Runoff Estimation and Water Quality Aspects for Groundwater Recharge

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Scientist-F & Head

1.0 Introduction

The first step in planning a recharge scheme is to demarcate the area of recharge. Such an area should, as far as possible, be a micro-watershed (2,000-4,000 ha) or a mini-watershed (40-50 ha). However, localized schemes can also be taken up for the benefit of a single hamlet or a village. In either case the demarcation of area should be based on the following broad criteria:

- Where ground water levels are declining due to over-exploitation.
- Where substantial part of the aquifer has already been de-saturated i.e. regeneration of water in wells and hand pumps is slow after some water has been drawn.
- Where availability of water from wells and hand pumps is inadequate during the lean months
- Where ground water quality is poor and there is no alternative source of water

Before undertaking a recharge scheme, it is important to first assess the availability of adequate water for recharge. Following are the main sources, which can be identified and assessed for adequacy:

- Precipitation (rainfall) over the demarcated area and the runoff to be available at the recharge site due to the rainfall
- Large roof areas from where rainwater can be collected and diverted for recharge
- Canals from large reservoirs from which water can be made available for recharge
- Natural streams from which surplus water can be diverted for recharge, without violating the rights of other users
- Properly treated municipal and industrial wastewaters. This water should be used only after ascertaining its quality.

"In situ" precipitation may be available at every location but may or may not be adequate for groundwater recharge purposes. In such cases, water from other sources may be explored for transmitting to the recharge site. Assessment of the available sources of water would require consideration of the following factors:

- Available quantity of water

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- Time for which the water would be available
- Quality of water and the pretreatment required
- Conveyance system required to bring the water to the recharge site

Infiltration capacity of soil is an important factor that governs the rate of saturation of the vadose zone and thereby the efficacy or otherwise of a recharge scheme. Infiltration capacity of different soil types are also to be known for estimation of recharge rate. The infiltration capacity can be determined from the field infiltration test.

Having known the information about availability of water including its quality together with the infiltration data, one can estimate the groundwater recharge rate. The subsequent sections discuss as to how to estimate different components require for estimation of groundwater recharge. With regard to estimation of water availability, this note describes the rainfall-runoff estimation from a catchment.

2.0 Rainfall-Runoff Process

The rainfall runoff process is well described in any hydrology book. A short description pertinent for estimation of runoff yields for rainfall events is presented here.

When rain falls, the first drops of water are intercepted by the leaves and stems of the vegetation. This is usually referred to as interception storage. As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage), after which runoff is generated.

The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity (of a dry soil) is high but, as the storm continues, it decreases until it reaches a steady value termed as final infiltration rate. The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration. Figure 1 illustrates relationship between rainfall, infiltration and runoff.

For better understanding of the difficulties of accurately predicting the amount of runoff resulting from a rainfall event, the major factors which influence the rainfall-runoff process are described here. Apart from rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors which have a direct bearing on the occurrence and volume of runoff. These are: (i) soil type, (ii) vegetation, (iii) Slope and catchment size.

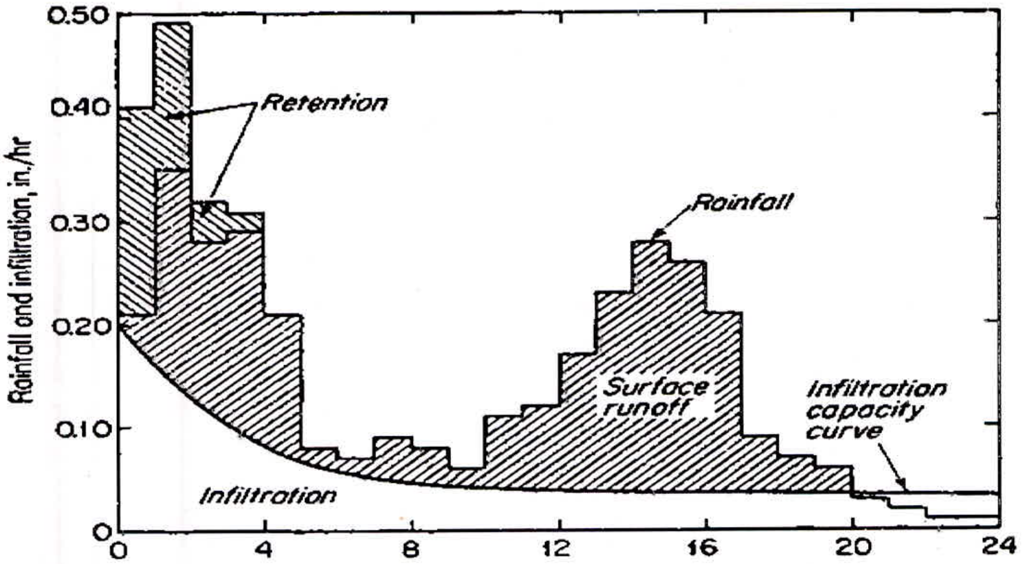

Figure 1. Schematic diagram illustrating relationship between rainfall, infiltration and runoff (Source: Linsley et al. 1958).

