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Application of deterministic conceptual model for water balance studies

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ABSTRACT. An attempt has been made to study the water balance of *Dandavathy* a tributory of *Tungabadhara* river basin in Karnataka by the application of Sacramento model which is a deterministic conceptual model.

In this technique precipitation and the evaporation data have been used to allocate the moisture in various layers of the soil and the resultant runoff compared with the actual runoff for the purpose of the calibration of the model. The model is then used to study the water balance by the well known hydrologic equation and results are found to be very encouraging.

1. Introduction

Since the beginning of mankind, water has been considered to be the most essential natural resource and it was for this reason that all the ancient civilizations were located near the river banks. With the advance of civilization, more and more land was brought under cultivation, urbanisation, industrialisation etc and all this resulted in manifold increase in water demand. To meet this rapidly growing need of water, integrated development of water resources of river basins, are being planned all over the world. For the purpose of assessment of water resources, water balance studies are taken up basin or subbasin-wise on short-term and long-term basis. Short term water balance studies on weekly, monthly or seasonal basis are necessary for irrigation scheduling, assessing extreme events like floods and droughts etc and the monthly and seasonal water balance studies are required for river and reservoir regulation and groundwater recharge assesment. The long-term water balance studies for period of a year or more are needed for general development of river basins including multi-purpose river valley projects and interlinking of river basins.

2. Methodology

2.1. For water balance studies, the basic hydrologic equation depicting the unending hydrologic cycle in nature is $P=R+E$, where P is the precipitation, R is the total runoff which is comprised of underground flow U and surface flow S, *i.e.*, $R=U+S$, and E is the evapotranspiration. The evapotranspiration is very closely related to soil moisture W defined as $W=P-S=U+E$. The importance of W 'soil moistening' can be appreciated only when short-term water balance studies are undertaken. In the initial stages, W accounts for the major portion of the precipitation input and is, therefore, an important parameter in agricultural meteorology. It determines the extent to which the requirements of field capacity are met. Latest technique to measure this parameter is neutron probe method. But in order to obtain a continuous profile, mathematical models can be formulated. Of the various mathematical models which can be formulated to tackle the water resources problems, the deterministic conceptual models have been preferred over the exact numerical solutions in the wake of scarcity of the required infiltration data and the widespread variability of the parameter in the basin.

2.2 *Deterministic conceptual model*

In formulating a model of the response of a watershed, we conceptualize the physical processes involved and express them in mathematical terms. The model may be deterministic

