced from 1.06-1.16 to 2.33-2.78 in SFRs designed at 80 per cent probability of exceedence of rainfall and runoff. Besides cropping intensity can be increased from 62.5-100 to 200 per cent.

Improvement of ground water status (rise in water table from 0.25-1.75 m) which facilitated conjuctive use of surface and ground water, additional employment generation, increased value of cropped land and conducive environment for crop diversification and mixed forming are the added intangible benefits accrued from the adoption of SFR based farming system.

In a nutshell, the investigations revealed the techno-economic feasibility of improvements in the present rainfed farming system which could be brought to the level of agriculture in irrigated environments with practically no sign of resource base degradation. The approach is rather eco-friendly where environment improves with the improvement in farming practices.

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## APPENDIX I : A PROGRAMME IN MS EXCELL 5.0 USING CONDITIONAL STATEMENTS FOR RUNOFF ESTIMATION (CN)

| Column | Particulars | Conditional Statements |
|---|---|---|
| A | Month | 1 - 12 |
| B. | Date | 1 - 28/29/30/31 |
| C | Rainfall | Daily, amount in mm |
| D | Sum of previous 5 days rainfall | = sum (C4 : C9) |
| E | Crop cover | |
| | R-2 | =IF(A9<4,"Good",IF(A9<6,"PF",IF(A9<9,"Poor",IF (A9<12 ,"Fair" "Good")))) |
| | R-1,J-1 and J-2 | =IF(A9<2,"Fair",IF(A9<4,"Good",IF(A9<6,"PF",IF (A9<8,"Poor",IF(A9<9,"Fair",IF(A9<11,"Good", "Poor")))))) |
| F | Assigning CN for AMC II | |
| | R-2 | =IF(A9<4,"89",IF(A9<6,"94",IF(A9<9,"91",IF(A9<12," 90","89")))) |
| | R-1,J-1andJ-2 | IF(A9<2,"90",IF(A9<4,"89",IF(A9<6,"94,IF(A9<8,"91", IF(A9<9,"90",IF(A9<11,"89","91")))))) |
| G | Designating AMC | |
| | R-1 and R-2 | |
| | Growing season | =IF(D9<36,"1",IF(D9<53,"2","3")) |
| | Dormant season | =IF(D9<12,"1",IF(D9<29,"2","3")) |
| | J-1 and J-2 | |
| | Monsoon season | = IF(D9<10,"1","3")) |
| | Non-monsoon season | =IF(D9<10,"1",IF(D9<19,"2","3")) |
| H | New CN for AMC | |
| | All MWs (4,5)* | =IF(G9<2,"86.8",IF(G9<3,"94","97.6")) |
| | J-1, J-2(6,7,11,12) | =IF(G9<2,"80.2","96.4") |
| | J-1, J-2 (8,1) | =IF(G9<2,"78","96") |
| | J-1,J-2(9,10,2,3) | =IF(G9<2,"76.5","95.5") |

| | | |
|---|---|---|
| | R-1 (6,7,11,12) and R-2 (6,7,8) | =IF(G9<2,"80.2",IF(G9<3,"91","96.4")) |
| | R-1 (8,1) and | =IF(G9<2,"78",IF(G9<3,"90","96")) |
| | R-2, (9,10,11) | |
| | R-1 (9,10,2,3) and R-2 (12,1,2,3) | =IF(G9<2,"76.5",IF(G9<3,"89","95.5")) |
| I | Calculation of S | = ((1000/H9)-10)* 25.4 |
| J | Q for non-rice area | =IF(C9<2,0,((C9-0.1*I9)$^2$ / (C9+0.9*I9)) |
| K | Q for rice area | |
| | low land | =IF(C9<2,0,IF(C9<50,(C9-1.33864)$^2$ / (C9+12.0316), (C9-50-1.33684)$^2$ / (C9-50+12.0316)))) |
| | Upland | = IF(C9<25,0,IF(C9<50,(C9-1.38864)$^2$ / (C9+12.0316), (C9-50-1.33684)$^2$ / (C9-50+12.0316)))) |
| L | Weighted runoff | |
| | J-1 | =((1.25*J9)+(0.5*K9)) / 1.75 |
| | J-2 | =((1.58*J9)+(0.17*K9)) / 1.75 |

+ month number; 1 ...... 12 for Jan to Dec.

