STUDIES ON HYDROLOGIC MODELLING OF WATER YIELD FROM MICROWATERSHEDS

BY

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CERTIFICATE

This is to certify that the thesis entitled "STUDIES ON HYDROLOGIC MODELLING OF WATER YIELD FROM MICROWATERSHEDS" submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agricultural Engineering embodies the results of bona-fide research carried out by Mr. K. Sreenivas Reddy under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma. I further certify that such help or source of information as has been availed of in this connection is duly acknowledged.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations of the variables used in the model are given in Appendices B and C. Some of the remaining abbreviations and symbols used in the text are listed here.

A.D.	Anno Domini
AMC	Antecedent moisture condition
cm	Centimetre
CN	Curve number
Cu. m	Cubic metre
DVC	Damodar Valley Corporation
ED	Earthen dam
ft	Feet
hp	Horse power
ha	Hectare
hr	Hour
i.e.	That is
ICRISAT	Internatnal Crop Research Institute for Semi-Arid Tropics
kg	Kilogram
km	Kilometre
l	Litre
l/s	Litre per second
MSL	Mean sea level
mm	Millimetre
min	Minutes
m ha	Million hectare
mt	Million tonnes
MW	Microwatershed

PVC	Poly venyl chloride
Rs.	Rupees
sq. m	Square metres
USDA	United States Department of Agriculture
USA	United States of America
UDV	Upper Damodar Valley

Symbols

$>$	Greater than
$<$	Less than
^{0}F	Degree Fahrenheit
^{0}C	Degree Centigrade
%	Per cent
@	At the rate of
$\geqslant$	Greater than or equal to
$\leq$	Less than or equal to
i	row wise
j	column wise

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ABSTRACT

Land and water are the two critical natural resources which have to be judiciously managed to increase agricultural production and productivity. The origin of all water resources is rainfall which is a stochastic hydrologic event. Surface runoff, the main form of surface water resource is the result of interaction between the rainfall and watershed parameters. Development and use of hydrologic models are important hydrologic research tools used for the establishment of a

reliable correspondence between rainfall and runoff via the rainfall and watershed parameters.

The present study was undertaken in a few selected microwatersheds of Upper Damodar Valley, Bihar state, with the major objectives to develop and validate a suitable hydrologic model and to use same to study the possible utilization of stored runoff in small reservoirs.

Initial investigations were done to establish an appropriate reservoir infiltration rate and relate the reservoir water spread area and storage volume with the depth of storage.

A surface water yield model (SWYMOD) was developed based on hydrologic soil cover complex method integrated with reservoir water budgetting. The model optimized the lumped parameter, curve number for different prevalent land uses by reducing the average absolute deviation between the observed and the predicted reservoir water depths to a value lower than a pre-assigned tolerance limit.

The model SWYMOD was used with the long term daily rainfall data in kharif season to generate the information on the temporal distribution of the availability of stored runoff in the reservoirs. This was compared with the estimated gross deficits in the water requirements of three commonly grown irrigated crops in the study area, namely paddy, maize and pigeon pea. On the basis of this comparison and using a linear programming model, several alternative crop plans were studied and an optimal crop plan was identified. For this crop plan, the irrigation demand can be fulfilled at 75 % probability level assuring a high value of benefit : cost ratio.

The study revealed that the curve number based approach of hydrologic modelling is sound but requires identification of curve numbers specific to a given region. The recommended curve numbers based on the general features of the watershed and land use may not always be applicable. The modelling approach allows its use in conjunction with long term weather data such that the stochasticity of rainfall is reflected in the pattern of runoff behaviour and can be meaningfully analysed. The modelling approach allows a realistic assessment of the worth of stored water and enables its scientific allocation among competitive crop activities in the command of the reservoirs.

For the area of study, an optimal crop plan comprised growing maize and pigeon pea on 18.69 ha and 0.33 ha of the total irrigable area, respectively. The benefit-cost ratio for 5 to 15 years amortization periods varied from 4.4 to 6.7 and 5.6 to 7.9 correspondingly when the reservoir cost is included and excluded from the analysis.

A study was undertaken to examine the possibility of storage of some of the inevitable spillway discharge by increasing the reservoir capacity. This revealed that such a step is not advisable and beneficial for irrigation as the additional water remains available only for a few weeks and will not be useful for ensuring irrigation.

CHAPTER I

INTRODUCTION

Ever increasing population and declining per capita land availability for producing agricultural commodities have increased the gap between the demand and the supply of food, fibre, fuel, timber etc. in the country. The total food grain requirement has been estimated about 225 mt by 2000 A.D from the present level of 180 mt (Singh, 1990). Land and water are the two critical natural resources that may enhance or jeopardise the agricultural production and productivity depending on whether these are managed properly or improperly respectively.

Though land resources are fixed and their physical characteristics are known, the water resources are highly variable in most parts of the country. The primary source to any form of the water resource is rainfall which is stochastic in nature. The annual rainfall varies greatly being higher than 2000 mm in some parts of eastern states and lower than 50 mm or practically nil in the deserts of Rajasthan. The classification of an area according to annual rainfall indicates that about 29 % area receives high rainfall (> 1125 mm), 36 % area comes under medium rainfall (750 to 1125 mm), low rainfall of 350-750 mm is received in 22 % area and 13 % area receives very low rainfall of < 350 mm (Singh, 1990). Moreover, 80 % of total rainfall is concentrated during the south-west monsoon (i.e., June - September) in most parts of the country. The pattern of rianfall indicates that this important source of water is not distributed uniformly over the country. The high rainfall areas with rainfall > 1125 mm and seasonal dry spells experience floods and erosion hazards in agricultrual lands which is of prime concern for soil and water conservation scientists and its programme planners. It has been estimated that 50-60 % of rainfall goes as flood washing away 16 tonnes/ha of top soil annually. This results, on one hand accute soil moisture deficits over the land surface and soil profile, and on the other hand siltation of multipurpose reservoirs (Singh, 1990) threatening their safety and reducing their active life.

Looking into the gravity of the above problems in the country, the Govt. of India had created 27 River Valley Projects (RVP) in VIIth five year plan with the primary objectives of controlling flood and subsequent erosion hazard by promoting soil and water conservation practices on watershed basis.

Soil and water conservation programmes include both engineering and agronomic practices. The engineering practices include the construction of contour bunds, terracing, graded bunds etc. across the slope of land and water or silt detention structures accross the gully formations to moderate floods as well as to check erosion. Such structures create temporary storage of water and facilitates ground water recharge. Though, an appropriate combination of agronomic and engineering measures substantially reduces the runoff and erosion, complete withdrawal of runoff by its absorption (storage) in the soil profile is rather impossible under a tropical climate. The next best alternative to manage the inevitable runoff is to store it in small water detention structures. This helps in localising the use of runoff water which is cheaper and socially more acceptable rather than conveying the same for long distances and storing it in the reservoirs of large dams.

Esssentially, there is a requirement of multiplicity in the number of such structures. This requires funding and land. Further, to have alternate use of the stored water eg. irrigation, fisheries etc, in addition to the gound water recharge, the designs of such structures are to be based on a scientific understanding of the process of runoff generation and a quantitative estimate of the runoff. Since runoff is a natural stochastic event, development and use of hydrologic models have become important hydrologic reserach tools as wide spread monitoring of rainfall - runoff phenomenon across the length and breadth of the country is laborious, expensive and time consuming.

A major objective of using such models is to scientifically estimate the water yield of the watersheds to enable development of appropriate management strategy of this important resource. Hydrological phenomenon, the interaction of which yield runoff are extremely complex. The flow of any stream is determined by two different factors. One is climate, mainly precipitation and the other is the physical characteristics of the drainage basin. The rates and amounts of water yield depend on the amount of rainfall, its intensity, the physical conditions of soil and cover in the watershed, the physical properties of the soils and shape, size and drainage pattern of the watershed.

Hydrologic modelling involves the systematic evaluation and synthesis of different watershed parameters through mathematical equations that simulate the physical processes in the watershed to get a reliable estimate of runoff as a consequence to rainfall. At present, there are several sophisticated and complicated models starting from continuous watershed models to event based watershed models and empirical relations. The most oftenly faced problem while applying the above models to the Indian watersheds is their large input data requirement (which is seldom available) for calibration and optimization of model parameters and their location specific use.

Moreover, the above models have been developed for the climatic conditions out side the country. Thus, these models when applied to the Indian conditions having erratic distribution of rainfall, different land use patterns and soils, are expected to produce erroneous results. This indicates the necessity to develop simpler model to be understood by a practical worker with minimum input data requirement like daily rainfall data and land use information which are in general available in the microwatersheds of the country. Unfortunately, small watershed hydrology has mostly been a neglected field in the country and proper small stream gauging data are extremely scanty. Besides, the limited data available in a few organisations (River Valley Projects) have not been analysed and interpreted to enable a critical evaluation of the small water detention works. Thus, the adequacy of their design, their utility in terms of the possible uses of the stored water for irrigation are not well understood.

The present study is, therefore, undertaken in a few selected microwatersheds in the Upper Damodar Valley in Bihar state with the following objectives :

1. To develop a suitable hydrologic model to predict water yield of microwatersheds.
2. To validate the model on a few selected microwatersheds of Upper Damodar Valley.
3. To study the possible utilization of water yield from microwatersheds for agriculture.

CHAPTER II

REVIEW OF LITERATURE

Hydrologic models are needed for design of land treatments, water conservation and storage structures, deciding on supplemental irrigation strategies within watershed and similar activities. The expected quantum of water yield collected in the storage structure for the period of interest is one important aspect of the hydrological design consideration. This parameter is dynamic in nature and depends on the surface runoff characteristics of the watershed as well as the input of rainfall.

Recent advances in modelling surface hydrologic processes have yielded considerable information on complex modelling procedures. More and more improvements in the predictions became possible by including more and more specific processes at a particular area and time. However, such models were not generally applicable to all locations. Many such models need vast amount of input data to be able to operate satisfactorily.

The author has elected to review some of the existing hydrologic models used for computing runoff rate or runoff volume and comment on their applicability in the watersheds of the country.

2.1 WATER YIELD MODELS

2.1.1 Continuous watershed models

Continuous watershed models offer the most reliable method of estimating runoff from rainfall because they permit detailed analysis using even very short time intervals (less than an hour). Many of these models for estimating watershed yield are described by Fleming (1975). Examples of these kinds of models are many, the better known include the 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).

Most of these models partition the effect of rainfall into direct runoff, infiltration, evapotranspiration, interflow, deep percolation, base flow and stream flow. These models also monitor water storage within the soil during rain free intervals between storms and its depletion to evaporation, deep percolation and base flow until the next rain event occurs. However, these models require a large input data recorded continuously over a watershed to calibrate the different parameters on best fit basis. A lack of detailed input data and a compromise on this leads to unrealistic parameter values over a watershed, limiting the general applicability of such models.

2.1.2 Event based watershed models

Event based watershed models include both lumped and distributed parameter models depending upon whether spatial distribution of parameter is neglected or taken into account.

2.1.2.1 Lumped models

In most cases, efforts were made to develop an instantaneous unit hydrograph (IUH) or a unit hydrograph (UH) for the watershed under consideration. A unit hydrograph was defined as a characteristic hydrograph of surface runoff produced by a uniform rainfall excess of unit depth generated over the watershed in a unit duration. An instantaneous unit hydrograph was a mathematical abstraction and defined as a unit hydrograph of infinitesimally small unit duration.

Sherman (1932) introduced the theory of unit hydrograph under the following assumptions :

(i) The rainfall is uniformly distributed over space and time.

(ii) The time base of the direct runoff hydrograph due to the rainfall of unit duration is constant and

(iii) The ordinates of the direct runoff hydrograph of the same time base are proportional to the total amount of direct runoff.

The IUH was first proposed by Clark (1945). The historical review of development of IUH was given by Diskin (1964). The IUH in conjunction with the design storm can be used to obtain the design flood by using a convolution integral. Both mathematical as well as conceptual models have been used for the determination or derivation of IUH.

The investigation by Nash (1957) and Dooge (1959) are some of the pioneering works in this area of using conceptual linear models for studying the rainfall - runoff relationship. In the development of these conceptual models, the concepts of linear reservoir and linear channels have been used. A linear reservoir is a hypothetical reservoir in which the storage 'S' is directly proportional to outflow 'Q' (i.e., S = K Q, where K is storage coefficient). By combining this principle and continuity equation, the IUH of linear reservoir has been derived as follows :

$$h(t) = (1/k)\ e^{-t/k} \qquad ...(2.1)$$

where,

h (t) is the ordinate of IUH.

In a linear channel, the time 't' required to translate the discharge (Q) of any magnitude through a given reach of any length (L) is a constant. Thus, when an inflow hydrograph is routed through a linear channel, its shape will remain same but will be lagged by the time of translation (t). For a linear channel at any given section, the water area (A) and discharge (Q) are related by A = CQ where, C is translation coefficient.

Nash (1957) used a cascade of n linear reservoirs of equal size to represent the watershed, having the same storage coefficient (K). For an instantaneous unit input, after repeated convolutions, the outflow from the n^{th} linear reservoir ($Q_n(t)$) gives the ordinates of IUH for the watershed. This model is one of the most popular models for computing IUH. However, in many cases, it was found that the model inadequately accounts for the net storage of the watershed. As a result of it, the computed peaks of DRH (Direct runoff hydrograph) were found to be higher and occuring somewhat earlier than expected.

A general theory of conceptual models based on combination of linear reservoirs and linear channels was proposed by Dooge (1959). Models propsed by Nash (1957) and Clark (1945) became particular cases of this model. Dooge model considered routing input, I(t) through a cascade of linear reservoirs having different storage coefficients and translation times between upstream elemental area and watershed outlet by dividing watershed into sub areas by the isochrones. However, Dooge's general equation for the IUH is not directly usable because it was not specified as how to determine different storage coefficients and time of concentration. To overcome the difficulties of Dooge model for practical applications, Singh (1962) developed a simplified version only by considering a linear channel of pure translation and two linear reservoirs of different storage coefficients in series. These models have been developed for larger watersheds.

Diskin (1964) proposed a model consisting of two parallel cascades of linear reservoirs with four model parameters and unique determination of these parameters remained a difficult task in applying this model. Kulandaisamy (1964) considered the rainfall and runoff relationship by system analysis. The storage was considered to be function of input (I), output (O) and their higher order derivatives. The users hesitate in using this model for its vast computation requirements.

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 for both the input and output. Chow and Kulandaisamy (1982) described two simple and practical forms of the general hydrologic system (GHS) model including a 5 parameter and 3 parameter models and compared their instantaneous unit hydrograph. It was shown that the 3 parameter model could be derived from the five parameter model by modifying the assumptions on boundary conditions in solving the differential equation that represent the model. The time area histogram model for rainfall - runoff transformation has been applied for a Himalayan watershed of

Rama ganga river and it was found that the peak runoff rates were lower than the observed one (Raghuwanshi *et al.*, 1987).

Satapathy and Satyanarayana (1989) analysed the hydrologic data from 17 storms with reference to pertinent characteristics of a 93 sq. km. Nagwan watershed. They derived certain hydrologic tools like coaxial relationships for predicting runoff volume from rainfall on similar watersheds, to derive unit hydrographs and S-curves and to evolve coefficients for synthesis of unit hydrographs.

Mathematical model of the instantaneous unit hydrograph for a small agricultural watershed 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.

2.1.2.2 Distributed models

In a distributed model, the spatial variations of land characteristics like soil type, vegetation and topography can be utilized directly in determining runoff. In general, the watershed is divided into a number of elements and runoff volumes are first calculated separately for each element. Unlike the more common lumped parameter models utilizing the average values of the watershed characteristics resulting significant error in estimation of runoff, a distributed model removes this constraint on simulation accuracy by virtue of its ability to use segment-wise applicable relevant characteristics.

One approach to distributed parameter modelling is the use of a grid system to delineate watershed elements. The initial development of this concept was reported by Huggins and Monke (1968) and it was applied to two small areas (about one hectare each) in Indiana, U.S.A, using a grid size of 7.6 by 7.6 m. The slope direction for each element was used to route the runoff form one element to two adjoining elements. To facilitate application to larger watersheds, an improved method of incorporating channel flow effects was done (Huggins *et al.*, 1973) along with various other improvements. This work at Purdue university, U.S.A., led to the development of more comprehensive ANSWERS (Aerial Non - point Source Watershed Environment Response Simulation) model by Beasley (1977). Application of the ANSWERS model to two Indiana, U.S.A., watersheds having areas of 714 and 942 ha was described (Huggins *et al.*, 1977).

Gupta and Solomon (1977) have developed a distributed model for predicting both runoff and sediment discharge. They used the square elements as in ANSWERS model.

Ross *et al.*, 1978 developed and tested a distributed parameter model for predicting watershed runoff, erosion and sedimentation. The model was applied to six small watersheds in Virginia, U.S.A., varying in size from 74 ha to 428 ha. The watershed was divided into different hydrological response units (HRU) each having a certain combination of soil type and land use. Runoff volumes were calculated for each HRU. The dynamic flow equations solved by means of finite elements were used for channel routing. All model parameters were measured or estimated from watershed characteristics and the results were interpreted as poor to excellent.

A physically based forest hydrology model was developed based on ANSWERS and tested in various mountainous upland watersheds of Mississippi, U.S.A. (Thomas and Beasley I and II , 1986).

Mishra and Haan (1990) studied the applicability of ANSWERS model to simulate runoff on a Oklahoma grassland watershed in U.S.A. They observed that smaller grid size predicts flood hydrograph properly. The grid sizes used in the study were, 0.07 ha and 0.27 ha.

Though the above discussion reveals better accuracy in the prediction of runoff by using distributed models, their increased complexity, huge data requirements and time of computation are the major limiting factors in the application of such models.

2.1.3 Wave theory based models

Transformation of rainfall excess into the runoff reaching the watershed outlet is basically a non-linear and spatially distributed function which is vastly influenced by the geomorphic details of the watershed. In surface water hydrology, the basin hydrodynamic equations, popularly known as the St. Venant equations are based on fundamental laws governing conservation of mass (continuity) and conservation of linear momentum applied to a control volume or fixed section of channel. These equations are quasi-linear partial differential equations and require the boundary conditions of upstream inflow hydrograph and down stream rating curve for every reach for their solutions. Numerical solutions for these equations have been discussed by Mahmood (1975). The wave theory based models can broadly be classified as Dynamic wave models and Kinematic wave models.

The dynamic wave models are generally applied where the elements of mass and force are taken care of by the dynamics of fluid mass controls and the movement of fluid. Though these models are not popularly applied for computations of the overland surface runoff, the same have been used for modelling of flood flows through river reaches (Amin and Fang, 1970 and Ponce, 1986 etc.).

When inertial and presure forces are not important to the movement of wave, kinematic wave governs the flows. Flows of this nature will not be accelerating appreciably and remain approximately uniform (De Vries and Mac Arthen, 1979). The Kinematic wave models are particularly of much use for overland flow modelling and many researchers have applied these on smal watersheds under different conditions (Singh, 1974 ; Cundy and Tento, 1985 ; Moore *et al.*, 1985, 87 ; Akan, 1988 etc.). For the watersheds in India, the Kinematic wave models have been applied by Hossain (1989). In general, these models are quite complicated and requirement of data for supplying the boundary and initial conditions is very large.

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 reasonable accuracy. However, in most of these models, the continuous measurement of rainfall and soil moisture are needed as input which require sophisticated instrumentation to measure them in the field. Hence, some of the research workers have developed water yield models with larger time intervals like annual, seasonal, monthly, weekly and daily runoff with rainfall as input which obviates the use of continuous rainfall records etc. Therefore, the author has elected to review some of such models and discuss certain short comings.

2.1.4 Discrete interval water yield models

2.1.4.1 Annual water yield models

This part of the review constitutes models developed for estimating annual and seasonal runoff volumes from the watersheds.

Binnie (1872) 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 15 to 40 for annual rainfall variation from 500 to 1100 mm.

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 mehod 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.

A simple and direct method of estimating watershed yield of annual or seasonal runoff (Q) is to deduct some amount of losses (L) in the catchment from the rainfall (P) and account the rest for runoff.

$$\text{Runoff} = \text{Rainfall} - \text{Losses} \qquad ...(2.2)$$

This approach was used in the past by irrigation engineers. The runoff quantities estimated by this method are approximate and involve errors. The various linear forms that have been used are :

$$Q = ap \qquad ...(2.3)$$

$$Q = p - b \qquad ...(2.4)$$

$$Q = a\,(p - b) \qquad ...(2.5)$$

Where,

Q = Annual runoff, cm

P = Annual rainfall, cm

a and b are constants.

Equation (2.3) implies that some runoff occurs even for extremely low value of annual rainfall and losses increase indefinitely with rainfall. Equation (2.4) implies that above a certain value, losses are constant and independent of annual rainfall. Equation (2.5) being a two parameter equation is more versatile than the other two, but suffers from the short coming that losses are assumed to increase indefinitely with rainfall. Some of the empirical formulae, commonly used to estimate runoff are given in Table 2.1.

Many other studies have been directed at correlating annual runoff with rainfall, agricultural practices, crop cover conditions and physical characteristics of the watershed (Sopper and Lall, 1965 ; Blank and Beer,

Table 2.1 Empirical formulae for estimating runoff from a catchment.

(Source : Verma, 1987)

Sl.No.	Name	Formula
1.	Inglis formula for Ghat areas	$Q = 0.85P - 30.5$
2.	Inglis formula for Non-Ghat areas	$Q = [(P - 17.8)/254] . P$
3.	Lacey's formula	$Q = P / [1 + (304.8\ F/P.S)]$
4.	Khosla's formula	$Q = [P - \{(T - 32) / 3.74\}]$
5.	Parker's formula for British isles	$Q = 0.94\ P - 35.6$
6.	Parker's formula for Germany	$Q = 0.94\ P - 40.6$
7.	Parker's formula for East USA	$Q = 0.80\ P - 41.9$

Q = Annual runoff, cm

P = Annual rainfall, cm

F = Monsoon duration factor

S = A catchment factor

T = Mean temperature, ^0F

Note : The first four formulae were developed for Indian catchments.

1968 ; Ryan and Pereira, 1978). But these studies are restricted to certain regions and a limited range of watershed characteristics.

Das *et al.* (1971) analysed runoff and rainfall data of 17 small watersheds of Nilgiri hills, Tamilnadu and developed the following formula :

$$Q = \frac{1.511\ P^{1.44}}{T_m^{\ 1.34}\ A^{0.0613}} \qquad ...(2.6)$$

Where Q = Annual runoff, cm

P = Annual rainfall, cm

A = Watershed area, sq. km

T_m = Mean annual temp., ^{0}C.

Similarly, different power equations have been developed relating rainfall to runoff considering different factors like vegetal cover factor, annual rainfall and mean annual temperature (Kothyari *et al.*, 1985). However, these are very location specific.

Singh (1988) developed different regression equations using the concepts 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 microwatershed varied from 0.10 to 0.72 ha m ha^{-1} indicating the scope for construction of water storage structure.

2.1.4.2 Monthly water yield models

A season or a year is a large time unit to adopt in the design of any water storage structure in the rainfed areas. Monthly runoff estimation is more appropriate in the case of design of storage structure. Water losses in a given month vary with a number of factors other than monthly rainfall, and runoff in a given month is affected by rainfall in the preceding and perhaps earlier months. Multivariate regressions are generally used to develop relationship between rainfall and runoff. Some regional monthly rainfall- runoff models have been developed which can be used for estimating runoff from rainfall (Blank and Beer, 1968; Krishnaswamy, 1976 and Rao and Minikou, 1983).

Haan (1972) developed a monthly water yield model considering four parameters namely (i) a maximum infillration rate (mm/hr), (ii) maximum rate of seepage from soil water zone (mm/ day), (iii) maximum soil water storage capacity (mm) and (iv) the fraction of seepage from the soil water zone that becomes stream flow. The model requires daily rainfall as input, and a long term stream flow record is needed for optimizing the above parameters.

Gulati (1987) used various polynomial/power equations of first degree and second degree to develop relationship between 15 day rainfall and the runoff for paddy area, irrigated non-paddy area, fallow land and uncultivable area.

2.1.4.3 Daily water yield models

The storm or daily rainfall - runoff relation that has had maximum application in water storage structure design is Soil Conservatin Service runoff curve number method developed by SCS, USDA (1964). This method, also known as hydrologic soil cover complex 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 from a particular storm is determined by using the equation :

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \qquad P > 0.2\,S \qquad ...(2.7)$$

$$Q = 0 \qquad P \leq 0.2\,S \qquad ...(2.8)$$

Where,

Q = Runoff depth, mm

P = Rainfall depth, mm

S = Potential maximum retention, mm

The potential maximum retention (S) is determined by the equation :

$$CN = \frac{25400}{254 + S} \qquad ...(2.9)$$

Where, CN = Curve number

The detailed procedure has been very well documented in the SCS National Engineering Handbook (1964).

The original SCS curve number method used an antecedent rainfall indices based on 5-day previous rainfall totals as AMC I, AMC II and AMC III. 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.

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 modificaion for semi-arid tropics.

Rawls *et al.* (1980) developed SCS curve number for cases of conservation tillage and no tillage practices for estimating runoff using tillage and crop data from small watersheds and simulated rainfall.

Singh (1981) suggested the procedure to estimate runoff from reclaimed soils on the basis of SCS curve number method and reported alternate curve numbers corresponding to ESP (Exchangeable Sodium Percentage) changes or changes in storage capacity in the reclaimed alkali soils.

Harikrishna (1982) developed a parametric water balance model to simulate runoff from agricultural watesheds of ICRISAT, India. Some of the models based on water balance approach have been reported (Neilsen and Panda, 1988; Rama Prasad, 1988) and these models required the daily recording of climatic data, hourly rainfall data and soil moisture in watershed which are rarely available in most parts of the country.

Sharma (1983) adopted SCS curve number method for estimating runoff for different assumed curve numbers and used in the water balance studies to determine the surface drainage coefficient. He compared predicted ground water recharge with the observed as the measured runoff data were not available.

Similarly, several researchers have used the SCS curve number method in different studies like efficient use of rainwater for rainfed crops, development of runoff simulation models, ground water recharge through percolation ponds and development of curve numbers for prevalent land uses in Himalayan watershed (Verma, 1987; Borah, 1989; Borah and Ashraf, 1990; Selvarajan, 1990; and Dube *et al.*, 1991).

Ram Babu and Dhruva Narayana (1983) developed regression equation to predict runoff volume and peak rate of runoff basd on the watershed parameters like area, channel length, duration of storm, total rainfall, maximum rainfall occuring in any interval of 30 min during storm and antecedent precipitation index (API) based on the previous 7 days rainfall values for the small watersheds of Doon valley. In the similar approach, regression equations for small agricultural watersheds were developed in shivaliks (Agnihotri *et al.*, 1988).

Shrivastava and Bhatia (1988) studied the effect of land treatments on runoff behaviour in deep vertisols. They revealed that the land treatments, broad bed and furrow system produced greater volume of runoff as well as greater peak rate of runoff than the flat sowing on grade systyem.

Hawkins (1990) determined curve numbers for event rainfall-runoff data sets by ordering the variables separately and re-pairing the individual rainfall and runoff, based on the assumption that the return periods are identical for storm rainfalls and runoffs. This method violates the general concept that the amount of runoff from the watershed depends on the degree of wetness of watershed.

Adhikari and Chittaranjan (1990) used water balance of watershed as a tool to analyse the performance of the system and to locate the problems in the water harvesting process. The water lost due to seepage and deep percolation have been quantified. He reported that the annual runoff values observed were 1.4 %, 1.3 % and 3 % during 1985, 1986 and 1987 respectively.

Pramod Kumar *et al.* (1991) developed curve numbers for the prevalent land uses in Kaliaghai river basin, West Bengal by adopting IRS data base for estimating land use/land cover/soil complex characteristics. In this approach, SCS model was used.

2.2 VALIDATION OF MODEL

Validation of a developed model is one of the important aspects of hydrologic modelling. Validation procedure of any hydrologic model involves the checking of the appropriateness of the model response to a given input. This is done by comparing the predicted response with some corresponding observed information. Such comparisons can be made by using appropriate statistical procedures, which may be parametric or non-parametric.

Different research workers have developed several hydrologic models to compute runoff rate or volume as discussed in the preceding sub-sections. In all these models, the predicted runoff depths or runoff rates showed reasonable agreement, visually, with the observed data. No tests of significance were done to know the extent of agreement between the observed and the predicted hydrologic data series.

However, some of the workers have used non-parametric tests and correlation analysis for knowing the agreement between the observed and the predicted data series.

Bhattacharya (1977) used a non-parametric statistical procedure called Wilcoxon matched pairs signed ranks test to examine the closeness of the agreement between the observed water table depths and the predicted water table depths, while validating the water balance model for different soil types. The same procedure was used in ground water recharge studies while examining the agreement between the observed and the predicted 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 while studying the applicability of SWRRB (Simulator for Water Resources in Rural Basins), over rangeland watersheds. The SWRRB model was developed by Williams *et al.* (1985).

De Coursey and Seely (1988) studied the validation of different individual processes in the SWAM (Small Watershed Model) model. Though, it was mentioned that SWAM model predicted individual components of model satisfactorily with the observed values, it was however not indicated the type of statistical procedure used in validating the model output.

2.3 UTILIZATION OF WATER YIELD FOR CROP PRODUCTION

Runoff is inevitable in most of the rainfed areas even after adoption of *in situ* moisture conservation practices. Such runoff collected in water storage structures can be used to get maximum return per unit of water stored. The stored water can be used for fish farming, tree plantation, intensive irrigation to a small area and extensive supplemental irrigation to rainfed crops. Despite good control of seepage losses, water losses from storage structures are significant. The volume of water goes on reducing with the passage of time after monsoon and within monsoon if long dry spells exist. Hence, the unit cost of water increases with time. Stored water in a detention structure is a developed resource and there is a cost associated with it. Hence, there is a need to utilize it judiciously and efficiently.

There is a controversy as to whether the benefit from crop returns is increased by limited supplemental irrigation over large area or by intensive irrigations according to the optimum water demand over a small area. The former approach ensures drought insurance to more area or more farmers and maximum returns of water applied. But this costs more on lengthy water conveyance and application systems, which are to be used for a very small period in a year (Zimmerman, 1966). Thus, for a particular area, it becomes essential to know whether a fixed amount of irrigation water is utilized more efficiently by the full irrigation to a small area or by the supplemental irrigation to larger area that could otherwise be under rainfed farming. Maximising yield per unit area through intensive irrigation is economically justified where water is readily available and irrigatin 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 maximize yields per unit of available water (Stegmen *et al.,* 1980).

Correct timing of supplemental irrigation requires knowledge of crop response to applied water at different growth stages. During some particular growth stages, the plants are more sensitive to moisture stress than at others and these moisture sensitive (critical) periods differ with crop and varieties. These critical periods for various crops have been described in detail by Hukkeri and Pandey (1977) and Rao (1991). Application of water stored in a storage structure as supplemental irrigation at these critical growth stages is more productive than when applied at other stages because moisture stress during these periods will considerably reduce crop yield which can not be recovered by subsequent application of water at later stages.

Verma (1987) reviewed various works done in connection to application of stored water as supplemental irrigation and its benefits for different crops like wheat, maize, gram etc. and concluded that extensive irrigation increased the water use efficiency of crops.

Srivastava *et al.* (1987) tested two rice varieties Archana and Jayanti with eight moisture regimes. The yield data revealed that it was not always necessary to follow the practice of continuous submergence in rice cultivation.

Varma (1990) studied the increase in the productivity of different crops and crop intensity in the rainfed microwatersheds after the construction of water harvesting structures. An increase of 73 to 281 per cent in the productivity of various crops and 56 per cent increase in cropping intensity was observed after the provision of these structures.

2.3.1 Optimal allocation of water resources and benefits from watershed management programmes

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 availability at the beginning of the season. Aron (1968) used dynamic programming to optimize the conservation and use of a ground water - surface water system involving several streams, reservoir recharge facilities, distribution of pipelines and aquifers.

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. The results of the empirical application includes water requirement forecasts, inter-regional water transfer requirements, efficient production, cropping pattern and an optimal investment programme for water resource projects.

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.

Vedula and Rogers (1981) formulated a linear programming model for a river basin in India in the context of multi-objective analysis of irrigation planning.

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. Senapati (1988) presented a linear programming model with the objectives of maximizing net returns and production under various levels of canal release and project efficiency for assisting management.

Varshney (1990) developed linear goal programming (LGP) model within the conflicting goals of maximizing 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.

A multi-objective optimization procedure using the goal programming technique was developed to assist planners so as to sustain the productivity of land at desired level (Pandit and Senapati, 1991). In this procedure, out of 12 crop-area allocation models developed, the best model was obtained when the canal system was operated at its 80 per cent design flow with the project efficiency being maintained at 60 per cent.

Agnihotri *et al.* (1990) observed that the watershed management programme even without rainwater harvesting and recycling, resulted in increased gross returns when compared with the cost associated with the watershed management programme, with benefit-cost ratio of 1.67.

Shukla *et al.* (1991) presented a case study in one of the catchments of Upper Damodar Valley, highlighting the agricultural production enhancement and other benefits as a result of adopting soil and water conservation measures. It was found that while hectarage under little millets and pulses reduced by 33 and 44 per cent, there were 2 and 10 fold increase in the rice and wheat areas, respectively.

2.4 CRITIQUE OF LITERATURE REVIEW

The review on water yield models reveal that there is no shortage of suitable techniques for estimating runoff from small cropped watersheds which can be applied to watersheds having some period of concurrent rainfall and stream flow records. Unfortunately, no stream flow records are available in most of the parts of the country except at very few research stations.

The continuous watershed and event based runoff models provide the most accurate predictions of runoff at smaller time interval (i.e., less than a day). However, these models require a huge measured data base for the calibration and optimization of different watershed parameters limiting the general applicability in most parts of the country. Besides huge data requirement, these models are more complex and complicated taking more time of computation and need good expertise for operating the model.

Annual runoff estimation was done in general by developing regression equations relating runoff to different watershed parameters. This annual runoff estimation does not help much in the design of water storage structures in rainfed farming because water is needed at some critical stages of crop. Annual runoff coefficients and rainfall - runoff relations do not give any idea of runoff availability during the relatively short period of cropping season. There is some scope of monthly rainfall-runoff relationship for the design of water storage structure, but mulitvariate regression models available are very location specific and thus can not be used for other watersheds.

Daily water yield models are better suited for the design of storage structure and to study the availability of stored water for proper crop planning in the rainfed farming. Though, there are some water balance and regression models based on daily rainfall, they require detailed measured data for calibration of model parameters and have limited applicability over other watersheds. The most commonly used method is SCS curve number method for estimation of runoff from small watersheds because of its simplicity. The SCS curve number method requires daily rainfall data which is available at most of the regions. Design estimates of CN based on soil, cover and land use are given in Handbook of hydrology (Anonymous, 1972) for Indian conditions. These CN values are determined by extrapolation from CN values documented in SCS, USDA (1964) and not based on actual studies over a wide range of watersheds through analysis of rainfall and stream gauging records.

However, two problems arise in application of SCS curve number method. First, the calculation of runoff is more sensitive to chosen CN value than to the rainfall depths. That is, errors in CN value have a more grievous effect on the estimation of runoff than do similar levels of error in the storm rainfall depth in equation (2.7). This is unfortunate, since the data confidence situation is reverse : rainfall information is vigorously pursued and widely published, while CN ground truth is rare. Secondly, while soil defined CN may be best estimated for traditional agricultural watersheds, they are less well estimated for semi-arid range lands and most poorly for forested watersheds (Hawkins, 1990). Because of the sensitivity of the method to CN value and the uncertainity of CN estimates from source handbooks, the curve numbers should be developed based on the real life data of rainfall and runoff.

The review on utilization of water yield for crop production indicates that for maximum benefit, limited stored water should be applied as a supplemental irrigation to the most responsive crop at its critical stage.

