DESIGN CRITERIA FOR SEDIMENT BASINS

by

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INTRODUCTION

The need for controlling construction induced sediment to keep it from entering the nation's waterways is generally accepted. Efficient means and methods for sediment control, however, are not simple, and in some cases have not been developed to a high degree. A look at the overall picture of sediment control shows two distinct approaches: (1) Control of erosion, and (2) interception of errant soil once erosion has taken place.

Obviously erosion control (mainly by vegetation) is the preferred approach. However, during periods of active construction and before vegetation is established, erosion is inevitable. The problem is then to intercept the waterborne sediment produced and confine it to the construction area.

According to William M. Smith, County of Fairfax Public Works, flows below 15 CFS* based on a 10-year rain can be controlled by berms, and straw and brush dams, which are less expensive than silt ponds or basins. On the other hand flows in excess of 400 CFS (again based on the 10-year storm) are too large for the practical design of silt basins, so efforts should be concentrated on protecting the stream from construction by placing traps, berms, and barriers along the stream banks. So, in essence, use of the siltation pond or basin is limited to situations where high flows will range from perhaps somewhat less than 15 CFS to a maximum of 400 CFS, based on the 10-year storm event.

Finally, this short report will consider only the volume aspects, or trap efficiency, of the ponds and not the design of the dam, riser pipe, spillway, etc.

FACTORS FOR CONSIDERATION

A brief look at the settling rates of mineral particles in a water suspension shows that true clay sized particles (less than .002 millimeters) settle approximately 1 inch in 4 hours; whereas, .03-millimeter material will settle 1 inch in 1 minute. Consequently, it is obvious that we cannot design for the removal of clay or near-colloidal size particles.

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* CFS = cubic feet/second.

The residence time of the storm water in the pond would have to be in the order of days. This would require an unreasonably large impoundment and is clearly not practical. The best we can reasonably hope to trap would be the particles around .03 millimeters and greater. If we could approach this level it would certainly be an outstanding accomplishment.

Soil Loss Formulas

The Soil Conservation Service uses soil loss formulas extensively in their design procedure. A manual titled "Soil Loss Prediction Guide for Construction Sites in Virginia" has been prepared by the SCS (November 1970) and contains some good information on erosion rates for the various soils throughout the state. The SCS will often compute the volume of soil they expect will be eroded from a construction site and then design a sediment basin of that same volume. This appears to be a risky method since the volume of water runoff and trap efficiency are not considered. This practice could lead to both too high and too low basin volumes in specific cases.

In summary, while soil loss formulas may be of value in many cases, their use as a fundamental basis for the design of silt basin size seems to be unsound.

Runoff and Peak Flow Determinations

A study by Vice, Guy, and Ferguson (1969) on the Scotts Run watershed in northern Virginia indicated that during highway construction, 99% of the silt load of Scotts Run occurred during storm or high water events which prevailed some 3% of the time. This finding indicates that sediment traps must be designed with periods of high flow in mind, since these are the periods when suspended sediment is significant.

Two of the most common methods for computing peak runoff are: (1) The rational method, and (2) Cook's method. The rational method involves the equation

$$Q = CiA$$

where: Q = Peak flow in CFS
C = Coefficient of runoff
i = Rainfall intensity in inches/hr.
A = Area in acres

Values for C are determined from Table 1 of the Appendix. Values for i are determined using Figures 2 and 3 of the Appendix.

While the rational method is very commonly used it does have limitations. Cook's method attempts to overcome these inadequacies by graphing or tabulating more data input. Figure 4, taken from the Handbook for Albemarle County (for soil erosion), shows the factors used in Cook's method. Sample problems using the rational method and Cook's method are worked out in this appendix.

Capacity/Inflow and Trap Efficiency

A classical paper by Brune (1953) titled "Trap Efficiency of Reservoirs" includes some very interesting and significant data on the ratio of reservoir capacity over annual inflow of water. Figure 1 of the Appendix, taken from Brune's paper, shows the percent of sediment trapped vs. the ratio of reservoir capacity/annual inflow. This method of presenting trap efficiency appears to be logical and Brune indicates that the curve should apply for any size reservoir.

A possible weakness in this approach may be the lack of sensitivity to peak flow intensity. In other words, this curve would yield the same capacity/inflow ratio whether the area precipitation would be expected as gentle rains or as intense storm events.

