Water & Hydrologic Cycle in Agriculture: Water Balance Method

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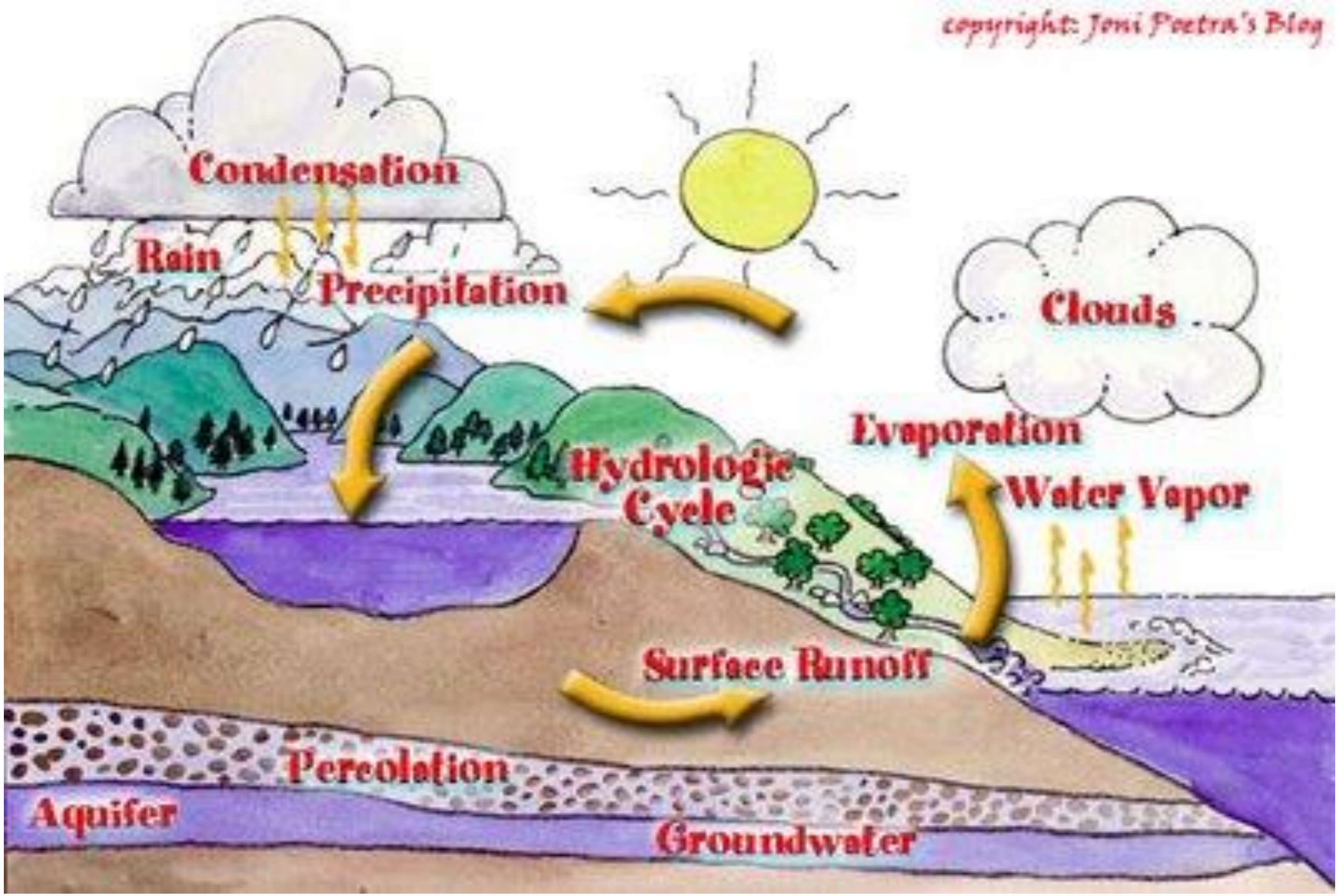
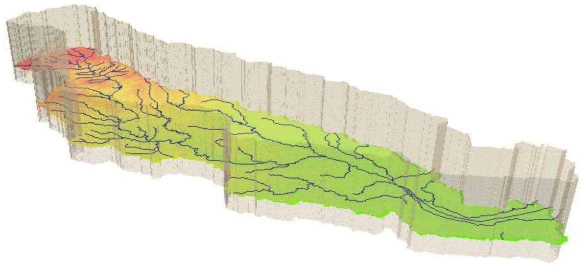
Schematic representation of Hydrologic cycle



- The hydrologic cycle describes the continuous recirculation transport of the water of the earth, linking atmosphere, land, and oceans.
- The process is quite complex, containing many sub cycles.
- To explain it briefly, water evaporates from the ocean surface, driven by energy from the sun, and joins the atmosphere, moving inland.
- Once inland, atmospheric conditions act to condense and precipitate water onto the land surface, where, driven by gravitational forces, it returns to the ocean through streams and rivers.