Also, the review on optimal allocation of water resources and benefits from watershed management programmes reveal that linear programming is widely used technique in obtaining the maximum returns for different crop plans under various constraints and the adoption of soil and water conservation programmes on watershed basis resulted in improvement of socio-economic condition of the local farmers.

CHAPTER III

THEORETICAL CONSIDERATIONS

One of the major works undertaken by the Soil Conservation Department of DVC, Hazaribagh is to construct small storage structures across the gully formations in the microwatersheds of Upper Damodar Valley. The major purposes of these structures are to check soil erosion, flood control, ground water recharge and providing irrigation facilities to the command lying below the structure. Thus, the present study is aimed to study the hydrologic behaviour of such microwatersheds linking the dynamics of stored water behind the structure.

3.1 PREDICTION OF WATER LEVELS IN THE STORAGE STURCTURES BY USING SCS CURVE NUMBER METHOD

In this section, the theoretical basis of estimating runoff from the microwatersheds of Upper Damodar Valley catchment by using SCS curve number method has been discussed. This is followed by a discussion on the runoff accumulation in the storage structure through reservoir water balance. The SCS curve number mehtod was first developed by SCS, USDA (1964). This method requires daily rainfall, land use type, hydrologic soil group and antecedent moisture condition of watershed as input. In this method, the potential maximum retention storage of watershed is related to a discrete number called curve number which is a function of land use, different land treatments, antecedent moisture condition of the watershed and soil type. Curve number is dimensionless and its value varies from 0 to 100.

The governing equations developed by SCS, USDA (1964) to estimate runoff and its storage in the structure should sufficiently describe the real physical system under study. In the process of achieving this, the following aspects and assumptions are considered as the back ground of the solution to the problem (Fig. 3.1).

(i) It is assumed that SCS curve number method is applicable to the microwatersheds considered for the present study in Upper Damodar Valley as it is widely applied over Indian watersheds for estimating runoff because of its simplicity.

(ii) The inter flow component in the watershed is assumed to be negligible as the areas of selected watesheds are very small and soils are sandy loam.

(iii) The direct rainfall contribution to incrèase the volume of water stored in the structure is assumed to be negligible.

(iv) It is assumed that ther is no water loss across the bund of the storage structure and the major loss is seepage through the wetted surface of a structure.

(v) In general, all the water detention structures are irregular in shape at different depths of storage in the study area selected. However, it is assumed that water spread area is approximated as wetted surface area of structure at particular time and depth under consideration.

3.1.1 SCS curve number method

The most generally available rainfall data in most parts of the country are the amounts measured at non-recording rain gauges. The data

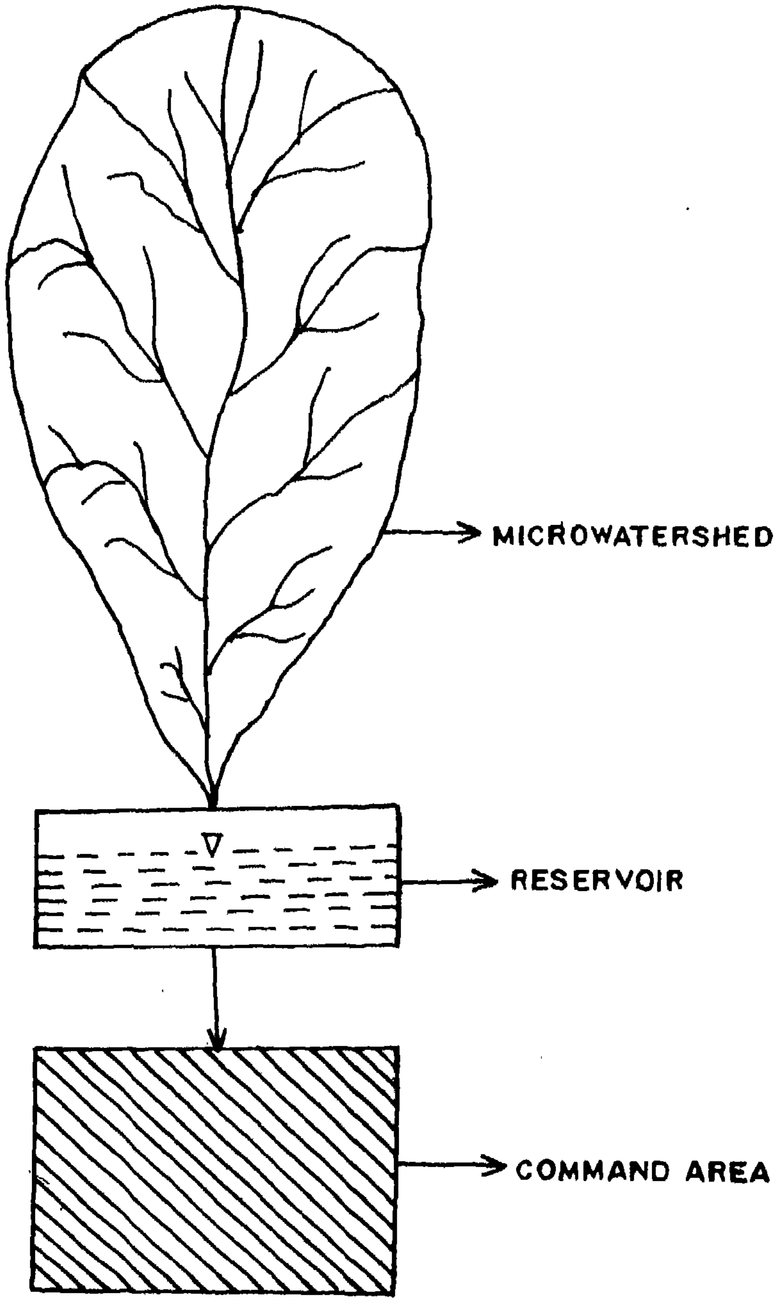


Fig.3.1. Schematic representation of microwatershed, reservoir and command area system.

are totals for one or more storms occuring in a calendar day and nothing is known about its time distribution. Therefore, the rainfall - runoff relation excludes time component as an explicit variable, which means that rainfall intensity is ignored.

Developement

For the simpler storm, the relation between rainfall, runoff and retention in which rainfall and runoff begin simultaneously over a watershed is given by :

$$\frac{F}{S'} = \frac{Q}{P} \qquad \text{...(3.1)}$$

Where,

F	=	Actual retention, mm
S′	=	Potential maximum retention ($S' \geqslant F$), mm
Q	=	Actual runoff, mm
P	=	Potential maximum runoff ($P \geqslant Q$), mm

The parameters in equatin (3.1) do not contain the initial abstraction. The retention S′ is a constant for a particular storm because it is the maximum possible retention over a watershed under existing conditions, if the storm continues for longer duration. The retention (F) varies because it is the difference between P and Q at any point on the mass cruve. i.e,

$$F = P - Q \qquad \text{...(3.2)}$$

Then, equation (3.1) becomes,

$$\frac{P - Q}{S'} = \frac{Q}{P} \qquad \text{...(3.3)}$$

Solving for Q, equation (3.3) produces,

$$Q = \frac{P^2}{P + S'} \qquad ...(3.4)$$

Which is rainfall - runoff relation in which the initial abstraction is ignored.

Taking initial abstraction into consideration and replacing retention parameter S′ by S, the equation (3.1) becomes :

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad ...(3.5)$$

Where I_a is the initial abstraction, $F \leq S$ and $Q \leq (P - I_a)$. The parameter S includes I_a i.e., $S = S' + I_a$

Now, equation (3.2) becomes,

$$F = (P - I_a) - Q \qquad ...(3.6)$$

Equation (3.3) becomes,

$$\frac{(P - I_a) - Q}{S} = \frac{Q}{P - I_a} \qquad ...(3.7)$$

Solving equation (3.7) for Q gives,

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad ...(3.8)$$

Which is rainfall - runoff relation with the initial abstration (I_a).

Where Q = Runoff depth, mm

P = Rainfall depth, mm

S = Maximum retention potential, mm

The initial abstraction consists mainly of interception, infiltration and surface storage which occur over the watershed before runoff begins. The relation between I_a and S was developed by means of rainfall and runoff data from experimental small watersheds (SCS, USDA, 1964) as :

$$I_a = 0.2\ S \qquad ...(3.9).$$

Therefore, the final equation for Q becomes,

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \quad \text{for } P > 0.2\ S \qquad ...(3.10)$$

$$Q = 0 \quad \text{for } P \leq 0.2\ S \qquad ...(3.11)$$

In the SCS method, the retention parameter (S) is determined based on antecedent moisture condition (AMC) determined by the total rainfall in 5-day period preceding a storm. Three levels of AMC are used to define the wetness of a watershed. The AMC limits are given in Table A.1 in Appendix A.

AMC I — is the lower limit of moisture or the upper limit of 'S'

AMC II — is the average level of moisture in the watershed.

AMC III — is the upper limit of moisture or lower limit of 'S' in the watershed.

The parameter CN (Curve number) is related to the retention parameter as :

$$CN = \frac{25400}{254 + S} \qquad ...(3.12)$$

Where S is in mm.

The parameter CN in equation (3.12) is dimensionless and selected based on the qualitative information available like soil type, land use or cover, land treatment and condition of the land cover over a watershed, which can be easily known either from watershed maps or by reconnaissance survey.

Thus, SCS method is chosen as the basis for the development of curve numbers for various prevalent land uses in the watersheds by comparing with the observed and predicted water levels in the storage structure along with the estimation of runoff. The detailed methodology to achieve this is described in the next chapter.

CHAPTER IV

MATERIALS AND METHODS

4.1 UPPER DAMODAR VALLEY

The Upper Damodar Valley (UDV) covers an area of 1.75 m ha draining into the river Damodar and its main tributaries Barakar and Konar. It lies in the Chotanagapur plateau covering the districts of Hazaribagh, Ranchi, Palamau, Giridih, Santhal Parganas and Dhanbad in Bihar and some parts of West Bengal adjacent to Dhanbad. The multipurpose reservoirs constructed by Damodar Valley Corporation (DVC) with its head quarters at Calcutta, West Bengal in Upper Damodar Valley are Maithon, Panchet, Konar and Tilaiya.

The Upper Damodar - Barakar river system is infested with the serious problem of land degradation due to soil erosion affecting the agricultural lands, forest and wastelands of the region. The problem of soil erosion is a complex one which demands multi-disciplinary approach and the practices of soil and water conservation suitable to the geoclimatic conditions of the region.

To achieve the above objective, Damodar Valley Corporation, one of the prime River Valley Projects of the country had set up Soil Conservation Department with its headquarters at Hazaribagh, Bihar in 1949. The Soil Conservation Department (SCD) has several special divisions involving themselves with activities on afforestration, agriculture, conservation engineering, soil science and hydrology etc. to promote soil and water conservation practices. Besides SCD, there are state Government agencies executing the soil conservation programmes under funding from the DVC.

Both sheet and gully erosion are very active in the Upper Damodar Valley. The problem of erosion has gained additional importance due to an accelerated rate of filling up of multi-purpose reservoirs. The soil conservation programme undertaken in UDV aims at delineating the areas of active erosion, the active and potential sediment sources and treat them by proper land management and structural measures.

The Engineering Division is engaged in adopting structural measures such as planning and execution of water disposal and storage structures as well as spillways and silt detention structures across the small streams and tributaries. Besides these programmes, the DVC imparts training to state/central government employees on monitoring sediment and hydrologic data in small watersheds and to the graduate engineering students from universities all over India in techniques of soil conservation.

4.2 PROJECT AREA

The Upper Damodar-Barakar catchment has been sub-divided into 39 sub-catchments on the basis of natural drainage (Fig. 4.1). In order to plan the soil conservation programmes effectively on watershed basis, the sub-catchments were further divided into several small watersheds (Fig. 4.2). The project area of the present study is located on a segment in the sub-catchment 8 which hereafter is being refered to as watershed no. 8/5. This watershed 8/5 has an area of 24,753 ha and is rectangular in shape with a length-width ratio 2 : 1.

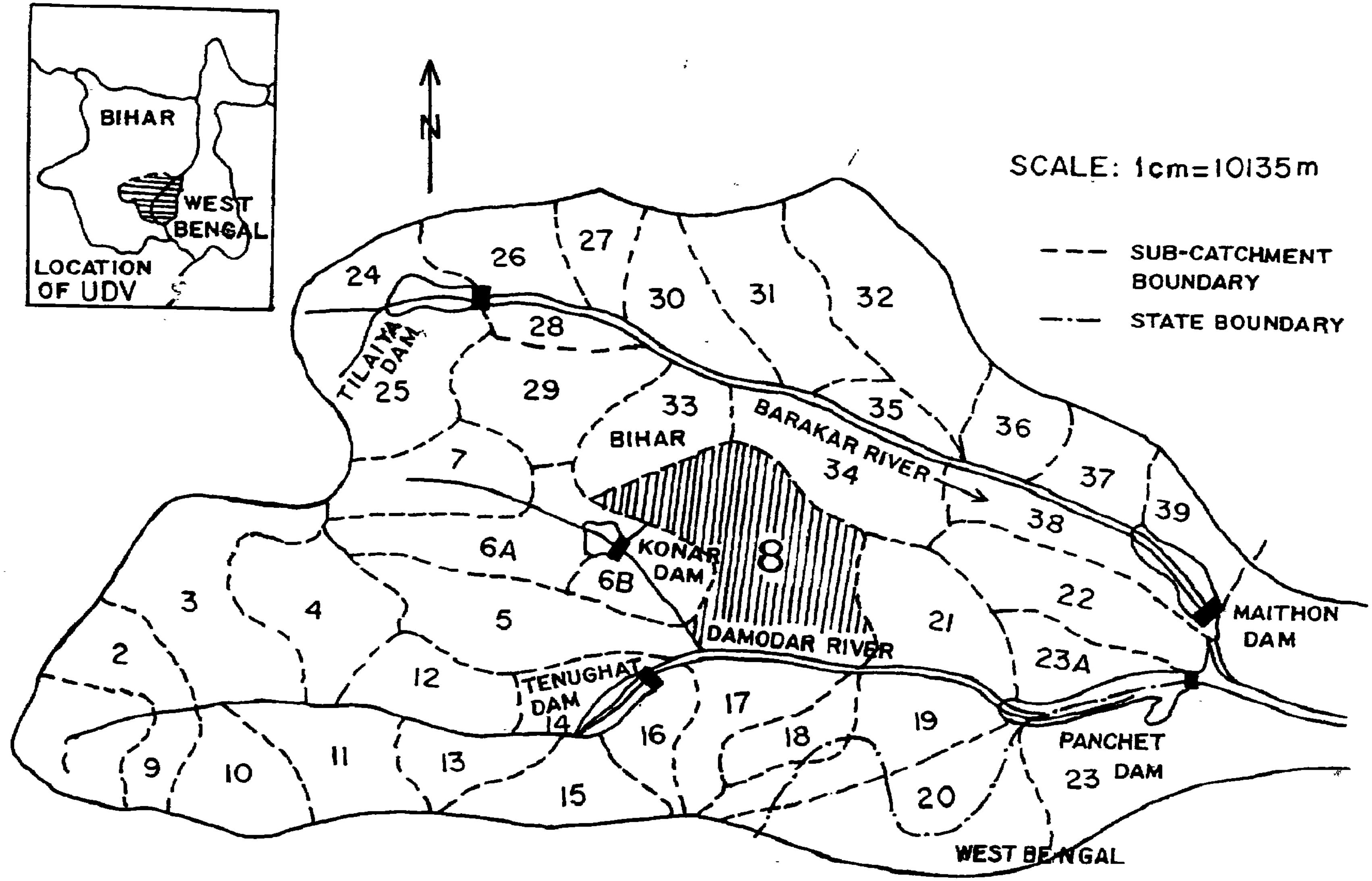


Fig. 4.1. Location map of sub-catchment 8 in Upper Damodar Valley.

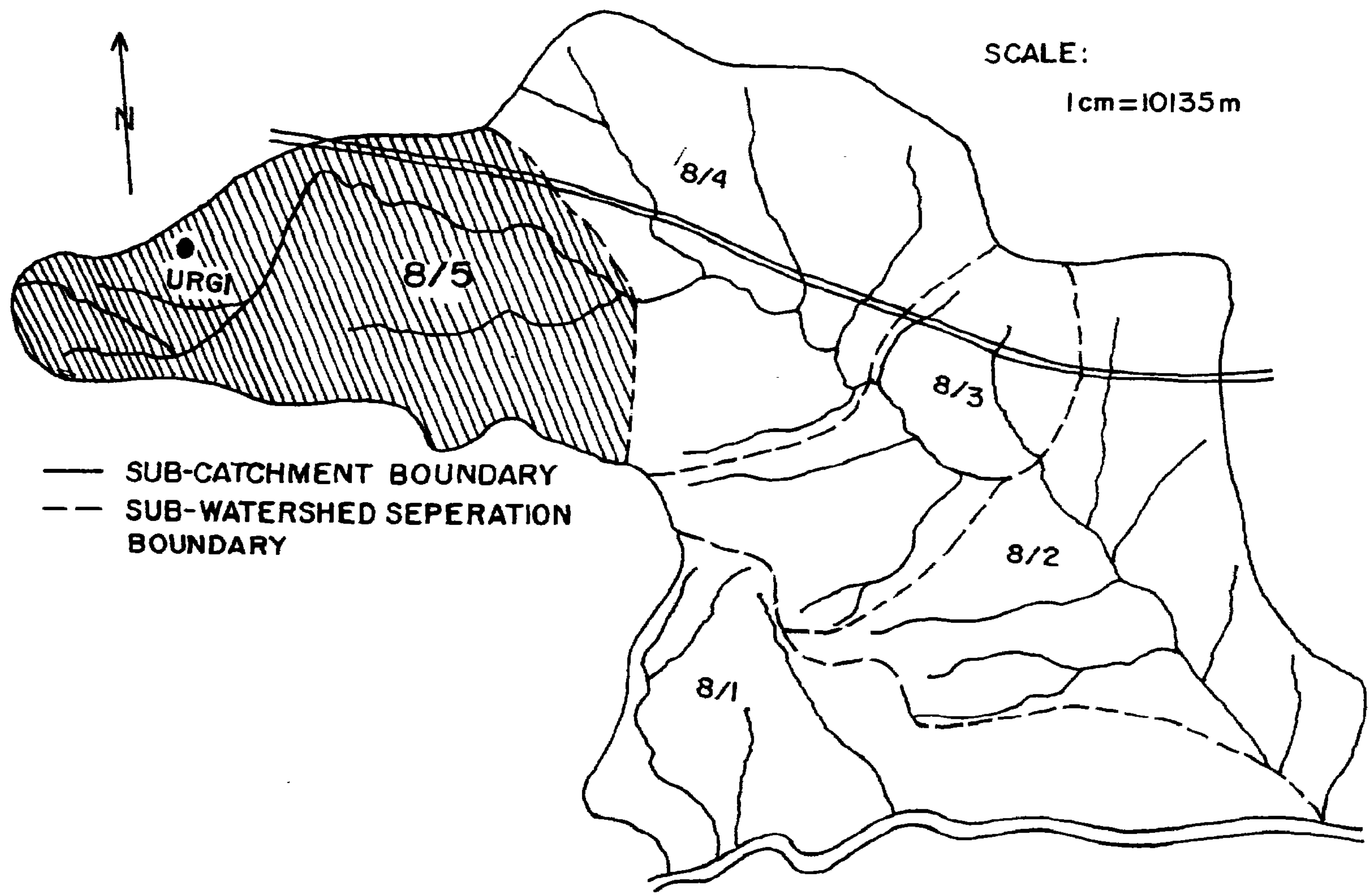


Fig.4.2. Location map of sub-watershed 8/5 in sub-catchment 8

The project site is situated nearby the village Urgi in watershed 8/5 Which is 42 km away from Hazaribagh and 2 km from Bishungarh. The latitude and longitude of the Urgi are 24^0 2' N and 85^0 43' E respectively with the elevation of 485 m above MSL.

4.2.1 Climate and annual rainfall

The climate of the study area is sub-humid tropical. Monsoon starts from middle of the June and continues through september during which 90% of the annual rainfall occurs. The average annual maximum and minimum temperatures are 43.4 ^{0}C and 4.5 ^{0}C respectively. The mean annual temperature of the area is 24.9 ^{0}C.

The maximum and minimum annual rainfall in the region are 2092.2 mm and 692.9 mm respectively. The mean annual rainfall is 1201.8 mm. The rainfall intensity in the study area varies from 40-310 mm/hr (Anonymous, 1984). The length of rainfall record used was 20 years.

4.2.2 Soils, geology, topography and land use

The soils are of red sandy loam type. The surface soil is coarse textured and rapidly permeable, while the sub-soil is moderately heavy to heavy in texture and slowly permeable. The soils of study area were grouped under hydrologic group B. The soils under the group B will have moderate infiltration rates when thoroughly wetted and consist of moderately deep to deep, moderately well to well drained soil with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission. The soils in the study area come under land capability class-II.

The study area consists of granites and granite gneiss of igneous and metamorphic origin and alluvial deposits. The topography is undulating with varying slope from 1 to 5%.

The major land uses in the study area are forest, agriculture and bare land. The forest cover in the study area was classified as (Anonymous, 1984) :

F_o = Forest with no canopy

F_1 = Thin forest with sparce vegetation.

4.2.3 Problems of agricultural production

In general, the soils are highly permeable with undulating topography and poor water holding capacity leading to poor moisture retention in the root zone of the crops. The major crops grown in the study area are upland paddy, maize and pigeon pea in kharif season. Monsoon breaks of upto 20 days are very common in the region resulting in frequent failures of even single kharif crop.

The farmers of the region are basically tribes with poor socio-economic condition. The main problems of the area are :

(i) Inadequate and deep ground water

(ii) Low soil fertility due to severe erosion of top soil in agricultural lands with gully formations

(iii) Poor socio-economic condition of farmers due to small and fragmented individual holdings and

(iv) Subsistance type farming without adopting short duration improved crop varieties suiting to upland farming.

4.3 SELECTION OF MICROWATERSHEDS AND DATA COLLECTION FOR THE STUDY

The Engineering Division of SCD, Hazaribagh constructed several earthen dams as silt detention structures across the gully formations nearby Urgi village. These earthen dams act as storage structures for the runoff coming from the microwatersheds. Out of these, five earhen dams, their up stream reservoirs, the contributing microwatersheds and their down stream command area were selected for the present study. The five earthen dams were named as ED 5, ED 14, ED 18, ED 19 and ED 21. These structures were constructed across the main drainage channel and its sub-channels (Fig. 4.3). Hereafter, the selected microwatersheds are designated by their respective reservoir number as MW 5, MW 14, MW 18, MW 19, and MW 21. The structures ED 18, ED 19 and ED 21 are the upstream reservoirs of ED 5 and ED 14.

4.3.1 Rainfall measurement

One non-recording raingauge was installed near the DVC camp office of Bishungarh village which is 2 km away from study area, Urgi and the daily rainfall measurements were recorded from 13th June to 7th July, 1992 for model validation.

4.3.2 Estimation of land use

Reconnaissance survey was carried out to know the extent of land use cover in each of microwatersheds chosen for the study. As these microwatersheds are of small size, it was very difficult to estimate the distribution of cover from the land use maps of SCD, Hazaribagh. Hence, a vigorous reconnaissance survey was made in the selected watersheds to know the distribution of different types of land cover within

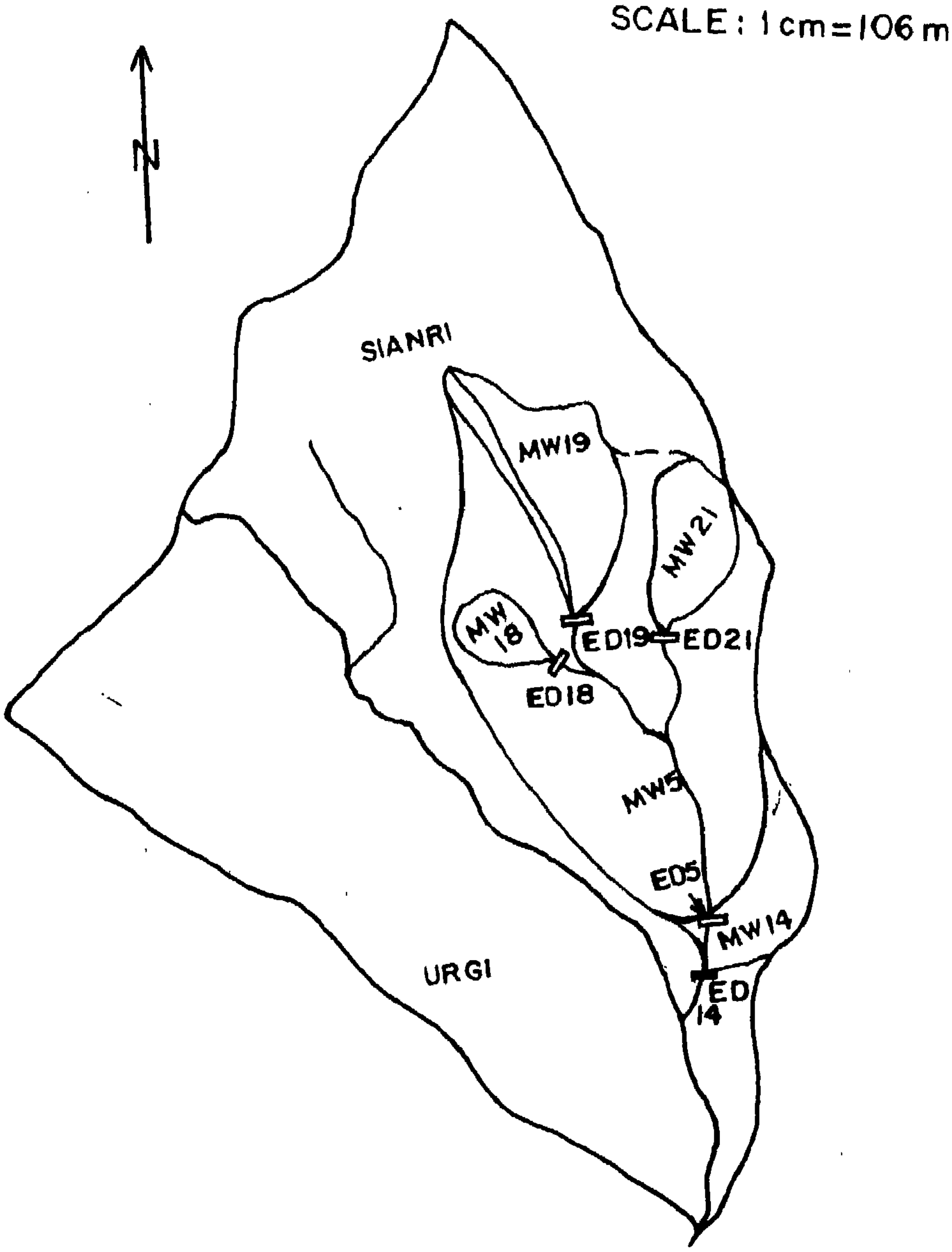


Fig. 4.3. Location map of microwatersheds in sub-watershed 8/5.

microwatersheds. The details are presented in Table 4.1 for different microwatersheds.

4.3.3 Estimation of drainage density and slope of microwatersheds

The stream channels in the form of gullies within microwatershed were observed to carry runoff into the storage reservoirs. The lengths of such stream channels were measured for all the selected microwatersheds. The watershed morphological parameter called drainage density (D) was estimated for each microwatershed by using the formula :

$$D = \frac{\text{Total length of stream channel}}{\text{Area of microwatershed}} \qquad ...(4.1)$$

The average slope of microwatersheds was calculated from the contour map of the study site.

4.3.4 Infiltration measurement

A single ring infiltrometer was used to measure the infiltration rate at different time inervals in the bottom of the storage reservoirs ED 5 and ED 18. The standard test procedure was followed in conducting the field test. This test was not done in other storage structures because of their similar nature to either ED 5 or ED 18. The infiltration curves for the soils of ED 5 and ED 18 were drawn.

4.3.5 Capacity survey of storage structures

The range line method was used to measure the levels at different intervals of distance in the storage structure as shown in Fig. 4.4. In this method, a rope with markings at every 5 m distance was first tied along the longitudinal axis of the storage structure, which is called central line.

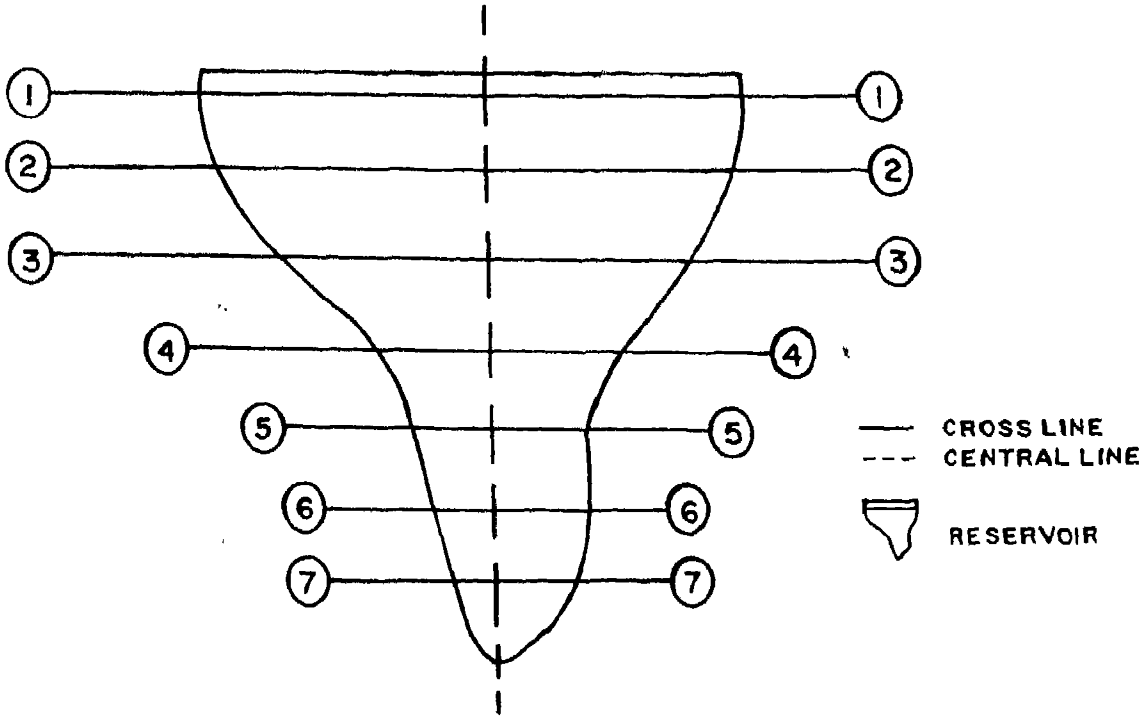


Fig.4.4. Schematic presentation of range line survey.

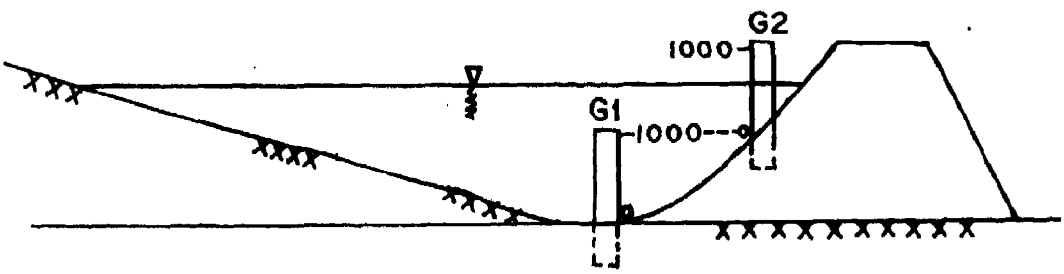


Fig.4.5. Schematic presentation of gauging reservoir.

Another rope marked at evey 5 m interval was run across the cental line perpendicularly, which is known as the cross line. Ground elevations were first noted along the central line at each interval of 5 m. After this, the cross lines were run perpendicular to central line at each of the earlier marked points at 5 m interval and ground elevations were noted with the help of a dumpy level and levelling staff.

The range line survey was done in all the five storage structures and their surface contours were drawn as shown in Fig. 4.6 through Fig. 4.10. The area encircled by each contour was measured by planimeter and the depth-water spread area and the depth-storage relationships were developed for all the five selected reservoirs, as shown in Fig. 4.11 through Fig. 4.13.

4.3.6 Gauging storage reservoirs

The method of gauging involves the fixation of different wooden gauges in the storage reservoirs by fixing the levels of zero reading in each gauge with the help of dumpy level. Based on the available depth of storage in structures determined from the capacity survey, the number of gauges to be fixed were chosen. The wooden gauges were taken from the Engineering Division, SCD, Hazaribagh. Each gauge was marked from zero to 1000 mm with 100 mm interval, starting zero reading at 30 cm from the bottom of the gauge. The 100 mm was again sub-divided into four intervals of 25 mm each with black and white paint markings. The least readable increment was 25 mm on the gauge.

