Training Course

On

Hydrological Processes in an Ungauged Catchment

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CHAPTER-4

Geomorphological Parameters Using Remote Sensing and GIS

By

D.S. Rathore
Scientist-E2

Organized under Hydrology Project - II

National Institute of Hydrology
Roorkee – 247667 (Uttrakhand)

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GEOMORPHOLOGICAL PARAMETERS USING REMOTE SENSING AND GIS

D.S. Rathore
Scientist E2
National Institute of Hydrology, Roorkee–247 667

4.0 INTRODUCTION

Remote Sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter. As per General Assembly Resolutions and International Treaties Pertaining to the Peaceful Uses of Outer Space of United Nations, the term Remote Sensing means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment. A hydrological model is a mathematical model used to simulate river or stream flow and calculate water quality parameters. Runoff estimation is useful in water resources planning, design of hydraulic structures, bridges etc. Impact of land use/ climatic changes on hydrological cycle can be studied through simulation studies. Inundation mapping can also be done in river basin using hydrologic/ hydraulic mathematical models. Data preparation is a time consuming task in hydrological modeling. With the advent of GIS and remote sensing technology, the work can be expedited. Data such and land use cover can be extracted from satellite remotely sensed data and can be input in hydrological models for extracting hydrological parameters. DEM obtained from satellite observations, can be input in GIS to extract catchment and channel characteristics.

4.1 STREAM ORDER

Basin area, channel dimension and the discharge are related to the order of the stream. Stream order is used in classifying the streams. Streams of larger orders have larger basin, channel size and the discharge. Stream order can be assigned as per Horton, Strahler, Shreve or Scheidegger methods of stream ordering (Fig. 1). As per Horton method of stream ordering, all fingertip streams having no branched are classified as first order streams. Steams having braches of only first order are classified as second order streams. Likewise, all higher order streams are classified. A parent stream is assigned same order up to the headwaters. When a stream joins at larger angle or when angles are equal and the stream is shorter, the steam is termed as tributary stream. Strahler modified the Horton method of stream ordering. This method is widely used and is less subjective. All fingertip streams are classified as first order streams. These streams normally carry wet weather discharge and are normally dry. Second order streams form when two first order stream confluences. Likewise other order streams are classified. Thus, second and higher order streams do not extend up to the headwaters. This ordering system has disadvantage is trellis pattern where large number of stream join a higher order stream without change of order of that stream. Thus though discharge will increase in that stream, its order remains same. Shreve ordering scheme improves the Strahler scheme. In this scheme, order of a stream downsteam of a junction is a sum of the order of the streams upstream of the junction. Scheidegger further modified the Shreve scheme. In Shreve scheme, the order of stream increases rapidly. However, Scheidegger scheme allows for slower increase in the order of higher order streams. Initially streams are ordered as per Shreve scheme except the order of all fingertip stream is two to start with. After ordering is complete, a logarithm to base two is taken of the stream orders, resulting in Scheidegger stream order.

4.1.1 Laws of Basin Geometry

Stream order has power relationship with several of the basin geometric measurements. The relationships form the laws of basin geometry. As per these laws, the stream number, average length and basin area are related to the stream order. As the stream order increase number of streams, average area and slope decreases, whereas average stream length increases.

$$N_u = R_b^{s-u} \tag{4.1}$$

$$\overline{L}_u = \overline{L}_1 R_l^{u-1} \tag{4.2}$$

$$\overline{A}_u = \overline{A}_1 R_a^{u-1} \tag{4.3}$$

Where,
N_u= Number of streams of order u
s=Highest order of the basin
L_u= Average stream length of order u
A_u= Average basin area of order u
R_b= Bifurcation ratio
R_l= Stream length ratio
R_a=Basin area ratio

(i) Bifurcation ratio

Bifurcation ratio is a ratio of number of stream in a given order to that in a higher order. Since number of streams decreases with increasing order, bifurcation ratio is always higher than unity. Its value ranges from 2 to 5. Elongated basins in general have higher bifurcation ratio.