Hydrologic System



Hydrologic Budget

Hydrologic budget is simply an H_2O mass balance

Basic equation:

$$P - ET - R - G = \Delta S$$

- **P = Rain**
- **ET = Evapotranspiration**
- **R = Runoff**
- **G = Groundwater recharge**
- **ΔS = Change in storage**

$$\left\{ \begin{array}{c} \text{rate of} \\ \text{mass in} \end{array} \right\} - \left\{ \begin{array}{c} \text{rate of} \\ \text{mass out} \end{array} \right\} = \left\{ \begin{array}{c} \text{change in} \\ \text{storage} \end{array} \right\} \quad (1)$$

- *A hydrologic system is “a structure or volume in space surrounded by a boundary, that accepts water and other inputs, operates on them internally, and produces them as outputs”*

Hydrologic Variables

Runoff: That portion of precipitation that flows from a drainage area on the land surface, in open channels, or in storm water conveyance systems.

- endothermic process (requires energy input)
- requires *relative humidity* $\leq$ 100

Evapotranspiration: Physical Process

Precipitation: Physical Process

Precipitation denotes all forms of water that reach the earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost, and dew. For precipitation to form:

(1) the atmosphere must have moisture,

(2) there must be sufficient nuclei present to aid condensation,

(3) weather conditions must be good for condensation of water vapor to take places

(4) the products of condensation must reach the earth.

The precipitation at a place and its form depend upon a number of meteorological factors, such as, wind, temperature, humidity and pressure in the area enclosing the clouds and the ground surface at the given place.

Atmospheric Water Balance

The atmospheric water balance equation for India can be written by equating inflow with outflow plus the change in storage: $\mathbf{V_I + E_T + V_{AI} = P + V_0 + V_{AE} + €}$ where, V_I represents the inflow of water vapor to the Indian atmosphere from land routes and sea routes, E_T is the total evapotranspiration, V_{AI} is the initial water vapour present in the atmosphere, P is the total precipitation, V_0 is the outgoing water vapour, V_{AE} is the water vapour present at the end of period under consideration.

Hydrologic Water Balance

The equation for hydrologic water balance of the country for average annual conditions can be written as:

$$P + I = Q_S + E_T + Q_g + \Delta S + \varepsilon$$

Where, P is the total precipitation, E_T is total evapotranspiration, I is the total inflow as surface water (I_s) and ground water (I_g), Q_s is the outflow as surface water to oceans and other countries, (Q_g) is the ground outflow, and □S represents the change in soil moisture storage.

Measurement of Components of Hydrologic Cycle

- Precipitation
- Surface Runoff
- Deep Drinage
- Measurement of change in water storage
- Evapotranspiration

Evaporation

- The change of state of water from solid and liquid to the vapour and diffusion into the atmosphere is referred to as evaporation. It plays a major role in the redistribution of thermal energy between the earth and the atmosphere, and as essential part of the hydrological cycle.
- There are several simple devised and ermpirical methods of estimation of evaporation.
- The rate of evaporation is fairly independent of the size of the measuring pan under high humid condition. Whereas, when the air is dry, the size of the pan greatly influences the rate of evaporation.
- There are four types of evaporimeter or pans used for measuring evaporation. These are floating pans, pans placed above the ground, pan sunk in the soil and devices with special evaporation surfaces.

Class A pan evaporimeter

Factors that affect evaporation

- Wind assists evaporation.
- Heat assists evaporation; for example, in summer clothes dry faster than in winter.
- Increase in surface area exposed assists evaporation.
- Dryness assists evaporation; for instance, clothes dry faster in summer than during the monsoon when the air is humid.
- 5. Rate of evaporation depends upon the nature of the liquid.
- 6. Vapor pressure: if pressure is applied on the surface of a liquid, evaporation is hindered.

