Groundwater inflow

Danube-Black Sea Canal at Murfatlar, Romania, a key groundwater inflow source. Image: Christian Chirita

Groundwater inflow represents an important part of groundwater assessment methodology within the hydrological cycle. This article reviews chief methodology for estimating the various inputs to groundwater inflow. Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrological cycle. The study of water balance requires the systematic presentation of data on the water supply and its use within a given study area for a specific period. The estimation of groundwater balance of a region requires quantification of all individual inflows to or outflows from a groundwater system and change in groundwater storage over a given time period. The basic concept of water balance is:

Input to the system ? outflow from the system = change in storage of the system (over a period of time)

The general methodology of computing groundwater balance consists of the following:

- Identification of significant components,
- Evaluating and quantifying individual components, and
- Presentation in the form of water balance equation.

The various inflow components of the groundwater balance equation may be estimated through appropriate empirical relationships suitable for a region, field experiments or other methods, as discussed below:

Recharge from Rainfall (R_r)

Rainfall is the major source of recharge to groundwater. Part of the rain water, that falls on the ground, is infiltrated into the soil. A part of this infiltrated water is utilized in filling the soil moisture deficiency while the remaining portion percolates down to reach the water table, which is termed as rainfall recharge to theaquifer. The amount of rainfall recharge depends on various hydrometeorological and topographic factors, soil characteristics and depth to water table. The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions, groundwater balance approach, and soil moisture data based methods.

(a) Empirical Methods

Several empirical formulae have been worked out for specific regions on the basis of detailed studies. Those relationships, tentatively proposed for specific hydrogeological conditions, need to be examined and established or suitably altered for application to other areas.

(b) Groundwater Balance Approach

In this method, all components of the groundwater balance equation (1), except the rainfall recharge, are estimated individually. The algebraic sum of all input and output components is equated to the change in groundwater storage, as reflected by the water table fluctuation, which in turn yields the single unknown in the equation, namely, the rainfall recharge. A pre?requisite for successful application of this technique is the availability of very extensive and accurate hydrological and meteorological data. The groundwater balance approach is valid for the areas where the year can be divided into monsoon and non?monsoon seasons with the bulk of rainfall occurring in former.

Groundwater balance study for monsoon and non?monsoon periods is carried out separately. The former yields an estimate of recharge coefficient and the later determines the degree of accuracy with which the components of water balance equation have been estimated. Alternatively, the average specific yield in the zone of fluctuation can be determined from a groundwater balance study for the non?monsoon period and using this specific yield, the recharge due to rainfall can be determined using the groundwater balance components for the monsoon period.

(c) Soil Moisture Data Based Methods

Soil moisture data based methods are the lumped and distributed model and the nuclear methods. In the lumped model, the variation of soil moisture content in the vertical direction is ignored and any effective input into the soil is assumed to increase the soil moisture content uniformly. Recharge is calculated as the remainder when losses, identified in the form of runoff and [[[evapotranspiration]], have been deducted from the precipitation with proper accounting of soil moisture deficit. In the distributed model, variation of soil moisture content in the vertical direction is accounted and the method involves the numerical solution of partial differential equation (Richards equation) governing one?dimensional flow through unsaturated medium, with appropriate initial and boundary conditions.

(d) Soil Water Balance Method

Water balance models were developed in the 1940s by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955). The method is essentially a book?keeping procedure which estimates the balance between the inflow and outflow of water. When applying this method to estimate the recharge for a catchment area, the calculation should be repeated for areas with different precipitation,evapotranspiration, crop type and soil type. The soil water balance method is of limited practical value, because evapotranspiration is not directly measurable. Moreover, storage of moisture in the unsaturated zone and the rates of infiltration along the various possible routes to the aquifer form important and uncertain factors. Another aspect that deserves attention is the depth of the root zone which may vary in semi?arid regions between 1 and 30 meters. Results from this model are of very limited value without calibration and validation, because of the substantial uncertainty in input data.

(e) Nuclear Methods

Nuclear techniques can be used for the determination of recharge by measuring the travel of moisture through a soil column. The technique is based upon the existence of a linear relation between neutron count rate and moisture content (% by volume) for the range of moisture contents generally occurring in the unsaturated soil zone. The mixture of beryllium (Be) and radium (Ra) is taken as the source of neutrons. Another method is the gamma ray transmission method based upon the attenuation of gamma rays in a medium through which it passes. The extent of attenuation is closely linked with moisture content of the soil medium.