## APPENDX II : A COMPUTER PROGRAMME IN C ++ FOR RUNOFF ESTIMATION BY CURVE NUMBER METHOD

```
#include<stdio.h>
#include<conio.h>
#include<string.h>
#include<math.h>
#include<stdlib.h>
void main()
{typedef struct { int date, m;
                float rf, p5t,jt;
                float ncnr,s,q,ml,ll,a[365],mw1,mw2;
                char ccr[3];
                int cnr,amcr1; } record ;
FILE *fp,*fc,*fpp; record r; char printer[]="LPT1";
int n=0,k=0; char choice,ch; clrscr();
while(1)
{ clrscr(); gotoxy(15,10);
printf("APPENDEX II  :  A COMPUTER  PROGRAMME  IN\n");
printf("                    C++ FOR RUNOFF ESTIMATION BY\n");
printf("               CURVE NUMBER METHOD"); getch(); clrscr();
gotoxy(25,10); printf("MENU"); gotoxy(24,11); printf("*******"); gotoxy(10,12);
 printf(" \n\t A.DISPLAY THE RAIN-FALL REPORT FROM RAIPUR M.W.1");
 printf(" \n\t B.DISPLAY THE RAIN-FALL REPORT FROM RAIPUR M.W.2");
 printf(" \n\t C.DISPLAY THE RAIN-FALL REPORT FROM JAGDALPUR");
 printf(" \n\t D.EXIT");
 printf("\n\n\n\n\t\t ENTER YOUR CHOICE(A,B,C OR D Any One) = "); scanf("%c",&ch);fflush(stdin);
switch(ch)
{case 'A':
{add:clrscr();
 gotoxy(25,10); printf("MENU OF RAIPUR R-1"); gotoxy(24,11);
 printf("********************"); gotoxy(10,12);
 printf(" \n\t 1.DISPLAY THE RAIN-FALL REPORT FROM RAIPUR M.W.1");
 printf(" \n\t 2.WRITING NEW RAIN-FALL DATA IN RAIPUR M.W.1(REFRESS OLD DATA)");
 printf(" \n\t 3.Print");    printf(" \n\t 4.EXIT");
 printf("\n\n\n\n\t\t ENTER YOUR CHOICE(1,2,3 OR 4 Any One) = ");
 scanf("%d",&choice);fflush(stdin);
switch(choice)
{case 1:
{fp=fopen("rain1.dat","r");   int r1=7;clrscr();
   gotoxy(1,2); printf("APPENDX  III  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
RAIPUR(R-1)\n");
   gotoxy(1,3); printf("            SAMPLE OF PROGRAMME OUTPUT");
   gotoxy(1,4); printf("----------------------------------------------------------------------");
   gotoxy(1,5); printf("DA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN  Calc. Q for  Q'from rice "  );
   gotoxy(1,6); printf("TE th  fall  Total cover AMCII     AMC     S   n.rice  M.L.  L.L.  ");
   gotoxy(1,7); printf("----------------------------------------------------------------------\n");
while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f ",&r.date,&r.m,&r.rf,&r.p5t , r.ccr,&r.cnr,
&r.amcr1, &r.ncnr, &r.s,&r.q,&r.ml,&r.ll)!=EOF)
   {if(r1==24)
    {printf("PLEASE WAIT ---------------\n Press Any key To Continue........... ");
    getch();clrscr();
    gotoxy(1,2); printf("APPENDX  III  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
RAIPUR(R-1)\n");
    gotoxy(1,3); printf("            SAMPLE OF PROGRAMME OUTPUT");
    gotoxy(1,4); printf("----------------------------------------------------------------------");
    gotoxy(1,5); printf("DA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN  Calc. Q for  Q'from rice "  );
    gotoxy(1,6); printf("TE th  fall  Total cover AMCII     AMC     S   n.rice  M.L.  L.L.  ");
    gotoxy(1,7); printf("----------------------------------------------------------------------\n"); r1=7;}
   printf("%2d %2d %6.1f %6.1f %4s %5d %3d  %5.1f  %5.1f  %6.2f  %5.2f %5.2f\n",
r.date,r.m,r.rf,r.p5t ,r.ccr, r.cnr, r.amcr1, r.ncnr,r.s, r.q,r.ml,r.ll);
   r1=r1+1;}fclose(fp);
```

```
  gotoxy(5,23); printf("\npress any key to continue ..........."); getch(); } goto add;
case 2:
{clrscr(); int n1=0,nm,k=0; fp=fopen("rain1.dat","w");
gotoxy(5,5); printf("                RECORD-ENTERY\n");
gotoxy(5,6); printf("            ***************\n\n");
printf("Enter date,month & rain-fall (Date in DD, Month in MM & Rain-Fall in milli-meter)\n\n");
printf("Enetr number of record to input :-");
scanf("%d",&nm); fflush(stdin);
while(n1!=nm)
{ printf("\n\nEnter Date(in DD):-");  scanf("%d",&r.date); fflush(stdin);
  printf("\Enter Month(in MM):-"); scanf("%d",&r.m); fflush(stdin);
  printf("\Enter Rain-Fall(in milli-meter):-"); scanf("%f",&r.rf); fflush(stdin);
  fprintf(fp,"%d %d %f\n",r.date,r.m,r.rf); n1=n1+1;} fclose(fp); clrscr();
  printf("press any key to continue ..........."); getch();
 fp=fopen("rain1.dat","r"); fc=fopen("RR.NEW","w");
 char crop [4][3]={"PF","FA","GD","PR"};
while(fscanf(fp,"%d %d %f",&r.date,&r.m,&r.rf)!=EOF)
 { r.a[n]=r.rf;
if(n>4)  { r.p5t=(r.a[0+k])+(r.a[1+k])+(r.a[2+k])+(r.a[3+k])+(r.a[4+k]);  k=k+1; } else r.p5t=0;
   if(r.m>0 && r.m<3)              strcpy(r.ccr,crop[2]);    if(r.m>2 && r.m<6)       strcpy(r.ccr,crop[0]);
   if(r.m>8 && r.m<12)        strcpy(r.ccr,crop[1]);   if(r.m==12)              strcpy(r.ccr,crop[2]);
   if(r.m>5 && r.m<9)        strcpy(r.ccr,crop[3]);    fflush(stdin);          if(r.m==1) r.cnr=90;
   if(r.m>1 && r.m<4) r.cnr=89; if((r.m>3) && (r.m<6)) r.cnr=94;
   if((r.m>5) && (r.m<8)) r.cnr=91;
   if(r.m==8)  r.cnr=90;   if((r.m>8) && (r.m<11))  r.cnr=89;
   if((r.m>10) && (r.m<13)) r.cnr=91;
   if(r.m==4 || r.m==5)         { if(r.p5t<12)   r.amcr1=1;
   if(r.p5t>12 && r.p5t<29)      r.amcr1=2;    if(r.p5t>28)             r.amcr1=3;}
  else { if(r.p5t<36)          r.amcr1=1;  if(r.p5t>35 && r.p5t<54) r.amcr1=2;
   if(r.p5t>53)              r.amcr1=3;  }
   if(r.m>1 && r.m<4)  { if(r.amcr1==1)  r.ncnr=76.5;      if(r.amcr1==2)           r.ncnr=89;
    if(r.amcr1==3)            r.ncnr=95.5;}  if(r.m==4 || r.m==5)           { if(r.amcr1==1)   r.ncnr=86.8;
     if(r.amcr1==2)           r.ncnr=94;    if(r.amcr1==3)          r.ncnr=97.6;}
 if(r.m>5 && r.m<8)            {if(r.amcr1==1)     r.ncnr=80.2;
    else if(r.amcr1==2)         r.ncnr=91;     else if(r.amcr1==3)        r.ncnr=96.4;}
 if(r.m==1 || r.m==8)          {if(r.amcr1==1)     r.ncnr=78;
    if(r.amcr1==2)            r.ncnr=90;       if(r.amcr1==3)          r.ncnr=96;} if(r.m>8 && r.m<11)
 {if(r.amcr1==1)    r.ncnr=76.5;
    if(r.amcr1==2)            r.ncnr=89;    if(r.amcr1==3)                r.ncnr=95.5; } if(r.m==11 ||
 r.m==12)        {if(r.amcr1==1)    r.ncnr=80.2;
    else if(r.amcr1==2)         r.ncnr=91;     else if(r.amcr1==3)        r.ncnr=96.4; }
    r.s=((1000/r.ncnr)-10)*25.4;    int k; k=0.1*r.s;
    if(r.rf>k)     r.q=pow((r.rf-(0.1*r.s)),2)/(r.rf+(0.9*r.s));  else r.q=0;
    int c,j; if(r.m==6) {    if(c==11)        {  if(r.rf<1.4)      r.ll=0;
      else r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
      if(r.rf>1.4 && r.rf<50)   r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf<25)  r.ml=0;    else r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf>25 && r.rf<50)     r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf>50)   {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
  r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);}}else { r.jt=r.jt+r.rf;
  if(r.jt>=140)       {j=r.jt-140; r.ll=pow((j-1.33684),2)/(j+12.0316);
   r.ml=pow((j-1.33684),2)/(j+12.0316);    c=11; r.jt=0; } else{ r.ll=0; r.ml=0;}
     }} if(r.m<6 && r.m>6)
 { if(r.rf<1.4) r.ll=0; else r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
      if(r.rf>1.4 && r.rf<50)  r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf<25) r.ml=0; else r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
  if(r.rf>25 && r.rf<50)  r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
  if(r.rf>50) {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
      r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);}}
  fprintf( fc,"%d %d %f %f %s %d %d %f %f %f %f %f \n", r.date,r.m, r.rf,r.p5t,r.ccr,r.cnr, r.amcr1, r.ncnr
 , r.s,r.q, r.ml,r.ll);    n=n+1; } fclose(fp); fclose(fc);
    remove("rain1.dat"); rename("RR.NEW","rain1.dat"); fclose(fp);}goto add;
```

```
case 3:
{ fp=fopen("rain1.DAT","r");  fpp=fopen(printer,"w");clrscr();
 fprintf(fpp,"APPENDX  III  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
RAIPUR(R-1)");
  fprintf(fpp,"              SAMPLE OF PROGRAMME OUTPUT");
  fprintf(fpp,"-----------------------------------------------------------------------");
  fprintf(fpp,"\nDA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN   Calc. Q for   Q'from rice");
  fprintf(fpp,"\nTE th   fall  Total cover AMCII     AMC     S    n.rice  M.L.  L.L.");
  fprintf(fpp,"\n-----------------------------------------------------------------------");
 while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f
",&r.date,&r.m,&r.rf,&r.p5t,r.ccr,&r.cnr,&r.amcr1,&r.ncnr,&r.s,&r.q,&r.ml,&r.ll)!=EOF)
 fprintf(fpp,"\n%2d  %02d %5.1f %5.1f %4s %4d  %3d  %5.1f  %6.2f %6.2f %6.2f
%6.2f",r.date,r.m,r.rf,r.p5t,r.ccr,r.cnr,r.amcr1,r.ncnr,r.s,r.q,r.ml,r.ll);
 fclose(fp); gotoxy(5,5); printf("press any key to continue ...........\n");
 printf("please on the printer  'wait & exit'"); getch(); }
case 4:
{ clrscr();gotoxy(20,15);printf("RETURN TO MAIN PROGRAME");
 gotoxy(20,16); printf(" press any key to continue ......."); getch();}}}break;
case 'B':
{ add1:  clrscr();  gotoxy(25,10); printf("MENU OF RAIPUR R-2"); gotoxy(24,11);
printf("*********************"); gotoxy(10,12);   printf(" \n\t 1.DISPLAY THE RAIN-FALL REPORT FROM
RAIPUR M.W.2");
  printf(" \n\t 2.WRITING NEW RAIN-FALL DATA IN RAIPUR M.W.2(REFRESS OLD DATA)");
  printf(" \n\t 3.PRINT");  printf(" \n\t 4.EXIT");
  printf("\n\n\n\n\t\t ENTER YOUR CHOICE(1,2,3 OR 4 Any One) = ");
  scanf("%d",&choice);  fflush(stdin);
switch(choice)
{case 1:
 {fp=fopen("rain2.dat","r"); int r1=7; clrscr();
   gotoxy(1,1); printf("APPENDX  IV  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
RAIPUR(R-2)\n");
   gotoxy(1,2); printf("              SAMPLE OF PROGRAMME OUTPUT");
   gotoxy(1,3); printf("-----------------------------------------------------------------------");
   gotoxy(1,4); printf("DA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN   Calc. Q for   Q'from rice "  );
   gotoxy(1,5); printf("TE th   fall  Total cover AMCII     AMC     S    n.rice  M.L.  L.L.  ");
   gotoxy(1,6); printf("-----------------------------------------------------------------------\n");
   while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f ",&r.date, &r.m,&r.rf,&r.p5t, r.ccr,&r.cnr,
&r.amcr1, &r.ncnr,&r.s,&r.q,&r.ml,&r.ll)!=EOF)
   { if(r1==24)
{ printf(" PLEASE WAIT ----------------\n Press Any key To Continue........... "); getch(); clrscr();
   gotoxy(1,1); printf("APPENDX  IV  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
RAIPUR(R-2)\n");
   gotoxy(1,2); printf("              SAMPLE OF PROGRAMME OUTPUT");
   gotoxy(1,3); printf("-----------------------------------------------------------------------");
   gotoxy(1,4); printf("DA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN   Calc. Q for   Q'from rice "  );
   gotoxy(1,5); printf("TE th   fall  Total cover AMCII     AMC     S    n.rice  M.L.  L.L.  ");
   gotoxy(1,6); printf("-----------------------------------------------------------------------\n");    r1=7;}
   printf("%2d %2d %6.1f %6.1f %4s %5d %3d  %5.1f   %5.1f  %6.2f  %5.2f %5.2f\n", r.date,r.m,r.rf,
r.p5t,r.ccr, r.cnr, r.amcr1,r.ncnr,r.s,r.q,r.ml,r.ll);
   r1=r1+1;} fclose(fp); gotoxy(5,23);  printf("\npress any key to continue ...........");  getch(); } goto
add1;
case 2:
{ clrscr(); int n1=0,nm,k=0; fp=fopen("rain2.dat","w");
gotoxy(5,5); printf("                RECORD-ENTERY\n");
gotoxy(5,6); printf("                ****************\n\n");
printf("Enter date,month & rain-fall (Date in DD, Month in MM & Rain-Fall in milli-meter)\n\n");
printf("Enetr number of record to input :-"); scanf("%d",&nm); fflush(stdin);
while(n1!=nm)
{  printf("\n\nEnter Date(in DD):-"); scanf("%d",&r.date);  fflush(stdin);
  printf("\Enter Month(in MM):-");  scanf("%d",&r.m);  fflush(stdin);
  printf("\Enter Rain-Fall(in milli-meter):-");  scanf("%f",&r.rf); fflush(stdin);
  fprintf(fp,"%d %d %6.2f\n",r.date,r.m,r.rf); n1=n1+1; } fclose(fp); clrscr();
```

```
 printf("press any key to continue ..........."); getch();
fp=fopen("rain2.dat","r"); fc=fopen("RR1.NEW","w");
