TRAINING COURSE

ON

COMPUTER APPLICATIONS IN HYDROLOGY

(UNDER WORLD BANK AIDED HYDROLOGY PROJECT)

Module 11

Irrigation Return Flow

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IRRIGATION RETURN FLOW

In the management of Groundwater resources, man intervenes with the hydrologic cycle in order to achieve beneficial goals. This intervention takes the form of modifications imposed on the various components of the water balance. In context with the groundwater regime of the hydrologic cycle, the movement of water towards an aquifer takes place in the following ways

(1) Groundwater inflow through aquifer boundaries and leakage from overlying or underlying aquifers
(2) Natural replenishment (infiltration) from precipitation over the area
(3) Return flow from irrigation
(4) Artificial recharge
(5) Seepage from influent streams

In irrigation practice, certain portion of the applied water, over and above the consumptive use, infiltrates into the ground to reach either an aquifer as deep percolation or to a nearby stream as interflow. This contributory replenishment from irrigation is referred to as '**Irrigation Return Flow**'.

Percolation from applied irrigation water, derived both from surface water and ground water sources, constitutes one of the major components of ground water recharge in areas under wet crops like paddy, in view of the continuous submergence of the soil for long durations. For irrigation of dry crops, the water applied is much less as the soil is required to be saturated for short periods, with the result that the greater part of the water applied is abstracted from the soil and lost to the atmosphere through evapotranspiration, leaving only a small fraction, if any, to recharge the ground water.

Irrigation return flow is estimated as 20 to 40% of the volume of water applied for irrigation. It includes the subsurface flow resulting due to the excess percolation during irrigation from field.

During the early years of irrigation practice, excessive quantities of water are usually diverted and conveyed to the fields. Large portions of the excess deliveries percolates to ground water storage gradually raising the levels of water tables. Subsequently the high levels of water table causes interflow towards natural surface drainage courses. However, the high ground water table also leads to development of salt problems and causes large water losses due to excessive evaporation and transpiration through non-useful vegetation. As a remedial measure, artificial drainage systems are constructed to reclaim the water-logged area and prevent further damages to the cropped areas.

In absence of any studies, irrigation return flow is usually taken as 35% of the water applied for irrigation in case of canal irrigation and 30% in case of irrigation from ground water.

Irrigation return flow is one of the most significant components in the water balance of irrigation command areas. It depends upon the soil moisture characteristics, meteorological parameters, crop types, method of irrigation and depth to water table etc. Application of fertilizers and leaching requirement of soil salts may need more water and therefore increase the irrigation return flow. In view of various agroclimatic zones, its magnitude may vary widely across the country.

Factors Affecting Irrigation Return Flow

As the irrigation return flow may amount to as much as 20 to 40 % of the volume of water used for irrigation. This amount reaching the aquifer as return flow depends on the following factors

(i) Conveyance and irrigation efficiencies :

The rates of return flow are observed to decrease with increase in the conveyance and irrigation efficiencies as higher efficiencies lead to lesser water losses consequently lesser quantities of return flows.

(ii) Amounts of water diverted for irrigation :

It is observed that as the amounts of water diverted for irrigation (over and above the required) is increased, there is a corresponding increase in the rates of return flow.

(iii)Period of years the lands have been irrigated :

Irrigation return flow also depends on the history of irrigation practices.

(iv) Hydrological properties of the soil :

The hydraulic properties of the soil and the structure of soil strata influence the rates of return flow significantly. The antecedent soil moisture conditions in the irrigated lands and the existing conditions of salts in the soil also have a characteristic influence on the rates of return flow. The first irrigation during the cropping season leads to less quantity of return flow (as the soil is dry). However, this increases with the number of applications of irrigated water.

Estimation of Irrigation Return Flow

Ground water Estimation committee (1997) recommended the following norms for the estimation of return flow from irrigation based on the source of irrigation (ground water or surface water), the type of crop (paddy, non-paddy) and the depth of water table below ground level.

Recharge as percentage of application

Source of irrigation	Type of crop	Water table below ground level		
		< 10 m	10-25 m	> 25 m
Ground water	Non-paddy	25	15	5
Surface water	Non-paddy	30	20	10
Ground water	Paddy	45	35	20
Surface water	Paddy	50	40	25

For the correct assessment of the quantum of return flow by applied irrigation, studies are required to be carried out on experimental plots under different crops in different seasonal conditions. The different methods for the estimation of irrigation return flow has been described below.

1.0 WATER BALANCE APPROACH

This method of estimation comprise application of the water balance equation involving input and output of water in experimental fields.

The water balance of unsaturated zone is (ILRI, No. 16, Vol III, 1980):

$$(Pr + Irr - Ro) - Evpt - (Per-Cap) = \Delta Sm$$

where, Pr = Precipitation; Irr = Irrigation supply; Ro = Surface runoff; Evpt = Evapotranspiration; Per = Percolation; Cap = Capillary rise and ΔSm = Change in soil moisture storage.

Fields selected for experimental studies are watered, manured, and protected with pesticides, in accordance with local agricultural practices. They should also be free of burrow holes etc. and should not be bordered by unirrigated areas or under different crops. All particulars such as variety of crop, stage of growth, daily inflows and outflows (if any) of water, are recorded. A rain gauge and pan evaporimeter should be installed within the field, or as close to it as possible. Inflows and outflows are measured by V-notch or Parshal flumes. All quantities in the equation are directly measurable, except for Percolation and capillary and this is nothing but irrigation return flow.