In each structure, one gauge was fixed at the bottom of the structure by inserting the gauge into ground with zero level touching the ground

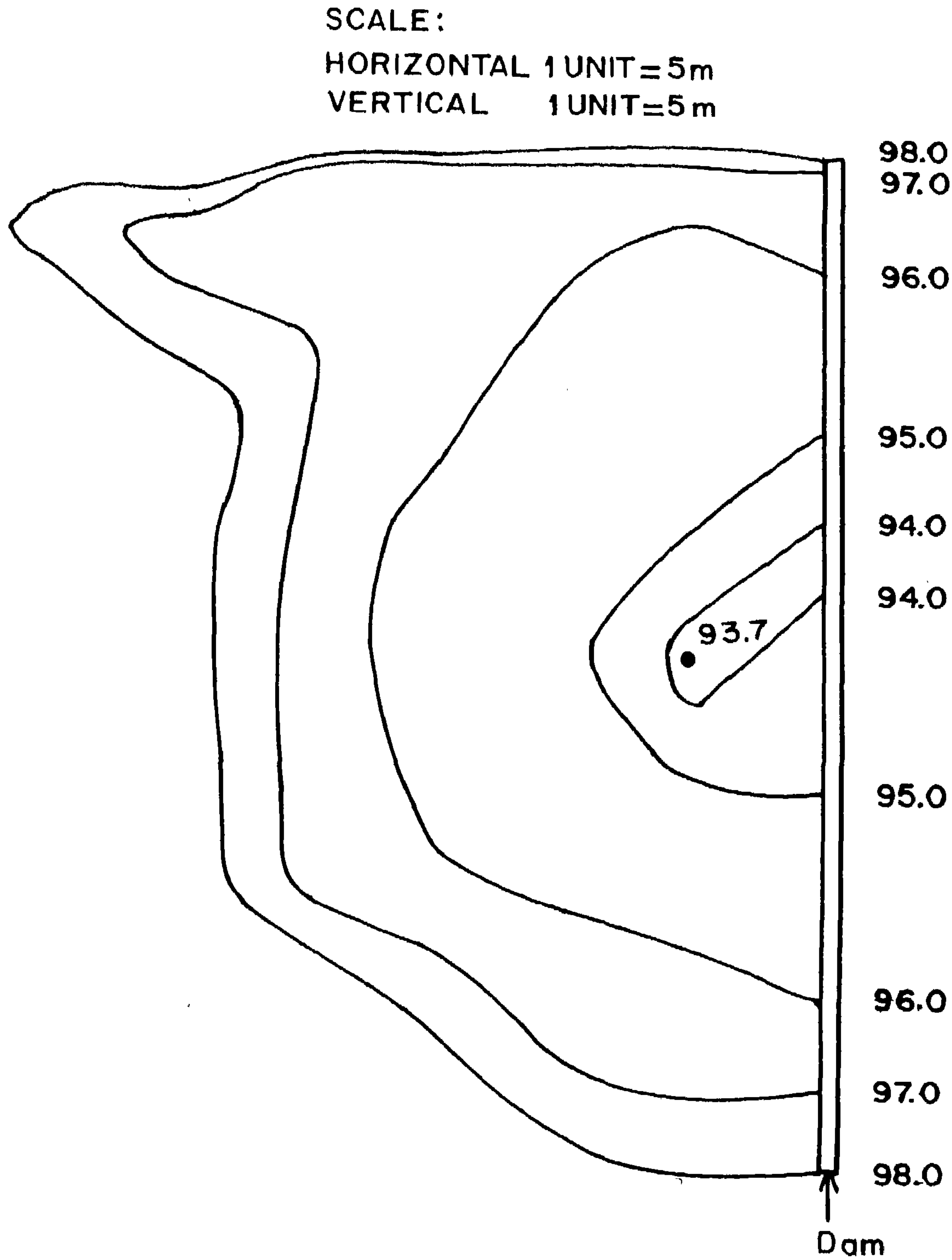


Fig. 4.6. Surface contours (m) of the reservoir ED 5

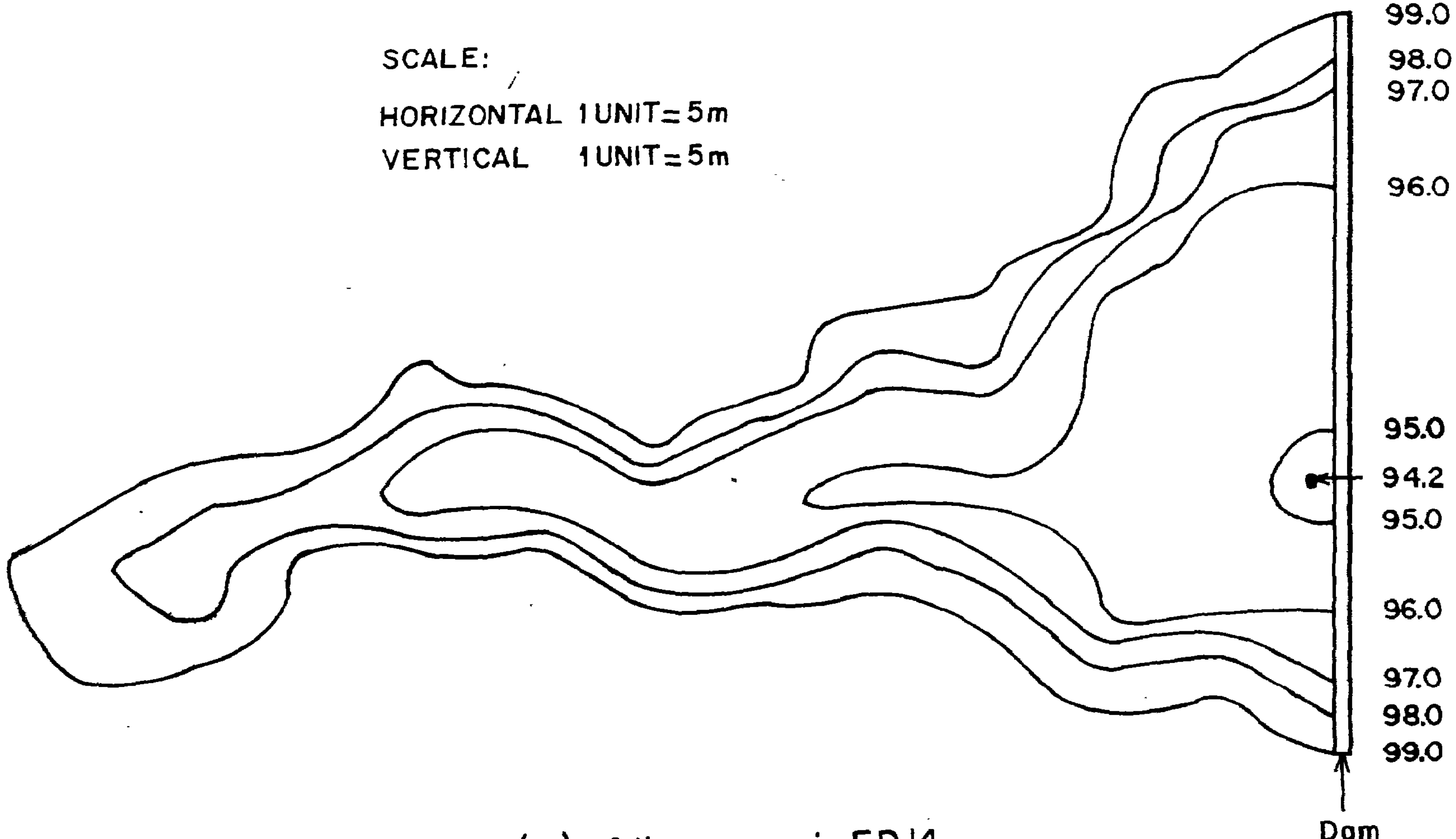


Fig. 4.7. Surface contours (m) of the reservoir ED14

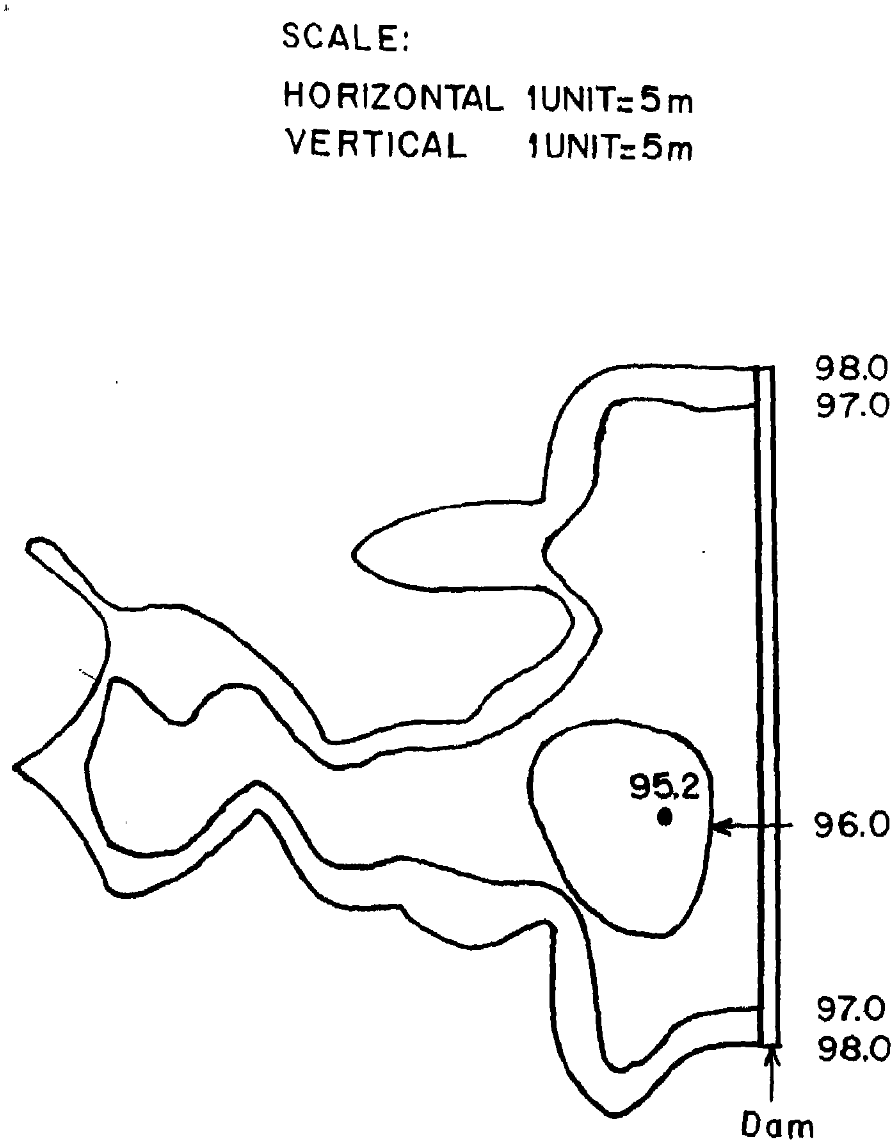


Fig. 4.8. Surface contours (m) of the reservoir ED18

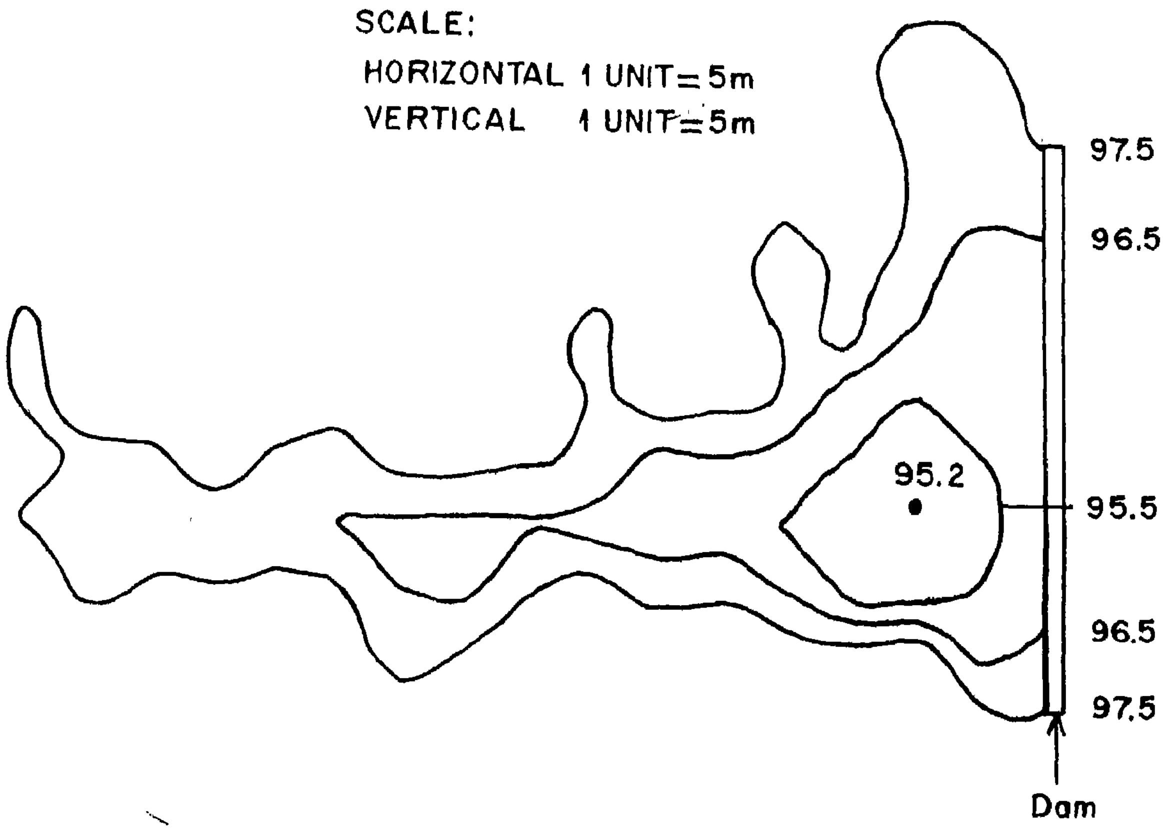


Fig.4.9. Surface contours (m) of the reservoir ED19

SCALE:
HORIZONTAL 1 UNIT = 5 m
VERTICAL 1 UNIT = 5 m

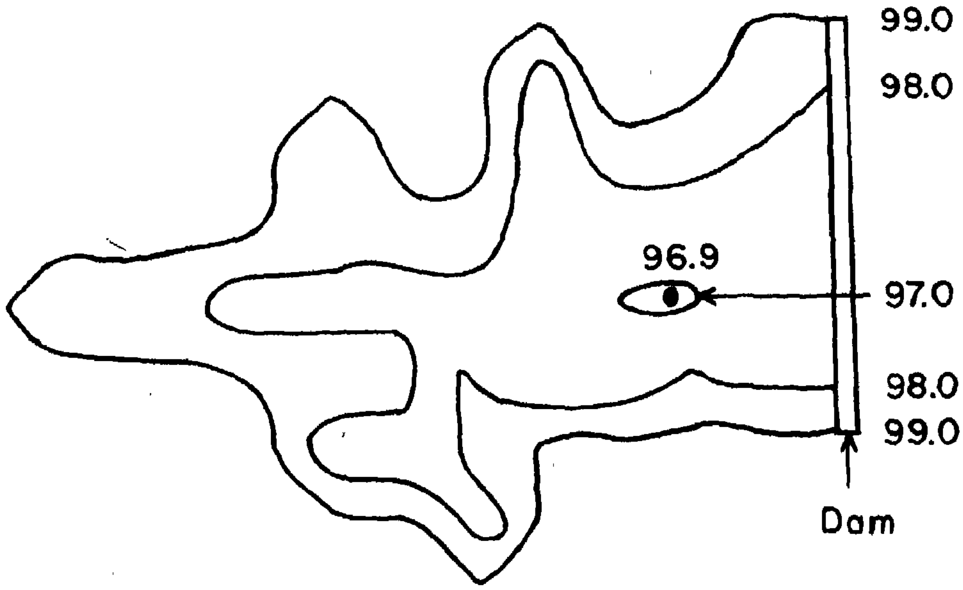


Fig. 4.10. Surface contours (m) of the reservoir ED 21

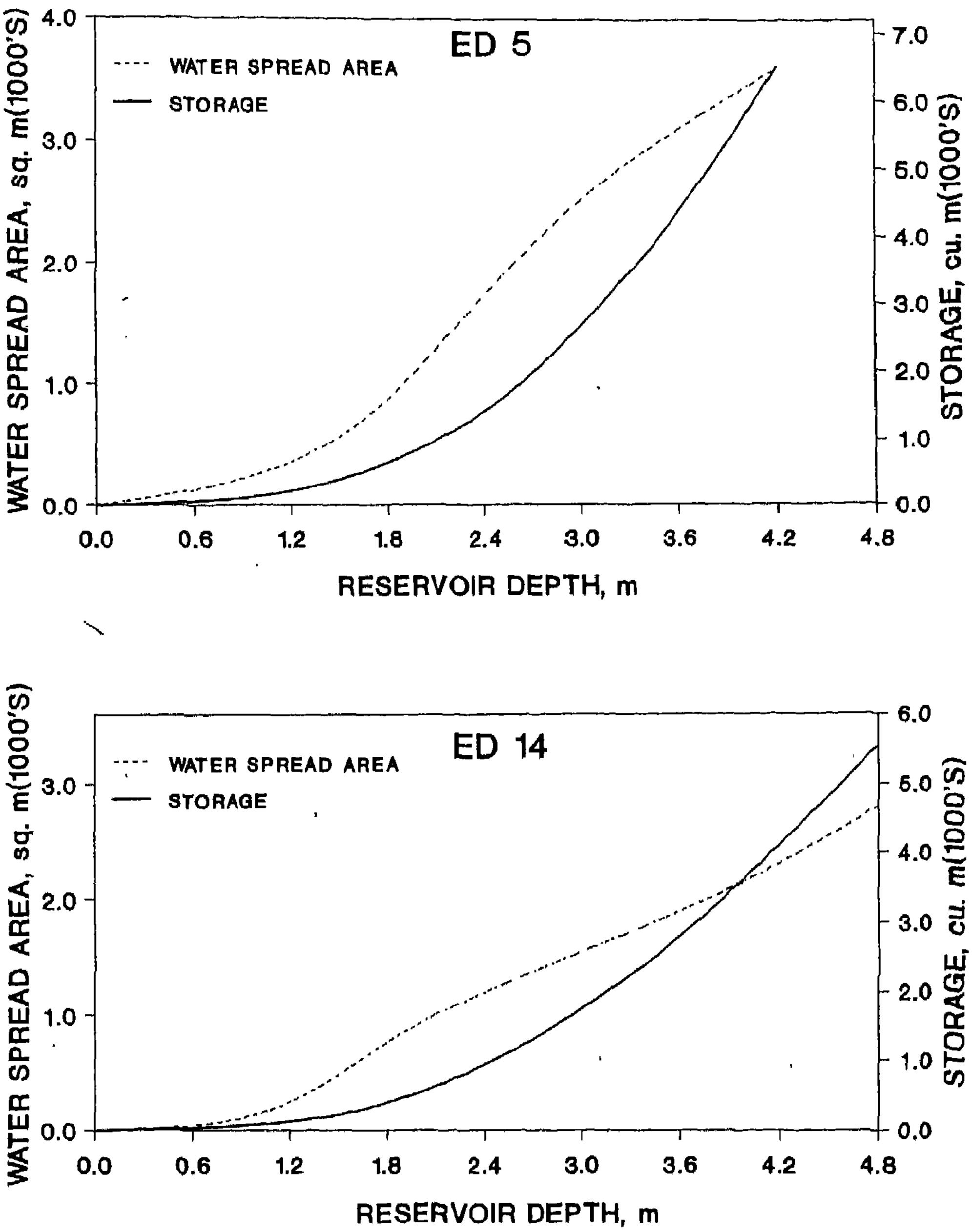


FIG. 4.11 DEPTH-WATER SPREAD AREA AND DEPTH-STORAGE RELATIONSHIPS FOR INDICATED RESERVOIRS

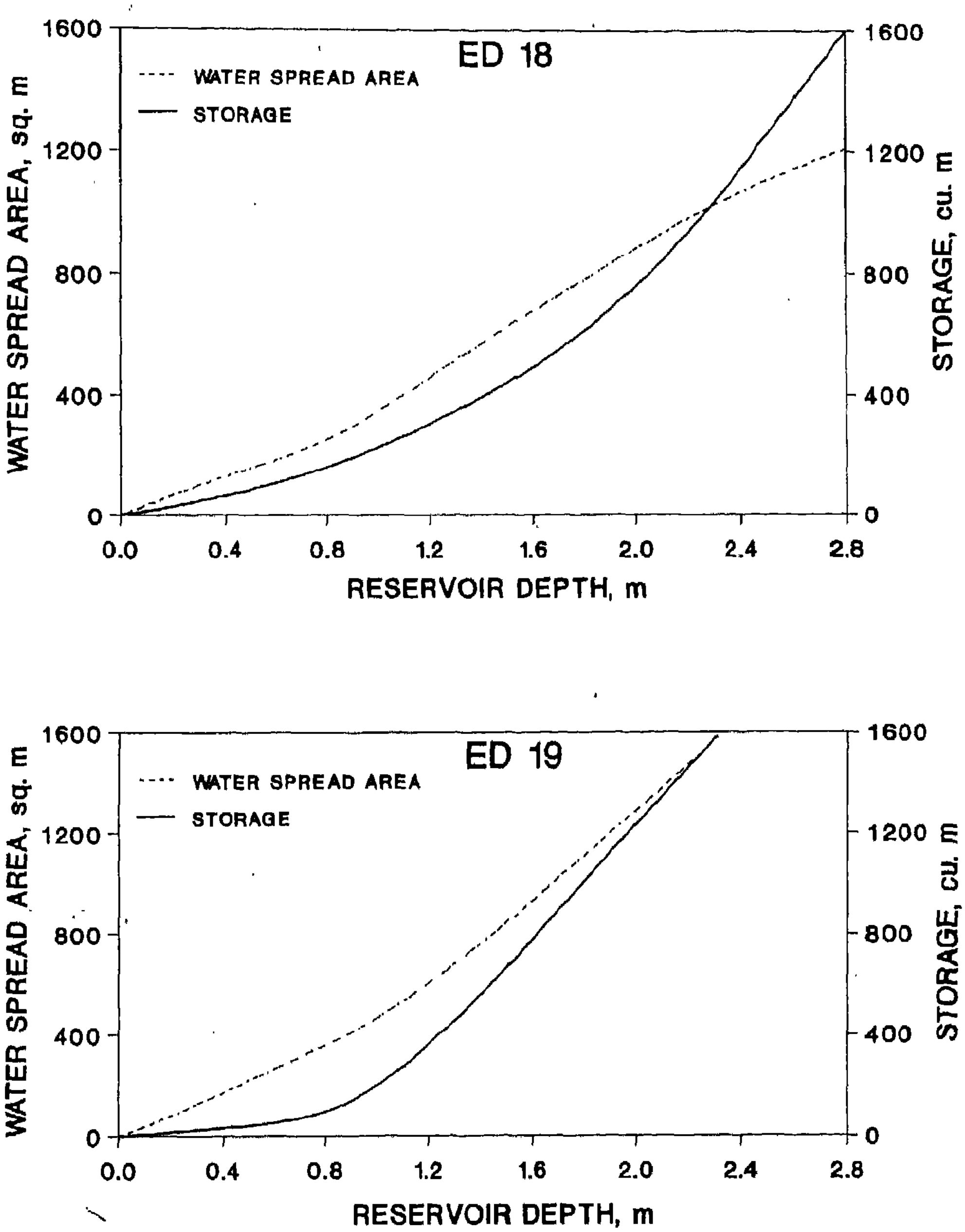


FIG. 4.12 DEPTH-WATER SPREAD AREA AND DEPTH-STORAGE RELATIONSHIPS FOR INDICATED RESERVOIRS

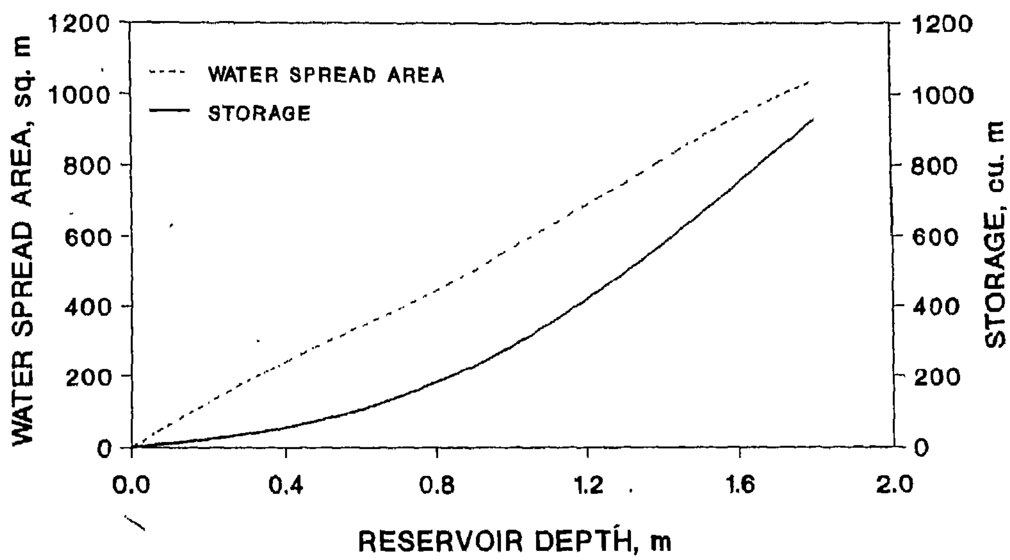


FIG. 4.13 DEPTH-WATER SPREAD AREA AND DEPTH-STORAGE RELATIONSHIPS FOR THE RESERVOIR ED 21

surface. Then, the level was taken at zero reading of the first gauge and the second gauge was fixed at 1000 mm above the first gauge zero level so that the water level at 1000 mm of first gauge touches the zero level of the second gauge as shown in Fig. 4.5. The initial water levels in ED 5, ED 14 and ED 19 were noted down. The other two i.e., ED 18 and ED 21 were dry at the time of instrumentation which was before the monsoon started.

4.3.7 Observation of runoff depth and water losses in the reservoirs

The runoff from selected microwatersheds was measured as accumulated water depth in their respective storage reservoirs with help of the installed gauges. The runoff water collected in the structures were measured immediately after the rainfall event took place on each day of observaton. During non-rainy period, the decline in the reservoir water level resulting from the seepage and evaporation losses were noted down in each of selected reservoirs at different depths on each day during the observation period (13^{th} June to 7^{th} July, 1992).

4.3.8 Pan evaporation data

As there was no pan evaporation data available from the nearby meteorological observatories, the data was taken from the literature (Ruthore and Biswas, 1988) for a nearby place called Konar which is 12 km away from study area. This data were required for model validation, calculation of PET of crops and the subsequent use of model with long term rainfall data. The data obtained was mean daily values over a month. The data are 7 mm/day for June, 5 mm/day for July, 4 mm/day for August and September and 3 mm/day for October and November months.

4.3.9 Collection of crop details and long term rainfall data

In order to study the availability and utilization of water yield in the study area, the information with respect to crop production, irrigation methods, cost of cultivation etc. were obtained from the direct interviews with the tribal farmers in the area. The long term seasonal daily rainfall data from 1972 to 1991 (20 years) was obtained from the Engineering Division, SCD, Hazaribagh.

4.4 SURFACE WATER YIELD MODEL (SWYMOD)

The surface water yield model developed in the study has the primary purpose of developing curve number for the prevalent land uses in the microwatersheds. The model uses the hydrologic soil cover complex method for calculating surface runoff and integrated with reservoir water budgetting to predict the water levels and its corresponding volumes both at start and at the end of the day. The model uses daily rainfall data, distribution of land use cover within microwatershed, curve number array as given in Table A.2 in Appendix A, the AMC condition of microwatershed and observed reservoir water depths. A flow chart indicating various operations in model is given in Fig. 4.14. The detailed programme of SWYMOD is given in Appendix B.

The various assumptions made in developing SWYMOD are given in section 3.1. The model operates in different runs, asking the user to enter curve numbers for AMC II condition and the distribution of land use cover as per cent of net area of microwatershed, by comparing the predicted and the observed storage depths of reservoir based on a test criterion. The test criterion used was the "Average absolute deviation" between the observed

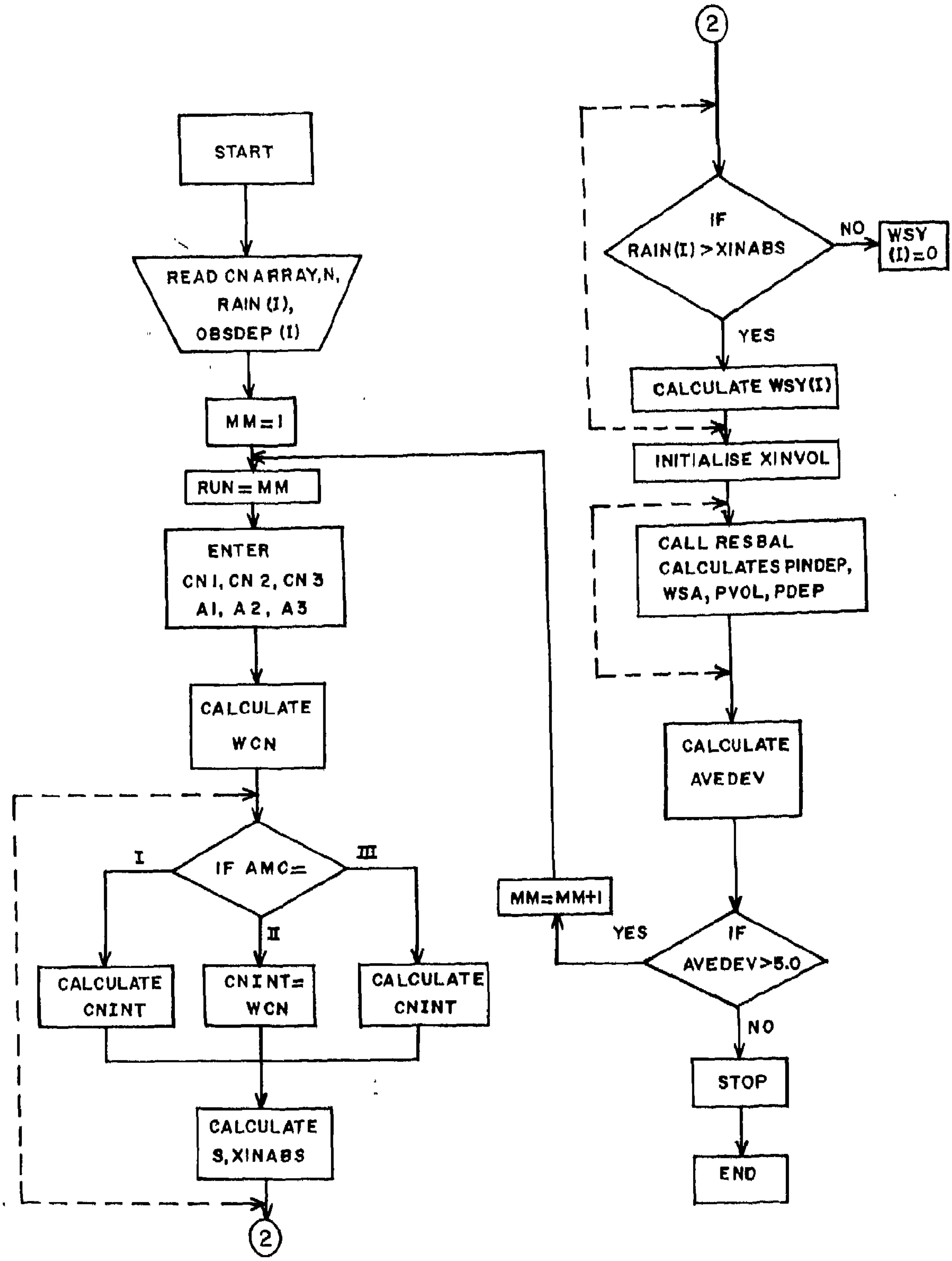


Fig.4.14. Flow chart showing different operations in SWYMOD

and the predicted water depths. A pre-assigned value called "tolerance limit" was fixed as 50 mm with which the value of average absolute deviation between the observed and predicted water depths was compared in each run of model operation. To achieve the above procedure, the model makes use of the subroutines COMPARE and RESBAL as part of main programme.

4.4.1 Subroutine COMPARE

The function of this subroutine is to convert the weighted curve number for AMC II to the corresponding value of AMC I and AMC III depending upon the moisture condition on the day of computation. The user, while operating the main programme (SWYMOD), selects curve number for the different land uses and finds a weighted average curve number WCN by weighting with area. This WCN is for AMC II condition. The main programme also identifies the actual AMC status on the day of computation. If the moisture status is as per AMC I or AMC III, then the information on WCN and AMC is transformed to the subroutine COMPARE. This subroutine then picks up the two consecutive curve numbers above and below WCN for AMC II and uses another subroutine INT to obtain the corresponding interpolated CN value for AMC I or AMC III as the case may be on the day of computation. This CN is named as CNINT, which is used for calculating the runoff in the main programme.

4.4.2 Subroutine RESBAL

The subroutine RESBAL (REServoir BALance) was developed to calculate storage water depths and corresponding storage volumes in the reservoir on a daily basis. In the process of above computation, the basic input to the RESBAL is daily runoff (WSY), net area of microwatershed

(WSHAR), initial volume of storage (XINVOL) and maximum capacity (PMAXVL) of the reservoir. The RESBAL inturn uses the subroutines VOLDEP, AREADEP and RESLOSS for water budgetting. The subroutines VOLDEP and AREADEP are used to simulate water depth and its corresponding water spread area through linear interpolation at different volumes and depth ranges respectively. The daily rates of the addition of storage (TRNVOL) is computed based on the following logical statements.

The volume of water in the storage structure (PVOL) of present time step calculated as follows :

(i) First, the volume of total runoff (TRNVOL (LL)) for the 24 hour preceeding the time LL is calculated

(ii) During the same period, the evaporation loss from the water surface is calculated as [EVAPO (LL)* APOND (LL)].

(iii) Seepage loss for the same period is calculated as [SEEP (LL) * APOND (LL)].

The subroutine RESLOSS (RESeivoir LOSSes) does the allocation of values for rate variables of SEEP and EVAPO at different depths, coming as output from VOLDEP subroutine. The water budgetting for each time step is done by the equation :

$$PVOL(LL) = TRNVOL(LL) - SEEP(LL) * APOND(LL) - EVAPO(LL) * APOND(LL) \quad ...(4.2)$$

The storage volume (PVOL) thus obtained is initialised for the next time step and added to the volume of runoff (RUNVOL) coming form microwatershed to get the total of volume of storage (TRNVOL) in the reservoir. This is checked for the spill for every time step by a decision switch. The depth calculations of PINDEP and PDEP are done through linear interpolation by the subroutine VOLDEP corresponding to the variable TRNVOL and PVOL respectively. Using the storage depth PINDEP, water spread areea (APOND) calculation is made by subroutine AREADEP and the values for SEEP and EVAPO are taken from subroutine RESLOSS (Fig. 4.15), which are again input to the next time step for computation of losses (ii) and (iii) described above.

The statistical parameter, average absolute deviation (AVEDEV) is computed between the observed water depths (OBSDEP) and the predicted water depths in the begining of the day (PINDEP) at each run of model. The tolerance limit for the average absolute deviation is fixed as 50 mm. Then the model is operated for different runs by entering different set of curve numbers for each land use till the AVEDEV lies below or equal to the pre-assigned tolerance limit in each run of model. Thus, the curve numbers are fixed for different land uses prevailing over the selected microwatersheds.

4.5 VALIDATION OF MODEL

Hydrologic model in simple term is a set of mathematical equations describing hydrologic processes in a given watershed or any physical system under consideration. As described elsewhere, the mathematical equations do not possess unique solution due to the implicit nature of the inputs to the equations.

Hence, the model developers are interested to test the accuracy of prediction of their models to decide upon its applicability and use.

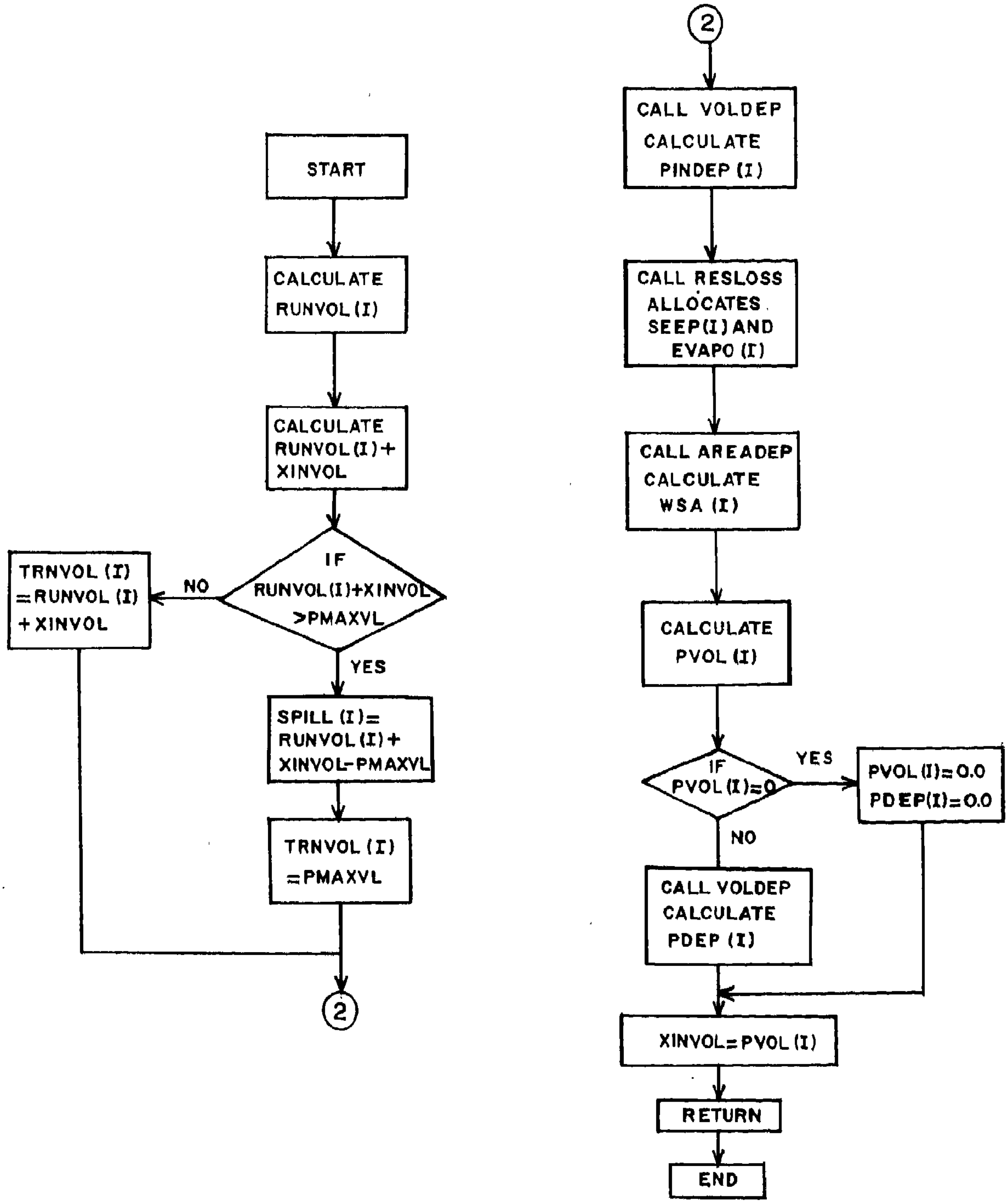


Fig.4.15. Flow chart showing different operations in subroutine RESBAL

Different workers have used different terms describing this process of testing. Thus, terms like calibration, verification and validation of models are commonly used. To avoid ambiguity, the author wishes to define these terms as given below :

Calibration is a trial and error process by which the logical sections of the model are tuned to represent the reality as closely as possible.

