Assessment of Surface Water Potential and Peak Runoff Rate of a Hilly Watershed Using Remote Sensing and GIS Technique

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ABSTRACT

Land use/Land cover maps are one of the essential prerequisites for land and water resources planning and management. In this study land use/land cover maps were generated using IRS-1B LISS II satellite data. The Soil Conservation Service (SCS) model and rational method has been applied for estimation of surface water potential and peak rate of runoff respectively from the sub-watersheds of Dikrong river basin (Arunachal Pradesh), India. The vector layers viz. land-use /land cover and soil map were generated in ARC/INFO GIS (Geographic Information System) and used as input to derive weighted curve number for the study area. Annual surface water potential and peak rate of runoff for 10 years and 25 years recurrence interval were estimated for the design and planning of soil and water conservation structures.

INTRODUCTION

Runoff is an important part of precipitation which traverses over surface / subsurface after composition of various losses. Annual surface water potential refers to the total volume of water per unit area available form the watershed. Estimation of surface runoff plays an important role in planning of soil conservation measures. The physical characteristics of the basin influence these hydrological parameters to a great extent. Among these the land use/ land cover information is an important factor. Remotely sensed data may provide valuable and up-to-date spatial information on natural resources and physical terrain parameters. In India, satellite based remote sensing inputs over the past two decades have been playing a key role in the management of its natural resources. The GIS technology allows the modeler to acquire, organize, analyze and display model input and output data (Burrough, 1986). With the help of GIS (Geographic Information System) the remote sensing derived information can be well integrated with the conventional database. Satellite data has been widely used in the fields of watershed management and hydrology (Rao et al., 1996; Saxena et al. 2000). Remote sensing data can be very helpful to the hydrologists for deriving the curve numbers from the SCS (Soil Conservation Service) table. Several researchers have used remote sensing based landuse/ landcover information for computation of runoff (Pandey and Sahu, 2004; Pandey and Dabral 2004). In the study area due to undulated topography much of the naturally incoming water flows out quickly as runoff and results in poor recharge of underground water reserves. The light textured and very permeable soils are able to hold limited quantity of water in root zone. Therefore, there is an urgent need for developing integrated watershed management plan. The watershed management planning of soil and water conservation structures such as bunds and terraces, waterways, grade stabilization and gully control structures, water harvesting structures, etc. can be carried out by considering surface water potential and peak runoff to be handled by these structures. Therefore, the present study was planned to estimate the runoff potential and peak rate of runoff for the each sub-watersheds of Dikrong river basin to provide guidelines for hydrologic design of soil conservation structures using satellite data and GIS

MATERIALS AND METHOD

Study Area

The Dikrong river basin is situated in the western part of the Arunachal Pradesh. It is located between 27° 00' to 27° 25' N latitude and 93° 00'to 94° 15' E longitude (Fig. 1). The total catchment area of Dikrong river basin is 1528 sq. km, out of which 1250 sq. km falls in Arunachal Pradesh and rest in Assam. The total length of the river is 145 km, out of which its length within Arunachal Pradesh is 113 km and rest 32 km is in Assam. The annual average rainfall during monsoon season varies between 1519.4 to 4169.4 mm. The temperature of the study area varies widely between 100 C to 32 0 C.

Satellite Data

The IRS-1B LISS II geocoded imagery of 19th January 1997 was collected from State Remote Sensing and Application Centre, Itanagar. The path 15, row 48 and band 2, 3 and 4 of the satellite were used to prepare the land use / land cover map of the study area.

Hardware and Software Used for Data Analysis

The ARC INFO GIS software was used for digitizing the land use / land cover map and soil maps. The ARC-VIEW software was used for further processing of the data's and taking the output.

Land use /Cover Classification

In the present study the visual interpretation of satellite imagery has been done and the study area has been classified into different classes, namely Dense forest, Open forest, Cultivated land, Paddy cultivation, Waste land, water body, Habitant, Unclassified (Fig. 2). After classification of satellite data land use / land cover map was geo-referenced and digitised in vector form in polygon mode.

