CS-15

SOIL WATER ACCOUNTING USING SCS HYDROLOGIC SOIL CLASSIFICATION

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ABSTRACT

The Soil Conservation Service (SCS) method is the most widely used method for soil moisture accounting and estimating runoff amounts from agricultural watersheds. The soil moisture accounting and volume of runoff depends on both meteorologic and watershed characteristics. The precipitation volume and actual evapotranspiration rate are the most important meteorological factors required in estimating soil moisture storage. The soil type, land use and the hydrologic condition of the cover are the watershed factors that will have the most significant effects on soil moisture storage.

The SCS method has used an antecedent rainfall index to estimate three antecedent moisture conditions (dry, normal and wet respectively). The relationship between rainfall and runoff for these three conditions is expressed as curve numbers. Each storm in a rainfall series is assigned one of the three curve numbers according to antecedent rainfall. In reality, curve number varies continuously with soil moisture and thus has many values instead of only three.

A case study has been taken for Ginnore sub-basin of Narmada basin for estimating soil moisture storage by SCS method. Using the basic SCS rainfall-runoff relationship and mass balance approach, a procedure has been developed for soil moisture accounting. The data used are daily rainfall , potential evapotranspiration, field capacity, wilting point, root depth and initial soil moisture. Any change in soil moisture storage will be due to evapotranspiration, rainfall and runoff occuring at that time which has been estimated and presented.

1.0 INTRODUCTION

The Soil Conservation Service (SCS) procedure, which came into common use in the year 1954, is the product of more than 20 years of studies of rainfall-runoff relationships for small rural watershed areas. The SCS method was originated by, and is still strongly identified with the United State Department of Agriculture, Soil Conservation Service. The procedure which is basically empirical was developed to provide a rational basis for estimating the effects of land treatment and land use changes upon runoff resulting from strom rainfall. Because of its simplicity, however, it use has spread through the spectrum of hydrologic application by Agriculturists, Hydrologists and by Soil Conservation Engineers. The ultimate reference document on the methodology is in National Engineering Handbook, Section 4, Hydrology.

The SCS method is the most widely used method for soil moisture index accounting and to estimate runoff amounts from agricultural watersheds with areas upto 2590 km^2(1000 Sq.miles). It is also the basis of the hydrologic component of several models used for agricultural lands, for example CREAMS model, USDAHL-74 model etc.

The SCS method is widely used becuase 1) it is a reliable procedure that has been used for many years in different parts of the world, 2) it is computationally efficient, 3) the required inputs are generally available, and 4) it relates runoff to soil type, land use and management practices.

The soil moisture accounting and volume of runoff depends on both meteorologic and watershed characteristics. The precipitation volume is probably the single most important meteorological characteristic in estimating the soil moisture storage. The soil type, land use and the hydrologic condition of the cover are the watershed factors that will have the most significant effect on soil moisture storage.

The SCS developed an index, which is called the runoff curve number(CN) to represent the combined hydrologic effect of soil, land use, agricultural land treatment class, hydrologic condition and antecedent soil moisture. The SCS has also developed a soil classification system that consists of four hydrologic groups according to their minimum infiltration rate, which is obtained for a bare soil after prolonged wetting. The groups are identified by the letters A,B,C and D and the soil characteristics associated with the each group have been determined. The hydrologic soil groups (SCS,1972) are:

Group A-Soils having high infiltration rates(Low runoff potential)

Group B- Soils having moderate infiltration rates,

Group C- Soils having slow infiltration rates, and

Group D- Soils having very slow infiltration rates(High runoff potential).

Traditionally the SCS has used an antecedent rainfall index to estimate three antecedent moisture conditions (I-dry, II-normal, and III-wet). The relationship between rainfall and runoff for these three conditions is expressed as curve numbers, CN. Each storm in a rainfall series is assigned one of the three curve numbers according to antecedent rainfall.

In reality CN varies continuously with soil moisture and thus has many values instead of only three. Runoff prediction accuracy can be improved considerably by developing and using a soil moisture accounting procedure to estimate the curve number for each storm.

A case study has been taken for Ginnore sub basin of Narmada basin for estimating soil moisture storage by SCS method. Using the basic SCS rainfall-runoff relationship and mass balance approach, a procedure has been developed for soil moisture accounting.

2.0 REVIEW

In 1954 the Soil Conservation Service (SCS) developed a unique procedure for estimating direct runoff resulting from storm rainfall. This procedure was the end product of a major field investigation effort and the work of numerous early investigators (Andrews, 1954; Mockus, 1949; Ogrosky, 1956; Shermen, 1949). A major development for getting this procedure to the field was due to the Watershed Protection and Flood Prevention Act in August 1954 in U.S.A. The SCS procedure which is basically empirical was developed to provide a rational basis for estimating the effects of land treatment and land use changes upon runoff resulting from storm rainfall. It was initially used by SCS in project planning for the small watershed programs.

2.1 Historical Background

2.1.1 Experimental watersheds

The need for hydrologic data in the designs of conservation practices became acute in the mid-1930's when SCS was established and entrusted with setting up demonstration conservation projects and examining the design and construction of soil and water conservation practices. As a result of this need, experimental watersheds were established at a number of locations in the U.S.A. to obtain data on rainfall, runoff and associated factors. Many of these were elaborate studies involving watershed areas of several square miles. After the Flood Control Act of 1936 was passed, the Department of

Agriculture was authorized to carry out surveys and investigations of watersheds to install measure for retarding runoff and waterflow and preventing soil erosion. A classic problem which was encountered early was the evaluation of the effect of watershed treatment and or conservation measures on the rainfall-runoff process.

According to Andrews (1954), data from the experimental watersheds were meager and covered only a small fraction of the conditions encountered in any watershed. To obtain the basic data necessary to evaluate the effects of the proposed conservation measures, infiltrometer studies were made.

2.1.2 Infiltrometer studies

Thousands of infiltrometer runs were made during the late 1930's and early 1940's with vast majority using the sprinkling-type infiltrometer. The type F infiltrometer (Sharp et al.,1940) was found most satisfactory, but because the plots used were 6 feet wide and multiples of 12 feet long, the handling of equipment was cumbersome and its operation somewhat expensive. As an economy measure, later on a type FA infiltrometer was devised for a plot measuring 12 by 30 inches and was used extensively.

Using primarily the data from infiltrometer plots, three private consultants-W.H.Hormer, R.E.Horton, and R.K.Sherman were employed by SCS to aid in developing a rational method for estimating the runoff from any given plot of land under various cover conditions. The results of these studies was a series of rainfall retention rate curves that were used, together with precipitation-excess and time of excess curves, to obtain the volume of runoff from any given physical land unit. Because this method required the availability of a recording raingauge, its use was seriously limited in many areas.

Other methods of estimating runoff, devised during the early 1940's, used infiltration data for developing rainfall runoff relationship. Andrews(1954) grouped the infiltrometer data from Texas, Oklahoma, Arkansas, and Louisiana and found that texture class was the only soil characteristics that was consistent within each group.

2.1.3 Rainfall-runoff relationship

Sherman (1949) was one of the first to propose plotting direct runoff versus storm rainfall. Mockus (1949) proposed that surface runoff could be estimated from the following information:

1. Soils; types, areal extents, and locations,
2. Land use; kinds, areal extents, and locations,
3. Antecedent rainfall,
4. Duration of a storm and associated rainfall amount,
5. Average annual temperature and data of storm.

Mockus (1949) combined these parameters into an index value, b which can be written as

$$b = \frac{0.374(10)^{0.229\,M}\quad C^{1.061}}{T^{1.990}\,D^{1.333}(10)^{2.271(\frac{S}{D}\quad)}} \qquad ...(1)$$

where

M = 5 day antecedent rainfall in inches,

C = cover practice index,

T = Seasonal index, which is a function of data and temperature(^{o}F),

D = Duration of storm in hours, and

S = Soil index in inches per hour

Resulting b values were used as the second independent variable

(P being the initial independent variable) in a graph of P vs Q, in which

$$Q = P\,[1 - (10)^{-bP}] \quad (2)$$

where

Q = direct runoff in inches and

P = storm rainfall in inches.

