GROUND WATER BALANCE

By

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1.0 General

Water balance techniques are extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle.

2.0 Definition

The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specific period.

3.0 Necessity of Study

With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system. For proper assessment of potential, present use and additional exploitability of water resources at optimal level, a water balance study is necessary.

4.0 Components of Study

The basic concept of water balance is:Input to the system - outflow from the system

= change in storage of the system

The general methods of computations of water balance include

i) identification of significant components,

ii) evaluating and quantifying individual components and

iii) presentation in the form of water balance equation as

Inflow -Outflow = Change in Storage

4.1 Ground Water Balance Equation

Considering the various sources of recharge to and discharge from the ground water reservoir and change in storage in the ground water, the basic equation of ground water balance for a time period can be written as :

$$R_i + R_c + R_r + R_d + S_i + I_g = E_t + T_p + S_e + O_g + \Delta S \quad .. (1)$$

where,

R_i = Recharge from rainfall;

R_c = Recharge from canal seepage;

R_r = Recharge from field irrigation;

R_d = Recharge from depression storage;

S_i = Influent seepage from rivers;

I_g = Inflow into the basin from other basins;

E_t = Evapotranspiration;

T_p = Draft from ground water;

S_e = Effluent seepage to rivers;

O_g = Outflow from the basin to other basins;

ΔS = Change in ground water storage.

5.0 Methodology of Water Balance

5.1 Study Area

The study area for ground water balance study should preferably be taken as doab where ground water constitutes a substantial water resource and the ground water basin can be characterised by prominent drainages.

5.2 Models and Study Periods

Model Types :

The models may be broadly classified as lumped or distributed. A spatially lumped model is considered with the entire area as a single unit and average values of the parameters of the area are taken or assumed for study. A geometrically distributed model, on the other hand, expresses spatial variability in terms of the location of the point. Hence the area under study is subdivided into nodal points according to geohydrological considerations. The subarea influenced by each nodal point is marked and the equations are applied for the subarea of each nodal point. In fact, the hydrologic water balance equation is mainly based on a lumped model study.

Study Period :

Precipitation is the main source of supplies. Although its distribution varies greatly from period to period, yet the variance from year to year is not so marked and precipitation over the area under study follows a net annual pattern. The period of study for hydrologic water balance is therefore generally taken as a year.

The level of the ground water table fluctuates according to the input to the ground water reservoir. The water input is received during the monsoon, while withdrawal from it takes place during the non-monsoon period. The water table is therefore at its maximum level of the year at the end of or somewhat after the monsoon. The period between two consecutive yearly peaks of the water table is termed 'water year'. In the case of arid regions this period may be taken from the time when the water table is at its minimum during a year. The water year may be further subdivided into smaller periods of a year for detailed study.

In areas where most of the rainfall occurs in a part of year, it is desirable to conduct water balance study on part year basis; that is, for monsoon period and non-monsoon period, Generally, the periods for study in such situations will be from the time of maximum water table elevation to the time of minimum water table elevation as the non-monsoon period and from the time of minimum water table to the time of maximum water table elevation as monsoon period. For northern India, the water year can be taken as November 1 to October 31 next year. The monsoon and non-monsoon periods can be taken as June to October and November to May next year respectively.

It is desirable to use the data of a number of years preferably covering one cycle of a dry and a wet year. This will enable to determine the recharge for an average year. so that the ground water potential of the area is known. Any development of the area beyond this average recharge would cause the water table go down and it would not only be expensive due to the cost of pumping but also affect the surface supply of the bounding streams. It is, therefore, necessary to limit the exploitation of ground water reservoir to the safe yield of the aquifer.

6.0 DATA REQUIREMENT

The data required for carrying out the water balance study can be enumerated as follows;

6.1 Rainfall Data

Monthly rainfall data of sufficient number of stations lying within or around the area should be available. The location of raingauges should be marked on a map.

6.2 Land Use Data and Cropping Patterns

Land use data are required for estimating the evapotranspiration losses from the water table through forests and orchards. Crop data are necessary for estimating the spatial and temporal distributions of the ground water withdrawals and canal releases, if required. Evapotranspiration data should also be available at few locations for estimation of consumptive use requirements of different crops.

