I.1 Introduction

The concept of water balance has recently gained considerable importance among the climatologists, Meteorologists, Geographers, Geologists, Hydrologists and from other disciplines concerned primarily with water problems. It is thus very useful to study water balance and to apply this concept in the study of agricultural landuse with the aim of achieving efficient and better landuse planning and rational conservation of water resources.

Water balance may be defined as the income of water from precipitation and other sources and the loss or outflow of water by means of evapotranspiration which represents the combined loss of water from the earth by means of evaporation and transpiration as well as from other sources. In other words, the process of evapotranspiration is actually the reversal of the process of precipitation. Thornthwaite has suggested an equation for water balance which is Precipitation = Potential evapotranspiration - Deficit + Surplus = storage change.¹ Prof. Sutcliffe in his study of

world water balance on the proceedings of the Reading Symposium, July, 1970 pointed out that World Water Balance must pay regard not only to all modes and abundance of water, but also to all fluxes, inter-modal and intra-modal and also to many phenomena of different scabs in time and space and their generally non-linear interactions........

According to Horton, the water balance equation may be written as \( E = I - O - S \) where \( E \) is the Evaporation, \( I \) is the inflow of water or precipitation, \( O \) is the outflow or total run-off, and \( S \) is the change in reservoir contents.\(^{3}\) The outflow of the above equation may involve outflow due to sub-surface seepage. Seepage is usually the most difficult item of evaluate since it must be estimated indirectly from measurements of groundwater levels, permeability etc. when seepage nearly equals or exceeds evaporation, the water balance method can not be taken to be very reliable. If a stage-seepage relation can be derived, the water balance becomes applicable on a continuing basis. Recent studies show that a simultaneous solution of the water balance and heat transfer equations can produce estimates of evaporation and seepage.\(^{4}\)


I.2 Global Waterbalance

In connection with the study of Global Waterbalance, Budyko and his co-workers suggested that waterbalance involves not only precipitation \( P \), evaporation \( E \) and run off \( r \) but also water exchange \( W \) between oceans.\(^5\)

Similarly it may be suggested that other factors remaining constant the water balance of a basin may be calculated by the formula \( P + r = E + W \) where \( W \) represents the change of storage.

I.3 Waterbalance of a drainage basin

A.P.Bochkov and A.B.Zavodchikov suggested a method for computation of water balance in terms of a drainage basin. According to them, water balance equation, which includes the main components of income \( A \) and of expenditure \( B \) and the variation of water storage on a watershed \( C \) for any particular period of time \( P \), may be written as follows\(^6\) :-

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Income/Input

\[ A = B + C + P \]

\[ A = X + r + n \]

Expenditure/Output

\[ B = Y + E + Y \]

Storage Condition

\[ C = x + x_a + xa + W + W + U \]

where

\[ X = \text{Precipitation} \]

\[ = \text{Inflow of Water from adjacent basins.} \]

\[ n = \text{Partial return of water used for agricultural purpose} \]

\[ r = \text{the rest of water income in the basin.} \]

\[ Y = \text{stream flow in the outlet of the basin.} \]

\[ E = \text{Total evaporation from the surface soil, water, snow, ice and transpiration by vegetation (minus condensation).} \]

\[ Y = \text{Water intake from the river for agricultural purpose. (Water supply, irrigation, transportation of water to the other basin etc.)} \]

\[ X_a = \text{Variation of water storage in river channels.} \]

\[ W = \text{Variation of water storage in the upper (1 metre) soil layer.} \]

\[ W = \text{Variation of water storage in the lower layers of the soil of the aeration zone (from 1 m. depth down to the groundwater table).} \]

\[ U = \text{Variation in the ground water storage.} \]

\[ P = \text{The discrepancy of Waterbalance obtained as a residual term of the equation, including all the errors of determination of waterbalance elements as well as stream flow underneath the river bed (underflow) and water exchange with other basins and aquifers not drained by the river.} \]

I.4 Waterbalance Over time

In order to compute waterbalance of a particular basin for individual months and seasons, it will be more rational to divide the total stream flow in two components: Surface components \((Y_s)\) (+) and underground components \((Y_g)\) \((Y_s = Y_s + Y_g)\).