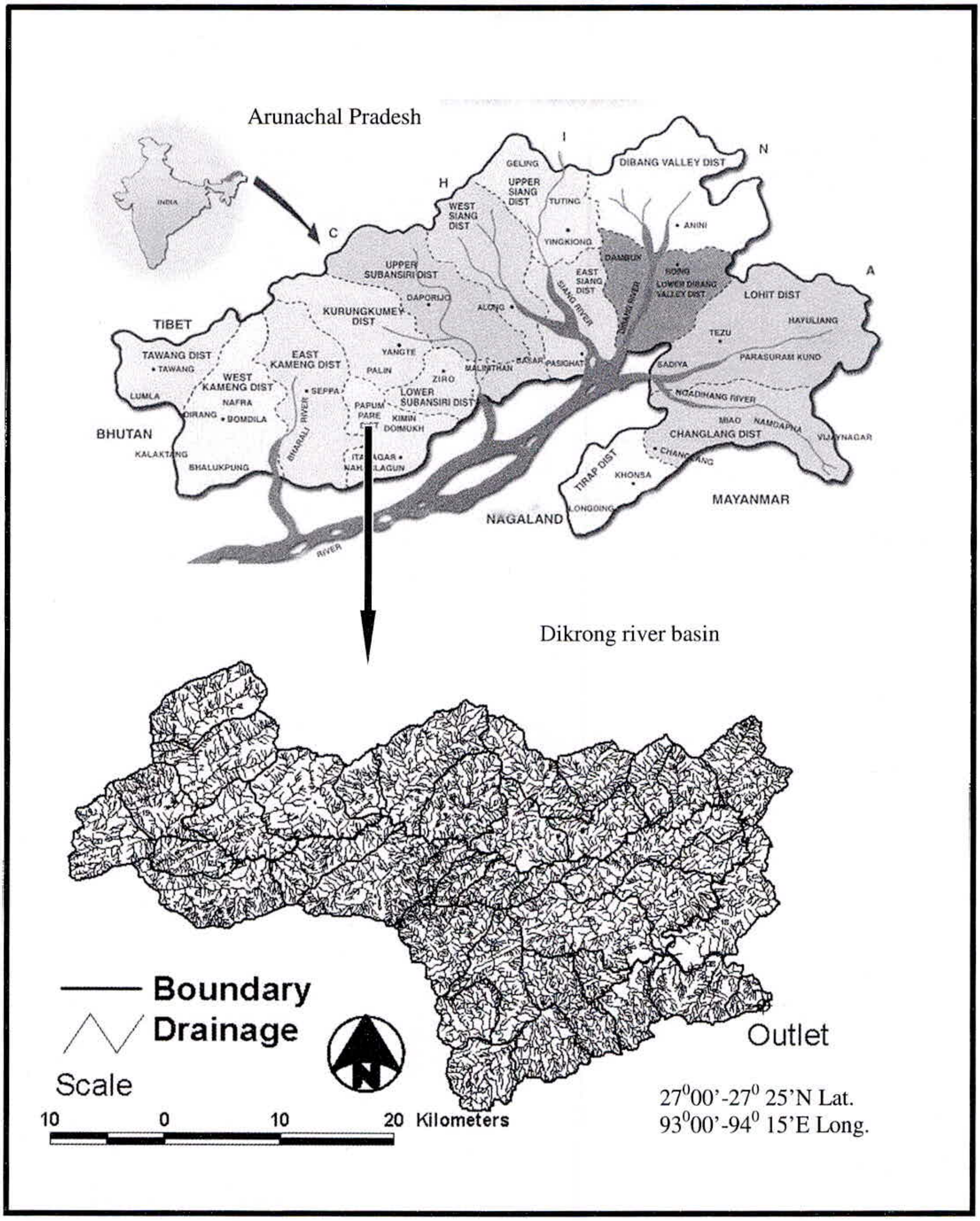

Fig. 1 : Location map of the Dikrong river basin

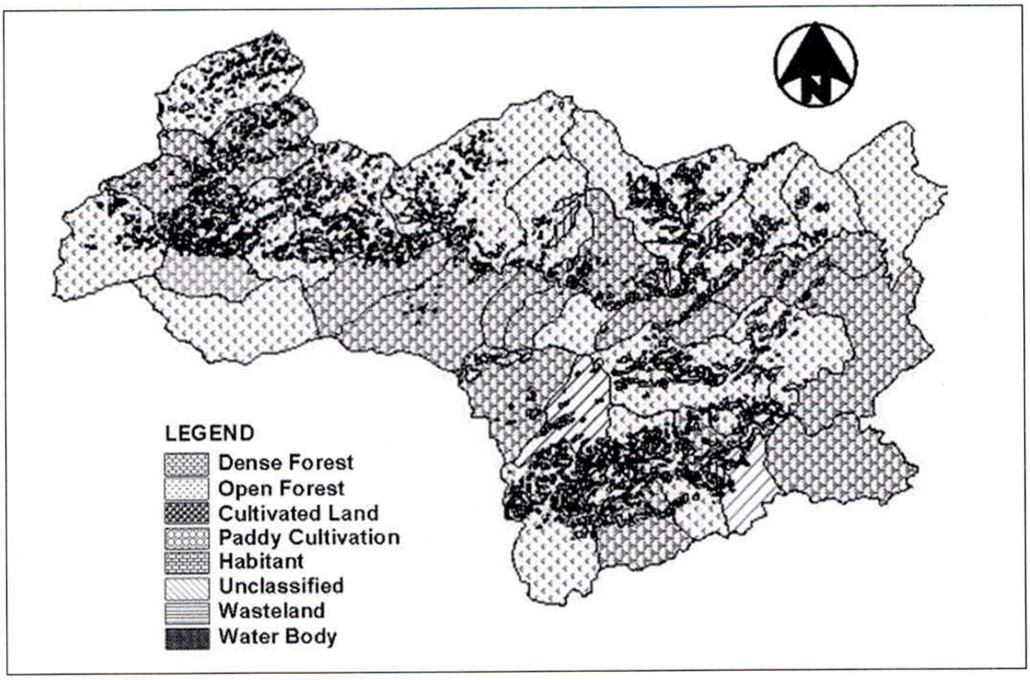

Fig. 2 : Land use / Land cover map of Dikrong river basin

Establishment of Digital Soil Coverage

The soil map collected from Remote Sensing and Application Centre, Itanagar was geo-referenced and digitized in polygon mode (Fig. 3).

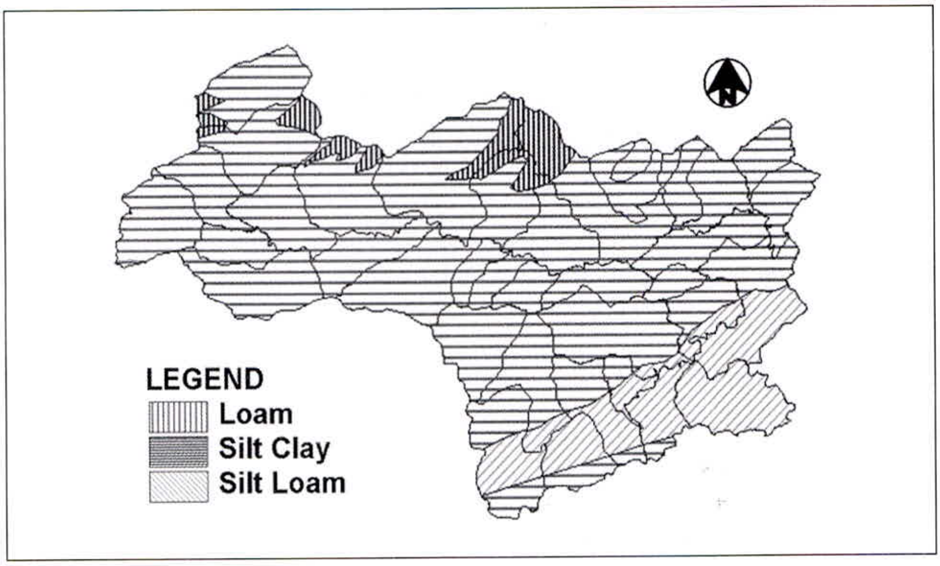

Fig. 3 : Soil map of Dikrong river basin

Determination of Curve Number and Assessment of Surface Water Potential

The Curve Number method (SCS, 1972), also known as the Hydrological Soil Cover Complex Method, is a versatile and widely used procedure for runoff estimation. In the past 30 years, the SCS method has been used by a few researchers because it gives consistently usable results (Pandey et al. 2005; Sharma and Kumar, 2002; Sharma *et al.* 2001; Chandrmohan and Durbude, 2001) for runoff estimation. The SCS method with initial abstraction consideration is given below:

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \quad (1)$$

The maximum potential retention, S is then worked out using the following relationship between it and the curve number.