2.0 DRUM-CULTURE METHOD

In the drum-culture method, the paddy crop is raised under controlled conditions in drums of standard size, in representative paddy plots. Drums (or tubs) of size 0.9 X 0.9 X 1.0 m dimension have been widely used. Two drums, one with the bottom open and the other with the bottom closed are sunk into the plot to a depth of 75 cm. Both are filled with the same soil to field level. Within the open-ended drum, all agricultural operations are carried out as in the surrounding plot. The heights of the water columns in the drums are maintained equal to that outside. Water levels in the drums are observed twice a day, with the help of gauges, to determine the water consumed. Rainfall and evaporation data are recorded in the hydrometeorological station.

The water loss from the drum with the closed bottom gives the consumptive use, while that from the drum with open bottom gives the consumptive use plus infiltration. The difference in values of the water applied in the two drums gives the infiltration.

3.0 EXPERIMENTAL DETERMINATION OF IRRIGATION RETURN FLOW

The component of irrigation return flow due to percolation from irrigated field can be ascertained from soil moisture balance in the root zone.

The flow through any section of soil is given by the Darcy's law:

$$q_z = -K(\psi)\left(\frac{\partial\psi}{\partial Z} - 1\right)$$

where, q_z= Darcy's flux in Z-direction (positive downward); $K(\psi)$ = Hydraulic conductivity; ψ = Pressure (suction) head; Z = Depth.

Suction head can be measured at various depths in the soil, from which the hydraulic gradient $\left(\frac{\partial\psi}{\partial Z} - 1\right)$ can be calculated. After knowing the hydraulic gradient and hydraulic conductivity of particular section of soil, one can calculate the flux through unit area of that section using Darcy's law. Irrigation return flow can be calculated by continuously monitoring the suction head in the field and is given by the following equation

$$I_R = \int_{t_1}^{t_2}\left[-K(\psi)\left(\frac{\partial\psi}{\partial Z} - 1\right)\right]_{Z_0} dt$$

where, I_R = Irrigation return flow; t_1 = Starting of irrigation prior to sowing; t_2 = End of harvesting.

The cumulative values of return flow is calculated at root zone depth up to the required time level. This method will compute the losses from irrigation application at micro level.

Step by step Procedure:

1. Find Irrigation depth at the surface
2. Find the suction head below the ground surface up to the root zone depth at different

levels by tensiometer.

3. Calculate the moisture content for the corresponding values of suction head from the relation θ-ψ.
4. Calculate the unsaturated hydraulic conductivity for the corresponding value of pressure head from the relation K-ψ.
5. Calculate the pressure gradients along the depth for all points.
6. Calculate the Darcy's flux at different depths.
7. Irrigation return flow at the root zone will be

$$I_R = \int_{t_1}^{t_2} \left[K(\psi) \left(\frac{\partial \psi}{\partial Z} - 1 \right) \right]_{Z_o} dt$$

4.0 SOIL MOISTURE MODELLING

Irrigation return flow can also be estimated by modelling the soil moisture movement in the unsaturated zone. Most of the processes involving soil-water interactions in the field, and particularly the flow of water in the rooting zone of most crop plants, occur while the soil is in an unsaturated condition. In general unsaturated flow processes are complicated and difficult to describe quantitatively, since they often entail changes in the state and content of soil water during flow. Such changes involve complex relations among the variable soil wetness, suction, and conductivity, whose inter-relations may be further complicated by hysteresis. The formulation and solution of unsaturated flow problems very often require the use of indirect methods of analysis, based on approximations or numerical techniques. For this reason, the development of rigorous theoretical and experimental methods for treating these problems was rather late in coming. In recent decades, however, unsaturated flow has become one of the most important and active topics of research and this research has resulted in significant theoretical and practical advances.

Application of the principle of mass conservation and Darcy's law in unsaturated soil profile yields the following one-dimensional Richards equation (Freeze & Cherry, 1979)

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K(\psi) \left(\frac{\partial \psi}{\partial z} - 1 \right) \right] - Si\ (z, t)$$

where θ is the moisture content; K(ψ) is the hydraulic conductivity (cm/s); ψ is the soil water pressure head (relative to the atmosphere) expressed in cm of water; z is the gravitational head(cm) considered positive in downward direction; Si is the sink term representing the rate of withdrawal of water per unit volume of the soil. The sink term will be computed using potential evapotranspiration, crop coefficient, soil moisture status and variation of root density with depth.

$$Si\ (z, t) = K_c E_p \left[\frac{\theta - \theta_w}{\theta_d - \theta_{an}} \right] \quad ;\ \text{if } -15800\ \text{cm} < \psi < -400\ \text{cm}$$

$$Si\ (z,t) = K_c E_p \qquad ;\ \text{if } -400\ \text{cm} < \psi < -50\ \text{cm}$$

$$Si\ (z,t) = K_c E_p \left[\frac{\theta_s - \theta}{\theta_s - \theta_{an}} \right] \qquad ;\ \text{if } -50\ \text{cm} < \psi < 0\ \text{cm}$$

where, K_c is the Crop coefficient; E_p is the potential evapotranspiration; θ is the moisture content; θ_w is the moisture content at wilting point (at $\psi = -15800$ cm); θ_d is the moisture content at $\psi = -400$ cm; θ_{an} is the moisture content at anaerobiosis point (at $\psi = -50$ cm); θ_s is the saturated moisture content.

Richards equation is used as the basic mathematical expression that underlies unsaturated flow phenomena. Soil water flow, however, is highly non-linear, as both the hydraulic conductivity and pressure head depend on the soil moisture content. Since the governing equation is non-linear parabolic partial differential equation, so the exact analytical solutions are possible only for simplified cases under a number of restrictive assumptions. Numerical solution of the flow equation on the other hand offers a powerful tool in approximating the real nature of the unsaturated zone for a wide variety of soil systems and external conditions. Solution of the 1-D Richards equation can be obtained by using the implicit finite-difference method with suitable initial conditions and boundary conditions.

5.0 REFERENCES

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