2.1 Soil type

The infiltration capacity is dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities. The infiltration capacity depends furthermore on the moisture content prevailing in a soil at the onset of a rainstorm. Figure 2 illustrates the difference in infiltration capacities measured in different soil types.

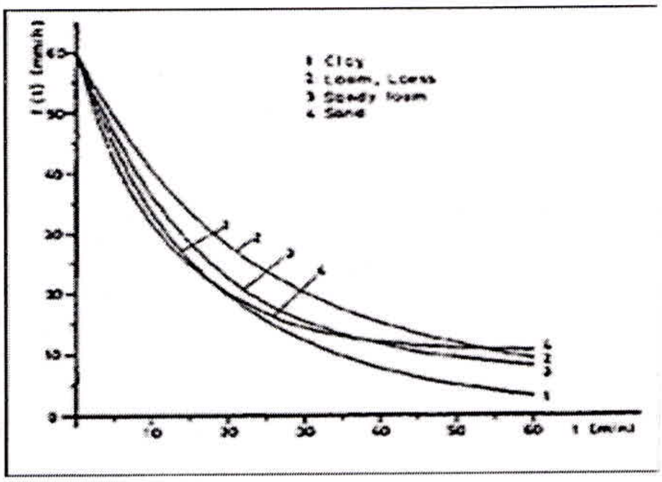

Figure 2. Infiltration capacity of different soils.

2.2 Vegetation

The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. Values of interception vary between 1 and 4 mm. Vegetation effects the infiltration capacity of soil. An area densely covered with vegetation, yields less runoff than bare ground.

2.3 Slope and catchment size

Investigations had shown that steep slope plots yield more runoff than those with gentle slopes. It was observed that the quantity of runoff decreased with increasing slope length. This is mainly due to lower flow velocities and subsequently a longer time of concentration. This means that the water is exposed for a longer duration to infiltration and evaporation before it reaches the measuring point. The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency. Figure 3 illustrates a relationship between runoff efficiency as a function of catchment size.

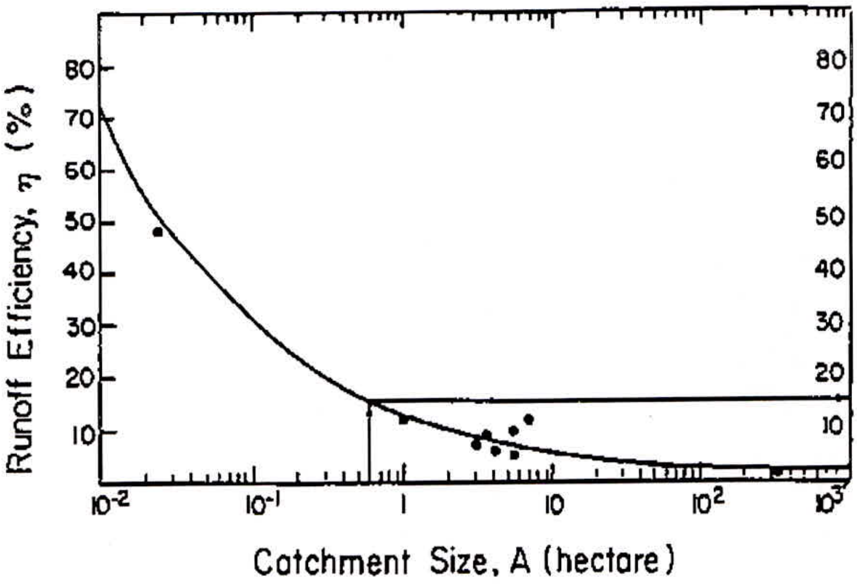

Figure 3. Runoff efficiency as a function of catchment size.

3.0 Rainfall-Runoff Modeling

Rainfall runoff models may be grouped in two general classifications, illustrated in Figs. 3 and 4. The first approach uses the concept of effective rainfall in which a part of the rainfall intensity is taken as loss, and the remaining rainfall is considered to be effective rainfall termed as hyetograph. The effective rainfall is then used as input to a catchment model to produce the runoff hydrograph. It follows from this approach that the infiltration process ceases at the end of the storm duration.

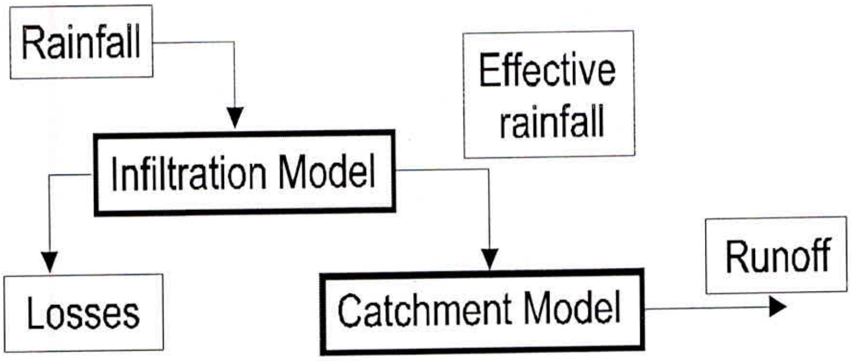

Figure 3: A rainfall-runoff models using effective rainfall.