It also follows that the slope, b, in equation[2] is related to the watershed and storm characteristics, and that it is possible to predict Q for any storm on any watershed when these characteristics are known for that watershed and storm, (Mockus, 1949).

2.1.4 SCS runoff equation

By the early 1950's, SCS needed a procedure that could be applied for estimation of runoff from agricultural watershed with the kinds of data that were available. The models of Sherman and other (1949) were for gaged watersheds. The rainfall-runoff relations developed by Andrews (1954) and Mockus (1949) were somewhat generalized; it was desirable-but not necessary-to have a stream gage on the problem watershed, but the relationship could be developed equally well for an ungaged watershed.

The work of Andrews(1954) and Mockus (1949) is the basis for the generalized SCS rainfall-runoff relation, which can be expressed as follows: when accumulated natural runoff is plotted versus accumulated natural rainfall, runoff starts after some rainfall has accumulated and the line of relation curves becomes asymptotic to a line of 45^{o} slope. Figure 1 shows a typical relationship. When data from infiltrometer runs are used, the resulting curve is similar but it is generally asymptotic to a line of less than 45^{o} slope, because

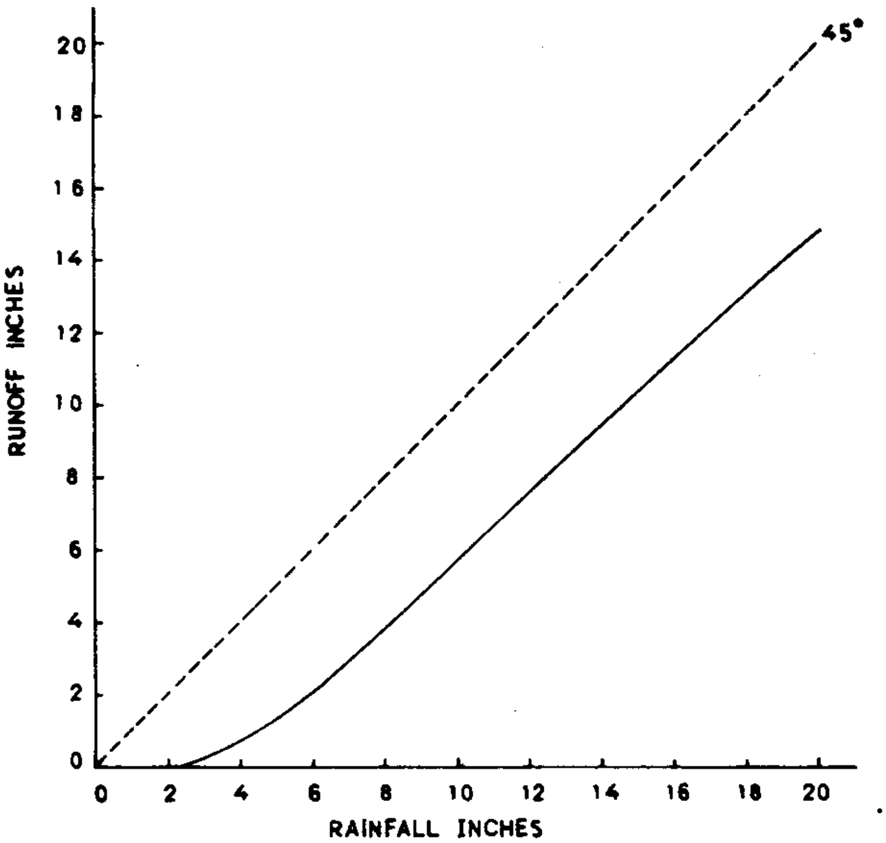

FIGURE 1- ACCUMULATED RAINFALL AND RUNOFF

of lateral flow below the infiltration plot.

2.1.5 Development of curve numbers

Curve numbers(CN) for a particular combination of soil and cover characteristics was developed by plotting storm rainfall for a watershed having one soil and one cover. Laid over this plot was a graph of the curve number array constructed at the same scale. Then, a median curve was selected, which divided the plotting into two equal number of points. Curve numbers were developed for many soil cover complexes and were published in the SCS National Engineering Handbook, Section 4 (NEH-4, 1972).

To explain the rationale used to develop individual cuve numbers, Mockus wrote, " The CN associated with the soil cover complexes are median values, roughly representing average conditions on a watershed. He took the average condition to mean average soil moisture condition because he had to ignore rainfall intensity".

The runoff equation of Mockus (1964) is based on the hypothesis that states

$$\frac{F}{S} = \frac{Q}{P} \qquad (3)$$

in which

F = actual retention of precipitation during a storm

S= potential maximum retention,

Q = direct runoff,

P = total precipitation

He justifies equation (3) on the grounds that it produces rainfall-runoff curves of a type found on natural watersheds. Mockus has given the following remarks in respect of curve number and SCS method:

1. Other equations will also produce rainfall runoff curves similar to equation [3] but these other equations have three or more parameters to be determined in advance and this is difficult to do with ordinarily obtainable data.
3. The CN's have been verified experimentally since they are based on data from research watershed where the experiment was to determine the runoff for different soil and cover conditions.
3. The particular CN used by the SCS are not the only ones that can be developed for use with equation $Q=[P - 0.2S]^2/[P + 0.8S]$. By using other storm or watershed characteristics, other kind of CN can be obtained. The practical value of the results will depend on how well the chosen characteristics can be represented by the data ordinarily at hand.
4. The research watersheds from which data were used are located in various parts of the United States, so that the developed values of CN applied throughout U.S.A.

2.2 Limits of SCS Equation Application

Mockus (1964) noted several characteristics of the proposed equation that limit its use. The equation does not contain any expression for time. It is for estimating runoff from single storms. In practice, the amount of daily rainfall is used; total runoff from storms of greater duration is calculated as the sum of daily increments. For a continuous storm-one with no breaks in the rainfall-SCS equation can be used to calculate the accumulated runoff. For a discontinuous storm, which has intervals of no rain, there is some recovery of infiltration rates during the intervals. If the period does not exceed an hour or so, it can be ignored and the estimates will be reasonably accurate. When the rainless periods are over an hour, a new higher CN is usually selected on the basis of the change in antecedent moisture.

Discussing the limits of application of the SCS runoff procedure, Kent (1966) States:

The procedure are primarily for establishing safe limits in design and for comparing the effectiveness of alternative systems of measures within a watershed project. They are not used to recreate specific features of an actual storm.

The SCS runoff equation was developed for conditions usually encountered in small watersheds in which only daily rainfall and watershed data are ordinarily available. It was developed from data and for situations where total amount of rainfall of one or more storms occuring in a calender day is known but without knowing their distribution with respect to time.

Cowan (1957) summarizes the reasons why time factor was not incorporated in SCS equation: Time was not incorporated in the method for estimating runoff for two important, practical reasons. First, sufficient reliable data were not available to define curves of infiltration capacity versus time for a wide range of soil, land use, and cover conditions. Second if time had been incorporated in the method, it would have required a determination of the time distribution of rainfall in storms for which runoff was to be estimated. In the majority of the cases, rainfall records on the watersheds do not permit reliable determinations of the time distribution of individual storms. Because of the way the curves were developed, their use for estimating increments of runoff for incremental periods within a storm is questionable unless the incremental periods are long enough to include infiltration recovery.

Hawkins (1979) has reported "despite widespread usage, curve numbers are infrequent topic in hydrology literature, and most readings on the topic are authorative rather than developmental innovative, or critical.

Hjelmfelt (1980) observed that "tests verifying the (CN) procedure have not been widely published, which raises some questions concerning its validity. Hjelmfelt (1980) did show that for some selected watershed the CN methodology could be used as an effective transformation from rainfall to runoff frequency distributions. The CN used for each of the basins in the test, however, was not calculated from the watershed soil-land use complex information, but rather was obtained from a visual best fit of observed rainfall-runoff data. For individual storm events, Hawkins (1975) showed that an accurate CN is more important to the estimation of an accurate runoff volume than is an accurate estimation of basin rainfall.