6.3 River Data

River data are required for estimating the inter-flows between the aquifer and hydraulically connected rivers. The data required for these computations are the river gauge data, monthly flows and the river cross-sections at a few locations.

6.4 Canal Data

Monthwise releases into the canal and its distributories alongwith running days each month will be required. To account for the seepage losses, the seepage loss test data will be required in different canal reaches and distributories.

6.5 Tank Data

Monthly tank gauges and releases should be available. In addition to this, depth vs area and depth vs capacity curves should also be available. These will be required for computing the evaporation and the seepage losses from tanks. Also field test data will be required for computing final infiltration capacity to be used to evaluate the recharge from depression storage.

6.6 Water Table Data

Monthly water table data or atleast pre-monsoon and post-monsoon data of sufficient number of wells should be available. The well locations should be marked on map. The wells should be adequate in number and well distributed within the area, so as to permit reasonably accurate interpolation for contour plotting. The available data should comprise reduced level (R.L) of water table and depth to water table.

6.7 Aquifer Parameters

The specific yield and transmissivity data should be available at points sufficient in number to account for the variation of these parameters within the area.

6.8 Details of Draft from Wells

A complete inventory of the wells operating in the area, their running hours each month and discharge are required for estimating ground water withdrawals. If draft from wells is not known, this can be obtained by carrying out sample surveys. For getting the draft each month, the consumptive use of crops can be adopted for evaluating the same.

7.0 Components of Water Balance Equation

Considering the ground water balance equation, the various terms can be evaluated as below :

7.1 Recharge from Rainfall (R_i)

Part of the rain water, that falls on the ground, is infiltrated into the soil. This infiltrated water is utilised partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. The amount of 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. Some of them are as follows :

Chaturvedi Formula

This formula was developed for the Ganga-Yamuna doab in 1936 and gives recharge as a function of annual precipitation.

$$R = 2.0\ (P-15)^{0.4} \qquad \ldots\ldots \qquad (2)$$

where,

R = net recharge due to precipitation during the year, in inches, and

P = annual precipitation, in inches.

This formula was later modified by further work at the U.P.Irrigation Research Institute, Roorkee and the modified form of the formula is

$$R = 1.35\ (P-14)^{0.5} \qquad \ldots\ldots (3)$$

Amritsar Formula

This formula is given by Irrigation and Power Research Institute, Amritsar, Punjab.

$$R = 2.5\ (P-16)^{0.5} \qquad \ldots\ldots (4)$$

where, R and P are both measured in inches.

C.G.W.B. Studies

The Central Ground Water Board has concluded on the basis of a number of studies that the rainfall recharge in western Uttar Pradesh can be estimated as 15% of annual rainfall, viz.

$$R = 0.15\ P \qquad \ldots\ldots (5)$$

The recharge from rainfall can also be estimated by nuclear methods and from ground water balance.

Nuclear Methods

Nuclear techniques have been extensively used for the determination of recharge by measuring the travel of moisture through the 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 Berryllium (Be) and Radium (Ra) provide a convenient 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 or absorption is closely linked with moisture content of the soil medium. The method can be used without using health hazards.

Water Balance Approach

In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. The rainfall recharge is calculated by substituting these estimates in the water balance equation. A pre-requisite for successful application of this technique is very extensive and accurate hydrological and meteorological data. The water balance study for monsoon (rainy) and non-monsoon (dry) periods is carried out separately. The former yields an estimate of recharge coefficient and the latter determines the degree of accuracy with which the components of water balance equation have been estimated.

7.2 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 surface water bodies often constitute a significant part of the total recharge to ground water system. A number of investigations have been carried out to study the seepage losses from canals. In the alluvial tracts, seepage losses from canals are generally taken as 1.7 to 2.3 cumec per million square meter of the wetted area. The following formulae are in vogue for the estimation of seepage losses.

a) In Uttar Pradesh, the losses per million square meter of wetted area in unlined channels are usually taken as 2.5 cumecs for ordinary clay loam to about 5 cumecs for sandy loam. Empirically the seepage losses can be computed using the following formula -

$$\text{Losses in cumecs/Km} = \frac{C}{200} (B+D)^{2/3} \qquad \ldots (6)$$

where, B and D are the bed width and depth of the channel in metres. C is a constant, being 1.0 for intermittent running channels and 0.75 for constant running channels.

b) In Punjab, the loss formula for estimation of seepage losses from lined channels is a function of channel discharge.

$$S = 1.25\, Q^{0.56} \qquad \ldots(7)$$

where, S is the seepage loss in cusecs per million square foot of wetted perimeter and Q is the discharge carried by the channel.