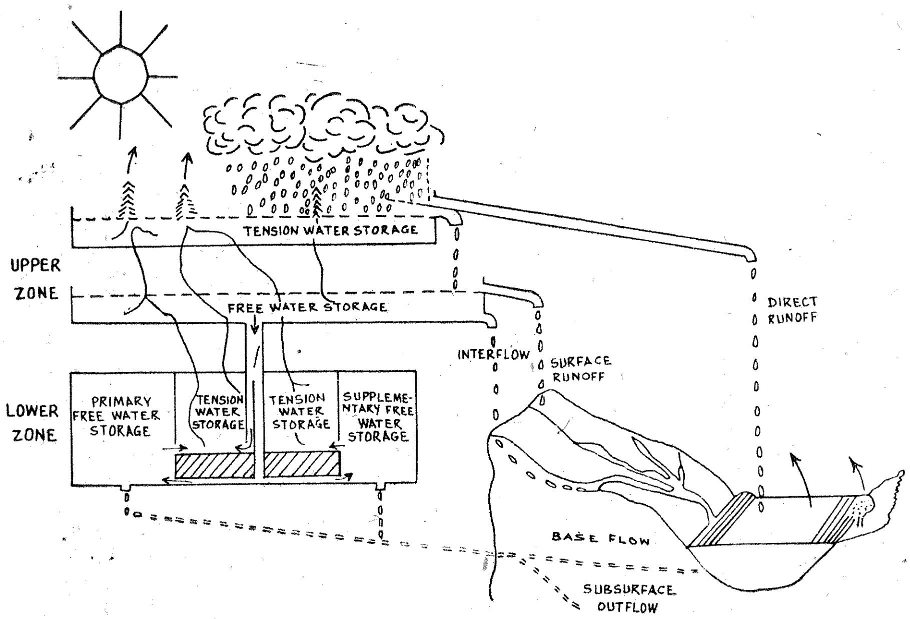

Fig. 1. Generalized Sacramento model

or stochastic, linear or non-linear, lumped or distributed, time independent or time varying, stationary or some combination of these. The choice of the model depends on the nature and purpose of the analysis to be made. During the precomputer period, conventional approaches to hydrologic analysis lacked in one respect that no attempt was made to analyse the land phase of the hydrologic cycle mainly due to limited computational capacity. For instance, in the study of floods, one of the main uncertainties was the determination of rainfall excess since it was affected by antecedent soil conditions of the watershed. Likewise the evaluation of drought conditions was based entirely on the analysis of historical records and no effort was made in understanding the actual physical processes taking place in the watershed or its water balance. Taking into consideration the long-term plan of the watershed development and the likelihood of the physical changes taking place in the watershed during the course of time, it becomes necessary that the method of hydrologic analysis should then allow for incorporating these physical changes into the analysis. Under these conditions the parameters used in determining the response of the watershed should have physical meaning. It may be possible to relate mathematically derived parameters of a response function to physical parameters of the watershed and thus account for changing watershed conditions.

Numerical simulation offers an important advance in the solution of hydrologic problems. One of the first and most successful efforts to simulate the entire runoff process for watershed was the 'stanford watershed model'. In the past, several models have come forth as modification to stanford watershed model. These models operate by receiving precipitation, transferring moisture between various storage elements and discharging moisture through evapotranspiration, deep percolation and streamflow. Most of these models differ mainly in identification of the number of components a hydrograph be sub-divided into and in the functional relationships chosen to represent various physical processes occurring in the watershed.

In deterministic conceptual model, if all the physical processes are included in formulating the model and its parameters have real physical meaning, then a detailed analysis of the watershed, comprising of the status of difficiencies of different soil zones, actual evapotranspiration, etc, may be possible. In as much as, it may be possible to simulate water balance of the watershed at any instant of time, although it depends upon the time period considered for each computation in the model under consideration. It may be hourly, 6 hourly or daily. While considering the potential of this technique, it may be pointed out, as a word of caution that in order to find out the values of the parameters the calibration should be done over a wide range of watershed conditions.

3. Sacramento deterministic conceptual model

3.1. Sacramento model is a conceptual system for modelling the land phase of the hydrological cycle. The detailed portion of the model along with the method of finding out the initial values of the parameters have been discussed in an earlier paper by Gosain and Abbi (1980).

However, a general description of the model is included here. The model is based on a system of percolation, soil-moisture storage, drainage, and evapotranspiration characteristics which are intended to represent the significant hydrologic processes in a rational manner. The magnitudes of the model parameters are achieved by establishing a soil moisture computation which allows the determination of basin streamflow from basin precipitation. Effective moisture storage capacities in the soil profile are estimated not by sampling the soil profile, but by inference from the rainfall and discharge records.

Rainfall occurring over the basin is considered as falling on two areas : (*i*) permeable portion of the soil mantle and (*ii*) other portion of the soil mantle covered by streams, lakes, marshes, or other impervious material directly connected to the streamflow network. The permeable area produces runoff when rainfall rates are sufficiently heavy, while the second area produces direct runoff from any rain. In the permeable portion of the basin, the model conceptualizes an initial soil-moisture storage identified as upper zone tension (Fig. 1) which must be totally filled before moisture becomes available to other storages. Tension water, which is closely bound to soil particles, represents that volume of precipitation which would be required under dry conditions to meet all interception requirements and to provide sufficient moisture to the upper soil mantle so that percolation to deeper zones and sometimes horizontal drainage can begin. After the upper zone tension volume is filled, excess moisture above its capacity is temporarily accumulated in upper zone free water. Free water is not bound to soil particles but is free to more vertically downward as percolation to lower zones or to move laterally through the soil under gravitational and pressure forces as interflow. Interflow is proportional to the available free water volume after percolation demand has been met with. The rate of vertical drainage, *i.e.*, the percolation from the upper zone free water has been given the first preference, though it is controlled by the contents of the upper zone free water and the deficiency of lower zone soil moisture volume. When the precipitation rate exceeds the percolation rate and the interflow drainage capacity, then the upper zone free water capacity is filled completely and the excess precipitation will result in surface runoff. Under this system, surface runoff is highly dependent upon the rate of precipitation and the degree of dryness of the different zones.