There have also been some efforts for modifying the CN methodology. Williams and Laseur (1976) developed a procedure for allowing the CN to vary continuously with soil moisture in a continuous daily water yield model. Hawkins (1973) has shown that a strong relationship exists between CN and storm rainfall for several small western forested watersheds. Based on that observation, Hawkins (1979) modified the CN procedure to allow the CN to vary with rainfall volume on watersheds with an apparent constant source area.

Rallison and Cronshey (1979) provide guidelines for possible local calibration of CN. The major points of their method are:

(1) Daily rainfall and runoff volumes for the annual floods are used.

(2) P Vs Q plots are made in arithmetic cross section paper, and these plots are overlaid by a plotted grid of CN with $I_a = 0.2S$ allowing selection of the median CN; and

(3) These plots (P Vs Q and CN) are used to define upper and lower AMC Limits with near or total enveloping curves.

According to Rallison and Cronshey, these AMC relationships represent the variability of not only antecedent soil moisture, but infiltration, evapotranspiration, lagtime, rainfall intensity, temperature etc.

3.0 STATEMENT OF THE PROBLEM

For prediction of runoff from small watershed by S.C.S.method, it is appropriate to have continuous accounting of soil moisture. The soil moisture is governed by precipitation, evapotranspiration, soil type, land use characteristics, runoff etc. Depending on the soil cover, soil type, land use, an estimation of the initial curve number before onset of Ist storm can be made. Knowing the initial curve number, it is possible to predict the runoff and water which infiltrates into the ground. Depending on the quantity of water infiltrated, the soil moisture of the crop root zone will be brought to field capacity or it will be upgraded. The soil moisture will be subsequently depleted due to evapotranspiration.

It is aimed to estimate the daily soil moisture by a lumped water balance model considering precipitation, evapaotranspiration, root growth depth and the storage parameter'S'. Using storage parameter, it is required to find the curve number, soil moisture and surface runoff.

4.0 DESCRIPTION OF STUDY AREA:

The Ginnore sub-basin of Narmada basin has been selected as study area.

4.1 Narmada basin

Narmada river basin is the fifth largest basin of India and Narmada river is the largest west flowing river of peninsula. Total length of the river is 1312 km and catchment area is 98796 sq.km. The basin lies in the northern extremity of the Deccan plateau between east longitudes $72^{o}32'$ to $81^{o}45'$, and northern latitudes $21^{o}20'$ to $23^{o}45'$. The basin has an elongated shape with a maximum length of 953 km from East to West and a maximum width of 234 km from North to South. The basin is bounded on the North by the Vindhya hill ranges, on the South by the Satpura hill ranges, on the East by the Maikala hill ranges and on the West by the Arabian sea. The basin has five well defined physiographic zones and they are upper hilly areas, upper plains, middle plains, lower hilly areas and lower plains. The river Narmada rises from the Amar Kantak plateau of the Maikala hill ranges at $22^{o}40'$ north latitude and $81^{o}45'$ east longitude at an elevation of 900 meter from Mean Seal Level(MSL). The river has 41 tributaries of which 22 are on the left bank and 19 on the right. Narmada river basin is shown in figure 2 indicating location of the Ginnore sub basin.

Climate of the basin is humid and tropical although at places extremes of heat and cold are often encountered. In the year, four distinct seasons occur and they are cold, hot, southwest monsoon and post monsoon. In the cold weather, the mean temperature varies from 17.5°C to 20°C and in the hot weather from 30°C to 32°C. In the South-west monsoon, the temperature ranges from 27.5 to 30°C. In the post monsoon season it varies between 25° to 27.5°C.

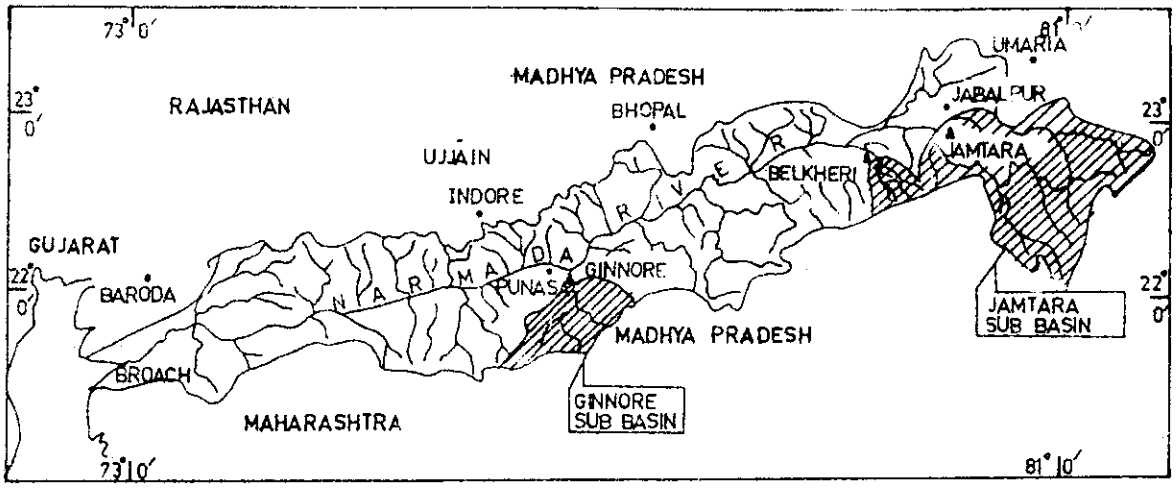

FIGURE 2 - INDEX MAP SHOWING LOCATIONS OF JAMTARA AND GINNORE SUB-BASINS IN NARMADA BASIN

Southwest monsoon from June to September is the principal rainy season and accounts for about 90% of the annual rainfall. During this period a series of tropical storms originating in Bay of Bengal move in West Northwest direction towards the basin and sometimes move parallel along the length of the basin and emerge into Arabian Sea. The average annual rainfall over the Narmada basin is 1230 mm. Annual rainfall varies from over 1550 mm in the Eastern part to 750mm in the Western part.

4.2 Ginnore basin

The Ginnore basin is the basin of river Chotta-Tawa from its source upto discharge measuring site at Ginnore. Catchment area of the basin is 4816 sq.km. The basin lies between East longitudes $85^{o}50'$ to $77^{o}11'$ and North latitude $21^{o}27'$ to $22^{o}11'$. The river Chhota-Tawa, a left bank tributary of river Narmada, rises in the Satpura range in the west Nimar district of Madhya Pradesh near Kakora village at north latitude $21^{o}31'$ and east longitude $75^{o}50'$ and flows for a total length of 169 km in a north eastern direction to join the Narmada river at its 829 km reach from source, north of Purni village. The river Chhota-Tawa is next in size to the Tawa among the left bank tributaries of Narmada river. The basin falls in the lower plains (Zone-3) of the Narmada basin. Southern border of the basin is the water divide line of the Satpura mountain range. The basin gradually slopes down in the north-northeast direction. R.L. of the gauging station in Ginnore is 218 m. Average slope of river is 1:400. Details of the basin are shown in figure 3.

The basin has two types of soil. Soil in the main part of the basin covering central and lower reaches is of medium black variety. Texture of the soil is silty clay loam and soil cover varies from 50 to 100 cm. Soil reaction is slightly alkaline. Soil of the upper reach of the catchment is shallow black variety. Texture of the soil is clay loam and soil cover varies from 25 to 50 cm.

Upper and some part of the central region is under forest cover amounting to about 32% of the basin area. About 60% area is culturable and remaining part is under shrub, suitable for grazing. Good quality Teak woods grow in upper reaches of the basin. Main crops under agriculture in the basin are wheat, pulses(mainly Arhar), oilseed, Sesame, and rice. Large quantity of cotton also grows in the basin. Groundnuts is another cash crop that grows in the basin.