Verification is the process by which the model is tested further for its predictability in one location during a specific time period. This is performed by comparing the observed and the predicted series with or without statistical test.

Validation is the process by which the observed and predicted series are tested for their statistical acceptability over several locations and at all times.

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

(i) Calibration of the model for one site by changing the hydrological representation of the watershed through adopting various curve numerbs by trial and error.

(ii) Comparison between the observed and the predicted water levels in the reservoirs to verify the correctness of the chosen curve number of step (i).

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

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

It is necessary (but usually overlooked) 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. Considering that in the present case, the success of the model is to be judged by the closeness of agreement between the observed and the predicted reservoir water depths during the period 13th June to 7th July, 1992, the following parametric tests could be used :

(i) Testing the equality of variances of predicted and observed samples by using F-test.

(ii) Testing the equality of two means of above samples by using t-test.

(iii) Testing the agreement between two samples by paired t-test.

(iv) Testing of goodness of fit between observed and predicted series by Chi-square test.

However, there are certain limitations in using the parametric test. For example, in testing the equality of means and variances between two samples, the individual variations between any two pairs of values are ignored. In the paired t-test and the Chi-square test, the directional differences between the observed and the predicted series are ignored. Further, one of the important basic assumption in using the above tests is that the basic data are normally distributed and are independent to each other. With limited number of observations, it is difficult to reliably prove or disprove the normality of the data.

Moreover, in modelling as has been done in the present case, the treatment of the predicted and observed data as independent to each other is questionable, as the same causative factors are responsible for both. It is due to this reason that the use of non-parametric statistical tests are quite common in ascertaining the closeness of agreement between the observed and the predicted data series (Bhattacharya, 1977 and Selvarajan, 1990).

In non-parametric tests, many of the above shortcomings can be circumvented. A powerful test for related samples called "The Wilcoxon matched pairs signed ranks test" (Seigel, 1956) was used in the present study. This test considers both the magnitude and direction of deviations between the observed and the predicted reservoir water levels. In the present case, the observed and the predicted reservoir water levels are considered related as the same physical processes are involved in the rise and decline in water levels in the model as well as the real life situation (observed).

4.6 UTILIZATION OF WATER YIELD FOR CROP PRODUCTION

The methodology involves the assessment of water availability in the selected storage reservoirs to meet the soil moisture deficits for different crops like paddy, maize and pigeon pea, commonly grown as rainfed crops in the study area. The long term daily rainfall data were used to study the possible utilization of water yield for crop production. For studying the possibility of irrigation in rainfed agriculture, the rainfall data should be analysed at least on a weekly basis (Verma, 1987). Hence, the standard weeks from 23 to 44 covering the kharif season of crops were selected for analysis towards the assessment of water availability and deficits.

4.6.1 Assessment of water availability

The model (SWYMOD) developed in the present study was used to generate the information on storage volumes of reservoirs throughout the kharif season for 20 years. The model was operated individually over each selected microwatershed by taking the developed curve numbers for different land uses. The curve numbers are assumed to be constant through out the season as there was no historical runoff data available to know any changes in CN values with respect to time.

While applying the SWYMOD over the microwatersheds of MW 5 and MW 14, the model was modified to account for the spill volumes coming as inflow into the storage reservoirs ED 5 and ED 14. In the selected study area, ED 18, ED 19 and ED 21 are the upstream reservoirs to ED 5 and ED 14 lies just below the structure ED 5 as shown in Fig. 4.3. The structure ED 5 receives spill volumes from ED 18, ED 19 and ED 21 as inflow and ED 14 receives spill volume from ED 5. The modified SWYMOD was then called as SPMOD 5. In SPMOD 5, spill volumes coming from ED 18, ED 19 and ED 21 on a particular day of computation was treated as overland flow spreading over the entire area of 19.02 ha lying above ED 5 reservoir. This was assumed because there is no channel existing in the area of 19.02 ha because this total area was converted into agriculture land and hence the water flows as a sheet of water over the agricultural lands. To account for the losses in overland flow, the total spill volume of ED 18, ED 19 and ED 21 was multiplied with the runoff -rainfall ratio on the particular day of spill occurrence to obtain the actual spill volume contributing as inflow into the structure ED 5. Subsequently, the spill volumes from ED 5 were directly added to the runoff volume coming from the area contributing to ED 14 as it lies just below the structure ED 5. The computer programme of SPMOD 5 is given in Appendix C.

The storage volumes thus generated for the kharif season for 20 years were subjected to probability analysis by using Weibull's equation which is widely adopted for most of the practical purposes (Mutreja, 1990). The probability analysis was done by selecting minimum assured volume of water in the structure in different standard weeks for the 20 years. Thus, the availability of assured water in the selected reservoirs were estimated at 75% probability of exceedance in every standard week of the crop season.

4.6.2 Estimation of gross water deficits of different crops

In the selected site, the area available for cultivation is 19.02 ha in the microwatershed, MW 5. The commonly grown crops under rainfed farming are paddy, maize and pigeon pea. Hence, these crops were chosen to calculate the deficits on weekly basis by using water balance equation:

$$R + S_p = WR_0 + PET + PERCO \pm \Delta S \qquad ...(4.3)$$

Where,

	R	=	Rainfall, mm
	S_p	=	Absorbed spill depth, mm
	WR_0	=	Weighted runoff, mm
	PET	=	Potential evapotranspiration of crop, mm
	PERCO	=	Deep percolation, mm
and	ΔS	=	Surplus (+ve) or Deficit (-ve), mm.

Water deficits were calculated by using the above equation (4.3) on weekly basis for all the three crops selected. The weekly total of rainfall and runoff were obtained from the SPMOD 5 output. The potential evapotranspiration of crop was calculated by assuming that the total area is under crop selected for the total season by using the equation :

$$PET = K_c * K_p * E_p \quad ...(4.4)$$

Where,

K_c = Crop coefficient,

K_p = Pan coefficient,

and E_p = Pan evaporation, mm/day.

The crop coefficient for paddy was taken as 1.10 and the pan coefficient as 0.7 (Michael, 1978). The crop coefficents for maize and pigeon pea at different growth periods were obtained from FAO Manual (Crichley and Siegert, 1991) and the Division of Agronomy, IARI (Anonymous, 1993) respectively. The values are given in the Table D.1 in Appendix D. The pan evaporation data as given in sub-section 4.3.7 were used in calculating PET. Also, deep percolation of 7 mm/day was used for sandy loam soils under paddy cultivation (Vamadevan, 1978).

The deficits were first calculated for paddy and subsequently subjected to probability analysis to estimate the deficits in different weeks at 75 % probability of exceedance. Similarly, deficits for maize and pigeon pea were obtained on weekly basis by excluding the deep percolation component as the maize and pigeon pea do not need standing water as in the case of paddy. A sample sheet showing calculation of water deficits for paddy is given in Table F.2 in Appendix F.

After estimating the deficits in each week, the gross deficits were calculated by dividing the deficits with irrigation application efficiency of 65 % in sandy loam soils (Hukkeri and Pandey, 1977). The gross deficits of crops thus calculated on weekly basis at 75% probability level were matched with total water availability in the storage structures.

4.6.3 Estimation of maximum crop returns

Based on the information available on crop production, cost of product and cultivation and the gross deficits in different weeks of crop season (kharif), the maximum crop return was estimated by using the Linear Programming (LP) model formulated as

Objective function

$$\text{Maximize } Z = \sum_{j=1}^{4} C_j X_j \qquad \text{...(4.5)}$$

subjected to,

$$\sum_{i=1}^{17} \sum_{j=1}^{4} a_{ij} X_j \leq 19.02 \qquad \text{...(4.6)}$$

$$\sum_{i=1}^{17} \sum_{j=1}^{4} D_{ij} X_j \leq V_i \qquad \text{...(4.7)}$$

$$X_j \geqslant 0 \qquad \text{... (4.8)}$$

where,

Z	=	Maximum net crop return, Rs.
C_j	=	Return net of cultivation cost (in which irrigation cost was not included) of j^{th} crop, Rs./ha
X_j	=	J^{th} crop activity, (j = 1 for paddy, j = 2 for maize, j = 3 for pigeon pea and j = 4 for rainfed crop).
a_{ij}	=	Land required per unit of j^{th} crop activity, ha
D_{ij}	=	Gross deficit of j^{th} crop in i^{th} week, mm
V_i	=	Total water availability in i^{th} week, ha mm.
i	=	28^{th} to 40^{th} week i.e., 1 to 13 for paddy
	=	25^{th} to 39^{th} week i.e., 1 to 15 for maize
	=	25^{th} to 41^{st} week i.e., 1 to 17 for pigeon pea.

In the above formulation, the rainfed crop is taken as little millet with local name Gundli in project area. The above LP model was used for two optimal crop plans. One was imposing no restriction on any of 4 crop activities selected and second was with restriction on paddy to an extent of 2.83 ha area. The optimal crop plans were obtained with their maximum net crop returns. For these two optimal crop plans, the economic feasibility of irrigation in the project area for different amortization periods was worked out based on the current market prices of the inputs and the produce.

CHAPTER V

RESULTS AND DISCUSSION

5.1 GENERAL

The present study reported in this dissertation consists of two parts. In the first part, the surface water yield model (SWYMOD) as explained in section 4.4 was validated individually over the selected five microwatersheds. In the second part, 20 years of daily rainfall data in the kharif season (3rd June to 4th November) was used and the model was run to generate the information on water availability from the selected microwatersheds. Further, the possible utilization of runoff stored in small reservoirs by using it for irrigating the commonly grown crops in the project site was also investigated.

5.2 PRELIMINARY INVESTIGATIONS

In order to accomplish the above objectives, certain preliminary studies were done. These were : establishment of graphical relationship between reservoir water spread area and storage volume as functions of storage depth; establishment of reservoir losses due to seepage and evaporation as functions of storage depth and establishment of a test criteria in the form of "tolerance limit" of the reservoir water level to be used for model validation purpose. These three aspects are described first in the following three sub-sections.

5.2.1 Reservoir depth - water spread area and storage relationships

The depth - water spread area and storage relationships were obtained for different selected reservoirs in the study area by undertaking reservoir capacity survey. These relationships were developed as the catchment model was integrated with the water budgetting in the reservoirs. Hence, it was necessary to update the water spread area with respect to the depth of storage as a consequence to the combined effect of runoff, seepage loss and evaporation loss. Initially, regression analyses were done to fit the data on water spread area and storage volume at different depths, separately for the five reservoirs and the relationship obtained were of the general form :

$$WSA \text{ or } ST = a\, d^{b} \qquad ...(5.1)$$

where,	WSA	=	Water spread area, sq. m
	ST	=	Storage volume, cu. m
	d	=	Depth of storage, m
and	a, b	=	constants.

The different equations obtained for the five reservoirs are presented in Table D.2 in Appendix D. Though, the r^2 values were high for both the water spread area and storage relationships in all the reservoirs, it is seen from the Appendix D that the average absolute deviation between the measured and the calculated water spread area and storage volume varies from 6.2 to 33.6 per cent and 0.9 to 21.1 per cent respectively. Such errors in determining water spread area lead to incorrect estimates of the storage volume which is primary input to the water budgetting equation 4.1 at each time step.

To overcome the above difficulty in using such regression equations developed with limited data points, the linear interpolation approach was used for estimating water spread area and storage volume at a given storage depth. Also, it can be seen from the Table D.2 in Appendix D, the adoption of linear interpolation technique in estimating the water spread area and storage volumes has drastically reduced the average absolute deviation between measured and calculated values when compared to the estimation by the use of regression equations. Two subroutines namely VOLDEP and AREADEP were developed and used, respectively, for estimating the depth of storage corresponding to a given inflow volume and estimating the waterspread area corresponding to the depth of storage using linear interpolation approach.

5.2.2 Reservoir depth - water losses

Water losses in the reservoir include both seepage through wetted surface and evaporation from the water surface as rate variables. Seepage loss in the reservoir depends on the soil type, its hydraulic poperties and the hydraulic head of water available in the reservoir whereas evaporation loss depends on the areal extent of water surface exposed to the atmosphere. Though, pan evaporation data could be obtained for a nearby area of project site as given in Chapter IV, the data on type of soil and its hydraulic properties were not available with the SCD, Hazaribagh. This necessiated analyses of the reservoir soil samples for knowing the textural composition and to study the infiltration characteristics of the soils in the selected reservoirs.

The mechanical analysis of reservoir soil samles done in the soil science laboratory of SCD, Hazaribagh indicated that the soils belonged to the sandy loam type with major constituent of sand, varying from 53.7 to 68.3 per cent. (Table 5.1). The soil analysis gave an indication that the soils of ED 5 and ED 14 were similar and the soils of ED 18, ED 19 and ED 21 were similar though, between these two groups, there was difference. Hence, the seepage losses of these two groups are also expected to be different. Accordingly, infillration test was conducted in the reservoirs ED 5 and ED 18 as representative soils for the two groups. The basic infillration rates obtained were 6 mm/hr and 10 mm/hr for ED 5 and ED 14 respectively (Fig. 5.1 and Fig. 5.2). These values correspond to 144 mm/day and 240 mm/day respectively.

Table 5.1 Textural compositon of reservoir soils

Reservoir identification	Reservoir soil texture		
	Sand (%)	Silt (%)	Clay (%)
ED 5	55.0	17.5	27.5
ED 14	53.7	22.9	23.4
ED 18	68.3	13.3	18.4
ED 19	65.6	14.8	19.6
ED 21	64.2	16.3	19.5

However, to ascertain the agreement between the basic infillration rate and the actual reservoir seepage loss, observation on the decline of water depth in the selected reservoirs were made durig non-rainy days within the observation period from 13^{th} June to 7^{th} July, 1992. Before monsoon started, the initial water levels in the reservoirs ED 5, ED 14 and ED 19 were recorded as 1.75 m, 2.0 m and 0.4 m respectively. The other two reservoirs were dry. The maximum water depths of runoff accumulation recorded were 2.025 m, 2.125 m, 0.625 m, 1.125 m and 0.6 m and the recorded water losses at these depths were 25 mm/day,

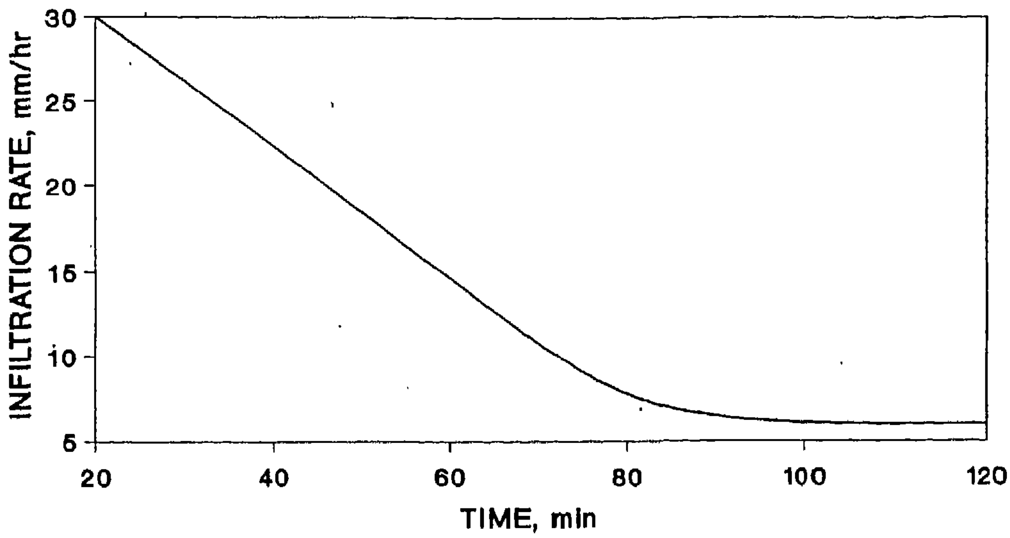


FIG. 5.1 INFILTRATION CURVE FOR THE SOIL OF RESERVOIR ED 5

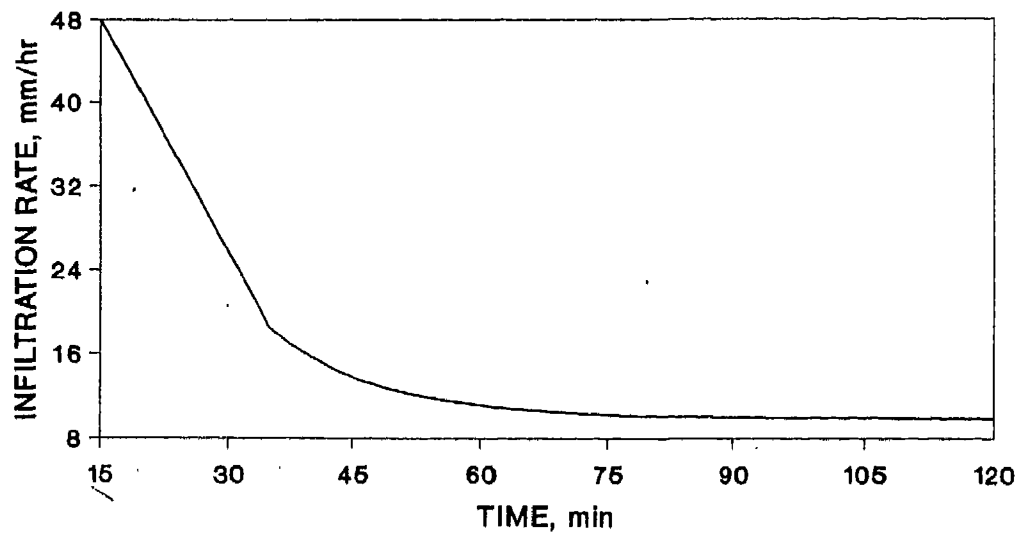


FIG. 5.2 INFILTRARTION CURVE FOR THE SOIL OF RESERVOIR ED 18

25 mm/day, 150 mm/day, 150 mm/day and 175 mm/day in the reservoirs ED 5, ED 14, ED 18, ED 19 and ED 21 respectively. Though the constant rate of water loss of 25 mm/day was obseved at the water storage depth ≤ 2.025 m and ≤ 2.125 m in the reservoirs ED 5 and Ed 14, the rate of water loss varied from 25 to 175 mm/day at the water depths of ≤ 0.625 m, ≤ 1.125 m and ≤ 0.6 m in the reservoirs of ED 18, ED 19 and ED 21 respectively. A comparison of above water losses with the basic infiltration rate reveals that the former are lower than the latter and one may infer that assumption of basic infillration rate as seepage loss in the reservoirs would give erroneous results during water budgetting calculations.

Under the circumstances, it was decided to rely more on a few information on the claculated reservoir loss based on the recorded data of water table decline during non-rainy days. Since such observations were limited in number, the reservoir loss corresponding to the storage depths falling between any two recorded depths was taken as the average of the losses observed for the upper and the lower value of the recorded depths. When depth of storage occured between the upper most recorded depth and the spill level, the reservoir loss was assumed to take place at the rate computed corresponding to the upper most recorded depth. When the storage depth occured between the lower most recorded depth and zero (the reservoir dry), the reservoir loss was assumed to take place at a rate computed corresponding to the lower most recorded depth. The quantitative aspects of the above discussion is summarised in Table 5.2 with respect to each of the five selected microwatersheds. The information given in Table 5.2 were useful in estimating the reservoir losses during the operation of the model SWYMOD with long term rainfall data, when the

Table 5.2 Observed water losses in the reservoirs and their projected values for different ranges of storage depths

Reservoir identification	Depth of storage (m)	Observed seepage + Evaporation loss (mm/day)	Range of storage depth (d) (m)	Assumed seepage + evaporation for the indicated depth range (mm/day)
ED 5	≤ 2.025	25.0	0 < d ≤ 2.5	25.0
	3.4	75.0	2.5 < d ≤ 3.4	50.0*
	4.3	125.0	3.4 < d ≤ 4.3	100.0*
ED 14	≤ 2.125	25.0	0 < d ≤ 2.5	25.0
	3.7	75.0	2.5 < d ≤ 3.7	50.0*
	4.8	125.0	3.7 < d ≤ 4.8	100.0*
ED 18	≤ 0.3	25.0	0 < d ≤ 0.3	25.0
	0.475	100.0	0.3 < d ≤ 0.475	62.5
	0.625	150.0	0.475 < d ≤ 0.625	125.0
			0.625 < d ≤ 2.8	125.0*
ED 19	≤ 0.35	0.0		
	0.40	25.0	0 < d ≤ 0.4	12.5
	0.925	100.0	0.4 < d ≤ 0.925	62.5
	1.125	150.0	0.925 < d ≤ 1.125	125.0
			1.125 < d ≤ 2.3	125.0*
ED 21	≤ 0.075	25.0	0 < d ≤ 0.125	37.5
	0.125	50.0	0.125 < d ≤ 0.325	62.5
	0.325	75.0	0.325 < d ≤ 0.600	125.0
	0.600	175.0	0.600 < d ≤ 1.800	125.0*

Note : The values marked with * are the extended values from the observed depths to spill level of storage for the later use of SWYMOD with long term daily rainfall data.

computed reservoir water levels varied over a much wider range than were observed during the field data collection in the monsoon of 1992.

The reservoir water losses discussed above include both seepage and evaporation components. The reservoir water budgetting requires both seepage and evaporation losses separately as rate variables corresponding to the depth of storage resulting from a given inflow of runoff into the reservoir. To accomplish this, a separate subroutine RESLOSS was developed. The subroutine RESLOSS supplies both seepage and evaporation as inputs to water budgetting on each time step of computation. The pan evaporation values obtained for a nearby area were used to separate seepage loss.

5.2.3 Tolerance limit of reservoir storage depth for model validation

The test criterion used in the model to develop curve numbers for prevalent land uses in the microwatersheds of project site, was the statistial parameter, average absolute deviation. This is calculated between the observed (OBSDEP) and the predicted (PINDEP) water levels of accumulated runoff in the storage reservoirs in each run of the model. The model operates in various runs for each set of selected curve numbers for the forest (CN1), agricultural land (CN2) and bare land (CN3) conditions and their corresponding per cent areas A1, A2 and A3 respectively (Fig. 4.14). If the average absolute deviation between the observed and predicted strorage depths is more than a pre-assigned value, called tolerance limit, the model picks up another set of curve numbers. This process continues till the average absolute deviation becomes equal to or less than the tolerance limit.

Thus, it was necessary to analyse the practical implication of variations in volume of water at the selected tolerance limits at different depths of storage. The tolerance limits of the predicted storage depths chosen for this analysis were 10, 50, 100 mm. Accordingly, the possible variation in volume of water were obtained from depth - storage relationships of reservoirs for the chosen tolerance limits at lower, middle and maximum (spill level) water levels of the reservoirs as presented in Table 5.3. The analysis presented in Table 5.3 reveals that the per cent variation of volume increased at lower depths for all the tolerance limits and in general, varied from 0.5 to 5 per cent, 2.3 to 14.5 per cent and 4.5 to 50 per cent at 10, 50 and 100 mm tolerance limits respectively. However, the per cent variation in volume of storage at higher depths is more important in terms of practical utility of runoff for irrigation.

Therefore, to study the practical implications of tolerance limits in terms of area reduction in irrigation, the maximum variations in volume of water were further analysed. The maximum variations in volume of water were obtained in ED 5, varying from 35 to 380 cu.m at the spill level as the tolerance limit increased and the minimum variations in volume of water were observed in reservoir ED 21, varying from 1 to 10 cu.m at 0.2 m storage depth as tolerance limit increased (Table 5.3). Two crops of paddy and maize/pigeon pea were considered with applicaton rates of irrigation 5 cm and 2 cm respectively at any time of irrigation.

The per cent area reductions were calculated for maximum variations of volume of water at selected tolerance limits for both paddy and maize/pigeon pea crops. The results obtained were : 0.1, 2.0, 4.0 per cent area reductions in irrigation for paddy and 0.9, 5.0, 10.0 per cent area

Table 5.3 Maximum deviation in estimated storage volume at different tolerance limits on model predicted depth of storage

Reservoir identification	Water depth	Actual storage	Maximum deviation in predicted storage volume (cu. m and %) for the following tolerance limits (mm) of predicted storage depth					
			10		50		100	
	(m)	(cu. m)	(cu. m)	(%) of actual	(cu. m)	(%) of actual	(cu. m)	(%) of actual
ED 5	2.3	1180.0	14.0	1.2	70.0	5.9	140.0	11.9
	3.3	3360.0	26.0	0.8	130.0	3.9	260.0	7.7
	4.3	6510.0	35.0	0.5	190.0	2.9	380.0	5.8
ED 14	2.4	900.0	10.0	1.1	50.0	5.6	100.0	11.1
	3.6	2760.0	17.0	0.6	85.0	3.1	170.0	6.2
	4.8	5550.0	25.0	0.5	125.0	2.3	250.0	4.5
ED 18	0.4	62.0	2.0	3.2	9.0	14.5	17.0	27.4
	1.4	392.0	5.0	1.3	22.0	5.6	44.0	11.2
	2.8	1600.0	12.0	0.8	60.0	3.8	120.0	7.5
ED 19	0.3	30.0	1.0	3.3	4.0	13.3	10.0	33.3
	1.3	450.0	10.0	2.2	35.0	7.8	100.0	22.2
	2.3	1580.0	12.0	0.8	60.0	3.8	120.0	7.6
ED 21	0.2	20.0	1.0	5.0	2.0	10.0	10.0	50.0
	1.0	272.0	3.0	1.1	22.0	8.1	48.0	17.6
	1.8	930.0	10.0	1.1	47.0	5.1	90.0	9.7

reductions for maize/pigeon pea at 10, 50 and 100 mm tolerance limits respectively (Table 5.4). Though a tolerance limit of 10 mm is seen to result in more accuracy with < 1 per cent area reduction in irrigation, it is very difficult to achieve in hydrologic predictions of such real life situations. A tolerance limit of 100 mm resulted in between 4 to 10 per cent area reduction which is more when compared to per cent area reductions with 50 mm tolerance limit. Hence, a tolerance limit of 50 mm was considered as a compromise between the other two for model validation.

Table 5.4. Maximum reduction in the irrigated area at three tolerance limits of predicted reservoir water depth (vide Table 5.3).

Tolerance limit (mm)	Max. volume reduction (cu.m)	Reduction in irrigated area (ha)	
		Paddy *@ 5 cm per application	Maize/pigeon pea *@ 2 cm per application
10	35.0	0.02 (0.1)	0.18 (0.9)
50	190.0	0.38 (2.0)	0.95 (5.0)
100	380.0	0.76 (4.0)	1.90 (10.0)

Note : (1) The values within the parentheses are percentiles of total area of 19.02 ha available for agriculture in microwatersheds

(2) *Assumed application rates.

5.3 MODEL VALIDATION

5.3.1 Development of curve numbers for prevalent land uses in microwatersheds of Upper Damodar Valley

The basic flow chart to develop curve numbers for the three prevalent land uses of the selected microwatersheds has been shown in Fig. 4.14. In the selected microwatersheds namely MW 5, MW 14, MW 18, MW 19 and MW 21, the major land use characteistics were forest, agricultural land and bare land. However, microwatersheds MW 18, MW 19 and MW 21 were basically forest watersheds. A major portion (85.4 %) of MW 5 was agricultural land. MW 14 includes all the other microwatersheds. The detailed break-up of the microwatersheds according to land uses have already been given in Table 4.1.

The model SWYMOD provides an user interface to select a set of curve umbers in each run of model operation. A run implies : First, weighted curve number (WCN) over total area of watershed is calculated for a given set of curve numbers for different land uses and its interpolated curve number (CNINT) for a particular AMC of microwatershed is used for calculating runoff; the runoff depths for all the measured daily rainfall events and the corresponding storage depths in the reservoir are computed; the average absolute deviation between observed and predicted reservoir water levels is determined; and the average absolute deviation is then checked with a pre-assigned value called tolerance limit. The model operates in different runs till the average absolute deviation becomes equal to or less than a tolerance limit. This sequence of operation provides an idea to the user whether to increase or decrease the curve number for the next run of the model.

The model was first verified on microwatershed MW 21 which has 100 per cent forest. The verification of the model was done for the data obtained during the observation period from 13th June to 7th July, 1992 in all the microwatersheds. The detailed programme is given in Appendix C. In MW 21, the model was verified by selecting curve numbers starting from 80 and increasing with an increment of 5 in each run of the model. In this case, the curve number for agricultural land and bare land were assigned to zero as there were nil area under these two land uses. It was found that a CN1 of 90, resulted in the average absolute deviation between the observed and predicted reservoir water levels to be 40.5 mm, which was below the pre-asigned tolerance limit of 50 mm. In an attempt to refine the estimate further, smaller increment of CN1 (forest) were tried out in the vicinity of 90 and a CN1 of 91.2 resulted in the minimum average absolute deviation of 38.0 mm. A sample output of model is given in Appendix F for the microwatershed MW 21.

Similar procedure was used in developing curve numbers for agricultural land (CN2) and bare land (CN3) in watersheds of MW 5 and MW 19, respectively. In developing curve number, CN3 on MW 19, a set of curve numbers for forest (CN1) and bare land (CN3) with the values starting from CN1 equal to 80 and CN3 equal to 85 were selected. It may be noted that though for MW 21 (100 % forest), the most appropriate CN1 was worked out to be 91.2, yet for the forest portion of MW 19, the same value was not adopted. This was because, in MW 21, the land under the forest was gullied, indicating a higher runoff potential. Hence in MW 19, even for the forest portion of watershed, the process of fitting curve number was repeated, starting from an initial value of 80. The starting curve number for the bare land was fixed at a higher value than that of the forest portion of the watershed as the former obviously has a higher runoff potential. Various trial runs in the case of MW 19 resulted in a curve number of 90.5 for the forest portion and 94.5 for the bare land. With this combination, the average absolute deviation between the observed and predicted reservoir water levels was found to be 45.3 mm which was within the pre-assigned tolerance limit. No further refinement in CN was possible in this case.

While developing curve number (CN2) for agricultural land with ploughed hydrologic conditon in MW 5, the curve number (CN1) for forest and the curve number (CN3) for bare land were fixed as determined corresponding to the minimum average absolute deviation in MW 21 and MW 19. Successive runs were made with incremental CN2 values for agricultural land as 60, 65, 70, 75 and 80. Noting the trend of result, further refinement was done by selecting curve number (CN2) in the vicinity of 80 and a minimum average absolute deviatin of 10.6 mm was obtained corresponding to a CN2 of 79.3 for the agricultural portion of the watershed MW 5.

In the microwatershed MW 18, the existing land uses were forest (91.7 %) and bare land (8.3 %). The curve numbers CN1 of 91.2 for forest and CN3 of 94.5 for bare land were used in the verification of model on MW 18. The corresponding minimum average absolute deviation in MW 18 was 33.4 mm. Similarly, CN1 of 91.2 for forest was used in the verification of model on microwatershed MW 14 and the minimum average absolute deviation obtained was 35.2 mm.

All the above mentioned curve numbers pertain to AMC II Conditon. On any particular day, if a different AMC condition prevailed, the weighted curve number (WCN) of AMC II for selected values of CN1, CN2 and CN3 as per the land use of particular microwatershed, was converted to the prevailing AMC condition in the programme by refering to the Table A.2 given in Appendix A.

All the results pertaining to the developement of curve numbers for the prevalent land uses of microwatersheds are summarised in Table 5.5. It is seen from this table that the area under forest land use behaves identically in all the microwatersheds with the obtained curve numbers ranging from 90.5 to 91.2. However, though the soils in the sub-watershed 8/5 were classified under hydrologic soil group B (Anonymous, 1984) indicating moderate runoff potential in the watershed, the higher curve numbers obtained for forest (90.5 to 91.2), agriculture land (79.3) and bare land (94.5) indicate the higher potential of runoff in the selected microwatersheds of 8/5. This is due to the fact that watershed response to rainfall depends on surface condition of soil, its infiltration characteristics and drainage pattern within watershed. As observed by the author in the selected microwatersheds during his data collection, the soils with forest land use were found to be compacted and had gully formations of 2 m deep within microwatershed. The gullies within the watershed will act as stream channels to carry runoff into the storage structure provided at the outlet of microwatersheds. Hence, the morphological parameter called drainage density was calculated by actual field measurements for all microwatersheds and are presented in Table 5.6. The Table 5.6 shows high drainage density in forest dominated microwatesheds of MW 18,

Table 5.5 Developed curve numbers for prevalent land uses in microwatersheds for AMC II condition.

Micro watershed identification	Land use	Individual curve numbers	Weighted curve number of watershed	Minimum average absolute deviation (mm)
MW 5	Forest	91.2		
	Agriculture	79.3	81.2	10.6
	Bare land	94.5		
MW 14	Forest	91.2	91.2	35.2
MW 18	Forest	91.2	91.5	33.4
	Bare land	94.5		
MW 19	Forest	90.5	90.6	45.3
	Bare land	94.5		
MW 21	Forest	91.2	91.2	38.0

MW 19 and MW 21 with the values 15.8 km^{-1}, 13.5 km^{-1} and 16.2 km^{-1}, respectively.

More drainage density indicates more runoff accumulation in storage structures after fulfilling the requirement of initial abstraction of watershed. Hence, this emphasizes the need to develop curve numbers for different land uses even in approximately similar watersheds due to varying local hydrologic soil conditions and type of vegetation which affect the hydrologic response of watershed to produce runoff.

Table 5.6 Drainage density and slope of microwatersheds

Microwatershed identification	Drainage density (km^{-1})	Average land slope (%)
MW 5	5.2	3.0
MW 14	5.3	3.0
MW 18	15.8	2.0
MW 19	13.5	4.0
MW 21	16.2	4.5

5.3.2 Comparison of observed and predicted water levels

In the preceding sub-section, the fixing of curve numbers for prevalent land uses of forest, agricultural land and bare land in selected microwatersheds was discussed. The criterion for this was to achieve minimum possible average absolute deviation between observed and predicted water levels under the maximum pre-assigned tolerance limit of 50 mm. The graphical presentation of the above subject is discussed in the present sub-section.