(ii) Stream length ratio

It is a ratio of average length of streams of given order to that of a stream of next lower order.

(iii) Basin area ratio

It is a ratio of average area of basins of given order to that of the basins of next higher order.

Miscellaneous morph metric measures

(i) Drainage density

Drainage density is a ratio of total stream length to the basin area. It has unit of inverse of length. Small drainage density signifies higher infiltration in a basin. It also reflects climate pattern, geology, soil and vegetation cover. Areas devoid of vegetation, and with semi arid climate characterized by intense thunder storm possess high value of the drainage density.

(ii) Constant of channel maintenance

It is a ratio of basin area to total stream length. It has unit of length.

(iii) Relief ratio

Relief ratio is a ratio of difference of the elevation at the basin outlet and highest point in the basin and basin length. The basin length is measured along the main stream. Sediment yield increases with increase in the relief ratio.

(iv) Mean stream slope

Mean stream slope is ratio of difference in elevations at the outlet and source and the length of the stream.

(v) Mean catchment slope

Mean catchment slope is a ratio of difference in elevation at 85% and 10% of the maximum length of the basin measured from the basin outlet and the basin length (75% of the total length of the basin) for which the elevations are taken in account for obtaining the elevation difference. Average slope of the basin is also obtained by averaging the slopes of the grid points in the basin.

(vi) Longitudinal profile

Longitudinal profile is a plot of elevation vs distance. The distance is measured from a downstream point. In general, the shape of profile is concave. Local topography, bed rock features and bed material also influence the profile. For erodible bed material, the bed slope is flatter.

(v) Hypsometric curve

It is a plot of cumulative area above a given elevation vs the elevation. Elevation is plotted on y- axis and area is plotted on abscissa. Both elevation and area may also be expressed in percentages. To obtain the hypsometric curve, area enclosed by successive contour lines is measured. The cumulative area is obtained from these measured values to obtain the hypsometric curve. The curve is useful in describing the hydrological variables, e.g. rainfall and snow cover, that are altitude dependent.

(vi) Basin shape

Several measures are used to describe the basin shape. These are form factor, elongation ratio, circularity ratio. Except for the compactness coefficient, which has values greater than unity, all other shape factors have values less than unity.

Form factor: Form factor is a ratio of basin area and square of the basin length. Basin length is measured parallel to the main stream in the basin. It is a dimensionless ratio. Its value is in general less than unity.

$$F_f = \frac{A}{L^2} \tag{4.4}$$

Where F_f= Form factor
A= Basin area
L= Basin length measured parallel to the main stream