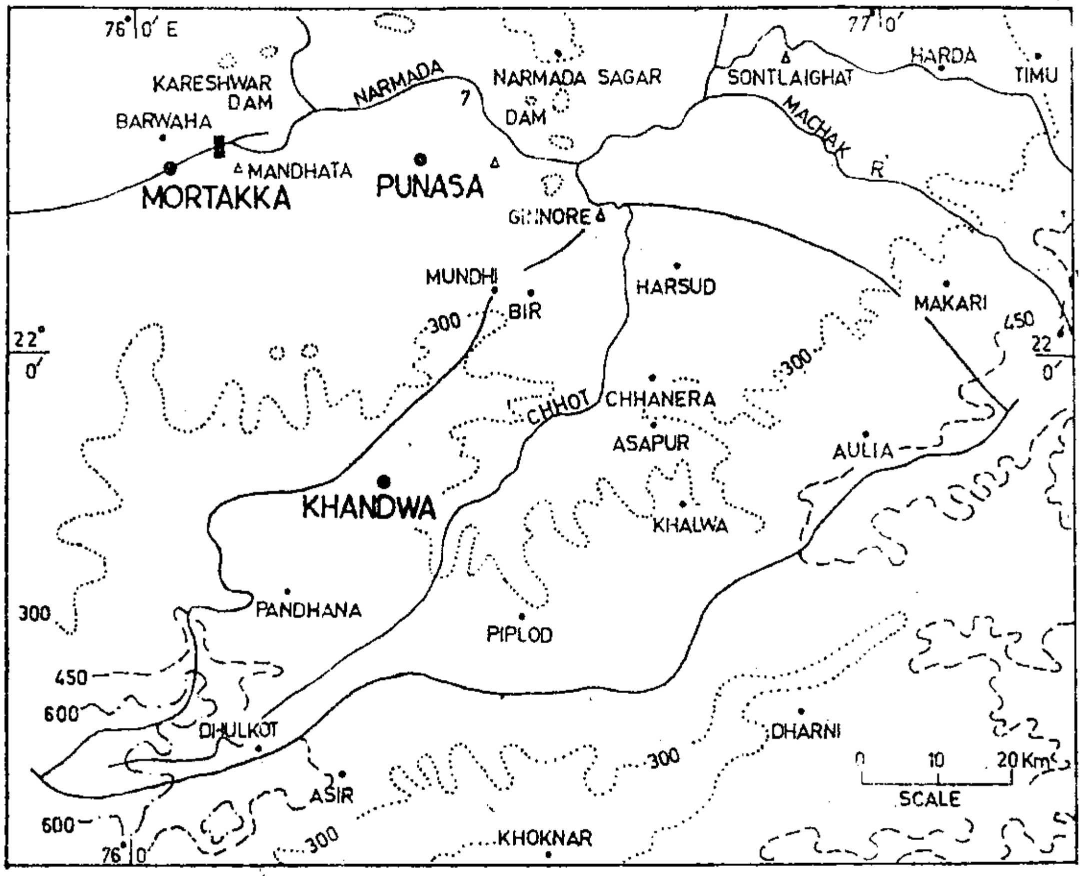

FIGURE 3 - DETAILED MAP OF GINNORE BASIN

Only 4.5% of cultivated area is under irrigation. Wheat is the most important crop in the basin.

The maximum and minimum temperatures at Khandwa and Punasa towns in the four quarters of the year are given in table 1.

Table 1: Maximum and Minimum Temperatures of Khandwa and Punasa Stations, °C.

Station	Jan.- Max.	Mar. Min.	Apr.- Max.	Jun. Min.	July.- Max.	Sept. Min.	Oct.- Max.	Dec. Min.
Khandwa	38.0	11.8	41.5	24.3	30.5	22.6	31.3	11.1
Punasa	38.8	11.9	42.9	24.2	31.1	22.9	33.1	12.0

Salient features of Ginnore basins has been given in table 2.

4.3 Hydrometeorology of the Ginnore Basins

Average annual rainfall of the Ginnore sub basins is 855 mm. Southwest monsoon from June to September accounts 87.6% of the average annual rainfall for the Ginnore sub-basins. July and August are the two most rainy months. Details of average annual, average monsoon and monthly average rainfall of the Ginnore basins are given in table 3.

Table 2. Salient Features of Ginnore sub-basins in Narmada basin

Sl.No.	Features	Ginnore sub-basin
1.	Name of river	Chhota-tawa
2.	Gauging Station	Ginnore
3.	Location of sub-basin in Narmada basin	Middle plains
4.	Source of river	Satpura hill range
5.	RL of river at source	600 meter
6.	RL of Gauging station	218 meter
7.	Length of river from source to gauging station	155 km.
8.	Average river bed slope	1:400
9.	Soil	Silty clay loam

Table 3: Monthly Average Rainfall of the Ginnore basin in mm.

Month	Average Rainfall
January	5.5
February	3.5
March	3.5
April	1.5
May	9.0
June	135.5
July	274.0
August	190.0
September	169.5
October	35.5
November	21.0
December	6.5
Annual Average Rainfall	855.00

5.0 AVAILABILITY OF DATA

Following data of Ginnore basins were used for soil moisture accounting by S.C.S.method.

(1) Daily rainfall data of station Khandwa and Punasa for 1974.

(2) Monthly mean of daily evapotranspirations of Ginnore basin for twelve months taken from I.M.D.report (Rao et al 1971).

(3) Topographic map, soil map and forest map.

(4) Information on crops, soil type, land use pattern, Root Depth etc.

(5) Field capacity, wilting point.

6.0 METHODOLOGY

6.1 SCS Runoff Procedure (NEH-4, 1972)

The SCS assumed the following rainfall-runoff relationship, which is shown schematically in figure 4.

$$\frac{F}{S'} = \frac{Q}{P} \qquad \ldots(4)$$

where,

F = actual retention

S' = potential maximum retention ($S' > F$)

Q = actual runoff

P = potential maximum runoff ($P > Q$)

The parameter S' in above equation does not contain the initial abstraction. The retention parameter S' is a constant for a particular storm because it is the maximum that can occur under the existing conditions. The retention F varies because it is the difference between P and Q at any point on the mass curve, or

$$F = P - Q \qquad \ldots(5)$$

Substituting F value in equation (4),

$$\frac{P - Q}{S'} = \frac{Q}{P} \qquad \ldots(6)$$

$$Q = \frac{P^2}{P + S'} \qquad \ldots(7)$$

Equation (6) gives the rainfall-runoff relation where initial abstraction is ignored.

Subtracting the initial abstraction from the rainfall, equation (4) becomes

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad \ldots(8)$$

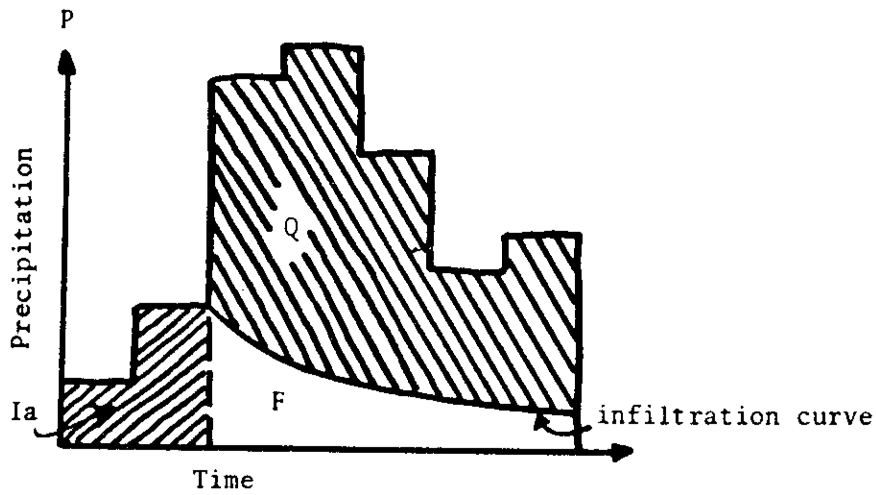

FIG. 4 - RELATIONSHIP BETWEEN PRECIPITATION, RUNOFF AND RETENTION

where I_a is the initial abstraction [S=S' + I_a)

Including I_a term in equation (5)

$$F = (P - I_a) - Q \qquad \ldots(9)$$

then equation (6) becomes

$$\frac{(P-I_a) - Q}{S} = \frac{Q}{(P-I_a)} \qquad \ldots(10)$$

and equation (7) becomes

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \ldots(11)$$

which is the rainfall-runoff relationship with the initial abstraction taken into account. The factors in equation (11) are best understood when placed in the form of a mass curve of Q vs P as shown in figure 5.