Lower zone tension water is the depth of water held by the lower zone soil after wetting and drainage and is generally available for evapotranspiration. The two lower zone free water storages, primary and supplemental, represent those volumes which are available for drainage as baseflow or sub-surface outflow. These storages are filled simultaneously from percolated water and drain independently at different rates, resulting in a variable ground water recession.

The percolation mechanics is designed to have a close correspondence with observed characteristics of moisture movement through soil. Percolation rate is minimum when the lower zone is totally saturated and is maximum when the lower zone is dry and the upper zone is full.

3.2. *Model parameters*

The parameters for model dealing with various phases of the soil moisture accounting are :

Direct runoff

PCTIM — Fraction of impervious basin contiguous with stream channels.

ADIMP — That fraction of basin which becomes impervious as all the tension water requirements are met.

SARVA — Fraction of basin covered by streams, lakes and riparian vegetation.

Upper soil moisture zone

UZTWM — Upper zone tension water maximum capacity in mm.

UZFWM — Upper zone free water maximum capacity in mm.

UZK — Lateral drainage rate of upper zone free water expressed as fraction of contents per day.

Percolation

ZPERC — A factor used to define the proportional increase in percolation from saturated to dry lower zone moisture conditions.

REXP — An exponent determining the rate of change of the percolation rate as the lower zone deficiency ratio varies from 1 to 0.

Lower zone

UZTWM — Maximum capacity of lower zone tension water in mm.

LZFSM — Maximum capacity of lower zone supplemented free water storage in mm.

LZSK — Lateral drainage rate of lower zone supplemental free water expressed as fraction of contents per day.

LZFPM — Maximum capacity of lower zone primary free water storage in mm.

LZPK — Lateral drainage rate of lower zone primary free water expressed as fraction of contents per day.

PFREE — The percentage of percolation water which directly enters the lower zone free water without a prior claim by lower zone tension water.

RSERV — Fraction of lower zone free water not available for transpiration purposes.

SIDE — The ratio of unobserved to observed base flow.

SSOUT — A fixed rate of discharge lost from the total channel flow.

3.3. *Initial parameter estimation*

A brief description of making an initial guess of model parameters, using the past historical data records of rainfall discharge and the basin characteristics is as follows: Semilogarithmic hydrograph plots, taking discharge on log-scale, have been used to separate hydrographs into principal flow component of surface runoff, interflow and groundwater. On semi-loggraphs, it is observed that the recession portion has two distinct linear slopes representing two separate sources of base-flow with separate exponential decaying functions. For this model, these are supplemental and primary free water storages. Analysis of the recession provide methods for estimating the depletion rates and storage for the two soil zones. A brief description of how this is accomplished for each free water storage is as follows:

Primary (LZPK and LZFPM)

Select a period on semi-log plot when the recession is the flatest. Primary daily recession rate is :

$$K_p = (Q_{P_2}/Q_{P_1})^{1/t}$$

where Q_{P_2} and Q_{P_1} are the discharge values at lower and higher points respectively for the selected period of the recession curve and t is the time in days for this period.

The daily depletion rate is given by:

$$\text{LZPK} = 1 - K_p$$

and $\text{LZFPM} = Q_{P_{\max}}/\text{LZPK}$

for any other value of $Q_P < Q_{P\max}$, lower zone free primary content is

$$\text{LZFPC} = Q_P/\text{LZPK}$$

Supplemental (LZSK and LZFSM)

Similar computations as for primary storage values, though after substracting the primary contribution, are made to find the slope representing supplemental baseflow:

$$K_S = (Q_{S_2}/Q_{S_1})^{1/t}.$$

supplemental daily depletion rate is

$$\text{LZSK} = 1 - K_S$$

and $\text{LZFSM} = Q_{S\max}/\text{LZSK}$

Percent Impervious (PCTIM)

A small rise on the hydrograph during an extended dry period may be used to compute a value for PCTIM

$$\text{PCTIM} = \Sigma\text{Direct Runoff}/\Sigma\text{Rain}$$

Lower Zone Tension water Maximum (LZTWM)

Select a period following an extended dry period where the discharge Q_1 and Q_2 at time t_1 and t_2 respectively represents only baseflow

at t_1 : $Q_1 = Q_{S1} + Q_{P1}$

and at t_2 : $Q_2 = Q_{S2} + Q_{P2}$

Primary and supplemental free water storage contents (LZFPC and LZFSC) for each of the two times t_1 and t_2 are computed as

$$\text{LZFPC} = Q_P/\text{LZPK}$$

$$\text{LZFSC} = Q_S/\text{LZSK}$$

Assuming that UZTW is full and UZFWC is empty at times t_1 and t_2, the water balance for the period may be expressed as

$$P_X - R_O - P_E - \triangle\text{LZFSC} - \triangle\text{LZFPC} - \triangle\text{LZTWC} = 0$$

where P_X is precipitation during the storm in mm
R_1 is the total runoff in mm
P_E is the evapotranspiration from basin in mm, $\triangle$ LZTWC is the change in lower zone tension water.

