APPENDIX "B"
RATIONAL METHOD "C" VALUES

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APPENDIX "B"
RATIONAL METHOD "C" VALUES

1. **General Discussion** Section VI-E discusses the principle of rainfall losses, and Section VI-F-1 provides information pertaining to the Rational Method. Thus far, little has been said about the Rational Method "C" value or runoff coefficient, which is the only means of accounting for rainfall loss in the Rational Method.

2. **Development of "C" Values** Several of the assumptions that the Rational Method is based upon pertain to "C" values. Initially, these values were only dependent upon land use or surface type. However, through the years hydrologists have attempted to correct or mitigate these poor assumptions by introducing means of varying "C" values based upon other parameters besides surface type.

   a. **Storm Frequency** Originally, the same "C" value was recommended regardless of storm frequency (or intensity). Recently, it has become common practice to modify "C" values to account for the effects of intensity. Many now apply factors to published "C" values, such as "1.0" for 2-10 year storms; and "1.1", "1.2", and "1.25" for 25-, 50-, and 100-year storms, respectively, with a ceiling "C" value of 0.95 or 0.98. However, this procedure assumes that there is a similar increase for various surface types as intensity increases, which is not the case. UD&FCD provides a list that is based in part on field measurements, which throws greater increase due to storm intensity for more pervious surfaces, and less for other areas. Variation in runoff coefficients with rainfall intensity has been graphed for use in Kern County, California, as is reproduced in Figure "B-1" as taken from Ponce. It can be seen that rainfall intensity may have a dramatic effect on "C" values, particularly for more pervious areas.

   b. **Soil Type** Originally, "C" values were published as being independent of soil type. Now, many lists allow for the impact of soil type, which is significant for more pervious areas.

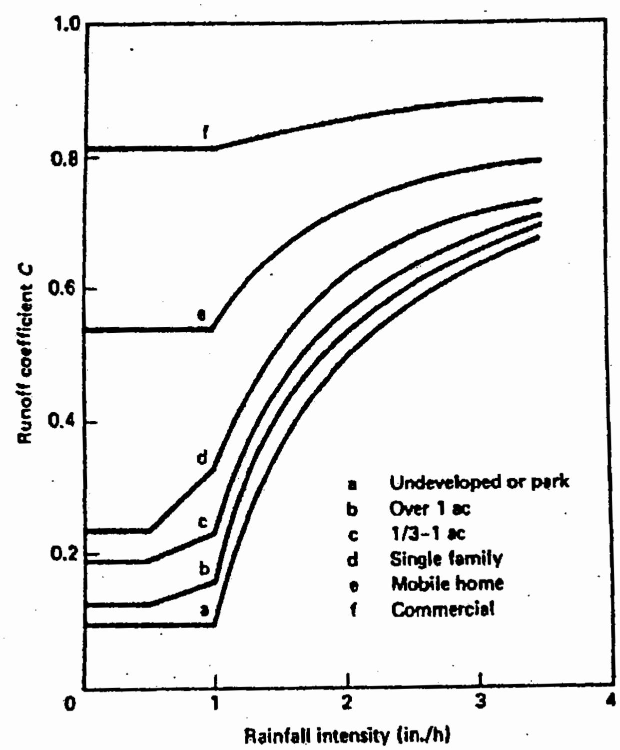
   c. **Surface Slope** Originally, "C" values did not account for surface slope either. However, it is known that, as slope increases, velocity generally increases which reduces infiltration into the soil. Published lists of "C" values which vary with slope are now fairly common.

   d. **Storm Duration** Rainfall losses usually start out high and decrease rapidly and then reach a rate that is more or less uniform. Rational Method runoff coefficients produce a constant rainfall loss from beginning to end of rainfall. Therefore, a "C" value must be selected which represents a good average loss rate. However, an average rate of loss would be less as the storm duration (which is set to Tc) increases. Therefore, all other factors being equal, "C" values should be more for watersheds having a long Tc, and lower for shorter Tc values. The author is unaware of any work that has been done to account for this phenomenon. It may well be likely that, in this day of computerization, that engineers and hydrologists will forsake the use of the Rational Method for more complex but refined modeling methods before any work is done to substantiate "C" value adjustment due to storm duration. However, to allow for other site specific differences, lists are often published with a range of values for each condition, allowing for engineering judgement. This may likely be the best procedure for addressing differences due to storm duration as well.

3. <u>Standardization of Runoff Coefficients</u> Nearly every book, manual, or paper that discusses the Rational Method provides a list of "C" values. Such a wide range of values may be found that one could almost justify anything. In order to provide a reasonable level of consistency, standardization is felt necessary. Consequently, Table "B-1" is provided as the standard which must be followed. Although there may be room for improvement in the list, it is based upon the best listings available to the author.

4. <u>Composite Runoff Coefficients</u> The need for and means of obtaining composite runoff coefficients is discussed in VI-E-4. A worksheet is provided on Table "B-2".

REPRODUCED FROM "ENGINEERING HYDROLOGY"



VARIATION OF RUNOFF WITH RAINFALL INTENSITY | FIGURE "B-1"

LAND USE OR SURFACE CHARACTERISTICS	SCS HYDROLOGIC SOIL GROUP (SEE APPENDIX "C" FOR DESCRIPTIONS)											
	A			B			C			D		
	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
UNDEVELOPED AREAS												
Bare ground	.10 - .20 .14 - .24	.16 - .26 .22 - .32	.25 - .35 .30 - .40	.14 - .22 .20 - .28	.22 - .30 .28 - .36	.30 - .38 .37 - .45	.20 - .28 .26 - .34	.28 - .36 .35 - .43	.36 - .44 .40 - .48	.24 - .32 .30 - .38	.30 - .38 .40 - .48	.40 - .48 .50 - .58
Cultivated/Agricultural	.08 - .18 .14 - .24	.13 - .23 .18 - .28	.16 - .26 .22 - .32	.11 - .19 .16 - .24	.15 - .23 .21 - .29	.21 - .29 .28 - .36	.14 - .22 .20 - .28	.19 - .27 .25 - .33	.26 - .34 .34 - .42	.18 - .26 .24 - .32	.23 - .31 .29 - .37	.31 - .39 .41 - .49
Pasture	.12 - .22 .15 - .25	.20 - .30 .25 - .35	.30 - .40 .37 - .47	.18 - .26 .23 - .31	.28 - .36 .34 - .42	.37 - .45 .45 - .53	.24 - .32 .30 - .38	.34 - .42 .42 - .50	.44 - .52 .52 - .60	.30 - .38 .37 - .45	.40 - .48 .50 - .58	.50 - .58 .62 - .70
Meadow	.10 - .20 .14 - .24	.16 - .26 .22 - .32	.25 - .35 .30 - .40	.14 - .22 .20 - .28	.22 - .30 .28 - .36	.30 - .38 .37 - .45	.20 - .28 .26 - .34	.28 - .36 .35 - .43	.36 - .44 .44 - .52	.24 - .32 .30 - .38	.30 - .38 .40 - .48	.40 - .48 .50 - .58
Forest	.05 - .15 .08 - .18	.08 - .18 .11 - .21	.11 - .21 .14 - .24	.08 - .16 .10 - .18	.11 - .19 .14 - .22	.14 - .22 .18 - .26	.10 - .18 .12 - .20	.13 - .21 .16 - .24	.16 - .24 .20 - .28	.12 - .20 .15 - .23	.16 - .24 .20 - .28	.20 - .28 .25 - .33
RESIDENTIAL AREAS												
1/8 acre per unit	.40 - .50 .48 - .58	.43 - .53 .52 - .62	.46 - .56 .55 - .65	.42 - .50 .50 - .58	.45 - .53 .54 - .62	.50 - .58 .59 - .67	.45 - .53 .53 - .61	.48 - .56 .57 - .65	.53 - .61 .64 - .72	.48 - .56 .56 - .64	.51 - .59 .60 - .68	.57 - .65 .69 - .77
1/4 acre per unit	.27 - .37 .35 - .45	.31 - .41 .39 - .49	.34 - .44 .42 - .52	.29 - .37 .38 - .46	.34 - .42 .42 - .50	.38 - .46 .47 - .55	.32 - .40 .41 - .49	.36 - .44 .45 - .53	.41 - .49 .52 - .60	.35 - .43 .43 - .51	.39 - .47 .47 - .55	.45 - .53 .57 - .65
1/3 acre per unit	.22 - .32 .31 - .41	.26 - .36 .35 - .45	.29 - .39 .38 - .48	.25 - .33 .33 - .41	.29 - .37 .38 - .46	.33 - .41 .42 - .50	.28 - .36 .36 - .44	.32 - .40 .41 - .49	.37 - .45 .48 - .56	.31 - .39 .39 - .47	.35 - .43 .43 - .51	.42 - .50 .53 - .61
1/2 acre per unit	.16 - .26 .25 - .35	.20 - .30 .29 - .39	.24 - .34 .32 - .42	.19 - .27 .28 - .36	.23 - .31 .32 - .40	.28 - .36 .36 - .44	.22 - .30 .31 - .39	.27 - .35 .35 - .43	.32 - .40 .42 - .50	.26 - .34 .34 - .42	.30 - .38 .38 - .46	.37 - .45 .48 - .56
1 acre per unit	.14 - .24 .22 - .32	.19 - .29 .26 - .36	.22 - .32 .29 - .39	.17 - .25 .24 - .32	.21 - .29 .28 - .36	.26 - .34 .34 - .42	.20 - .28 .28 - .36	.25 - .33 .32 - .40	.31 - .39 .40 - .48	.24 - .32 .31 - .39	.29 - .37 .35 - .43	.35 - .43 .46 - .54
MISC. SURFACES												
Pavement and roofs	.93 .95	.94 .96	.95 .97	.93 .95	.94 .96	.95 .97	.93 .95	.94 .96	.95 .97	.93 .95	.94 .96	.95 .97
Traffic areas (soil and gravel)	.55 - .65 .65 - .70	.60 - .70 .70 - .75	.64 - .74 .74 - .79	.60 - .68 .68 - .76	.64 - .72 .72 - .80	.67 - .75 .75 - .83	.64 - .72 .72 - .80	.67 - .75 .75 - .83	.69 - .77 .77 - .85	.72 - .80 .79 - .87	.75 - .83 .82 - .90	.77 - .85 .84 - .92
Green landscaping (lawns, parks)	.10 - .20 .14 - .24	.16 - .26 .22 - .32	.25 - .35 .30 - .40	.14 - .22 .20 - .28	.22 - .30 .28 - .36	.30 - .38 .37 - .45	.20 - .28 .26 - .34	.28 - .36 .35 - .43	.36 - .44 .42 - .52	.24 - .32 .30 - .38	.30 - .38 .40 - .48	.40 - .48 .50 - .58
Non-green and gravel landscaping	.30 - .40 .34 - .44	.36 - .46 .42 - .52	.45 - .55 .50 - .60	.45 - .55 .50 - .60	.42 - .50 .48 - .56	.50 - .58 .57 - .65	.40 - .48 .46 - .54	.48 - .56 .55 - .63	.56 - .64 .64 - .72	.44 - .52 .50 - .58	.50 - .58 .60 - .68	.60 - .68 .70 - .78
Cemeteries, playgrounds	.20 - .30 .24 - .34	.26 - .36 .32 - .42	.35 - .45 .40 - .50	.35 - .45 .40 - .50	.32 - .40 .38 - .46	.40 - .48 .47 - .55	.30 - .38 .36 - .44	.38 - .44 .45 - .53	.46 - .54 .54 - .62	.34 - .42 .40 - .48	.40 - .48 .50 - .58	.50 - .58 .60 - .68

NOTES:

1. Values above and below pertain to the 2-year and 100-year storms, respectively.
2. The range of values provided allows for engineering judgement of site conditions such as basic shape, homogeneity of surface type, surface depression storage, and storm duration. In general, during shorter duration storms ($Tc \leq 10$ minutes), infiltration capacity is higher, allowing use of a "C" value in the low range. Conversely, for longer duration storms (Tc) 30 minutes), use a ""C value in the higher range.
3. For residential development at less than 1/8 acre per unit or greater than 1 acre per unit, and also for commercial and industrial areas, use values under MISC SURFACES to estimate "C" value ranges for use.

RATIONAL METHOD RUNOFF COEFFICIENTS
(Modified from Table 4, UC-Davis, which appears to be a modification of work done by Rawls)

TABLE "B-1"

SUBBASIN I.D.	LAND USE OR SURFACE CHARACTERISTICS	STORM FREQ.	SCS HYDROLOGIC SOIL GROUP AND NAME (eg - "B:ABERT")								COMPOSITE C VALUE $\Sigma\left(\frac{C \times \%}{100}\right)$
			A:		B:		C:		D:		
			% OF SUBBASIN	"C" VALUE	% OF SUBBASIN	"C" VALUE	% OF SUBBASIN	"C" VALUE	% OF SUBBASIN	"C" VALUE	
ZZ	EXAMPLE		10	.60	40	.70	40	.80	10	.90	.75

SEE APPENDIX "C" FOR SOIL DESCRIPTIONS. SEE TABLE "B-1" FOR APPROXIMATE "C" VALUES

COMPOSITE RUNOFF COEFFICIENTS WORKSHEET — TABLE "B-2"

APPENDIX "C"
SCS CURVE NUMBERS

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APPENDIX "C"
SCS CURVE NUMBERS

1. <u>General Discussion</u> The SCS-CN method and limitations have been discussed in Section VI-F-2a. In this Appendix, guidelines in the use of CN values are provided to assist in CN value selection.Also provided are SCS published curve numbers.

2. <u>Antecedent Moisture/Runoff Conditions</u> In order to account for varying soil moisture conditions prior to a storm event, three "antecedent moisture conditions" (AMC) or "antecedent runoff conditions" (ARC), as they are now called, were developed.

ARCs are classified by the conditions shown in Table "C-1" below.

Table "C-1"
Classification of Antecedent Runoff Conditions

ARC	Total 5-day Antecedent Rainfall (in.)	
	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5-1.1	1.4-2.1
III	Over 1.1	Over 2.1

In arid and semi-arid regions, it is fair to say that most of the time soils fit the ARC category of I. Having more than 1.4 inches of rain in a 5-day period in arid and semi-arid areas would not be common, and statistically could be shown to be a rare event preceeding a "design" storm. Therefore, one might justify using an ARC of I, particularly with the added SCS description that soils which are dry enough for satisfactory plowing or cultivation have an ARC of I.

Notwithstanding the above, use of an ARC of I is not recommended when selecting CN values for design storm analyses. This is because higher intensity storms tend to seal the soil, a phenomenon discussed in the next section.