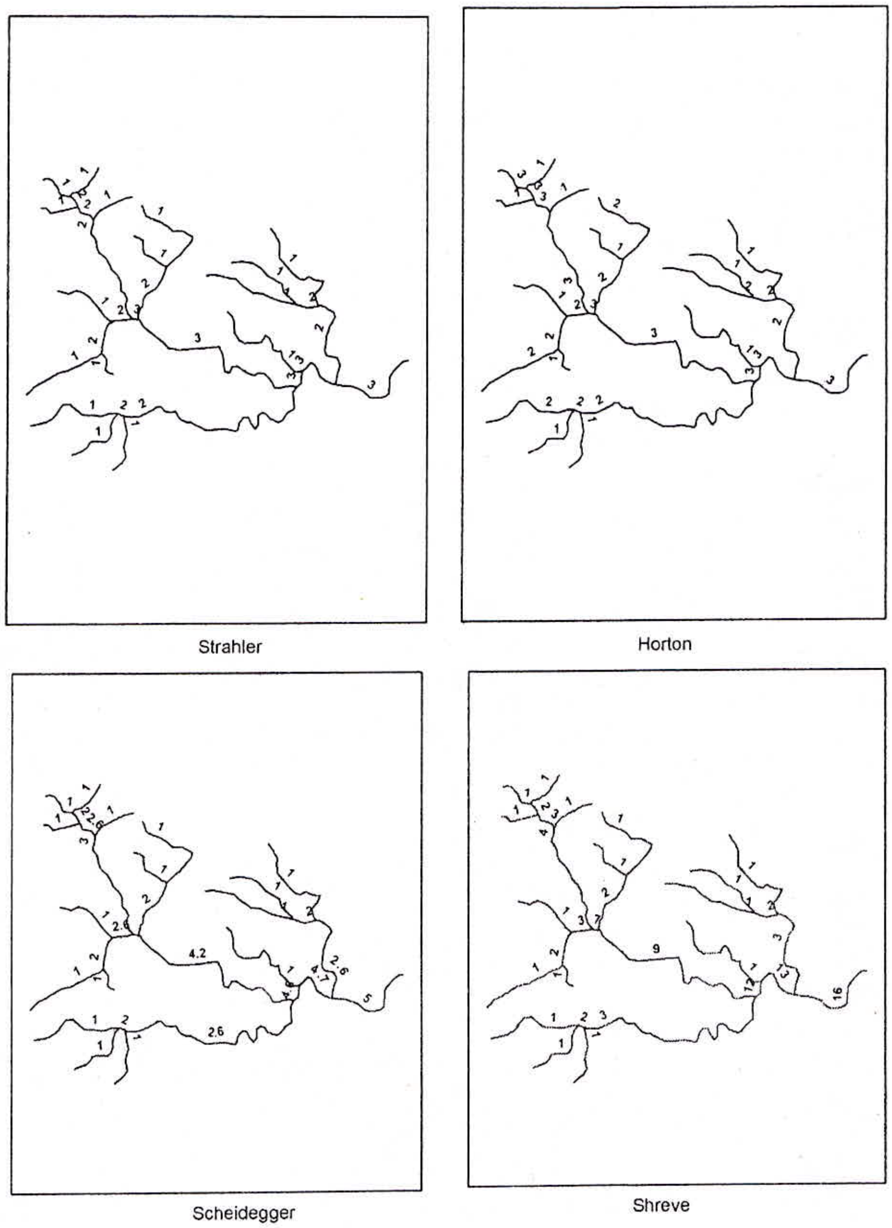

Fig. 1 Methods of stream ordering

Fig 4.1

Elongation ratio: It is a ratio of diameter of circle having same area as the area of the basin to the length of the basin. It is a dimensionless ratio. Its value is in general less than unity.

$$E_r = \left(\frac{A}{0.786}\right)^{0.5} \frac{1}{L} \tag{4.5}$$

Where E_r= Elongation ratio
A= Basin area
L= Basin length measured parallel to the main stream

Compactness coefficient: The coefficient is a ratio of perimeter of the basin to the circumference of a circle with area equal to the area of the basin.

$$C_C = 0.2821\left(\frac{P}{A^{0.5}}\right) \tag{4.6}$$

Where C_c= Compactness ratio
P= Perimeter of the basin
A=Area of the basin

Circularity ratio: The ratio is obtained by dividing the area of basin to the area of the circle having same perimeter as the perimeter of the basin.

$$C_r = 12.57\left(\frac{A}{P^2}\right) \tag{4.7}$$

Where C_r=Circularity ratio
A= Basin area
P= Basin perimeter

4.1 HYDROLOGICAL MODELS

4.1.1 HEC- HMS (Hydrologic Modeling Centre- Hydrologic Modeling System)

The model was developed by Hydrologic Engineering Centre of US Army Corps of Engineers. The model is a successor and replacement of earlier software HEC-1. The model simulates rainfall- runoff and routing processes.