In unlined channels, the loss rate on an average is four times of this value.

c) U.S.B.R. has recomended the following values for channel losses based on the channel bed material :

Material	Losses in cumecs per million square metre of wetted area
Clay and clay loam	1.5
Sandy loam	2.4
Sandy and gravelly soil	8.03
Concrete lining	1.2

However, the various guidelines for estimating losses in the distribution system as given above 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:

i) <u>Inflow-Outflow Method</u>

The inflow-outflow method consists in measuring the water that flows into and out of the section of irrigation canal being studied. The difference between the quantities of water flowing into and out of the canal reach is attributed to seepage.

ii) <u>Ponding Method</u>

The ponding method consists in measuring the rate of drop in a pool formed in the canal reach being tested.

A modification of the ponding method consists in adding water to the pond to maintain a constant water surface elevation. The accurately measured volume of added water is considered equal to the total losses, and the elapsed time establishes the rate of loss.

iii) Seepage Meter Method

Seepage meters are suitable for measuring local seepage rates in canals or ponds and used only in unlined or earth-lined canals. Various types of seepage meters have been developed. The two most important are (a) seepage meter with submerged flexible water bag and (b) falling head seepage meter.

The total losses from the canal and field channels 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 canal and water courses.

7.3 Recharge from Field Irrigation (R_r)

Water requirements of crops is met in parts by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigation fields for growing crops is lost in consumptive use and the balance infiltrates to recharge the ground water. Infiltration from applied irrigation water, derived both from surface water and ground water, constitutes one of the major components of ground water recharge in areas under wet crops. 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 efficiency of irrigation with the system of application of water is usually about 0.60 for canal irrigation and 0.65 for tubewell irrigation.

7.4 Recharge from Depression Storage (R_d)

The surface water may be stored in the depressions which may be fed by rainfall or from canals. The change in depression storage at the beginning and at the end of the study period can be estimated from the field survey, and attributed to ground water recharge from depression storage.

7.5 Influent and Effluent Seepage (S_i & S_e)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent). In order to estimate the contribution of water from the ground water reservoir (aquifer) to the stream as regenerated flow, the following equation can be used :

$$Q_d . \Delta t = Q_u . \Delta t + Q_g . \Delta t - E . \Delta t - Q_o . \Delta t + S_{RB} \qquad \ldots(8)$$

where,

Q_d = discharge at the downstream section,

Q_u = discharge at the upstream section,

Q_g = ground water contribution (to be evaluated) from both banks of the river,

E = rate of evaporation from river water surface and flood plain,

Q_o = discharge diverted from river, and

S_{RB} = change in the storage of the river bank area.

This equation will give the ground water contribution to rivers over a certain interval of time Δt from both sides of the river. The contribution from each side can be separated by any of the following methods :

a) The contribution from both sides can be assumed to be proportionate to the areas commanded on either side.

b) The transmissivities and gradients on either side are determined. The contribution from either side is then determined in proportion to the product of transmissivities and gradients.

$$\text{Contribution from left} = \frac{I_L T_L}{I_L T_L + I_R T_R} Q_g \qquad \ldots (9)$$

$$\text{Contribution from right} = \frac{I_R T_R}{I_L T_L + I_R T_R} . Q_g \qquad \ldots (10)$$