char crop [4][3]={"PF","FA","GD","PR"};
while(fscanf(fp,"%d %d %f",&r.date,&r.m,&r.rf)!=EOF)
{r.a[n]=r.rf; if(n>4)
{ r.p5t=(r.a[0+k])+(r.a[1+k])+(r.a[2+k])+(r.a[3+k])+(r.a[4+k]); k=k+1; } else r.p5t=0;
  if(r.m>0 && r.m<4)   strcpy(r.ccr,crop[2]);   if(r.m>3 && r.m<6)   strcpy(r.ccr,crop[0]);
  if(r.m>8 && r.m<12)  strcpy(r.ccr,crop[1]);   if(r.m==12)          strcpy(r.ccr,crop[2]);
  if(r.m>5 && r.m<9)   strcpy(r.ccr,crop[3]);   fflush(stdin);
  if(r.m>0 && r.m<4)             r.cnr=89;   if((r.m>3) && (r.m<6))       r.cnr=94;
  if((r.m>5) && (r.m<9))         r.cnr=91;   if((r.m>8) && (r.m<12))   r.cnr=90;
  if(r.m==12)              r.cnr=89;   if(r.m==4 || r.m==5)
  { if(r.p5t<12)           r.amcr1=1;  if(r.p5t>12 && r.p5t<29)   r.amcr1=2;
  if(r.p5t>28)       r.amcr1=3;} else  { if(r.p5t<36)       r.amcr1=1;
  if(r.p5t>35 && r.p5t<54)    r.amcr1=2;     if(r.p5t>53)   r.amcr1=3;  }
  if(r.m>1 && r.m<4)
   { if(r.amcr1==1)    r.ncnr=76.5;     if(r.amcr1==2)    r.ncnr=89;
   if(r.amcr1==3)      r.ncnr=95.5;}    if(r.m==4 || r.m==5)
   { if(r.amcr1==1)    r.ncnr=86.8;     if(r.amcr1==2)    r.ncnr=94;
    if(r.amcr1==3)     r.ncnr=97.6;}    if(r.m>5 && r.m<9)
   {if(r.amcr1==1)     r.ncnr=80.2;     else if(r.amcr1==2) r.ncnr=91;
   else if(r.amcr1==3)  r.ncnr=96.4;}
 if(r.m>8 && r.m<12)   {if(r.amcr1==1)   r.ncnr=78;
    if(r.amcr1==2)   r.ncnr=90;    if(r.amcr1==3)     r.ncnr=96; }
 if( r.m==12)       {if(r.amcr1==1)    r.ncnr=76.5;
   else if(r.amcr1==2)    r.ncnr=89;   else if(r.amcr1==3) r.ncnr=95.5; }
   r.s=((1000/r.ncnr)-10)*25.4;   int k;  k=0.1*r.s;
   if(r.rf>k) r.q=pow((r.rf-(0.1*r.s)),2)/(r.rf+(0.9*r.s));   else r.q=0;
   int c,j; if(r.m==6) { if(c==11) {   if(r.rf<1.4)  r.ll=0;
    else r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
    if(r.rf>1.4 && r.rf<50) r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
if(r.rf<25) r.ml=0; else r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
if(r.rf>25 && r.rf<50) r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
if(r.rf>50) {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
   r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);}} else
   {  r.jt=r.jt+r.rf;  if(r.jt>=140)   {j=r.jt-140;   r.ll=pow((j-1.33684),2)/(j+12.0316);
    r.ml=pow((j-1.33684),2)/(j+12.0316); c=11; r.jt=0; }
   else{ r.ll=0; r.ml=0;}}}     if(r.m<6 && r.m>6)
{ if(r.rf<1.4) r.ll=0;  else r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
if(r.rf>1.4 && r.rf<50)  r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf<25)    r.ml=0;  else r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf>25 && r.rf<50)  r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);
 if(r.rf>50) {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
  r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);}}
   fprintf( fc,"%d %d %f %f %s %d %d %f %f %f %f %f \n", r.date,r.m,r.rf, r.p5t,r.ccr,r.cnr,
r.amcr1,r.ncnr, r.s, r.q, r.ml,r.ll);  n=n+1;}fclose(fp);fclose(fc);
remove("rain2.dat"); rename("RR1.NEW","rain2.dat");fclose(fp);  } goto add1;
case 3:
{ fp=fopen("rain2.DAT","r"); fpp=fopen(printer,"w"); clrscr();
 fprintf(fpp,"APPENDX  IV  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE : RAIPUR(R-
2)");
    fprintf(fpp,"              SAMPLE OF PROGRAMME OUTPUT");
    fprintf(fpp,"------------------------------------------------------------------\n");
    fprintf(fpp,"DA Mon  Rain  P5DAY crop  C.N.  AMC  N.CN   Calc.  Q for   Q'from rice\n"  );
    fprintf(fpp,"TE th   fall  Total cover AMCII     AMC      S    n.rice  M.L.  L.L.\n");
    fprintf(fpp,"------------------------------------------------------------------\n");
 while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f
",&r.date,&r.m,&r.rf,&r.p5t,r.ccr,&r.cnr,&r.amcr1,&r.ncnr,&r.s,&r.q,&r.ml,&r.ll)!=EOF)
fprintf(fpp,"%2d  %02d  %5.1f   %5.1f %4s %4d  %3d  %5.1f  %6.2f %6.2f  %6.2f
%6.2f\n",r.date,r.m,r.rf,r.p5t,r.ccr,r.cnr,r.amcr1,r.ncnr,r.s,r.q,r.ml,r.ll);
fclose(fp); gotoxy(5,5); printf("press any key to continue ...........\n");
printf("please on the printer  'wait & exit'"); getch();} goto add1;
```

```
case 4:
{clrscr(); gotoxy(20,15); printf("RETURN TO MAIN PROGRAME"); gotoxy(20,16);
 printf(" press any key to continue ......."); getch(); }}} break;
case 'C':
{ add2:  clrscr();  gotoxy(25,10); printf("MENU OF JAGADALPUR J-1 & J-2"); gotoxy(24,11);
printf("********************************"); gotoxy(10,12);
  printf(" \n\t 1.DISPLAY THE RAIN-FALL REPORT FROM JAGADALPUR");
  printf(" \n\t 2.WRITING NEW RAIN-FALL DATA IN JAGADALPUR(REFRESS OLD DATA)");
  printf(" \n\t 3.PRINT");
  printf(" \n\t 4.EXIT");
printf("\n\n\n\n\t\t ENTER YOUR CHOICE(1,2,3 OR 4 Any One) = ");
 scanf("%d",&choice);  fflush(stdin); switch(choice)
{case 1:
   {fp=fopen("rain5.dat","r");    int r1=7;clrscr();
   gotoxy(1,1); printf("APPENDX  V  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
JAGDALPUR(J-1, J-2)\n");
   gotoxy(1,2); printf("            SAMPLE OF PROGRAMME OUTPUT");
   gotoxy(1,3); printf("--------------------------------------------------------------------------\n");
   gotoxy(1,4); printf("DA M  Rain  P5DAY crop  C.N.  AMC  N.CN  Calc. Q for  Q'from rice Wt.Run-off"
);
   gotoxy(1,5); printf("TE    fall  Total cover AMCII     AMC     S   n.rice M.L.  L.L.  J-1   J-2 ");
   gotoxy(1,6); printf("--------------------------------------------------------------------------");
while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f %f
%f",&r.date,&r.m,&r.rf,&r.p5t,r.ccr,&r.cnr,&r.amcr1,&r.ncnr,&r.s,&r.q,&r.ml,&r.ll,&r.mw1,&r.mw2)!=EOF)
   {if(r1==24){
     printf("\n PLEASE WAIT ----------------\n Press Any key To Continue........... ");getch(); clrscr();
   gotoxy(1,1); printf("APPENDX  V  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
JAGDALPUR(J-1, J-2)\n");
   gotoxy(1,2); printf("            SAMPLE OF PROGRAMME OUTPUT");
   gotoxy(1,3); printf("--------------------------------------------------------------------------\n");
   gotoxy(1,4); printf("DA M  Rain  P5DAY crop  C.N.  AMC  N.CN  Calc. Q for  Q'from rice Wt.Run-off"
);
   gotoxy(1,5); printf("TE    fall  Total cover AMCII     AMC     S   n.rice M.L.  L.L.  J-1   J-2 ");
   gotoxy(1,6); printf("--------------------------------------------------------------------------"); r1=7;}
   printf("\n%2d %02d %5.1f %5.1f %3s  %4d %4d   %4.1f  %5.1f  %5.2f %5.2f %5.2f %5.2f %5.2f",
 r.date, r.m, r.rf, r.p5t, r.ccr,r.cnr,r.amcr1,r.ncnr,r.s,r.q,r.ml,r.ll,r.mw1,r.mw2);   r1=r1+1;}   fclose(fp);
 gotoxy(5,23);
   printf("\npress any key to continue ...........");getch();} goto add2;
 case 2:
 {clrscr(); int n1=0,nm,k=0; fp=fopen("rain5.dat","w");
 gotoxy(5,5);printf("                RECORD-ENTERY\n");
 gotoxy(5,6);printf("                ****************\n\n");
 printf("Enter date,month & rain-fall (Date in DD, Month in MM & Rain-Fall in milli-meter)\n\n");
 printf("Enetr number of record to input :-");
 scanf("%d",&nm);fflush(stdin);
 while(n1!=nm)
 {printf("\n\nEnter Date(in DD):-");  scanf("%d",&r.date);  fflush(stdin);
   printf("\Enter Month(in MM):-");  scanf("%d",&r.m);  fflush(stdin);
   printf("\Enter Rain-Fall(in milli-meter):-");  scanf("%f",&r.rf);fflush(stdin);
   fprintf(fp,"%d %d %f\n",r.date,r.m,r.rf);  n1=n1+1;}  fclose(fp);  clrscr();
   printf("press any key to continue ...........");  getch();
  fp=fopen("rain5.dat","r"); fc=fopen("RR.NEW","w");
  char crop [4][3]={"PF","FA","GD","PR"};
 while(fscanf(fp,"%d %d %6.2f",&r.date,&r.m,&r.rf)!=EOF)
 { r.a[n]=r.rf;  if(n>4)
    {r.p5t=(r.a[0+k])+(r.a[1+k])+(r.a[2+k])+(r.a[3+k])+(r.a[4+k]);
    k=k+1;}else r.p5t=0;
    if(r.m>0 && r.m<3)    strcpy(r.ccr,crop[2]);   if(r.m>2 && r.m<6)   strcpy(r.ccr,crop[0]);
    if(r.m>8 && r.m<12)  strcpy(r.ccr,crop[1]);   if(r.m==12)        strcpy(r.ccr,crop[2]);
    if(r.m>5 && r.m<9)  strcpy(r.ccr,crop[3]);  fflush(stdin);
  if(r.m==1)    r.cnr=90;    if(r.m>1 && r.m<4)    r.cnr=89;
  if((r.m>3) && (r.m<6))    r.cnr=94;    if((r.m>5) && (r.m<8))    r.cnr=91;
```

```
if(r.m==8)   r.cnr=90;   if((r.m>8) && (r.m<11))   r.cnr=89;
if((r.m>10) && (r.m<13))   r.cnr=91;
if(r.m>5 && r.m<11) {if(r.p5t<10)   r.amcr1=1;   else   r.amcr1=3;}
if(r.m>10 && r.m<13)   {if(r.p5t<10)   r.amcr1=1;
if(r.p5t>9.9 && r.p5t<18.1)   r.amcr1=2;   if(r.p5t>18)   r.amcr1=3;}
if(r.m>0 && r.m<6)   {if(r.p5t<10)   r.amcr1=1;
if(r.p5t>9.9 && r.p5t<18.1)   r.amcr1=2;   if(r.p5t>18)   r.amcr1=3;}
if(r.m>1 && r.m<4) {if(r.amcr1==1)   r.ncnr=76.5;   if(r.amcr1==2)   r.ncnr=89;
  if(r.amcr1==3)   r.ncnr=95.5;} if(r.m==4 || r.m==5)   { if(r.amcr1==1)   r.ncnr=86.8;
  if(r.amcr1==2)   r.ncnr=94;   if(r.amcr1==3)   r.ncnr=97.6;}
if(r.m>5 && r.m<8)   {if(r.amcr1==1)   r.ncnr=80.2;
  else if(r.amcr1==2)   r.ncnr=91;   else if(r.amcr1==3)   r.ncnr=96.4;}
if(r.m==1 || r.m==8)   {if(r.amcr1==1)   r.ncnr=78;
  if(r.amcr1==2)   r.ncnr=90;   if(r.amcr1==3)   r.ncnr=96;}
if(r.m>8 && r.m<11)   {if(r.amcr1==1)   r.ncnr=76.5;
  if(r.amcr1==2)   r.ncnr=89;   if(r.amcr1==3)   r.ncnr=95.5; }
if(r.m==11 || r.m==12)   {if(r.amcr1==1)   r.ncnr=80.2;
else if(r.amcr1==2)   r.ncnr=91;  else if(r.amcr1==3)   r.ncnr=96.4;}
  r.s=((1000/r.ncnr)-10)*25.4; int k;   k=0.1*r.s;
  if(r.rf>k)  r.q=pow((r.rf-(0.1*r.s)),2)/(r.rf+(0.9*r.s));
  else  r.q=0; int c,j; if(r.m==6)   {if(c==11)   {if(r.rf>1.4)
   r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);   else r.ll=0;
  if(r.rf>25)   r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316); else r.ml=0;
  if(r.rf>50)  {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
  r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);} }
  else{ r.jt=r.jt+r.rf; if(r.jt>=140)   {j=r.jt-140;  r.ll=pow((j-1.33684),2)/(j+12.0316);
   r.ml=pow((j-1.33684),2)/(j+12.0316);   c=11; r.jt=0; }
  else{ r.ll=0; r.ml=0;}}}  else { if(r.rf>1.4) r.ll=pow((r.rf-1.33684),2)/(r.rf+12.0316);  else r.ll=0;
  if(r.rf>25)  r.ml=pow((r.rf-1.33684),2)/(r.rf+12.0316);  else r.ml=0;
  if(r.rf>50) {r.ll=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);
   r.ml=pow((r.rf-50-1.33684),2)/(r.rf-50+12.0316);}}
 r.mw1=((1.25*r.q)+0.5*r.ll)/1.75;  r.mw2=((1.58*r.q)+0.17*r.ll)/1.75;
fprintf( fc,"%d %d %f %f %s %d %d %f %f %f %f %f %f %f\n",r.date,r.m,r.rf,r.p5t,r.ccr, r.cnr,r.amcr1,
r.ncnr, r.s, r.q,r.ml,r.ll,r.mw1,r.mw2);   n=n+1; }   fclose(fp);   fclose(fc);
remove("rain5.dat"); rename("RR.NEW","rain5.dat"); fclose(fp); }  goto add2;
 case 3:
{fp=fopen("rain5.DAT","r"); fpp=fopen(printer,"w"); clrscr();
   fprintf(fpp,"APPENDX  V  : RUNOFF RSTIMATION BY CURVE NUMBER TECHNIQUE :
JAGDALPUR(J-1, J-2)");
   fprintf(fpp,"                    SAMPLE OF PROGRAMME OUTPUT");
   fprintf(fpp,"-----------------------------------------------------------------------------\n");
   fprintf(fpp,"DA Mon  Rain   P5DAY crop  C.N.  AMC  N.CN   Calc. Q for Q'from rice Wt.runoff\n");
   fprintf(fpp,"TE th   fall   Total cover AMCII     AMC      S   n.ric M.L.  L.L.  J-1  J-2\n");
   fprintf(fpp,"-----------------------------------------------------------------------------\n");
while(fscanf(fp,"%d %d %f %f %s %d %d %f %f %f %f %f %f %f",&r.date,&r.m,&r.rf, &r.p5t,r.ccr,
&r.cnr, &r.amcr1, &r.ncnr,&r.s,&r.q,&r.ml,&r.ll,&r.mw1,&r.mw2)!=EOF)
fprintf(fpp,"%2d %02d  %5.1f   %5.1f %3s %4d %4d    %5.1f  %5.2f %5.2f %5.2f %5.2f %5.2f
%5.2f\n", r.date, r.m,r.rf,r.p5t,r.ccr,r.cnr,r.amcr1,r.ncnr,r.s,r.q,r.ml,r.ll,r.mw1,r.mw2);
fclose(fp); gotoxy(5,5); printf("press any key to continue ...........\n");
printf("please on the printer  'wait & exit'"); getch(); } goto add2;
 case 4:
 {clrscr(); gotoxy(20,15);printf("RETURN TO MAIN PROGRAME");
 gotoxy(20,17); printf("press any key to continue ......."); getch(); }}} break;
 case 'D':
 {clrscr(); gotoxy(20,15);printf("EXIT THIS PROGRAME");
 gotoxy(20,17); printf("press any key to continue ......."); getch(); exit(1); } break; }}}
```