Transpiration

- Most of the water absorbed by plants is lost to the atmosphere.
- This loss of water from living plants is called transpiration.
- It can be stomatal, cuticular or lenticular.
- Light, humidity, temperature, wind, root/shoot ratio, availability of water, leaf characteristics control the rate of transpiration.
- Transpiration is often called necessary evils.
- Cooling due to transpiration saves plnts from excessive high temperature

Factors that Affect the Rate of Transpiration

- **Humidity:**
- The rate of transpiration is roughly inversely proportional to atmospheric humidity. As the outward diffusion of water vapors through stomata is in accordance with the law of simple diffusion, the rate of transpiration is greatly reduced when the atmosphere is very humid. As the air becomes dry, the rate of transpiration also increases proportionately.
- **Temperature:** With the increase in atmospheric temperature, the rate of transpiration also increases. This is not only because evaporation occurs quickly in warmer air but also because warm air is capable of holding more water vapors than the cold air.
- **Light:**

The rate of transpiration is roughly proportional to the intensity of light. The mode of action of light is both direct and indirect. The increasing light intensity raises the temperature of leaf cells and thus increases the rate at which liquid water is transformed into vapors. Direct effect of light is on the opening and closing of stomata. Bright light is the chief stimulus which causes stomata to open. It is simply because of this reason that all plants show a daily periodicity of transpiration rate.

- **Wind Velocity:**

The velocity of wind greatly affects the rate of transpiration. Fast moving air currents continually bring fresh, dry masses of air in contact with leaf surfaces and thus maintain a high rate of transpiration.

- **Soil Water Content:**
- Availability of soil water greatly affects the rate of transpiration. If there is little water available, the resulting tendency for dehydration of the leaf causes stomatal closure and a consequent fall in transpiration. Such a condition usually occurs during periods of drought and when the soil is frozen or at a temperature so low that water is not absorbed by roots.
- **Atmospheric Pressure:** The rate of transpiration is inversely proportional to the atmospheric pressure.
- **Carbon Dioxide Concentration:** Reduced CO_2 concentration favours opening of stomata while an increase in CO_2 concentration promotes stomatal closing.

Evapotranspiration/Potential Evapotranspiration

- Evapotranspiration is the combined loss of water from vegetation-both as evaporation from soil and transpiration from plants.
- Both the processes are basically the same and involve a chnnge of state-from liquid to vapour.
- When water is adequately available at the site of transformation, the rate of evapotranspiration is primarily controlled by meteorological factors like solar radiation, wind, temperature and evaporating power of the atmosphere.
- Potential Evapotranspiration is the upper level of evapotranspiration.
- Potential evapotrapiration is the water transpired from a uniform, short, green, actively growing vegetation when water is unlimited.

Evapotranspiration measurements by Gravimetric/volumetric lysimeters installed in crop environment

FACTORS AFFECTING EVAPOTRANSPIRATION

- **Temperature:** It has been estimated that transpiration occurs nearly twice as fast at 30 degrees than at 20 degrees.
- **Stomatal Opening:** The rate of transpiration is directly related to the degree of stomatal opening, and to the evaporative demand of the atmosphere surrounding the leaf. The number, size, position, and degree of opening control most transpiration.
- **Humidity:** The presence of humidity decreases the rate of transpiration.
- **Wind Velocities:** Greater is the blowing of wind; greater will be the rate of transpiration.
- **Leaf anatomy, size and shape:** Leaf size and shape has also affects. Large leaves retain a thicker boundary layer than small leaves thus having more transpiration. Leaves may also change shape to maintain a boundary layer, such as the curling or rolling of grass blades during drought. All such result in lower transpiration.
- Similarly, orientation also determines energy absorbed by the leaf, and subsequently leaf temperature, the availability of energy available for vaporization, thus affecting the rate of transpiration.
- **Root- shoot ratio:** Root/Shoot ratios can also affect transpiration. Decreased root growth increases resistance of water absorption which results in partial stomatal closure.