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

7.6 Inflow and Outflow from the Basin (I_g & O_g)

If a doab is considered for analysis, it will be bounded on two sides by two streams and on the other two sides by other aquifers or extension of the same aquifer. In such analysis, it is desirable to take these boundaries as one along a water table contour. The flow into the region or out of the region will be governed mainly by the hydraulic gradient and the transmissivity of the aquifer. The hydraulic gradient can be determined by taking the slope of the water table normal to water table contour. The length of the section, across which ground water inflow/outflow occurs, is determined from contour maps, the length being measured parallel to the contour. Then the inflow or outflow can be determined by the following relationship :

$$Q = \sum^{L} T\ I\ \Delta L \qquad \ldots\ (11)$$

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

7.7 Evapotranspiration (E_t)

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from the plant will be at the maximum possible rate, i.e. at potential rate. This potential evapotranspiration will take place in a waterlogged tract due to the rise in the water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such area can be worked out by usual methods of computing evapotranspiration using the known data.

7.8 Draft from Ground Water (T_p)

Draft is the amount of water lifted from the acuifer by means of various lifting devices. The withdrawal may be obtained by means of

i) State tubewells

ii) Private tubewells

iii) Open wells

In the case of state tubewells, information about the number of running hours and discharge is obtained to calculate the volume pumped in each month. Similar information is also needed for private tubewells and open wells (including those with mechanical devices). In order to find the draft from private tubewells and open wells, sample surveys have to be conducted regarding their number, discharge and withdrawals over the year.

Where wells are energised, power consumption data give adequate information to compute the draft from the wells. By conducting tests on wells, the average draft per unit of electricity consumed can be determined for different ranges in depth to water levels. By noting the depth to water level at each distribution point and multiplying the average draft value with the number of units of electricity consumed, the draft at each point can be computed for every month.

7.9 Change in Ground Water Storage (ΔS) :

The change in ground water storage is an indicator of the long term availabilities of ground water. The change in ground water storage between the beginning and end of the non-monsoon season indicates the total quantity of water withdrawn from ground water storage, while the change between the beginning and end of monsoon season indicates the volume of water gone into the reservoir. During the monsoon season, the recharge is more than the extraction and hence the ground water storage increases, which can be utilised in the subsequent non-monsoon season.

To assess the change in ground water storage, the water levels are observed through a network of observation wells spread over the area. The water levels are highest immediately after monsoon in the month of October or November and lowest just before rainfall in the month of May or June. The change in storage can be computed from the following equation :

Change in storage, $\Delta S = \Sigma\ h.A.\ Sy$ ... (12)

where,

h = change in water level

A = area influenced by that well, and

Sy = specific yield.

The value of the specific yield can be determined by pump test or if that is not available, the following values worked out by U.S.G.S. Hydrologic Laboratory can be used :

Soil Type	Specific Yield
Clay	1
Silty clay	2
Sandy clay	3
Clay silt	5
Silt	7
Clay sand	7
Silty sand	20
Sandy silt	14
Fine sand	26
Medium sand	35
Coarse sand	33
Sand (undifferentiated)	32
Fine gravel	25
Medium gravel	20
Coarse gravel	14

A committee 'Ground Water Estimation Committee' was constituted in 1982 to improve the existing methodologies for estimation of the ground water resource potential. The recommendations of the committee are given below :

Recommendations of the Ground Water Estimation Committee (1983)

The ground water estimation committee after making a review of the various aspects and after considering the data collected by the Central Ground Water Board, State Ground Water Organisations, Research Organisations, Universities and the report of the Ground Water Over Exploitation Committee have made the following recommendations.

It is recommended that the ground water recharge should be estimated based on ground water level fluctuation method. However, in areas, where ground water level monitoring is not being done regularly, or where adequate data about ground water level fluctuation is not available, adhoc norms of rainfall infiltration may be adopted. As a guideline, following norms may be adopted.

1. Recharge from Rainfall :

i)	Alluvial areas	
	In sandy areas	20 to 25 percent of normal rainfall.
	In areas with higher clay content	10 to 20 percent of normal rainfall.
ii)	Semi-consolidated sandstones-Friable and highly porous	10 to 15 percent of normal rainfall.

iii) Hard rock areas

Granite Terrain- weathered and fractured	10 to 15 percent of normal rainfall.
Unweathered	5 to 10 percent of normal rainfall.
Basaltic Terrain- Vesicular and jointed Basalt	10 to 15 percent of normal rainfall.
Weathered Basalt	4 to 10 percent of normal rainfall.
Phyllites, limestones, sand stones, quartzites, shales, etc.	3 to 10 percent of normal rainfall.