The model has two main components, namely basin and channel. The hydrological processes in the basin components are simulated at the subbasin level. The component converts precipitation in to excess precipitation and transforms this excess precipitation to the flow at the outlet of a subbasin. Excess precipitation can be obtained using several methods, namely initial and constant rate, deficit and constant rate, NRCS curve number, Green and Ampt and continuous soil moisture accounting (SMA). Excess precipitation is transformed to outflow using empirical unit hydrograph or kinematic wave model. The channel component routs the flow in the river network using hydrologic routing technique.

4.1.2 HEC- GeoHMS

GeoHMS is a geospatial hydrology toolkit. It is an extension written in Avenue scripting language for ArcView 3.2 platform. It is useful in expediting the delineation of watersheds, river network, extraction of basin and channel characteristics and set up of the HMS basin model.

(i) History

(a) HEC- SAM: Grid- cell based data analysis software for hydrologic and flood damage calculation developed by HEC in 1970. The software was based on concepts developed by School of Landscape Architecture, Harvard University.
(b) Model data structure: The model data structure was formulated by HEC and Dr D. Maidment, University of Texas.
(c) PrePro: PrePro was developed at Centre for Research in Water Resources, University of Texas. It was the predecessor of GeoHMS under direction of Dr. F. Olivera.
(d) HEC- GeoHMS: It was developed by HEC and ESRI as a component of a Cooperative Research and Development Agreement between the two agencies. Support was obtained from Centre for Research in Water Resources, University of Texas in this endeavor.

(ii) Terrain preprocessing

In terrain preprocessing, river network and subbasins are automatically delineated from digital elevation model. Various steps performed in the preprocessing are described below.
(a) Depressionless DEM: Many of the depression or pits are artifacts results from DEM creation processes. Depression can also be natural. In the process, depressions are filled up to create a depressionless DEM. This DEM is suitable for hydrological processing.
(b) DEM reconditioning: Due to artifacts in DEM, the flow direction can arbitrarily change away from actual stream course. In DEM reconditioning, the actual river course can be burned in to the DEM to avoid this problem. In addition to burning in, in a buffer around the burn in vector, smoothing of the terrain can also be done. Further, sharp drop can be imposed from this smoothened burned in area. Alternately, terrain can be raised (fenced) in a process similar to this.
(c) Flow direction: The method is based on eight- flow direction approach. In this approach, flow from a cell can be directed towards one of the eight flow directions, namely E, SE, S, SW, W, NW, N, NE from the central cell.
(d) Flow accumulation: Flow accumulation depicts the count of upstream cells that drain into a cell.
(e) Stream network: Cells with flow accumulation greater than a threshold are assumed to be the cells falling on the stream network. The threshold indicates minimum flow accumulation area necessary for initiation of a channel. Default value is 1% of the largest basin area.
(f) Stream segmentation: The process assigns unique value to each stream segment. The segments can be converted into a vector map.
(g) Watershed delineation: Watershed corresponding to each stream segment is delineated. The watersheds can be converted into a vector map.
(h) Watershed aggregation: All the watersheds up to lowest junction point are aggregated.

Additional features, namely finding catchment area at a stream location, flow tracing downstream a user defined point are also available. Former feature is particularly useful in locating a gauge point in the network from the information on catchment area up the gauge point. Rivers can be extended or merged. River elevation profile can also be plotted.

Further, the basin and river network can be modified. Basins can be merged, subdivided or split at the confluence. This will lead to a desired subbasins configuration for the model.

(iii) Stream and watershed characteristics

For all stream segments, their lengths and slopes are computed. Slope is computed as elevation difference at the end point of the stream segments divided by the length of the segment. The elevations at the end points are extracted from DEM automatically.

For watersheds, their area and centroid locations are determined. The centroid are determined using one of the four methods, namely centre of the bounding box, centre of bounding ellipse, mid point of longest flow path and user defined location. A centroid shape file is created in one of the first three methods. For assigning user defined centroid, the centroid shape file obtained from one of the other three methods is edited to move the centroid to a location of once choice. The elevation of the centroid is automatically placed extracted from DEM and placed in the centroid and watershed shape file attribute tables.