All values except $\triangle$LZTWC are measurable or estimated. As this gives us the change in LZTW during the time interval considered and may not completely saturate this zone. Moreover the LZTW would probably not have been entirely empty prior to the storm, a small percentage (10 to 20 per cent) should be added to $\triangle$LZTWC to arrive at an initial estimate for LZTWM.

Upper Zone Tension Water Maximum (UZTWM)

All period of rain following a dry period are examined to determine the amount of precipitation the pervious area can hold without surface runoff occuring, which gives as an initial estimate of UZTWM.

Upper Zone Free Water Maximum (UZFWM) and Drainage rate (UZK)

Although UZK cannot be obtained directly from hydrograph analysis as interflow recession does not produce a straight line on semi-log plot, it is roughly related to the amount of time that interflow occurs following a period with major direct and surface runoff. If we assume that interflow becomes insignificant when its contribution reduces to about 10 per cent of what it is at maximum rate, then the following simple relation can be used for UZK :

$$(1-\text{UZK})^{N}=0.10$$

where, N is the average number of days that interflow is observed.

A value of UZFWM can be determined using the UZK computed above and the discharge, corrected for supplemental and primary baseflow, at the time of the highest interflow without surface waster contribution. Then UZFWM :

$$\text{UZFWM}=\text{Max. Interflow/UZK}$$

Percolation Water Percentage (PFREE)

An estimate of relative importance of PFREE can be determined from investigating storms following long dry spells that do produce runoff (UZTW completely filled) if the hydrograph returns to approximately the same baseflow as before (indicating little or no addition to the lower zone free water storage), then PFREE is of little significance and has value ranging from 0 to 0.2. If there is significant increase in baseflow following this type of storm, then PFREE can have a value as high as 0.5.

Sub-Surface Outflow Along Stream Channel (SSOUT)

Usually its value is zero but a value other than zero can be applied only if the *Q*-log plot requires a constant addition to the baseflow in order to achieve a valid recession characteristics.

Fraction of Basin Covered by Streams, etc (SARVA)

This factor is determined directly from maps showing water and riparian vegetation areas.

Percolation Parameters (ZPERC and REXP)

These parameters are mainly responsible for interaction between lower zone and upper zone. If the lower zone free water storage are full and the upper zone free water is also at its maximum. Then the rate of percolation is equal to PBASE which is defined by

$$\text{PBASE}=(\text{LZFPM}\times\text{LZPK}+\text{LZFSM}\times\text{LZSK})$$

As the lower zone soil moisture becomes deficient the percolation rate increases. When the lower free water storages are completely dry (100 per cent deficient), the percolation rate (assuming UZFW full) occurs at its maximum and is equal to:

Maximum Percolation rate=
(1+ZPERC)× PBASE

Percolation rate under any condition is equa to Percolation rate=PBASE (1+ZPERC×

$$\times\text{DEFR REXP})\times\text{UZFWC/UZFWM}$$

where, ZPERC is a factor used to define the proportional increase in percolation from saturated to dry lower zone moisture conditions, and REXP is an exponent determining the rate of change of percolation rate as the lower zone deficiency ratio varies from 1 to 0.

The relative values of these parameters could possibly be estimated from the soil percolation characteristics. However, the best first estimate is to use values from similar nearby basins that have been previously simulated.

Parameters Requiring Nominal Starting Values (SIDE, ADIMP and RSERV)

SIDE=0	(If considerable groundwater bypassed the surface channel, a value other than zero should be used).
RSERV=0.3	(It is that fraction of lower zone free water which unavailable for transpiration).
ADIMP=0.1	(This is additional area of the basin which becomes impervious as all tension water requirements are met. Its value may be higher for heavy rainfall areas).