# APPENDIX III : RUNOFF ESTIMATION BY CURVE NUMBER METHOD; RAIPUR (R-1) - SAMPLE OF PROGRAMME OUTPUT

******************* DETAILE OF RAIN-FALL REPORT FOR 'RAIPUR MW1'***********
##################################################

| DA TE | Mon th | Rain fall | P5DAY Total | croop cover | C.N. AMCII | AMC | N.C.No AMC | Calc. S | Q for n.rice | Q'from M.L. | rice L.L. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 23 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 24 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 25 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 26 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 27 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 28 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 29 | 05 | 1.60 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 30 | 05 | 4.60 | 1.60 | PF | 94 | 1 | 86.80 | 38.63 | 0.01 | 0.00 | 0.00 |
| 31 | 05 | 0.00 | 6.20 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 1 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 2 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 3 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 4 | 06 | 0.00 | 4.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 5 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 6 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 7 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 8 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 9 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 10 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 11 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 12 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 13 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 14 | 06 | 3.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 15 | 06 | 0.00 | 3.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 16 | 06 | 0.60 | 3.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 17 | 06 | 1.60 | 3.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 18 | 06 | 0.00 | 5.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 19 | 06 | 39.00 | 5.20 | PR | 91 | 1 | 80.20 | 62.71 | 11.22 | 0.00 | 0.00 |
| 20 | 06 | 15.60 | 41.20 | PR | 91 | 2 | 91.00 | 25.12 | 4.48 | 0.00 | 0.00 |
| 21 | 06 | 154.80 | 56.80 | PR | 91 | 3 | 96.40 | 9.49 | 144.92 | 61.37 | 61.37 |
| 22 | 06 | 1.10 | 211.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 23 | 06 | 7.00 | 210.50 | PR | 91 | 3 | 96.40 | 9.49 | 2.36 | 0.00 | 1.69 |
| 24 | 06 | 105.40 | 217.50 | PR | 91 | 3 | 96.40 | 9.49 | 95.76 | 43.35 | 43.35 |
| 25 | 06 | 45.20 | 283.90 | PR | 91 | 3 | 96.40 | 9.49 | 36.44 | 33.62 | 33.62 |
| 26 | 06 | 22.20 | 313.50 | PR | 91 | 3 | 96.40 | 9.49 | 14.69 | 0.00 | 12.72 |
| 27 | 06 | 20.20 | 180.90 | PR | 91 | 3 | 96.40 | 9.49 | 12.90 | 0.00 | 11.04 |
| 28 | 06 | 70.20 | 200.00 | PR | 91 | 3 | 96.40 | 9.49 | 60.91 | 11.04 | 11.04 |
| 29 | 06 | 26.80 | 263.20 | PR | 91 | 3 | 96.40 | 9.49 | 18.91 | 16.70 | 16.70 |
| 30 | 06 | 0.50 | 184.60 | PR | 91 | 3 | 96.40 | 9.49 | 0.02 | 0.00 | 0.00 |
| 31 | 06 | 0.00 | 139.90 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 1 | 07 | 0.00 | 117.70 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 2 | 07 | 0.00 | 97.50 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 3 | 07 | 0.00 | 27.30 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 4 | 07 | 0.00 | 0.50 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 5 | 07 | 22.50 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 3.34 | 0.00 | 0.00 |
| 6 | 07 | 0.00 | 22.50 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |

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# PENDIX IV : RUNOFF ESTIMATION BY CURVE NUMBER METHOD : RAIPUR (R-2)-SAMPLE OF PROGRAMME OUTPUT