3. <u>Impact of Storm Intensity</u> Published CN values are most applicable for storms of 2-year intensity or less. As expressed in Limitations, Chapter 2, SCS TR-55, modeling accuracy decreases with historical storms, or storms of greater intensity. Also stated is the fact that the CN equation does not account for rainfall intensity. This would indicate that, while CN values provided in SCS TR-55 are very useful for estimating peak flows for frequent storms or for volume and annual yield calculations, they may not be as applicable for typical design storms

used in peak runoff analysis. This is because water absorption rates for soils are limited and, as storm activity increases, precipitation overwhelms percolation, thus "sealing" the soil (Williams 1990). Thus, when estimating peak runoffs, higher CN values may be required to account for this phenomenon.

An example of the above is a calibrated study performed for the desert sands area east of Yuma, Arizona (Williams 1988). The SCS mapped soil type for the entire area had a listed permeability of 0.6 - 2.0 inches per hour. Field observations confirmed the SCS Soils Report for soil type. Yuma receives an average of 3.0 inches of rainfall per year. Rain-gauge data were available from a nearby military airport, as was crest-stage data from USGS. Prior to a significant rainfall and flood event, there had been no rainfall whatsoever. Certainly an ARC of I could be argued for by SCS guidelines, which would result in a CN value of 62. A CN value of 84.1 was found to be required to calibrate the model, which is even above the table ARC-II value of 79.

Granted, the above is a single case study, from which limited conclusions can be made. However, it would be justifiable to say that using an ARC of I for design storms is not advisable. Furthermore, when selecting CN values for 100-year events, it may be appropriate to select on the high side of ARC II values.

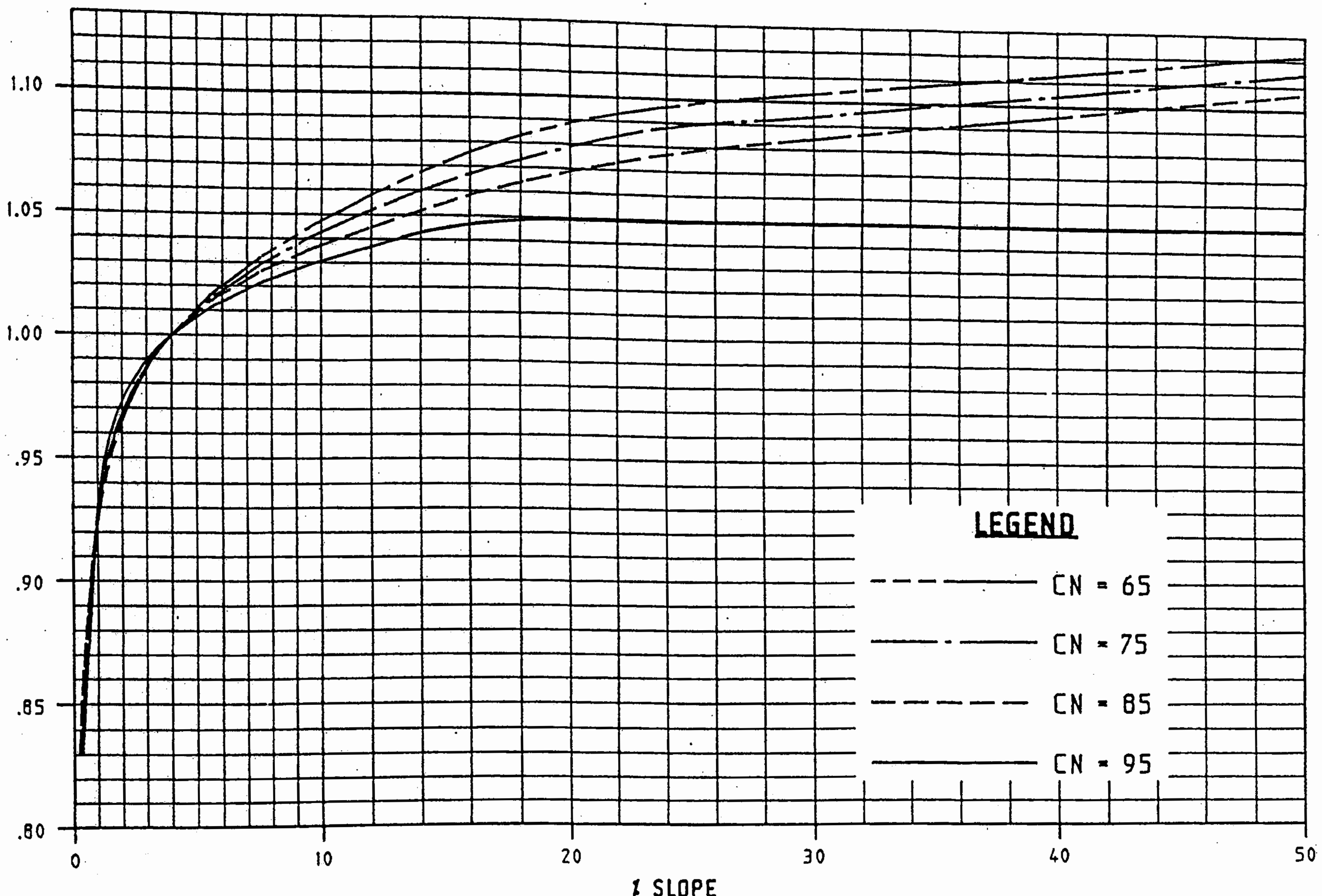
4. **Impact of Slope** CN values are based on abstraction capability which depends on four (4) phenomena. Interception and evapotranspiration are not affected by watershed slope, but initial infiltration and surface depression storage are. In general, slope will impact runoff.

Impact of slope on peak runoff is not a new concept — it has been acknowledged for many years. The 1975 edition of SCS TR-55, and the 1984 edition of an SCS Supplement for Colorado provide curves which allow for runoff adjustment due to slope. The curves were used in conjunction with the SCS Chart Method which, because of unrelated disadvantages, was dropped from the 1986 SCS TR-55. The adjustments for slope accounted not only for changed runoff travel speed (and thereby time of concentration change), but also for changed infiltration rates and surface depression storage.

It is implied by the adjustments that published CN values are, on the average, based upon slopes of 4%. Flatter slopes resulted in more infiltration, and therefore the CN value was adjusted down, and the opposite is true for steeper slopes.

Using current SCS procedures, it may be difficult to determine how much "preliminary" CN values found in tables should be adjusted, if any, to properly account for slope variance from 4%. A method was developed to convert the old SCS peak flow adjustment curves to adjustment of CN values for use in current procedures (Williams 1990). These curves are shown in Figure "C-1". However, it is unknown how appropriate the original adjustment curves are, and consequently the converted curves may be of limited or questionable value. Nonetheless, one may benefit from keeping in mind the potential impact that slope may have on infiltration and CN values, particularly for very flat and very steep watersheds.

USE OF THIS FIGURE IS NOT REQUIRED. USE AS A GUIDE ONLY.



(CURVES ARE BASED UPON SCS 1975 CHART METHOD CURVES)

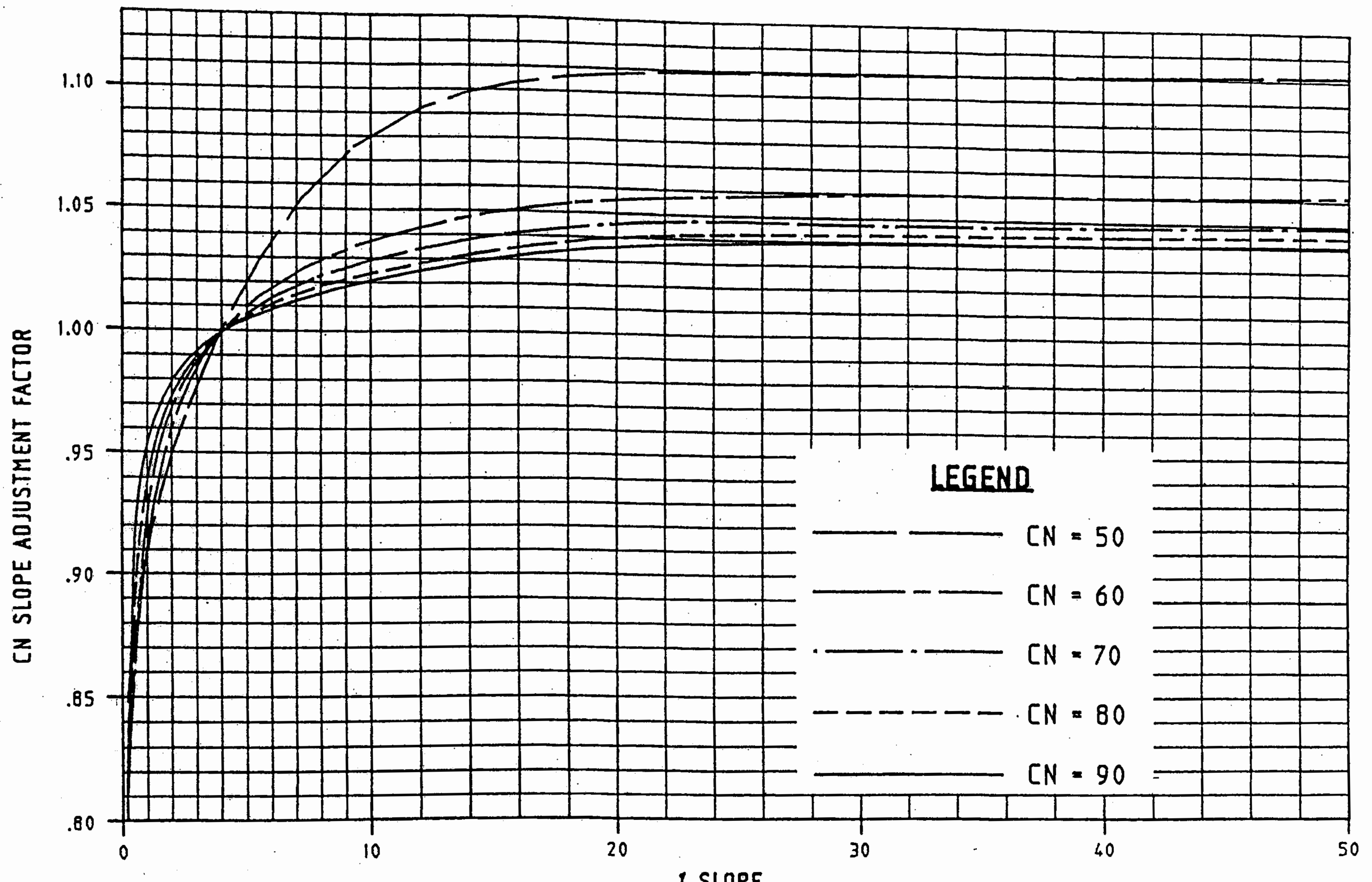
(REPRODUCED FROM "WILLIAMS 1990")

CN ADJUSTMENT FOR SLOPE

URBAN CONDITION: TYPE II STORM

FIGURE "C-1a"

USE OF THIS FIGURE IS NOT REQUIRED. USE AS A GUIDE ONLY.



(CURVES ARE BASED UPON SCS 1975 CHART METHOD CURVES)

(REPRODUCED FROM "WILLIAMS 1990")

CN ADJUSTMENT FOR SLOPE

RURAL CONDITION: TYPE II STORM

FIGURE "C-1b"

5. <u>Hydrologic Soil Group</u> In addition to values being listed by ARC classification, they are also listed according to a hydrologic soil group (HSG). Infiltration varies considerably with soil type, and the difference is accounted for by selecting a CN value under the appropriate soil type. The four HSGs are defined by SCS TR-55 as follows:

<u>Group A</u> soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr).

<u>Group B</u> soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

<u>Group C</u> soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

<u>Group D</u> soils have high runoff potential. They have low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0.-0.05 in/hr).

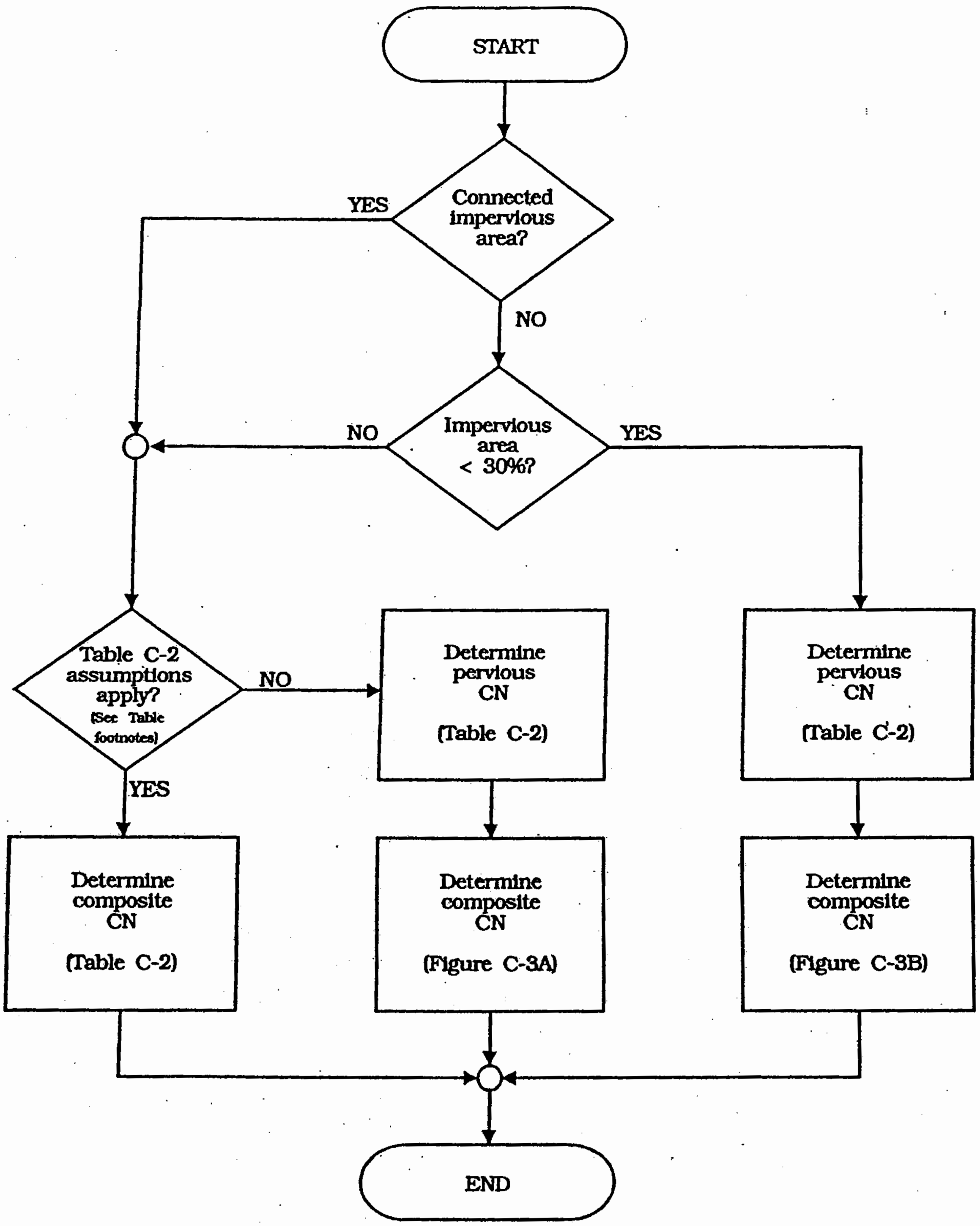
The SCS has published Soil Surveys for most areas, which map out soil "names" along with hydraulic properties allowing one to classify the HSG. Most soil surveys already contain a listing of the HSG, however. Another source that classifies the HSG once the soil "name" is known is the SCS TR-55 or NEH-4 (SCS 1972 & 1986).