As mentioned earlier, the fixing of an appropriate curve number was done through trial and error precedure wherein in each trial, a set of curve numbers were selected corresponding to the different land uses of the microwatersheds. A sample sheet of the behaviour of the predicted reservoir water levels for the reservoir ED 21 whose microwatershed was under 100 per cent forest cover is shown in Fig. 5.3. The figure indicates that the overall concept of the use of hydrologic soil cover complex method

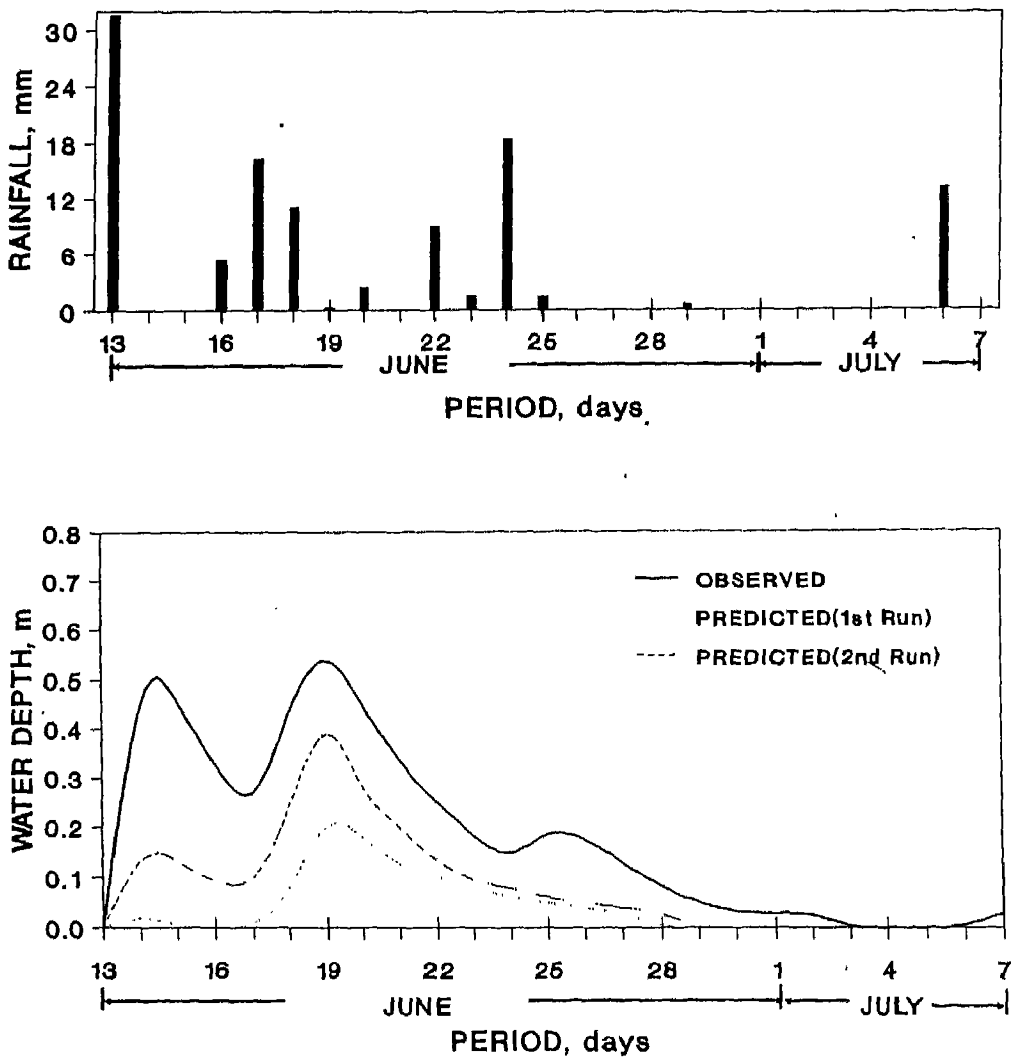


FIG. 5.3 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS IN TWO TRIAL RUNS OF MODEL SWYMOD FOR MW 21.

YEAR:1992

is justified as the responses of the predicted water levels are following the same trend as that of the observed water levels. In the actual programme of SWYMOD, this comparison was performed by the use of criteria of average absolute deviation between the observed and the predicted reservoir water levels, the details of which have already been discussed. Therefore, for ED 21, as well as for other four reservoirs, no further graphical comparison was done.

The final output corresponding to the fitted curve numbers, which resulted in minimum average absolute deviation between the observed and the predicted reservoir water levels are shown in Figures 5.4 through 5.8. In these figures, the observed reservoir water levels as well as the input rainfall have been shown. From these five figures, the agreement between the observed and predicted reservoir water levels is found to be satisfactory. These figures also show the closeness of the agreement with respect to : both trend in rise and decline of reservoir water depth, the number of rises and the extent of rise. The latter two features further signifies the sensitivity of the adopted approach in reproducing the effecft of input variable of rainfall and the assumed initial abstraction (XINABS) which was taken as XINABS = 0.2 S. As S can be seen from the sub-section 3.1.1 of chapter III (Equation 3.12), the model algorithem calculates the value of potential maximum retention (S) for every interpolated curve number (CNINT) of WCN of selected set of curve numbers and then calculates the initial abstraction (XINABS) as XINABS = 0.2 S. This initial abstraction is being checked against the actual rainfall on a particular day and the model decides whether there will be an occurrence of runoff or not. If there is a rainfall and if rain > XINABS, the quantity of rainfall

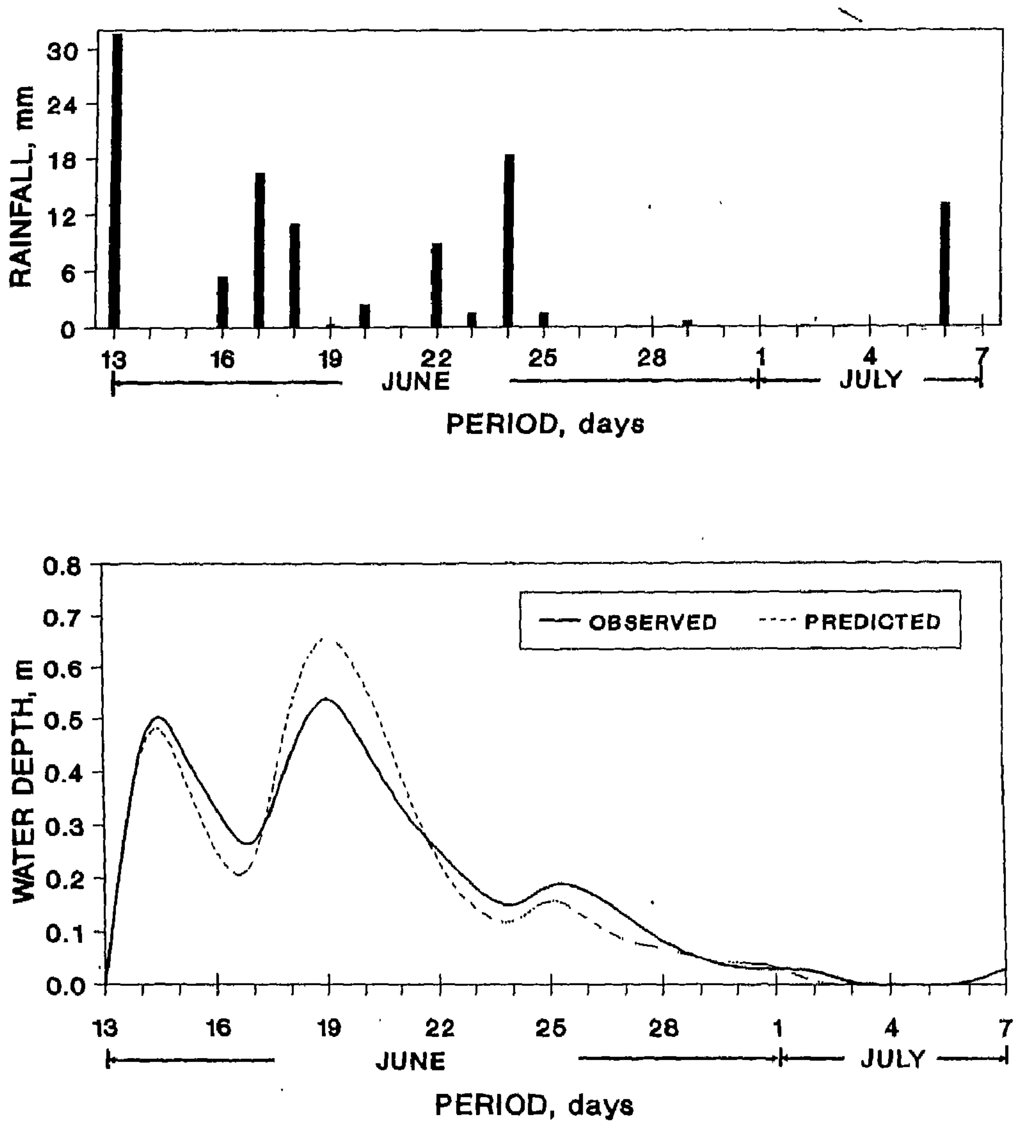


FIG. 5.4 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS FOR ED 21

YEAR:1992

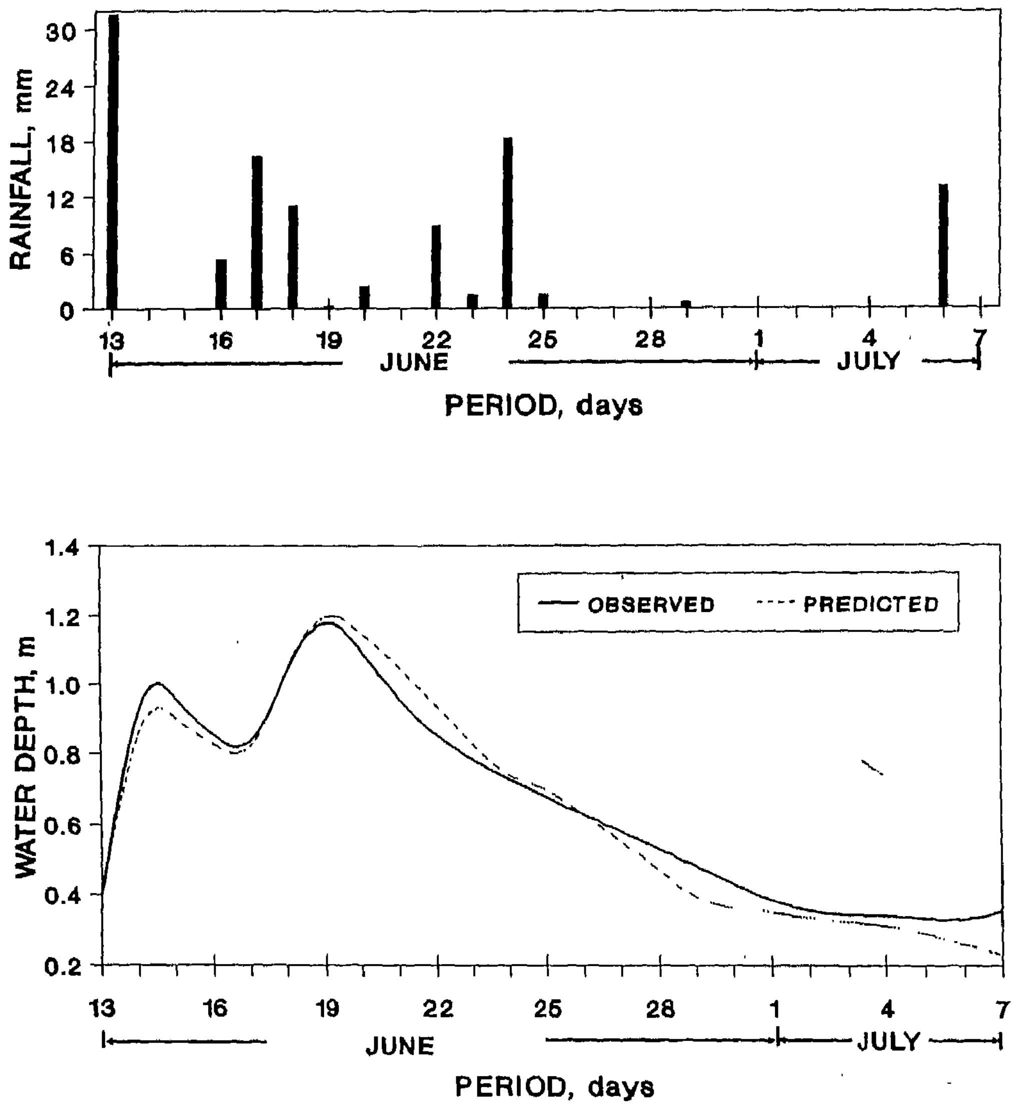


FIG. 5.5 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS FOR ED 19

YEAR:1992

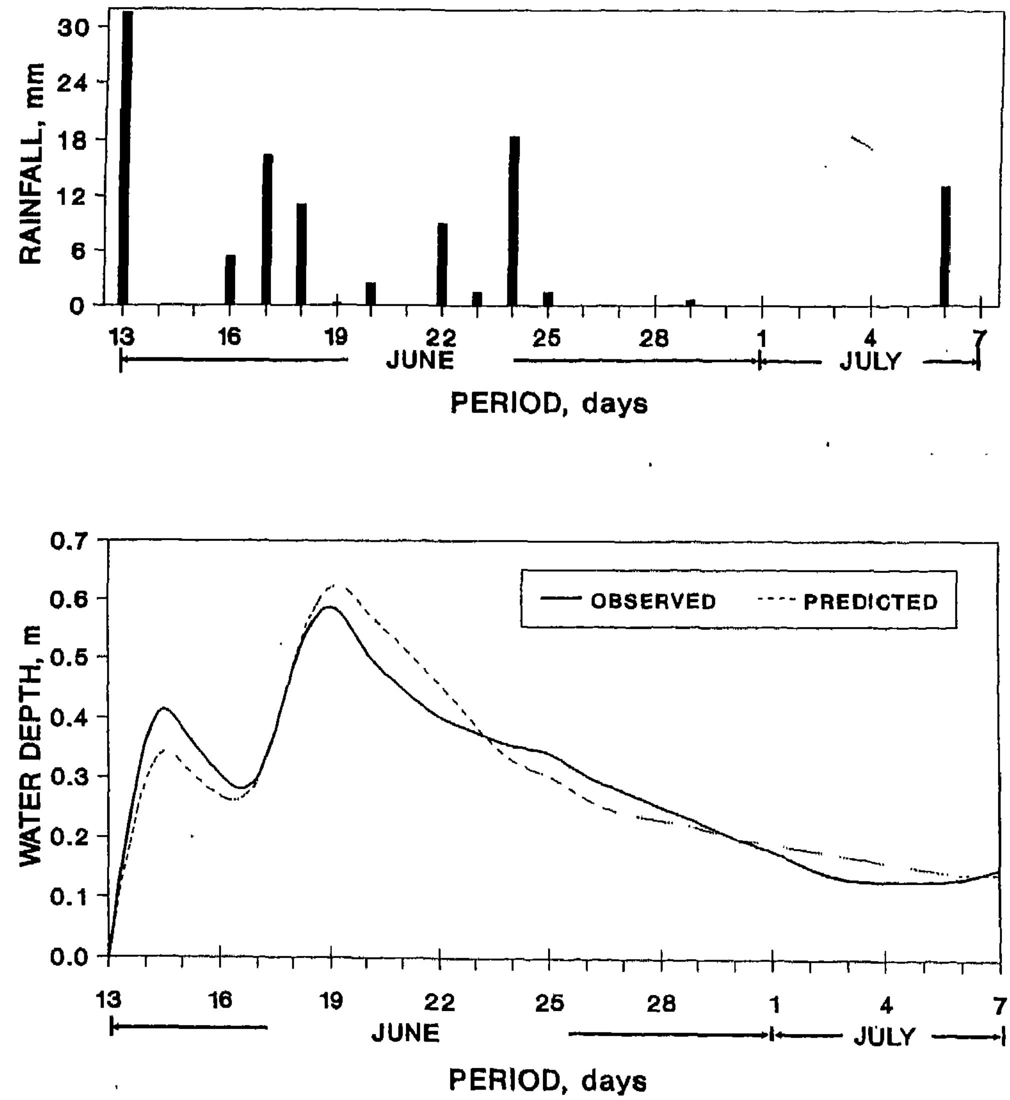
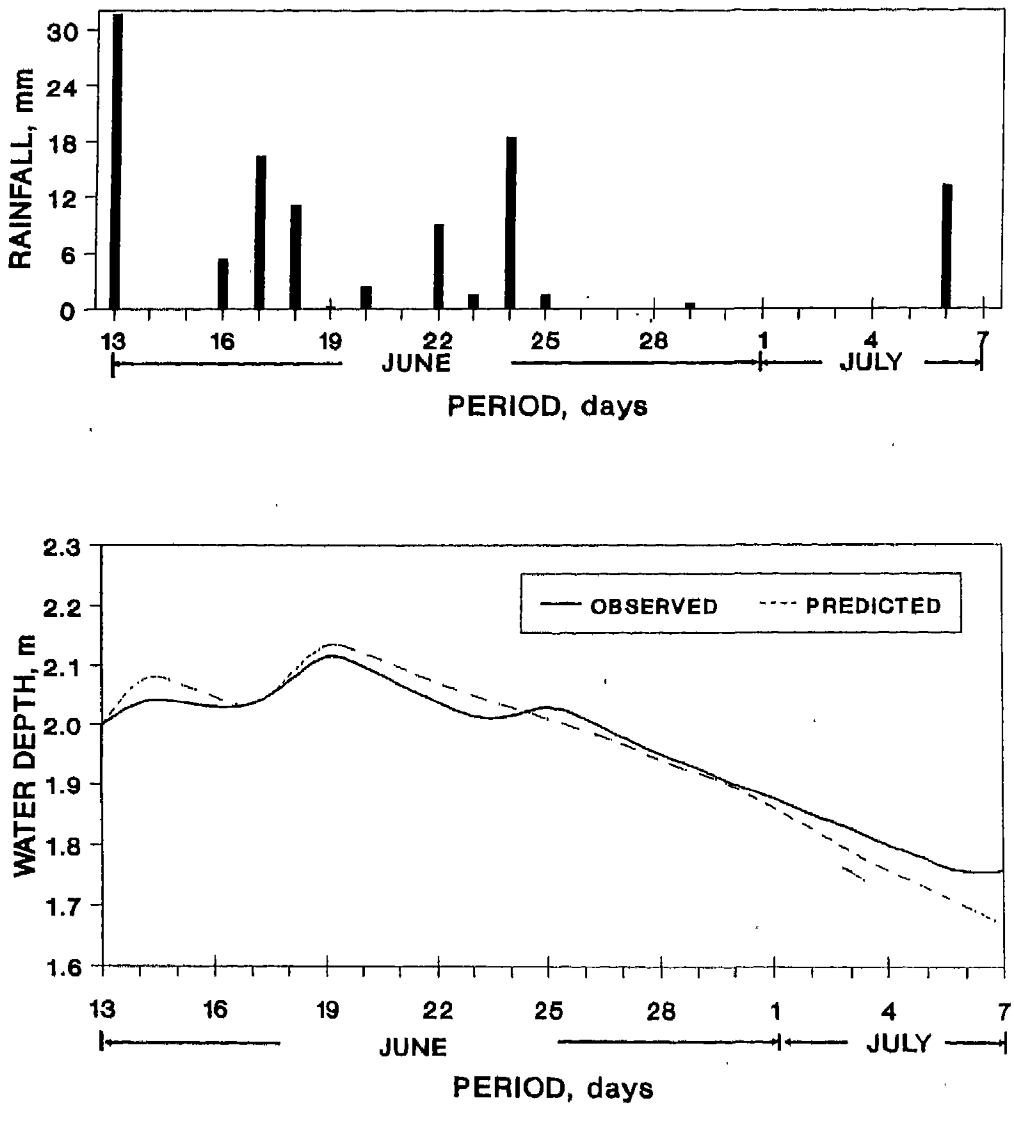


FIG. 5.6 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS FOR ED 18

YEAR:1992



YEAR:1992

FIG. 5.7 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS FOR ED 14

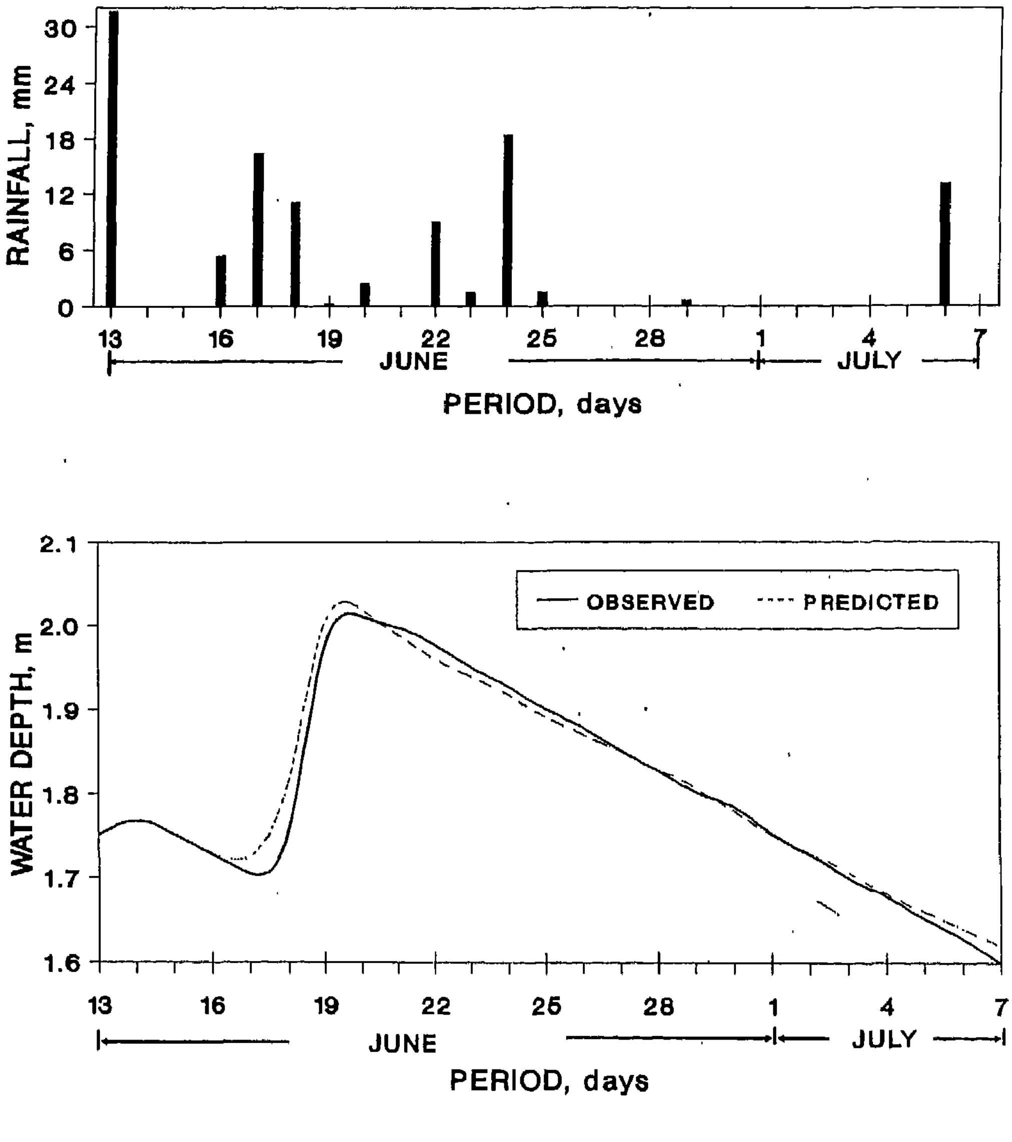


FIG. 5.8 PREDICTED AND OBSERVED RESERVOIR WATER DEPTHS FOR ED 5

YEAR:1992

to be accounted for in runoff computation is also getting fixed. These features of the model possibly imparts in it the desired sensitivity which has resulted in a better estimation of runoff as can be seen from the close agreement between the observed and predicted reservoir water levels in all five reservoirs.

A general user of this model result need not go into the details of model operation. For him, it will suffice to adopt the curve numbers arrived at in the present study and calculate the weighted average curve numbers by weighting the curve numbers for different land uses with the respective areas. He can use standard graphs given in SCS, USDA (1964) for the estimation of runoff.

The curve numbers proposed in SCS, USDA (1964) and the curve numbers obtained by SWYMOD in the present study are presented in Table 5.7. This table shows that the curve numbers obtained by SWYMOD for both the forest and bare land cover are more than the curve numbers proposed in SCS, USDA (1964) for the hydrologic conditions of poor, fair and good for forest and fallow for bareland. This is due to the reason that the forest watersheds are extensively gullied and the forest cover was with no canopy indicating more runoff potential. Also, the surface condition of the forest watersheds was observed to be compact. The bare land was observed to be fallow without any cover. Hence, the curve numbers obtained for forest and bareland are reasonable. However, the curve number (79.3) for agricultural land use is similar to the one proposed in SCS, USDA (1964) for poor and good hydrologic conditions with straight row land treatment and poor of contoured land teatment.

Table 5.7 Comarison of curve numbers for AMC II condition and XINABS = 0.2 . S.

Land use	Treatment	Hydrologic condition	Hydrologic soil group B	
			Curve numbers from SCS USDA (1964)	Curve numbers obtained by SWYMOD
Forest or Woods	—	Poor	66	90.5 to 91.2
		Fair	60	
		Good	55	
Agriculture or Row crops	Straight row	Poor	81	79.3
		Good	78	
	Contoured	Poor	79	
		Good	75	
	Bare land	Fallow	86	94.5

Note : XINABS = Initial abstraction, mm
S = Potential maximum retention, mm
AMC = Antecedent moisture condition.

In this and preceding sub-sections, the agreement between observed and predicted reservoir water levels has been discussed with respect to one numerical parameter (i.e., the average absolute deviation between two) and some qualitative aspects through graphical representation. Since, the validated model (SWYMOD) was planned to be used with long term weather data for prediction of time distribution of reservoir water levels in different years, it was thought appropriate to study the correctness of the model predictions by using a statistical test. This aspect is discussed in the next sub-section.

5.3.3 Statistical tests of agreement between the observed and the predicted reservoir water depths

To gain more insight into the performance of SWYMOD, a non-parametric test explained in chapter IV was used to determine if there is any significant difference between observed and predicted water depths in the selected reservoirs. Aitken (1973) suggested to use a simple Sign test, but a Sign test only considers the directions of differences between two series of data without considering the magnitude of the differences. Wilcoxon's matched pairs signed ranks test is considered superior to the simple Sign test as the former takes into account both the direction and magnitude of differences between observed and predicted series of data. The pair of observed and predicted water depths in the reservoir for the same day is considered to be related, because in the model as well as in the physical situation, the same main causative factors like runoff volume (RUNVOL) on present day and losses in the reservoir both seepage (SEEP) and evaportion (EVAPO) on the same day are responsible to the rise and fall of water level in the reservoirs respectively.

In the Wilcoxon matched pairs signed ranks test, the null (H_0) and alternate (H_a) hypotheses were :

H_0 : There is no significant difference between the observed and predicted water depths in the reservoir

H_a : The observed and predicted water depths in the reservoir are significantly different.

The result of the Wilcoxon's matched pairs singned ranks test are presented in the Table 5.8. It is seen from this table that the model predictions in all the selected reservoirs are acceptable due to the reason

Table 5.8 Results of the Wilcoxon matched pairs signed ranks test for observed and predicted water depths in the reservoirs and the mean of reservoir water depths

Reservoir identification	Fig. No.	* Significance level	Mean	
			Observed (m)	Predicted (m)
ED 21	5.4	0.05	0.1967	0.1958
ED 19	5.5	0.05	0.6712	0.6529
ED 18	5.6	0.05	0.3029	0.3017
ED 14	5.7	0.05	1.9600	1.9567
ED 5	5.8	0.05	1.8063	1.8104

Note : Values under the column with * are the size of type I error for which the null hypothesis is accepted.

that the null hypothesis is accepted at 0.05 size of the rejection region for all the cases. Thus, it can be said that the model predictions are good in all the selected microwatersheds and the general applicability of model is possible in similiar microwatersheds.

5.4 UTILIZATION OF STORED RUNOFF FOR CROP PRODUCTION

5.4.1 Assured water availability in the reservoirs

The causative factor of rainfall and the consequent outcome in the form of runoff are stochastic hydrologic events. To estimate the runoff at desired degree of assurance, one would require long term runoff data recorded over many years at the study site. It is needless to mention that such data are seldom available. Hydrologic modelling as in the present case of development and operation of SWYMOD helps to generate long term runoff data corresponding to long term rainfall data which is usually available.

Following the detail procedure described in sub-section 4.6.1, 75 % probable values of minimum weekly storage volumes, individually for all the selected reeserviors are given in Table 5.9. It may be pointed out that the probability analysis done to arrive at the values in Table 5.9 was with the minimum predicted volume of reservoir storage within each standard week. In general, it is seen from the Table 5.9 that the possible contribution of water for irrigation from the resrviors ED 18, ED 19 and ED 21 is less when compared to the reservoirs ED 5 and ED 14. This is due to the reason that the available maximum total storage in the reservoirs ED 18, ED 19 and ED 21 accounts for only 31% of maximum total storage available in all the five reservoirs (Table 5.10). Also, the losses in these reservoirs were observed to be more when compared to ED 5 and ED 14 as discussed in the sub-section 5.2.2.

The total volume of water availability increased from 25th to 33rd week with the maximum value of 5113.3 m^3 of water in 33rd week indicating the rainfall distribution over the weeks is more and then it reduced till 44th week indicating dry spells over the weeks from 37th to 44th week. This coincides with the observation from local farmers that the upstream reservoirs ED 18 and ED 21 become dry. Some water was however reported to be left in the reservoirs in ED 19, ED 5 and ED 14 indicating the possibility of giving pre-sowing irrigation to the rabi crop over small area, near the reservoirs ED 19, ED 5 and ED 14.

Table 5.9 Assured water availability in the reservoirs at 75 % probability level

Standard week No.	Storage volume (cu. m)					Total volume (cu. m)
	ED 5	ED 14	ED 18	ED 19	ED 21	
23	437.9	370.0	0.0	24.5	0.0	832.4
24	360.2	253.5	0.0	12.4	0.0	626.1
25	336.7	228.6	0.7	11.3	0.0	577.4
26	460.2	207.7	19.6	15.7	0.0	703.2
27	741.5	260.1	25.1	25.0	0.0	1051.7
28	819.3	265.2	34.0	38.3	2.6	1159.4
29	924.2	292.7	46.9	91.4	4.5	1359.7
30	2004.1	655.0	68.9	121.9	14.6	2864.5
31	2255.4	1000.1	56.7	83.0	3.0	3398.2
32	2279.7	1164.3	108.9	134.6	12.3	3699.8
33	2953.1	1872.4	123.1	155.9	8.8	5113.3
34	2267.0	1714.4	53.5	74.8	5.5	4115.2
35	1635.8	1280.8	35.2	30.1	0.2	2982.1
36	1330.1	969.9	28.0	19.5	0.0	2347.5
37	1747.1	839.9	33.6	33.8	2.0	2656.4
38	1365.7	730.2	34.2	32.0	2.2	2164.3
39	1139.6	657.2	27.0	27.1	0.0	1850.8
40	1037.5	601.1	22.4	18.4	0.0	1679.5
41	1016.9	504.8	20.9	10.9	0.0	1553.5
42	711.0	379.2	15.1	7.4	0.0	1112.7
43	741.7	306.1	13.0	5.6	0.0	1066.4
44	594.0	212.5	10.1	3.7	0.0	820.3

Table 5.10 Maximum water spread area and capacity of the reserviors.

Reservoir identification	Maximum water spread area. (sq. m.)	Maximum capacity of reservoir (cu.m.)	
ED 5	3600.0	6510.0	
ED 14	2800.0	5550.0	
ED 18	1210.0	1600.0	(A)
ED 19	1570.0	1580.0	(B)
ED 21	1040.0	930.0	(C)
	Total :	16,170.0	(D)

Note : The total of A + B + C is about 31% of D.

5.4.2 Gross water deficits of the crops

The crops generally grown in the projet site are upland paddy, maize and pigeon pea during kharif season. The area for cultivation available in microwatershed, MW 5 is 19.02 ha. From the preceding sub-section, it can be infered that the water availability after 44th week is going to be decreased as it is dry period without any rainfall. Hence, the available water in the reservoirs could be effectively utilized in kharif season only.

Thus, to study the water deficits under different crops individually, water balance approach as explained in sub-section 4.6.2 was used. The sowing of paddy, maize and pigeon pea was assumed to commence in the 25th week as the local farmers in general undertake this activity during 15th to 25th of June in kharif season. The durations of crop for paddy, maize and pigeon pea were taken as 115 days (25th to 41st week), 110 days (25th to 40th week) and 125 days (25th to 42nd week) as suggested by Mahapatra (1990) and Hukkeri and Pandey (1977). The gross deficits of water in different standard weeks of crop growing season were estimated following the procedure given in sub-section 4.6.2. The results of deficit analysis at 75 % probability of exceedance in each week are presented in Table 5.11. This table shows that paddy has deficits in all the weeks of growing period, varying from 13.2 to 65.1 mm with minimum in 29th week and mazimum occuring in 39th week. This is due to the reason that paddy crop needs more water to meet the demand of percolation and PET in sandy loam soils and under the local climate. Similarly, the gross deficits varied from 5.6 to 16.5 mm with minimum in 35th week and maximum in 34th week for maize and 4.8 to 6.3 mm with minimum in 40th week and maximum in 41st week of growing season for pigeon pea respectively. However, the gross deficits which have to be met with total assured available water in the project site at 75% probability level are less for maize and pigeon pea when compared with the demand of paddy. Hence, this suggests that more area could be brought under cultivation with maize and pigeon pea by replacing paddy in the project site. This aspect is discussed in the next sub-section.

5.4.3 Irrigation strategies

In the present section, the individual (i.e., mutually exclusive) irrigation strategies for paddy, maize and pigeon pea are discussed.

There are two alternatives of irrigation planning, one being the extensive irrigation without fulfilling the entire water requirement of crop and another is intensive irrigation with fulfilling the entire water requirement of crop with the available water. The former is widely used

Table 5.11 Matching of available water with gross deficits for different crops at 75% probability level to estimate irrigable area

Week No. (1)	Available water depth @ 19.02 ha (mm) (2)	Paddy: Gross deficit (mm) (3)	Paddy: Irrigable area with available water under col. (2) (ha) (4)	Maize: Gross deficit (mm) (5)	Maize: Irrigable area with available water under col. (2) (ha) (6)	Pigeon pea: Gross deficit (mm) (7)	Pigeon pea: Irrigable area with available water under col. (2) (ha) (8)
25	3.0	-	-	S	NI	S	NI
26	3.7	-	-	S	NI	S	NI
27	5.5	-	-	S	NI	S	NI
28	6.1	27.4	4.23	S	NI	S	NI
29	7.1	13.2	10.23	S	NI	S	NI
30	15.1	16.4	17.51	S	NI	S	NI
31	17.9	29.8	11.41	S	NI	S	NI
32	19.4	28.4	12.99	S	NI	S	NI
33	26.9	14.5	19.02	S	NI	S	NI
34	21.6	28.7	6.99	16.5	19.02	5.0	19.02
35	15.7	24.9	11.99	5.6	19.02	S	NI
36	12.3	33.0	7.09	S	NI	S	NI
37	14.0	43.4	6.13	7.8	19.02	S	NI
38	11.4	43.4	4.99	11.6	18.69*	S	NI
39	9.7	65.1	2.83*	8.0	NI	S	NI
40	8.8	55.3	3.02	-	-	4.8	19.02
41	8.2	-	-	-	-	6.3	19.02*
42	5.9	-	-	-	-	-	-

Note : (1) S = Surplus ; NI = No irrigation
(2) The values marked with * are maximum possible areas under the crops when they are mutually exclusive crop activities.
(3) Gross deficits are considered upto one week prior to harvesting for each crop.
(4) Gross deficits in the weeks 25, 26 and 27 (Nursery) are not included in the analysis for paddy as the area under nursery will be very small.

when unit cost of water becomes more under limited water supply and the latter is used when unit cost of water is less with unlimited supply of water (Verma, 1987). The area irrigated is less in intensive irigation and more in case of extensive irrigation.