An alternative approach is a surface water budget model that incorporates the loss mechanism into the catchment model. In this approach, the incident rainfall hyetograph is used as input and the estimation of infiltration and other losses is made as an integral part of the calculation of runoff. This approach implies that infiltration will continue to occur as long as the average depth of excess water on the surface is finite.

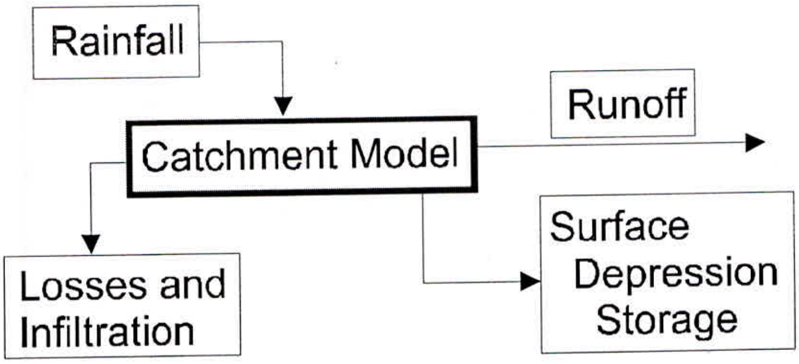

Figure 4: A rainfall-runoff model using a surface water budget

Numerous models and methods are available on the above approaches in literature for rainfall-runoff modeling. However, the most widely used methods are the Rational Formula and the Soil Conservation Service or SCS - Curve Number (SCS-CN) method for determining the peak runoff. The subsequent section discusses details about the Rational Formula and the "SCS-CN" method.

3.1 Rational Formula

The Rational equation is the simplest method to determine peak discharge from drainage basin runoff. It is characterized by:

- consideration of the entire drainage area as a single unit,
- estimation of flow at the most downstream point only,
- the assumption that rainfall is uniformly distributed over the drainage area.

The Rational Formula is given by:

$$Q_p = 0.28\ C\ I\ A \qquad (1)$$

Where Q_p = peak runoff rate (m^3/sec); C = runoff coefficient (dimensionless); I = rainfall intensity (mm/hr); A = drainage area (km^2).

The Rational Formula follows the assumption that:

- the predicted peak discharge has the same probability of occurrence (return period) as the used rainfall intensity (I),
- the runoff coefficient (C) is constant during the rain storm, and
- the recession time is equal to the time of rise.

In the modified version of the Rational Formula, a storage coefficient is included to account for a recession time larger than the time the hydrograph takes to rise. The Modified Rational Formula is given by:

$$Q_p = 0.28\ C_s\ C\ I\ A \qquad (2)$$

where C_s = storage coefficient (dimensionless).

The maximum runoff rate in a catchment is reached when all parts of the watershed are contributing to the outflow. This happens when the time of concentration, the time after which the runoff rate equals the excess rainfall rate, is reached. The Kirpich/Ramser has given an equation to calculate the time of concentration as follows:

$$t_c = 0.0195\ L^{0.77}\ S^{-0.385} \qquad (3)$$

where t_c = time of concentration (min); L = length of main river (m); S = distance weighted channel slope (m/m).

The Rational method runoff coefficient (C) is a function of the soil type and drainage basin slope. A simplified table indicating values of runoff coefficient for different ground covers is given in Table-1. The rainfall intensity, I can be obtained by deriving Intensity/ Duration/Frequency curves for rainfall events in the geographical region of interest. The duration is usually taken equivalent to the time of concentration of the drainage area.

3.2 SCS-Curve Number Model

The SCS-CN model is the most popular method for computing of surface runoff for rainfall event. This approach involves the use of simple empirical formula and readily available tables and curves. It is only one method, which incorporates the land-use for computation of runoff from rainfall.

Table 1: Simplified Table of Rational Method Runoff Coefficients

Ground Cover	**Runoff Coefficient, C**
Lawns	0.05 - 0.35
Forest	0.05 - 0.25
Cultivated land	0.08-0.41
Meadow	0.1 - 0.5
Parks, cemeteries	0.1 - 0.25
Unimproved areas	0.1 - 0.3
Pasture	0.12 - 0.62
Residential areas	0.3 - 0.75
Business areas	0.5 - 0.95
Industrial areas	0.5 - 0.9
Asphalt streets	0.7 - 0.95
Brick streets	0.7 - 0.85
Roofs	0.75 - 0.95
Concrete streets	0.7 - 0.95

The runoff curve number (called simply, CN) is an empirical parameter used for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hillslope plots monitored by the USDA. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