RECOMMENDED PRACTICE FOR THE VIRGINIA DEPARTMENT OF HIGHWAYS

Based on a combination of the background input factors of published literature, agency experiences, and our own observations, I would offer the following design scheme for use in Virginia.

First, use the reservoir capacity/inflow curve developed by Brune and shown in the Appendix as Figure 1. Use of this curve requires two things: (1) A decision on desired trap efficiency (percent of sediment trapped*) and, (2) a computation of the annual inflow of water (see Figure 5 of the Appendix for annual precipitation in Virginia). With this information the required capacity of the basin can be easily determined (see example in Appendix).

After the capacity has been determined in this manner, it is necessary to compute peak runoff or flow into the basin so that the detention time of the water can be determined. This can be done either by the rational method or Cook's method (see Appendix for an example).

Discussions with W. M. Smith of the Fairfax County Division of Public Works have indicated that Fairfax designs on the basis of a 10- to 15-minute detention time during a 10-year storm. I would recommend that the Department design on the basis of a 5-year storm and a minimum detention period of 15 minutes. With this design, much of the .03-mm material could be removed.

With this in mind, the peak flow computed in CFS from the rational or Cook's method and based on a 5-year storm can then be used to determine how long it would take to fill the basin with incoming water, or how long it would take to displace all of the water in the basin if it were full. This will be the detention time of the sediment laden water in the basin.

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* Eighty percent might be a logical value here.

If this detention time is 15 minutes or longer then use the capacity determined from Brune's curve. If it is less than 15 minutes, the basin should be enlarged to a capacity that would detain the incoming waters for a period of 15 minutes.

Finally, it should be pointed out that the performance of the sediment traps is only as good as the maintenance performed on them. It is urged that basins never be allowed to become over half filled with sediment. Otherwise, the trap efficiency will be lowered to an unacceptable level and the design and construction efforts essentially nullified.

REFERENCES

Brune, G. M. (1953). "Trap Efficiency of Reservoirs", Transactions of the American Geophysical Union, Vol. 34, No. 3, pp. 407-418.

Thomas Jefferson Soil and Water Conservation District (1971). "Handbook for Albemarle County", prepared for a committee appointed by the Albemarle County Board of Supervisors to look into an Erosion and Siltation Ordinance for Albemarle County, Virginia, 46 pp. and Appendices.

U. S. Department of Agriculture, Soil Conservation Service (1970). "Soil Loss Prediction Guide for Construction Sites in Virginia", Tables and Sample Problems.

Vice, R. B., Guy, H. P., and Ferguson, G. E. (1969). "Sediment Movement in an Area of Suburban Highway Construction, Scotts Run Basin, Fairfax County, Virginia, 1961-64", U. S. Geological Survey Water-Supply, Paper 1591-E, 41 pp.

APPENDIX

As an example of the use of the method proposed here — assume a 10-acre watershed, one-half to be denuded by construction and one-half to remain in forest. The area is moderately steep (slopes 10%) with normally permeable soils, a 36-inch annual rainfall, and a 5-year storm event. The height (relief) is 50 ft. and the length (distance) is 2,000 ft.

First we must compute the annual flow from the area. This is done by finding the annual rainfall for the area in inches and multiplying it by the average runoff coefficient "C" (from Table 1) and by the square feet of total area.

$$\underset{\text{(rainfall)}}{(3\text{ ft.})}\quad \underset{\text{(coefficient of runoff)}}{(\text{sum of } .5 \times .10 \text{ and } .5 \times .50)}\quad \underset{\text{(area ft.}^2)}{(10 \times 44{,}100)} = \text{total annual flow in ft.}^3$$

$$(3)\ (.30)\ (441{,}000) = 396{,}800 \text{ ft.}^3$$

Using this value for "I" (Brune's annual inflow) and looking at the curve in Figure 1 we get the value .06 for the fraction C/I that would remove 80% of the sediment, thus

$$.06 = C/198{,}450$$

$$C \text{ (capacity)} = 11{,}907 \text{ ft.}^3$$

Assuming this capacity of 11,907 ft.^{3}, we now compute a 15-minute detention time for a 5-year storm. This is done by computing the peak flow in CFS by the rational method and by Cook's method. First, the rational method with i determined using Figures 2 and 3 yields the following:

$Q = CiA$ (In order to determine i, Tc (time of concentration) must be found using Figure 2. The Hydraulics people also add on 5 minutes to Tc as overland accumulation time—giving 16 minutes in this case.)

$$Q = \underset{\text{(coefficient of runoff)}}{(\text{sum of } .5 \times .10 \text{ and } .5 \times .50)}\ \underset{\text{(Intensity)}}{(5.0)}\ \underset{\text{(Area-acres)}}{(10)}$$

$$Q = (.30)\ (5.0)\ (10)$$

$$Q = 15 \text{ CFS}$$

Then we can find the volume of water flowing at 15 CFS for 15 minutes

$$\underset{\text{(Minutes)}}{(15)}\ \underset{\text{(Seconds)}}{(60)}\ \underset{\text{(CFS)}}{(15)} = 13{,}500 \text{ ft.}^3$$

In this case the 13,500 ft.^{3} computed by the peak runoff method is slightly higher than the 11,907 ft.^{3} computed by Brune's C/I curve. So the basin capacity should be designed to 13,500 ft.^{3}

If Cook's method is preferred over the rational method for peak flow computation, then the procedure explained in Figure 4 is used. Based on the above information the value for peak flow by Cook's method would work out to be 15.57 CFS, a figure very close to the 15 CFS determined by the rational method.

The following values were used to determine the 15.57 CFS by Cook's method. Using the data given in Figure 4 we get:

Relief	15	
Soil infiltration	10	
Vegetal cover	15	
Surface storage	10	
Total	50 = W	(watershed characteristics)

Using watershed characteristics (W) = 50 and 10 acres we find a value of 29 CFS for a 50-year storm event in Figure 4. This value then is recomputed using the values in Table 2 for a 5-year period event (29 CFS x .61 = 17.69 CFS) and again by a shape factor (Figure 4) based on a length/width ratio of 2/1 (17.69 CFS x .88 = 15.57 CFS).

However, since these two methods (the rational method and Cook's method) should and often do give similar results and since the Department has extensive experience using the rational method, perhaps this method may be the preferred one at this time.

TABLE 1. "C" VALUES FOR USE IN RATIONAL METHOD OF

ESTIMATING RUNOFF

Type of Surface	C Factor
For all watertight roof surfaces	.75 to .95
For asphalt run way pavements	.80 to .95
For concrete run way pavements	.70 to .90
For gravel or macadam pavements	.35 to .70
* For impervious soils (heavy)	.40 to .65
* For impervious soils, with turf	.30 to .55
* For slightly pervious soils	.15 to .40
* For slightly pervious soils, with turf	.10 to .30
* For moderately pervious soils	.05 to .20
* For moderately pervious soils, with turf	.00 to .10

* For slopes from 1% to 2%.

TABLE 2. FREQUENCY FACTOR TABLE BASED ON VALUE OF 1.00 FOR THE 50-YEAR OCCURRENCE

Frequency of Occurrence	Frequency Factor
Once in 100 years	1.14
Once in 25 years	0.83
Once in 10 years	0.71
Once in 5 years	0.61