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Where,

Q=Runoff depth, mm

P=Rainfall, mm

S= Maximum recharge capacity of watershed after 5 days rainfall antecedent

Ia=0.3S (initial abstraction of rainfall by soil and vegetation, mm)

CN= Curve Number

CN has been calculated from standard table for different land use and conservation practices. Since, it has different values under different situations; the weighted CN has been worked out in the following manner:

$$Weighted\ Curve\ Number = \frac{\sum(CNi \times A_i)}{A} \quad (3)$$

Where,

WCN= Weighted curve number

CNi = Curve number from 1 to any no. N

Ai =area with curve number CNi

A =the total area of the watershed

Thus, the WCN corresponding to AMC-II condition is arrived at for each of the sub watersheds. The equivalent curve number for dry condition (AMC-II) or wet condition

(AMC-III) were deduced from the normal condition (AMC-II) by the relationships:

$$CN\ (I) = \frac{4.2 \times CN(II)}{10 - 0.058 \times CN(II)} \qquad (4)$$

$$CN\ (II) = \frac{23 \times CN(II)}{10 + 0.13 \times CN(II)} \qquad (5)$$

The Antecedent moisture condition (AMC) refers to the wetness of the soil surface or the amount of soil moisture available in the soil profile before the start of monsoon. The National Engineering Hand Book (1971) uses the 5-days antecedent rainfall for the determination of AMC. This was classified into three categories depending on the antecedent 5-days rainfall in the growing season: AMC- I (< 36 mm rainfall), AMC- II (< 36-53 mm rainfall) and AMC- III (> 53 mm rainfall). The value of CN changes with the change in AMC. The CN corresponding to the AMC-I refers to the dry season or the lowest runoff potential; that to AMC-III to the wet CN or the highest runoff potential; and that to AMC-II stands for average runoff potential. Using the curve number, recharge capacity of the different sub watershed was estimated for 10 years. Surface water potential was then calculated for each sub-watershed. The daily rainfall data for the years 1995-2004 of the study area and the values of maximum potential retention, S obtained from weighted CN for the watershed area were used for the estimation of runoff from SCS model.

ESTIMATION OF PEAK RATE OF RUNOFF

The Rational method was used to estimate peak rate of runoff for all the 39 sub-watersheds for 10 years and 25 years recurrence interval. In this method, Runoff coefficient for different types of land cover of Dikrong river basin was taken from Narayana (2002). Weighted average runoff coefficient was also calculated. Time of concentration was calculated using Kirpich formula. Using a chart given by Singh (1990) intensity of the rainfall for 10 years and 25 years recurrence interval were determined. Finally, peak rate of runoff of different sub watersheds were calculated using Rational method. It is the maximum rate of runoff that could occur from a particular catchment. Peak rate of runoff (Q p) in m3 sec-1 by rational formula is

$$\mathbf{Q_p} = \frac{\mathbf{CIA}}{360} \qquad (6)$$

Where, I is the intensity of rainfall (mm/hr), A is the drainage area in hectares and C is runoff coefficient of the watershed (Singh et al., 1990).

The weighed value of C factor was derived using the formula:-

$$C=C_1 {}^*A_1+C_2{}^*A_2+\dots\dots\dots+C_n{}^*A_n\ /(A_1+A_2+\dots\dots\dots+A_n) \qquad (7)$$

Here, A_i is the area of the watershed with the corresponding land use factor Ci Intensity of rainfall is for a duration equal to time of concentration (tc).

RESULTS AND DISCUSSIONS

The curve numbers for different sub-watersheds were generated using land use/ land cover map, hydrologic soil group map and standard curve number table for Indian condition (Narayan, 1993). These curve number were used for determining the recharge capacity, which in turn are used for determining the runoff. The average weighted curve numbers for AMC I, II and III conditions were found to be 30.28, 50.32 and 69.59 respectively for the entire river basin.

The surface water potential was calculated using Curve Number method. The average runoff and total runoff for 10 years for 39 sub-watersheds is given in Table 1. Dikrong river basin is also given in Table 1. The lowest value of average runoff of 482.02 ha-m found to be in 39th sub watershed and the highest value was observed to be 4470 ha-m found in the 3rd sub watershed. The average runoff values ranges from 482.02 ha-m to 4470 ha-m. The total estimated average runoff from the Dikrong river basin was found to be 20848.59 ha-m. This high value of runoff leads to soil erosion problem and flood dame to the region.

The peak rate of runoff was calculated using rational method. The low and high value of Peak rate of runoff for 10 years recurrence interval was observed to be 109.81 m3 sec-1 (39th sub watershed) and 796.18 m3 sec-1(3rd sub-watershed) respectively. The low and high value of peak rate of runoff for 25 years recurrence interval was observed to be 149.57 m3sec-1 (39th sub watershed) and 918.67 m3sec-1 (3rd sub watershed) (Table 2). In the present study, peak runoff rate of runoff for specified intervals of 10 yrs and 25 yrs was assessed. Based on these values a suitable soil conservation structure can be selected (Table 3).