********** DETAILE OF RAIN-FALL REPORT FOR 'RAIPUR MW2'**********
##########################################################

| DA TE | Mon th | Rain fall | P5DAY Total | croop cover | C.N. AMCII | AMC | N.C.No AMC | Calc. S | Q for n.rice | Q'from rice M.L. | L.L. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 23 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 24 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 25 | 00 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 26 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 27 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 28 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 29 | 05 | 1.60 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 30 | 05 | 0.00 | 1.60 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 |
| 31 | 05 | 4.60 | 1.60 | PF | 94 | 1 | 86.80 | 38.63 | 0.01 | 0.00 | 0.00 |
| 1 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 2 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 3 | 06 | 0.00 | 6.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 4 | 06 | 0.00 | 4.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 5 | 06 | 0.00 | 4.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 6 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 7 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 8 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 9 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 10 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 11 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 12 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 13 | 06 | 0.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 14 | 06 | 3.00 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 15 | 06 | 0.00 | 3.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 16 | 06 | 0.60 | 3.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 17 | 06 | 1.60 | 3.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 18 | 06 | 0.00 | 5.20 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 19 | 06 | 39.00 | 5.20 | PR | 91 | 1 | 80.20 | 62.71 | 11.22 | 0.00 | 0.00 |
| 20 | 06 | 15.60 | 41.20 | PR | 91 | 2 | 91.00 | 25.12 | 4.48 | 0.00 | 0.00 |
| 21 | 06 | 154.80 | 56.80 | PR | 91 | 3 | 96.40 | 9.49 | 144.92 | 61.37 | 61.37 |
| 22 | 06 | 1.10 | 211.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 23 | 06 | 7.00 | 210.50 | PR | 91 | 3 | 96.40 | 9.49 | 2.36 | 0.00 | 1.69 |
| 24 | 06 | 105.40 | 217.50 | PR | 91 | 3 | 96.40 | 9.49 | 95.76 | 43.35 | 43.35 |
| 25 | 06 | 45.20 | 283.90 | PR | 91 | 3 | 96.40 | 9.49 | 36.44 | 33.62 | 33.62 |
| 26 | 06 | 22.20 | 313.50 | PR | 91 | 3 | 96.40 | 9.49 | 14.69 | 0.00 | 12.72 |
| 27 | 06 | 20.20 | 180.90 | PR | 91 | 3 | 96.40 | 9.49 | 12.90 | 0.00 | 11.04 |
| 28 | 06 | 70.20 | 200.00 | PR | 91 | 3 | 96.40 | 9.49 | 60.91 | 11.04 | 11.04 |
| 29 | 06 | 26.80 | 263.20 | PR | 91 | 3 | 96.40 | 9.49 | 18.91 | 16.70 | 16.70 |
| 30 | 06 | 0.50 | 184.60 | PR | 91 | 3 | 96.40 | 9.49 | 0.02 | 0.00 | 0.00 |
| 1 | 07 | 0.00 | 139.90 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 2 | 07 | 0.00 | 117.70 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 3 | 07 | 0.00 | 97.50 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 |
| 4 | 07 | 0.00 | 27.30 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 5 | 07 | 22.50 | 0.50 | PR | 91 | 1 | 80.20 | 62.71 | 3.34 | 0.00 | 0.00 |
| 6 | 07 | 0.00 | 22.50 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |
| 7 | 07 | 5.80 | 22.50 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 |

# PPENDIX V : RUNOFF ESTIMATION BY CURVE NUMBER METHOD : JAGDALPUR (J-1, J-2) -SAMPLE OF PROGRAMME OUTPUT

********** DETAILE OF RAIN-FALL REPORT FOR 'JAGADALPUR' *********
##########################################################

| DA TE | Mon th | Rain fall | P5DAY Total | croop cover | C.N. AMCII | AMC | N.C.No AMC | Calc. S | Q for n.ric | Q'from M.L. | rice L.L. | Weg.r-of MW1 | MW2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 23 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 24 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 25 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 26 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 27 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 28 | 05 | 0.00 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 29 | 05 | 4.90 | 0.00 | PF | 94 | 1 | 86.80 | 38.63 | 0.03 | 0.00 | 0.75 | 0.23 | 0.10 |
| 30 | 05 | 0.00 | 4.90 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 31 | 05 | 2.20 | 4.90 | PF | 94 | 1 | 86.80 | 38.63 | 0.00 | 0.00 | 0.05 | 0.01 | 0.01 |
| 1 | 06 | 0.00 | 7.10 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 06 | 0.00 | 7.10 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 06 | 0.30 | 7.10 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 06 | 0.10 | 2.50 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 06 | 0.00 | 2.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 06 | 0.00 | 0.40 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 06 | 0.00 | 0.40 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7 | 06 | 0.00 | 0.40 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 06 | 0.00 | 0.10 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10 | 06 | 9.60 | 0.00 | PR | 91 | 1 | 80.20 | 62.71 | 0.17 | 0.00 | 3.16 | 1.02 | 0.00 |
| 11 | 06 | 0.00 | 9.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 06 | 12.30 | 9.60 | PR | 91 | 1 | 80.20 | 62.71 | 0.53 | 0.00 | 4.94 | 1.79 | 0.00 |
| 13 | 06 | 0.00 | 21.90 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 14 | 06 | 0.10 | 21.90 | PR | 91 | 3 | 96.40 | 9.49 | 0.08 | 0.00 | 0.00 | 0.06 | 0.00 |
| 15 | 06 | 3.60 | 22.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.58 | 0.00 | 0.33 | 0.51 | 0.00 |
| 16 | 06 | 9.00 | 16.00 | PR | 91 | 3 | 96.40 | 9.49 | 3.70 | 0.00 | 2.79 | 3.44 | 3.61 |
| 17 | 06 | 0.80 | 25.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 18 | 06 | 1.80 | 13.50 | PR | 91 | 3 | 96.40 | 9.49 | 0.07 | 0.00 | 0.02 | 0.05 | 0.07 |
| 19 | 06 | 0.00 | 15.30 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 06 | 75.40 | 15.20 | PR | 91 | 3 | 96.40 | 9.49 | 66.04 | 15.47 | 15.47 | 51.59 | 61.11 |
| 21 | 06 | 16.00 | 87.00 | PR | 91 | 3 | 96.40 | 9.49 | 9.23 | 0.00 | 7.67 | 8.79 | 9.08 |
| 22 | 06 | 4.50 | 94.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.97 | 0.00 | 0.61 | 0.86 | 0.94 |
| 23 | 06 | 5.70 | 97.70 | PR | 91 | 3 | 96.40 | 9.49 | 1.59 | 0.00 | 1.07 | 1.44 | 1.54 |
| 24 | 06 | 41.40 | 101.60 | PR | 91 | 3 | 96.40 | 9.49 | 32.77 | 30.04 | 30.04 | 31.99 | 32.50 |
| 25 | 06 | 26.70 | 143.00 | PR | 91 | 3 | 96.40 | 9.49 | 18.82 | 16.61 | 16.61 | 18.19 | 18.60 |
| 26 | 06 | 9.60 | 94.30 | PR | 91 | 3 | 96.40 | 9.49 | 4.13 | 0.00 | 3.16 | 3.85 | 4.04 |
| 27 | 06 | 19.10 | 87.90 | PR | 91 | 3 | 96.40 | 9.49 | 11.92 | 0.00 | 10.14 | 11.41 | 11.75 |
| 28 | 06 | 19.50 | 102.50 | PR | 91 | 3 | 96.40 | 9.49 | 12.28 | 0.00 | 10.46 | 11.76 | 12.10 |
| 29 | 06 | 2.10 | 116.30 | PR | 91 | 3 | 96.40 | 9.49 | 0.12 | 0.00 | 0.04 | 0.10 | 0.12 |
| 30 | 06 | 0.00 | 77.00 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 07 | 0.00 | 50.30 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 07 | 0.00 | 40.70 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 07 | 26.70 | 21.60 | PR | 91 | 3 | 96.40 | 9.49 | 18.82 | 16.61 | 16.61 | 18.19 | 18.6 |
| 4 | 07 | 0.50 | 28.80 | PR | 91 | 3 | 96.40 | 9.49 | 0.02 | 0.00 | 0.00 | 0.02 | 0.0 |
| 5 | 07 | 0.00 | 27.20 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 6 | 07 | 0.00 | 27.20 | PR | 91 | 3 | 96.40 | 9.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 7 | 07 | 0.20 | 27.20 | PR | 91 | 3 | 96.40 | 9.49 | 0.06 | 0.00 | 0.00 | 0.05 | 0.0 |
| 8 | 07 | 8.70 | 27.40 | PR | 91 | 3 | 96.40 | 9.49 | 3.49 | 0.00 | 2.62 | 3.24 | 3.4 |
| 9 | 07 | 1.70 | 9.40 | PR | 91 | 1 | 80.20 | 62.71 | 0.00 | 0.00 | 0.01 | 0.00 | 0.0 |
| 10 | 07 | 2.60 | 10.60 | PR | 91 | 3 | 96.40 | 9.49 | 0.24 | 0.00 | 0.11 | 0.21 | 0.2 |

## APPENDIX VI : ECONOMICS OF PRODUCTION ACTIVITIES IN MWs R-1 AND R-2 UNDER OPTIMAL CROP PLAN; CASE - I

| Production activity | R-1 | | | | R-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | **80%** | **75%** | **60%** | **50%** | **80%** | **75%** | **60%** | **50%** |
| | **Annual Cost of Cultivation (Rs.)** | | | | | | | |
| Rice 2+M++ | 3,729 | 3,643 | 3,386 | 3,172 | 3,703 | 3,575 | 2,724 | 2,256 |
| Vegetables RM | 11,698 | 11,429 | 10,622 | 9,950 | 12,684 | 12,247 | 9,331 | 7,727 |
| Fish seed enhanc. | 4,354 | 4,749 | 6,728 | 7,916 | 3,958 | 4,749 | 11,873 | 15,831 |
| Vegetables 1M | 7,432 | 7,026 | 5,810 | 4,796 | 8,790 | 8,102 | 3,514 | 991 |
| Vegetable 2M | 276 | 522 | 1,258 | 1,873 | 79 | 488 | 3,214 | 4,713 |
| Mustard 2PM | 268 | 262 | 244 | 228 | 195 | 189 | 144 | 119 |
| Gram 2PM | 288 | 281 | 261 | 245 | 246 | 238 | 181 | 150 |
| **Total** | **28,044** | **27,912** | **28,309** | **28,179** | **29,655** | **29,587** | **30,981** | **31,787** |
| | **Annual Gross Returns (Rs.)** | | | | | | | |
| Rice 2M | 6,899 | 6,740 | 6,264 | 5,868 | 5,944 | 5,739 | 4,373 | 3,621 |
| Vegetables RM | 36,193 | 35,361 | 32,865 | 30,785 | 40,358 | 38,967 | 29,689 | 24,586 |
| Fish Seed enhanc. | 8,050 | 8,781 | 12,440 | 14,636 | 7,318 | 8,781 | 21,953 | 29,271 |
| Vegetables 1PM | 36,780 | 34,773 | 28,752 | 23,736 | 39,182 | 36,114 | 15,663 | 4,415 |
| Vegetables 2PM | 1,847 | 3,490 | 8,418 | 12,528 | 468 | 2,904 | 19,139 | 28,067 |
| Mustard 2PM | 651 | 636 | 591 | 554 | 288 | 278 | 212 | 176 |
| Gram 2PM | 729 | 713 | 544 | 620 | 301 | 290 | 221 | 183 |
| **Total** | **91,149** | **90,494** | **89,874** | **88,726** | **93,860** | **93,074** | **91,250** | **90,320** |
| | **Annual Net Returns (Rs.)** | | | | | | | |
| Rice 2M | 3,170 | 3,097 | 2,878 | 2,696 | 2,241 | 2,164 | 1,649 | 1,365 |
| Vegetables RM | 24,495 | 23,932 | 22,243 | 20,835 | 27,674 | 26,720 | 20,358 | 16,859 |
| Fish Seed enhanc. | 3,696 | 4,032 | 5,712 | 6,720 | 3,360 | 4,032 | 10,080 | 13,440 |
| Vegetables 1PM | 29,349 | 27,747 | 22,942 | 18,940 | 30,392 | 28,012 | 12,149 | 3,425 |
| Vegetables 2PM | 1,571 | 2,968 | 7,159 | 10,655 | 390 | 2,416 | 1,925 | 23,354 |
| Mustard 2PM | 383 | 374 | 347 | 325 | 93 | 90 | 69 | 57 |
| Gram 2PM | 442 | 432 | 283 | 376 | 54 | 52 | 40 | 33 |
| **Total** | **63,105** | **62,582** | **61,565** | **60,547** | **64,205** | **63,487** | **60,270** | **58,533** |