Length of the longest flow path and flow path up to point on the longest flow path nearest to the centroid of the basin are useful parameters in determining synthetic unit hydrographs. In the step for determining the longest flow path, shape file is created. The lengths, elevations of the end points, slope between points at 10% and 85% from the downstream location of the segment, slope between end points are populated automatically in the longest flow path and watershed shape file attribute tables.

For obtaining centroidal flow path, the centroid location file is used. In the method the point of the longest flow path nearest to the centroid is determined. A shape file of the segments up to this point is created. The length of the segments is populated in both centroidal flow path and watershed shape file attribute tables.

Basin slope can be computed by intersecting the slope raster and watershed shape file. In the operation, average is determined at all the cells of the slope raster falling in a watershed.

Additionally, curve number raster intersected with the watershed shape file to obtain average curve number for each watershed.

Basin slope, curve number and basin length values are used to estimate the lag time using NRCS basin lag formula.

4.1.3 SWAT (Soil and Water Assessment Tool)

SWAT was developed by Jeff Arnold for USDA to predict the impact of management practices on water, sediment and chemical yield from large watershed. The model is physical based and thus suitable for studying the impact of weather, vegetation and management practices. The model may be used for both gauged or un gauged watersheds. The model is continuous time model and is not designed for detailed single event flood routing. ArcSWAT is a ArcGIS extension and provides a GUI for the SWAT model. The extension is evolved from an earlier version, namely AVSWAT which was developed for ArcView 3.1. The interface allows for automatic delineation of basins/ sub basins, river network, computation of catchment and river characteristics, delineation of hydrologic response units based on land use, soil and topography, input of weather data and running of the model etc. Reach database fields sub basin numbers (current and downstream), cumulative drainage area, reach length and slope (in percent), minimum and maximum elevations are filled through DEM processing. Sub basin properties namely area, slope, centroid location and elevation, minimum and maximum elevation, longest flow path length, reach length and slope are also computed.

4.2 GIS INTERFACE FOR MODELS

GIS interfaces are implemented in the models in variety of ways. These are described here (Table 4.1).

Tailor- made software: In this type of interface, specialized software tailor made software are used for converting the GIS data in the format acceptable to the hydrological models. After hydrological models are run, the output files are again formatted through software to a format acceptable to GIS software.

GIS interface: In this approach, GIS interface is developed. Through this interface, the data in a format acceptable to hydrological software are prepared. Like wise, the output files are

displayed. Thus, separate programs are not required to be run. Typical examples of this approach are HEC- GeoHMS, GeoRAS, AVSWAT, ArcSWAT etc. Several of these interfaces are written in industry standard scripting languages such as VBScript, JScript, Python etc. Older generation GIS software required inbuilt GIS scripts e.g. Arc Avenue was used in ArcView 3.2 software.
Embedded GIS software: In this approach, GIS functionalities are embedded in to the hydrological models.

4.3 REMOTE SENSING IN MODELING

A hydrological model is a mathematical model used to simulate river or stream flow and calculate water quality parameters. Runoff estimation is useful in water resources planning, design of hydraulic structures, bridges etc. Impact of land use/ climatic changes on hydrological cycle can be studied through simulation studies. Inundation mapping can also be done in river basin using hydrologic/ hydraulic mathematical models. Remotely sensing data are important data source in modeling. Land use and its management practices affect runoff from basins. Land use and cover maps, up to level IV, can be prepared using remotely sensed data. Soil texture and types can also be interpreted. SRTM (Shuttle Radar Topographic Mapping Mission) Digital elevation models (DEM) are available at 90 m spatial resolution and 1 m least count for the world. Rainfall data are available at 15' geographic and 3 hourly temporal resolution from TRMM (Tropical Rainfall Measuring Mission). Water and land temperature can be monitored using satellite data.

4.3.1 Land Use and Cover Classification

Information on existing land use and their changes over time is needed in water resources planning and management, amelioration of land degradation etc. Information is available from past land use maps, topographic maps etc. Due to time variant nature of this geographical data, satellite remote sensing is very useful.