Prof. Baumgartner and Reichel, while studying the water budget of a unit area of the earth's surface, suggested that the major components of waterbalance are Precipitation \((P)\), Evaporation \((E)\), Discharge/Runoff \((D)\), Reserve/Storage \((R)\), and consumptive Use \((U)\). Thus waterbalance, according to them, can be expressed by the following equation:

\[
P = E + D + R + U
\]

The equation states that water added to the earth surface by precipitation is partitioned among the component \(E, D\) and \(U\). Here \(D\) can signify surface runoff or interflow. \(R\) is the temporary storage of water in the soils and \(U\) designates chemically or physically bound water. In order to compute long-term waterbalance, only \(P, D\) and \(E\) are taken into consideration assuming that \(R\) and \(U\) are constant. Thus fluctuations of these quantities become insignificant in the waterbalance. The long-term water balance can be expressed by the following equation. 8

The major components of waterbalance can be conveniently shown by the following equation as suggested by A.N. Strahler and A.H. Strahler.

\[ P = E + G + R \]

When \( P \) is precipitation

\( E \) is evaporation

\( G \) is net gain or loss of the water in the system storage term and \( R \) is run off (positive when out of the continents, negative when into the oceans).

It is to be mentioned in this connection that when applied over the span of a year and averaged over many years, the storage term \( G \) can be neglected. Since the system is essentially closed so far as matter is concerned. The quantities of water in storage in the atmosphere, on the lands and in the oceans will remain about constant from year to year.\(^9\)

The equation then can be simplified to: \( P = E + R \).

I.5 Waterbalance and Hydrologic Cycle

The study of water balance necessitates the study of hydrologic cycle since the balance is based mainly on two

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elements, viz., Precipitation, the income or input element and evapotranspiration the expenditure or output element which are largely governed by the hydrological cycle which means a simple link but a group of numerous arcs which represents the different paths through which the water in nature circulates and is transformed. These arcs penetrate three parts of the system, atmosphere, hydrosphere and lithosphere and undergo various complicated processes of evaporation, precipitation, interception, transpiration, infiltration, percolation, storage and run-off. 10

The broad hydrologic cycle involves the loss of water from hydrosphere and lithosphere primarily by evaporation followed by positive change of water storage mainly by precipitation which in turn is distributed by the process of run off.

(Evapo-transpiration — Precipitation — Run off).

Within this broad hydrologic cycle many sub-cycles are to be found because of the relative change of the variables on the hydrosphere, atmosphere and lithosphere.

These sub cycles can be summed up as follows :-

1. Evaporation from Oceans — Condensation and —
   storage of water in atmosphere — Precipitation —
   direct return of water to Ocean.

2. Evaporation from Ocean / river/ depression — conden-
   sation of water in the atomosphere — driven by wind —
   centred on land — Precipitation — Surface run off
   into river/ocean/depression.

3. 'E — P — interception by vegetal cover — transpi-
   ration — return to atmosphere.

4. E — P — Surface Run off — interception in the zone
   of aeration leading to soil-moisture storate — soil
   moisture evaporation — return to atmosphere.

5. E — P — S.R — Percolation — Ground Water storage —
   base flow to river/ocean — return of water to natural
   storages.


7. E — Precipitation — Surface storage of water in the
   form of ice — melting — (surface run off — return
   to natural storage ) — again evaporation — atmospheric
   storage. 11

From the study of the hydrologic cycle it appears
that the three major phases of the hydrologic cycle viz.,
the phase of evaporation, the phase of precipitation and the

phase of run-off, largely affect the nature of water storage and waterbalance as shown by the following table:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Types of storage</th>
<th>Nature of water balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase of Evaporation Transpiration</td>
<td>Atmospheric storage of water</td>
<td>Negative waterbalance $E &gt; P$</td>
</tr>
<tr>
<td>Phase of Precipitation &amp; Run Off</td>
<td>Surface storage, interception storage, soil-moisture storage Ground water storage and Deep Ground water storage</td>
<td>Positive waterbalance $P &gt; E$ (increasing water balance) Positive waterbalance $P+R &gt; E$ (Decreasing water balance.)</td>
</tr>
</tbody>
</table>

The importance of considering the various components of the hydrologic cycle for water balance was also stressed by A.A. Sokolov who suggested the necessity of designing hydrometeorological regime after considering the hydrometeorological elements viz., precipitation, air humidity, wind, evaporation from water surface, bank storage, accumulation component of waterbalance etc.\(^1\)\(^2\)\(^3\) Water balance for a particular river basin can be represented by the following equation as suggested by Lvovich:

\[
P = S+U+E, \quad W = P-S = U+E, \quad R = S+U, \quad (K_v = \frac{U}{W})
\]

\[
K_E = \frac{E}{W} = 1 - K_U
\]