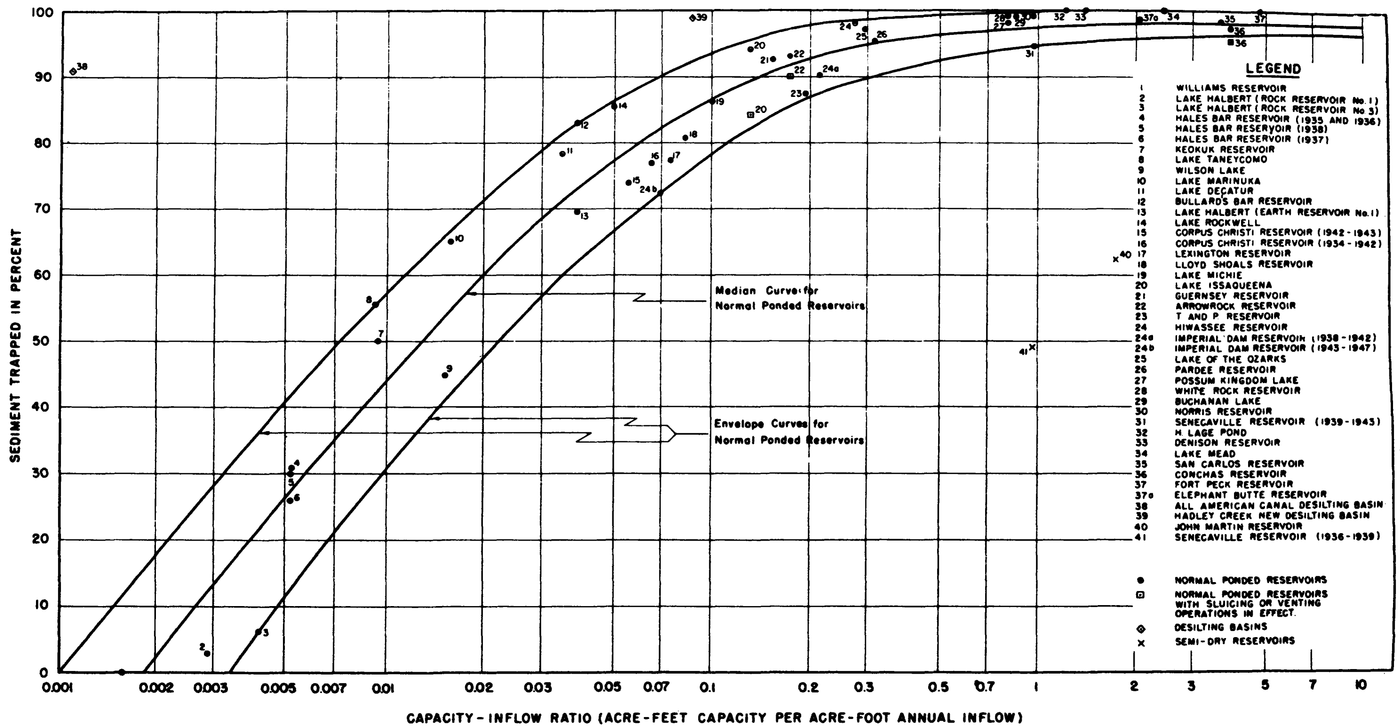


Figure 1. Trap efficiency as related to capacity-inflow ratio, type of reservoir, and method of operation. (After Brune 1953.)