In the present case, the above two alternatives are discussed with respect to the total availability of water in the reservoirs for a planned cropping activity in the agricultural area of 19.02 ha at the upstream of the ED 5 reservoir. In extensive irrigation, the application of water to the upland paddy, pigeon pea and maize at their critical stages increased their yields (Singh, 1983 and Verma, 1987). The deficits of the three crops in the last week of their growing period, i.e 41 for paddy, 40 for maize and 42 for pigeon pea are not considered due to reason that the farmers in general keep the field dry before harvesting. However, for paddy, the nursery is grown in first three weeks during 25^{th} to 27^{th} week which require less water. Hence, the effective growing period for paddy is from 26^{th} to 39^{th} week after transplantation which requires more water.

The critical stages of paddy include panicle initiation to heading (50-83 DAS), heading to flowering stage (83-90 DAS) and flowering to maturity stage (90-115 DAS). The critical growth stages for maize are tasselling to silking (45-60 DAS) and grain filling (70-85 DAS) and pigeoon pea has critical stages of branching stage (30-40 DAS) and pod filling stage (85-95 DAS) as reported by Rao (1991). From Table 5.11, it is seen that the critical stages of paddy fall in the weeks from 32 to 39 with maximum deficit of 65.1 mm in 39^{th} week during flowering to maturity stage. However, for the maize crop during the critical stage of taselling to silking stage from 31^{st} to 33^{rd} week, there is no deficit indicating adequate rainfall in the weeks to meet the PET requirement of crop. But, in grain filling stage from 34th to 36th week, the maize crop has maximum deficit of 16.5 mm in 34th week. For pigeon pea, at the branching stage falling during 29th to 31st week, there is no deficit observed. The same is true during the pod filling stage from 36th to 38th week also (Table 5.11).

While looking at the available water depths calculated over an area of 19.02 ha in Table 5.11, it can be seen that the water available in different weeks of critical stages of paddy as discussed in above paragraph, could be utilized only over small areas. The other crops maize and pigeon pea could be grown with full irrigation, if planned individually over an entire area. During the critical stage of grain filling (34th to 36th week) for maize crop, the water available in 34th week is 21.6 mm against the deficit of 16.5 mm, which indicates surplus water availability after meeting the deficit. Similar is the case with pigeon pea also.

The other approach of intensive irrigation considers the meeting of full demand of water requirement by crops. The maximum deficits obtained in the weeks from 28 to 39 (i.e., effective duration) for paddy, 25 to 40 for maize and 25 to 41 for pigeon pea are 65.1 mm on 39th week with 9.7 mm of water available depth, 16.5 mm on 38th week with 21.6 mm of water available depth and 6.3 mm on 41st week with 8.2 mm of water available depth respectively. However, for maize in 38th week, available water of 11.4 mm does not fulfil the actual requirement of 11.6 mm deficit.

Based on these figures, the maximum possible crop areas which could be brought under intensive irrigation with available water depths are 2.83 ha (15 %) under paddy, 18.69 ha (98.3 %) under maize and 19.02 ha (100 %) under pigeon pea out of the total area 19.02 ha available for cultivation in microwatershed MW 5 (Table 5.11). All the above three crop activities are mutually exclusive. In the first two cases, the remaining area after paddy and maize, respectively, 16.19 ha and 0.33 ha can however be put under the crop of little millet as rainfed crop. A preliminary cost analysis was done for these three mutually exclusive crop activities to know the annual net benefit of each crop activity using basic information given in Table 5.12. The annual running costs were estimated for the three irrigtated crops (i.e., paddy, maize and pigeon pea). The annual capital cost was estimated for three amortization periods of 5, 10 and 15 years. This was done for two options. First option was inclusive of reservoir cost and the second option was exclusive of reservoir cost. The annual cost considering the first option is the situation in which local farmers themselves are involved in constructing the storage reservoir. The annual capital cost considering the second option is the situation in which the goverment agency is involved in constructing storage reservoirs as soil and water consrvation measure and the farmers are not expected to repay the cost to the government. The estimates of annual capital cost for the two options and the running costs of three irrigated crops are given in Appendix E.

The annual net benefits which are net of cultivation cost, running cost and capital cost, were worked out as presented in Table 5.13. This table reveals that the individual cropping plan comprising maize and rainfed crop (little millet) resulted in higher annual net benefits when comared to the other two for all the amortization periods.

Table 5.12 Cost details of different crops in the project area

Sl. No. (1)	Name of the crop (2)	*Cost of cultivation Rs./q (3)	Cost of product Rs./q (4)	Crop yield q/ha (5)	Return net of Cultivation cost Rs./ha (4) x (5) - (3)
1.	Paddy	2500	300	27.5	5750
2.	Maize	1250	400	25.0	8750
3.	Pigeon pea	1000	600	10.0	5000
4.	Little millet	250	100	12.5	1000

Note : 1. Little millet is taken as rainfed crop.
2. Values in columns 3, 4 and 5 were obtained from the personal enquiries with local farmers.
3. *Excluding irrigation cost.

Table 5.13 Annual net benefit for mutually exsclusive cropping patterns for different amortization periods

Amortization period (years)	* Annual net benefit, Rs./ha					
	Paddy + Little millet		Maize + Little millet		Pigeon pea	
	A	B	A	B	A	B
5	-	-	7007.81	7297.20	3671.9	3961.33
10	-	-	7363.81	7549.89	4027.98	4214.02
15	-	-	7470.63	7625.66	4134.8	4289.83

Note :1. A = inclusive of reservoir cost.

2. B = Exclusive of reservoir cost

3. * net of cultivation, running and capital costs, which are given in Appendix E.

4. The columns with blanks actually have negative values because sum of running and annual capital costs is more than the annual returns

5.4.4 *Optimal crop planning*

In the preceding sub-section, the crop activities of paddy, maize and pigeon pea were considered as mutually exclusive to each other for irrigation planning. The present sub-section deals with an optimal allocation of available water to a combination of different crop activities to get maximum returns from crop production. A maximum of 4 possible crop activities namely paddy, maize, pigeon pea and little millet were considered in the study. Of these four, the little millet was a rainfed crop requiring no allocation of water from the reservoirs.

To achieve an optimal crop plan, Linear Programming (LP) model as explained in sub-section 4.6.3 was used. The data given in Table 5.12 were used as the basic information on various crops and their return (net of cultivation cost only) in the LP model. The LP model was tried for two imposed conditions of crop activities namely, no restriction on the area under any of the four crops and with restriction on the area under paddy crop.

Table 5.14 reveals that between the two imposed conditions, the crop plan comprising maize and pigeon pea gives the maximum return when compard to the crop plan comprising paddy, pigeon pea and rainfed crop (i.e., Little millet). The difference in the return between the two crop plans is Rs. 1,23,834 (i.e., Rs. 6510.72/ha). It may be noted that the 'return' mentioned here is the net of cultivation cost only and does not the over all net return as irrigation cost has not been considered at this stage. In the second crop plan, paddy cultivation was made compulsory to the extent of 2.83 ha (which was the maximum irrigable area for paddy with the available storage volume) keeping in mind the natural choice of the

Table 5.14 Cropping plans and the corresponding returns (Maximum area : 19.02 ha)

crop plan	Area under the crop (ha)				Return*	
	Paddy	Maize	Pigeon pea	Rainfed crop	Total (Rs.)	Per hectare (Rs.)
1. Imposing no restriction on any of 4 maximum crop activities.	-	18.69	0.33	-	1,65,195.00	8685.33
2. Imposing restriction on paddy to the maximum possible area of 2.83 ha.	2.83	-	2.22	13.97	41,360.95	2174.60

* Net of cultivation cost only.

farmers. Due to this restriction on paddy, there is substantial area of 13.97 ha left for rainfed crop namely little millet which is commonly grown in the study area without irrigation and gives very low return. A small area of 2.22 ha goes to pigeon pea and no area goes to maize. The overall effect of imposing the paddy area is a drastic reduction in the return from total production. This is an undesirable feature with respect to the overall developement of the conditions of the farmers in the study area.

5.4.5 Economic feasibility of irrigation by the reservoirs

The detailed economic analysis for both the crop plans discussed in the above sub-section is given in Appendix E. The following assumptions were made in the economic analysis.

(i) Gravity irrigatin is not feasible as the command is at the upstream of the reservoirs.

(ii) The life period of diesel engine, pump along with accessories and PVC pipe line (needed for pumping irrigation water) is taken as 15 years.

(iii) The depreciation cost and repairs and maintenance cost of diesel engine and pump with accessories are taken as 10% and 5% of their initial costs respectively.

(iv) Desiltation of reservoirs ED 5 and ED 14 is done every year to maintain the storage capacity at its original level.

(v) The value of land or its possible enhancement due to the provision of irrigation facility have not been considered.

The PVC pipe length was estimated from the delivery of diesel pump to the top most point of agricultural land as measured by the author during his field work. As agricultural land is sloping downwards, it is considered to pump the water into a diversion box constructed on top of the cultivable land. The pumped water is then distributed over the fields by gravity flow.

In the economic analysis, the reservoir capacities of ED 5 and ED 14 were only considered due to the reason that these reservoirs contribute about 90 % of total water availability in the study area when compared to the upstream reservoirs of ED 18, ED 19 and ED 21. The total quantity of water to be pumped from the reservoirs ED 5 and ED 14 was estimated based on the gross deficits of crops multiplied with their respective areas in both the crop plans. The detailed estimates of annual capital cost, anual running cost and the annual net benefits for both the options of inclusive of reservoir cost and exclusive of reservoir cost are given in Appendix E. The results of economic analysis for different assumed amortization periods are presented in Table 5.15 and Table 5.16 for both the crop plans. In these tables, the benefit-cost ratios were worked out for two options of annual costs (i.e., inclusive and exclusive of reservoir cost).

A comparison between the Table 5.15 and Table 5.16 reveals that the annual running cost (including the cost of diesel, labour, desiltation, depreciation and repairs and maintenance of diesel engine and pump) of Rs. 599.72/ha is much less in crop plan comprising maize and pigeon pea when compared to Rs. 1297.76/ha (i.e., 2.2 times of former) of the crop plan comprising paddy, pigeon pea and little millet as rainfed crop. This is because the total pumping period and hence pumping cost is much higher when paddy is grown, which faces water deficit in every week during its

Table 5.15 Benefit - cost ratio for crop plan comprising maize and pigeon pea for different amortization periods

Amortization Period (year)	Annual capital cost (Rs./ha)		Annual running cost Rs./ha	Annual capital and running cost (Rs./ha)		Annual benefit (net of cultivation cost) (Rs./ha)	Annual net benefit (Rs./ha)		Benefit-cost ratio	
	A	B		A	B		A	B	A	B
5	996.93	707.54	599.72	1596.65	1307.26	8685.33	7088.68	7378.07	4.4	5.6
10	640.89	454.85	599.72	1240.61	1054.57	8685.33	7444.72	7630.76	6.0	7.2
15	534.07	379.04	599.72	1133.75	978.76	8685.33	7551.58	7706.57	6.7	7.9

A : Inclusive of reservoir cost.
B : Exclusive of reservoir cost.

Table 5.16 Benefit - cost ratio for crop plan comprising paddy, pigeon pea and little millet for different amortization periods

Amortization Period (year)	Annual capital cost (Rs./ha)		Annual running cost (Rs./ha)	Annual capital and running cost (Rs./ha)		Annual benefit (net of cultivation cost) (Rs./ha)	Annual net benefit Rs./ha		Benefit-cost ratio	
	A	B		A	B		A	B	A	B
5	659.65	370.26	1297.76	1957.41	1668.02	2174.60	217.19	506.58	0.10	0.30
10	424.06	238.02	1297.76	1721.82	1535.78	2174.60	452.78	638.82	0.26	0.42
15	353.38	198.35	1297.76	1651.14	1496.11	2174.60	523.46	678.49	0.32	0.45

A : Inclusive of reservoir cost

B : Exclusive of reservoir cost

growth period. Also, the annual net benefit, i.e., the difference between annual benefit net of cultivation cost and sum of annualized capital cost and running cost is substantially more in the former crop plan when compared to the latter for all the amortization periods considered. The benefit-cost ratios in both the options of including and excluding reservoir cost are more than 1 with increasing trend as amortization period increased in the crop plan comprising maize and pigeon pea (Table 5.15). In the crop plan comprising paddy, pigeon pea and little millet, the annual net benefits (i.e., the difference between annual benefit net of cultivation cost and sum of the annual capital and running costs) are low for all the amortization periods (Table 5.16). This indicates the crop plan with compulsory inclusion of paddy is not economically beneficial to the farmers as the benefit-cost ratio is less than one.

The above discussion indicates that the farmers in the study area may consider discontinuing the cultivation of paddy and substitute it by maize and pigeon pea which are more economical at all the amortization periods considered in the present economic analysis. However, if the farmers stick to the present practice of cultivating paddy in the project site, they may adopt high yielding hybrid crop varieties of upland paddy with shorter duration of 70 days, which would enhance the crop yield at decreased running cost because of shorter duration of crop. In the present study, the crop duration for paddy considered was 115 days (25th to 41st week) in which paddy requires more water in all the crop growth stages to meet both percolation and PET of crop in the light texture (sandy loam) soils of study area. If the short duration paddy of 70 days (25th to 34th weeks) is grown in the project area, more area could be brought under paddy cultivation due to more availability of water to meet the gross deficits of crop during the weeks 25 to 34 as evident from Table 5.11. However, the consequence of this in terms of benefit-cost ratio has not been investigated in the present study.

5.4.6 Possibility of enhacing reservoir capacity

In the preceding sub-sections, the utilization of water yield was discussed based on the existing storage volumes of the reservoirs in crop production and its subsequent economic benefits. In the present sub-section, the possibility of storing a part of spill volumes from ED 5 and ED 14 by increasing their storage capacities is discussed. The spill volumes of ED 18, ED 19 and ED 21 were not considered for their possible storage because providing the additional storage in these reservoirs requires the cutting of forest in their respective microwatersheds which may not be ecologically acceptable.

For ED 5 and ED 14, probability analysis of annual maximum spill volumes in 20 years was done to estimate the amount of spill at 75% probability of exceedance. The resutlt are presented in Table 5.17. The spill volumes at 75% probability level in the reservoirs ED 5 and Ed 14 are 10741.5 m^3 and 10298.7 m^3 respectively. This volume of water has to be stored over and above the existing storage capacity of 6510 m^3 and 5550 m^3 in ED 5 and ED 14 respectively. The seepage and evaporation loss is assumed to take place at the rate of 100 mm/day above the existing spill levels of reservoirs if additional storage is provided to store the spill volumes as shown in Table 5.17.

Table 5.17 indicates that the spill volume at 75% probability level is likely to exhaust as a consequence of both seepage and evaporation loss

Table 5.17 Possible storage of spill volumes in the reservoirs

Reservoir identification	Spill volume at 75% Probability (cu. m)	Assumed Seepage + Evaporation loss at spill level (mm/day)	Volume of water Loss (cu. m/day)	Maximum retention time if spill volume is stored (weeks)
ED 5	10,741.5	100.0	380.0	4
ED 14	10,298.7	100.0	250.0	5.9

within 4 weeks in ED 5 and within 5.9 weeks in ED 14 respectively. This is because providing additonal storage in the reservoir results in an increased water spread area with increased water loss from the reservoirs. Also, increased storage involves increased investment on the construction of reservoir structures.

Under the circumstances explained above, it may not be feasible to store the spill volumes in ED 5 and ED 14 by enhancing their existing storage capacities. In principle, however any activity which reduces the runoff and hence soil erosion is desirable. Among the various possible activities, the harnessing of excess runoff by increasing the reservoir capacity has been found to be of little use for the purpose of irrigation. Without going into the detailed economic analysis, it may perhaps be not unrealistic to suggest adoption of low cost, but intensive soil and water conservation measures such as contour bunding, terrace cultivation, gully plugging etc. all of which are likely to reduce the runoff potential and hence reduce the spill volume which is a waste. Such activities may help in a better soil moisture storage over a longer duration as well as in enhancing ground water recharge.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Land and water are the two critical natural resources that may enhance or jeopardise the agricultural production and productivity depending on whether these are managed properly or not. Though, land resources are fixed, it is observed that the water resource is highly variable in time and space.

Water detention structures are useful in terms of checking soil erosion, flood control, irrigation, fisheries and ground water recharge. The construction of such structures was undertaken by River Valley Projects in the country as a measure of soil and water conservation on watershed basis . The quantity of water to be stored in water detention structures and its distribution over time are more important in terms of its localised use for irrigation in crop production. Hence, the estimation of water yield in the microwatersheds as a consequence to the input rainfall is necessary.

Since, runoff is a natural stochastic event, developement and use of hydrologic models have become important hydrologic research tools for the establishment of a reliable correspondance between rainfall and runoff. This is so because the other alternative of developing such correspondance based on long term actually observed data of rainfall and runoff is laborious, time-consuming and expensive. Though several complex and sophisticated hydrologic models were developed across the world, it is observed that application of such models may lead to erroneous estimates of runoff due to limited hydrologic data available from microwatersheds in the country.

The major objectives of the present study were to develop surface water yield model with the data generally available in the watersheds, validation of the model over a few selected microwatersheds of Upper Damodar Valley in Bihar state and to study the possible utilization of stored water in the reservoirs for crop production.

The capacity survey of reservoirs was done in order to develop rating curves of waterspread area and storage volumes as functions of reservoir storage depth. Wooden gauges were fixed in the storage reservoirs to measure the accumulated runoff depth and its corresponding water loss during non-rainy days in the observation period from 13th June to 7th July, 1992. The details on land use information within the selected microwatersheds were estimated through reconnaissance survey. To ascertain the value of seepage loss component from the reservoir, infiltration tests were conducted at the bottom of the two representative reservoirs. These two reservoirs were selected for infiltration study based on the results of mechanical analysis of reservoir soil samples. The observations with respect to rise and fall of water levels in the reservoirs were recorded in order to estimate the losses in the reservoirs. The basic infiltration rate of the representative reservoir soils and the observed water loss were compared to arrive at an appropriate value of seepage loss for model validation.

Three pre-assigned tolerance limits were selected for test criterion called average absolute deviation between observed and predicted reservoir water depths for model validation. The practical implications of fixing such tolerance limits to average absolute deviation was investigated in terms of per cent deviation in volume of storage and its corresponding reductions in irrigable area for paddy and maize / pigeon pea cultivation.

A Surface Water Yield Model (SWYMOD) was developed based on the hydrologic soil cover complex method (SCS, USDA, 1964) integrated with reservoir water budgetting. The principal objective in developing this model was to determine curve number for different land uses in the selected microwatersheds by trial and error process. The test criterion used was a statistical parameter called "Average absolute deviation" between observed and predicted water depths of the reservoirs in each run of model operation. Each run of model operation includes selection of a set of curve numbers for the different land uses of forest, agricultural land and bare land and their corresponding per cent areas in the microwatershed.

The verification of model was done over the selected five microwatersheds of Upper Damodar Valley in Bihar state, with the daily observed data on reservoir water depths. The curve numbers were fixed for the different land uses of the selected microwatersheds when the minimum average absolute deviation between observed and predicted reservoir water depths was 50 mm or less. The non-parametric statistical test called Wilcoxon matched pairs signed ranks test was used to statistically test the agreement between the observed and the predicted reservoir water depths.

The SWYMOD was then used to generate information on water availability in all the selected microwatersheds corresponding to 20 years of available rainfall data. The assessment of stored water availability at 75% probability in the selected reservoirs was done in different standard weeks of kharif season. The gross deficits at 75 % probability of different crops commonly grown (i.e., paddy, maize and pigeon pea) in the project site were estimated in different standard weeks of kharif season by using water balance approach. Linear programming model was formulated based on the water availability and gross deficits of water over the cultivable land to determine the maximum returns for two crop plans in kharif season. Based on the maximum returns, the economic feasibility of irrigation by the reservoirs was studied for different amortization periods. The possible enhancement of reservoir capacity for storing spill volumes, currently going as waste from the two tail end reservoirs in the monsoon season, was investigated.

Based on this research, the following conclusions were drawn :

(1) The watershed runoff model integtrated with reservoir water budgetting (SWYMOD) has been found to simulate the watershed rainfall-runoff process reasonably well as evidenced by the comparison of the model predicted and the actually observed reservoir water depths in all the cases of five selected microwatersheds (Fig. 5.3 through Fig. 5.8 and Table 5.8)

(2) The modelling reported in item (1) is primarily based on the hydrologic soil cover complex method and the model results indicate that this concept is applicable for the microwatersheds of Upper Damodar Valley in the Chotanagapur region of Bihar.

(3) The process of fitting appropriate curve number to achieve a pre-assigned minimum average absolute deviation between the observed and the model predicted reservoir water depths revealed a difference in the fitted curve numbers for different

land uses than those would be expected from the existing standards. Briefly, the fitted curve numbers for the forest and the bare land were seen to be higher than those obtained as per the existing standards. However, the fitted curve number for the land use of agriculture was seen to be close to the recommended values as per the existing standards (Table 5.7).

(4) Loss of water from the storage of the reservoir has two components, namely, evaporation and infiltration. The present study revealed that the estimation of infiltration through infiltrometer observations resulted in substantially higher infiltration rates than estimated through the observed values of decline in the reservoir water level. As it is not possible through infiltrometer test to map the infiltration behaviour of a large area as that of the reservoirs, it is felt that for the modelling purposes, actual observed data of reservoir water level decline should be used to estimate the infiltration component of the reservoir water.

(5) The modelling operation required updating of the water spread area and the storage volume for every time step consequent to accretion or depletion of storage volume during the preceding time step. In an attempt to do this as a continuous function of storage depth, separate logarithemic relations of water spread area and storage volume as a function of storage depth were developed. Though, the r^2 value with respect to these developed relations were 0.947 or

higher, the average absolute deviation between the observed and estimated water spread area and storage volume were rather high. To improve the estimation of these two parameters, the adoption of linear interpolation technique resulted in much closer agreement between the two. This is shown through the information in Table D.2 in Appendix D. In view of this analysis, the updating of water spread area and storage volume during the model operation was done by using the linear interpolation technique. The conclusions arrived at item 4 and 5 may be useful for the future researchers who may be working on the hydrologic modelling of watersheds.

(6) A comparison of the availabe stored water in the reservoirs and estimated gross deficits in the water requirements for three commonly grown irrigated crops in the area namely paddy, maize and pigeon pea revealed that at 75 % probability, the maximum possible area under these crops would be 2.83 ha (15 %), 18.69 ha (98.3 %) and 19.02 ha (100 %) of the total available cultivable land of 19.02 ha. All these crop activities are mutually exclusive. In the first two cases, the remaining area after paddy and maize, respectively, 16.19 ha and 0.33 ha can however be put under the crop of little millet. For above three cases, the maximum annual net benefit of Rs. 7625.66 per hectare was obtained for the individual crop activity comprising maize and little millet. (Table 5.11 and Table 5.13).

(7) A Linear programming approach adopted for optimally allocating available water for the above three irrigated crop activities with a view to maximizing the net benefit reveal that :

(i) The returns net of cultivation cost (in which irrigation cost was not included) is the highest when no water is allocated to paddy (implying that paddy is not to be grown). If paddy is to be grown on the maximum possible area based on the water availability alone, this return reduces drastically (Table 5.14).

(ii) The benefit-cost ratio for all the three considered amortization periods and for the two cases when reservoir cost is included and excluded from the analysis are always greater than one for the crop plan in which paddy is excluded (Table 5.15).

(iii) The annual benefit net of cultivation, capital and running costs are a very low positive values for all the cases of amortization periods even when the reservoir cost is excluded from the analysis, but when paddy is included in the crop plan, for all the amortization periods considered, the benefit-cost ratios are less than 1.0, corroborating the infeasibility of the adoption of paddy as an economic option (Table 5.16).

(8) In view of a considerable volume of spill after satisfying the existing storage capacities, an analysis was done to explore the possibility of storing a part of the spill volume by

increasing the reservoir capacity to store 75 % probable value of spill. In view of very high seepage and evaporation losses due to increased water spread area in case of additional storage, it is concluded that the alternative of increasing the reservoir capacity may not be acceptable as the stored water lasts for hardly 6 weeks (Table 5.17).

(9) A general conclusion which can be arrived at in view of the study and the eight previous conclusions is that judicious utilization of stored water for irrigation for an appropriate group of crop activities may improve the farmers economic condition substantially from the present practice of adopting rainfed agriculture.

SUGGESTIONS FOR FURTHER WORK

(1) Field studies should be conducted to monitor the water depth in the reservoirs continuously over time which leads to proper estimation of water losses in the water storage structures.

(2) The SWYMOD developed in the present study can then be applied with the above observed data to determine curve numbers for different land uses in the microwatersheds with minimum available input data of daily rainfall, distribution of land cover within microwatersheds and the rating curves for water spread area and storage volume of reservoirs.

(3) A systematic approach should be deviced to link the present water yield model with crop growth simulation models to evaluate different design criteria in providing such storage structures and to systematically evaluate the economic feasibility of irrigation for different cropping patterns.

(4) Studies on conjunctive use of both surface and ground water for irrigation should be undertaken in similar microwatersheds to estimate the recharge from storage structures and its utility in rainfed agriculture for irrigation.

(5) Studies on yield response of different crops to the supplemental irrigation at the critical stages of the crops should be conducted at field level, which enables in turn to study the utility of water resource developed by constructing such small reservoirs.

(6) The present approach developed may be made user friendly so that the practical worker at field level can design the soil and water consdervation structures and plan the developed water resource more efficiently for agriculture.

REFERENCES

Adhikari, R.N. and S. Chittaranjan. 1990. Estimation of water balance and other hydrological components for treated watershed. *Hydrology Journal of IAH*, vol. XIII, No. 4, pp. 186-197.

Agnihotri, Y., S.P. Mittal, A.D. Sud, R.C. Bansal and S.K.N. Dyal. 1988. Modelling runoff from small agricultural watersheds. *Journals of Soil and Water Conservation*, **32** (3 & 4) : 161-165.

Agnihotri, Y., S.P. Mittal and S.L. Arya. 1990. Economics of watershed management sans benefits from irrigation in Shivalik foot hill villages. *J. of Soil and Water Conservation*, Soil Conservation Society of India, **34** (2, 3 & 4) : 114-120.

Aitken, A.P. 1973. Assessing systematic errors in rainfall-runoff models. *Journal of Hydrology*, **20** : 121-136.

Akan, A.O. 1988. Kinematic wave methods for peak runoff estimates. *Journal of Trans. Civil. Engg. ASCE*, **111** (4) : 419-425.

Amorocho, J. 1967. The non-linear prediction problem in the study of the runoff cycle. *Water Resources Research*, (3) : 861-880.

Amin, M. and C.S. Fang. 1970. Implicit flood routing in natural channels. *Journal of the Hydraulics division, ASCE*, **HY 12** (96) : 2481-2500.

Anonymous 1972. *Handbook of hydrology*. Ministry of Agriculture and Co-operation, New Delhi.

Anonymous 1984. Watershed management plan of sub-watershed no. 8/5, SCD, DVC, Hazaribagh.

Anonymous 1985. Annual report of Soil Conservation Department. DVC, Hazaribagh.

Anonymous 1992. Soil conservation engineering dams - A boon to farmers of the Damodar Valley region of Bihar. A note by the Engineering Division of Soil Conservation Department, DVC, Hazaribagh.

Anonymous 1993. A note on crop coefficients. Division of Agronomy, IARI, New Delhi

Aron, G. 1968. Optimization of conjuctively managed surface and ground water resources. Water resource centre, Contribution No. 130, University of California, California, U.S.A.

Bargur, J. 1972. Dynamic multisector programming approach to regional water resource management. *Water Resources Research*, **4** (4) : 801-817.

Beasley, D.B. 1977. ANSWERS : A mathematical model for simulating the effects of land use and management on water quality. Ph.D. Thesis, Purdue University.

Bhattacharya, A.K. 1977. Hydrologic and economic models for sub-surface drainage. Ph.D. Thesis, McGill University, Montreal, Canada.

Blank, D. and C.E. Beer. 1968. Factors affecting water yields from small watersheds in Iowa. *Transactions of ASAE*, 11 : 701-704.

Boughton, W.C. 1966. A mathematical model relating to rainfall with daily data. *Trans. Inst. Engineers (Aust.)*, **7** : 83.

Boughton, W.C. and J.J. Stone. 1985. Variation of runoff with watershed area in a semi-arid location. *Journal of Arid Environment*, **9** (1) : 13-25.

Borah, D.K. 1989. Runoff simulation model for small watersheds. *Transactions of the ASAE*, **32** (3) : 881-886.

Borah, D.K. and M.S. Ashraf. 1990. Modeling storm runoff and sediment with seasonal variations. *Transactions of the ASAE*, **33** (1) : 105-110.

Burton, J.R. 1965. Water storage on farm. Water Research Foundation of Australia, Bulletin No. 9, Vol. 1, pp. 230.

Chow, V.T. 1964. *Handbook of Applied Hydrology*, New York : Mcgraw Hill.

Chow, V.T. and V.C. Kulandaisamy. 1982. The IUH of general hydrologic system model. *Journal of the Hydraulics Division, ASCE*, **HY7** (108) : 830-843.

Clark, C.O. 1945. Storage and unit hydrograph. *Transaction of the American Society of Civil Engineers,* **110** : 1419-46.

Crawford, N.H. and R.K. Lonsley. 1966. Digital simulation in hydrology : Stanford Model IV. Tech. report 39, Stanford University, Civil Engg. Dept.

Critchley, W. and K. Siegert. 1991. Water harvesting. FAO Manual.

Cundy, T.W. and S.W. Tento. 1985. Solution to the kinematic wave approach to overland flow routing with rainfall excess given by Philips equation. *Water Resources Research,* vol. **21** (8) : 1132-1140.

Das, D.C., K. Kurian and V. Lakshmanan. 1971. Annual report of CSWCRTI, Dehradun.

DeCoursey, D.G. and E.G. Seely. 1988. Validation tests of the small watershed model (SWAM). Proceedings of the 1988 International symposium on modelling agricultural, forest and range land hydrology. Dec. 12-13, Hyatt Regency, Chicago, Illinois, ASAE publication 07-88, pp. 307-314.

De Vries, J.J. and R.C. Mac Arthen. 1979. Introduction and application of kinematic wave routing technique using HEC-1. Hydrologic Engineering Centre, Davis, California.

Diskin, M.H. 1964. A basic study of the linearity of the rainfall-runoff process in watersheds. Ph.D. Dissertation, University of Illinois, Urbana.

Dooge, J.C.I. 1959. A general theory of the unit hydrograph. *Journal of Geophysical Research,* **64** (2) : 241-256.

Dube, S., R.K. Mehta and Ghanshyam Das. 1991. Development of curve numbers for prevalent land use in an Himalayan watershed. Paper Presented at XXVII Annual Convention of ISAE held at IARI from 9-11 October.

Fleming, G. 1975. Deterministic models in hydrology. FAO, Irrigation and Drainage Paper No. 32, Rome.

Gupta, S.K., K.G. Tejwani and Ram Babu. 1971. Drainage coefficient for surface drainage of agricultural land for different parts of the country. *Journal of the Central Board of Irrigation and Power*, vol. 28 (1) : 53-60.

Gupta, S.K. and S.I. Solomon. 1977. Distributed numerical model for estimating runoff and sediment discharge of ungaged rivers. I. The Information System. *Water Resources Research*, **13** (3).

Gupta, S.C. and V.K. Kapoor. 1983. *Fundamentals of Mathematical Statistics.* Sultan Chand and Sons Publishers, New Delhi.

Gulati, H.S. 1987. Water balance simulation for conjunctive use of water resources in canal command area. Ph.D. Thesis, IARI, New Delhi.

Haan, C.T. 1972. A water yield model for small watersheds. *Water Resources Research*, **8** (1) : 58-69.

Haan, C.T. 1982. Hydrologic modelling of small watersheds. ASAE Monograph No. 5. American Society of Agricultural Engineers. St. Joseph, Michigen.

Hall, W.A., W.S. Butcher and A. Esogbue. 1968. Optimization of the operation of multipurpose reservoir system by dyanmic programming. *Water Resources Research*, **4** (3) : 471-477.

Hawkins, R.H. 1978. Runoff curve numbers with varying site moisture. *Journal of Irrigation and Drainage Division, ASCE*, **IR4** (104) : 389-398.

Harikrishna, J. 1982. A parametric model to estimate runoff from small agricultural watersheds in the semi-arid tropics. *Journal of Hydrology*, **55** (4) : 43-51.

Hawkins, R.H. 1990. Asymptotic determination of curve numbers from rainfall-runoff data. Draft paper presented in Symposium of Institution of Engineers at Hyderabad, Andhra Pradesh.

Heady, E.I., H.C. Madsen, K.J. Nicol and S.H. Hargrove. 1973. Agricultural water allocation, land use and policy. Paper of the Technical Council on water resources planning and management. *J. of Hydraulic division, ASCE*, **99** (Hy 10) : 1795-1812.

Helweg, O.J., J. Amorocho and R.H. Firich. 1982. Improvement of non-linear rainfall-runoff model. *Journal of the Hydraulics Division, ASCE,* HY7 (108) : 813-821.

Holtan, H.N. and M.C. Lopez. 1971. USDAHL-70 model of watershed hydrology. USDA Tech. Bulletin No. 1425. Washington DC.

Hossain, M.M. 1989. Application of kinematic wave theory to small watersheads. Ph.D. dissertation. Dept. of Hydrology, University of Roorkee, Roorkee.

Huggins, L.F. and E.J. Monke. 1968. A mathematical model for simulating the hydrologic response of a watershed. *Water Resources Research,* **4** (3).

Huggins, L.F., J.R. Burney, P.S. Kundu and E.J. Monke. 1973. Simulation of the hydrology of ungaged watersheds. Water Resources Research Centre, Purdue University Tech. Report No. 38.

Huggins, L.F., D.B. Beasley, A. Bottcher and E.J. Monke. 1977. Environmental impact of land use on water quality. Sec. 4.9 Modelling. Environmental Protection Agency Report EPA-905/9-77-007-B.

Hukkeri, S.B. and S.L. Pandey. 1977. Water requirement and irrigation of crops. WTC, Monograph No. 4, IARI, New Delhi, pp. 163-273.

Kothyari, U.C., R.J. Garde and S.M. Seth. 1985. Estimation of annual runoff from catchments. *Irrigation and Power,* CBIP, pp. 319-327.

Krishnaswamy, G. 1976. Prediction for monthly runoff. *Irrigation and Power,* 33 (4) : 503-514.

Kulandaisamy, V.C. 1964. A basic study of rainfall excess-surface runoff relationship in a basin system. Ph.D. Thesis, Deptt. of Civil Engineering, University of Illinois, Urbana.

Mahapatra, I.C. 1990. Production constraints and prospects of rice in eastern India. Proceedings of the First International Symposium on Natural Resource Management for a Sustainable Agriculture, volume 1, pp. 242-312.

Mahmood, K. and V. Yevjevich. 1975. Unsteady flow in open channels. Vol. I and II. W.R. Publications, Fort Collins, Colorado 80522, USA.

Mathur, B.S., R. Singh and N.K. Goel. 1992. Indo-German bilateral project on watershed management : Development of Hydrological Watershed Simulation Model (Phase-I), Review and Recommended Approach, Dept. of Hydrology, University of Roorkee, Roorkee (India).

Michael, A.M. 1978. *Irrigation Theory and Practice.* Vikas Publishing Company, India.

Michael, A.M. and S.D. Khepar. 1985. *Water Well and Pump Engineering.* McGraw Hill Publishers.

Mishra, N. and C.T. Haan. 1990. Predicting storm runoff from a small watershed with the 'ANSWERS' simulation model. Proceedings of the XXVI Annual Convention of ISAE held at Haryana Agril. University, pp. 130-144.

Moore, I.D. and P.I.A. Kinnel. 1985. Kinematic overland flow II. Generalisation of Rose's approximate solution. *Journal of Hydrology,* **82** : 233-245.

Moore, I.D. and P.I.A. Kinnel. 1987. Kinematic overland flow II : Generalisation of Rose's approximate solution. *Journal of Hydrology,* 92 : 351-362.

Mutreja, K.N. 1990. *Applied Hydrology.* Tata McGraw Hill Company, New Delhi.