Where P is precipitation, R = river flow, S = surface (flood) run off, U = groundwater (permanent) discharge into rivers, E = Evapotranspiration which is the sum of N (Soil evaporation) and T (Transpiration), W=overall soil moistening, or the amount of rain and snow water that infiltrates the soil, $K_U$ and $K_E$ are, respectively, the co-efficient of evaporation, showing what portion of the total water that moistures of soil (W) becomes groundwater which discharge into rivers, and what portion evaporates.  

It is to be noted in this connection that computation of water balance for a river basin is fairly complicated as it is found that during the periods of low precipitation as during the winter months and in dry seasons, rivers are fed exclusively by groundwater. This necessitates for the calculation of the share of groundwater in stream flow.

I.6 The Parameters & Computations of Waterbalance

From the study of hydrologic cycle it appears that the elements within the cycle largely determines the waterbalance of a particular area. These elements can be regarded as parameters of water balance study. For the present purpose five parameters are considered viz., Temperature, Precipitation, Humidity, Evapotranspiration and Soil Moisture.

The amount of temperature over different periods for a particular area largely controls the nature of water-balance and the effect of temperature has an inverse relation with the amount of water-balance.

Where $T$ is Temperature and $Wb$ is Waterbalance.

Thus it appears that the temperature factor largely controls the expenditure elements of waterbalance viz., evapotranspiration and hence the effect of temperature has a direct relation with the amount of evapotranspiration.

$$T = f(Ev)$$

where $T$ is Temperature and $Ev$ is Evapotranspiration.

As suggested by Harding, evaporation is effected by temperature by both the air and water. The rate of vapour omission is dependent upon water temperature. The rate of vapour removal is effected by the temperature of the air. The vapour holding capacity of the air varies with its temperature, the difference in vapour pressure between the water and air is directly effected by the temperature of the air. \(^\text{15}\)

Thus in order to find out the effect of expenditure element of water balance, source of heat affecting the amount

of temperature should be taken into consideration. The primary source of heat is insolation which largely determines the amount of temperature and controls the degree of evapotranspiration. Besides, local rock factor is also responsible for the greater absorption in solar radiation and also affect the diurnal range of temperature.

Evapotranspiration is regarded as an important negative element of water balance. The process represents a combined loss of water by evaporation from land surface and transpiration by plants. In other words the process may be regarded as a consumptive use of water.

The rate of evaporation, will be determined by the difference between the vapor pressure of the body of water and that of the water above the water surface. Under given condition, evaporation is proportional to the deficit in vapor pressure, which is the difference between the pressure of saturated vapor at the temperature of the water and the aqueous vapor pressure of the air. Several attempts have been made to find out the evaporation equations as follows 16:

Dalton (1802) \[ E = C (e_w - e_a) \]

Fitzgerald (1886) \[ E = C (e_w - e_a) = 0.4 + 0.199 W \]

Mayer (1915) \[ E = C (e_w - e_a) = 1 + 0.1 \]

Horton (1917) \[ E = 0.4 (e_w - e_a) = 2 - c - 0.2 w \]

For large areas \( E \) is multiplied by \((1-p) \frac{P-1}{h}\)

Rohwin (1931) \[ E = 0.771(1.465 - 0.0186)(e_w - e_a) = 0.44 + 0.118 w \]

Lake Hefuer (1954) \[ E = 0.00177 W (e_w - e_a) \]

Lake Moad (1958) \[ E = 0.001813 w (e_w - e_a) t(1 - 0.03) \]

\[ (T_a - T_w) \]

The factors which control the amount of evaporation are the amount of temperature, wind, atmospheric pressure, soluble solids and nature and shape of the surface.

Evaporation is usually measured in four different ways, viz., pan evaporation method, water balance method, energy balance method and mass-transfer method.