In initial selection of the Hydrologic Soil Group (A, B, C, or D), care should be taken in matching soil profile conditions. Hydrologic Soil Groups (HSGs) taken from SCS Soil Surveys generally consider the profile to a depth to 60 inches, which is adequate, but they only reflect information found at the time of the survey. Earthwork in the area may have changed conditions, and there may have been changes in groundwater levels as well. These should be considered.

Some areas may not be mapped by an SCS Soil Survey. HSG must be selected by other general descriptions such as those summarized below.

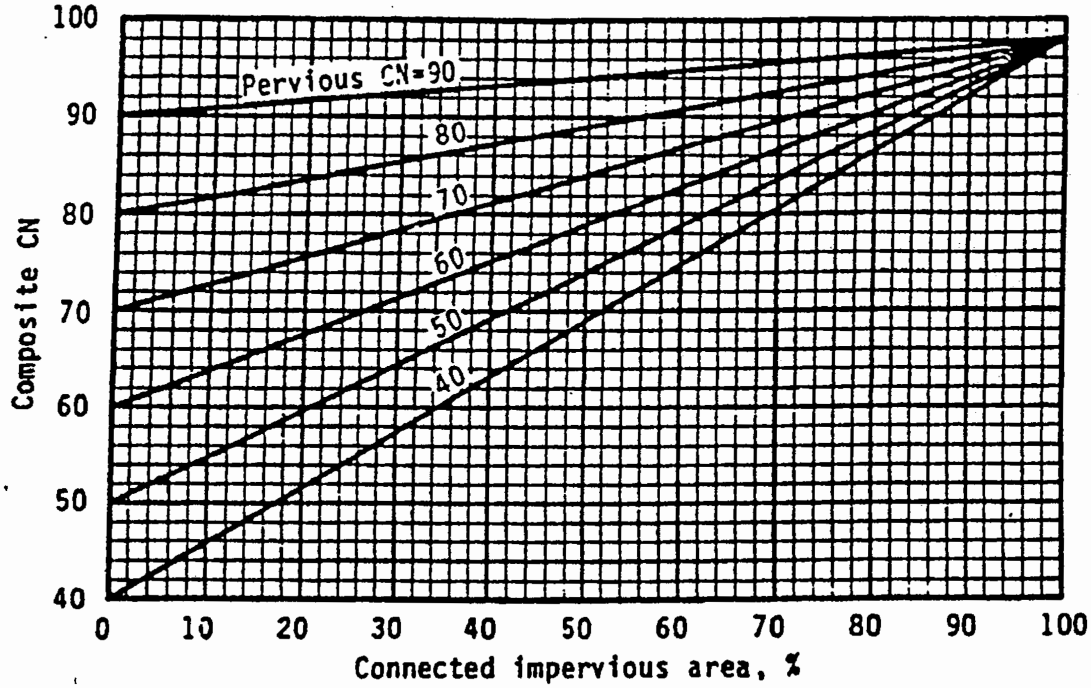
HSG	Soil textures
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam

REPRODUCED FROM SCS 1986 TR-55, FIGURE 2-2

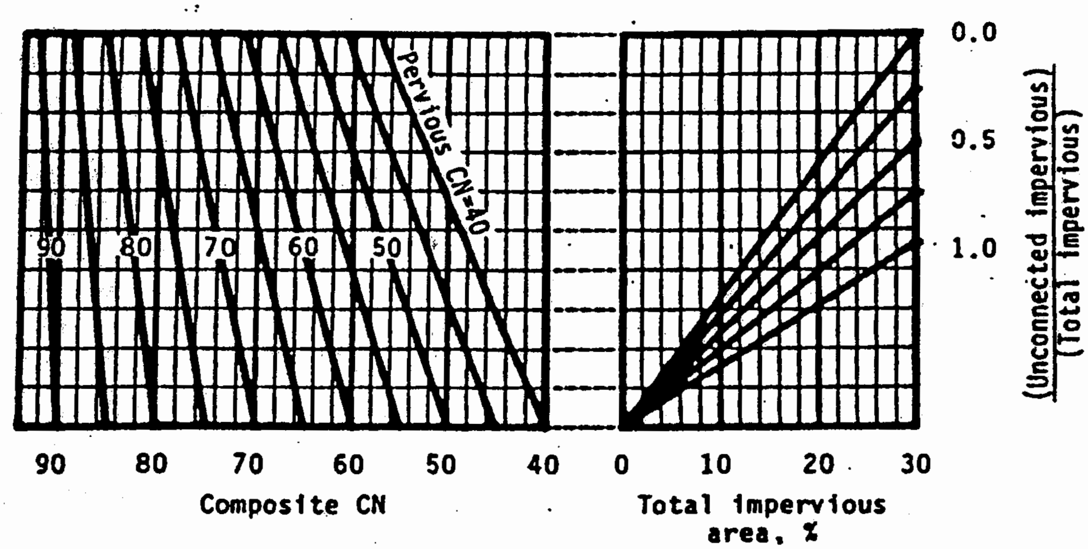


FLOW CHART OF CN TABLE AND FIGURE USAGE	FIGURE C-2

USE THIS FIGURE ONLY IN ACCORDANCE WITH FIGURE "C-2"



A - COMPOSITE CN WITH CONNECTED IMPERVIOUS AREA.



B - COMPOSITE CN WITH UNCONNECTED IMPERVIOUS AREAS AND TOTAL IMPERVIOUS AREA LESS THAN 30%.

CN ADJUSTMENT DUE TO DIFFERENT CONDITIONS OF IMPERVIOUS AREAS (REPRODUCED FROM TR-55 (SCS 1986))	FIGURE C-3

DO NOT USE THIS TABLE ALONE. USE IN CONJUNCTION WITH FIGURES "C-2" AND "C-3"[1]

Cover Description	Average Percent Impervious Area[2]	Curve Numbers for Hydrologic Soil Group			
Cover Type and Hydrologic Condition		A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 50%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (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
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
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)[5]		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table "C-2C"		68	79	86	89

[1]Average runoff condition (ARC = II), and $I_a = 0.2S$.

[2]The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CNs for other combinations of conditions may be computed using Figure "C-3A" or "C-3B". See Figure "C-2" for more direction.

[3]CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

[4]Composite CNs for natural desert landscaping should be computed using Figures "C-3A" or "C-3B" based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

[5]Composite CNs to use for the design of temporary measures during grading and construction should be computed using Figures "C-3A" or "C-3B", based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

[Reproduced from TR-55 (SCS 1986)]

SCS CURVE NUMBERS: Preliminary Values for Urban Areas

TABLE "C-2a"

DO NOT USE THIS TABLE ALONE. USE IN CONJUNCTION WITH FIGURES "C-2" AND "C-3"[1]

Cover Description			Curve Numbers for Hydrologic Soil Group			
Cover Type	Treatment[2]	Hydrologic Condition[3]	A	B	C	D
Fallow	Bare soil	--	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		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	94	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	91
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	76	80	83
		Good	51	67	76	80

[1]Average runoff condition, and $I_a = 0.2S$.

[2]*Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.

[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, the amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

[Reproduced from TR-55 (SCS 1986)]

SCS CURVE NUMBERS: Preliminary Values for Cultivated Agricultural Lands

TABLE "C-2b"

DO NOT USE THIS TABLE ALONE. USE IN CONJUNCTION WITH FIGURES "C-2" AND "C-3"[1]

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover Type	Hydrologic condition	A	B	C	D
Pasture, grassland or range — continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	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.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods — grass combination (orchard or tree farm).[4]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[5] [This is not forests — See C-6 for discussion]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads — buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1]Average runoff condition, and $I_a = 0.2S$.

[2]*Poor:* < 50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* < 50% ground cover.
Fair: 50 to 75% ground cover.
Good: > 75% ground cover.

[4]Actual curve number is less than 30% use CN = 30 for runoff computations.

[5]CNs shown were computed for areas with 50% woods and 50% grass {pasture} cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned and some forest litter covers the soil.
Good: Woods are protected from grazing and litter and brush inadequately cover the soil.

[Reproduced from TR-55 (SCS 1986)]

SCS CURVE NUMBERS: Preliminary Values for Other Agricultural Lands

TABLE "C-2c"

DO NOT USE THIS TABLE ALONE. USE IN CONJUNCTION WITH FIGURES "C-2" AND "C-3"[1]

Cover Description		Curve Numbers for Hydrologic Soil Group			
Cover Type	Hydrologic Condition[2]	A[3]	B	C	D
Herbaceous — mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen — mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper — pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub — major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1]Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use Table "C-2C".

[2]*Poor:* < 30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.

[3]Curve numbers for group A have been developed only for desert shrub.

[Reproduced from TR-55 (SCS 1986)]

SCS CURVE NUMBERS: Preliminary Values for Arid and Semiarid Rangelands

TABLE "C-2d"

SUBBASIN I.D.	LAND USE OR SURFACE CHARAC-TERISTICS	STORM FREQ.	SCS HYDROLOGIC SOIL GROUP AND NAME (eg - "B:ABERT") A:		B:		C:		D:		COMPOSITE CN VALUE $\sum\left(\frac{CN \times \%}{100}\right)$
			% OF SUBBASIN	"CN" VALUE	% OF SUBBASIN	"CN" VALUE	% OF SUBBASIN	"CN" VALUE	% OF SUBBASIN	"CN" VALUE	
ZZ	EXAMPLE		10	60	40	70	40	80	10	90	75

SEE TABLE "C-2" FOR SCS CN VALUES.

COMPOSITE SCS CURVE NUMBERS WORKSHEET — **TABLE "C-3"**

APPENDIX "D"
GREEN & AMPT METHOD

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<u>List of Tables</u>

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APPENDIX "D"
GREEN & AMPT METHOD

1. **General Discussion** Appendices "B" and "C" discuss, respectively, the assumptions and corresponding limitations of the Rational Method and SCS Curve Number rainfall loss methods. The Green & Ampt Method is a much more complex method, but is not much more difficult to use. The Green & Ampt Method is rapidly gaining favor because of improved results. Moreover, the method may be used with the SCS unit hydrograph or other runoff methods. Discussion herein will pertain to its use in HEC-1, where information is input on the "LG" record.

2. **Surface Retention Loss (HEC-1 "IA" Parameter)** The Green and Ampt Method involves the simulation of rainfall loss as a two phase process, as shown in Figure "D-1". The first phase of rainfall loss is called initial abstraction (IA) or surface retention loss, which involves vegetation interception, evaporation, and surface depression storage. Typical surface retention loss values are shown in Table "D-1".

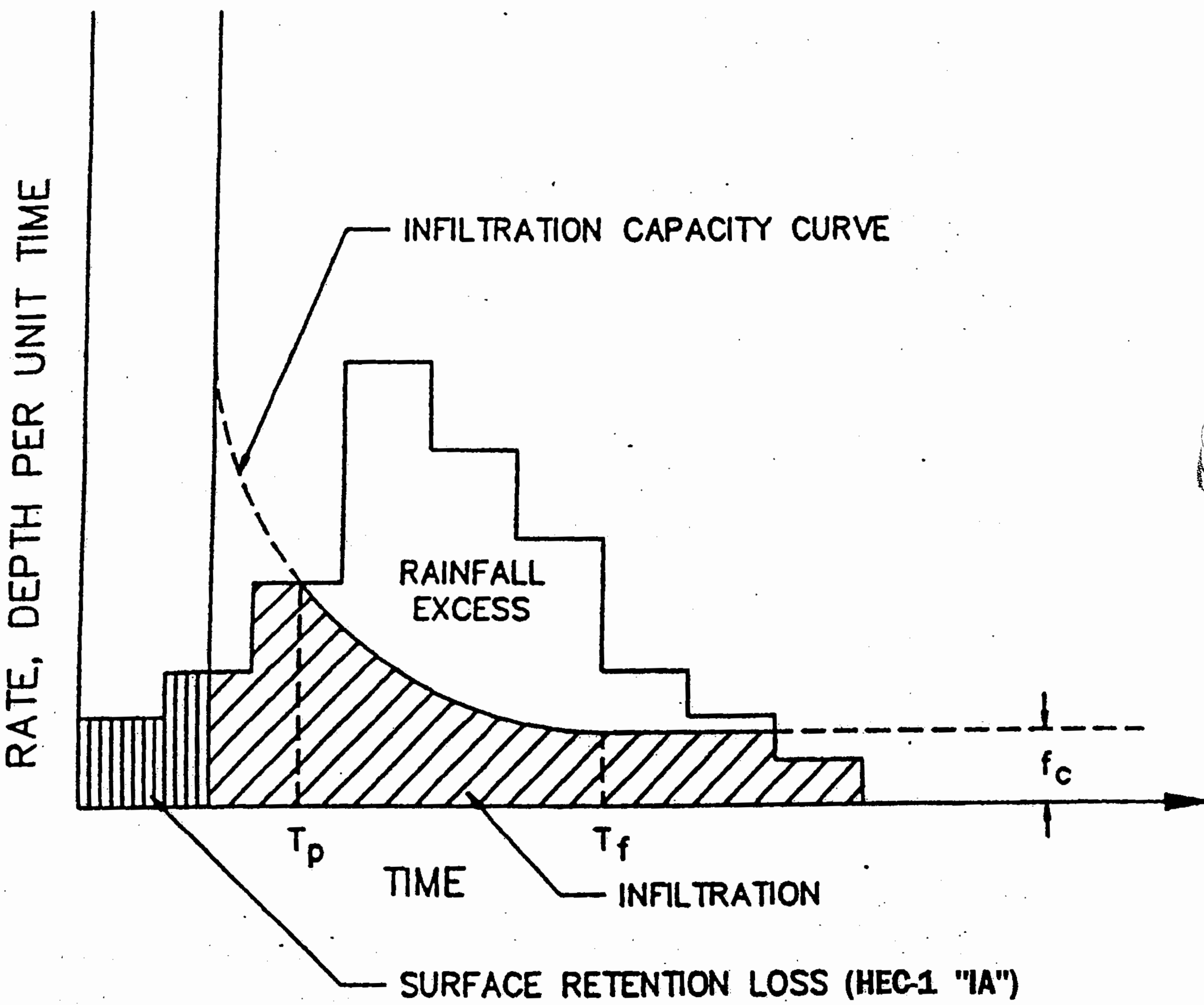
Table "D-1"
Surface Retention Loss

Land-use and/or Surface Cover	Surface Retention Loss IA, inches
Natural	
Desert and rangeland, flat slope	0.35
Desert hillslopes	0.15
Mountain, with vegetated surface	0.25
Developed (Residential and Commercial)	
Lawn and turf	0.20
Desert landscape	0.10
Pavement	0.05
Agricultural	
Tilled fields and irrigated pasture	0.50

Reproduced from work prepared by George Sabol and Associates (Maricopa County)

3. **Infiltration Loss Parameters** The second phase of the rainfall loss process is infiltration of rainfall into the soil. As shown in Figure "D-1", the infiltration is assumed to begin after the surface retention loss is completely satisfied.