\+ Numerical shows number of irrigations, R - rainfed crop

++ Letter M - Monsoon Season, PM - Post monsoon season

## APPENDIX VII : ECONOMICS OF PRODUCTION ACTIVITIES IN MWs J-1 AND J-2 UNDER OPTIMAL CROP PLAN; CASE - I

| Production activity | J-1 | | | | J-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | 80% | 75% | 60% | 50% | 80% | 75% | 60% | 50% |
| | **Annual Cost of Cultivation (Rs.)** | | | | | | | |
| Rice 2M | 4,690 | 4,602 | 4,311 | 4,136 | 4,669 | 4,582 | 4,292 | 4,118 |
| Soybean 2M | - | - | - | - | 899 | 882 | 826 | 793 |
| Vegetables RM | 8,006 | 7,397 | 5,365 | 4,115 | 7,633 | 7,020 | 4,980 | 3,757 |
| Vegetables 2M | 13,300 | 13,544 | 14,364 | 14,855 | 12,072 | 12,337 | 13,218 | 13,747 |
| Vegetables 2PM | 13,756 | 13,500 | 12,645 | 12,132 | 15,301 | 15,016 | 14,066 | 13,496 |
| Mustard 2PM | 404 | 397 | 371 | 356 | - | - | - | - |
| Gram 2PM | 534 | 524 | 491 | 471 | 534 | 524 | 491 | 471 |
| Fruits 4M+PM | 1,138 | 1,117 | 1,046 | 1,004 | 1,670 | 1,639 | 1,535 | 1,473 |
| Tubers 4M+PM | 787 | 772 | 724 | 694 | 607 | 596 | 558 | 535 |
| Fish rearing | 1,712 | 1,849 | 2,397 | 2,740 | 2,661 | 2,874 | 3,725 | 4,258 |
| **Total** | **44,326** | **43,702** | **41,714** | **40,534** | **46,047** | **45,471** | **43,693** | **42,647** |
| | **Annual Gross Returns (Rs.)** | | | | | | | |
| Rice 2M | 7,997 | 7,830 | 7,335 | 7,038 | 7,670 | 7,528 | 7,051 | 6,765 |
| Soybean 2M | - | - | - | - | 2,264 | 2,222 | 2,081 | 1,997 |
| Vegetables RM | 22,660 | 20,938 | 15,184 | 11,733 | 20,340 | 18,707 | 13,272 | 10,011 |
| Vegetables 2M | 43,318 | 44,115 | 46,785 | 48,385 | 36,508 | 37,310 | 39,974 | 41,573 |
| Vegetables 2PM | 57,380 | 56,311 | 52,747 | 50,609 | 61,814 | 60,663 | 56,823 | 54,519 |
| Mustard 2PM | 1,081 | 1,061 | 994 | 954 | - | - | - | - |
| Gram 2PM | 1,587 | 1,558 | 1,459 | 1,400 | 1,423 | 1,397 | 1,308 | 1,255 |
| Fruits 4M+PM | 2,727 | 2,677 | 2,507 | 2,406 | 5,077 | 4,983 | 4,667 | 4,478 |
| Tubers 4M+Pm | 3,685 | 3,616 | 3,387 | 3,250 | 2,830 | 2,778 | 2,602 | 2,496 |
| Fish rearing | 6,356 | 6,865 | 8,899 | 10,170 | 10,299 | 11,123 | 14,418 | 16,478 |
| **Total** | **146775** | **144971** | **139297** | **135944** | **148226** | **146709** | **142197** | **139573** |
| | **Annual Net Returns (Rs.)** | | | | | | | |
| Rice 2M | 3,290 | 3,228 | 3,024 | 2,901 | 3,001 | 2,945 | 2,759 | 2,647 |
| Soybean 2M | - | - | - | - | 1,365 | 1,340 | 1,255 | 1,204 |
| Vegetables RM | 14,645 | 13,540 | 9,819 | 7,588 | 12,708 | 11,687 | 8,292 | 6,254 |
| Vegetables 2M | 30,019 | 30,571 | 32,421 | 33,530 | 24,436 | 24,973 | 26,756 | 27,826 |
| Vegetables 2PM | 43,625 | 42,812 | 40,102 | 38,476 | 46,513 | 45,646 | 42,757 | 41,024 |
| Mustard 2PM | 677 | 664 | 622 | 597 | - | - | - | - |
| Gram 2PM | 1,054 | 1,034 | 969 | 929 | 890 | 873 | 818 | 785 |
| Fruits 4M+PM | 1,589 | 1,560 | 1,461 | 1,402 | 3,407 | 3,343 | 3,132 | 3,005 |
| Tubers 4M+PM | 2,898 | 2,844 | 2,664 | 2,556 | 2,224 | 2,182 | 2,044 | 1,961 |
| Fish rearing | 4,644 | 5,016 | 6,502 | 7,430 | 7,638 | 8,249 | 10,693 | 12,220 |
| **Total** | **102449** | **101269** | **97584** | **95410** | **102180** | **101238** | **98505** | **96926** |

## APPENDIX VIII : ECONOMICS OF PRODUCTION ACTIVITIES IN MWs R-1 AND R-2 UNDER OPTIMAL CROP PLAN; CASE - II

| Production activity | R-1 | | | | R-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | 80% | 75% | 60% | 50% | 80% | 75% | 60% | 50% |
| | **Annual Cost of Cultivation (Rs.)** | | | | | | | |
| Rice 1M | 2,486 | 2,429 | 2,257 | 2,114 | 2,469 | 2,383 | 1,816 | 1,504 |
| Vegetables RM | 13,369 | 13,061 | 12,139 | 11,371 | 14,496 | 13,996 | 10,664 | 8,831 |
| Fish fingerlings | 4,354 | 4,749 | 6,728 | 7,916 | 3,958 | 4,749 | 11,873 | 15,831 |
| Vegetables 1PM | 6,862 | 6,470 | 5,293 | 4,311 | 8,265 | 7,897 | 3,128 | 670 |
| Vegetables 2PM | 887 | 1,118 | 1,914 | 2,393 | 640 | 949 | 3,626 | 5,055 |
| Mustard 2PM | 268 | 262 | 244 | 228 | 195 | 144 | 144 | 119 |
| Gram 2PM | 288 | 281 | 261 | 245 | 246 | 181 | 181 | 150 |
| **Total** | **28,514** | **28,371** | **28,737** | **28,577** | **30,269** | **30,300** | **31,432** | **32,161** |
| | **Annual Gross Returns (Rs.)** | | | | | | | |
| Rice 1M | 4,599 | 4,493 | 4,176 | 3,912 | 3,963 | 3,826 | 2,915 | 2,414 |
| Vegetables RM | 41,363 | 40,412 | 37,560 | 35,183 | 46,124 | 44,533 | 33,930 | 28,098 |
| Fish fingerlings | 8,050 | 8,781 | 12,440 | 14,636 | 7,318 | 8,781 | 21,953 | 29,271 |
| Vegetables 1PM | 33,962 | 32,023 | 26,195 | 21,335 | 36,841 | 35,201 | 13,942 | 2,987 |
| Vegetables 2PM | 5,936 | 7,480 | 12,133 | 16,004 | 3,812 | 5,650 | 21,596 | 30,107 |
| Mustard 2PM | 651 | 636 | 591 | 554 | 288 | 212 | 212 | 176 |
| Gram 2PM | 729 | 713 | 544 | 620 | 301 | 221 | 221 | 183 |
| **Total** | **95,290** | **94,538** | **93,639** | **92,243** | **98,646** | **98,425** | **94,771** | **93,236** |
| | **Annual Net Returns (Rs.)** | | | | | | | |
| Rice 1M | 2,113 | 2,065 | 1,919 | 1,797 | 1,494 | 1,443 | 1,099 | 910 |
| Vegetables RM | 27,995 | 27,351 | 25,420 | 23,811 | 31,628 | 30,537 | 23,266 | 19,267 |
| Fish fingerlings | 3,696 | 4,032 | 5,712 | 6,720 | 3,360 | 4,032 | 10,080 | 13,440 |
| Vegetables 1PM | 27,099 | 25,552 | 20,902 | 17,024 | 28,576 | 27,304 | 10,814 | 2,317 |
| Vegetables 2PM | 5,049 | 6,362 | 10,319 | 13,611 | 3,172 | 4,701 | 17,970 | 25,051 |
| Mustard 2PM | 383 | 374 | 347 | 325 | 93 | 69 | 69 | 57 |
| Vram 2PM | 442 | 432 | 283 | 376 | 54 | 40 | 40 | 33 |
| **Total** | **66,776** | **66,167** | **64,903** | **63,665** | **68,377** | **68,125** | **63,338** | **61,076** |