For computation of water balance of a particular area, evaporation should also include soil-moisture evaporation from the soil surface.
Water is also lost from the vegetal cover by the process of transpiration which include different form viz., stomatal transpiration when water escapes through numerous pores of the stomata in the leaves, cuticular transpiration when water evaporates from moist memberance into the atmosphere through the cuticule, Gortiation when water is forced out of the plant through special organs called hydathodes when transpiration is at low rate. Under certain conditions, water may also exudate from cut surfaces of the plant. Of all the sources of water loss by plants, stomatal transpiration is the most important aspect.

The factors which control the amount of transpiration include amount of temperature, solar radiation, wind and soil moisture.

Thus evapotranspiration includes evaporation from all water, soil, snow, ice and transpiration from vegetative and other surface. According to Thornthwaite, soil moisture may have an effect upon evapotranspiration and thus be suggested potential evapotranspiration if there is an adequate supply of soil moisture at all times.  

Several methods widely used to determine the amount of evapotranspiration and potential evapotranspiration include soil-moisture sampling, lysimeter measurements, inflow-outflow measurements, integration method, methods of energy balance, vapour transfer and ground water fluctuations.

The method of soil moisture sampling is usually suitable for irrigated field plot where soil is fairly uniform and the depth of groundwater in such a way that it will not influence soil moisture fluctuations within the root zone. Soil samplers are weighed and dried and the dry weight are determined. From the moisture percentage thus obtained, the quantity of water in acre-inches per acre (inches) removed by evapotranspiration from each foot of soil is computed by $D = \frac{P \cdot v \cdot d}{100}$.

Where $P$ is the moisture percentage of the soil by weight, $v$ is the apparent specific gravity or volume weight of the soil, $d$ is the depth of soil in inches, and $D$ is the equivalent depth of water in the inches lost by the soil.\(^{18}\)

Lysimeter method is commonly used to determine evapotranspiration of individual crops and natural vegetation by growing the plants in tanks of lysimeters and then measuring

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the losses of water necessary to maintain the growth satisfactorily.

Inflow -outflow method involves the application of the water balance principle. The amount of water entering a known area is measured and compared with the recorded precipitation on the area for the same period. The difference between these two items and the amount flowing out of the area, adjusted by the change in the ground water storage, during the same period will be a measure of losses by evapotranspiration for the same period.

The integration method determines evapotranspiration for each crop times its area plus the evapotranspiration of natural vegetation times its area plus water surface evaporation times water surface area plus evaporation from bare land times its area.\(^1\)

\[
E = E_c \times cL^2 + E_v \times v L^2 + E_w \times wL^2 + E_s \times sL^2
\]

where \( E \) = Evapotranspiration.
\( E_c \) = Evaporation from crops.
\( E_v \) = Transpiration from vegetal cover.
\( E_w \) = Evaporation from water surface.
\( E_s \) = Evaporation from bare land surface.
\( L^2 \) = Area

\(^{19}\) Blaney, H.F., P.A. Ewing, K.V. Morin and W.D. Criddle, Consumptive water use and requirements, report of the participating.
Evapotranspiration can also be estimated by the Energy balance Method which assumes that the amount of energy received from insolation is equal to that used for evaporation, atmospheric heating, and absorption of heat in the soil layers.

The other methods for the estimation of evapotranspiration include study of vapor transfer and fluctuations in the ground water. The vapor transfer method is a modification by Pasquill of Thornthwaite-Holzman's equation for evapotranspiration. But the estimation of evapotranspiration by this method requires the idea of an accurate boundary conditions as regards the transfer of vapour from one area to another. The method of groundwater fluctuation for evapotranspiration consider the negative aspect of water loss and consequent fluctuation of water table. But this method can not give us the exact estimate of evapotranspiration as rise or fall of water table is also brought about by other aspects of hydrology.

The lack of basic data particularly regarding transpiration and the difficulties in the measurements have led to the development of evapotranspiration equations.\(^\text{20}\) The Hedke equation is the method by which evapotranspiration is estimated by summatting for the growing season the values of

available heat and is expressed by the following equation:

\[ U = KH \]

where \( U \) = evapotranspiration for given period.

\( K \) = annual, season and monthly coefficient of evapotranspiration or consumptive use and

\( H \) = accumulated degree-days above minimum growing temperature for growing season.

The Lowry-Johnson equation assumes a linear relationship between effective heat and evapotranspiration. This equation is particularly useful in estimating annual consumptive use for agricultural fields in terms of a valley and is expressed by the following equation:

\[ U = 0.000156 H + 0.8 \]

where \( U \) = evapotranspiration for the given period.