Penman Method of Estimation of Evapotranspiration

- Penman gave the following formula for estimation of Potential Evapotranspiration from free water evaporation.
- PET=K Eo

$$E_o = \frac{\Delta H_o + \gamma E_a}{\Delta + \gamma}$$

- Where PET= Potential Evapotranspiration
- K= Constant for which Penman gave values
- Eo= Evaporation from open water surface in mm per day
- Where Ho= Net radiation in mm water

γ = Psychrometric Constant=

Eo= An Aerodynamic Component

Δ =Slope of Saturation vapour pressure vs Temperature Curve

SOIL MOISTURE Observations

- Manual Methods: Use of augurs. Delay in obtaining data. Arial Sampling problems
- Need for determination of Bulk Density profiles. Manual and Powered core Samplers
- Sensors: Electrode Blocks. Temperature Sensors. Pressure Gauges

Application of Irrigation

- **Input:** **Phase-wise water requirement of different crops.**
- **Soil moisture status.**
- **Application based on past weather as well as weather forecast particularly rainfall forecast expected ET losses.**
- **Output:** **When and how much water to apply i.e. pre- poning / post-poning of irrigation.**

Evapo-transpiration and water balance

- **To know the extent of potential demands of water through evapo- transpiration.**
- **Study of water stress in plants, and the growth and yields.**

THORNTHWAITE'S WATER BALANCE TECHNIQUE

- WATER BALANCE REFERS TO THE BALANCE BETN. WATER INCOME(PPTN.) AND LOSS OF WATER BY EVAPOTRANSPIRATION CAUSING CHANGE IN SOIL MOISTURE AND RUNOFF.

- BASIC EQUN.

P= ET+CHANGE IN 'S' +RO

- SOIL ACTS AS A MEDIUM FOR STORING WATER (UPTO A LIMIT) DURING EXCESSIVE RF AND RELEASING THE SAME (IN A RESTRICTED MANNER) AT OTHER TIMES FOR EVAP. AND TRANSPIRATION.
- FOR WATER BALANCE COMPUTATION 3 PARAMETERS REQD.: ET, P, AWC (FC)

- DURING THE PERIODS OF EXCESSIVE 'RF' THE BALANCE OF WATER, AFTER MEETING CROP DEMAND RECHARGES THE SOIL TILL 'FC' IS ATTAINED. ANY FURTHER ADDITION MEANS 'RO'.
- 'AWC' OF A PLACE DEPENDS ON THE TYPE OF SOIL AND THE ROOT ZONE DEPTH OF THE CROP.
- DURING DEFICIENT 'RF' 'SM' IS USED FOR 'ET' PURPOSES. AS SOIL DRIES , ET RATE DECREASES. ACC. TO THORNTHWAITE, THE RELEASE OF MOSTURE FROM SOIL FOLLOWS THE FOLLOWING EQUN.:

S=FC.exp –APME/FC

S= Moisture remaining in the soil as storage

Agromet product for taking decision on Irrigation scheduling (through Water Balance)

A water balance model is a simple method to calculate the crop water use. Water balance models can be used in a number of ways. It can be used in intelligent planning of long range water resource management. This knowledge can be used to modify the components of water balance so that water can be best utilised in crop production.

Input parameters

- **Static:** Station name, Latitude, Longitude, Height, Field capacity (mm), Soil type, Climate, Agro climatic zone, Potential Evapotranspiration (PET)
- **Dynamic:** Rainfall (RF)
- **Output parameters**
- Actual Evapotranspiration (ET), Soil moisture storage (S), Change in Storage (dS), Soil Moisture Deficit (WD), Soil Moisture Surplus (WS), Water Run-off (RO), Total moisture Detention (DT)

Algorithm used for estimating different parameters

- Soil moisture storage (S)

(i) When RF exceeds PET

S = RF – PET

(ii) When PET exceeds RF

S = (FC) * e (Acc. RF- PET) / FC

Acc. (RF- PET) is the accumulated potential water loss. FC is the field capacity (mm) per meter depth of soil.

Change in storage (dS)

It is the difference between soil moisture storage (S) of two consecutive weeks.

Evapotranspiration (ET)

(i) When RF exceeds PET

$$ET = PET$$

(ii) When PET exceeds RF

$$ET = RF + dS$$

Water deficit (WD)

It is the difference between PET and ET.

Water surplus (WS)

(i) Surplus exists when soil moisture storage (S) is Field capacity and more and rainfall exceeds potential evapotranspiration.