## APPENDIX IX : ECONOMICS OF PRODUCTION ACTIVITIES UNDER OPTIMAL CROP PLAN IN MWs J-1 AND J-2; CASE - II

| Production activity | J-1 | | | | J-2 | | | |
|---|---|---|---|---|---|---|---|---|
| | 80% | 75% | 60% | 50% | 80% | 75% | 60% | 50% |
| | **Annual Cost of Cultivation (Rs.)** | | | | | | | |
| Rice 2M | 2,814 | 2,761 | 2,587 | 2,482 | 2,796 | 2,749 | 2,575 | 2,471 |
| Soybean | - | - | - | - | 899 | 882 | 826 | 793 |
| Vegetables RM | 6,960 | 6,369 | 4,403 | 3,223 | 5,760 | 5,973 | 3,999 | 2,816 |
| Vegetables 2M | 17,789 | 17950 | 18,489 | 18,813 | 15,701 | 16,703 | 17,308 | 17,671 |
| Vegetables 2PM | 13,756 | 13,500 | 12,645 | - | 15,301 | 15,016 | 14,066 | 13,496 |
| Mustard 2PM | 404 | 397 | 371 | 356 | - | - | - | - |
| Gram 2PM | 534 | 524 | 491 | 471 | 534 | 524 | 491 | - |
| Fruits 4M+PM | 1,138 | 1,117 | 1,046 | 1,004 | 1,670 | 1,639 | 1,535 | 1,473 |
| Tubers 2M+PM | 787 | 772 | 724 | 694 | 1,214 | 596 | 558 | 535 |
| Fish rearing | 1,712 | 1,849 | 2,397 | 2,740 | 2,661 | 2,874 | 3,725 | 4,258 |
| **Total** | **45,894** | **45,239** | **43,253** | **29,782** | **46,537** | **46,956** | **45,084** | **43,512** |
| | **Annual Gross Returns (Rs.)** | | | | | | | |
| Rice 2M | 4,787 | 4,698 | 4,401 | 4,223 | 4,593 | 4,517 | 4,231 | 4,059 |
| Soybean ·2M | - | - | - | - | 2,264 | 2,222 | 2,081 | 1,997 |
| Vegetables RM | 19,701 | 18,028 | 12,462 | 9,139 | 15,351 | 15,918 | 10,658 | 7,503 |
| Vegetables 2M | 57,939 | 58,464 | 60,221 | 61,276 | 47,484 | 50,512 | 52,342 | 53,439 |
| Vegetables 2PM | 57,380 | 56,311 | 52,747 | - | 61,814 | 60,663 | 56,823 | 54,519 |
| Mustard 2PM | 1,081 | 1,061 | 994 | 954 | - | - | - | - |
| Vram 2PM | 1,587 | 1,558 | 1,459 | 1,400 | 1,423 | 1,397 | 1,308 | - |
| Fruits 4M+PM | 2,727 | 2,677 | 2,507 | 2,406 | 5,077 | 4,983 | 4,667 | 4,478 |
| Tibers 2M+PM | 3,685 | 3,616 | 3,387 | 3,250 | 5,661 | 2,778 | 2,602 | 2,496 |
| Fish rearing | 6,356 | 6,865 | 8,899 | 10,170 | 10,299 | 1,1234 | 14,418 | 16,478 |
| **Total** | **1,55,245** | **1,53,278** | **1,47,077** | **92,817** | **1,53,966** | **1,54,110** | **1,49,131** | **1,44,970** |
| | **Annual Net Returns (Rs.)** | | | | | | | |
| Rice 2M | 1,974 | 1,937 | 1,814 | 1,741 | 1,797 | 1,767 | 1,655 | 1,588 |
| Soybean 2M | - | - | - | - | 1,365 | 1,340 | 1,255 | 1,204 |
| Vegetables RM | 12,740 | 11,658 | 8,059 | 5,916 | 9,590 | 9,945 | 6,659 | 4,687 |
| Vegetab les 2M | 40,151 | 40,514 | 41,732 | 42,463 | 31,782 | 33,809 | 35,034 | 35,768 |
| Vegetables 2PM | 43,625 | 42,812 | 40,102 | - | 46,513 | 45,646 | 42,757 | 41,024 |
| Mustard 2PM | 677 | 664 | 622 | 597 | - | - | - | - |
| Gram 2PM | 1,054 | 1,034 | 969 | 929 | 890 | 873 | 818 | - |
| Fruit 4M+PM | 1,589 | 1,560 | 1,461 | 1,402 | 3,407 | 3,343 | 3,132 | 3,005 |
| Tubers 2M+Pm | 2,898 | 2,844 | 2,664 | 2,556 | 4,447 | 2,182 | 2,044 | 1,961 |
| Fish rearing | 4,644 | 5,016 | 6,502 | 7,430 | 7,638 | 8,249 | 10,693 | 12,220 |
| **Total** | **1,09,351** | **1,08,039** | **1,03,925** | **63,035** | **1,07,429** | **1,07,154** | **1,04,046** | **1,01,458** |

## APPENDIX X : ECONOMICS OF PRODUCTION ACTIVITIES IN MWs UNDER OPTIMAL CROP PLAN; CASE - III

| Production activity | 80% | 75% | 60% | 50% | 80% | 75% | 60% | 50% |
|---|---|---|---|---|---|---|---|---|
| R-1 & R-2 | | | | Annual Cost of Cultivation | | | | |
| | | R-1 | | | | | R-2 | |
| Vegetables RM | 16,711 | 17,327 | 15,174 | 14,214 | 18,120 | 17,496 | 13,330 | 11,039 |
| Fish fingerlings | 4,354 | 4,728 | 6,728 | 7,916 | 3,958 | 4,749 | 11,873 | 15,831 |
| Vegetables 1PM | 6,874 | 6,481 | 5,303 | 4,321 | 8,528 | 7,848 | 3,321 | 830 |
| Vegetables 2PM | 1,792 | 2,003 | 2,635 | 3,162 | 1,412 | 1,775 | 4,195 | 5,526 |
| **Total** | **29,730** | **29,560** | **29,840** | **23,612** | **32,018** | **31,868** | **32,719** | **33,226** |
| | | | Annual Gross Returns | | | | | |
| Vegetables RM | 51,704 | 50,516 | 46,950 | 43,978 | 57,655 | 55,667 | 42,413 | 35,123 |
| Fish fingerlings | 8,050 | 8,781 | 12,440 | 14,636 | 7,318 | 8,781 | 21,953 | 29,271 |
| Vegetables 1PM | 34,020 | 32,076 | 26,244 | 21,384 | 38,013 | 34,986 | 11,774 | 3,700 |
| Vegetables 2PM | 11,985 | 13,395 | 17,625 | 21,150 | 8,407 | 10,569 | 24,981 | 32,907 |
| **Total** | **105759** | **104768** | **103259** | **101148** | **111393** | **110002** | **101121** | **101002** |
| | | | Annual Net Profit | | | | | |
| Vegetables RM | 34,993 | 34,189 | 31,775 | 29,764 | 39,535 | 38,171 | 29,083 | 24,084 |
| Fish fingerlings | 3,696 | 4,032 | 5,712 | 6,720 | 3,360 | 4,032 | 10,080 | 13,440 |
| Vegetables 1PM | 27,146 | 25,595 | 20,941 | 17,063 | 29,485 | 27,137 | 8,453 | 2,870 |
| Vegetables 2PM | 10,193 | 11,392 | 14,990 | 17,988 | 6,995 | 8,794 | 20,786 | 27,382 |
| **Total** | **76,028** | **75,208** | **73,419** | **71,535** | **79,375** | **78,134** | **68,402** | **67,776** |
| J-1 & J-2 | | | | Annual Cost of Cultivation | | | | |
| | | J-1 | | | | | J-2 | |
| Vegetables RM | - | - | - | - | - | - | 5,245 | 3,051 |
| Vegetables 2M | 26,483 | 26,484 | 26,483 | 26,483 | 26,255 | 26,255 | 26,255 | 26,255 |
| Fish rearing | 1,712 | 1,849 | 2,397 | 2,740 | 2,661 | 2,874 | 3,725 | 4,258 |
| Vegetables 2PM | 17,195 | 16,874 | 15,806 | 15,166 | 17,002 | 16,685 | - | - |
| **Total** | **45,391** | **45,207** | **44,687** | **44,389** | **45,918** | **45,814** | **34,226** | **33,564** |
| | | | Annual Gross Return | | | | | |
| Vegetables RM | - | - | - | - | - | - | 11,312 | 8,130 |
| Vegetables 2M | 86,260 | 86,260 | 86,260 | 86,260 | 79,397 | 79,40 | 79,401 | 79,401 |
| Fish rearing | 6,356 | 6,865 | 8,899 | 10,170 | 10.299 | 11,123 | 14,418 | 17,478 |
| Vegetables 2PM | 71,726 | 70,389 | 65,934 | 63,261 | 69,683 | 67,403 | - | - |
| **Total** | **164342** | **163514** | **161092** | **159691** | **158378** | **157926** | **105131** | **104009** |
| | | | Annual Net Profit | | | | | |
| Vegetables RM | - | - | - | - | - | - | 7,067 | 5,079 |
| Vegetables 2M | 59,777 | 59,776 | 59,776 | 59,776 | 53,141 | 53,145 | 53,145 | 53,145 |
| Fish rearing | 4,644 | 5,016 | 6,502 | 7,430 | 7,638 | 8,249 | 10,693 | 12,220 |
| Vegetables 2PM | 54,531 | 53,515 | 50,128 | 48,095 | 51,681 | 50,718 | - | - |
| **Total** | **118951** | **118307** | **116405** | **115302** | **112460** | **112112** | **70905** | **70445** |