Land use refers to, man's activities on land which are directly related to the land. Land cover, on the other hand, describe, the vegetation and artificial constructions covering the land surface. USGS (United States Geological Survey) has developed a land use and land cover classification system for use with remotely sensed data. The system has four hierarchical levels, namely, I to IV. Levels I and II (Table 2) are useful for national, statewide classification. Other two levels are useful for intrastate, regional, county and municipal level classification. Latter levels classes are developed by users. First two levels have standard and well defined classes. Level I and II classes can be delineated using medium resolution satellite data, e.g. IRS LISS-III, Landsat TM etc. Level III and IV classes can be delineated using fine resolution data, e.g. IRS LISS- IV, Panchromatic, aerial photographs etc.

Multi date satellite remotely sensed data in single season may be used in crop type discrimination. In particular, satellite data may be very useful in discrimination in paddy (seasonal) and sugarcane (perennial) crops. Staggered sowing and different duration in crops pose problem is accurate classification of crop types. Horticulture areas have different signature than crops.

NRCS Curve number technique

NRCS curve number technique was developed by Ogrosky and Mockus in 1957. The method is used to estimate direct runoff volume from a catchment using information on land use and cover, soil, cover treatment practices and hydrologic condition and antecedent rainfall condition and precipitation in a catchment. The technique operates at daily time step. However, event modeling can also be done by applying the technique to cumulative precipitation at different time.

Curve number is determined for the watershed for antecedent moisture condition II from known land use and cover, cover treatment practices and hydrologic condition and hydrologic soil group. For these basin characteristics, the curve number can be read from tabulated values for cultivated and other agricultural land and urban area (Table 3 to 5). For an urban area, the impervious area is assumed to be directly connected to the drains and has CN of 98. The pervious area is assumed to be open land with good hydrologic condition. The curve number can be derived as area weighted sum of CN for impervious area directly connected to drain (98) and CN for open land with good hydrologic condition. Antecedent conditions are listed in Table 6. Antecedent condition is obtained from cumulative precipitation for antecedent five days.

Good hydrologic condition indicates that the land favors greater infiltration and thus less runoff is generated from the area. Factors namely density and canopy of vegetative areas, amount of year-round cover, amount of grass or closed-seeded legumes in rotations, percent of residue cover on land surface (good > 20 percent), and degree of roughness are considered in determining the hydrologic condition. Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year. Treatment and hydrologic condition are often difficult to obtain from remotely sensed data. Thus, general condition and treatment are obtained from field knowledge. For cultivated area, multi date satellite data are needed to obtain crop types. The crop types can often be distinguished based on differences in the sowing dates, difference in crop vigor etc. In general, from single date data, the crop type mapping is difficult.

Impervious area is seen in cyan color on standard FCC. Thus, impervious area can be mapped from satellite data. Some times fallow also show similar signature. These are may be located in the periphery of the urban area. Developing urban areas are difficult to delineate in the satellite images. It is difficult to distinguish impervious area directly connect to drain from that draining in to open spaces from satellite data. This information has to be obtained from ground truth data.

Table 4.1 Hydrological Models

Model	GIS	Remark
TRIWACO (Quasi 3-D FEM GW model)	ESRI	FEM equilateral triangles were generated
WetSpa (Physically based distributed catchment model)	Embedded	Hydrological processing of DEM is done
Travel time method	ArcView	Hydrological processing of DEM is done
HSPF/ SWAT	Basin 3.0	-
TOPMODEL/ WMS 5.1	Computer programs	GRIDATB (for Topographic Index) TOPAZ (For hydrological processing of DEM)
Modflow/ MT3D	ArcView (with 3D Analyst)	Generate mesh, pre, post processing, Launch of model
HYDROTEL (Distributed/ semi-distributed catchment model)	Embedded	PHYSITEL- Hydrological processing of DEM and computation of internal drainage structure) Interpolation
HEC- HMS	CRWR- PrePro GeoHMS ArcView, Spatial Analysis	DEM processing, topologic structure generation (junction, sink, sub basin and reach), parameter generation, export to ASCII file (basin model)