The initial abstraction consists mainly of interception, infiltration, and surface storage all of which occurs before runoff begins. The relationship between I_a and S was developed by means of rainfall and runoff data from experimental small watershed. The empirical relationship is given by

$$I_a = 0.2\ S \qquad \ldots(12)$$

Substituting I_a value in equation (11)

$$Q = \frac{[P - 0.2S]^2}{[P + 0.8S]} \qquad \ldots(13)$$

which is the rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall.

In the equation[13], only storage index, S is unknown which is an indicator of land condition and may vary from 0 (an impervious watershed; Q=P) to infinity (a completely absorbent watershed; Q=0), with virtually all realistic values falling in between.

6.0 METHODOLOGY

6.1 SCS Runoff Procedure (NEH-4, 1972)

The SCS assumed the following rainfall-runoff relationship, which is shown schematically in figure 4.

$$\frac{F}{S'} = \frac{Q}{P} \qquad \ldots(4)$$

where,

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S' = potential maximum retention ($S' > F$)

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Equation (6) gives the rainfall-runoff relation where initial abstraction is ignored.

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$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad \ldots(8)$$

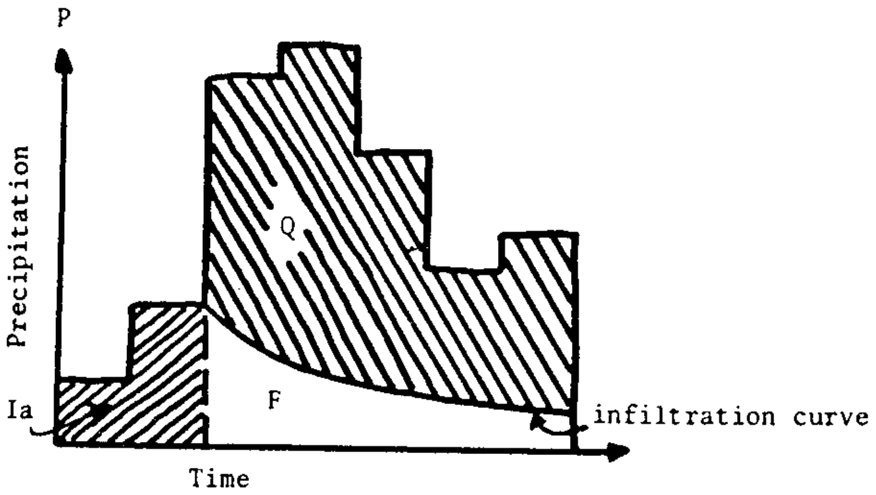

FIG. 4 - RELATIONSHIP BETWEEN PRECIPITATION, RUNOFF AND RETENTION

where I_a is the initial abstraction [$S=S' + I_a$)

Including I_a term in equation (5)

$$F = (P - I_a) - Q \qquad \text{...(9)}$$

then equation (6) becomes

$$\frac{(P-I_a) - Q}{S} = \frac{Q}{(P-I_a)} \qquad \text{...(10)}$$

and equation (7) becomes

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{..(11)}$$

which is the rainfall-runoff relationship with the initial abstraction taken into account. The factors in equation (11) are best understood when placed in the form of a mass curve of Q vs P as shown in figure 5.

The initial abstraction consists mainly of interception, infiltration, and surface storage all of which occurs before runoff begins. Tne relationship between I_a and S was developed by means of rainfall and runoff data from experimental small watershed. The empirical relationship is given by

$$I_a = 0.2\ S \qquad \text{...(12)}$$

Substituting I_a value in equation (11)

$$Q = \frac{[P - 0.2S]^2}{[P + 0.8S]} \qquad \text{...(13)}$$

which is the rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall.

In the equation[13], only storage index, S is unknown which is an indicator of land condition and may vary from 0 (an impervious watershed; Q=P) to infinity (a completely absorbent watershed; Q=0), with virtually all realistic values falling in between.

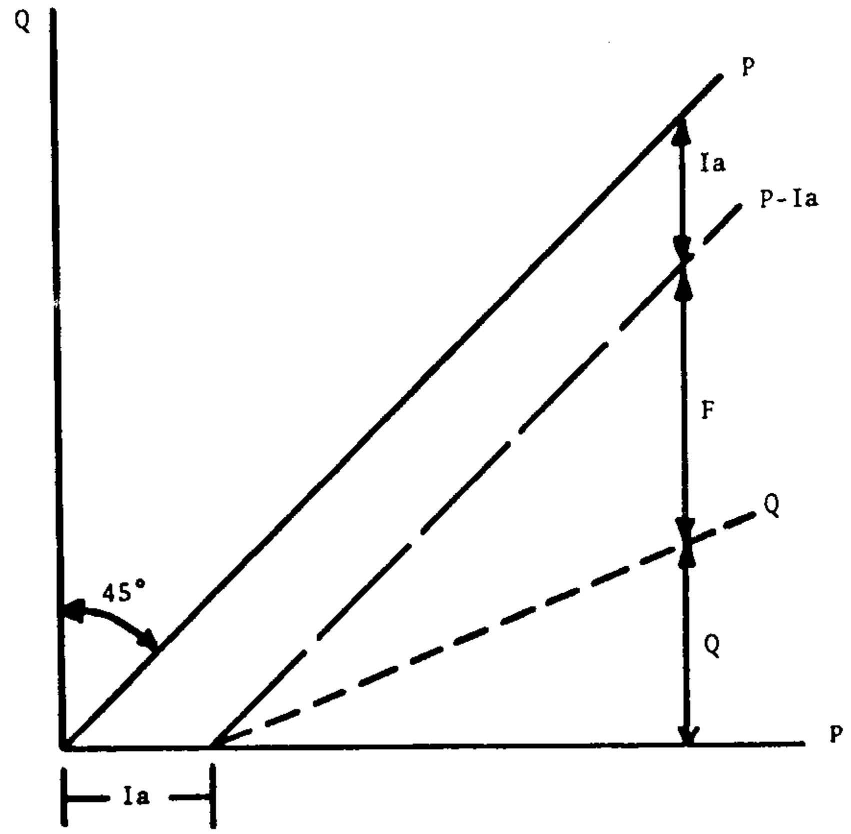

FIG. 5 - A MASS CURVE REPRESENTATION OF THE SCS RAINFALL-RUNOFF RELATIONSHIP

Equation [13] states that 20 percent of the potential maximum retention S is the initial abstraction I_a, which is the interception, infiltration and surface storage occuring before runoff begins. The remaining 80 percent is mainly the infiltration occuring after runoff begins. The later infiltration is controlled mainly by the following

- rate of infiltration at the soil surface,
- rate of transmission in the soil profile, or
- the water storage capacity of the profile whichever is the limiting factor.

A succession of storms, such as one a day for a week, reduces the magnitude of S each day because the limiting factor does not have the opportunity to completely recover its rate or capacity through weathering, evapotranspiration or drainage. But there is a enough recovery, depending on the soil cover complex, to limit the reduction. During such a storm period the magnitude of S remains virtually the same after the second or third day even if the rains are large so that there is a lower limit to S for a given soil cover complex. Similarly there is a practical upper limit to S, again depending on the soil cover complex, beyond which the recovery cannot take S unless the complex is altered.