3.4. *Computational method for water balance*

The effectiveness with which the water balance studies can be made through the conceptual model depends mainly upon the closeness with which the concepts adopted for the physical processes represent those actually prevailing in the catchment. While formulating the sacramento model, special attention has been given to recognise the various physical processes predominent in the catchment and to represent them mathematically as closely as possible, within the constraints of the degital computer.

The movement of moisture through the soil mantle is a continuous process in which the rate of flow at various points varies with the rate of moisture supply and with the contents of various storages so that the water balance of the basin is maintained. But, for solving a continuous process on a degital computer, discretization is essential. Thus the choice of time step becomes an important factor, as a single time step computation involves the assumption that the movement of moisture during the time step is defined

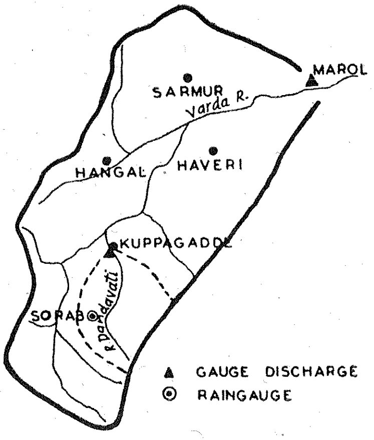

Fig. 2. Dandavathy river catchment

by the conditions at the beginning of the time step, which is not a valid assumption. A better assumption is made by taking a volume dependent step length in such a way that no more than 5 mm of water is involved in one computation. The 5 mm limit is semiarbitrary being small enough to logically fulfill the functions and not so small as to consume lot of computer time.

The model involves 17 parameters (Gosain and Abbi 1980). Some of these parameters are rapidly found out from the past observed data of rainfall and runoff and from catchment characteristics. The values of the remaining parameters are found by calibrating the model over a number of years.

3.5 *Water balance studies of Dandavathy basin*

Dandavathy river basin is a small basin with an area of 482 sq. km. It is a tributary of *Varda* river which in turn is a tributary of *Tungabadhra* river. The discharge station on river Dandavathy is located at Kuppagadde, (75° 07′E, 14° 30′N) as shown in Fig. 2.

3.5.1. *Data used*

Daily discharge data at Kuppagadde for four years (1970-1973) was utilised. Rainfall data was taken of a single station Sorab, which is situated almost in the centre of the catchment. The available daily rainfall data was uniformly distributed over each day to get 6 hourly data as required for the model. For evapotranspiration demand curve, mean monthly values of Hebbal, an agromet. station (India Met. Deptt., 1970) were taken as the values on 16th of each month. These mid-month values are linearly interpolated to get the daily evapotranspiration demand curve. However, if actual evapotranspiration data is available, this curve can be used as evapotranspiration adjustment factors.

TABLE 1

Final parameter values for the watershed

Parameter	Value	Parameter	Value
UZTWM	25.0	LZTWM	150.0
UZFWM	25.0	LZFSM	100.0
UZK	0.300	LZFPM	140.0
PCTIM	0.002	LZSK	0.044
ADIMP	0.100	LZPK	0.003
SARVA	0.100	PFREE	0.30
ZPERC	30.0	RSERV	0.30
REXP	1.80	SIDE	0.0

3.5.2. *Model calibration*

Model has been calibrated with three years of data and then validated for the fourth year. The final set of parameter values adopted, after calibration are given in Table 1.

3.5.3. *Water balance evaluation of the basin*

As mentioned earlier, the extent of accuracy with which the water balance of a basin can be evaluated by these models depends upon the degree of conceptuability with which the different physical processes have been represented in the model. One needs to have an observational check, and the readily available observation is that of discharge. The model is conceptually true if it is able to simulate discharge values comparable with those of observed one over a long period, although the degree of conceptuability depends upon how closely the model is able to simulate the observed hydrographs.

As the computations are made on 6 hourly basis, the soil moisture allocation to the various compartments and the distribution of runoff into different components can be had after every 6 hours. The various components are :

(*i*) Impervious runoff from permanent impervious area.

(*ii*) Direct runoff from temporary impervious area.