(ii) When storage values are moving up towards Field capacity, the first surplus (WS) will be

$$RF - PET - dS$$

Water Run-off (RO)

RO is one-half of the surplus (S), the rest half goes to the next month. This should be added to the surplus of that week/month. Again one-half of that week/month will be the run-off. Add the remaining one-half to the S of the next week/month, and the procedure continues.

Total moisture Detention (DT)

$$DT = S + RO \text{ (Total run-off)}$$

	J	F	M	A	M	J	JY	A	S	O	N	D
PE	75.1	94.5	153.1	180.7	224.4	129.4	116.4	110.4	107.0	112.0	88.2	69.7
P	13.2	21.8	29.6	49.8	134.6	263.2	320.1	318.1	252.7	134.2	29.2	3.6
P-PE	-61.9	-72.7	-123.5	-130.9	-89.8	133.8	203.7	207.7	145.7	22.2	-59.0	-66.1
Acc. P-PE	-187.0	-259.7	-383.2	-514.1	-603.9						-59.0	-125.1
S	78.5	54.5	29.4	15.2	9.7	143.5	200.0	200.0	200.0	200.0	148.9	106.9
S*	-28.4	-24.0	-25.1	-14.2	-5.5	133.8	56.5	0.0	0.0	0.0	-51.1	-42.0
AE	41.6	45.8	54.7	64.0	140.1	129.4	116.4	110.4	107.0	112.0	80.3	45.6
WD	33.5	48.7	98.4	116.7	84.3	0.0	0.0	0.0	0.0	0.0	7.9	24.1
WS	0.0	0.0	0.0	0.0	0.0	0.0	147.2	207.7	145.7	22.2	0.0	0.0
RO	10.3	5.1	2.5	1.2	0.6	0.3	73.7	140.7	143.2	82.7	41.3	20.6

Irrigation Application

Algorithm

$Qi=[(QsLa)- Qr]\ Kc/E$

Where,

Qi = Volume of water Used

Qs = Water Stored in the respective root zone

La = Relative loss of available water

Qr = Rainfall

Kc = Crop Coefficient

E = Irrigation Efficiency

Qs has been calculated by the following equation (Todorov 1982)

$Qs=(Fc - WP) \times b \times c/10$

Where Fc and WP are the field capacity and wilting point respectively, b is the bulk density of the soil in gm/cc & c is the thickness (ht) of soil layer in cm.

Kc = AE / PE

AE = Actual evapotranspiration obtained from lysimeter observation / water balance technique

PE = Potential evapotranspiration calculated by Penman's equation

As per IW/CPE ratio

Climatological approach for scheduling irrigation i.e. when to irrigate: IW/CPE ratio is fixed for the different crops in different locations, generally ranges from 0.4 to 1.0.

Example: $\frac{IW}{CPE} = 0.8$ **or 0.6 (depending on the crop stage and soil type)**

Where IW = Irrigation water depth i.e. 5 cm or 6 cm

CPE = Cumulative pan evaporation from the date of irrigation

$$\frac{50mm}{CPE} = 0.8$$

$$CPE = \frac{50}{0.8} = 62.5mm$$

When cumulative pan evaporation reaches 62.5 mm, the crop should be irrigated.

- **Soil moisture status**

➢ Direct gravimetric or other method e.g. Tensiometric Gypsum Block, Neutron Probe, Time Domain Refractometer (TDR) or FDR)

➢ Soil type along with Field Capacity and Wilting Point

➢ Depth of water table

Water requirement of crops

Crop	Water requirement (mm)	Critical growth stages
Wheat	440-460	Crown root initiation, tillering, jointing, flowering, milk and dough stage
Rice	600 - 1100	Tillering, panicle initiation and booting
Maize	460 - 600	Seedling stage, knee-height stage, flowering (tasseling and silking stage) and grain filling stage
Jowar	Kharif – 120-250 Rabi- 240-350 Summer – 550-900	Knee-height stage, flowering and grain filling stages
Bajra	450-500	Maximum tillering, flowering, and grain filling stage
Barley	400-500	Seedling or sprouting, active tillering stage *i.e.* 30-35 days after sowing, flag leaf stage, milk stage or soft dough stage or grain filling stage.
Gram	150	Flowering and grain development stage
Soyabean	640-760	Sprouting stage, flowering, pod initiation and bean filling stages
Rapeseed and mustard	310-400	Flowering stage pod (siliqua) formation stage
Cotton	600-700	Sympodial branching flowering , boll formation stage and boll bursting

Thank You