The basic assumption of the SCS-CN model is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions, results in the following equation:

$$Q = \frac{(P - I_a)^2}{(P + I_a) + S} \qquad for \quad P > I_a \tag{4a}$$

$$Q = 0 \qquad for \quad P \le I_a \tag{4b}$$

where Q is runoff [in dimension of length]; P is rainfall [in dimension of length]; S is the potential maximum soil moisture retention after runoff begins [in dimension of length]; I_a is the initial abstraction [in dimension of length] or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and $\mathbf{I_a = \lambda S}$. The Curve Number (CN) in MKS unit is given by:

$$S = \frac{25400}{CN} \quad - \quad 254 \tag{5}$$

In which, S is the maximum potential retention (mm); λ is the initial abstraction weight as a fraction of S, normally $0 \leq \lambda \leq 0.3$, conventionally taken as 0.2; and 25400 and 254 in Eq. (5) are arbitrary constants in units of S. Theoretically, S varies between 0 to ∞ for CN ranges from 100 to 0; the lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. Substituting S as given by Eq.(5), and λ=0.2, Eq. (5) yields to :

$$Q = \frac{25.4\left[\dfrac{P}{25.4} - \dfrac{200}{CN} + 2\right]^2}{\left[\dfrac{P}{25.4} + \dfrac{800}{CN} - 8\right]} \quad ; \quad valid\ for\ P > 0.2S \tag{6}$$

The general equation for the SCS-CN model can be explained as follows:

The initial equation (4a) is based on trends observed in data from collected sites; therefore it is an empirical equation instead of a physically based equation. After further empirical evaluation of the trends in the data base, the initial abstractions, I_a, could be defined as a percentage of S (Eq. 5). With this assumption, the equation (6) could be written in a more simplified form with only 3 variables. The parameter CN is a transformation of S, and it is used to make interpolating, averaging, and weighting operations more linear form as given by equation (5).

Figure 5 gives the variation of runoff (in inches) for varying rainfall events (in inches for values of CN. From the Fig. 5, the amount of runoff can be found if the rainfall amount (in inches) and curve number is known.

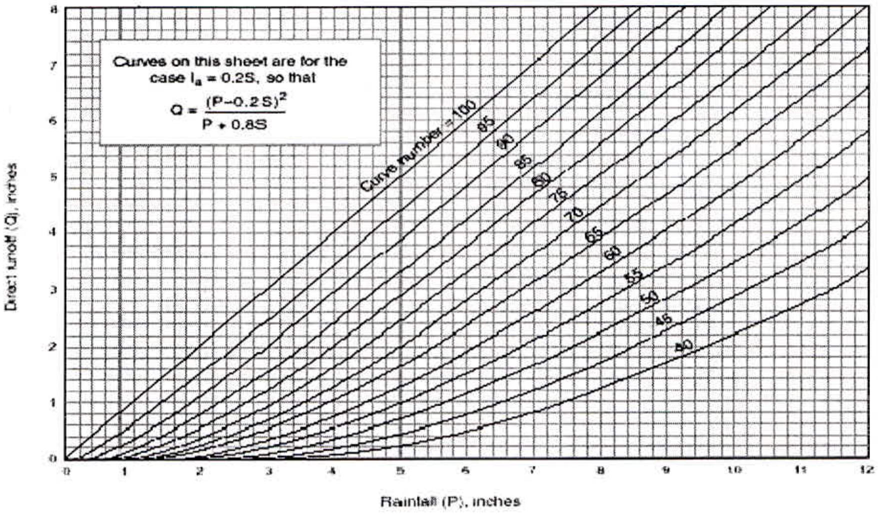

Figure 5: Rainfall-runoff variation for different values of CN: rainfall and runoff are in inches.

Table -2 indicates values of Curve Number (CN) for different hydrologic soil groups, land-uses and land covers condition developed by USDA. The hydrologic soil groups A, B, C, and D represent the following characteristics:

- Group A is composed of soils considered to have low runoff potential. These soils have a high infiltration rate even when thoroughly wetted.
- Group B soils have a moderate infiltration rate when thoroughly wetted.
- Soils Group C are those which have slow infiltration rates when thoroughly wetted.
- Group D soils are those which are considered to have a high potential for runoff. Since they have slow infiltration rates when thoroughly wetted.

3.2.1 Antecedent moisture condition (AMC) adjustment

Runoff is affected by the soil moisture before a precipitation event, or the A*ntecedent Moisture Condition* (AMC). A curve number, as calculated using Table-2 , may also be termed AMC II or CN_{II}, or average soil moisture. The other moisture conditions are dry, AMC I or CN_I, and moist, AMC III or CN_{III}. The curve number can be adjusted by *factors* to CN_{II}, where CN_I factors are less than 1 (reduce *CN* and potential runoff), while CN_{III} factor are greater than 1 (increase *CN* and potential runoff). The soil moisture condition is classified in three A*ntecedent Moisture Condition classes as follows:*

AMC I : The soils in the drainage basin are practically dry *(i.e. the soil moisture content is at wilting point).*

AMC II : Average condition.

AMC III : The soils in the drainage basins are practically saturated from antecedent rainfalls *(i.e. the soil moisture content is at field capacity).*

These classes are based on the 5-day antecedent rainfall *(i.e the accumulated total rainfall preceding the runoff under consideration).*

The watershed specific-CNs relating to the antecedent moisture condition (AMC) is given by:

$$CN_I = \frac{4.2\, CN_{II}}{10 - 0.058\, CN_{II}} \tag{7}$$

$$CN_{III} = \frac{23\ \ CN_{II}}{10 + 0.13\, CN_{II}} \tag{8}$$

where subscripts indicate the AMC, I being dry, II normal, and III wet.