(*iii*) Surface runoff due to precipitation occurring at a rate faster than percolation and interflow can take place when both upper zone storages are full,

TABLE 2

Precipitation, Evapotranspiration and Runoff volume (mm) for water year 1972

	Impervious runoff	Direct runoff	Surface runoff	Interflow	Baseflow	Total runoff	Precipitation	Potential E_T	Actual E_T
Oct	0.2	0.4	0.0	3.3	15.4	13.7	95.7	153.9	89.4
Nov	0.0	0.0	0.0	0.0	10.5	5.2	0.5	141.1	30.6
Dec	0.0	0.0	0.0	0.0	7.8	3.9	0.0	143.8	14.3
Jan	0.0	0.0	0.0	0.0	6.6	3.3	0.0	172.0	8.3
Feb	0.0	0.0	0.0	0.0	5.5	2.8	0.0	213.9	4.9
Mar	0.0	0.0	0.0	0.0	5.4	2.7	0.0	270.7	3.4
Apr	0.1	0.0	0.0	0.0	4.7	2.4	26.4	270.8	17.5
May	0.3	0.2	0.0	2.2	9.0	7.8	162.1	265.9	136.6
Jun	0.3	1.1	0.0	4.0	8.5	10.6	167.4	222.0	76.3
Jul	0.9	26.0	48.5	57.6	55.3	187.1	472.8	204.3	196.7
Aug	0.2	0.2	0.0	0.5	25.7	23.3	111.8	182.1	154.0
Sep	0.2	0.8	0.0	3.7	14.5	14.3	120.2	166.3	110.0

TABLE 3

Precipitation, Evapotranspiration and Runoff Volume (mm) For water year 1973

	Impervious runoff	Direct runoff	Surface runoff	Interflow	Baseflow	Total runoff	Precipitation	Potential E_T	Actual E_T
Oct	0.2	1.3	0.0	3.6	16.6	17.7	106.8	153.9	116.0
Nov	0.0	0.0	0.0	0.0	9.1	4.9	22.2	141.1	63.0
Dec	0.0	0.0	0.0	0.0	6.9	3.5	5.4	143.8	29.5
Jan	0.0	0.0	0.0	0.0	5.8	2.9	0.0	172.0	12.4
Feb	0.0	0.0	0.0	0.0	4.7	2.4	0.0	205.8	6.2
Mar	0.0	0.0	0.0	0.0	4.8	2.4	0.0	270.7	3.7
Apr	0.0	0.0	0.0	0.0	4.2	2.1	11.0	270.8	3.3
May	0.2	0.0	0.0	0.0	4.7	2.6	97.2	265.9	83.9
Jun	0.6	4.8	3.6	10.8	15.8	31.9	293.0	222.0	167.3
Jul	0.9	23.3	22.1	61.9	55.7	162.0	454.4	204.3	190.5
Aug	0.5	6.5	0.0	20.8	38.4	65.0	266.0	182.1	173.9
Sep	0.1	0.0	0.0	0.0	21.7	17.3	31.3	166.3	124.7

TABLE 4

Soil moisture contents (mm) at end of each month for water year 1972

	UZTWC	UZFWC	LZTWC	LZFSC	LZFPC
Oct	3	0	40	4	97
Nov	0	0	18	1	88
Dec	0	0	8	0	80
Jan	0	0	3	0	73
Feb	0	0	1	0	67
Mar	0	0	0	0	61
Apr	11	0	0	0	56
May	1	0	22	4	58
Jun	25	4	62	12	63
Jul	10	0	125	25	104
Aug	9	0	84	7	95
Sep	21	0	71	7	90

(iv) Interflow resulting from the lateral drainage of a temporary free water storage.

(v) Baseflow resulting from the depletion of primary and supplemental storages.

Tables 2 and 3 depict the monthly volumes in mm for the above described components of runoff along with total simulated runoff precipitation, potential evapotranspiration and actual evapotranspiration as simulated for water years 1972 and 1973 respectively. It may be mentioned here that these values can also be obtained at six hours interval. Soil moisture content values, in mm, at the end of each month of water year 1972 and 1973 for different soil moisture compartments namely : Upper zone tension water content (UZTWC), upper zone free water content (UZFWC), Lower Zone Tension Water Content (LZTWC), Lower Zone Free Supplemental Water Content (LZFSC) and Lower Zone Free Primary Water Content (LZFPC) have been shown in Tables 4 and 5 respectively. Tables 6 and 7 show the change in moisture in the various soil moisture compartments during each month of these two years respectively. As mentioned earlier, the contents of the various soil moisture contents and therefore the changes in their status may be known at shorter time intervals, upto 6 hours, if required.