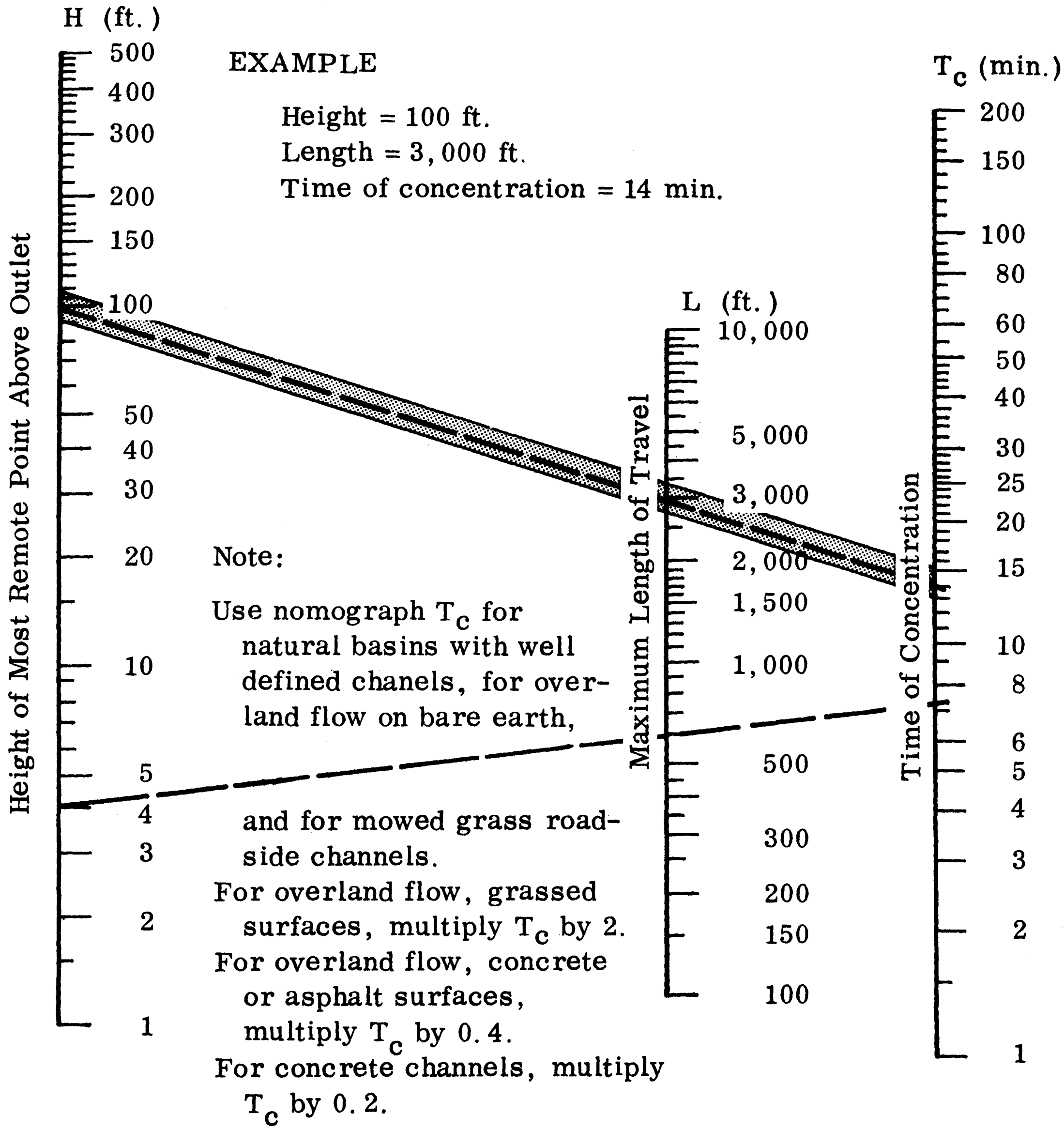


Figure 2. Time of concentration (T_c) of rainfall on small drainage areas. (Taken from Albemarle County Handbook.)