Table-2: CN for different hydrologic soil group, land-uses and land covers.

Land Use Description on Input Screen	**Description and Curve Numbers from TR-55**					
	Cover Description		Curve Number for Hydrologic Soil Group			
	Cover Type and Hydrologic Condition	**% Impervious Areas**	**A**	**B**	**C**	**D**
Agricultural	Row Crops - Straight Rows + Crop Residue Cover- Good Condition		64	75	82	85
Commercial	Urban Districts: Commerical and Business	85	89	92	94	95
Forest	Woods – Good Condition		30	55	70	77
Grass/Pasture	Pasture, Grassland, or Range - Good Condition		39	61	74	80
High Density Residential	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Industrial	Urban district: Industrial	72	81	88	91	93
Low Density Residential	Residential districts by average lot size: 1/2 acre lot	25	54	70	80	85
Open Spaces	Open Space (lawns, parks, golf courses, cemeteries, etc.), Fair Condition (grass cover 50% to 70%)		49	69	79	84
Parking and Paved Spaces	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	100	98	98	98	98
Residential 1/8 acre	Residential districts by average lot size: 1/8 acre or less	65	77	85	90	92
Residential 1/4 acre	Residential districts by average lot size: 1/4 acre	38	61	75	83	87
Residential 1/3 acre	Residential districts by average lot size: 1/3 acre	30	57	72	81	86
Residential 1/2 acre	Residential districts by average lot size: 1/2 acre	25	54	70	80	85
Residential 1 acre	Residential districts by average lot size: 1 acre	20	51	68	79	84
Residential 2 acres	Residential districts by average lot size: 2 acre	12	46	65	77	82
Water/ Wetlands		0	0	0	0	0

4.0 Illustrated Examples

(i) Runoff Estimation by SCS-CN model

Example 1 : Suppose we have an ungauged drainage basin of flat rangeland. The soils have a low infiltration rate and a dense grass cover. As rainfall data, we have the intensity duration-frequency data as given below. For this basin we would like to know depth of the direct runoff with a return period of 10 years for Antecedent Moisture Condition Class II.

Duration (hour)	Design rainfall	
	Intensity (mm/hour)	Depth (mm)
1	88	88
2	53	106
3	39	117
4	32	128
5	27	135
24	8.7	209
48	5.6	269
72	4.6	331

Solution:

First, we estimate the CN value for the basin. The land use is given as rangeland and the treatment practice is taken as contoured since the area is flat. Because of the dense grass cover, we select the hydrological condition 'good'. The infiltration rate of the soils is described as low and we therefore select Hydrological Soil Group C. Using Table-4.2 we now find a CN value of 71 for AMC Class II. Using Eq.(5) we obtain for this value of CN, a potential maximum retention S as 104 mm.

Next, we determine the appropriate rainfall data from the duration-intensity for the given return period of 10 years. The values are given in table above. Corresponding to the values of the design rainfall data, using Eq.(6) straight we can calculate the direct runoff.

If we assume that the antecedent moisture condition in the drainage basin is not characterized as Class II but as Class III, the CN value of 71 should be adjusted by using Eq.(8). This yields an adjusted CN value of nearly 85. Making use of this CN value and utilizing the design rainfall data in Eq.(6), we can calculate the direct runoff.

Example 2: Suppose we have an ungauged drainage basin of 100 ha; out of which 50 ha is comprised of agricultural land, 25 ha is pasture, and remaining 25 ha forest cover. The soils have a high to medium infiltration rate and the hydrological condition can be characterized as poor to moderate soil classes having CN for agricultural land as 65, for pasture as 70, and that for forest is 75. The duration-intensity-depth of rainfall of the drainage basin is as given in Example 1. We are required to find the direct runoff corresponding to the given rainfall events.

Solution:

First we estimate the average CN value for the basin taking the average mean as follows:

$$CN_{II} = \frac{50 * 65 + 25 * 70 + 25 * 75}{100} \approx 69$$

Making use of this CN value and utilizing the data of rainfall depth, the corresponding direct runoff can be determined using Eq.(6).

5.0 Water Quality Aspects of Artificial Groundwater Recharge

Problems which arise as a result of recharge to ground water are mainly related to the quality of raw waters that are available for recharge and which generally require some sort of treatment before being used in recharge installations. They are also related to the changes in the soil structure and the biological phenomena, which take place when infiltration begins, thereby causing environmental concerns. The chemical and bacteriological analysis of source water and that of ground water is therefore essential.

A major requirement for waters that are to be used in recharge projects is that they be silt free. Silt may be defined as the content of un-dissolved solid matter, usually measured in mg/l, which settles in stagnant water or in flowing water with velocities, which do not exceed 0.1 m/hr.