Naef, F. 1981. Can we model the rainfall-runoff process to-day ? *Hydrologic Service Bulletin,* **26** (3) : 281-289.

Nash, J.E. 1957. The form of instantaneous unit hydrograph. *International Association of Scientific Hydrology Publication,* **45** (3) : 114-121.

Niesen, S.A. and J.C. Panda. 1988. A water yield model for small semi-arid watersheds of India. *Indian J. Dryland Agric. Res. and Dev.,* 3 (2) : 63-76.

Pandit, K.N. and P.C. Senapati. 1991. Land and water resources planning for optimal cropping pattern. *Journal of Agricultural Engineering,* ISAE, special issue : Soil and Water Conservation Engineering, pp. 23-34.

Pathak, P., K.B. Laryea and R. Sudi. 1989. A runoff model for small watersheds in the semi-arid tropics. *Transactions of the ASAE*, **32** (5) : 1619-1624.

Pedersen, J.T., J.C. Peters and O.J. Helweg. 1980. Hydrographs by single linear reservoir model. *Journal of the Hydraulics Division, ASCE*, **HY5** : 837-852.

Ponce, V.M. 1986. Diffusion wave modelling of catchment dynamics. *Journal of the Hydraulics Division, ASCE*, **HY4** (93) : 201-221.

Promod Kumar, K.N. Tiwari and D.K. Pal. 1991. Establishing SCS runoff curve number from IRS digital data base. Souvenir, XXVII annual convention of ISAE, held at IARI, New Delhi, Oct. 9-11.

Raghuwanshi, N.S., R.A. Rastogi and Santhosh Kumar. 1987. Estimation of direct runoff from a Himalayan sub-watershed of Ramaganga river. *Hydrology Journal of IAH, Vol.* X, No. 2, pp. 1-8.

Ram Babu and V.V. Dhruvanarayana. 1983. Estimation of runoff from small watersheds of Doon valley. *IE (I) Journal*, EN. 64.1.

Rama Prasad. 1988. A hydrological model for small agricultural watersheds. *Indian J. Dryland Agric. Res. and Dev.*, **3** (2) : 77-86.

Rao, A.R. and M. Minikou. 1983. Regional monthly rainfall-runoff model. *Journal of Water Resources Planning and Management*, 109 (1) : 75-93.

Rao, N.H. 1991. Irrigation scheduling with limited water supply. CBIP Publication No. 218, New Delhi.

Rathore, L.S. and B.C. Biswas. 1989. Pan evaporation over India. Workshop on Evaporation from Open Water Surfaces, Vadodara, 7-14 November, pp. 61-68.

Rawls, W.J., C.A. Onstad and H.H. Rechardson. 1980. Residue and tillage effect on SCS runoff curve number. *Transactions of the ASAE*, **23** (1-3) : 357-361.

Ross, B.B., V.O. Shanholtz, D.N. Contractor and J.C. Carr. 1978. A model for evaluating the effect of land uses on flood flows. Virginia Water Resources Research Centre Bulletin No. 85.

Ryan, G.J. and M. Pereira. 1978. Deviation of empirical models for the prediction of runoff on small agricultural watershed in the semi-arid tropics. Paper presented at the International Workshop on the Agro-climatological Research Needs of Semi-arid Tropics, ICRISAT, Hyderabad.

Sharma, S.D. 1983. Development of efficient drainage systems for canal command areas in monsoon dominated rainfall regions. Ph.D. Thesis, IARI, New Delhi.

Sarkar, T.K. and G.C. Basu. 1985. Sedimentation studies of silt detention structures. National Seminar on Soil Conservation and Watershed Management, held at New Delhi, 17-18 Sept. pp. 151-163.

Satapathy, K.K. and T. Satyanarayana. 1989 . Analyses of hydrologic data from a selected mini-watershed in Damodar valley. *J. of Agric. Engg., ISAE,* **26** (3) :241-250.

Savabi, M.R., J.G. Arnold and C.W. Richardson. 1988. Application of SWRRB on range land watersheds. Proceedings of the 1988 International symposium on Modelling agricultural, forest and range land hydrology, Dec. 12-13, Hyatt Regency, Chicago, Illinois, ASAE publication 07-88, pp. 219-231.

Seigel, S. 1956. *Non Parametric Statistics.* McGraw Hill Book Company.

Selvarajan, M. 1990. Studies on ground water recharge through percolation ponds. Ph.D. Thesis, IARI, New Delhi.

Senapati, P.C. 1988. Water resources planning for canal command areas of Orissa. Ph.D. Thesis, Dept. of Soil and Water Conservation Engineering, Orissa University of Agriculture and Technology, Bhubaneswar, india.

Sherman, L.K. 1932. Streamflow from rainfall by the unit graph method. *Engineering News Res.* **108** : 501-505.

Shrivastava, N.C. and O.P. Bhatia. 1988. Effect of land treatments on runoff behaviour. *J. of Agric. Engg., ISAE,* **XXV** (2) : 154-158.

Shukla, D.N., G.C. Basu and Sanjay Kumar. 1991. Effect of water conservation measures on crop production in a watershed of the Uppder Damodar valley - A case study. Souvenir, XXVII Annual Convention of ISAE, held at IARI, New Delhi, from Oct. 9-11, pp. 32.

Singh, K.P. 1962. A non-linear approach to the instantaneous unit hydrograph theory. Ph.D. Dissertation, University of Illinois, Urbana.

Singh, V.P. 1974. A non-linear kinematic wave model of surface runoff. Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado.

Singh, O.P. 1981. Runoff curve numbers for alkali watersheds in transient state of reclamation. *Journal of Agril. Engineering,* **18** (2) : 67-73.

Singh, R.P. 1983. Farm pond. Project bulletin No. 6. All India Co-ordinated Research Project on Dryland Agriculture, Hyderabad.

Singh, A. 1988. Effect of farming systems on hydrological behaviour in hilly microwatersheds. *Indian Journal of Dryland Agricultural Research and Development,* **3** (2) : 87-94.

Singh, H.S. 1990. Management of soil and water resources for sustainable agriculture. *Sustainable Agriculture,* Volume I, pp. 40-64.

Sing, G. 1990. Rainwater harvesting and recycling for sustainable agricultural production. Proceedings of International Symposium on Water Erosion, Sedimentation and Resource Conservation, Dehradun, pp. 157-168.

Soil Conservation Service, USDA. 1964. Hydrology, Section 4, National Engineering Handbook, Washington, D.C., Revised Edition.

Soni, B. 1984. A goal programming approach to some aspects of agricultural planning. Ph.D. Thesis. Dept. of Agricultural Engineering, IIT, Kharagpur, West Bengal, India.

Sopper, W.E. and H.W. Lall. 1965. Streamflow characteristics of physiographic units in the north-east. *Water Resources Research,* 1 (1) : 115-124.

Srivastava, V.C., R.N. Prasad and A.K. Sinha. 1987. Water management studies in transplanted rice. *Journal of Soil and Water Conservation*, 31 (3 & 4) : 273-278.

Stegman, E.C., J.J. Musick and B.A. Stewart. 1980. Irrigation water management : *Design and Operation of Farm Irrigation Systems*. Ed. M.E. Jenson, ASAE, pp. 761-816.

Taneja, D.S. and S.K. Sondhi. 1988. *Handbook of Indian Pumps for Irrigation*, pp.121.

Thomas, D.L. and D.B. Beasley. 1986. A physically based forest hydrology model II : Evaluation under natural conditions. *Transactions of the ASAE*, **29** (4) : 973-981.

Thomas, D.L. and D.B. Beasley. 1986. A physically based forest hydrology model I : Development and sensitivity of components. *Transactions of the ASAE*, **29** (4) : 962-972.

U.S. Army Corps of Engineers. 1968. Daily stream flow simulation. Hydrologic Engineering Centre, Sacramento, California.

Vamadevan, V.K. 1978. Water management practices, Rice Production Manual. ICAR Publications, pp. 122-138.

Varshney, K.G. 1990. Optimal crop planning for a canal command area, Proc. of the 26th Annual Convention, ISAE, Soil and Water Engineering, Haryana Agricultural University, Hissar. pp. 78-95.

Varma, V. 1990. Runoff harvesting for irrigation in rainfed areas. *J. of Soil and Water Conservation*, Soil Conservation Society of India, **34** (2, 3 & 4) : 138-140.

Vedula, S. and P.P. Rogers. 1981. Multi-objective analysis of irrigation planning in river basin development. *Water Resource Research*, 17 (5) : 1304-1310.

Verma, H.N. 1987. Studies on efficient use of rainwater for rainfed crops. Ph.D. Thesis, IARI, New Delhi.

Vinod Kumar and R.A. Rastogi. 1989. Determination of direct runoff from a small agricultural watershed. *J. of Agric. Engg., ISAE*, **26** (3) : 223-228.

Williams, J.R. and W.V. LaSeur. 1976. Water yield model using SCS curve numbers. *Journal of the Hydraulics Division, ASCE,* **HY9** (102) : 1241-1253.

Williams, J.R., A.D. Nicks and J.G. Arnold. 1985. simulative for water resources in rural basins. *J. of Hydraulics division, ASCE,* **111** (6) : 970-987.

Zimmerman, J.D. 1966. *Irrigation.* John Wiley and Sons.

APPENDIX - A

Table A.1. Seasonal rainfall limits to determine antecedent moisture condition

AMC Group	Total 5-day antecedent rainfall (mm)	
	Dormant season	Grwoing season
I	< 12.7	< 35.6
II	12.7 to 27.9	35.6 to 53.3
III	> 27.9	> 53.3

Source : (Anonymous, 1972)

Table A.2. Stored array of curve numbers for different antecedent moisture conditions

Curve numbers		
AMC I	AMC II	AMC III
22.0	40.0	60.0
31.0	50.0	70.0
40.0	60.0	78.0
51.0	70.0	85.0
63.0	80.0	91.0
'78.0	90.0	96.0
100.0	100.0	100.0

Source : (SCS, USDA, 1964).

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C ***************************************************************
C *                         APPENDIX-B                          *
C * B. Listing computer program of S W Y M O D                  *
C ***************************************************************
C *                   Surface Water Yield Model                 *
C *                        ( S W Y M O D )                      *
C ***************************************************************
C *                     Variable Definition                     *
C ***************************************************************
C * RAIN= DAILY RAINFALL DEPTH,mm;CN(I,J)=STORED ARRAY OF CURVE *
C * NUMBERS;OBSDEP=OBSERVED WATER DEPTHS OF RESERVIOR,m         *
C * WCN=WEIGHTED CURVE NUMBER;CNINT=INTERPOLATED CURVE NUMBER   *
C * FOR PARTICULAR AMC CONDITION OF MICROWATERSHED;S=POTENTIAL  *
C * MAXIMUM STORAGE,mm;XINABS=INITIAL ABSTRACTION,mm;WSY=WATERS *
C * -HED YIELD,mm;XINVOL=INITIAL STORAGE VOLUME OF RESERVIOR    *
C * ,cu.m;RUNVOL=RUNOFF VOLUME IN A DAY,cu.m;TRNVOL=TOTAL RUNOFF*
C * VOLUME IN A DAY,cu.m;WSHAR=WATERSHED AREA,sq.m;PMAXVL=MAXIM *
C * -UM STORAGE VOLUME(AT SPILL LEVEL),cu.m;SPILL=SPILL VOLUME  *
C * IN A DAY,cu.m;PINDEP=STORAGE WATER DEPTH AT THE START OF A  *
C * DAY,m;PDEP=STORAGE WATER DEPTH AT THE END OF A DAY,cu.m;    *
C * PVOL=STORAGE VOLUME AT THE END OF A DAY,cu.m;APOND=WATER    *
C * SPREAD AREA,sq.m;SEEP=SEEPAGE RATE,mm/day;EVAPO=EVAPORATION *
C * RATE,mm/day;AVEDEV=AVERAGE ABSOLUTE DEVIATION BETWEEN OBSER *
C * -VED(OBSDEP) AND PREDICTED RESERVIOR WATER DEPTHS(PINDEP),cm*
C ***************************************************************
      COMMON CN
      DIMENSION RAIN(50),CN(7,3),WSY(50),OBSDEP(30),PINDEP(30)
      DIMENSION DEV(30)
      OPEN(7,FILE='RAIN.DAT',STATUS='OLD')
      OPEN(8,FILE='CNVALUE.DAT',STATUS='OLD')
      OPEN(9,FILE='OBSDATA',STATUS='OLD')
      OPEN(11,FILE='Q.OUT',STATUS='NEW')
C **************************************************************
C   SELECTING CURVE NUMBERS AND ENTERING CN VALUES FOR DIFFERENT
C   LAND USES AND READING AS INPUT TO THE PROGRAMME BASED ON THE
C   HYDROLOGICAL SOIL COVER COMPLEX METHOD BY TRIAL AND ERROR.
C **************************************************************
    READ(8,*)((CN(I,J),J=1,3),I=1,7)
    READ(7,*)N,(RAIN(I),I=1,N)
    READ(9,*)(OBSDEP(I),I=1,N-5)
    MM=1
  5 WRITE(*,14)'RUN NO:',MM
 14 FORMAT(1X,A,1X,I2)
    WRITE(*,10)
 10 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR FOREST(CN1):')
    READ(*,*) CN1
    WRITE(*,20)
 20 FORMAT(1X,'ENTER PERCENTAGE OF AREA UNDER FOREST(A1):')
    READ(*,*) A1
    WRITE(*,30)
 30 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR AGRI.LAND(CN2):')
    READ(*,*) CN2
    WRITE(*,40)
 40 FORMAT(1X,'ENTER PERCENTAGE OF AREA UNDER AGRI.LAND(A2):')
    READ(*,*) A2
     WRITE(*,50)
  50 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR FALLOW LAND
    1(CN3):')
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      READ(*,*)CN3
      WRITE(*,60)
   60 FORMAT(1X,'ENTER PERCENTAGE AREA UNDER FALLOW LAND (A3):')
      READ(*,*)A3
      WRITE(11,65)'RUN NO:',MM
   65 FORMAT(1X,A,1X,I2)
      WRITE(11,*)'TABLE:1 SELECTED (CN) AND (A)'
      WRITE(11,*)'-----------------------------------------------------------'
      WRITE(11,*)'  LAND USE                CN VALUE              AREA(%)  '
      WRITE(11,*)'-----------------------------------------------------------'
      WRITE(11,70)'FOREST',CN1,A1,'AGRICULTURE LAND',CN2,A2,
     &'FALLOW LAND',CN3,A3
   70 FORMAT(2X,A,17X,F6.2,13X,F6.2/1X,A,9X,F6.2,13X,F6.2/1X,A,13X,
     &F6.2,13X,F6.2)
      WRITE(11,*)'-----------------------------------------------------------'
C     CALCULATION OF WEIGHTED CURVE NUMBER,WCN
      WCN=(CN1*A1+CN2*A2+CN3*A3)/(A1+A2+A3)
      WRITE(11,15)WCN
   15 FORMAT(1X,'WEIGHTED CN VALUE=',F7.2)
      WRITE(11,*)
      WRITE(11,*)'TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF'
      WRITE(11,*)'         FOR DIFFERENT AMC AND CURVE NUMBERS'
      WRITE(11,*)'----------------------------------------------'
      WRITE(11,*)'RAINFALL   AMC    INTERPOLATED     RUNOFF'
      WRITE(11,*)' (mm)                CN VALUE        (mm) '
      WRITE(11,*)'----------------------------------------------'
      DO 110 K=6,N
C     CALCULATION OF ANTECEDENT MOISTURE CONDITION OF MICROWATERSHED
      AMC=0.0
      DO 80 K1=1,5
   80 AMC=AMC+RAIN(K-K1)
C     CHEKING OF AMC CONDITION OF MICROWATERSHED
      IF(AMC.LT.35.6) THEN
      J=1
      ELSE IF((AMC.LT.53.3).AND.(AMC.GT.35.6)) THEN
      J=2
      ELSE IF(AMC.GT.53.3) THEN
      J=3
      END IF
C     CALLING SUBROUTINE FOR INTERPOLATION OF CURVE NUMBER AND IT'S
C     CONVERSION FROM AMC2 TO AMC1 OR AMC3
      IF((J.EQ.1).OR.(J.EQ.3))THEN
      CALL COMPARE(WCN,CN,CNINT,J)
      ELSE
      CNINT=WCN
      ENDIF
C     CALCULATION OF MAXIMUM RETENTION STORAGE
      S=(25400/CNINT-254)
C     CALCULATION OF RUNOFF
      II=K-5
      XINABS=0.2*S
      IF(RAIN(K).GT.XINABS)THEN
      WSY(II)=((RAIN(K)-XINABS)**2)/(RAIN(K)+0.8*S)
      ELSE
      WSY(II)=0.0
      ENDIF
      WRITE(11,90)RAIN(K),J,CNINT,WSY(II)
   90 FORMAT(1X,F6.2,5X,I2,6X,F7.2,6X,F8.4)
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```
110 CONTINUE
    WRITE(11,*)'----------------------------------------'
    WRITE(11,*)'TABLE:3 RESERVIOR WATER LEVELS ON DAILY WATER BALANCE
    WRITE(11,*)'-----------------------------------------------------
   &-------------'
    WRITE(11,*)'DAY   RUNVOL    TRNVOL   PINDEP   APOND    PVOL    PDEP
   &     SPILL'
    WRITE(11,*)'NO.   (cu.m)    (cu.m)    (m)     (sq.m) (cu.m)    (m)
   &     (cu.m)'
    WRITE(11,*)'-----------------------------------------------------
   &-------------'
    XINVOL=0.0
    DO 120 NN=1,N-5
C   CALLING SUBROUTINE FOR PREDICTING RESERVIOR WATER LEVELS ON DAILY
C   WATER BUDGETTING
    CALL RESBAL(NN,XINVOL,WSY,PINDEP,APOND,PVOL,PDEP,SPILL)
120 CONTINUE
    WRITE(12,*)'-----------------------------------------------------
   &-------------'
    SUMDEV=0.0
    DO 130 JJ=1,N-5
    DEV(JJ)=ABS(PINDEP(JJ)-OBSDEP(JJ))
    SUMDEV=SUMDEV+DEV(JJ)
130 CONTINUE
C  CALCULATING AVERAGE ABSOLUTE DEVIATION BETWEEN OBSERVED AND
C  PREDICTED RESERVIOR WATER DEPTHS IN EACH RUN OF MODEL
    AVEDEV=(SUMDEV/24.0)*100.0
    WRITE(11,*)
    WRITE(11,*)'AVE.DEVIATION=',AVEDEV,' cm. '
    WRITE(*,*)'AVERAGE ABSOLUTE DEVIATION=',AVEDEV,' cm. '
C  CHECKING AVEDEV WITH PRE-ASSIGNED VALUE OF TOLERANCE LIMIT
    IF (AVEDEV.GT.5.0)THEN
    MM=MM+1
    GO TO 5
    END IF
    STOP
    END
C   SUBROUTINE FOR COMPARISION OF CURVE NUMBERS AND INTERPLOTES
C   WCN FOR PARTICULAR AMC CONDITION OF MICROWATERSHED
    SUBROUTINE COMPARE(WCN,CN,CNINT,J)
    DIMENSION CN(7,3)
    IF((WCN.GE.40).AND.(WCN.LT.50))THEN
    P=CN(1,J)
    Q=CN(2,J)
    CALL INT(40,WCN,50,P,Q,CNINT)
    ELSE IF((WCN.GE.50).AND.(WCN.LT.60))THEN
    P=CN(2,J)
    Q=CN(3,J)
    CALL INT(50,WCN,60,P,Q,CNINT)
    ELSE IF((WCN.GE.60).AND.(WCN.LT.70))THEN
    P=CN(3,J)
    Q=CN(4,J)
    CALL INT(60,WCN,70,P,Q,CNINT)
    ELSE IF((WCN.GE.70).AND.(WCN.LT.80))THEN
    P=CN(4,J)
    Q=CN(5,J)
    CALL INT(70,WCN,80,P,Q,CNINT)
    ELSE IF((WCN.GE.80).AND.(WCN.LT.90))THEN
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      P=CN(5,J)
      Q=CN(6,J)
      CALL INT(80,WCN,90,P,Q,CNINT)
      ELSE IF((WCN.GE.90).AND.(WCN.LE.100))THEN
      P=CN(6,J)
      Q=CN(7,J)
      CALL INT(90,WCN,100,P,Q,CNINT)
      END IF
      RETURN
      END
C     SUBROUTINE FOR INTERPOLATION OF CURVE NUMBER
      SUBROUTINE INT(N1AM2,WCN,N2AM2,CN1AM,CN2AM,CNINT)
      RATIO=(WCN-N1AM2)/(N2AM2-N1AM2)
      CNINT=CN1AM+RATIO*(CN2AM-CN1AM)
      RETURN
      END
C     SUBROUTINE FOR PREDICTING RESERVIOR WATER LEVELS ON DAILY WATER
C     BUDGETTING
      SUBROUTINE RESBAL(LL,XINVOL,WSY,PINDEP,APOND,PVOL,PDEP,SPILL)
      DIMENSION WSY(50),RUNVOL(50),TRNVOL(50),PINDEP(50),APOND(50)
      DIMENSION EVAPO(50),SEEP(50),PVOL(50),PDEP(50),SPILL(50)
      WSHAR=20235.00
      PMAXVL=930.0
      RUNVOL(LL)=(WSY(LL)/1000.)*WSHAR
      IF((RUNVOL(LL)+XINVOL).GE.PMAXVL)THEN
      TRNVOL(LL)=PMAXVL
      SPILL(LL)=RUNVOL(LL)+XINVOL-PMAXVL
      ELSE
      TRNVOL(LL)=RUNVOL(LL)+XINVOL
      SPILL(LL)=0.0
      END IF
      CALL VOLDEP(LL,TRNVOL,PINDEP)
      CALL RESLOSS(LL,PINDEP,EVAPO,SEEP)
      CALL AREADEP(LL,PINDEP,APOND)
      PVOL(LL)=TRNVOL(LL)-(EVAPO(LL)/1000.)*APOND(LL)-(SEEP(LL)/1000.)
     &*APOND(LL)
      IF (PVOL(LL).LE.0.0)THEN
      PVOL(LL)=0.0
      CALL VOLDEP(LL,PVOL,PDEP)
      ELSE
      CALL VOLDEP(LL,PVOL,PDEP)
      END IF
      WRITE(11,100)LL,RUNVOL(LL),TRNVOL(LL),PINDEP(LL),APOND(LL),
     &PVOL(LL),PDEP(LL),SPILL(LL)
 100  FORMAT(1X,I2,2X,F7.2,2X,F7.2,2X,F7.4,2X,F7.2,1X,F7.2,1X,F7.4,1X,
     &F7.2)
      XINVOL=PVOL(LL)
      RETURN
      END
C     SUBROUTINE TO CALCULATE RESERVIOR WATER DEPTH FROM VOLUME-DEPTH
C     RELATIONSHIPS FOR ED-21 RESERVIOR BY LINEAR INTERPOLATION
      SUBROUTINE VOLDEP(LL,PP,QQ)
      DIMENSION PP(50),QQ(50)
      IF ((PP(LL).GE.0.0).AND.(PP(LL).LE.0.19))THEN
      CALL LININT(LL,0.0,PP,0.19,0.0,0.03,QQ)
      ELSE IF ((PP(LL).GT.0.19).AND.(PP(LL).LE.20.0))THEN
      CALL LININT(LL,0.19,PP,20.0,0.03,0.20,QQ)
      ELSE IF ((PP(LL).GT.20.0).AND.(PP(LL).LE.50.0))THEN
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      CALL LININT(LL,20.0,PP,50.0,0.20,0.40,QQ)
      ELSE IF ((PP(LL).GT.50.0).AND.(PP(LL).LE.80.0))THEN
      CALL LININT(LL,50.0,PP,80.0,0.40,0.55,QQ)
      ELSE IF ((PP(LL).GT.80.0).AND.(PP(LL).LE.155.0))THEN
      CALL LININT(LL,80.0,PP,155.0,0.55,0.75,QQ)
      ELSE IF ((PP(LL).GT.155.0).AND.(PP(LL).LE.297.0))THEN
      CALL LININT(LL,155.0,PP,297.0,0.75,1.03,QQ)
      ELSE IF ((PP(LL).GT.297.0).AND.(PP(LL).LE.570.0))THEN
      CALL LININT(LL,297.0,PP,570.0,1.03,1.40,QQ)
      ELSE IF ((PP(LL).GT.570.0).AND.(PP(LL).LE.930.0))THEN
      CALL LININT(LL,570.0,PP,1150.0,1.40,1.80,QQ)
      END IF
      RETURN
      END
C   SUBROUTINE TO CALCULATE WATER SPREAD AREA FROM AREA-DEPTH
C   RLATIONSHIPS BY LINEAR INTERPOLATION FOR RESERVIOR NO. ED-21
      SUBROUTINE AREADEP(LL,XX,YY)
      DIMENSION XX(50),YY(50)
      IF ((XX(LL).GE.0.0).AND.(XX(LL).LE.0.41))THEN
      CALL LININT(LL,0.0,XX,0.41,0.0,245.0,YY)
      ELSE IF ((XX(LL).GT.0.41).AND.(XX(LL).LE.1.03))THEN
      CALL LININT(LL,0.41,XX,1.03,245.0,580.0,YY)
      ELSE IF ((XX(LL).GT.1.03).AND.(XX(LL).LE.1.52))THEN
      CALL LININT(LL,1.03,XX,1.52,580.0,890.0,YY)
      ELSE IF ((XX(LL).GT.1.52).AND.(XX(LL).LE.1.80))THEN
      CALL LININT(LL,1.52,XX,2.03,890.0,1040.0,YY)
      END IF
      RETURN
      END
C   SUBROUTINE TO INTERPOLATE DEPTH AND WATERSPREAD AREA
      SUBROUTINE LININT(LL,PQR,UU,QRS,TUV,UVW,VV)
      DIMENSION UU(30),VV(30)
      RATIO=(UU(LL)-PQR)/(QRS-PQR)
      VV(LL)=TUV+RATIO*(UVW-TUV)
      RETURN
      END
C   SUBROUTINE TO SEPERATE LOSSES AT DIFFERENT WATER DEPTHS IN
C   THE RESERVIOR NO. ED-21
      SUBROUTINE RESLOSS(LL,RR,SS,TT)
      DIMENSION RR(50),SS(50),TT(50)
      IF (LL.LE.17)THEN
      SS(LL)=7.0
      ELSE
      SS(LL)=5.0
      END IF
      IF ((RR(LL).GT.0.0).AND.(RR(LL).LE.0.125))THEN
      TOTLOS=37.5
      ELSE IF ((RR(LL).GT.0.125).AND.(RR(LL).LE.0.325))THEN
      TOTLOS=62.5
      ELSE IF ((RR(LL).GT.0.325).AND.(RR(LL).LE.1.80))THEN
      TOTLOS=125.0
      END IF
      TT(LL)=TOTLOS-SS(LL)
      RETURN
      END
```