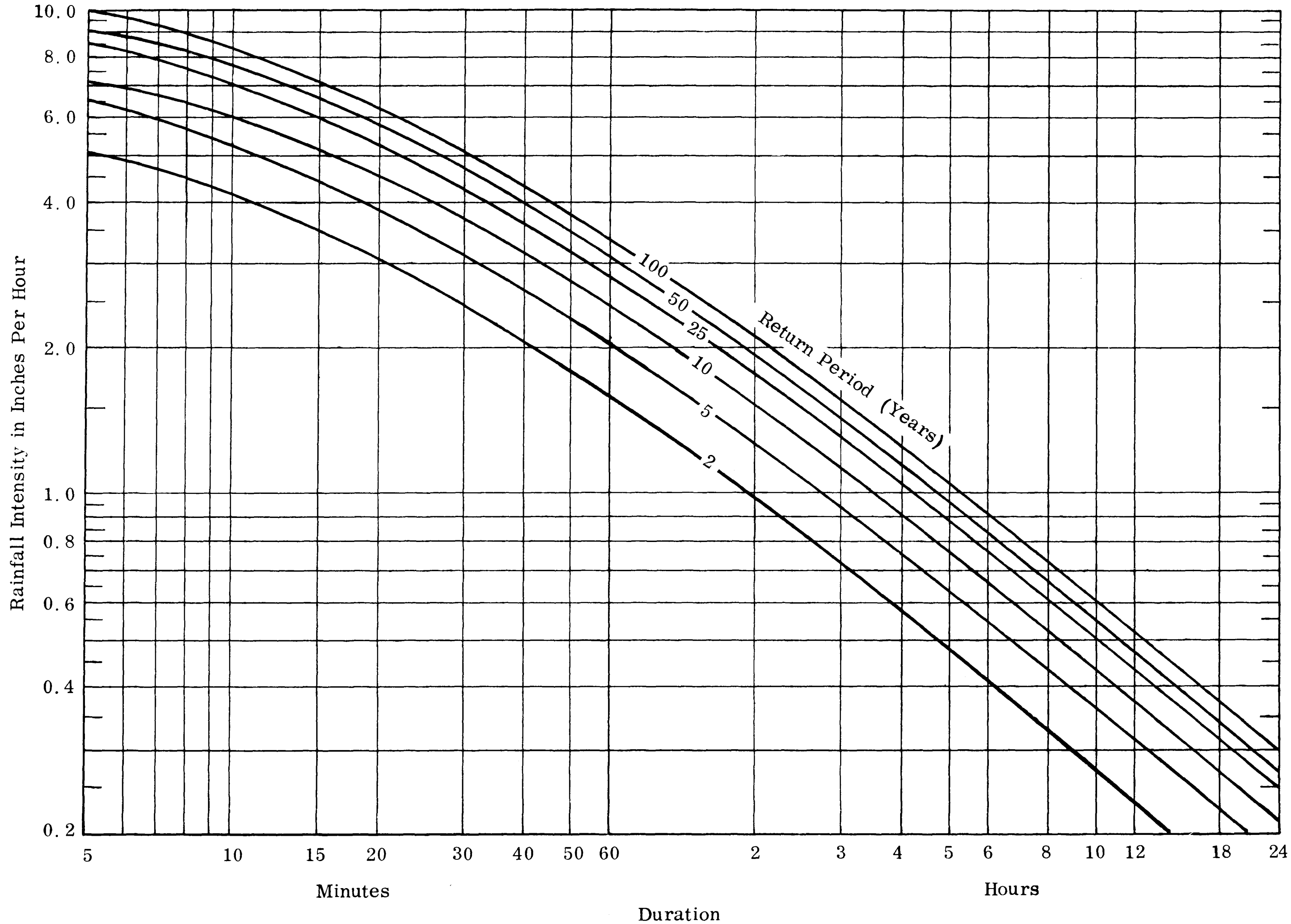


Figure 3. Rainfall intensity for various "durations" or times of concentration and return periods or frequencies. (Taken from Albemarle County Handbook.)

CHART FOR DETERMINING PEAK RATES OF RUNOFF BASED ON 50-YEARS FREQUENCY AND RAINFALL FACTOR OF 1.0

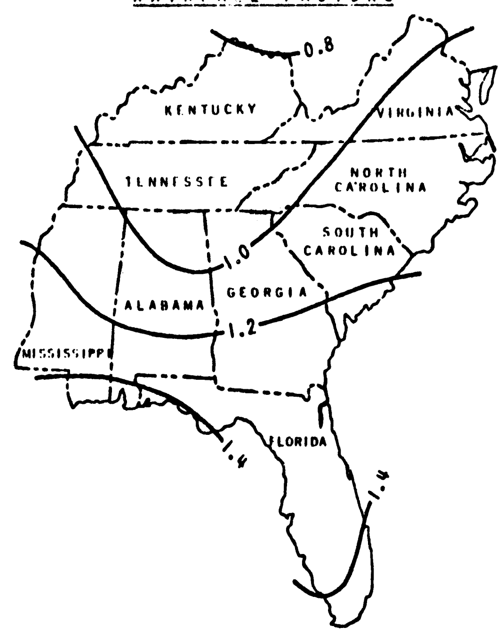
DRAINAGE AREA IN ACRES	WATERSHED CHARACTERISTICS—(ΣW)											
	25	30	35	40	45	50	55	60	65	70	75	85
	CUBIC FEET PER SECOND—(P_{50})											
4	5	7	10	11	13	14	15	18	21	24	28	34
6	6	8	11	14	15	18	23	25	30	34	40	48
8	7	10	13	17	18	24	28	34	40	45	52	62
10	8	11	15	19	24	29	35	43	50	58	66	75
12	9	12	17	22	28	34	41	50	59	68	78	88
14	10	14	19	25	32	39	47	57	68	78	90	101
16	11	15	21	28	36	44	53	64	76	87	100	114
18	12	17	24	31	40	49	59	71	84	96	110	126
20	13	19	26	33	43	53	64	77	92	105	120	138
25	16	22	31	40	52	64	78	93	110	128	146	168
30	18	25	36	47	60	75	91	109	128	149	172	198
35	20	28	41	53	68	86	104	124	146	170	196	228
40	22	31	45	59	76	97	117	139	164	190	221	257
45	24	34	49	65	84	107	130	154	182	210	245	286
50	26	37	53	71	92	117	142	168	200	230	267	315
60	29	43	62	82	108	136	165	197	234	270	314	366
70	32	49	70	93	123	155	188	226	268	310	360	425