Table 4.2 USGS land use and land cover classification system

Level I	Level II
1 Urban or Built-up Land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications, and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland 32 Shrub and Brush Rangeland 33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land
5 Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries
6 Wetland	61 Forested Wetland 62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats. 72 Beaches 73 Sandy Areas other than Beaches 74 Bare Exposed Rock 75 Strip Mines Quarries, and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground Tundra 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

Table 4.3 Runoff Curve Numbers for Urban Areas

Cover Type and Hydrologic Condition	Average Percent Impervious Area	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)					
• Poor condition (grass cover < 50%)		68	79	86	89
• Fair condition (grass cover 50% to 75%)		49	69	79	84
• Good condition (grass cover > 75%)		39	61	74	80
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
• Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
• Paved; open ditches (including right-of-way)		83	89	92	93
• Gravel (including right-of-way)		76	85	89	91
• Dirt (including right-of-way)		72	82	87	89
Urban districts:					
• Commercial and business	85	89	92	94	95
• Industrial	72	81	88	91	93
Residential districts by average lot size:					
• 1/8 acre or less (town houses)	65	77	85	90	92
• 1/4 acre	38	61	75	83	87
• 1/3 acre	30	57	72	81	86
• 1/2 acre	25	54	70	80	85
• 1 acre	20	51	68	79	84
• 2 acres	12	46	65	77	82
Developing urban areas:					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

Table 4.4 Runoff Curve Numbers for Cultivated Agricultural Land

Cover Type	Treatment	Hydrologic Condition	A	B	C	D
Fallow	Bare soil		77	86	91	94
	Crop residue	Poor	76	85	90	93
	cover (CR)	Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81

		Good	58	69	77	80
Close-seeded	SR	Poor	66	77	85	89
or broadcast		Good	58	72	81	85
Legumes or C		Poor	64	75	83	85
Rotation		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Table 4.5 Runoff Curve Numbers for Other Agricultural Lands

Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Meadow – continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush – brush-weed-grass mixture, with brush the major element	Poor Fair Good	48 35 30	67 56 48	77 70 65	83 77 73
Woods – grass combination (orchard or tree farm)	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods	Poor Fair Good	45 36 30	66 60 55	77 73 70	83 79 77
Farmsteads – buildings, lanes, driveways, and surrounding lots		59	74	82	86

Pasture: Poor is < 50% ground cover or heavily grazed with no mulch, Fair is 50% to 75% ground cover and not heavily grazed, and Good is >75% ground cover and lightly or only occasionally grazed.

Meadow: Poor is <50% ground cover, Fair is 50% to 75% ground cover, Good is >75% ground cover.

Woods/grass: RCNs shown were computed for areas with 50 percent grass (pasture) cover. Other combinations of conditions may be computed from RCNs for woods and pasture.

Woods: Poor is forest litter, small trees, and brush destroyed by heavy grazing or regular burning. Fair is woods grazed but not burned and with some forest litter covering the soil. Good is woods protected from grazing and with litter and brush adequately covering soil.

Table 4.6 Rainfall Groups for Antecedent Soil Moisture Conditions during Growing and Dormant Seasons

Antecedent Condition	Description	Growing Season 5-Day Antecedent Rainfall	Dormant Season 5-Day Antecedent Rainfall
Dry AMC I	An optimum condition of watershed soils, where soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes pace	Less than 1.4 in. or 35 mm	Less than 0.05 in. or 12 mm
Average AMC II	The average case for annual floods	1.4 in. to 2 in. or 35 to 53 mm	0.5 to 1 in. or 12 to 28 mm
Wet AMC III	When a heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm	Over 2 in. or 53mm	Over 1 in. or 28 mm