REPRODUCED FROM MARICOPA COUNTY, VOL. I



SIMPLIFIED REPRESENTATION OF RAINFALL LOSSES	FIGURE "D-1"

As named in HEC-1, there are three parameters involved in calculating infiltration:

i) "DTHETA", which is the volumetric soil moisture deficit at the start of rainfall;

ii) "PSIF", which is the wetting front capillary suction, or ability of the soil to draw moisture; and

iii) "XKSAT", which is the hydraulic conductivity of the soil at natural saturation.

Selection of these parameter values is discussed hereafter.

a. <u>Soil Texture Classification</u> Green & Ampt loss rate parameters are largely a function of properties associated with soil types. Classification types are shown in Figure "D-2", and may readily be determined by sieve analysis or by using SCS Soil Survey maps.

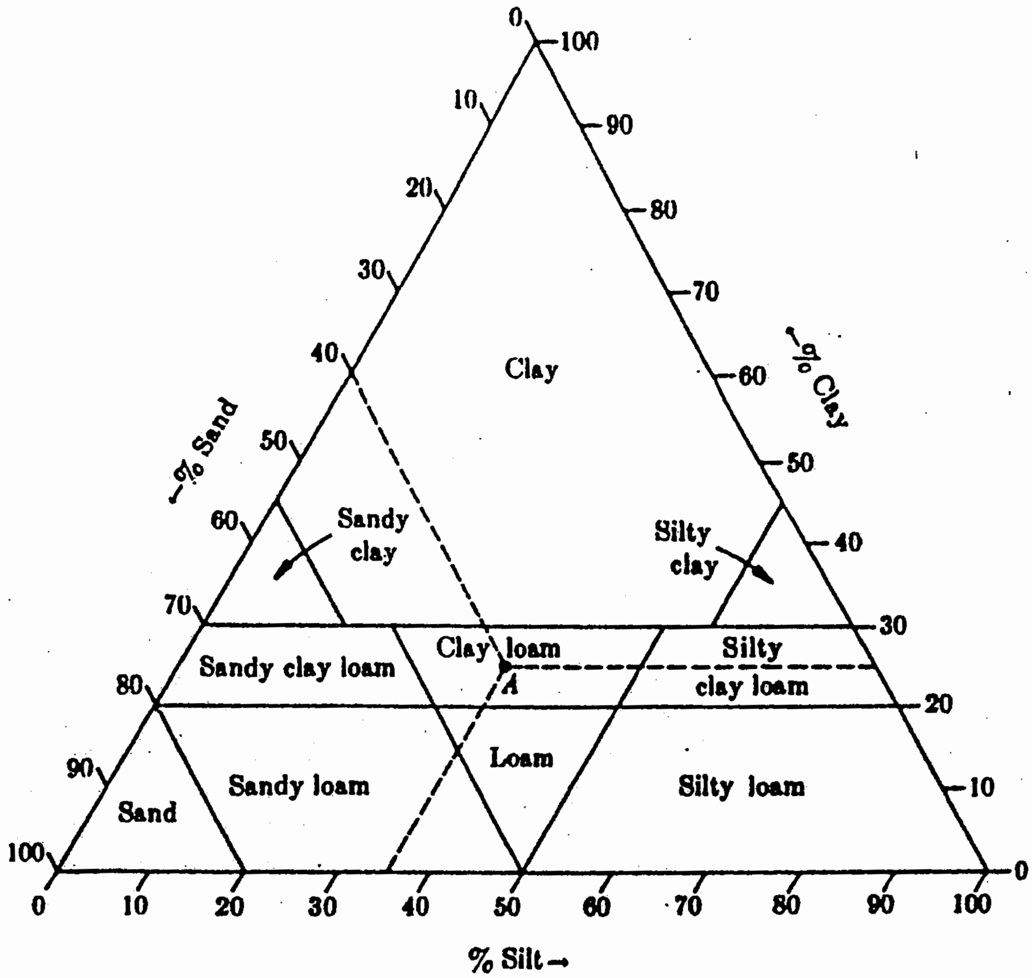
Using a SCS Soil Survey involves the following steps:

i) locate the watershed and subbasin boundaries on the detailed soil maps;

ii) list the map symbol and soil name for each soil that is contained within the watershed boundaries;

iii) read the description of each of the soil series and each mapping unit, trying to identify the soil texture that best describes each soil or at least the top 6 inches of layered soils; and

iv) consult soil properties tables of the soil survey, and from the columns for soil depth and dominant texture, make the final selection of soil texture that will control the infiltration rate. The size gradation data that is provided in the tables can also be used to assist in selecting the soil texture.



Definitions: Clay - mineral soil particles less than 0.002 mm in diameter.
Silt - mineral soil particles that range in diameter from 0.002 mm to 0.05 mm.
Sand - mineral soil particles that range in diameter from 0.05 mm to 2.0 mm.

Example: Point A is a soil composed of 40% sand, 35% silt, and 25% clay. It is classified as a clay loam.

SOIL TEXTURE CLASSIFICATION	FIGURE "D-2"

b. Soil Hydraulic Conductivity (HEC-1 "XKSAT" Parameter) The XKSAT parameter is based upon soil texture classification, as shown in Table "D-2".

Table "D-2"
Bare Ground "XKSAT" Values

Soil Texture Classification (see Figure "D-2")	SCS HSG (Appendix "C")	XKSAT (in/hr)
Loamy sand & sand	A	1.20
Sandy loam	B	0.40
Loam	B	0.25
Silty loam	C	0.15
Sandy clay loam	C	0.06
Clay loam	D	0.04
Silty clay loam	D	0.04
Sandy clay	D	0.02
Silty clay	D	0.02
Clay	D	0.01

XKSAT values should be determined based upon the soil texture classification, NOT the SCS HSG, which is only shown for reference purposes. Therefore, in order to select XKSAT values, a sieve analysis and/or use of an SCS Soil Survey map must be used in conjunction with Figure "D-2" and this table.

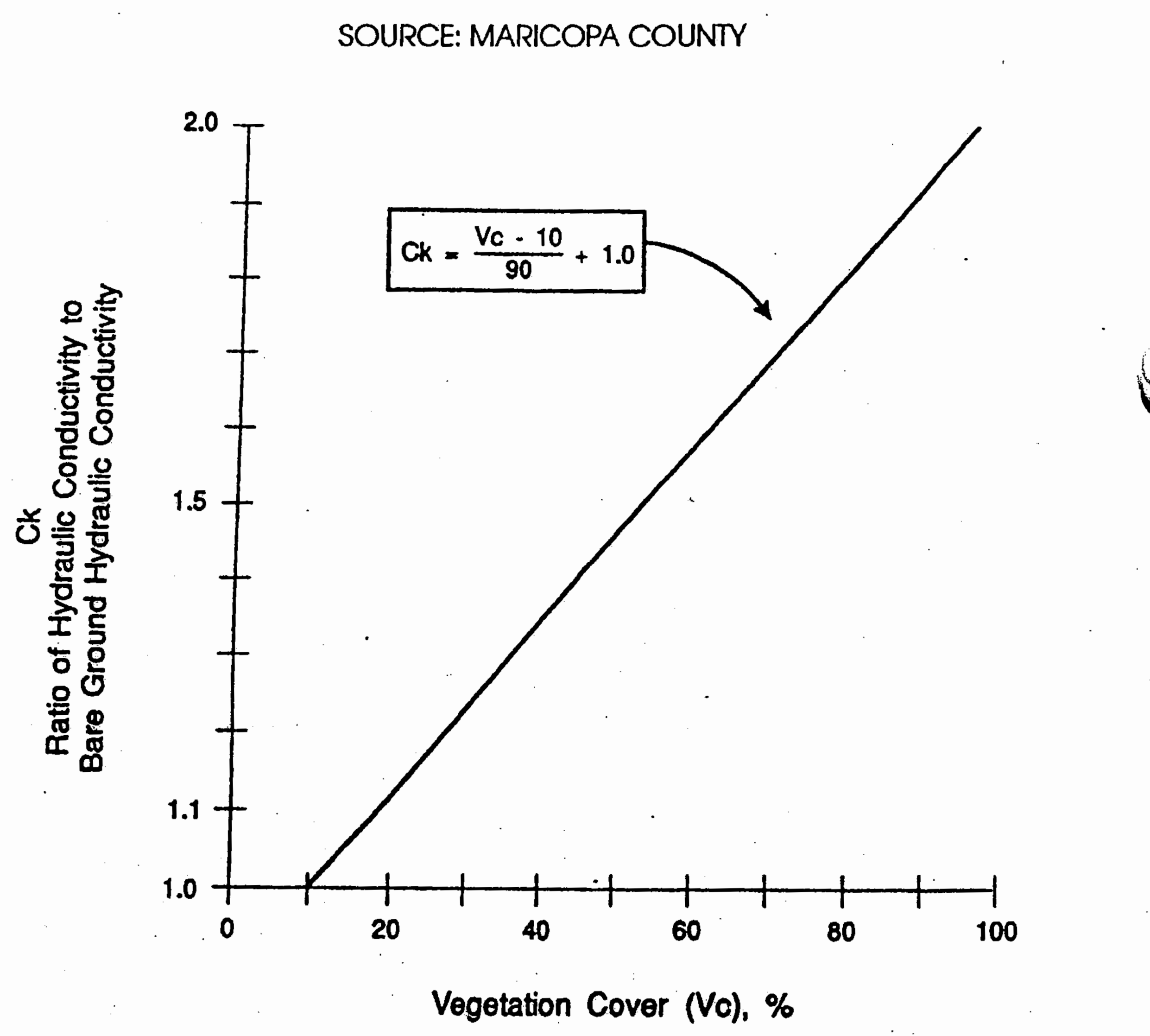
Source: Maricopa County

(1) Composite XKSAT Values Most drainage areas or subbasins will be composed of several subareas containing soils of different textures. Therefore, a composite value for Green and Ampt parameters must be determined.

(2) Adjusting XKSAT for Vegetation Cover Hydraulic conductivity XKSAT or "$\overline{\text{XKSAT}}$" as the case may be, can be affected by several factors besides soil texture, including soil crusting, tillage, and ground cover and canopy cover. The values of "XKSAT" that are presented for bare ground as a function of soil texture alone should be adjusted under certain soil cover conditions.

Ground cover, such as grass, litter, and gravel, will generally increase the infiltration rate over that of bare ground conditions. Similarly, canopy cover — such as from trees, brush, and tall grasses — can also increase the bare ground infiltration rate.

A simplified procedure for adjusting bare ground hydraulic conductivity to account for vegetation cover has been developed by George Sabol, and is shown in Figure "D-3" (Maricopa County).



"XKSAT" ADJUSTMENT FOR VEGETATION COVER	FIGURE "D-3"

c. Volumetric Soil Deficit (HEC-1 "DTHETA' Parameter) The soil moisture deficit DTHETA is a volumetric measure of the soil moisture storage capacity that is available at the start of the rainfall. DTHETA is a function of the effective porosity of the soil. The range of DTHETA is 0.0 to the effective porosity. If the soil is effectively saturated at the start of rainfall, then DTHETA equals 0.0. If the soil is devoid of moisture at the start of rainfall, then DTHETA equals the effective porosity of the soil.

Three conditions for DTHETA have been defined for use based on the antecedent soil moisture condition that could be expected to exist at the start of the design rainfall. These three conditions are:

- "Dry" for antecedent soil moisture near the vegetation wilting point;
- "Normal" for antecedent soil moisture condition near field capacity due to previous rainfall or irrigation applications on nonagricultural lands; and
- "Saturated" for antecedent soil moisture near effective saturation due to recent irrigation of agricultural lands.

The value of DTHETA "Saturated" is always equal to 0.0, because for this condition there is no available pore space in the soil matrix at the start of rainfall. DTHETA "Dry" should be used for soil that is usually in a state of low soil moisture such as would occur in the desert and rangelands. DTHETA "Normal" should be used for soil that is usually in a state of moderate soil moisture such as would occur in irrigated lawns, golf courses, parks, and irrigated pastures. DTHETA "Saturated" should be used for soil that can be expected to be in a state of high soil moisture such as irrigated agricultural land (Maricopa County).

DTHETA is a function of the soil and not vegetative ground cover, and therefore is based entirely upon the bare ground $\overline{XKSAT}$ value. DTHETA may be taken from Figure "D-4".