Recharge from Canal Seepage (R_c)

Seepage refers to the process of water movement from a canal into and through the bed and wall material. Seepage losses from irrigation canals often constitute a significant part of the total recharge to groundwatersystem. Hence, it is important to properly estimate these losses for recharge assessment to groundwater system. Recharge by seepage from canals depend upon the size and cross-section of the canal, depth of flow, characteristics of soils in the bed and sides, and location as well as level of drains on either side of the canal. A number of empirical formulae and formulae based on theoretical considerations have been proposed to estimate the seepage losses from canals.

Recharge from canals that are in direct hydraulic connection with a phreatic aquifer underlain by a horizontal impermeable layer at shallow depth, can be determined by Darcy's equation, provided the flow satisfies Dupuit assumptions.

$$R_c = K \frac{h_s - h_1}{L} A$$

where, h_s and h_l are water?level elevations above the impermeable base, respectively, at the canal, and at distance L from it. For calculating the area of flow cross?section, the average of the saturated thickness $(h_s + h_l)/2$ is taken. The crux of computation of seepage depends on correct assessment of the hydraulic conductivity, K. Knowing the percentage of sand, silt and clay, the hydraulic conductivity of undisturbed soil can be approximately determined using the soil classification triangle showing relation of hydraulic conductivity to texture for undisturbed sample (Johnson, 1963).

A number of investigations have been carried out to study the seepage losses from canals. U. S. B. R. recommended the channel losses based on the channel bed material as given below:

Material	**Seepage Losses (cumec per million square meter of wetted area)**
Clay and clay loam	1.50
Sandy loam	2.40
Sandy and gravely soil	8.03
Concrete lining	1.20

These values are valid if the water table is relatively deep. In shallow water table and water logged areas, the recharge from canal seepage may be suitably reduced. Specific results from case studies may be used, if available. The above norms take into consideration the type of soil in which the canal runs while computing seepage. However, the actual seepage will also be controlled by the width of canal (B), depth of flow (D), hydraulic conductivity of the bed material (K) and depth to water table.

Knowing the values of B and D, the range of seepage losses (R_{c_max} and R_{c_min}) from the canal may be obtained as

$R_{c\_max} = K (B + 2D)$ (in case of deeper water table)

$R_{c\_min} = K (B - 2D)$ (in case of water table at the level of channel bed)

However, the various guidelines for estimating losses in the canal system, are at best approximate. Thus, the seepage losses may best be estimated by conducting actual tests in the field. The methods most commonly adopted are:

Inflow ? outflow method: In this method, the water that flows into and out of the section of canal, under study, is measured using current meter or Parshall flume method. The difference between the quantities of water flowing into and out of the canal reach is attributed to seepage. This method is advantageous when seepage losses are to be measured in long canal reaches with few diversions.

Ponding method: In this method, bunds are constructed in the canal at two locations, one upstream and the other downstream of the reach of canal with water filled in it. The total change in storage in the reach is measured over a period of time by measuring the rate of drop of water surface elevation in the canal reach. Alternatively, water may be added to maintain a constant water surface elevation. In this case, the volume of water added is measured along with the elapsed time to compute the rate of seepage loss. The ponding method provides an accurate means of measuring seepage losses and is especially suitable when they are small (e.g. in lined canals).

Seepage meter method: The seepage meter is a modified version of permeameter developed for use under water. Various types of seepage meters have been developed. The two most important are seepage meter with submerged flexible water bag and falling head seepage meter. Seepage meters are suitable for measuring local seepage rates in canals or ponds and used only in unlined or earth?lined canals. They are quickly and easily installed and give reasonably satisfactory results for the conditions at the test site but it is difficult to obtain accurate results when seepage losses are low.

The total losses from the canal system generally consist of the evaporation losses (E_c) and the seepage losses (R_c). The evaporation losses are generally 10 to 15 percent of the total losses. Thus the R_c value is 85 to 90 percent of the losses from the canal system.