\( H \) = accumulated degree-days of maximum daily temperature above 32°F for growing season.

The Blaney-Criddle equation and Blaney-Morin equations are also same except that the latter considers an additional factor of relative humidity. The coefficient \( k \) varies with type of vegetal cover, time and space. The equations can be expressed as follows:

\[ U = K \leq p \frac{(114 - h)}{100} \]

where \( U \) = evapotranspiration for the given period.
K = annual, seasonal and monthly consumptive coefficient (From the study of seasonal consumptive-use of coefficient for selected crops, it appears that lower values of coefficients are meant for coastal areas and higher values for arid regions).

The Thornthwaite's equation is based on mean monthly temperature and mean monthly consumptive use. The equation gives the unadjusted potential evapotranspiration and expressed as:

\[ U = 1.6 \left( \frac{10t}{TE} \right)^{a} \]

where \( U \) = Evapotranspiration for the given period. 
\( t \) = Mean monthly temperature in °F. 
\( E \) = daily evaporation in m.m. 
\( a. = 0.000000675(TE)^3 - 0.000771(TE)^2 + 0.01792 \cdot TE + 0.49239 \)

Penman's equation is based on amount of radiative energy gained by the surface and is expressed as follows:

\[ U = \frac{AH + 0.27E}{A + 0.27} \]

where \( U \) = Evapotranspiration for the given period. 
\( A \) = Slope of saturated vapour-pressure curve of air at absolute temperature in °F. 
\( H \) = daily Heat budget at surface in m.m. of water.

Soil-moisture is an important aspect of the study of waterbalance. Porosity and moisture-retaining capacity of
the soil not only affects the amount of run off but also affects the amount of evaporation in the form of soil-evaporation, vertical circulation of water in the form of infiltration, leaching and capillary movements. Besides, soil layers form a good amount storage of precipitated water. Water-holding capacity, soil-moisture evaporation and vertical circulation of water through the soil layers vary over space and time depending on the physical, chemical and mineralogical composition of different soils and their relation with hydro-meteorological and agrometeorological aspects like nature, amount, duration and intensity and seasonality of precipitation, evaporation, transpiration, agricultural crop calender. Thus variation can partly be attributed to aspect of soil-moisture.

Thus to sum up, the hydrologic variables which influence the nature of water budget include Precipitation Evaporation and Transpiration, Groundwater flow and infiltration. There are certain vectors of these variables which occur above the surface (s) while others occur below the surface(g). Considering the fact that the basin is an open system, the budget above the surface, below the surface and the total budget can be shown by the equation and the model. (Fig. 1 & 2)

The following hydrologic equations are suggested by Viessman and Knapp:\(^{21}\):

FLOW OF INPUT AND OUTPUT ELEMENTS IN THE DAMODAR BASIN

KEY:
- P - Precipitation
- R - Runoff
- S - Streamflow
- E - Evaporation
- T - Transpiration
- G - Groundwater

- s - above the surface
- g - below the surface

Fig. no. 2

Level of Plastic rock
(No water below this level)
The hydrologic budget above the surface
\[ P + R_2 + R_1 - E_s - T_s - I = \Delta S_s \]  
... 1

The hydrologic budget below the surface
\[ I + G_1 - G_2 - R_s - E_g - T_g = \Delta S_g \]  
... 2

The hydrologic budget for the earth
\[ P - (R_2 - R_1) - (E_s + E_g) - (T_s + T_g) - (G_2 - G_1) \]
\[ = \Delta (S_s + S_g) \]  
... 3

I.7 Conclusion

The concept of waterbalance, as discussed, can be considered in examining the hydro-meteorological conditions and is useful in studying the agrometeorological conditions in a particular area. India is predominantly a monsoon country with agriculture as the mainstay in the economy. The nature and amount of temperature, evapotranspiration, precipitation, soil-moisture and fluctuation in the groundwater storage vary over space and time. Thus, the primary task of the Hydrologists, Geographers, Agronomist, Meteorologists, Economists and Regional Planners is to examine (a) the existing agricultural landuse character-how far they fit in the natural water budget system, (b) If not, what should be the optimal landuse planning as regards the moisture-retaining capacity of the soil, water requirement of crops in different periods and the period of favourable and unfavourable water balance and the relation to the cropping pattern. (c) the extent of rational conservation of water resource and efficient water resource planning and management.