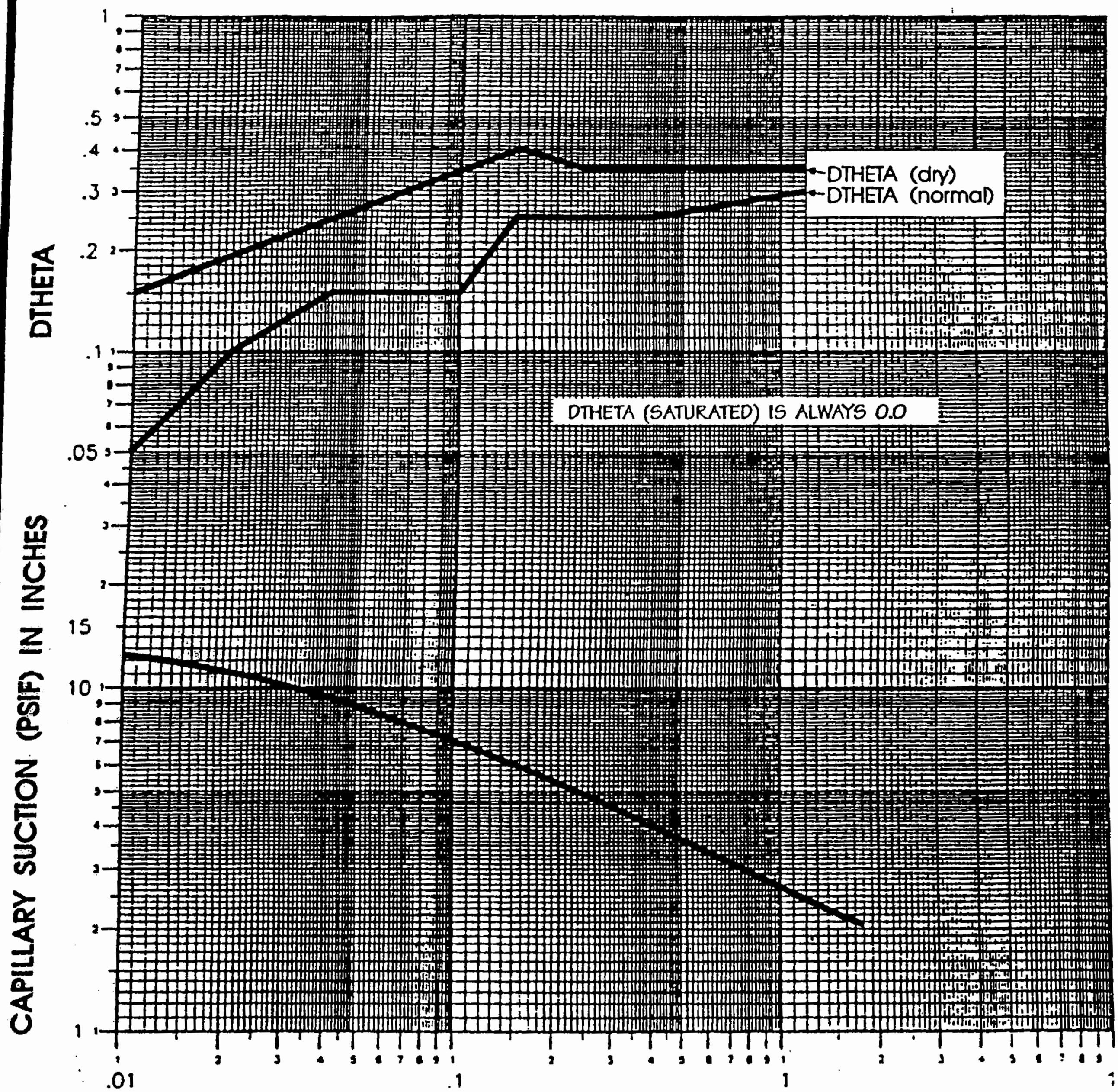
d. Wetting Front Capillary Suction (HEC-1 "PSIF" Parameter) This parameter is relatively insensitive to ground cover, and is a function of the average soil type represented by $\overline{XKSAT}$ (Maricopa County). Therefore, the PSIF value should be based upon the base ground $\overline{XKSAT}$ value, and taken from Figure "D-4".

4. Impervious Cover Percentage (HEC-1 "RTIMP" Parameter) The percent impervious value RTIMP is the percent of a subbasin for which 100 percent runoff will be computed. This means that the impervious area is assumed to be hydraulically connected to the concentration point.

SOURCE: MARICOPA COUNTY

SELECTION OF DTHETA CONDITION:

- DRY - USE THIS FOR NON-IRRIGATED LANDS, SUCH AS DESERT AND RANGELAND;
- NORMAL - USE THIS FOR IRRIGATED LAWN, TURF, AND PERMANENT PASTURE.
- SATURATED - USE THIS FOR IRRIGATED AGRICULTURAL LAND.



BARE GROUND "XKSAT" IN INCHES/HOUR

(DO NOT USE "XKSAT" VALUES WHICH ARE ADJUSTED FOR VEGETATION COVER.)

VALUES OF DTHETA AND PSIF AS A FUNCTION OF "XKSAT"	FIGURE "D-4"

For urban areas, RTIMP is the effective impervious area, which is usually less than the total imperious area. It only includes impervious area that has runoff that does not sheet flow over pervious areas.

For rock outcrop areas, RTIMP again pertains only to impervious areas that have runoff that does not sheet flow over pervious areas. For example, if the SCS soil description lists a soil group as having 25 percent rock outcrop, 25 percent of the area will contribute direct runoff to the outlet only if the rock outcrop areas are hydraulically connected, which is rarely the case.

Rainfall on bodies of water does not infiltrate; therefore, these areas should be considered as impermeable.

Good judgement should be used to assess flowpaths and the infiltration characteristics of soils adjacent to impervious areas when using the RTIMP variable.

5. <u>Summary of Application in HEC-1</u> Applying the Green and Ampt rainfall loss method in HEC-1 is not difficult, and is preferred over use of SCS curve numbers where soils are not sand. A summary of procedures used is provided below:

i) Prepare a base map of the drainage area delineating modeling subbasins, if used;

ii) Determine the land-use and/or soil cover for the drainage area and subbasins;

iii) Use Table "D-1" to estimate the surface retention loss (IA). Arithmetically area-weight average the values of IA if the drainage area or subbasin is composed of subareas of different IA;

iv) Delineate the subareas containing different soils (as determined from soil surveys, if available). Determine the soil texture for each soil type. Soils reports such as those of the Soil Conservation Service can be used, if available, or laboratory analysis of appropriate soil samples from the drainage area can be used if adequate documentation on the sampling and laboratory procedure is provided and approved. A soil texture classification triangle is provided on Figure "D-2". Select the bare ground XKSAT value from Table "D-2";

v) If the watershed or subbasin is composed of soils of different textures, then a composite bare ground $\overline{\text{XKSAT}}$ value must be calculated;

vi) Determine the vegetal cover adjustment factor "Ck", composite if appropriate, from Figure "D-3";

vii) Determine the adjusted XKSAT or $\overline{\text{XKSAT}}$ by multiplying the bare ground XKSAT or $\overline{\text{XKSAT}}$ by the adjustment factor "Ck";

viii) Select value of DTHETA from Figure "D-4" corresponding to the bare ground XKSAT or $\overline{\text{XKSAT}}$ value, as applicable, for the subbasin;

ix) Select value of PSIF from Figure "D-4" corresponding to the bare ground XKSAT or $\overline{\text{XKSAT}}$ value, as applicable, for the subbasin;

x) Estimate the impervious area (RTIMP) for the drainage area or subbasin, and arithmetically area-weight average, if necessary; and;

xi) On the LG record of the HEC-1 input file, enter the area-weighted values of IA, DTHETA, PSIF, XKSAT, and RTIMP for the drainage area or each subbasin.

The above steps are further systematized on Table "D-3".

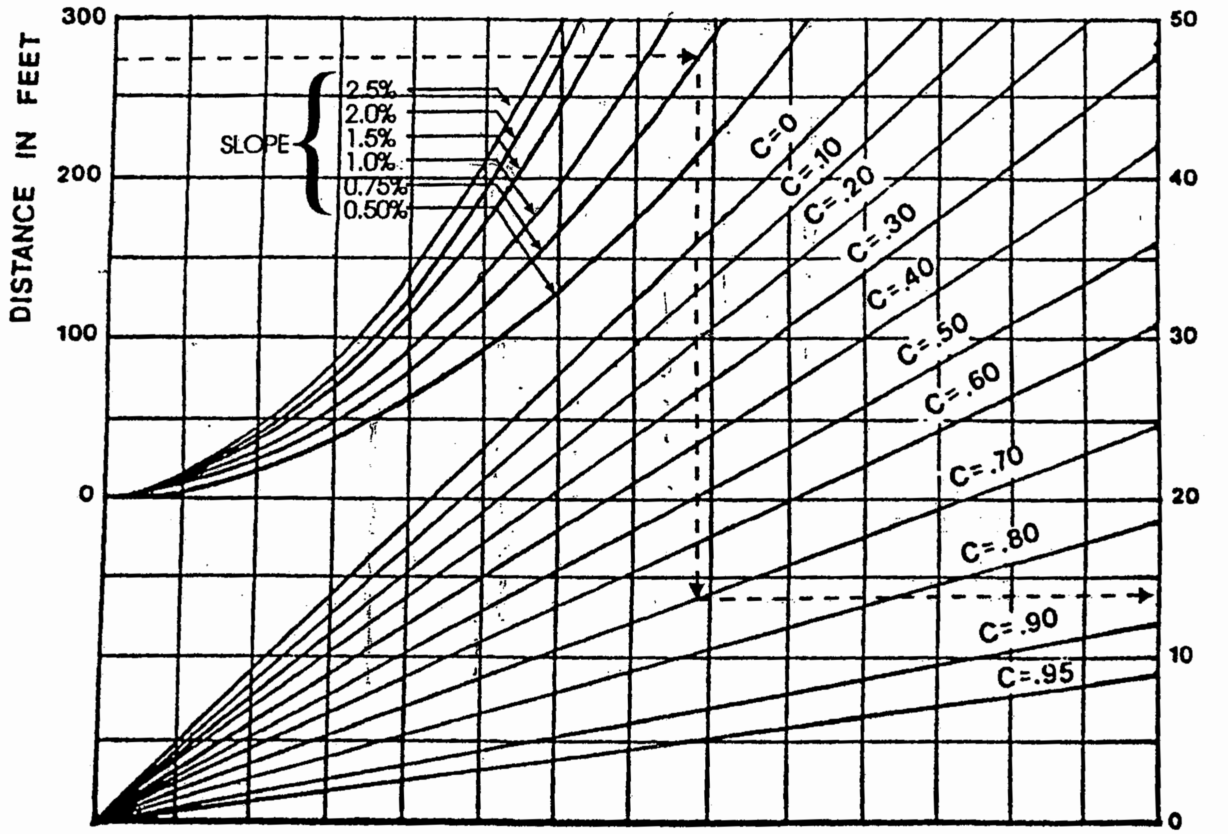
SUB-BASIN I.D. (i)	LAND USE OR SURFACE CHARACTER-ISTICS (ii)	SURFACE RET. LOSS "IA" (iii)	SOIL HYDRAULIC CONDUCTIVITY "XKSAT"									SOIL MOISTURE DEFICIT DTHETA (viii)	CAPILLARY SUCTION PSIF (ix)	IMP. AREA "RTMP" (x)
			BARE GROUND "XKSAT"							FACTOR "Ck" (vi)	ADJUSTED $\overline{\text{XKSAT}}$ (vii)			
			SOIL NO. 1		SOIL NO. 2		SOIL NO. 3		COMPOSITE					
			% OF AREA	XKSAT (iv)	% OF AREA	XKSAT (iv)	% OF AREA	XKSAT (iv)	$\overline{\text{XKSAT}}$ (v)					
ZZ	EXAMPLE	0.15	20	0.04	30	0.06	50	0.15	0.10	1.3	0.13	0.15	7.0	0.0

COLUMNS DENOTED ABOVE BY "I", ETC., PERTAIN TO THE BRIEF FOOTNOTES BELOW AND ALSO TO PROCEDURES EXPLAINED ON PAGES D-9 AND D-10. (i) IDENTIFY DELINEATED SUBBASINS. (ii) IDENTIFY LAND USES. (iii) SEE TABLE "D-1" - USE COMPOSITE VALUE IF APPROPRIATE. (iv) SEE FIGURE "D-2" AND TABLE "D-2" FOR BARE GROUND "XKSAT" VALUES. (v) COMPOSITE OR AVERAGE "XKSAT" VALUE. (vi) DETERMINE VEGETAL COVER FACTOR "Ck" FROM FIGURE "D-3". (vii) MULTIPLY THE BARE GROUND "XKSAT" OR "$\overline{\text{XKSAT}}$" BY "Ck" TO OBTAIN THE ADJUSTED "XKSAT" OR "$\overline{\text{XKSAT}}$" VALUE. (viii) & (ix) SELECT "DTHETA" AND "PSIF" FROM FIGURE "D-4" BASED UPON BARE GROUND "XKSAT" OR "$\overline{\text{XKSAT}}$", NOT THE ADJUSTED "XKSAT" OR "$\overline{\text{XKSAT}}$". (x) ESTIMATE THE IMPREVIOUS AREA "RTIMP" FOR THE AREA OR SUBBASIN. USE A COMPOSITE VALUE, IF APPROPRIATE.

GREEN & AMPT PARAMETER SELECTION WORKSHEET

TABLE "D-3"

MODIFIED FROM FIGURE 403, MESA COUNTY



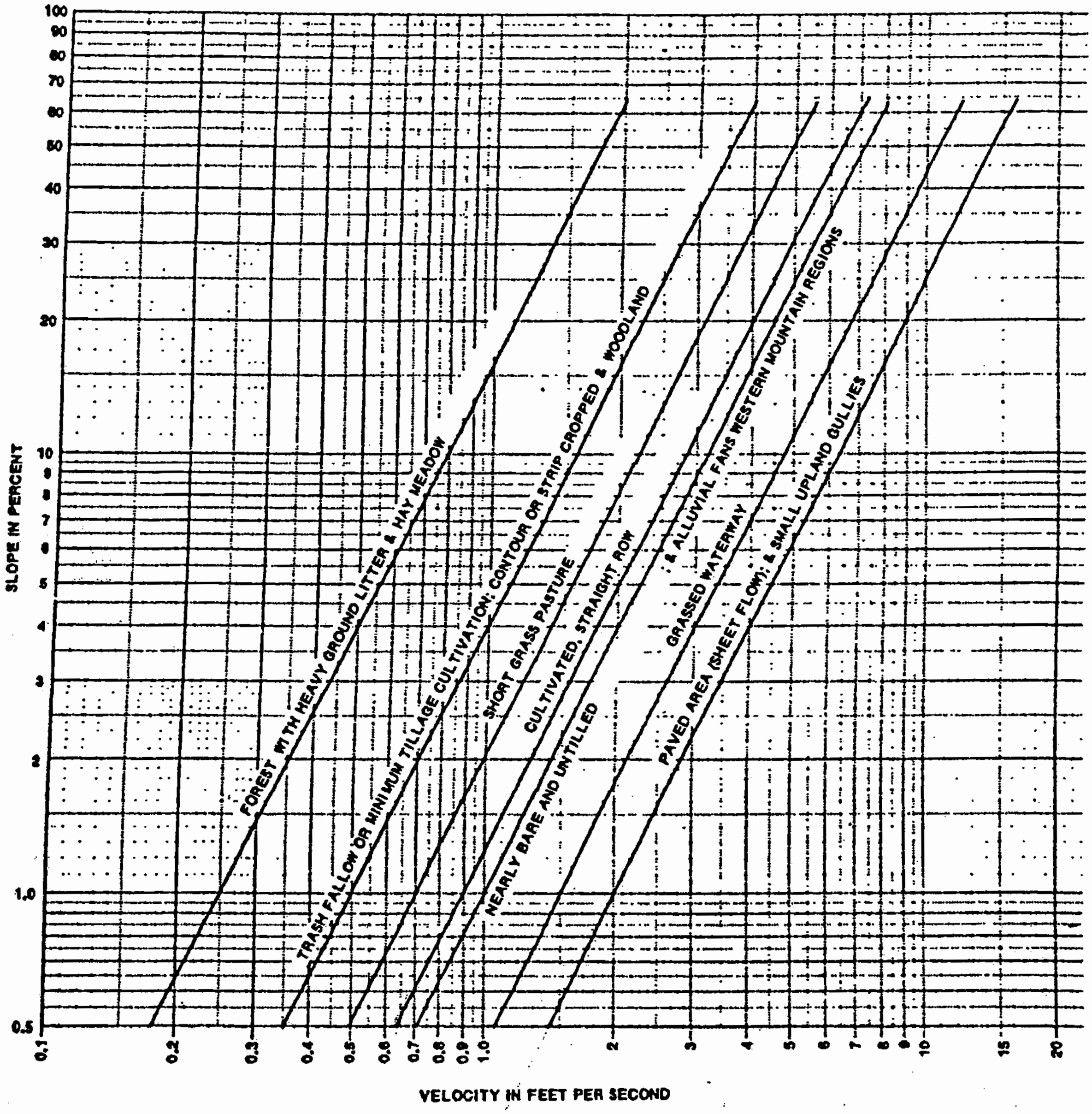
THE ABOVE CURVES ARE A SOLUTION OF THE FOLLOWING EQUATION:

$$T_o = \frac{1.8\,(1.1 - C)\sqrt{L}}{\sqrt[3]{S}}$$

WHERE: T_o = OVERLAND FLOW TIME (MIN.)
S = SLOPE OF BASIN (%)
C = RUNOFF COEFFICIENT (SEE TABLE "B-1" IN APPENDIX "B")
L = LENGTH OF BASIN (ft)