Virtually all groundwater comes from precipitation that soaks into the soil and passes down to the aquifer. Rainwater has a slightly acidic pH, therefore it tends to dissolve solid minerals in the soil and in the aquifer. Different rocks, e.g., sandstone, limestone and basalt all have different minerals and therefore, groundwater in contact with these materials will have different compositions. Rainwater is sodium-free, a benefit for persons on restricted sodium diets. Also, being soft water, rainwater extends the life of appliances as it does not form scale or mineral deposits. The environment, the catchment surface, and the storage tanks affect the quality of surface runoff. The falling raindrop acquires slight acidity as it dissolves carbon dioxide and nitrogen. Contaminants captured by the rain from the catchment surface and storage tanks are of concern for those intending to use rainwater as their potable water source. The catchment area may have dust, dirt, hazardous surface pollutants, fecal matter from birds and small animals, and plant debris such as leaves and twigs. Surface runoffs intended for artificial groundwater recharge thus may require monitoring of water quality constituents and treatment thereby before recharging to groundwater.

For those intending to harvest rainwater for potable use, the microbiological contaminants *E. coli*, *Cryptosporidium*, *Giardia lamblia*, total coliforms, legionella, fecal coliforms, and viruses, are probably of greatest concern, and rainwater should be tested to ensure that none of them are found.

5.1 Quality of Water for Recharge

The water used for recharge must be of suitable quality for ultimate recovery and use for its intended purpose. Any water proposed for recharge should be tested by a qualified laboratory.

Silt: Clay: Debris

Silt and clay introduced into a well will lodge in the gravel pack around the well or at the interface between the gravel pack and the aquifer and materially retard the movement of water. It may even penetrate the aquifer material itself and reduce permeability of the material surrounding the well. Accumulations of organic matter and other debris may reduce the rate of recharge or seal even large openings. The quality of ground water may be affected during the decaying process. However, organic debris entering a limestone aquifer may be beneficial. The decaying process gives off carbon dioxide which increases the ability of the water to dissolve limestone and thereby enlarge the voids in the aquifer.

Chemical Pollutants: Bacteria: Algae

Pollution must be avoided in recharging ground water. Sources of pollution include storm sewers, untreated sewage, waste products, detergents, pesticides, herbicides, toxic and noxious substances; fertilizers, saline water, and heat.

Organic wastes may either contain harmful bacteria or may promote their growth. In a recharge well, bacteria and algae may clog the well screen or the aquifer or both. The decay of organic materials may produce excess nitrates or other toxic by-products. Water from areas where large quantities of pesticides or herbicides have been applied or manufactured should not be used for recharge without careful study.

The danger that public water supplies may become polluted as a result of the movement of bacteria and chemicals with underground waters is a matter of great concern to health authorities. Field investigations indicated the travel of pollution from direct recharge into underground formations and of waste-water reclamation in relation to groundwater pollution. It shows that a definite hazard exists when polluted water is injected directly into the aquifer by means of wells or is recharged through large openings. A lesser hazard exists with surface spreading methods which permit aeration to reduce pollution. Migration of chemical pollutants was found to be greater than bacterial pollutants.

Dissolved Solids: Precipitates: Ion-exchange

The kind and amount of dissolved solids in water vary considerably from place to place and from one period of time to another. They depend upon the time and amount of precipitation, the chemical changes that take place in the soil and rocks, and availability of soluble substances.

Solubility of oxygen, carbon dioxide, sulphur dioxide, ammonia and other gases in water varies with physical and biological environment and changes with temperature and pressure. Presence of dissolved oxygen affects the habitat of aerobic bacteria which influence the decomposition of organic matter. The solubility of calcium carbonate varies with the carbon dioxide content of the water. The corrosive and electrolytic characteristics of the water will influence the selection of steel or other kinds of metals used for screens, pumps, pipes, and fittings to be used in wells. Serious incrustations by chemical action may occur in metal-cased wells, particularly where the perforations are above the normal water table and exposed to the air. Perforating only below the lowest elevation of water table is a partial remedy. The amount of incrustation will vary with the chemical quality of water.

Chemical and mineral wastes from mining and industrial areas often are toxic to plants and animals. Waters that contain a high concentration of sodium salts cause infiltration problems. Reactions between chemicals in recharge water and chemicals in the ground water or the mineral makeup of the aquifer may in some cases produce precipitates or an exchange of ions. These conditions could reduce the rate of recharge or the quality of the water.

Temperature: Dissolved Gases

The solubility of air in water is strongly influenced by temperature. Surface waters (the normal water used for recharge excepting industrial effluents) are normally saturated with air at their given temperature and pressure. This would mean that an injection well pumping 500 gallons per minute of water at 20 or 30° C into an aquifer where the temperature might be raised by 100° C, could potentially release over 500 cubic feet of free air into the aquifer daily. While some of the air might escape, most will take the form of tiny bubbles which fill the aquifer interstices and greatly reduce water intake. This is especially true of fine grained aquifers. To avoid this problem, injected water should have a temperature slightly higher than the temperature of the aquifer. On the other hand, some natural ground waters contain much dissolved gas which might be freed if the injected water is too warm.