80	36	54	78	104	137	173	211	255	301	350	406	478
90	40	59	85	114	151	193	233	281	334	389	448	530
100	43	64	92	124	165	210	255	307	365	426	490	590
120	49	74	107	144	192	246	300	359	427	500	574	690
140	55	84	121	164	218	281	345	410	487	570	658	790
160	61	94	134	183	243	315	390	460	547	640	740	890
180	67	103	147	202	268	349	430	510	607	710	820	990
200	73	111	160	220	292	383	470	560	667	780	900	1080
220	78	119	173	237	316	416	510	610	724	845	980	1170
240	83	127	186	254	340	449	550	660	781	910	1060	1260
260	88	135	199	271	363	481	590	704	838	970	1134	1350
280	93	143	211	288	386	513	630	748	894	1030	1207	1440
300	98	151	223	305	409	545	670	792	950	1090	1280	1530
320	103	159	235	322	432	576	705	836	1000	1150	1350	1620
340	108	167	247	339	455	604	740	880	1050	1210	1420	1710
360	113	174	259	356	478	633	775	924	1100	1270	1490	1800
380	118	182	270	373	501	662	810	967	1150	1330	1560	1890
400	123	190	281	390	523	691	845	1010	1200	1390	1630	1980
420	128	197	292	405	544	720	880	1048	1248	1448	1694	2064
440	133	204	303	420	565	748	915	1086	1296	1506	1758	2148
460	137	211	314	435	586	776	950	1124	1344	1564	1822	2232
480	141	218	325	450	607	803	985	1162	1392	1622	1886	2316
500	145	225	335	465	628	830	1020	1200	1440	1680	1950	2400