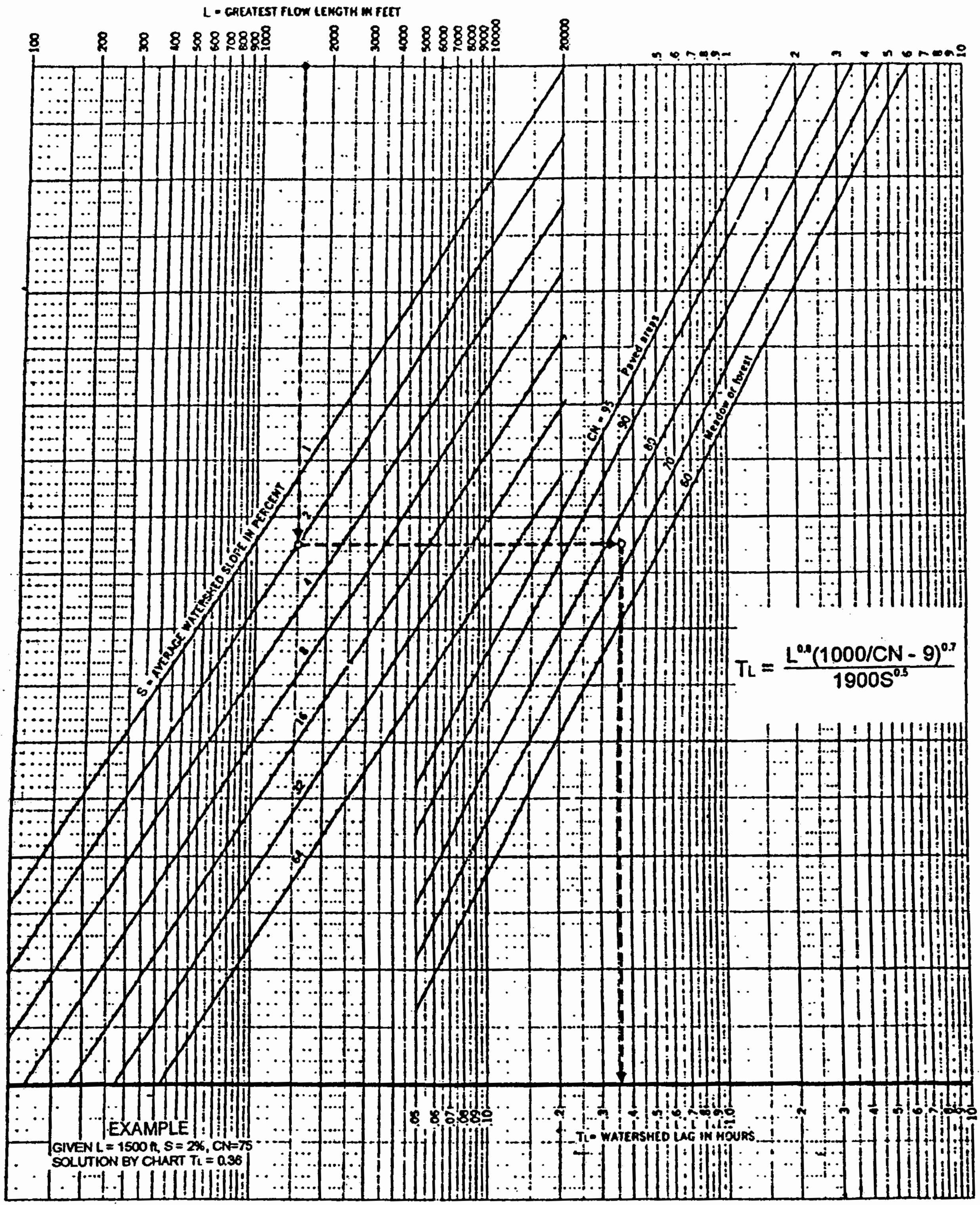
GRAPHICAL DETERMINATION OF "To:" FAA METHOD | **FIGURE "E-2"**

REPRODUCED FROM FIGURE 15.2, SCS 1972



DETERMINATION OF "Ts"	FIGURE "E-3"

REPRODUCED FROM FIGURE 15.3, SCS 1972



NOTE: THIS METHOD IS APPLICABLE FOR 2000 ACRES OR LESS, WITH CN VALUES BETWEEN 50 AND 95. THIS PROCEDURE MAY OVER ESTIMATE TL WHEN USED FOR MIXED SURFACE TYPE AREAS.

$$T_L = \frac{L^{0.8}(1000/CN - 9)^{0.7}}{1900S^{0.5}}$$

DIRECT DETERMINATION OF SCS "T_L"	FIGURE "E-4"

PROJECT:__________ JOB NO.__________ CALCULATED BY:____________________ DATE:__________

CHECKED BY:____________________ DATE:__________

(THE TABLE BELOW IS AN ADAPTATION OF A WORKSHEET PROVIDED IN THE SCS TR-55)

1) THIS TABLE MAY BE USED IN SUBBASIN Tc CALCULATION, OR FOR TRAVEL TIME OF SUBBASIN RUNOFF THROUGH A LOWER SUBBASIN REACH (Tr).
2) USE ONLY CHANNEL FLOW FOR Tr CALCULATIONS. NOTE THAT THE FLOW PATH AND CHANNEL FLOW LENGTH MAY NOT BE THE SAME FOR BOTH Tc AND Tr CALCULATIONS.

REACH	AREA IDENTIFIER										
	SEGEMENT IDENTIFICATION										
	Tc OR Tr THROUGH BASIN REACH										
OVERLAND FLOW	SURFACE DESCRIPTION (TABLE "E-1")										
	"N" VALUE (TABLE "E-1")										
	FLOW LENGTH, L (TOTAL ≤ 300 FT.)		(ft.)								
	LAND SLOPE, S		(ft./ft.)								
	To_2 (TABLE "E-2", OR FIGURE "E-1")		(min.)								
	To_{100} (TABLE "E-2" OR FIGURE "E-1")		(min.)								
SHALLOW CONCENTRATED FLOW	SURFACE DESCRIPTION (FIGURE "E-3")										
	FLOW LENGTH, L		(ft.)								
	FLOW SLOPE, S		(ft./ft.)								
	FLOW VELOCITY, V (FIGURE "E-3")		(fps.)								
	TRAVEL TIME = L/(60V)		(min.)								
CHANNEL FLOW	CROSS-SECTIONAL FLOW AREA, a		($ft.^2$)								
	WETTED PERIMETER, Pw		(ft.)								
	HYDRAULIC RADIUS, r = a/Pw		(ft.)								
	CHANNEL SLOPE, S		(ft./ft.)								
	MANNING'S COEFFICIENT, n (APPENDIX F)										
	$V = 1.49r^{.67}S^{.5}/n$		(fps.)								
	ASSUMED VELOCITY		(fps.)								
	FLOW LENGTH, L		(ft.)								
	TRAVEL TIME L/(60V)		(min.)								
Tc&Tr	Tc = To + Ts + Tch	2 YEAR	(min.)								
	Tr = Tch (See note (2) above)	100 YEAR	(min.)								
TL	TL = 0.6Tc or	2 YEAR	(min.)								
	FROM FIGURE "E-4"	100 YEAR	(min.)								

TRAVEL TIME WORKSHEET: HEC-12 METHOD TABLE "E-4"

PROJECT:__________ JOB NO.__________ CALCULATED BY:____________________ DATE:__________

CHECKED BY:____________________ DATE:__________

(THE TABLE BELOW IS AN ADAPTATION OF A WORKSHEET PROVIDED IN THE SCS TR-55)

1) THIS TABLE MAY BE USED IN SUBBASIN Tc CALCULATION, OR FOR TRAVEL TIME OF SUBBASIN RUNOFF THROUGH A LOWER SUBBASIN REACH (Tr).

2) USE ONLY CHANNEL FLOW FOR Tr CALCULATIONS. NOTE THAT THE FLOW PATH AND CHANNEL FLOW LENGTH MAY NOT BE THE SAME FOR BOTH Tc AND Tr CALCULATIONS.

REACH	AREA IDENTIFIER									
	SEGEMENT IDENTIFICATION									
	Tc OR Tr THROUGH BASIN REACH									
OVERLAND FLOW	SURFACE DESCRIPTION (TABLE "E-1")									
	"N" VALUE (TABLE "E-1")									
	FLOW LENGTH, L (TOTAL ≤ 300 FT.)	(ft.)								
	LAND SLOPE, S	(ft./ft.)								
	$To_2 = 0.42(NL)^{0.8}/(P_2^{0.5}S^{0.4})$	(min.)								
	$To_{100} = 0.42(NL)^{0.8}/(P_{100}^{0.5}S^{0.4})$	(min.)								
SHALLOW CONCENTRATED FLOW	SURFACE DESCRIPTION (FIGURE "E-3")									
	FLOW LENGTH, L	(ft.)								
	FLOW SLOPE, S	(ft./ft.)								
	FLOW VELOCITY, V (FIGURE "E-3")	(fps.)								
	TRAVEL TIME = L/(60V)	(min.)								
CHANNEL FLOW	CROSS-SECTIONAL FLOW AREA, a	($ft.^2$)								
	WETTED PERIMETER, Pw	(ft.)								
	HYDRAULIC RADIUS, r = a/Pw	(ft.)								
	CHANNEL SLOPE, S	(ft./ft.)								
	MANNING'S COEFFICIENT, n (APPENDIX F)									
	$V = 1.49r^{.67}S^{.5}/n$	(fps.)								
	ASSUMED VELOCITY	(fps.)								
	FLOW LENGTH, L	(ft.)								
	TRAVEL TIME L/(60V)	(min.)								
Tc&Tr	Tc = To + Ts + Tch	2 YEAR (min.)								
	Tr = Tch (See note (2) above)	100 YEAR (min.)								
TL	TL = 0.6Tc or	2 YEAR (min.)								
	FROM FIGURE "E-4"	100 YEAR (min.)								

TRAVEL TIME WORKSHEET: TR-55 METHOD

TABLE "E-3"

PROJECT: ______ JOB NO. ______ CALCULATED BY: ______ DATE: ______

CHECKED BY: ______ DATE: ______

(THE TABLE BELOW IS AN ADAPTATION OF A WORKSHEET PROVIDED IN THE SCS TR-55)

1) THIS TABLE MAY BE USED IN SUBBASIN Tc CALCULATION, OR FOR TRAVEL TIME OF SUBBASIN RUNOFF THROUGH A LOWER SUBBASIN REACH (Tr).

2) USE ONLY CHANNEL FLOW FOR Tr CALCULATIONS. NOTE THAT THE FLOW PATH AND CHANNEL FLOW LENGTH MAY NOT BE THE SAME FOR BOTH Tc AND Tr CALCULATIONS.

REACH	AREA IDENTIFIER									
	SEGEMENT IDENTIFICATION									
	Tc OR Tr THROUGH BASIN REACH									
OVERLAND FLOW	SURFACE DESCRIPTION (TABLE "A-1")									
	RATIONAL COEFFICIENT. C_2, C_{100} (TABLE "B-1")									
	FLOW LENGTH, L (TOTAL ≤ 300 FT.)	(ft.)								
	LAND SLOPE, S	(ft./ft.)								
	To_2 (FIGURE "E-2")	(min.)								
	To_{100} (FIGURE "E-2")	(min.)								
SHALLOW CONCENTRATED FLOW	SURFACE DESCRIPTION (FIGURE "E-3")									
	FLOW LENGTH, L	(ft.)								
	FLOW SLOPE, S	(ft./ft.)								
	FLOW VELOCITY, V (FIGURE "E-3")	(fps.)								
	TRAVEL TIME = L/(60V)	(min.)								
CHANNEL FLOW	CROSS-SECTIONAL FLOW AREA, a	($ft.^2$)								
	WETTED PERIMETER, Pw	(ft.)								
	HYDRAULIC RADIUS, r = a/Pw	(ft.)								
	CHANNEL SLOPE, S	(ft./ft.)								
	MANNING'S COEFFICIENT, n (APPENDIX F)									
	$V = 1.49r^{.67}S^{.5}/n$	(fps.)								
	ASSUMED VELOCITY	(fps.)								
	FLOW LENGTH, L	(ft.)								
	TRAVEL TIME L/(60V)	(min.)								
Tc&Tr	Tc = To + Ts + Tch	2 YEAR (min.)								
	Tr = Tch (See note (2) above)	100 YEAR (min.)								
TL	TL = 0.6Tc or	2 YEAR (min.)								
	FROM FIGURE "E-4"	100 YEAR (min.)								