```
C ****************************************************************
C *                          APPENDIX- C                         *
C *     C.  Listing computer program of S P M O D 5              *
C ****************************************************************
C *                          S P M O D 5                         *
C ****************************************************************
C *                      Variable Definition                     *
C ****************************************************************
C * WY1=RUNOFF FROM FOREST LAND,mm;WY2=RUNOFF FROM AGRI.LAND,mm *
C * WY3=RUNOFF FROM BARE LAND,mm;FRACT1,2,3=RUNOFF-RAINFALL RAT-*
C * IOS FOR FOREST,AGRI.LAND& BARE LAND;SPILL=SPILL VOLUMES FROM*
C * UPSTREAM RESERVIORS(ED18,19& 21),cu.m;TOTSP=TOTAL SPILL VOL-*
C * UME IN A DAY,cu.m; ACTSP=ACTUAL SPILL VOLUME AS INFLOW INTO *
C * ED5 cu.m;WWSY=WEIGHTED RUNOFF OVER TOTAL AREA,mm; SP = SPILL*
C * VOLUME  FROM ED 5 AS INFLOW INTO ED 14,cu.m                 *
C ****************************************************************
      COMMON CN
      DIMENSION RAIN(200),CN(7,3),WY1(200),WY2(200),WY3(200)
      DIMENSION FRACT1(200),SPILL(160,3),TOTSP(200),ACTSP(200)
      DIMENSION WWSY(200),FRACT2(200),FRACT3(200)
      OPEN(7,FILE='RAIN72.PRN',STATUS='OLD')
      OPEN(8,FILE='CNVALUE.DAT',STATUS='OLD')
      OPEN(9,FILE='SPILL72.PRN',STATUS='OLD')
      OPEN(16,FILE='SPOUT',STATUS='NEW')
      OPEN(11,FILE='QFOR',STATUS='NEW')
      OPEN(12,FILE='QCULT',STATUS='NEW')
      OPEN(13,FILE='QFALL',STATUS='NEW')
      OPEN(14,FILE='PONRES',STATUS='NEW')
      OPEN(15,FILE='WRUNOFF',STATUS='NEW')
      READ(8,*)((CN(I,J),J=1,3),I=1,7)
      READ(7,*)N,(RAIN(I),I=1,N)
      WRITE(*,10)
   10 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR FOREST(CN1):')
      READ(*,*) CN1
      WRITE(*,20)
   20 FORMAT(1X,'ENTER PERCENTAGE OF AREA UNDER FOREST(A1):')
      READ(*,*) A1
      WRITE(*,30)
   30 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR AGRI. LAND(CN2):')
      READ(*,*) CN2
      WRITE(*,40)
   40 FORMAT(1X,'ENTER PERCENTAGE OF AREA UNDER AGRI. LAND(A2):')
      READ(*,*) A2
      WRITE(*,50)
   50 FORMAT(1X,'ENTER CURVE NUMBER FOR AMC2 FOR FALLOW LAND(CN3):')
      READ(*,*)CN3
      WRITE(*,60)
   60 FORMAT(1X,'ENTER PERCENTAGE AREA UNDER FALLOW LAND (A3):')
      READ(*,*)A3
      WRITE(11,*)'TABLE:1 SELECTED (CN) AND (A)'
      WRITE(11,*)'-----------------------------------------------------
      WRITE(11,*)'  LAND USE                  CN VALUE           AREA(%)
      WRITE(11,*)'-----------------------------------------------------
      WRITE(11,70)'FOREST',CN1,A1,'AGRICULTURE LAND',CN2,A2,
     &'FALLOW LAND',CN3,A3
   70 FORMAT(2X,A,17X,F6.2,13X,F6.2/1X,A,9X,F6.2,13X,F6.2/1X,A,13X,
     &F6.2,13X,F6.2)
      WRITE(11,*)'-----------------------------------------------------
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```
      WRITE(11,*)
      WRITE(11,*)'TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR'
      WRITE(11,*)'        DIFFERENT AMC AND CURVE NUMBERS OF FOREST'
      WRITE(11,*)'-----------------------------------------------------'
      WRITE(11,*)'RAINFALL        AMC         INTERPOLATED        RUNOFF '
      WRITE(11,*)'  (mm)                         CN VALUE          (mm)  '
      WRITE(11,*)'-----------------------------------------------------'
      WRITE(12,*)'TABLE:3 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR'
      WRITE(12,*)'        DIFFERENT AMC AND CURVENUMBERS OF CULTIVATED'
      WRITE(12,*)'        LAND'
      WRITE(12,*)'-----------------------------------------------------'
      WRITE(12,*)'DAY  RAINFALL   AMC  INTERPOLATED   RUNOFF   RUNOFF '
      WRITE(12,*)'NO.    (mm)             CN VALUE      (mm)   FRACTION'
      WRITE(12,*)'-----------------------------------------------------'
      WRITE(13,*)'TABLE:4 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR'
      WRITE(13,*)'       DIFFERENT AMC AND CURVENUMBERS OF FALLOW LAND'
      WRITE(13,*)'-----------------------------------------------------'
      WRITE(13,*)'RAINFALL        AMC        INTERPOLATED        RUNOFF  '
      WRITE(13,*)'  (mm)                        CN VALUE          (mm)   '
      WRITE(13,*)'-----------------------------------------------------'
      DO 150 II=1,3
      IF (II.EQ.1)THEN
      DO 160 K=6,N
      AMC=0.0
      MM=K-5
      DO 162 K1=1,5
  162 AMC=AMC+RAIN(K-K1)
      WRITE(*,*)AMC
      CALL WATER(AMC,RAIN,K,MM,CN1,CN,CNIFOR,WY1,J)
      WRITE(*,*)WY1(MM)
      IF ((RAIN(K).GT.0.0).AND.(WY1(MM).GT.0.0))THEN
      FRACT1(MM)=WY1(MM)/RAIN(K)
      WRITE(*,*)FRACT1(MM)
      ELSE
      FRACT1(MM)=0.0
      END IF
      WRITE(11,22)RAIN(K),J,CNIFOR,WY1(MM)
   22 FORMAT(1X,F7.2,8X,I2,11X,F7.2,9X,F8.4)
  160 CONTINUE
      WRITE(11,*)'-----------------------------------------------------'
      ELSE IF (II.EQ.2)THEN
      DO 165 K=6,N
      AMC=0.0
      DO 167 K1=1,5
  167 AMC=AMC+RAIN(K-K1)
      MM=K-5
      CALL WATER(AMC,RAIN,K,MM,CN2,CN,CNICUL,WY2,J)
      IF ((RAIN(K).GT.0.0).AND.(WY2(MM).GT.0.0))THEN
      FRACT2(MM)=WY2(MM)/RAIN(K)
      ELSE
      FRACT2(MM)=0.0
      END IF
      WRITE(12,25)MM,RAIN(K),J,CNICUL,WY2(MM),FRACT2(MM)
   25 FORMAT(1X,I3,3X,F6.2,4X,I2,4X,F7.2,6X,F8.4,4X,F6.5)
  165 CONTINUE
      WRITE(12,*)'-----------------------------------------------------'
      ELSE
      DO 170 K=6,N
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```
      AMC=0.0
      DO 172 K1=1,5
  172 AMC=AMC+RAIN(K-K1)
      MM=K-5
      CALL WATER(AMC,RAIN,K,MM,CN3,CN,CNIFAL,WY3,J)
      IF((RAIN(K).GT.0.0).AND.(WY3(MM).GT.0.0))THEN
      FRACT3(MM)=WY3(MM)/RAIN(K)
      ELSE
      FRACT3(MM)=0.0
      END IF
      WRITE(13,23)RAIN(K),J,CNIFAL,WY3(MM)
   23 FORMAT(1X,F7.2,8X,I2,9X,F7.2,8X,F8.4)
  170 CONTINUE
      WRITE(13,*)'-----------------------------------------------------'
      END IF
  150 CONTINUE
      WRITE(16,*)'TABLE:5 SPILL VOLUMES FROM THE UPSTREAM RESERVIORS'
      WRITE(16,*)'         OF ED-5 (i.e.ED-18,ED-19&ED-21)'
      WRITE(16,*)'-----------------------------------------------------'
      WRITE(16,*)'DAY      TOTAL SPILL    FRACTION OF    ACTUAL SPILL '
      WRITE(16,*)'NO.     VOLUME (cu.m)   LOSSES          VOLUME (cu.m)'
      WRITE(16,*)'-----------------------------------------------------'
      WRITE(15,*)'TABLE:6 WEIGHTED RUNOFF OF ED-5'
      WRITE(15,*)'-----------------------------------------------------'
      WRITE(15,*)' DAY   WEIGHTED    FRACTION1    FRACTION2    FRACTION3'
      WRITE(15,*)' NO.   RUNOFF(mm) (FOREST)     (CULT.LAND)   (FALLOW) '
      WRITE(15,*)'-----------------------------------------------------'
      DO 175 KK=1,155
      WWSY(KK)=(WY1(KK)*A1+WY2(KK)*A2+WY3(KK)*A3)/(A1+A2+A3)
      WRITE (15,32)KK,WWSY(KK),FRACT1(KK),FRACT2(KK),FRACT3(KK)
   32 FORMAT(3X,I3,2X,F8.4,5X,F6.4,6X,F6.4,6X,F6.4)
      TOTSP(KK)=0.0
  175 CONTINUE
      WRITE(15,*)'-----------------------------------------------------'
      READ(9,*)((SPILL(I,J),J=1,3),I=1,155)
      DO 180 NN=1,155
      DO 185 JJ=1,3
      TOTSP(NN)=TOTSP(NN)+SPILL(NN,JJ)
  185 CONTINUE
      ACTSP(NN)=TOTSP(NN)*FRACT2(NN)
      WRITE(16,35)NN,TOTSP(NN),FRACT2(NN),ACTSP(NN)
   35 FORMAT(1X,I3,4X,F9.2,11X,F4.2,6X,F9.2)
  180 CONTINUE
      WRITE(16,*)'-----------------------------------------------------'
      WRITE(14,*)'TABLE:7 RESERVIOR WATER LEVELS OF ED-5'
      WRITE(14,*)'------------------------------------------------------
     &-------------'
      WRITE(14,*)'DAY    RUNVOL    TRNVOL     PINDEP    APOND    PVOL    PDEP
     &    SPILL'
      WRITE(14,*)'NO.    (cu.m)    (cu.m)      (m)      (sq.m)  (cu.m)   (m)
     &    (cu.m)'
      WRITE(14,*)'------------------------------------------------------
     &-------------'
      XINDEP=1.75
      CALL INT(1.35,XINDEP,1.80,240.0,600.0,XINVOL)
      DO 190 NNN=1,155
      CALL RESBAL(NNN,XINVOL,WWSY,ACTSP,PINDEP,APOND,PVOL,PDEP,SP)
  190 CONTINUE
```

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      WRITE(14,*)'--------------------------------------------------
     &-------------'
      STOP
      END
*     SUBROUTINE FOR CALCULATING WATERYIELD OF MICRO WATERSHED
      SUBROUTINE WATER(AMC,PRECIP,K,MM,X,CN,Y,WSY,J)
      DIMENSION PRECIP(200),WSY(200),CN(7,3)
      IF (AMC.LT.35.6)THEN
      J=1
      ELSE IF((AMC.LT.53.3).AND.(AMC.GT.35.6))THEN
      J=2
      ELSE
      J=3
      END IF
      IF((J.EQ.1).OR.(J.EQ.3))THEN
      CALL COMPARE(X,CN,Y,J)
      ELSE
      Y=X
      ENDIF
      S=(25400/Y-254)
      XINABS=0.2*S
      IF(PRECIP(K).GT.XINABS)THEN
      WSY(MM)=((PRECIP(K)-XINABS)**2)/(PRECIP(K)+0.8*S)
      ELSE
      WSY(MM)=0.0
      ENDIF
      RETURN
      END
C     SUBROUTINE FOR COMPARISION OF CURVE NUMBERS
      SUBROUTINE COMPARE(WCN,CN,CNINT,J)
      DIMENSION CN(7,3)
      IF((WCN.GE.40).AND.(WCN.LT.50))THEN
      P=CN(1,J)
      Q=CN(2,J)
      CALL INT(40.0,WCN,50.0,P,Q,CNINT)
      ELSE IF((WCN.GE.50).AND.(WCN.LT.60))THEN
      P=CN(2,J)
      Q=CN(3,J)
      CALL INT(50.0,WCN,60.0,P,Q,CNINT)
      ELSE IF((WCN.GE.60).AND.(WCN.LT.70))THEN
      P=CN(3,J)
      Q=CN(4,J)
      CALL INT(60.0,WCN,70.0,P,Q,CNINT)
      ELSE IF((WCN.GE.70).AND.(WCN.LT.80))THEN
      P=CN(4,J)
      Q=CN(5,J)
      CALL INT(70.0,WCN,80.0,P,Q,CNINT)
      ELSE IF((WCN.GE.80).AND.(WCN.LT.90))THEN
      P=CN(5,J)
      Q=CN(6,J)
      CALL INT(80.0,WCN,90.0,P,Q,CNINT)
      ELSE IF((WCN.GE.90).AND.(WCN.LE.100))THEN
      P=CN(6,J)
      Q=CN(7,J)
      CALL INT(90.0,WCN,100.0,P,Q,CNINT)
      END IF
      RETURN
      END
```

```
C     SUBROUTINE FOR INTERPOLATION OF CURVE NUMBER
      SUBROUTINE INT(CN1AM2,WCN,CN2AM2,CN1AM,CN2AM,CNINT)
      RATIO=(WCN-CN1AM2)/(CN2AM2-CN1AM2)
      CNINT=CN1AM+RATIO*(CN2AM-CN1AM)
      RETURN
      END
C     SUBROUTINE FOR PREDICTING RESERVIOR WATER LEVELS ON
C     DAILY WATER  BUDGETTING
      SUBROUTINE RESBAL(LL,XINVOL,WWSY,ACTSP,PINDEP,APOND,PVOL,PDEP,SP)
      DIMENSION WWSY(200),RUNVOL(200),TRNVOL(200),PINDEP(200),APOND(200)
      DIMENSION EVAPO(200),SEEP(200),PVOL(200),PDEP(200),ACTSP(200),
      DIMENSION SP(200)
      WSHAR=222585.0
      PMAXVL=6510.0
      RUNVOL(LL)=((WWSY(LL)/1000.)*WSHAR)+ACTSP(LL)
      IF((RUNVOL(LL)+XINVOL).GE.PMAXVL)THEN
      TRNVOL(LL)=PMAXVL
      SP(LL)=RUNVOL(LL)+XINVOL-PMAXVL
      ELSE
      TRNVOL(LL)=RUNVOL(LL)+XINVOL
      SP(LL)=0.0
      END IF
      CALL VOLDEP(LL,TRNVOL,PINDEP)
      CALL RELOSS(LL,PINDEP,EVAPO,SEEP)
      CALL AREADEP(LL,PINDEP,APOND)
      PVOL(LL)=TRNVOL(LL)-(EVAPO(LL)/1000.)*APOND(LL)-(SEEP(LL)/1000.)
     &*APOND(LL)
      IF (PVOL(LL).LE.0.0)THEN
      PVOL(LL)=0.0
      CALL VOLDEP(LL,PVOL,PDEP)
      ELSE
      CALL VOLDEP(LL,PVOL,PDEP)
      END IF
      WRITE(14,100)LL,RUNVOL(LL),TRNVOL(LL),PINDEP(LL),APOND(LL),
     &PVOL(LL),PDEP(LL),SP(LL)
100   FORMAT(1X,I3,1X,F9.2,2X,F7.2,2X,F6.3,2X,F7.2,1X,F7.2,1X,F6.3,1X,
     &F7.2)
      XINVOL=PVOL(LL)
      RETURN
      END
C     SUBROUTINE TO CALCULATE POND WATER DEPTH FROM VOLUME-DEPTH
C     RELATIONSHIPS FOR ED-5 RESERVIOR BY INTERPOLATION
      SUBROUTINE VOLDEP(LL,PP,QQ)
      DIMENSION PP(200),QQ(200)
      IF ((PP(LL).GE.0.0).AND.(PP(LL).LE.75.0))THEN
      CALL LININT(LL,0.0,PP,75.0,0.0,0.90,QQ)
      ELSE IF ((PP(LL).GT.75.0).AND.(PP(LL).LE.240.0))THEN
      CALL LININT(LL,75.0,PP,240.0,0.90,1.35,QQ)
      ELSE IF ((PP(LL).GT.240.0).AND.(PP(LL).LE.600.0))THEN
      CALL LININT(LL,240.0,PP,600.0,1.35,1.80,QQ)
      ELSE IF ((PP(LL).GT.600.0).AND.(PP(LL).LE.1230.0))THEN
      CALL LININT(LL,600.0,PP,1230.0,1.80,2.37,QQ)
      ELSE IF ((PP(LL).GT.1230.0).AND.(PP(LL).LE.1890.0))THEN
      CALL LININT(LL,1230.0,PP,1890.0,2.37,2.70,QQ)
      ELSE IF ((PP(LL).GT.1890.0).AND.(PP(LL).LE.3480.0))THEN
      CALL LININT(LL,1890.0,PP,3480.0,2.70,3.32,QQ)
      ELSE IF ((PP(LL).GT.3480.0).AND.(PP(LL).LE.6510.0))THEN
      CALL LININT(LL,3480.0,PP,6510.0,3.32,4.30,QQ)
```

```
      END IF
      RETURN
      END
C     SUBROUTINE TO CALCULATE WATERSPREAD AREA FROM AREA-DEPTH
C     RLATIONSHIPS BY INTERPOLATION FOR RESERVIOR NO. ED-5
      SUBROUTINE AREADEP(LL,XX,YY)
      DIMENSION XX(200),YY(200)
      IF ((XX(LL).GE.0.0).AND.(XX(LL).LE.1.05))THEN
      CALL LININT(LL,0.0,XX,1.05,0.0,220.0,YY)
      ELSE IF ((XX(LL).GT.1.05).AND.(XX(LL).LE.1.34))THEN
      CALL LININT(LL,1.05,XX,1.34,220.0,350.0,YY)
      ELSE IF ((XX(LL).GT.1.34).AND.(XX(LL).LE.1.65))THEN
      CALL LININT(LL,1.34,XX,1.65,350.0,650.0,YY)
      ELSE IF ((XX(LL).GT.1.65).AND.(XX(LL).LE.2.34))THEN
      CALL LININT(LL,1.65,XX,2.34,650.0,1650.0,YY)
      ELSE IF ((XX(LL).GT.2.34).AND.(XX(LL).LE.3.0))THEN
      CALL LININT(LL,2.34,XX,3.0,1650.0,2600.0,YY)
      ELSE IF ((XX(LL).GT.3.0).AND.(XX(LL).LE.3.34))THEN
      CALL LININT(LL,3.0,XX,3.34,2600.0,2910.0,YY)
      ELSE IF ((XX(LL).GT.3.34).AND.(XX(LL).LE.4.30))THEN
      CALL LININT(LL,3.34,XX,4.34,2910.0,3600.0,YY)
      END IF
      RETURN
      END
C     SUBROUTINE TO INTERPOLATE DEPTH AND WATERSPREAD AREA
      SUBROUTINE LININT(LL,PQR,UU,QRS,TUV,UVW,VV)
      DIMENSION UU(200),VV(200)
      RATIO=(UU(LL)-PQR)/(QRS-PQR)
      VV(LL)=TUV+RATIO*(UVW-TUV)
      RETURN
      END
C     SUBROUTINE TO SEPERATE LOSSES AT DIFFERENT WATER DEPTHS IN
C     THE RESERVIOR NO. ED-5
      SUBROUTINE RELOSS(LL,RR,SS,TT)
      DIMENSION RR(200),SS(200),TT(200)
      IF (LL.LE.28)THEN
      SS(LL)=7.0
      ELSE IF((LL.GT.28).AND.(LL.LE.59))THEN
      SS(LL)=5.0
      ELSE IF((LL.GT.59).AND.(LL.LE.120))THEN
      SS(LL)=4.0
      ELSE IF((LL.GT.120).AND.(LL.LE.155))THEN
      SS(LL)=3.0
      END IF
      IF ((RR(LL).GT.0.0).AND.(RR(LL).LE.2.50))THEN
      TOTLOS=25.0
      ELSE IF ((RR(LL).GT.2.50).AND.(RR(LL).LE.3.40))THEN
      TOTLOS=50.0
      ELSE IF ((RR(LL).GT.3.4).AND.(RR(LL).LE.4.3))THEN
      TOTLOS=100.0
      END IF
      TT(LL)=TOTLOS-SS(LL)
      RETURN
      END
```

APPENDIX - D

Table D.1. Crop coefficients (K_c) of maize and pigeon pea during different growth periods

Maize		Pigeon pea	
DAS	K_c	DAS	K_c
0-20	0.4	0-15	0.21
		15-30	0.27
20-55	0.8	30-50	0.38
55-95	1.15	50-70	0.77
		70-100	0.68
95-125	0.70	100-125	0.28

Table D.2. Comparison of average absolute deviation estimated by regression equations and linear interpolation for depth-waterspread area and depth-storage relationships

Reservoir identification	Regression equations	r^2 value	Average absolute deviation (%) Estimated by regression equation	Estimated by linear interpolation
ED 5	WSA = 270.4 $d^{1.91}$	0.975	13.6	0.9
	ST = 116.2 $d^{2.77}$	0.996	7.2	1.5
ED 14	WSA = 97.5 $d^{2.38}$	0.947	33.6	0.4
	ST = 36.1 $d^{3.36}$	0.988	21.1	1.2
ED 18	WSA = 339.3 $d^{1.25}$	0.987	8.0	0.9
	ST = 157.7 $d^{2.26}$	0.998	2.5	1.2
ED 19	WSA = 575.4 $d^{1.02}$	0.984	8.7	0.5
	ST = 282 $d^{1.97}$	0.997	3.8	0.4
ED 21	WSA = 525.8 $d^{1.18}$	0.988	6.2	0.3
	ST = 251.4 $d^{2.17}$	0.999	0.9	0.3
	Mean		10.5	0.8

WSA = Water spread area, sq. m., ST = Storage volume, cu.m.
d = Depth of storage, m.

APPENDIX E

Economic Analysis

(I) Power requirement

Length of suction pipe taken as per the maximum depth of storage in the reservoir	=	6.0 m
Elevation drop in the field	=	3.3 m
Length of pipe required to pump water from delivery to top most point of agriculture land	=	485 m
Total length of delivery pipe needed	=	488.3 m
Total pipe length required for both suction and delivery	=	494.3 m

Assuming at the rate of 10 l/s with 75 mm dia of PVC pipe at rating of 4.5 kg/cm^2,

Friction head loss/100 m length		
(Michael and Khepar, 1985)	=	6.60 m
Total friction loss	=	6.6 x 4.94
	=	32.60 m
Total head	=	32.6 + 6.0 + 3.3
	=	41.90 m
Power required = [(10 x 41.9)/75)]	=	5.6 hp
Assuming 55 % efficiency of diesel engine,		
Actual power required	=	5.6 / 0.55
	=	10.2 ~ 10 hp

According to the power requirement of 10 hp, pump available in market is selected with size 100 mm x 75 mm with 15.5 l/s discharge at 39 m total head (Taneja and Sondhi, 1988).

(II) Estimation of fixed cost when irrigated area is 19.02 ha (As per 1993 market prices)

a) Structure cost

Total volume of storage available from the reservoirs ED 5 and ED 14	=	6510 + 5550
	=	12060 cu.m
Cost of construction (Anonymous, 1992)	=	Rs. 2000/acre - ft
1 acre - ft	=	1226.84 cu.m
Cost of storage/cu.m	=	2000 / 1226.84
	=	Rs. 1.63
Total cost of structure	=	12060 x 1.63
	=	Rs. 19657.80

b) Pumping investment

Cost of diesel engine (10 hp)	=	Rs. 10835.00
Cost of trolley and coupling	=	Rs. 2850.00
Cost of pump (100 mm x 75 mm)	=	Rs. 1850.00
Cost of foot valve (100 mm)	=	Rs. 500.00
Total	=	**Rs. 16035.00**

c) Investment on PVC pipe (when total area of 19.02 ha is under irrigated agriculture).

Cost of PVC pipe of 100 mm with rating 4 kg/cm^2 (Market price, 1993)	=	Rs. 76.65/m
Cost of delivery pipe of 75 mm dia with 4 kg/cm^2 rating	=	Rs. 62.60/m
Cost of suction pipe	=	6 x 76.65
	=	Rs. 459.90
Cost of delivery pipe	=	488.3 x 62.6
	=	Rs. 30,567.58
Total cost of PVC pipe for suction and delivery	=	Rs. 31027.48

d) **Cost of diversion box is taken as Rs. 1000.00**

e) (i) Total capital cost including reservoir cost

= 19657.80 + 16035.0 + 31027.48 + 1000.0

= Rs. 67720.28

(ii) Total capital cost excluding reservoir cost

= Rs. 48062.48

f) Equivalent Annual Capital Cost

Amortization factor (AF) = $[\{r(1+r)^n\} / \{(1+r)^n - 1\}]$

where, r = interest rate (12 %),

n = chosen amortization period, years

Annual capital cost = Total capital cost * AF

(i) Annual capital cost including reservoir cost

when	1)	n = 5	=	Rs. 996.93/ha
	2)	n = 10	=	Rs. 640.89/ha
	3)	n = 15	=	Rs. 534.07/ha

(ii) Annual capital cost excluding reservoir cost

when	1)	n = 5	=	Rs. 707.54/ha
	2)	n = 10	=	Rs. 454.85/ha
	3)	n = 15	=	Rs. 379.04/ha

(III) Fixed cost when irrigated area is 2.83 ha

Reduced pipe length in delivery	=	74 m
Cost of delivery pipe = 74 x 62.6	=	Rs. 4632.4
Total cost of pipe = 4632.4 + 459.9	=	Rs. 5092.30
Total capital cost including reservoir cost	=	Rs. 41785.10
Total capital cost excluding reservoir cost	=	Rs. 22127.30

Annual capital cost including reservoir cost when

1)	n = 5 years	=	Rs. 615.13/ha
2)	n = 10 years	=	Rs. 395.44/ha
3)	n = 15 years	=	Rs. 329.54/ha

Annual capital cost excluding reservoir cost when

1)	n = 5 years	=	Rs. 325.74/ha
2)	n = 10 years	=	Rs. 209.41/ha
3)	n = 15 years	=	Rs. 174.50/ha

(IV) Fixed cost when irrigated area is 5.05 ha

Cost of delivery pipe for 5.05 ha area = Rs. 8116.00

Total capital cost including reservoir cost = Rs. 44808.80

Total capital cost excluding reservoir cost = Rs. 25151.00

Annual capital cost	Including reservoir cost (Rs./ha)	Excluding reservoir cost (Rs./ha)
when, n = 5 years	659.65	370.26
n = 10 years	424.06	238.02
n = 15 years	353.38	198.35

V. Estimation of running cost (including cost of diesel, labour, depreciation and repair, maintenance and desiltation)

(a) When Paddy is individual crop activity

Area to be irrigated = 2.83 ha

Total quantity of water to be pumped [Gross deficits (Table 5.11) * Area] = 1.292×10^7 l

No. of hours of diesel engine operation
= $(1.292 \times 10^7) / (15.5 \times 3600)$ = 231.54 hr

Cost of diesel @ 1.2 l/hr
consumption at Rs. 7/l = 231.54 x 1.2 x 7
= Rs. 1944.94

Cost of labour taking 2 labours
@ Rs. 30/8 hr (one labour for
operation + one for irrigation) = Rs. 1736.56

Total cost of diesel and labour = Rs. 1300.88/ha

Depreciation cost = Rs. 566.61/ha

Repairs and maintenance cost = Rs. 283.30/ha

Desiltation cost for removing silt
in reservoirs in each year at 7 %
of total volume (Sarkar and Basu, 1985)
of reservoirs ED 5 and ED 14 = Rs. 1376.05
= Rs.72.35/ha

Total running cost for individual
activity of paddy
= 1300.88 + 566.61 + 283.3 + 72.35 = Rs. 2223.14/ha

(b) When maize is grown as individual crop :

Area to be irrigated = 18.69 ha

Total quantity of water to be
pumped = 0.926 ha m.
= 0.926×10^7 l

No. of hours of diesel engine
operated = 165.95 hr

Diesel cost = Rs.74.58/ha

Labour cost (10 labours)	=	Rs.332.60/ha
Repairs and maintenance cost	=	Rs. 42.90/ha
Total running cost for maize = 74.58+85.79+42.90+332.60+72.35	=	Rs. 608.22

(c) When Pigeon pea is grown as individual crop :

Area to be irrigated	=	19.02 ha
Total quantity of water to be pumped	=	0.306 ha m.
No. of hours of diesel engine to be operated	=	54.83 hr
Diesel cost	=	Rs. 24.22/hr
Labour cost (10 labours)	=	Rs.108.10/ha
Depreciation and repairs + maintenance cost + Desiltation	=	Rs.198.80/ha
Total running cost	=	Rs.331.12/ha

(d) Annual net benefits when the crop activities are mutually exclusive (Calculations as per Table 5.12)

(i) Paddy + Rainfed crop (Little millet)

Annual benefit net of cultivation cost = Rs. 1706.76/ha

(ii) Annual benefit net of cultivation cost when maize + Little millet is considered = Rs. 8615.54/ha

(iii) Annual benefit net of cultivation cost when pigeon pea is considered = Rs. 5000/ha

(e) Annual running cost when crop plan comprising maize and Pigeon pea is considered :

Area under maize = 18.69 ha

Area under pigeon pea	=	0.33 ha
Cost involved in irrigating pigeon pea of 0.33 ha	=	Rs. 15.10
Cost involvled in irrigating maize of 18.69 ha	=	Rs. 7610.35
Total cost involved in irrigation of maize + pigeon pea	=	Rs. 7625.45
Depreciation cost	=	Rs. 1603.50
Repair and maintenance cost	=	Rs. 801.75
Desiltation cost	=	Rs. 1376.05
Total	=	Rs. 11406.75
Total running cost @ 19.02 ha	=	Rs. 599.72/ha
Annual benefit net of cultivation cost	=	Rs. 8685.35/ha

(f) Annual running cost when crop plan comprising paddy, pigeon pea and little millet is considered :

Area under paddy	=	2.83 ha
Area under pigeon pea	=	2.22 ha
Area under little millet	=	13.97 ha
Cost involved in irrigating paddy of 2.83 ha	=	Rs. 3681.49
Cost involved in irrigating pigeon pea of 2.22 ha	=	Rs. 101.58
Depreciation cost	=	Rs. 1603.50
Repairs and maintenance cost	=	Rs. 801.75
Total	=	Rs. 6188.32

Total cost of irrigation for paddy + pigeon pea @ 5.05 ha	= Rs. 1225.41/ha
Desiltation cost @ 19.02 ha	= Rs. 72.35/ha
Total	= Rs. 1297.76/ha
Annual running cost for the crop plan comprising paddy + pigeon pea and little millet	= Rs. 1297.76/ha
Annual benefit net of cultivation cost	= Rs. 2174.60/ha

****

APPENDIX F

F.1 Listing sample output of S W Y M O D for the microwatershed MW 21

****

RUN NO: 1

TABLE:1 SELECTED (CN) AND (A)

LAND USE	CN VALUE	AREA(%)
FOREST	80.00	100.00
AGRICULTURE LAND	.00	.00
FALLOW LAND	.00	.00

WEIGHTED CN VALUE= 80.00

TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR DIFFERENT AMC AND CURVE NUMBERS

RAINFALL (mm)	AMC	INTERPOLATED CN VALUE	RUNOFF (mm)
31.60	1	63.00	.0206
.00	3	91.00	.0000
.00	2	80.00	.0000
5.40	1	63.00	.0000
16.40	2	80.00	.2037
11.10	3	91.00	1.1833
.30	1	63.00	.0000
2.40	1	63.00	.0000
.00	2	80.00	.0000
9.00	1	63.00	.0000
1.50	1	63.00	.0000
18.40	1	63.00	.0000
1.50	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.60	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
.00	1	63.00	.0000
13.20	1	63.00	.0000

TABLE:3 RESERVIOR WATER LEVELS ON DAILY WATER BALANCE

DAY NO.	RUNVOL (cu.m)	TRNVOL (cu.m)	PINDEP (m)	APOND (sq.m)	PVOL (cu.m)	PDEP (m)	SPILL (cu.m)
1	.42	.42	.0320	19.09	.00	.0000	.0000
2	.00	.00	.0000	.00	.00	.0000	.0000
3	.00	.00	.0000	.00	.00	.0000	.0000
4	.00	.00	.0000	.00	.00	.0000	.0000
5	4.12	4.12	.0637	38.09	2.69	.0515	.0000

6	23.94	26.64	.2443	145.96	17.52	.1787	.0000
7	.00	17.52	.1787	106.77	10.84	.1214	.0000
8	.00	10.84	.1214	72.55	8.12	.0981	.0000
9	.00	8.12	.0981	58.60	5.92	.0792	.0000
10	.00	5.92	.0792	47.33	4.15	.0640	.0000
11	.00	4.15	.0640	38.23	2.72	.0517	.0000
12	.00	2.72	.0517	30.88	1.56	.0417	.0000
13	.00	1.56	.0417	24.94	.62	.0337	.0000
14	.00	.62	.0337	20.14	.00	.0000	.0000
15	.00	.00	.0000	.00	.00	.0000	.0000
16	.00	.00	.0000	.00	.00	.0000	.0000
17	.00	.00	.0000	.00	.00	.0000	.0000
18	.00	.00	.0000	.00	.00	.0000	.0000
19	.00	.00	.0000	.00	.00	.0000	.0000
20	.00	.00	.0000	.00	.00	.0000	.0000
21	.00	.00	.0000	.00	.00	.0000	.0000
22	.00	.00	.0000	.00	.00	.0000	.0000
23	.00	.00	.0000	.00	.00	.0000	.0000
24	.00	.00	.0000	.00	.00	.0000	.0000

AVE.DEVIATION= 15.2232100 cm.
RUN NO: 2
TABLE:1 SELECTED (CN) AND (A)

LAND USE	CN VALUE	AREA(%)
FOREST	85.00	100.00
AGRICULTURE LAND	.00	.00
FALLOW LAND	.00	.00

WEIGHTED CN VALUE= 85.00

TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR DIFFERENT AMC AND CURVE NUMBERS

RAINFALL (mm)	AMC	INTERPOLATED CN VALUE	RUNOFF (mm)
31.60	1	70.50	.9173
.00	3	93.50	.0000
.00	2	85.00	.0000
5.40	1	70.50	.0000
16.40	2	85.00	1.0579
11.10	3	93.50	2.2707
.30	1	70.50	.0000
2.40	1	70.50	.0000
.00	2	85.00	.0000
9.00	1	70.50	.0000
1.50	1	70.50	.0000
18.40	1	70.50	.0000
1.50	1	70.50	.0000
.00	1	70.50	.0000
.00	1	70.50	.0000
.00	1	70.50	.0000
.60	1	70.50	.0000
.00	1	70.50	.0000
.00	1	70.50	.0000

.00	1	70.50	.0000
.00	1	70.50	.0000
.00	1	70.50	.0000
.00	1	70.50	.0000
13.20	1	70.50	.0000

TABLE:3 RESERVIOR WATER LEVELS ON DAILY WATER BALANCE

DAY NO.	RUNVOL (cu.m)	TRNVOL (cu.m)	PINDEP (m)	APOND (sq.m)	PVOL (cu.m)	PDEP (m)	SPILL (cu.m)
1	18.56	18.56	.1877	112.14	11.55	.1275	.0000
2	.00	11.55	.1275	76.20	6.79	.0866	.0000
3	.00	6.79	.0866	51.78	4.85	.0700	.0000
4	.00	4.85	.0700	41.82	3.28	.0565	.0000
5	21.41	24.69	.2312	138.19	16.05	.1661	.0000
6	45.95	62.00	.4600	272.01	29.36	.2624	.0000
7	.00	29.36	.2624	156.79	19.56	.1962	.0000
8	.00	19.56	.1962	117.24	12.23	.1333	.0000
9	.00	12.23	.1333	79.67	7.25	.0906	.0000
10	.00	7.25	.0906	54.13	5.22	.0732	.0000
11	.00	5.22	.0732	43.72	3.58	.0591	.0000
12	.00	3.58	.0591	35.32	2.26	.0477	.0000
13	.00	2.26	.0477	28.52	1.19	.0386	.0000
14	.00	1.19	.0386	23.04	.32	.0311	.0000
15	.00	.32	.0311	18.61	.00	.0000	.0000
16	.00	.00	.0000	.00	.00	.0000	.0000
17	.00	.00	.0000	.00	.00	.0000	.0000
18	.00	.00	.0000	.00	.00	.0000	.0000
19	.00	.00	.0000	.00	.00	.0000	.0000
20	.00	.00	.0000	.00	.00	.0000	.0000
21	.00	.00	.0000	.00	.00	.0000	.0000
22	.00	.00	.0000	.00	.00	.0000	.0000
23	.00	.00	.0000	.00	.00	.0000	.0000
24	.00	.00	.0000	.00	.00	.0000	.0000

AVE.DEVIATION= 10.6948100 cm.
RUN NO: 3
TABLE:1 SELECTED (CN) AND (A)

LAND USE	CN VALUE	AREA(%)
FOREST	90.00	100.00
AGRICULTURE LAND	.00	.00
FALLOW LAND	.00	.00

WEIGHTED CN VALUE= 90.00

TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF
FOR DIFFERENT AMC AND CURVE NUMBERS

RAINFALL (mm)	AMC	INTERPOLATED CN VALUE	RUNOFF (mm)
31.60	1	78.00	3.3551
.00	3	96.00	.0000
.00	2	90.00	.0000

5.40	1	78.00	.0000
16.40	2	90.00	2.9679
11.10	3	96.00	4.1244
.30	1	78.00	.0000
2.40	1	78.00	.0000
.00	2	90.00	.0000
9.00	1	78.00	.0000
1.50	1	78.00	.0000
18.40	1	78.00	.2190
1.50	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.60	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
.00	1	78.00	.0000
13.20	1	78.00	.0000

TABLE:3 RESERVIOR WATER LEVELS ON DAILY WATER BALANCE

DAY NO.	RUNVOL (cu.m)	TRNVOL (cu.m)	PINDEP (m)	APOND (sq.m)	PVOL (cu.m)	PDEP (m)	SPILL (cu.m)
1	67.89	67.89	.4895	287.93	33.34	.2889	.0000
2	.00	33.34	.2889	172.65	22.55	.2170	.0000
3	.00	22.55	.2170	129.67	14.44	.1523	.0000
4	.00	14.44	.1523	91.02	8.76	.1035	.0000
5	60.06	68.81	.4941	290.42	33.96	.2931	.0000
6	83.46	117.42	.6498	374.56	72.47	.5124	.0000
7	.00	72.47	.5124	300.30	36.43	.3096	.0000
8	.00	36.43	.3096	184.98	24.87	.2325	.0000
9	.00	24.87	.2325	138.92	16.19	.1673	.0000
10	.00	16.19	.1673	99.97	9.94	.1137	.0000
11	.00	9.94	.1137	67.93	7.39	.0918	.0000
12	4.43	11.83	.1298	77.59	6.98	.0882	.0000
13	.00	6.98	.0882	52.72	5.00	.0713	.0000
14	.00	5.00	.0713	42.58	3.40	.0576	.0000
15	.00	3.40	.0576	34.40	2.11	.0465	.0000
16	.00	2.11	.0465	27.78	1.07	.0376	.0000
17	.00	1.07	.0376	22.44	.23	.0303	.0000
18	.00	.23	.0303	18.12	.00	.0000	.0000
19	.00	.00	.0000	.00	.00	.0000	.0000
20	.00	.00	.0000	.00	.00	.0000	.0000
21	.00	.00	.0000	.00	.00	.0000	.0000
22	.00	.00	.0000	.00	.00	.0000	.0000
23	.00	.00	.0000	.00	.00	.0000	.0000
24	.00	.00	.0000	.00	.00	.0000	.0000

AVE.DEVIATION= 4.0497380 cm.

CHECKING FOR CN1 IN VICINITY OF 90

RUN NO: 1

TABLE:1 SELECTED (CN) AND (A)

LAND USE	CN VALUE	AREA(%)
FOREST	91.20	100.00
AGRICULTURE LAND	.00	.00
FALLOW LAND	.00	.00

WEIGHTED CN VALUE= 91.20

TABLE:2 RELATIONSHIP BETWEEN RAINFALL AND RUNOFF FOR DIFFERENT AMC AND CURVE NUMBERS

RAINFALL (mm)	AMC	INTERPOLATED CN VALUE	RUNOFF (mm)
31.60	1	80.64	4.6839
.00	3	96.48	.0000
.00	2	91.20	.0000
5.40	1	80.64	.0000
16.40	2	91.20	3.6718
11.10	3	96.48	4.6182
.30	1	80.64	.0000
2.40	1	80.64	.0000
.00	2	91.20	.0000
9.00	1	80.64	.0000
1.50	1	80.64	.0000
18.40	1	80.64	.5729
1.50	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.60	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
.00	1	80.64	.0000
13.20	1	80.64	.0163

TABLE:3 RESERVIOR WATER LEVELS ON DAILY WATER BALANCE

DAY NO.	RUNVOL (cu.m)	TRNVOL (cu.m)	PINDEP (m)	APOND (sq.m)	PVOL (cu.m)	PDEP (m)	SPILL (cu.m)
1	94.78	94.78	.5894	341.94	53.75	.4187	.0000
2	.00	53.75	.4187	249.72	23.78	.2252	.0000
3	.00	23.78	.2252	134.57	15.37	.1603	.0000
4	.00	15.37	.1603	95.77	9.38	.1089	.0000
5	74.30	83.68	.5598	325.95	44.57	.3638	.0000
6	93.45	138.02	.7047	404.24	89.51	.5754	.0000
7	.00	89.51	.5754	334.35	49.39	.3959	.0000
8	.00	49.39	.3959	236.58	21.00	.2066	.0000
9	.00	21.00	.2066	123.48	13.28	.1423	.0000
10	.00	13.28	.1423	85.05	7.96	.0967	.0000
11	.00	7.96	.0967	57.79	5.80	.0781	.0000
12	11.59	17.39	.1776	106.12	10.76	.1207	.0000

13	.00	10.76	.1207	72.11	8.05	.0975	.0000
14	.00	8.05	.0975	58.24	5.87	.0787	.0000
15	.00	5.87	.0787	47.04	4.10	.0636	.0000
16	.00	4.10	.0636	38.00	2.68	.0514	.0000
17	.00	2.68	.0514	30.69	1.53	.0415	.0000
18	.00	1.53	.0415	24.79	.60	.0335	.0000
19	.00	.60	.0335	20.02	.00	.0000	.0000
20	.00	.00	.0000	.00	.00	.0000	.0000
21	.00	.00	.0000	.00	.00	.0000	.0000
22	.00	.00	.0000	.00	.00	.0000	.0000
23	.00	.00	.0000	.00	.00	.0000	.0000
24	.33	.33	.0312	18.64	.00	.0000	.0000

AVE.DEVIATION= 3.8025990 cm.

Table F.2 Sample calculation of weekly water deficits for paddy in the year 1972

Week No.	R (mm)	S_P (mm)	WR_O (mm)	PET (mm)	PERCO (mm)	± ΔS (mm)
23	0.0	0.0	0.0	37.7	49.0	-86.7
24	0.0	0.0	0.0	37.7	49.0	-86.7
25	12.10	0.0	0.0	37.7	49.0	-74.7
26	42.80	0.0	0.1	36.2	49.0	-42.5
27	61.30	0.0	3.0	27.0	69.0	-17.7
28	103.60	2.8	50.8	27.0	49.0	-20.4
29	87.90	8.2	27.1	27.0	49.0	-7.0
30	0.0	0.0	0.0	27.0	49.0	-76.0
31	24.7	0.0	0.2	23.1	49.0	-47.6
32	157.3	10.4	79.3	21.6	49.0	+17.8
33	70.9	0.0	5.0	21.6	49.0	-4.6
34	174.2	12.1	51.8	21.6	49.0	+64.0
35	24.7	0.7	6.2	21.6	49.0	-51.4
36	79.5	0.0	9.7	21.6	49.0	-0.8
37	158.7	7.0	85.0	21.6	49.0	+10.1
38	14.3	0.0	0.0	21.6	49.0	-56.3
39	6.7	0.0	0.0	21.6	49.0	-63.9
40	27.7	0.0	0.6	16.2	49.0	-38.1
41	25.5	0.0	1.0	16.2	49.0	-40.6
42	0.0	0.0	0.0	16.2	49.0	-65.2
43	0.0	0.0	0.0	16.2	49.0	-65.2
44	8.7	0.0	0.0	16.2	49.0	-56.5

Note :R = Rainfall; Sp = Absorbed spill depth; WR_o = Weighted runoff; PET = Potential evapotranspiration; PERCO = Deep percolation; ± ΔS = Deficit (-) or surplus (+).