TABLE 5

Soil moisture contents (mm) at end of each month for water year 1973

	UZTWC	UZFWC	LZTWC	LZFSC	LZFPC
Oct	10	0	62	4	85
Nov	3	0	33	1	78
Dec	0	0	15	0	71
Jan	0	0	6	0	65
Feb	0	0	2	0	60
Mar	0	0	0	0	54
Apr	0	0	0	0	50
May	4	0	7	1	47
Jun	3	0	78	12	63
Jul	5	0	119	33	109
Aug	17	0	149	20	107
Sep	1	0	75	5	97

TABLE 6

Change in storages of soil moisture components (mm) over each month for water year 1972

	△UZTW	△UZFW	△LZTW	△LZFWC	△LZFPW
Oct	—8	0	+5	0	—6
Nov	—3	0	—22	—3	—9
Dec	0	0	—10	—1	—8
Jan	0	0	—5	0	—7
Feb	0	0	—2	0	—6
Mar	0	0	—1	0	—6
Apr	+11	0	0	0	—5
May	—10	0	+22	+4	+2
Jun	+24	+4	+40	+8	+5
Jul	—15	0	+63	+13	+41
Aug	—1	0	—41	—18	—9
Sep	+12	0	—13	0	—5

TABLE 7

Change in storage of soil moisture components (mm) over each month for water year 1973

	△UZTW	△UZFW	△LZTW	△LZPSW	△LZFPW
Oct	—11	0	—9	—3	—5
Nov	—7	0	—29	—3	—7
Dec	0	0	—18	—1	—7
Jan	0	0	—9	0	—6
Feb	0	0	—4	0	—5
Mar	0	0	—2	0	—6
Apr	0	0	0	0	—4
May	+4	0	+7	+1	—3
Jun	—1	0	+71	+11	+16
Jul	+2	0	+41	+21	+46
Aug	+12	0	+30	—13	—2
Sep	—16	0	—74	—15	—10

TABLE 8

Water balance for water year 1972

	Rain	Runoff	E_T	Change in storage	Balance
Oct	95.7	13.7	9.4	—9	1.6
Nov	0.5	5.3	30.6	—37	+1.6
Dec	0	3.9	14.3	—19	+0.8
Jan	0	3.3	8.3	—15	+3.4
Feb	0	2.8	4.9	—8	+0.3
Mar	0	2.7	3.4	—7	+0.9
Apr	26.4	2.4	17.5	+6	+0.5
May	162.1	7.8	136.6	+18	—0.3
Jun	167.4	10.4	76.3	+81	—0.3
Jul	472.8	187.1	196.7	+102	—13.0
Aug	111.8	23.5	154.0	—69	+3.3
Sep	120.2	14.2	110.0	—6	+2.0

All quantities are in mm.

Change in storage : [+ Addition to the storage
— Substraction from the storage]

TABLE 9

Water balance for water year 1973

	Rain	Runoff	E_T	Change in storage	Balance
Oct	106.8	17.7	116.0	—28	+1.1
Nov	22.2	4.9	63.0	—46	+0.3
Dec	5.4	3.5	29.5	—26	—1.6
Jan	0	2.9	12.4	—15	—0.3
Feb	0	2.4	6.2	—9	+0.4
Mar	0	2.4	3.7	—8	+1.9
Apr	11.0	2.1	13·3	—4	—0.4
May	97.2	2.6	83.9	+9	+1.7
Jun	293.0	31.8	167.3	+97	—3.1
Jul	454.4	161.7	190.5	+110	—7.8
Aug	266.3	65.1	173.9	+27	+0.3
Sep	31.3	17.6	124.7	—115	+4.0

All quantities are in mm.

Change in storage : [+ Addition to the storage,
— Substraction from the storage].

4. **Discussion on the results**

Tables 8 and 9 respectively give the monthly rain, runoff, evapotranspiration and the change in storage in mm as yielded by the model. The last column in both the tables gives the difference in the water balance which is coming up after accounting the various components of the water balance equation that is

$$P = R + E_T + \Delta S$$

It may be seen from the last column that these differences are very small and may be due to the error in the estimation of the areal rainfall in the catchment on the basis of the single station data. The model has more or less reproduced the perfect balance in the hydrologic equation and therefore has the potential capability for the water balance Studies.

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References

Gosain, A.K. and Abbi, S.D.S., 1980, Application of Sacramento River Forecast Model to An Indian Catchment, *Mausam*, **31**, 1, pp. 55-64.

India met. Dep., 1970, Evaporation data (India), 1961-1968, Pt. II : Agrometeorological Observatories.