Suspended Solids and Clogging Problem

A major requirement for waters that are to be used in recharge projects is that they be silt-free. To obtain still clearer water, with only 10 – 12 mg/l suspended solids, further additions of flocculants and, frequently, agitation of the water must be resorted to.

First, near the surface the interstices of the soil may be filled up and a layer of mud may be deposited on the surface, on the other hand suspended particles may penetrate deeper into the soil and accumulate there.

Methods to minimize the clogging effect by suspended matter can be classified into broad groups:

a) Periodical removing of the mud-cake and dicing or scraping of the surface layer.

b) Installation of a filter on the surface, the permeability of which is lower than that of the natural strata (the filter must, of course, be removed and renewed periodically).

c) Addition of organic matter or chemicals to the uppermost layer.

d) Cultivation of certain plant-covers, notably certain kinds of grass.

Providing inverted filter consisting of fine sand coarse sand and gravel at the bottom of infiltration pits/trenches are very effective.

Clogging by biological activity depends upon the mineralogical and organic composition of the water and basin floor and upon the grain-size and permeability of the floor. The only feasible method of treatment developed so far consists in thoroughly drying the ground under the basin.

Measures for Improving Quality

Debris guards, desilting basins, or both should be installed to remove brush, leaves, junk, sediment or other undesirable material from recharge water. These measures will provide a threefold benefit of avoiding contamination of the underground water, keeping the intake areas open, and preventing clogging the aquifer. Flocculants may be used to hasten the removal of silt and clay. The use of polyelectrolytic flocculating agents has received much attention recently and the latest information available on their use and cost should be obtained if the need for flocculation is indicated.

Purifying chemicals may be used to treat the water that may be recovered for human use. These treatments usually are too expensive for water which will not be used for human consumption. Aeration may reduce some chemical and bacterial contaminants, but it may permit an increase in the growth of algae.

Chlorination of the recharge water, either continuously or in slugs, will reduce the growth of soil- or aquifer-clogging micro-organisms.

5.2 Chemical State of Groundwater

The chemical state of groundwater is generally defined in terms of three parameters: the temperature, pH, and oxidation-reduction potential (redox potential). These factors are often influenced by chemical reactions between the groundwater and aquifer materials or mixing with different waters and these factors in turn control the chemical composition of groundwater. For example, the total dissolved solids (TDS) in groundwater, largely derived from aquifer minerals that dissolve in groundwater, will change significantly as a function of temperature and pH.

Chemical compounds

In agricultural areas, rainwater may have a higher concentration of nitrates due to fertilizer residue in the atmosphere .Pesticide residues from crop dusting in agricultural areas may also be present. Hard water has a high mineral content, usually consisting of calcium and magnesium in the form of carbonates. In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air.

Indian Standard Drinking Water - Specification (BIS 10500: 1991)

Sl. No.	Substance or Characteristic	Requirement (Desirable Limit)	Permissible Limit in the absence of Alternate source
Essential characteristics			
1.	Colour, (Hazen units, Max)	5	25
2.	Odour	Unobjectonable	Unobjectionable
3.	Taste	Agreeable	Agreeable
4.	Turbidity (NTU, Max)	5	10
5.	pH Value	6.5 to 8.5	No Relaxsation
6.	Total Hardness (as $CaCo_3$) mg/lit, Max	300	600
7.	Iron (as Fe) mg/lit, Max	0.3	1.0
8.	Chlorides (as Cl) mg/lit, Max.	250	1000
9.	Residual,free chlorine, mg/lit, Min	0.2	--
Desirable Characteristics			
10.	Dissolved solids mg/lit, Max	500	2000
11.	Calcium (as Ca) mg/lit, Max	75	200
12.	Copper (as Cu) mg/lit, Max	0.05	1.5
13	Manganese (as Mn)mg/lit, Max	0.10	0.3
14	Sulfate (as SO_4) mg/lit, Max	200	400
15	Nitrate (as NO_3) mg/lit, Max	45	100
16	Fluoride (as F) mg/lit, Max	1.9	1.5
17	Phenolic Compounds (as C_6H_5OH)mg/lit, Max.	0.001	0.002
18	Mercury (as Hg)mg/lit, Max	0.001	No relaxation
19	Cadmiun (as Cd)mg/lit, Max	0.01	No relaxation
20	Selenium (as Se)mg/lit, Max	0.01	No relaxation
21	Arsenic (as As) mg/lit, Max	0.05	No relaxation
22	Cyanide (as CN) mg/lit, Max	0.05	No relaxation
23	Lead (as Pb) mg/lit, Max	0.05	No relaxation
24	Zinc (as Zn) mg/lit, Max	5	15
25	Anionic detergents (as MBAS) mg/lit, Max	0.2	1.0
26	Chromium (as Cr^{6+})mg/lit, Max	0.05	No relaxation
27	Polynuclear aromatic hydro carbons (as PAH) g/lit, Max	--	--
28	Mineral Oil mg/lit, Max	0.01	0.03
29	Pesticides mg/l, Max	Absent	0.001
30	Radioactive Materials		
	i. Alpha emitters Bq/l, Max	--	0.1
	ii. Beta emitters pci/l, Max	--	1.0
31	Alkalinity mg/lit. Max	200	600
32	Aluminium (as Al) mg/l, Max	0.03	0.2
33	Boron mg/lit, Max	1	5

Catchment surface

When rainwater comes in contact with a catchment surface, it can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into storage tanks. The longer the span of continuous number of dry days (days without rainfall), the more catchment debris is washed off by a rainfall event.