Runoff curve numbers CN are coefficients used for estimating surface runoff depth from rainstorms. The CN incorporates the effects of infiltration characteristics of the soil, land use and agricultural practices.

The index of the waterhsed wetness on the day of the storm is described as Antecedent Moisture Condition (AMC), determined by the total rainfall in the 5 days period preceding a storm. Three levels of AMC are used:

AMC-I Lowest runoff potential. The watersheds soils are dry enough for satisfactory plowing or cultivation.

AMC-II The average condition

AMC-III Highest runoff potential. The watersheds is practically saturated from antecedent rains.

The antecedent moisture (AMC groupings I, II and III) were established in an attempt to explain the variation in event runoff curve number (CN) which exists at a site. AMC-II is the event CN for a site as determined by fitting an average curve to a rainfall runoff plot. To explain the variation on either side of the average CN curve, enveloping CN lines were determined. The lower envelope CN curve represents AMC-I while the upper envelope CN represents AMC-III. The boundaries between the AMC groups vary depending on the time of the year (Table 4). Figure 6 shows the relationship between the three AMC levels and runoff.

Table 4: Seasonal Rainfall Limits for Antecedent Moisture Conditions (AMC), SCS 1972.

AMC group	Total 5 days antecedent rainfall	
	Dormant Season	Growing Season
	inches *	
I	<0.5	< 1.4
II	0.5 to 1.1	1.4 to 2.1
III	> 1.1	>2.1

* To convert inches to centimeters, multiply by 2.54. To linearize the relationship in equation (13), S was transformed by the equation

$$CN = \frac{1000}{(10 + S)} \qquad ...(14)$$

where CN = curve number. It is a dimensionless number and varies from

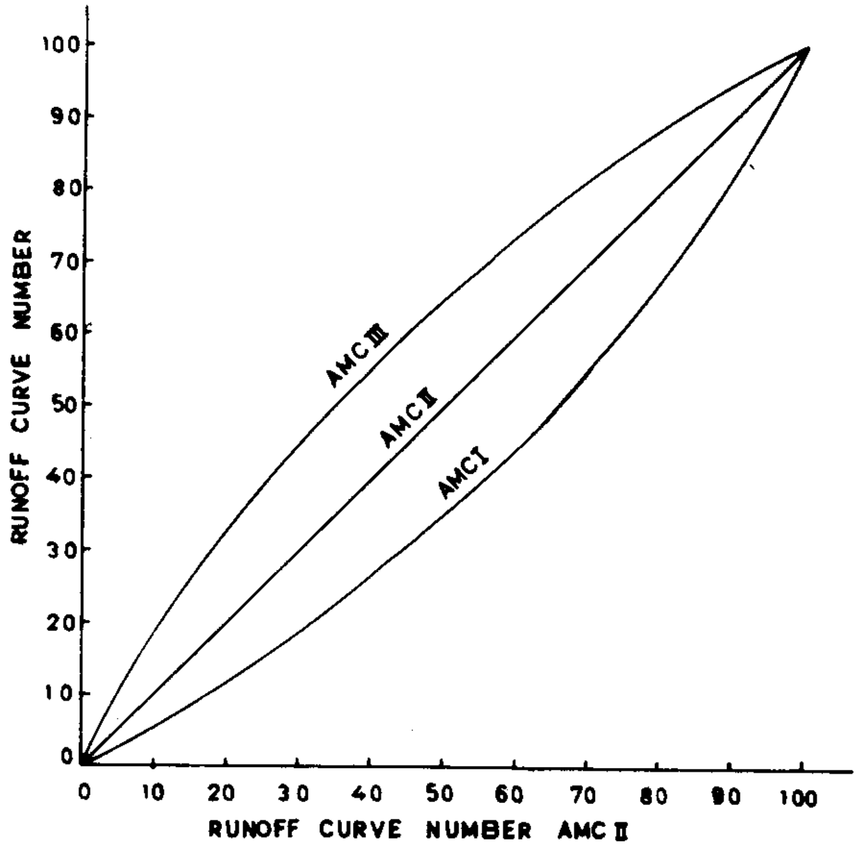

FIGURE 6 RELATIONSHIP BETWEEN ANTECEDENT MOISTURE CONDITIONS AND CURVE NUMBERS. SCS (1972)

100 (completely impervious, $Q = P$) to 0 (completely absorbent; $Q=0$)

If S is in mm, than

$$CN = \frac{25400}{(254 + S)} \qquad \ldots(15)$$

The division by 25.4 in equation (15) is included since rainfall and runoff data for the watersheds are expressed in mm also.

6.2 Mass Balance Approach for Soil Moisture Storage

Using the basic SCS rainfall runoff equation (13), expanding the numerator and applying polynomial division yields.

$$Q = P - S\left[1.2 - \frac{S}{P + 0.8\,S}\right], \quad P > 0.2\,S \qquad \ldots(16)$$

It can be seen from the equation (16) that the possible difference (as $P \to \infty$) between rainfall (P) and direct runoff is not S but 1.2 S. A geometric representation is shown in figure 7. Let $S^* = 1.2S$

At time t_1, the storage available is

$$S^*_1 = 1.2 \quad S_1 = 1.2\left(\frac{1000}{CN_1} - 10\right) \qquad \ldots(17)$$

Any change in S^*_1 will be due to the actual evapotranspiration losses (ETA), rainfall (P) and runoff (Q) occuring at that time so,

At time t_2,

$$S^*_2 = S^*_1 + ETA_1 - (P_1 - Q_1) = 1.2S_2 \qquad \ldots(18)$$

therefore $S^*_2 = 1.2\left(\frac{1000}{CN_1} - 10\right) + ETA_1 - (P_1 - Q_1) = 1.2\,S_2$

By definition $CN_2 = \frac{1000}{10 + S_2}$*, substituting S_2 value

$$CN_2 = \frac{1200}{\frac{1200}{CN_1} + [ETA_1 - (P_1 - Q_1)]}$$

Attime t_n

$$S^*_n = S^*_{n-1} = ETA_{n-1} - (P_{n-1} - Q_{n-1}) = 1.2\,S_n \qquad \ldots(19)$$

Soil moisture storage by SCS method can be estimated by using equation (19) for any real vale of P, Q and ETA.

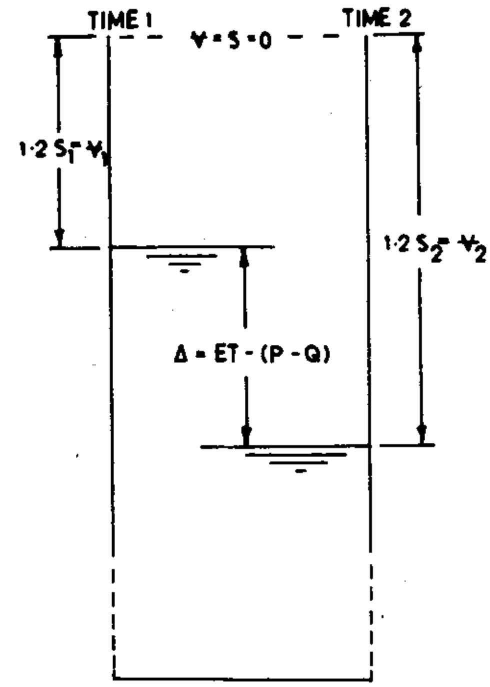

FIGURE 7 - DIAGRAMMATIC ANALOGY OF SITE MOISTURE DEFINING ¥, S, AND Δ

Actual evapotranspiration can be estimated by the relationship

$$ETA = \frac{ETP \times (\theta - WP)}{(FC - WP)} \qquad \ldots(20)$$

where,

θ = soil moisture

WP = av. wilting point,

FC = av.field capacity,

ETP = potential evapotranspiration.