TRAVEL TIME WORKSHEET: FAA METHOD

TABLE "E-5"

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APPENDIX "F"
MANNING "n" VALUES

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APPENDIX "F"
MANNING "n" VALUES

1. **General Discussion** Charts and tables containing Manning "n" values may be found in many publications. It should be understood, however, that the typical "n" values presented may not be particularly applicable to design storm conditions. Also, typical "n" values provided in charts may or may not account for surface irregularity, vegetation, channel cross-section variation, other obstructions, meandering, flow depth, or channel slope. Two approaches may be followed in selection of an appropriate "n" value: direct use of a chart or table "n" value that is applicable for all known site and design storm conditions, or selection of a base "n" value with adjustments as appropriate. Both procedures are presented herein.

2. **Debris and Sediment Impact** Typical "n" values are appropriate for normal conditions, non-turbulent flow, and also for semi-clean water flow. However, in design storm conditions, the significant presence of sediment, leaves, and other debris causes turbulence and internal rolling/tumbling friction so that, in effect, there is more wetted perimeter than the conduit or channel alone would provide. The normal way to account for this effect is to increase the "n" value. Under a 2-year storm condition, a slight increase in "n" values under certain circumstances may be justified. Under 100-year storm conditions, typical "n" values most likely should be increased to account for sediment, leaves, plastic and paper trash, and turbulence.

   The aforementioned phenomenon of debris and sediment influence on flow resistance is well documented by the USGS (Jarrett 1985) and others. An interesting example is provided by Phillip Williams (ASCE 1990). After discussing the impact of debris and sediment in runoff, the Army Corps of Engineers' Corte Madera Creek flood-control project is described. A smooth concrete channel was designed for the standard project flood using a typical table "n" value of 0.014. During a large but below design storm event, the runoff overflowed the channel banks. Measurements of peak flood elevations and flows made it possible to determine the actual "n" value, which turned out to be 0.030 instead of 0.014 — in a smooth concrete urban channel! Subsequent storms produced similar results. The Army Corps of Engineers concluded that much of the increase in roughness was due to the resistance effect of sediment bed forms moving down the channel.

3. **Supercritical Versus Subcritical** In the Corte Madera project previously described, the effect of sediment and grit flowing in the runoff water caused the flow in the channel to be subcritical instead of supercritical, resulting in a water surface elevation of approximately 6 feet higher than predicted. This is a common phenomenon — it occurs in urban and natural conveyance facilities. Sediment and debris caused turbulence is usually enough even in high-gradient streams and channels to change flow from super- to sub-critical conditions, except for in short segments located throughout the reach, which is well documented (Trieste, and also Jarrett 1984 & 1990). Hence the common FEMA practice having Flood Insurance Study mapping of floodplains and floodways be based upon subcritical flows, not supercritical, regardless of the channel gradient.

4. Minimum Urban "n" Values The following are minimum "n" values for urban stormwater conveyance calculations:

Street asphalt and gutter flow	— 0.016 (minimum)
Pipe flow (smooth bore concrete, PVC, PE, and other pipe)	— 0.012 (minimum)
Pipe flow (corrugated)	— See Table "F-1d"

5. Other Typical "n" Values A collection of "n" value charts and tables are presented in this appendix, as described below.

a. Table "F-1" — Typical Manning Base "n" Values Tables "F-1a" through "F-1e" provide typical base "n" values for various conveyance facilities. Some of the values presented allow adjustment for irregularity, flow depth, vegetation, and channel cross-section variation, although usually to a limited extent. The values do not necessarily account for high intensity storms. These values may be used directly if considered to be applicable to project and design storm conditions. Otherwise, a value should be selected and modified per Table "F-3" to obtain an appropriate value.

b. Table "F-2" — Base "n" Values for Riprap, Cobble, and Boulders In addition or as an alternative to values for cobble and riprap presented in Table "F-1", five equations with conditions are provided for selecting a base "n" value for riprap, cobble, and boulders.

c. Table "F-3" — "n" Value Adjustment Factors It may be difficult to find a table "n" value that matches in every respect channel conveyance conditions. An alternative approach is to select a base "n" value from Table "F-1" or "F-2" that is not yet adjusted (or adjusted for all conditions), and apply additional adjustment factors as appropriate to estimate the appropriate Manning "n" value using the equation

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, MD$$

where:

n = Manning adjusted "n" value;

n_0 = Base (unadjusted or partially adjusted) typical "n" value from Tables "F-1" or "F-2", which is primarily a function of the bed surface material;

n_1 = Adjustment factor to account for surface irregularities if not already accounted for;

n_2 = Adjustment factor to account for obstructions to flow if not already accounted for;

n_3 = Adjustment factor to account for vegetation obstruction if not already accounted for;

n_4 = Adjustment factor to account for variations in channel cross section if not already accounted for;

M = A correction factor to account for main channel meandering; and

D = An adjustment factor to account for variations in debris and sediment impact. (This factor will be at least 1.0. However, due to the wide variety of circumstances and debris potential, and the lack of supporting data, no further recommendations are made — it is left to engineering judgement based upon site specific conditions.)

d. **Chart "F-1" — Manning "n" Values for Vegetated Channels** These charts provide "n" value curves for various uniform man-made vegetated channels, and may be used in lieu of Tables "F-1" and "F-3".

6. **Composite "n" Values** Many computer programs allow for input of various flow resistance factors based upon vertical or horizontal location or flow conditions. It may be convenient to derive a composite "n" value for analysis of flow capacities. Chart "F-2" provides a method of obtaining a composite "n" value.

NOTE: THIS IS A REPRODUCTION OF TABLE I, APPENDIX A, "DESIGN CHARTS FOR OPEN CHANNEL FLOW", (HDS #3)

	Manning's n range [3]
I. Closed conduits:	
A. Concrete pipe	0.011–0.013
B. Corrugated-metal pipe or pipe-arch:	
1. 2⅔ by ½-in. corrugation (riveted pipe): [5]	
a. Plain or fully coated	0.024
b. Paved invert (range values are for 25 and 50 percent of circumference paved):	
(1) Flow full depth	0.021–0.018
(2) Flow 0.8 depth	0.021–0.016
(3) Flow 0.6 depth	0.019–0.013
2. 6 by 2-in. corrugation (field bolted)	0.03
C. Vitrified clay pipe	0.012–0.014
D. Cast-iron pipe, uncoated	0.013
E. Steel pipe	0.009–0.011
F. Brick	0.014–0.017
G. Monolithic concrete:	
1. Wood forms, rough	0.015–0.017
2. Wood forms, smooth	0.012–0.014
3. Steel forms	0.012–0.013
H. Cemented rubble masonry walls:	
1. Concrete floor and top	0.017–0.022
2. Natural floor	0.019–0.025
I. Laminated treated wood	0.015–0.017
J. Vitrified clay liner plates	0.015
II. Open channels, lined [4] (straight alinement): [6]	
A. Concrete, with surfaces as indicated:	
1. Formed, no finish	0.013–0.017
2. Trowel finish	0.012–0.014
3. Float finish	0.013–0.015
4. Float finish, some gravel on bottom	0.015–0.017
5. Gunite, good section	0.016–0.019
6. Gunite, wavy section	0.018–0.022
B. Concrete, bottom float finished, sides as indicated:	
1. Dressed stone in mortar	0.015–0.017
2. Random stone in mortar	0.017–0.020
3. Cement rubble masonry	0.020–0.025
4. Cement rubble masonry, plastered	0.016–0.020
5. Dry rubble (riprap)	0.020–0.030
C. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017–0.020
2. Random stone in mortar	0.020–0.023
3. Dry rubble (riprap)	0.023–0.033
D. Brick	0.014–0.017
E. Asphalt:	
1. Smooth	0.013
2. Rough	0.016
F. Wood, planed, clean	0.011–0.013
G. Concrete-lined excavated rock:	
1. Good section	0.017–0.020
2. Irregular section	0.022–0.027
III. Open channels, excavated [4] (straight alinement,[6] natural lining):	
A. Earth, uniform section:	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In gravelly soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides clean, gravel bottom	0.025–0.030
5. Sides clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock:	
1. Based on design section	0.035
2. Based on actual mean section:	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high stage	0.10–0.14

	Manning's n range [3]
IV. Highway channels and swales with maintained vegetation [4,7] (values shown are for velocities of 2 and 6 f.p.s.):	
A. Depth of flow up to 0.7 foot:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.07–0.045
b. Length 4–6 inches	0.09–0.05
2. Good stand, any grass:	
a. Length about 12 inches	0.18–0.09
b. Length about 24 inches	0.30–0.15
3. Fair stand, any grass:	
a. Length about 12 inches	0.14–0.08
b. Length about 24 inches	0.25–0.13
B. Depth of flow 0.7–1.5 feet:	
1. Bermudagrass, Kentucky bluegrass, buffalograss:	
a. Mowed to 2 inches	0.05–0.035
b. Length 4 to 6 inches	0.06–0.04
2. Good stand, any grass:	
a. Length about 12 inches	0.12–0.07
b. Length about 24 inches	0.20–0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10–0.06
b. Length about 24 inches	0.17–0.09
V. Street and expressway gutters:	
A. Concrete gutter, troweled finish	0.012
B. Asphalt pavement:	
1. Smooth texture	0.013
2. Rough texture	0.016
C. Concrete gutter with asphalt pavement:	
1. Smooth	0.013
2. Rough	0.015
D. Concrete pavement:	
1. Float finish	0.014
2. Broom finish	0.016
E. For gutters with small slope, where sediment may accumulate, increase above values of n by	*0.002*
VI. Natural stream channels:[8]	
A. Minor streams [9] (surface width at flood stage less than 100 ft.):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.035–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	*0.01–0.02*
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e about	*0.01–0.02*
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom of cobbles, with large boulders	0.05–0.07
B. Flood plains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas:	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees: [10]	
a. Winter	0.05–0.06
b. Summer	0.06–0.08
5. Medium to dense brush: [10]	
a. Winter	0.07–0.11
b. Summer	0.10–0.16
6. Dense willows, summer, not bent over by current	0.15–0.20
7. Cleared land with tree stumps, 100–150 per acre:	
a. No sprouts	0.04–0.05
b. With heavy growth of sprouts	0.06–0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10–0.12
b. Flood depth reaches branches	0.12–0.16
C. Major streams (surface width at flood stage more than 100 ft.): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited [8] if possible. The value of n for larger streams of most regular section, with no boulders or brush, may be in the range of	0.028–0.033

TYPICAL MANNING BASE "n" VALUES — **TABLE "F-1a"**

NOTE: THIS IS A REPRODUCTION OF TABLE 2-1 OF METCALFE & EDDY, AND ALSO THE HANDBOOK OF HYDRAULICS, PAGE 7-22.

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Smooth brass and glass pipe	0.009	0.010	0.011	0.013
Smooth lockbar and welded "OD" pipe	0.010	0.011*	0.013*	
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Vitrified sewer pipe	{0.010, 0.011}	0.013*	0.015	0.017
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Glazed brickwork	0.011	0.012	0.013*	0.015
Brick in cement mortar; brick sewers	0.012	0.013	0.015*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Wood stave pipe	0.010	0.011	0.012	0.013
Plank flumes				
Planed	0.010	0.012*	0.013	0.014
Unplaned	0.011	0.013*	0.014	0.015
With battens	0.012	0.015*	0.016	
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Dressed-ashlar surface	0.013	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.011	0.012	0.013	0.015
Semicircular metal flumes, corrugated	0.0225	0.025	0.0275	0.030
Canals and ditches				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033*	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged-earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035
Natural-stream channels				
1. Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
2. Same as (1), but some weeds and stones	0.030	0.033	0.035	0.040
3. Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
4. Same as (3), lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
5. Same as (3), some weeds and stones	0.035	0.040	0.045	0.050
6. Same as (4), stony sections	0.045	0.050	0.055	0.060
7. Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
8. Very weedy reaches	0.075	0.100	0.125	0.150

*Values commonly used in designing.

TYPICAL MANNING BASE "n" VALUES

TABLE "F-1b"

NOTE: THIS IS A REPRODUCTION OF TABLE 3 IN HEC-15.

Lining Category	Lining Type	n - value Flow Depth Ranges 0-0.5 ft	 0.5-2.0 ft	 >2.0 ft
Rigid	Concrete	0.015	0.013	0.013
	Grouted Riprap	0.040	0.030	0.028
	Stone Masonry	0.042	0.032	0.030
	Soil Cement	0.025	0.022	0.020
	Asphalt	0.018	0.016	0.016
Unlined	Bare Soil	0.023	0.020	0.020
	Rock Cut	0.045	0.035	0.025
Temporary*	Woven Paper Net	0.016	0.015	0.015
	Jute Net	0.028	0.022	0.019
	Fiberglass Roving	0.028	0.021	0.019
	Straw with Net	0.065	0.033	0.025
	Curled Wood Mat	0.066	0.035	0.028
	Synthetic Mat	0.036	0.025	0.021
Gravel Riprap	1-inch D_{50}	0.044	0.033	0.030
	2-inch D_{50}	0.066	0.041	0.034
Rock Riprap	6-inch D_{50}	0.104	0.069	0.035
	12-inch D_{50}	--	0.078	0.040

TYPICAL MANNING BASE "n" VALUES | TABLE "F-1c"

SOURCE: AISI 1980 & KAISER ALUMINUM AS FOUND IN CITY OF FORT COLLINS' MANUAL

CORRUGATED METAL PIPE - STEEL

Corrugations	Annular 2 2/3x1/2	Helical 1 1/2x1/4		Helical 2 2/3x1/2					
	All Dia.	8"	10"	12"	18"	24"	36"	48"	60"
Unpaved	.024	.012	.014	.011	.014	.016	.019	.020	.021
25% Paved	.021					.015	.017	.020	.019
Fully Paved	.012					.012	.012	.012	.012

Corrugations	Annular 3x1	Helical 3x1					
	All Dia.	48"	54"	60"	66"	72"	78"
Unpaved	.027	.023	.023	.024	.025	.026	.027
25% Paved	.023	.020	.020	.021	.022	.022	.023
Fully Paved	.012	.012	.012	.012	.012	.012	.012

Corrugations 6x2	Diameters 60"	72"	120"	180"
Plain - Unpaved	.033	.032	.030	.028
25% Paved	.028	.027	.026	.024

CORRUGATED METAL PIPE - ALUMINUM

Pipe Diameter	Helical 1/4x1 1/2	Helical 1/2x2 2/3	Annular 1/2x2 2/3	Helical 1x3	Annular 1x6	Helical 1x6	Annular 2 1/2x9
6	.010						
8	.013						
10	.016						
12		.010	.026				
15		.012	.025				
18		.014	.025				
21		.016	.025				
24		.017	0.25				
30		.018	.025	.019			
36		.019	.025	.020	.025		
42		.020	.024	.020	.024		
48		.020	.024	.020	.024	.020	
54		.020	.024	.021	.024	.020	
60		.021	.024	.021	.024	.021	.035
66		.021	.024	.021	.024	.021	.035
72		.021	.024	.021	.024	.021	.034
78		.021	.024	.021	.024	.021	.034
84		.021	.024	.022	.024	.021	.034
90		.021	.024	.022	.024	.021	.034
96		.021	.024	.022	.024	.021	.034
102				.022	.023	.021	.034
108				.022	.023	.022	.033
114				.022	.023	.022	.033
120				.022	.023	.022	.033
126							.033
168							.032
252							.031

NOTE: DO NOT USE AN "N" VALUE LESS THAN 0.013

TYPICAL MANNING BASE "n" VALUES

TABLE F-1d

THIS IS A REPRODUCTION OF TABLE 5-1, (ADOT)
(based upon Thompson and Hjalmerson, 1991)

BASE VALUES (n_o) OF MANNING'S ROUGHNESS COEFFICIENT FOR STRAIGHT, UNIFORM, STABLE CHANNELS

(USE WITH TABLE "F-3")

Channel Material	Size of Bed Material		Base Values, n_o	
	Millimeters	Inches	Benson and Dalrymple (1967)[a]	Chow (1959)[b]
Concrete	——	——	0.012-0.018	0.011
Rock Cut	——	——	———	.025
Firm Soil	——	——	.025- .032	.020
Coarse Sand	1-2	——	.026- .035	——
Fine Gravel	——	——	———	.024
Gravel	2-64	0.08- 2.5	.028- .035	——
Coarse Gravel	——	——	———	.028
Cobble	64-256	2.50-10.0	.030- .050	——
Boulder	>256	>10.0	.040- .070	——

[a]Straight uniform channel.