## APPENDIX XI : OPTIMAL CROP PLAN, WATER REQUIREMENT AND NET PROFIT FOR DIFFERENT ALTERNATIVE DESIGNS : MWs, R-1 AND R-2; CASE I

| Design parameter | Crops | Season | No. of irrigations | R-1 | | | R-2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Area, (ha.) | Water requiement ($m^3$) | Net profit (Rs.) | Area (ha) | Water reqirement ($m^3$) | Net profit, (Rs.) |
| 80% | Rice | M | 1 | 0.2610 | 130.5 | 3,170 | 0.2601 | 104.4 | 2,241 |
| | Vegetables* | M | R | 0.6090 | 0.0 | 24,495 | 0.6090 | 0.0 | 27,674 |
| | Mustard | PM | 1 | 0.0435 | 21.3 | 383 | 0.0435 | 21.8 | 93 |
| | Gram | PM | 1 | 0.0435 | 21.3 | 442 | 0.435 | 21.8 | 54 |
| | Vegetables** | PM | 2 | 0.0262 | 39.2 | 1,569 | 0.0065 | 9.7 | 388 |
| | Vegetables** | PM | 1 | 0.7568 | 567.6 | 29,350 | 0.7765 | 582,4 | 30,393 |
| | Monsoon | | | 0.87 | 130.5 | 27.665 | 0.87 | 104.4 | 29,915 |
| | Post-monsoon | | | 0.87 | 649.5 | 31,743 | 0.87 | 635.6 | 30,929 |
| | **Total** | | | **1.74** | **78.0** | **59,408** | **174** | **740,0** | **60,844** |
| 75% | Rice | M | 1 | 0.2550 | 127.5 | 3,097 | 0.2520 | 100.8 | 2,164 |
| | Vegetables | M | R | 0.5950 | 0.0 | 23.932 | 0.5880 | 0.0 | 26,720 |
| | Mustard | PM | 1 | 0.0425 | 20.8 | 374 | 0.0420 | 21.0 | 90 |
| | Gram | PM | 1 | 0.0425 | 20.8 | 432 | 0.0420 | 21.0 | 52 |
| | Vegetables** | PM | 2 | 0.0495 | 74.2 | 2,966 | 0.0403 | 60.4 | 2,415 |
| | Vegetables | Pm | 1 | 0.7155 | 56.6 | 27.748 | 0.7157 | 536.8 | 28,014 |
| | Monsoon | | | 0.85 | 127.5 | 27,029 | 0.84 | 100.8 | 28.884 |
| | Post-monsoon | | | 0.85 | 652.5 | 31,520 | 0.84 | 639.2 | 30,571 |
| | **Total** | | | **1.70** | **780.0** | **58,549** | **1.68** | **740.0** | **59,454** |
| 60% | Rice | M | 1 | 0.2370 | 118.5 | 2,878 | 0.1920 | 76.8 | 1,649 |
| | Vegetables | M | R | 0.5530 | 0.0 | 22,243 | 0.4480 | 0.0 | 20.358 |
| | Mustard | PM | 1 | 0.0395 | 19.4 | 347 | 0.0320 | 16.0 | 69 |
| | Gram | PM | 1 | 0.0395 | 19.4 | 401 | 0.0320 | 16.0 | 40 |
| | Vegetables** | PM | 2 | 0.1194 | 179.1 | 7,159 | 0.2656 | 398.4 | 15,925 |
| | Vegetables | Pm | 1 | 0.5916 | 443.7 | 22,943 | 0.3104 | 232.8 | 12,149 |
| | Monsoon | | | 0.79 | 118.5 | 25,121 | 0.64 | 76.8 | 22,007 |
| | Post-monsoon | | | 0.79 | 661.5 | 30.850 | 0.64 | 663.2 | 28,183 |
| | **Total** | | | **1.58** | **780.0** | **55,971** | **1.28** | **740.0** | **50,190** |
| 50% | Rice | M | 1 | 0.2220 | 111.0 | 2,696 | 0.1590 | 63.6 | 1,365 |
| | Vegetables | M | R | 0.5180 | 0.0 | 20,835 | 0.3710 | 0.0 | 16,859 |
| | Mustard | PM | 1 | 0.0370 | 18.1 | 325 | 0.0265 | 13.3 | 57 |
| | Gram | PM | 1 | 0.0370 | 18.1 | 376 | 0.0265 | 13.3 | 33 |
| | Vegetables** | PM | 2 | 0.1777 | 266.5 | 10,652 | 0.3895 | 584.3 | 23,356 |
| | Vegetables | PM | 1 | 0.4884 | 366.3 | 18,938 | 0.0875 | 65.6 | 3,424 |
| | Monsoon | | | 0.74 | 111.0 | | 0.53 | 63.6 | 18,224 |
| | Post-monsoon | | | 0.74 | 669.0 | 30,291 | 0.53 | 676.4 | 26,870 |
| | **Total** | | | **1.48** | **780.0** | **53,823** | **1.06** | **740.0** | **45,094** |

M - Monsoon
R - Rainfed
PM - Post-monsoon
* Okra followed by radish
** Radish

## APPENDIX XII : OPTIMAL CROP PLAN WATER REQUIREMENT AND NET PROFIT FOR DIFFERENT ALTERNATIVE DESIGNS : MWs, J-1 AND J-2, CASE I

| Design parameter | Crops | Season | No. of irrigations | J-1 | | | J-2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Area, (ha.) | Water requirement (m³) | Net profit (Rs.) | Area (ha) | Water reqirement(m³) | Net profit, (Rs.) |
| 80% | Rice | M | 2 | 0.4025 | 805.0 | 3,290 | 0.4025 | 805.0 | 3,001 |
| | Soybean | M | 2 | - | - | - | 0.0805 | 80.5 | 1,365 |
| | Mustard | PM | 2 | 0.0805 | 120.8 | 677 | - | - | - |
| | Gram | PM | 2 | 0.0805 | 120.8 | 1,054 | 0.0805 | 120.8 | 890 |
| | Vegetables | PM | 2 | 1,2880 | 3181.4 | 43,625 | 1.4490 | 3260.3 | 46,513 |
| | Tubers | M* | 1 | 0.0805 | 120.8 | 2,858 | 0.0805 | 60.4 | 2,193 |
| | Fruits | M+PM | 4 | 0.0805 | 96.6 | 1,589 | 0.0805 | 193.2 | 3,407 |
| | Vegetables | M | 2 | 0.6361 | 954.1 | 30,018 | 0.5824 | 873.6 | 24,437 |
| | Vegetables | M | R | 0.4104 | - | 14,655 | 0.3836 | - | 12,707 |
| | Monsoon | Total | | 1.61 | 1900 | 49,409 | 1.61 | 1900.0 | 45,406 |
| | Post-monsoon | Total | | 1.61 | 3,499 | 48,357 | 1.61 | 3493.7 | 49,106 |
| | **G. Total** | | | **3.22** | **5399** | **97,765** | **3.22** | **5393.7** | **94,512** |
| 75% | Rice | M | 2 | 0.3950 | 790.0 | 3,228 | 0.3950 | 790.0 | 2,945 |
| | Soybean | M | 2 | - | - | - | 0.0790 | 79.0 | 1,340 |
| | Mustard | PM | 2 | 0.0790 | 118.5 | 664 | - | - | - |
| | Gram | PM | 2 | 0.0790 | 118.5 | 1034 | 0.0790 | 118.5 | 873 |
| | Vegetables | PM | 2 | 1.2640 | 3122.1 | 42,812 | 1.4220 | 3199.5 | 45,646 |
| | Tubers | M* | 1 | 0.0790 | 118.5 | 2,805 | 0.0790 | 59.3 | 2,152 |
| | Fruits | M+PM | 4 | 0.0790 | 94.8 | 1,560 | 0.0790 | 189.6 | 3,343 |
| | Vegetables | M | 2 | 0.6478 | 971.7 | 30,572 | 0.5952 | 892.8 | 24,972 |
| | Vegetables | M | R | 0.3792 | - | 13,539 | 0.3528 | - | 11,688 |
| | Monsoon | Total | | 1.58 | 1,900 | 48,759 | 1.58 | 1900.0 | 44,769 |
| | Post-monsoon | Total | | 1.58 | 3,343 | 47,456 | 1.58 | 3428.6 | 48,191 |
| | **G. Total** | | | **3.16** | **5,334** | **96,215** | **3.16** | **5328.6** | **92,959** |
| 60% | Rice | M | 2 | 0.3700 | 740.0 | 3,024 | 0.37 | 740.0 | 2,759 |
| | Soybean | M | 2 | - | - | - | 0.074 | 74.0 | 1,255 |
| | Mustard | PM | 2 | 0.0740 | 111.0 | 622 | - | - | - |
| | Gram | PM | 2 | 0.0740 | 111.0 | 969 | 0.074 | 111.0 | 818 |
| | Vegetables | PM | 2 | 1.1840 | 2924.5 | 40,102 | 1.332 | 2997.0 | 42,757 |
| | Tub ers | M* | 1 | 0.0740 | 111.0 | 2,628 | 0.074 | 55.5 | 2,016 |
| | Fruits | M+PM | 4 | 0.0740 | 88.8 | 1,461 | 0.074 | 177.6 | 3,132 |
| | Vegetables | M | 2 | 0.6870 | 1030.5 | 32,421 | 0.6377 | 956.5 | 26,755 |
| | Vegetables | M | R | 0.2750 | - | 9,819 | 0.2503 | - | 8,293 |
| | Monsoon | Total | | 1.48 | 1,900 | 46,495 | 1.48 | 1900.0 | 42,643 |
| | Post-monsoon | Total | | 1.48 | 3216.8 | 44,452 | 1.48 | 3211.6 | 45,141 |
| | **G. Total** | | | **2.96** | **5116.8** | **91,046** | **2.96** | **5111.6** | **87,784** |
| 50% | Rice | M | 2 | 0.3550 | 710.0 | 2,901 | 0.355 | 710.0 | 2,647 |
| | Soybean | M | 2 | - | - | - | 0.071 | 71.0 | 1,204 |
| | Mustard | PM | 2 | 0.0710 | 106.5 | 597 | - | - | - |
| | Gram | PM | 2 | 0.0710 | 106.5 | 929 | 0.071 | 106.5 | 785 |
| | Vegetables | PM | 2 | 1.1360 | 2805.9 | 38,476 | 1.278 | 2875.5 | 41,024 |
| | Tubers | M* | 1 | 0.0710 | 106.5 | 2,521 | 0.071 | 53.3 | 1,934 |
| | Fruits | M+PM | 4 | 0.0710 | 85.2 | 1,402 | 0.071 | 170.4 | 3,005 |
| | Vegetables | M | 2 | 0.7105 | 1065.8 | 33,530 | 0.6632 | 994.8 | 27,825 |
| | Vegetables | M | R | 0.2125 | - | 7,588 | 0.1888 | - | 6,255 |
| | Monsoon | Total | | 1.42 | 1900. | 45,295 | 1.42 | 1900.0 | 41,368 |
| | Post-monsoon | Total | | 1.42 | 3,086 | 42,650 | 1.42 | 3081.4 | 43,311 |
| | **G. Total** | | | **2.84** | **4,986** | **87,945** | **2.84** | **4981.4** | **84.678** |



M - Monsoon; R - Rainfed; PM - Post-monsoon

* Tuber crop in J-2 was grown in monsoon season (Sweet potato) whereas in J-1 the