7.0 ANALYSIS AND RESULTS

The following steps were used for estimation of soil moisture storage;

(1) For a given land use and hydrologic soil cover complex, the initial value of CN has been assumed. The soil in Ginnore sub basin is of clay loam type which falls in Group C of S.C.S. hydrologic soil classification. Mostly in summer season, jowar, bajra, or cotton are grown. Based on this, initial curve number value (85) is taken from Table 9.1 of S.C.S.National Engineering Hand book, Section 4, Hydrology.

(2) Calculate the initial storage parameter value from the relationship.

$$S_1^* = 1.2S_1 = 1.2(\frac{1000}{CN_1} - 10)$$

(3) If the value of the rainfall for any day, is greater than 0.2 S_1, calculate Q from the equation (16), otherwise assume $Q_1 = 0$ for that particular day.

(4) Calculate the actual evapotranpiration using equation (20)

(5) Estimate S_2^* from the equation(18)i.e.$S_2^* = S_1^* + ETA_1 - P_1 + Q_1$

(6) Knowing S_2^*, CN_2 can be estimated from the relationship

$$CN_2 = \frac{1000}{S_2^* + 10} = \frac{1200}{\frac{1200}{CN_1} + [ETA_1 - P_1 + Q_1]}$$

(7) Estimate soil moisture value, which is a function of rainfall, runoff, ETA for that particular day.

For Ginnore subbasin, the initial soil moisture was assumed to be 0.10. Depending on the rainfall, runoff and actual evapotranspiration values, the soil moisture accounting is done for July, August and September months during which most of the rain occurs. The calculated values of soil moisture, storage parameter, curve numbers for July, August and September months are shown in Table 5, 6, and 7 respectively.

From the results, it was observed that soil moisture varies from 12.67% minimum to 27.06% maximum in the month of July. For August months, soil moisture varies from 24.16% of minimum to 27.41% maximum and for September month, it varies from 20.66% to 23.84% respectively.

The curve numbers varies from 85.0 to 96.04 for the July month, 92.12 to 98.77 for August month and 82.31 to 91.33 for September month.

A computer programme has been developed for estimation of soil moisture using S.C.S.method and is presented in Appendix-I.

Table 5: CALCULATED VALUES OF STORAGE PARAMETER, CURVE NUMBER, SOIL MOISTURE AND ACTUAL EVAPOTRANSPIRATION FOR THE MONTH OF JULY

Date	Rainfall (inch) (P)	Runoff (inch) Q	Actual Evapo-transpiration	Soil Moisture θ	Storage Parameter S	Curve Number's CN
2.7.74	1.040	0.192	0.1618	0.2191	1.7647	85.00
3.7.74	0.181	0.000	0.1618	0.2191	1.1936	89.34
4.7.74	0.527	0.058	0.1618	0.2352	1.1775	89.46
5.7.74	0.000	0.000	0.1142	0.1896	0.9211	91.56
6.7.74	0.000	0.000	0.0806	0.1627	1.0163	90.77
7.7.74	0.315	0.000	0.0674	0.1524	1.0834	90.22
8.7.74	0.000	0.000	0.0532	0.1372	1.1134	89.98
9.7.74	0.000	0.000	0.0421	0.1267	1.1578	89.62
10.7.74	0.759	0.159	0.1326	0.2308	1.1928	89.34
11.7.74	0.023	0.000	0.1144	0.2127	0.8023	92.57
12.7.74	1.208	0.558	0.1618	0.2706	0.8780	91.72
13.7.74	0.134	0.003	0.1562	0.2663	0.4709	95.50
14.7.74	0.114	0.000	0.1492	0.2607	0.4921	95.31
15.7.74	0.122	0.000	0.1457	0.2573	0.5223	95.03
16.7.74	0.138	0.002	0.1437	0.2563	0.5426	94.85
17.7.74	0.071	0.000	0.1362	0.2481	0.5488	94.79
18.7.74	0.000	0.000	0.1236	0.2336	0.6032	94.31
19.7.74	0.000	0.000	0.1122	0.2210	0.7063	93.40
20.7.74	0.000	0.000	0.1037	0.2101	0.8004	92.58
21.7.74	0.004	0.000	0.0956	0.2010	0.8868	91.85
22.7.74	0.701	0.175	0.1257	0.2389	0.9636	91.21
23.7.74	0.264	0.025	0.1329	0.2486	0.6305	94.06
24.7.74	0.079	0.000	0.1291	0.2442	0.5421	94.85
25.7.74	0.000	0.000	0.1208	0.2342	0.5840	94.48
26.7.74	0.000	0.000	0.1134	0.2251	0.6847	93.59
27.7.74	0.000	0.000	0.1067	0.2172	0.7792	92.77
28.7.74	0.047	0.000	0.1034	0.2132	0.8681	92.01
29.7.74	0.000	0.000	0.0980	0.2064	0.9149	91.61
30.7.74	1.953	1.118	0.1339	0.2532	0.9965	90.93
31.7.74	0.287	0.068	0.1377	0.2584	0.4215	96.04

TABLE 6: CALCULATED VALUES OF STORAGE PARAMETER, CURVE NUMBERS SOIL MOISTURE AND ACTUAL EVAPOTRANSPIRATION FOR THE MONTH OF AUGUST.

Date	Rainfall (inch) P	Runoff (inch) Q	Actual Evapotranspiration	Soil Moisture θ	Storage Parameter S	Curve numbers CN
1.8.74	0.433	0.1871	0.1332	0.2652	0.3445	96.67
2.8.74	1.543	1.2786	0.1384	0.2727	0.2506	97.55
3.8.74	0.240	0.1250	0.1373	0.2714	0.1453	98.57
4.8.74	2.724	2.5372	0.1391	0.2741	0.1637	98.38
5.8.74	1.094	0.9588	0.1387	0.2740	0.1237	98.77
6.8.74	0.011	0.0000	0.1340	0.2675	0.1263	98.75
7.8.74	0.307	0.1396	0.1353	0.2691	0.2282	97.77
8.8.74	0.000	0.0000	0.1303	0.2626	0.2012	98.03
9.8.74	0.000	0.0000	0.1258	0.2565	0.3098	96.99
10.8.74	0.007	0.0000	0.1218	0.2511	0.4146	96.02
11.8.74	1.370	0.9046	0.1323	0.2665	0.5096	95.15
12.8.74	1.811	1.5592	0.1364	0.2718	0.2324	97.73
13.8.74	2.039	1.8846	0.1364	0.2726	0.1362	98.65
14.8.74	0.633	0.5086	0.1360	0.2721	0.1211	98.80
15.8.74	0.311	0.1955	0.1353	0.2713	0.1303	98.71
16.8.74	0.000	0.0000	0.1319	0.2662	0.1470	98.55
17.8.74	0.177	0.0414	0.1318	0.2664	0.2568	97.49
18.8.74	0.441	0.2365	0.1336	0.2690	0.2535	97.52
19.8.74	1.618	1.4059	0.1357	0.2718	0.1945	98.09
20.8.74	1.055	0.9129	0.1355	0.2720	0.1307	98.71
21.8.74	0.094	0.0247	0.1340	0.2698	0.1253	98.76
22.8.74	0.071	0.0057	0.1322	0.2675	0.1788	98.24
23.8.74	0.338	0.1615	0.1337	0.2690	0.2348	97.71
24.8.74	0.086	0.0089	0.1319	0.2672	0.1983	98.06
25.8.74	0.000	0.0000	0.1289	0.2630	0.2436	97.62
26.8.74	0.000	0.0000	0.1261	0.2591	0.3510	96.61
27.8.74	0.000	0.0000	0.1233	0.2553	0.4561	95.63
28.8.74	0.000	0.0000	0.1207	0.2516	0.5589	94.71
29.8.74	0.000	0.0000	0.1183	0.2482	0.6596	93.81
30.8.74	0.000	0.0000	0.1190	0.2448	0.7581	92.95
31.8.74	0.000	0.0000	0.1136	0.2416	0.8547	92.12

TABLE 7: CALCULATED VALUES OF STORAGE PARAMETER, CURVE NUMBER, SOIL MOISTURE AND ACTUAL EVAPOTRANSPIRATION FOR THE MONTH OF SEPTEMBER