CONCLUSIONS

The weighted curve number for AMC I, II and III conditions were found to be 30.28, 50.32 and 69.59 respectively for the entire river basin. The average runoff from the Dikrong river basin was estimated to be about 20848.59 ha-m. The high value of Peak rate of runoff for 10 and 25 years recurrence interval was found to be 796.18 and 918.67 m3sec-1 respectively for the sub watershed no. 3. The present results will be of great help in water management of the Dikrong River basin. Rain water harvesting is well suited to the soils and mountainous topography of the region. It can significantly increase the availability of water for crop production. The rainwater harvesting facilities do not take much tine in construction and can deliver benefits the same year of construction. They can be adopted upon indigenous agricultural systems and are commensurate with the level of technology available in the region.

Table 1 : Annual surface water potential of different sub-watersheds.

SWS Number	Annual surface water Potential (ha-m)										
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Average Runoff
1	1116.83	1672.18	1452.83	2170.88	2214.72	1114.15	1251.52	1764.25	2048.08	1840.57	1664.60
2	1194.20	1832.58	1483.52	2327.01	2049.79	832.06	1210.99	1733.89	2522.63	2352.87	1753.95
3	4361.74	5246.51	4310.55	6700.96	5250.19	2146.97	2047.36	4368.50	4190.79	6076.48	4470.00
4	1364.80	1863.65	1552.17	2439.74	2012.71	762.85	923.63	1729.34	1572.87	2170.45	1639.22
5	504.83	688.37	639.47	768.34	832.09	646.62	648.11	662.88	1034.05	843.50	726.83
6	2495.78	3341.61	2763.18	4387.95	3572.25	1284.06	1537.12	2822.58	2641.10	3990.14	2883.58
7	1471.69	1931.32	1776.22	2356.20	2358.22	1011.85	1179.71	1814.86	1953.49	2077.02	1793.06
8	1022.96	1376.24	1291.64	1502.67	1647.66	1371.67	4134.35	4239.35	6216.06	4299.88	2710.25
9	886.58	1305.72	1137.10	1491.12	1560.22	1361.13	1338.41	1647.60	2128.21	1679.46	1453.55
10	724.47	1028.24	895.72	1282.63	1190.48	623.22	708.45	1043.84	1163.34	1227.66	988.80
11	881.83	1248.53	1074.87	1581.80	1452.69	687.49	799.73	1224.89	1323.11	1484.69	1175.96
12	827.84	1161.91	1065.56	1253.81	1371.41	1097.03	1065.95	1182.14	1635.80	1221.04	1188.25
13	716.95	963.89	905.54	1068.37	1174.64	935.84	901.19	1131.78	1437.83	1172.87	1040.89
14	1110.16	1681.81	1389.53	1860.92	6006.35	2213.92	2044.10	2370.79	3218.48	2303.21	2419.93
15	507.69	720.56	627.69	898.83	848.81	436.74	496.46	731.49	815.24	860.31	694.38
16	1149.75	1522.66	1441.07	1601.36	1873.33	1937.58	1561.93	1874.26	2473.06	1870.89	1730.59
17	1065.98	1500.08	1346.16	1787.35	3556.87	1131.29	1211.82	1644.04	1959.71	1823.46	1702.68
18	1456.66	2067.39	1805.20	2570.48	4169.19	1276.33	1443.97	2112.41	2202.72	2471.07	2157.54
19	894.29	1249.70	1132.83	1463.16	1471.36	1226.89	1058.47	1415.32	1704.46	1517.47	1313.39
20	1347.64	1783.24	1584.32	2243.64	2052.86	2982.65	959.71	1589.93	1613.14	2034.06	1819.12
21	711.93	880.26	864.24	854.48	2764.48	1299.09	1005.73	1145.09	1578.80	1097.19	1220.13
22	1404.02	1883.71	1771.33	2047.81	5544.71	2926.72	1859.88	2707.04	2955.55	2303.66	2540.44
23	1090.54	1378.32	1340.35	1376.50	4441.29	1951.01	1529.27	1768.25	2406.70	1713.78	1899.60
24	2166.91	2365.14	2434.79	2323.29	10164.11	7187.77	2581.14	2984.49	4062.08	2892.55	3916.23
25	434.88	537.70	527.91	521.95	1776.32	793.54	614.34	699.46	964.39	670.21	754.07
26	442.59	547.24	537.27	1938.29	3367.59	807.61	625.24	711.87	981.50	682.10	1064.13
27	424.83	579.29	538.14	646.59	1604.63	655.17	545.41	684.96	870.19	709.83	725.91
28	363.29	459.16	446.51	458.56	1480.50	649.94	509.45	589.06	801.75	570.91	632.91
29	1294.39	1699.34	1826.31	1743.39	5401.84	2087.27	1796.45	2072.59	2784.16	1914.03	2261.98
30	1900.53	2493.01	1741.76	3271.95	2564.70	1046.99	1081.01	2049.78	1870.57	2876.83	2089.71
31	695.94	935.64	1360.47	1037.07	1122.57	929.74	874.79	1098.61	1395.70	1196.75	1064.73
32	869.85	1169.46	1700.44	1296.22	1402.06	1162.08	1093.39	1373.15	1744.48	1495.81	1330.69
33	991.82	1387.11	1173.10	1793.08	2168.39	674.93	783.71	1284.77	1314.43	1631.71	1320.31
34	1033.71	1454.02	1305.74	1730.50	3521.59	1132.36	1178.42	1596.13	1905.17	1758.78	1661.64
35	1755.60	2413.72	2226.32	2733.82	6586.33	2226.32	2206.83	2812.50	3529.81	2950.31	2944.16
36	966.33	1175.74	964.94	796.45	934.11	464.19	459.78	913.64	803.06	1342.56	882.08
37	4003.82	4376.05	3686.72	663.51	3320.46	2457.91	1926.09	3452.31	3259.43	4966.47	3211.28
38	1040.85	1399.35	1314.63	1551.03	1731.52	1390.51	1308.33	1643.08	2087.40	1735.88	1520.26
39	282.16	356.61	346.79	356.14	1149.90	438.12	395.67	457.50	622.69	414.63	482.02
Total Runoff from Watershed	46976.65	61677.06	55782.91	68897.86	107712.95	55361.61	48897.88	67148.44	79792.03	76241.09	20848.59

