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Application of conceptual modelling in estimation of soil moisture

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सार – कृषि विज्ञान की दृष्टि से मृदा नमी संचयन् एक महत्वपूर्ण प्राचल है। जलीय चक्र के महत्वपूर्ण अंग होने के कारण, मृदा में इसके वितरण और मात्रा के आकलन को आवश्यक माना जाता है। इन मूल्यों के अनुकरण करने की मौजूदा प्रणालियों की अपनी सीमांए हैं। इस शोधपत्र में संकल्पनात्मक मॉडलिंग द्वारा मृदा नमी आकलित करने के लिए एक नई तकनीक प्रस्तुत की गई है।

ABSTRACT. Soil moisture storage is an important parameter from agricultural point of view. Being a significant component of the hydrologic cycle, it is necessary to estimate the quantity and its distribution in the soil. The existing methods to monitor these values have their own limitations. A recent technique for soil moisture estimation by conceptual modelling has been presented in this paper.

1. Introduction

Water exists in nature in various phases and its presence in the form of soil moisture is very signifcant from hydrological and agricultural point of view. Absence of soil moisture leads to droughts and its excess to water logging. In simple terms, soil moisture $W = P - S$, where, P is the precipitation and S is the surface flow. Soil moisture, W breaks into $U + E$, where U is the underground flow and E is the evaporation/evapotranspiration. Knowing the precipitation P and surface runoff S, soil moisture W can be estimated and from it underground flow U can be determined if evaporation/evapotranspiration E is known. In actual practice the problem is not that simple. Soil moisture depends on several factors like, rainfall intensity, type of the soil, depth of soil, movement of water through the unsaturated zone, forces influencing the infiltration process and to some extent on the use of fertilizers. If rainfall is very intense, major portion of it becomes direct runoff. A fine clay soil may initially have high infiltration rate than sand soil but later the infiltration rate becomes very small compared to that of sand soil. This is because the absorption force due to molecular attraction between soil particles and water molecules is extremely strong in close vicinity of the soil particles. Very early in a storm, the attractive forces of fine particles in a fairly dry soil are very high, and this contributes to the fact that the initial rate of infiltration for such a soil tends to be very high. When the soil is wet and each soil grain is surrounded by a thin layer of water, the absorptive attraction of the soil effectively becomes zero.

The surface tension force is also influenced by soil particle size or rather interparticle pore spaces. In a dry soil, the smaller the pore space, the larger will be the surface tension force, attracting water into that space. As water is absorbed around each particle and is held between particles by capillary action, the spaces through which water can move are considerably reduced and friction forces become large. Once the surface of the soil becomes wet, the attractive forces of successive soil layers to draw water into the soil are partially counterbalanced by the friction force exerted on the water by the surface layers. Friction forces are more significant for fine-grained than for the course-grained soils due to the initially smaller empty spaces in fine-grained material. If salts are present, water tends to be held in the soil by a force equal to the osmotic pressure of the salts, in addition to the capillary and absorptive forces. This explains why less water becomes available to plants if the water is saline.

Neutron probe technique is commonly used for the measurement of soil moisture. The instrument is called the 'Autoprobe' which is an automated soil moisture measuring device. In this device, the neutron probe is moved automatically up and down an access tube, stopping at present depths to measure and record the moisture content of the soil. The movement of the probe is controlled by compressed air and the data are stored on a micro data logger.

The limitation of above technique and other commonly used techniques for soil moisture measurement

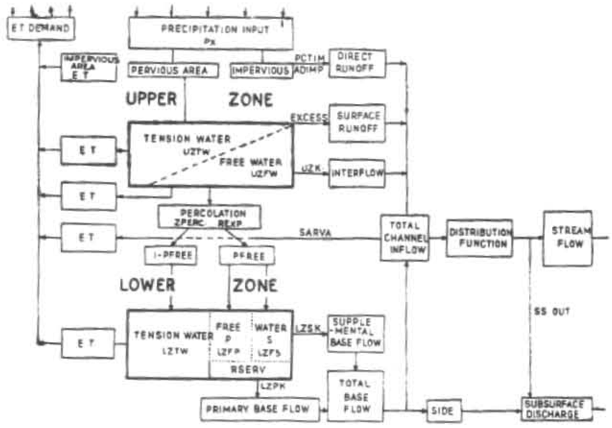

Fig. 1. Block diagram of Sacramento model (*From* NOAA Tech. Memo. NWS HYDRO-31)

TABLE 1

Monthly soil moisture contents (in mm)

	UZT WC	UZF WC	LZT WC	LZF SC	LZF PC
October	10	0	62	4	85
November	3	0	33	1	78
December	0	0	15	0	71
January	0	0	6	0	65
February	0	0	2	0	60
March	0	0	0	0	54
April	0	0	0	0	50
May	4	0	7	1	47
June	3	0	78	12	63
July	5	0	119	33	109
August	17	0	149	20	107
September	1	0	75	5	97

is that the estimation is made at discrete points and at different intervals of time. This does not provide an accurate estimation of quantity and distribution of soil moisture.