Date	Rainfall (inch) P	Runoff (inch) Q	Actual Evapotra-nspiration	Soil Moisture θ	Storage parameter S	Curve number CN
1.9.74	0.0000	0.0000	0.1183	0.2384	0.9494	91.33
2.9.74	0.0236	0.0000	0.1614	0.2359	1.0480	90.51
3.9.74	0.0000	0.0000	0.1141	0.2329	1.1253	89.88
4.9.74	0.0000	0.0000	0.1119	0.2300	1.2204	89.12
5.9.74	0.0039	0.0000	0.1098	0.2273	1.3137	88.38
6.9.74	0.0000	0.0000	0.1078	0.2246	1.4020	87.70
7.9.74	0.0000	0.0000	0.1058	0.2219	1.4918	87.02
8.9.74	0.0000	0.0000	0.1039	0.2195	1.5800	86.35
9.9.74	0.0000	0.0000	0.1021	0.2173	1.6666	85.71
10.9.74	0.0197	0.0000	0.1006	0.2156	1.7516	85.09
11.9.74	0.2047	0.0000	0.1023	0.2175	1.8191	84.61
12.9.74	0.0905	0.0000	0.1021	0.2172	1.7340	85.22
13.9.74	0.0118	0.0000	0.1006	0.2152	1.7434	85.15
14.9.74	0.0000	0.0000	0.0989	0.2130	1.8174	84.62
15.9.74	0.0000	0.0000	0.0974	0.2109	1.8999	84.03
16.9.74	0.0000	0.0000	0.0958	0.2088	1.9818	83.46
17.9.74	0.0000	0.0000	0.0943	0.2068	2.0610	82.91
18.9.74	0.0826	0.0000	0.0941	0.2066	2.1395	82.37
19.9.74	0.7244	0.0355	0.1032	0.2188	2.1491	82.31
20.9.74	0.0000	0.0000	0.1016	0.2167	1.6610	85.75
21.9.74	0.0551	0.0000	0.1009	0.2158	1.7456	85.14
22.9.74	0.0000	0.0000	0.0994	0.2138	1.7838	84.86
23.9.74	0.0000	0.0000	0.0980	0.2118	1.8666	84.27
24.9.74	0.7204	0.0480	0.1062	0.2230	1.9483	83.69
25.9.74	0.3661	0.0032	0.1099	0.2280	1.4764	87.13
26.9.74	0.3464	0.0064	0.1132	0.2324	1.2656	88.76
27.9.74	0.2677	0.0024	0.1153	0.2353	1.0765	90.28
28.9.74	0.2362	0.0021	0.1170	0.2375	0.9516	91.31
29.9.74	0.0000	0.0000	0.1153	0.2354	0.8540	92.13
30.9.74	0.2244	0.0012	0.1167	0.2313	0.9499	91.32

8.0 CONCLUSIONS

The S.C.S.method is the most widely used method for estimating runoff from agricultural watersheds, with areas upto 2590 km^2(1000 sq.miles). Soil moisture accounting, using the basic SCS rainfall runoff relationship and mass balance approach, has been done for Ginnore subbasin of Narmada basin, having catchment area of 4816 km^2. The data used are daily rainfall, potential evapotranspiration, initial soil moisture, soil type, land classification, crop type and root characteristics for estimation of soil moisture, storage parameter and curve numbers.

The limitation of S.C.S.method is that it does not contain any expression for time and the recovery of infiltration rate during the storms. Also there is no provision for estimating base flow. Despite of these limitations, SCS methods is frequently used for estimation of runoff and soil moisture because i) it is computationally efficient, 2) required inputs are generally available and 3) it relates runoff to soil type, land use and management practices.

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APPENDIX -I

Computer Program of SCS method for soil moisture accounting

```
      DIMENSION CN(365),S(365),ETP(365),THETA(365),SS(365)
      DIMENSION P(365),Q(365),ROOTD(365),F(365)
      DIMENSION ETA(365),RCN(365)
      OPEN(UNIT=1,FILE='SCS.DAT',STATUS='OLD')
      OPEN(UNIT=2,FILE='SCS.OUT',STATUS='NEW')
      READ (1,1) CN(1),AVFC,AVW,THETA(1),NDAYS
1     FORMAT (4F10.5,I3)
      S(1)=1000./CN(1)-10.
      SS(1)=1.2*S(1)
      RCN(1)=CN(1)
      READ (1,2) (ETP(I),I=1,NDAYS)
2     FORMAT (8F10.5)
      READ (1,2) (P(I),I=1,NDAYS)
      READ (1,2) (ROOTD(I),I=1,NDAYS)
      DO 101 I=1,NDAYS
      P(I)=P(I)/25.4
101   ETP(I)=ETP(I)/25.4
C     THE CN(1)IS THE INITIAL CURVE NUMBER TO BE ASCERTAINED
C     FROM LAND USE PRACTICE AND DRY CONDITION
C     INITIAL VALUE HAS BEEN OBTAINED FROM NEH(4)PUBLICATION.
C     S(1)=1000./CN(1)-10.
      IF (P(1).GT.(0.2*S(1)))GO TO 3
      Q(1)=0.
      F(1)=P(1)
C     F(1) IS THE TOTAL QUANTITY INFILTRATED
      GO TO 4
3     Q(1)=P(1)-S(1)*(1.2-S(1)/(P(1)+0.8*S(1)))
      F(1)=P(1)-Q(1)
4     CONTINUE
      IF ((AVFC-THETA(1))*ROOTD(1)-F(1))6,6,7
6     THETA(1)=AVFC
      GO TO 8
7     CONTINUE
      THETA(1)=THETA(1)+F(1)/ROOTD(1)
8     ETA(1)=ETP(1)*(THETA(1)-AVW)/(AVFC-AVW)
      THETA(1)=THETA(1)-ETA(1)/ROOTD(1)
      SS(2)=SS(1)+ETA(1)-F(1)
      S(2)=SS(2)/1.2
      CN(2)=1000./(10+S(2))
      RCN(2)=1200./(1200./CN(1)+ETA(1)-P(1)+Q(1))
      TYPE*,CN(2),RCN(2)
      DO 100 I=2,NDAYS
      IF (P(I).GT.(.2*S(I)))GO TO 30
      Q(I)=0.
      F(I)=P(I)
      GO TO 40
30    Q(I)=P(I)-S(I)*(1.2-S(I)/(P(I)+.8*S(I)))
      F(I)=P(I)-Q(I)
40    CONTINUE
      IF ((AVFC-THETA(I-1))*ROOTD(I)-F(I))60,60,70
60    THETA(I)=AVFC
      GO TO 80
```

```
70      THETA(I)=THETA(I-1)+F(I)/ROOTD(I)
80      ETA(I)=ETP(I)*(THETA(I)-AVW)/(AVFC-AVW)
        THETA(I)=THETA(I)-ETA(I)/ROOTD(I)
        CN(I)=1000./(10+S(I))
        RCN(I)=1200./(1200./CN(I-1)+ETA(I-1)-P(I-1)+Q(I-1))
        TYPE*,CN(I),RCN(I),I
        SS(I+1)=SS(I)+ETA(I)-F(I)
        S(I+1)=SS(I+1)/1.2
100     CONTINUE
        WRITE (2,2) (P(I),I=1,NDAYS)
        WRITE (2,2) (Q(I),I=1,NDAYS)
        WRITE (2,2) (F(I),I=1,NDAYS)
        WRITE (2,2) (ETP(I),I=1,NDAYS)
        WRITE (2,2) (ETA(I),I=1,NDAYS)
        WRITE (2,2) (THETA(I),I=1,NDAYS)
        WRITE (2,2) (ROOTD(I),I=1,NDAYS)
        WRITE (2,2) (S(I),I=1,NDAYS)
        WRITE (2,2) (CN(I),I=1,NDAYS)
        WRITE (2,2) (RCN(I),I=1,NDAYS)
        STOP
        END
```