The normal rainfall figures may be taken as given by India Meteorological Department. The ranges indicated above are given as a guideline and it does not automatically imply that upper limit can invariably be applied. Based upon the status of knowledge available, a value in between should be chosen.

2. Recharge due to seepage from unlined canals :

The following norms recommended by Ground Water Over Exploitation Committee may be adopted :

i) For unlined canals in normal type of soil with some clay content along with sand

15 to 20 ha m/day/10^6 Sq.m. of wetted area of canal or

6 to 8 cusec/10^6 sq. ft. of wetted area of canal or

1.8 to 2.5 cumec/10^6 sq.m. of wetted area.

ii) For unlined canals in sandy soils

25 to 30 ha m/day/10^6 sq.m. of wetted area or

10 to 12 cusec/10^6 sq.ft. of wetted area or

3 to 3.5 cumec/10^6 sq.m. of wetted area.

iii) For lined canals, the seepage losses may be taken as 20 percent of the above values.

3. Return Seepage from Irrigation Fields :

i) Irrigation by surface water sources :

a) 35 percent of water delivered at the outlet for application in the field.

b) 40 percent of water delivered at outlets for paddy irrigation only.

ii) Irrigation by ground water sources :

30 percent of the water delivered at outlet. For paddy irrigation 35 percent as return seepage of the water delivered may be taken.

In all the above cases return seepage figures include losses in field channel and these should not be accounted for separately.

4. Seepage from Tanks :

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, the seepage from the tanks may be taken as 44 to 60 cm. per year over the total water spread. 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 recharge component from percolation tanks so computed should be distributed for utilisation purposes under its (percolation tanks) command only.

5. Contribution from Influent Seepage :

Influent seepage from the rivers with a definite influent nature may be computed by using Darcy's law

$$Q = T I L$$

where, Q = rate of flow ;

T = Transmissivity of the aquifer ;

I = Hydraulic gradient ; and

L = Length of section through which flow is taking place.

Annual Recharge :

The annual recharge includes the following components :-

Total annual recharge = Recharge during monsoon + non-monsoon rainfall recharge + seepage from canals + return flow from irrigation

+ inflow from influent rivers etc.

+ recharge from submerged lands, lakes etc.

Losses of ground water from aquifers mainly arise out of the following factors :

1. <u>Outflow to Rivers</u> :

A river may have a losing reach or a gaining reach depending upon the relative water levels in the river and the adjoining aquifers. For losing reaches the effect on ground water regime is additive. In gaining reaches contribution from ground water to the river is confined to a relatively small strip adjoining the stream.

2. <u>Transpiration by Trees</u> :

Transpiration by deep rooted trees results in depletion of ground water equivalent to supplementary water requirement of tree for its growth. This is a loss to ground water and has to be regarded as unrecoverable.

3. <u>Evaporation from Shallow Water Table</u> :

This is controllable situation. These losses reduce to negligible proportion once the water table falls about 3 metres below the ground level. As such these losses need not be accounted for in ground water estimates. It is recommended that in waterlogged and shallow water table zones, ground water may be developed till the water level reaches 5 metres below ground level. The resources estimated based on the pre-monsoon water level to 5 metres depth are potential and would be available for development in addition to the annual recharge in these areas.

The total ground water resource computed would be available for irrigation, domestic and industrial uses. The base flow in rivers is a regenerated ground water resource and is sometimes committed for lift irrigation schemes, and other surface irrigation works. It is , therefore, recommended that 15 percent of total ground water resources be kept for drinking and industrial purposes for committed baseflow and to account for the unrecoverable losses. The remaining 85 percent ,subject to the stipulation specified, can be utilised for irrigation purposes.

The norms of development for various types of structures vary from state to state depending upon the existing agricultural practices, local hydrogeological conditions, availability of power etc. and as such it is recommended that regional norms may be developed based on sample surveys. In case of Public Tubewells, data for discharge and running hours is already available and that should be used for computation of draft.