2. Conceptual modelling

Conceptual modelling is an ideal technique to estimate a continuous profile of soil moisture. Abbi *et al.* (1980) have successfully used this technique for water balance studies over a small river catchment. The model used is 'Sacramento Model' developed by Joint Federal State River Forecasting Centre, U.S.A. It is a deterministic conceptual lumped model ideal for small and medium river catchments. In this model, the soil zone is characterised as 'Upper Zone' responsible for surface and interflow and 'Lower Zone' responsible for ground water flow. Mathematically, the water balance equation can be expressed as :

$$P - R - \Sigma E_T - \triangle \text{UZTW} - \triangle \text{UZFW} - \triangle \text{LZTW} - \triangle \text{LZFW} - \eta = 0 \qquad (1)$$

where,

- P : Precipitation in mm during the time interval under consideration,
- R : The total runoff,
- E_T : The total evapotranspiration from upper and lower soil zones,
- $\triangle$UZTW : The change in upper zone tension water storage,
- $\triangle$UZFW : The change in upper zone free water storage,
- $\triangle$LZTW : The change in lower zone tension water storage,
- $\triangle$LZFW : The change in lower zone free water storage
- η : The losses due to deep percolation.

The flow diagram of the model is given in Fig. 1.

TABLE 2

Changes in moisture contents in various moisture compartments during 1973

	△UZ TW	△UZ FW	△LZ TW	△LZP SW	△LZP FW
October	—11	0	—9	—3	—5
November	—7	0	—29	—3	—7
December	0	0	—18	—1	—7
January	0	0	—9	0	—6
February	0	0	—4	0	—5
March	0	0	—2	0	—6
April	0	0	0	0	—4
May	+4	0	+7	+1	—3
June	—1	0	+71	+11	+16
July	+2	0	+41	+21	+46
August	+12	0	+30	—13	—2
September	—16	0	—74	—15	—10

TABLE 3

Water balance for water year 1973

	Rain	Runoff	E_T	Change in storage	Balance
October	106.8	17.7	116.0	—28	+1.1
November	22.2	4.9	63.0	—46	+0.3
December	5.4	3.5	29.5	—26	—1.6
January	0	2.9	12.4	—15	—0.3
February	0	2.4	6.2	—9	+0.4
March	0	2.4	3.7	—8	+1.9
April	11.0	2.1	13.3	—4	—0.4
May	97.2	2.6	83.9	+9	+1.7
June	293.0	31.8	167.3	+97	—3.1
July	454.4	161.7	190.5	+110	—7.8
August	266.3	65.1	173.9	+27	+0.3
September	31.3	17.6	124.7	—115	+4.0

The model conceptualises an initial soil moisture storage identified as Upper Zone Tension 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 sometime 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 move vertically downward as percolation to lower zones or to move laterally through the soil under gravitational and pressure forces as interflow. 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. 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.

Using the Eqn. (1), a study of water balance for a small river catchment *Dandavathy*, a tributary of river *Tungabhadra* with catchment area of 482 sq. km was made (Abbi *et al.* 1980). The study revealed that the model more or less reproduced a perfect balance in the hydrologic equation. On the basis of this result, it can be safely concluded that the soil moisture content in the soil as simulated by the model is very close to the actual content in the soil. The above study conducted for the water year 1973, yielded the monthly values (Table 1) of soil moisture content in mm for different compartments, namely : Upper Zone Tension Water Content (UZTWC), Upper Zone Free Water Content (UZFWC), Lower Zone Tension Water Content (LZTWC), Lower Zone Free Supplementary Water Content (LZFSC) and Lower Zone Free Primary Water Content (LZFPC).

Consequently, the changes in moisture contents in various soil moisture compartments during each month of 1973 water year are as given in Table 2.

3. Discussion on the results

The results yielded by the model may be seen in Table 3 which gives water balance for the year 1973.

It may be seen from the last column of Table 3 that the model has more less reproduced the perfect balance in the hydrologic equation $P=R+E_T+\triangle S$ and therefore has the capability to estimate soil moisture daily or on 6 hourly basis depending upon the need to regulate irrigation schedules of the crops at their various stages of growth. Further, from soil moisture content, it is also possible to estimate ground water recharge as mentioned earlier. This will enable us to assess the ground water potential of the region, another vital source for irrigation.

Positive sign means excess of soil moisture while negative sign means the deficiency. During the rainy months of June, July and August, there is increase in soil moisture contents in upper zone tension water storage, lower zone tension water storage and lower zone tension water storage and lower zone free water (supplemenatary and primary) water storage. There is practi cally no change in the upper zone free water storage due to continuous percolation.

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