HOW TO USE THIS CHART

Determine the numerical value of runoff-producing characteristics (ΣW). From the table, under this numerical value and opposite the drainage area, read the probable runoff for a rainfall factor of 1.0. Multiply this runoff figure by the rainfall factor for the area concerned, as obtained from the map. This will give the expected runoff from a storm of 50-years frequency. For a storm of 25-years frequency, multiply the expected runoff by 0.83. For a 10-year storm, multiply by 0.71. If the length of the watershed is materially greater than its width, multiply by the applicable shape factor to correct the expected runoff figure.

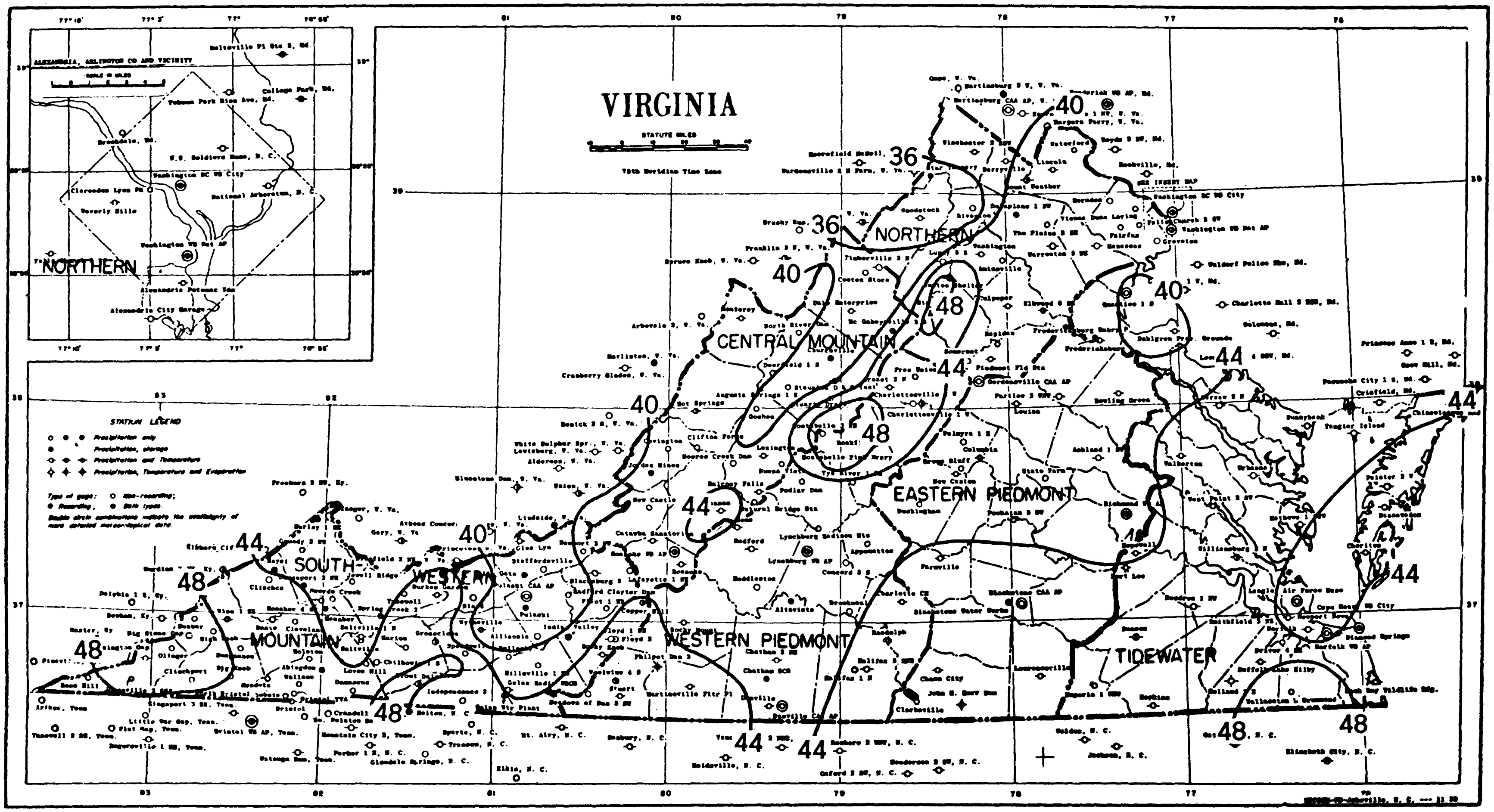
DESIGNATION OF WATERSHED CHARACTERISTICS	RUNOFF-PRODUCING CHARACTERISTICS			
	EXTREME	HIGH	NORMAL	LOW
RELIEF	(40) to (30) Steep, rugged terrain, with average slopes generally above 30%	(30) to (20) Hilly, with average slopes of 10% to 30%	(20) to (10) Rolling, with average slopes of 5% to 10%	(10) to (0) Relatively flat land, with average slopes of 0 to 5%
SOIL INFILTRATION	(20) No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity. Less than 0.1 in./hour	(15) Slow to take up water; Clay or other soil of low infiltration capacity. 0.1 to 0.3 in./hour	(10) Normal; deep permeable soils, such as Madison. 0.3 to 0.8 in./hour.	(5) High; sands, loamy sands, and other loose, open soils. Over 0.8 in./hour
VEGETAL COVER	(20) No effective plant cover; bare or very sparse cover	(15) Poor to fair; clean-cultivated crops or poor natural cover; less than 10% of drainage area under good cover	(10) Fair to good; about 50% of drainage area in good grassland, woodland, or equivalent cover; not more than 50% of area in clean-cultivated crops	(5) Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
SURFACE STORAGE	(20) Negligible; surface depressions few and shallow; drainageways steep and small; no ponds or marshes	(15) Low, well-defined system of small drainageways; no ponds or marshes	(10) Normal; considerable surface-depression storage; drainage system similar to that of typical prairie lands; lakes, ponds, and marshes less than 2% of drainage area	(5) High; surface-depression storage high; drainage system not sharply defined; large flood-plain storage or a large number of lakes, ponds, and marshes

RAINFALL FACTORS



SHAPE FACTORS				
RATIO OF LENGTH TO WIDTH	WATERSHED AREA IN ACRES			
	50	100	200	500
1	1.00	1.00	1.00	1.00
1-1/2	.92	.92	.91	.90
2	.88	.87	.86	.84
2-1/2	.85	.84	.82	.80
3	.81	.80	.78	.76
4	.76	.75	.73	.71
5	.74	.72	.70	.68
6	.72	.70	.68	.66
7	.70	.68	.66	.64
8	.68	.66	.64	.61

Figure 4. Determination of peak runoff rates. (Taken from Virginia Engineering Handbook for Work Unit Staff 1962, U.S.D.A., SCS, Richmond, Virginia.)



Based on period 1931-55

Isolines are drawn through points of approximately equal value. Caution should be used in interpolating on these maps, particularly in mountainous areas.

Figure 5. Mean annual precipitation in Virginia, in inches.