Bibliography

American Society of Civil Engineers (ASCE), 2001. "*Standard Guidelines for Artificial Recharge of Ground Water*". ASCE, EWRI/ASCE:34-01.

Aron, G.M., A.C. Miller, and D.F. Lakatos, 1977. *"Infiltration formula based on SCS curve number"*. Journal of Irrigation and Drainage, 103, pp. 419-427.

Asano T, ed. 1985. *Artificial recharge of groundwater.* Boston, USA, Butterworth Publishers.

Asano T, Wassermann, K.L.,1980. *"Groundwater recharge operations in California*". Journal of the American Water Works Association, 72(7):380–385.

Baumann, Paul, 1952. *"Ground-water movement controlled through spreading"*. Am. Soc. Civ. Eng. 117, pp. 1024-1085.

Bliss, E.S. and Johnnson, C. E., 1952. *"Some factors involved in ground-water replenishment"*. Am. Geophys. Union Trans., 33, pp. 547-558.

British Geological Survey (BGS), 2002. "*The Effectiveness of Artificial Recharge of Ground water*: A Review. Groundwater Systems and Water Quality Programme-Phase 1", Final Report No. CR/02/108N, 59p.

Bureau of Indian Standards (BIS), 2006. "*Guidelines for Artificial Recharge to Ground Water"*. WRD-03/T-18 (yet to publish), Bureau of Indian Standards, New Delhi, 21p.

Central Ground Water Board, Ministry of Water Resources, Govt. of India, 2000. Guide on Artificial Recharge to Ground Water, 59 p.

Chow, V.T., 1964. *"Handbook of applied hydrology"*. McGraw-Hill, London, 1418 p.

Chow, V.T., D.R. Maidment and L.W. Mays, 1988. *Applied hydrology*. McGraw-Hill, New York, 572 p.

Fogel, M.M., L.H. Hekman and L. Duckstein, 1980. *Predicting sediment yield from strip-mined land. Symposium on Watershed Management*, Boise, Idaho". Irrigation and Drainage Division of ASCE, pp. 176-187.

Gray, D.M., 1973. *"Handbook on the principles of hydrology"*. Water Information Center, Washington, 591 p.

Hawkins, R.H., 1978. *"Runoff curve numbers with varying site moisture"*. Journal of Irrigation and Drainage Division, 104, pp. 389-398.

Hall, W. A., Hagan, R. M., and Axtell, J.D., 1957. *"Recharging ground water by irrigation"*. Agr. Engineering. 38, pp. 98-100.

Hope, A.S. and R.E. Schulze, 1982. *"Improved estimates of storm flow volumes using the SCS curve number method"*. In: V.P. Singh (ed.), Rainfall-runoff relationships. Water Resources Publications, Littleton. pp. 419-431.

Jackson, T.J. and W.J. Rawls, 1981. *"SCS urban curve numbers from land sat data bases"*. Water Resources Bulletin, **17**, pp. 857-862.

Kirpich, Z.P., 1940. *"Time of concentration of small agricultural watersheds"*. Civil Engineering, 10(6), pp. 362.

Mockus, V., 1957. *"Use of storm and watershed characteristics in synthetic hydrograph analysis and application"*. American Geophysical Union, Southwest Region Meeting, Sacramento, California.

Rawls, W.J. and H.H. Richardson, 1983. *"Runoff curve numbers for conservation tillage"*. Journal of Soil and Water Conservation, 38, pp. 494-496.

Reevel, Ronald C., 1960. *"The transmission of water by soils as influenced by chemical and physical properties"*. V. Intern. Cong, of Agric. Engr. Trans. 1: pp. 21-32.

Richter, R.C., 1955. *"Geologic considerations of artificial recharge"*. Geol. Soc. Am. Bulletin. 66, 1661p.

Schiff, Leonard and Johnson, C.E., 1958. *"Some methods of alleviating surface clogging in water spreading with emphasis on filters"*, Trans. Am. Geophy. Union, 39:292-297, 1958.

Soil Conservation Service (SCS), 1964. *"National engineering handbook, Section 4, Hydrology"*. Department of Agriculture, Washington, 450 p.

Soil Conservation Service, 1972. *"National engineering handbook, Section 4, Hydrology"*. Department of Agriculture, Washington, 762 p.

Springer, E.P., B.J.McGurk, R.H. Hawkins and G.B. Coltharp, *1980. "Curve numbers from watershed data"*. pp. 938-950.

U.S. Weather Bureau, 1958. *"Rainfall intensity-frequency regime"*. U.S. Weather Bureau, Technical Paper, 29, Washington.