Recharge from Field Irrigation (R_i)

Water requirements of crops are met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated field crops is lost in consumptive use and the balance infiltrates to recharge the groundwater. The process of re?entry of a part of the water used for irrigation is called return flow. Percolation from applied irrigation water, derived both from surface water and groundwater sources, constitutes one of the major components of groundwater recharge. The irrigation return flow depends on the soil type, irrigation practice and type of crop. Therefore, irrigation return flows are site specific and will vary from one region to another.

For a correct assessment of the quantum of recharge by applied irrigation, studies are required to be carried out on experimental plots under different crops in different seasonal conditions. The method of estimation comprises application of the water balance equation involving input and output of water in experimental fields.

For surface water, the recharge is to be estimated based on water released at the outlet from the canal/distribution system. For groundwater, the recharge is to be estimated based on gross draft. Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used. Specific results from case studies may be used, if available.

Recharge from Tanks (R_t)

Studies have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity. However, as data on live storage capacity of large number of tanks may not be available, seepage from the tanks may be taken as 44 to 60 cm per year over the total water spread, taking into account the agro?climatic conditions in the area. The seepage from percolation tanks is higher and may be taken as 50 percent of its gross storage. In case of seepage from ponds and lakes, the norms as applied to tanks may be taken. The Groundwater Resource Estimation Committee (1997) has recommended that based on the average area of water spread, the recharge from storage tanks and ponds may be taken as 1.4 mm/day for the period in which tank has water. If data on the average area of water spread is not available, 60% of the maximum water spread area may be used instead of average area of water spread.

In case of percolation tanks, recharge may be taken as 50% of gross storage, considering the number of fillings, with half of this recharge occurring in monsoon season and the balance in non-monsoon season. Recharge due to check dams and nala bunds may be taken as 50% of gross storage (assuming annual desilting maintenance exists) with half of this recharge occurring in the monsoon season and the balance in the non-monsoon season.

Influent Seepage (S_i)

The river-aquifer interaction depends on the transmissivity of the aquifer system and the gradient of water table in respect to the river stage. Depending on the water level in the river and in the aquifer (in the vicinity of river), the river may recharge the aquifer (influent) or the aquifer may contribute to the river flow (effluent). The effluent or influent character of the river may vary from season to season and from reach to reach. The seepage from/to the river can be determined by dividing the river reach into small sub?reaches and observing the discharges at the two ends of the sub?reach along with the discharges of its tributaries and diversions, if any. The discharge at the downstream end is expressed as:

$$Q_d . \Delta t = Q_u . \Delta t + Q_g . \Delta t + Q_t . \Delta t \ ?\ Q_o . \Delta t \ ?\ E . \Delta t \pm S_{rb}$$

where,

Q_d = discharge at the downstream section;
Q_u = discharge at the upstream section;
Q_g = groundwater contribution (unknown quantity; -ve computed value indicates influent conditions);
Q_t = discharge of tributaries;
Q_o = discharge diverted from the river;
E = rate of evaporation from river water surface and flood plain (for extensive bodies of surface water and for long time periods, evaporation from open water surfaces can not be neglected);
S_{rb} = change in bank storage (+ for decrease and ? for increase); and
Δt = time period.

The change in bank storage can be determined by monitoring the water table along the cross?section normal to the river. Thus, using the above equation, seepage from/to the river over a certain period of time Δt can be computed. However, this would be the contribution from aquifers on both sides of the stream. The contribution from each side can be separated by the following method:

$$\text{Contribution from left bank} = \frac{I_L T_L}{I_L T_L + I_R T_R} . Q_g$$

$$Contribution\ from\ right\ bank = \frac{I_R T_R}{I_L T_L + I_R T_R} . Q_g$$

where, I_L and T_L are gradient and transmissivity respectively on the left side and I_R and T_R are those on the right.

Subsurface Inflow from Other Basins (I_g)

For the estimation of groundwater inflow/outflow from/to other basins, regional water table contour mapsare drawn based on the observed water level data from wells located within and outside the study area. The flows into and out of a region are governed mainly by the hydraulic gradient and transmissivity of theaquifer. The gradient can be determined by taking the slope of the water table normal to water table contour. The length of the section, across which groundwater inflow/outflow occurs, is determined from contour maps, the length being measured parallel to the contour. The inflow/outflow is determined as follows:

$$I_g\ or\ O_g = \sum^{L} T\ I\ \Delta L$$

where, T is the transmissivity and I is the hydraulic gradient averaged over a length ΔL of contour line.

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