Table 2 : Peak rate of Runoff

Sub watershed no.	Runoff Coefficient (C)	Tc (min)	Peak rate of runoff (m^3 sec^{-1})	
			10 yr frequency interval	25 yr frequency interval
1	0.4	34.44	549.97	730.13
2	0.4	37.87	612.02	830.60
3	0.4	51.27	796.18	918.67
4	0.4	56.17	492.22	614.29
5	0.4	29.06	239.53	259.16
6	0.4	39.74	738.21	958.38
7	0.4	33.39	744.53	749.27
8	0.4	42.50	409.73	565.82
9	0.4	48.61	367.86	542.11
10	0.4	24.19	369.45	506.28
11	0.4	29.50	394.01	560.58
12	0.4	29.06	251.14	338.32
13	0.4	28.21	335.79	450.45
14	0.4	41.95	529.53	727.49
15	0.4	36.99	212.87	289.58
16	0.4	39.23	456.36	625.38
17	0.4	31.39	497.96	666.76
18	0.4	41.95	592.30	813.73
19	0.4	31.80	418.64	567.64
20	0.4	30.43	484.93	654.66
21	0.4	24.95	250.37	340.59
22	0.4	30.16	629.20	853.16
23	0.4	48.73	347.59	512.24
24	0.4	32.56	666.96	913.98
25	0.4	28.74	168.09	225.96
26	0.4	23.45	190.70	260.81
27	0.4	24.95	221.40	304.01
28	0.4	32.56	141.39	192.58
29	0.4	30.16	560.50	755.05
30	0.4	48.31	419.69	618.49
31	0.4	24.19	357.75	490.25
32	0.4	28.21	407.40	546.52
33	0.4	28.21	403.99	541.93
34	0.4	24.19	503.48	716.33
35	0.4	32.77	813.41	1089.15
36	0.4	28.21	179.44	240.72
37	0.4	28.21	467.81	627.55
38	0.4	30.43	475.60	642.06
39	0.4	32.56	109.81	149.57

Table 3 : Recommended Maximum runoff frequencies for various types of structures

Types of Structure	Frequencies, Year
Storage and diversion dams having permanent spillways	50-100
Earth fill dams-storage having natural spillways	25-50
Stock water dams	25
Small permanent masonary gully control structures	10-15
Terrace outlets and vegetative waterways	10
Field diversion	15

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