[b]Smoothest channel attainable in indicated material.

TYPICAL MANNING BASE "n" VALUES	TABLE F-1e

BED SLOPE (ft/ft)	ROCK SHAPE	MINIMUM BED MATERIAL SIZE (feet)	RELATIVE SUBMERGENCE FACTOR d/D_x	EQUATION FOR BASE "n" VALUE	SOURCE
$S \leq 0.02$	ROUNDED	---	---	$n = \frac{(0.0926)R^{1/6}}{1.16 + 2.0 \log\left[\frac{R}{D_{84}}\right]}$	Limerinos 1970, as found in Jarrett 1984
$0.002 \leq S$	---	0.2	---	$n = 0.39S^{0.38}R^{-0.16}$	Jarrett 1984
$0.01 \leq S \leq 0.20$	---	---	$\frac{d}{D_{84}} \leq 7.3$	$n = 0.0456(D_{50} \cdot S)^{0.159}$	Abt 1988
See note 1	---	See note 1	$1.5 < \frac{d}{D_{50}} < 185$	$n = 0.093d^{0.167}$	FHWY HEC-11
See note 1	---	See note 1	$185 < \frac{d}{D_{50}} < 30{,}000$	$n = 0.019d^{0.167}$	FHWY HEC-11

NOTES:

1. If the slope is greater than 0.002 ft/ft and the bed material is larger than 0.2 ft, use equation by Jarrett.
2. Nomenclature: S = slope; d = average depth of flow; Dx = the rock or particle size for which "x"% of the stream bed surface particles are finer by weight; and R = hydraulic radius of stream.

BASE "n" VALUES FOR RIPRAP, COBBLE, AND BOULDERS — **TABLE "F-2"**

THIS TABLE IS A REPRODUCTION OF TABLE 5-2 (ADOT)

(from Thomsen and Hjalmarson, 1991)

Channel Conditions	Manning's n adjustment[a]	Example
Degree of irregularity:	n_1	
Smooth	0.000	Smoothest channel attainable in given bed material.
Minor	.001 - .005	Channels with slightly eroded or scoured side slopes.
Moderate	.006 - .010	Channels with moderately sloughed or eroded side slopes.
Severe	.011 - .020	Channels with badly sloughed banks; unshaped, jagged, and irregular surfaces of channels in rock.
Effects of obstruction[b]:	n_2	
Negligible	.000 - .004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
Minor	.005 - .015	Obstructions occupy 5 to 15 percent of the cross-sectional area and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
Appreciable	.020 - .030	Obstructions occupy from 15 to 50 percent of the cross-sectional area or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
Severe	.040 - .060	Obstructions occupy more than 50 percent of the cross-sectional area or the space between obstructions is small enough to cause turbulence across most of the cross section.

[a] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base n value before multiplying by the adjustment for meander.

[b] Conditions considered in other steps must not be reevaluated or duplicated in this section.

"n" VALUE ADJUSTMENT FACTORS	TABLE F-3a

THIS TABLE IS A REPRODUCTION OF TABLE 5-2 (ADOT)

Channel Conditions	Manning's n adjustment[c]	Example
Vegetation:	n_3	
Small	.002 - .010	Dense growths of flexible turf grass, such as Bermuda, or weeds where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrow weed, or saltcedar, where the average depth of flow is at least three times the height of the vegetation.
Medium	.010 - .025	Grass or weeds where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings, where the average depth of flow is from two to three times the height of the vegetation; moderately dense brush, similar to 1- to 2-year-old saltcedar in the dormant season, along the banks and to no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet.
Large	.025 - .050	Turf grass or weeds where the average depth to flow is about equal to the height of vegetation; small trees intergrown with some weeds and brush where the hydraulic radius exceeds 2 feet.
Very Large	.050 - .100	Turf grass or weeds where the average depth of flow is less than half the height of vegetation; small bushy trees intergrown with weeds along side slopes of dense cattails growing along channel bottom; trees intergrown with weeds and brush.
Variations in channel cross section:	n_4	
Gradual	.000	Size and shape of cross sections change gradually.
Alternating	.001 - .005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
Alternating	.010 - .015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.

[c] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base n value before multiplying by the adjustment for meander.

"n" VALUE ADJUSTMENT FACTORS	TABLE F-3b

THIS TABLE IS A REPRODUCTION OF TABLE 5-2 (ADOT)

Channel Conditions	Manning's n adjustment[d]	Example
Degree of meandering[e]:	m	
Minor	1.00	Ratio of the meander length to the straight length of the channel reach is 1.0 to 1.2.
Appreciable	1.15	Ratio of the meander length tc the straight length of the channel is 1.2 to 1.5.
Severe	1.30	Ratio of the meander length to the straight length of the channel is greater than 1.5.

[d] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base n value before multiplying by the adjustment for meander.

[e] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders. The adjustment is a multiplier.

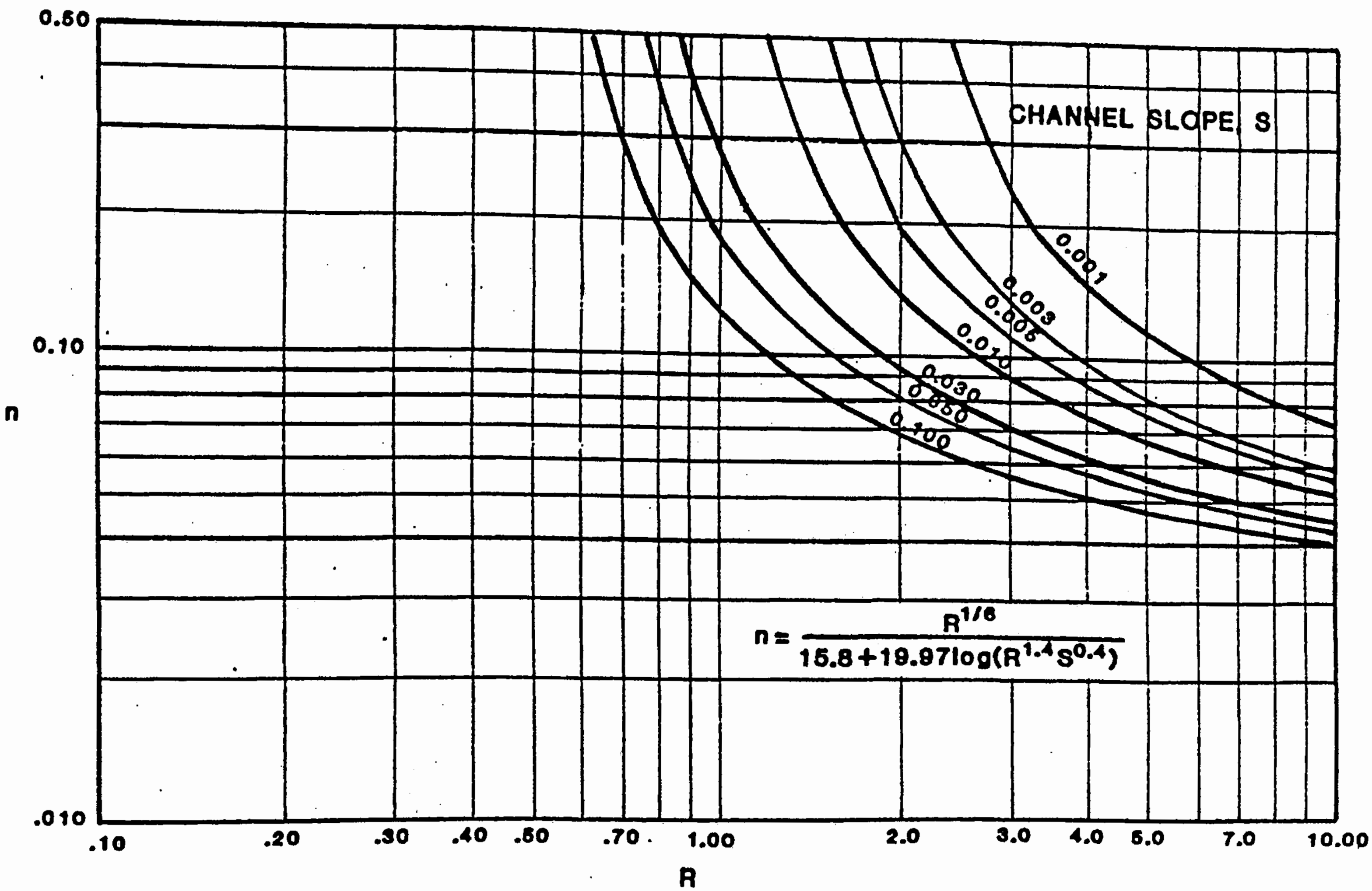
"n" VALUE ADJUSTMENT FACTORS

TABLE F-3c

MANNING "n" VALUES FOR VEGETATED CHANNELS

CHART "F-1a"

NOTE: THIS IS A REPRODUCTION OF CHART 5 IN HEC-15



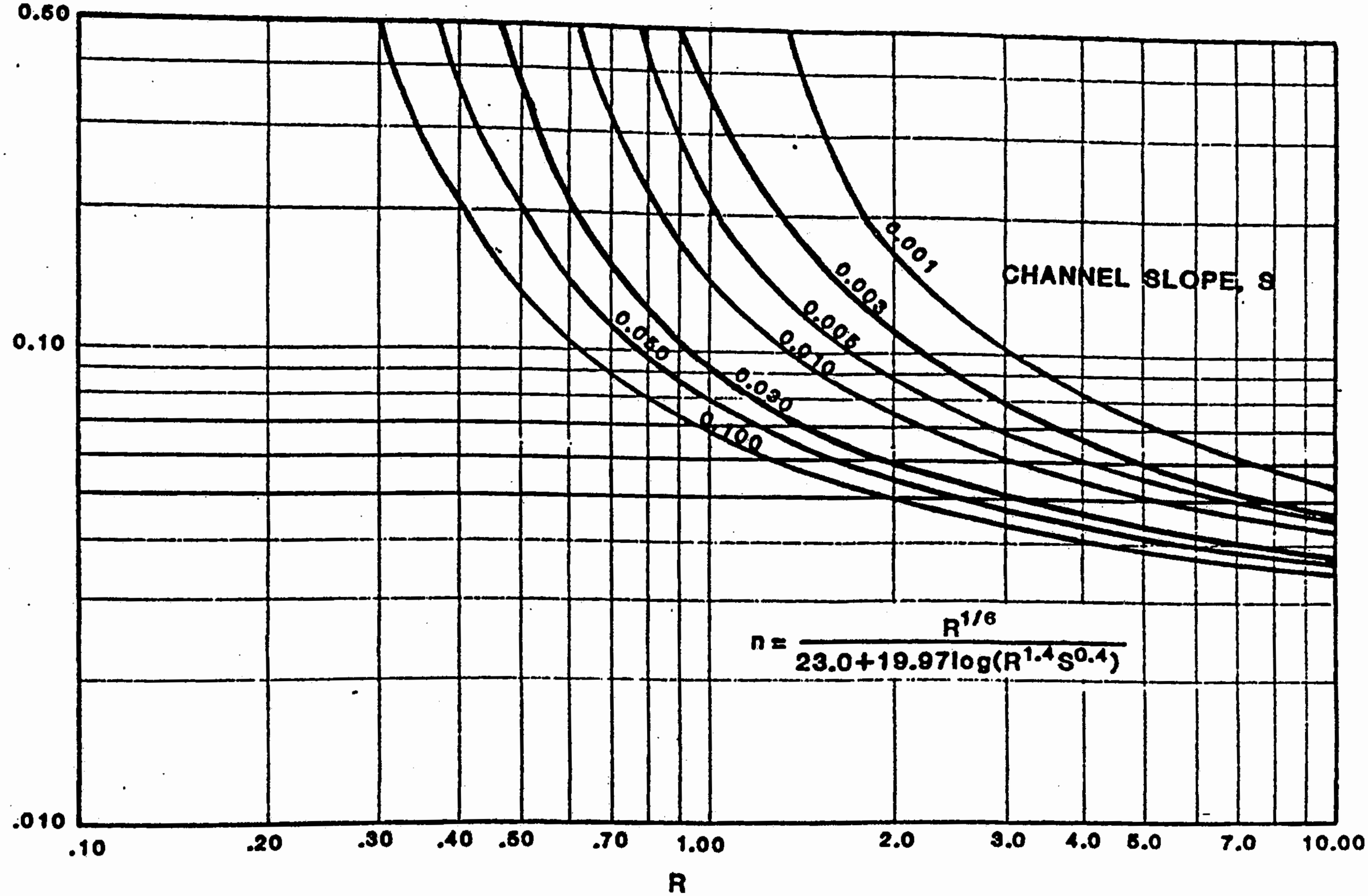
Manning's "n" versus hydraulic radius, R, for class A vegetation.

(See Chart F-1f for Vegetation class)

MANNING "n" VALUES FOR VEGETATED CHANNELS

CHART "F-1b"

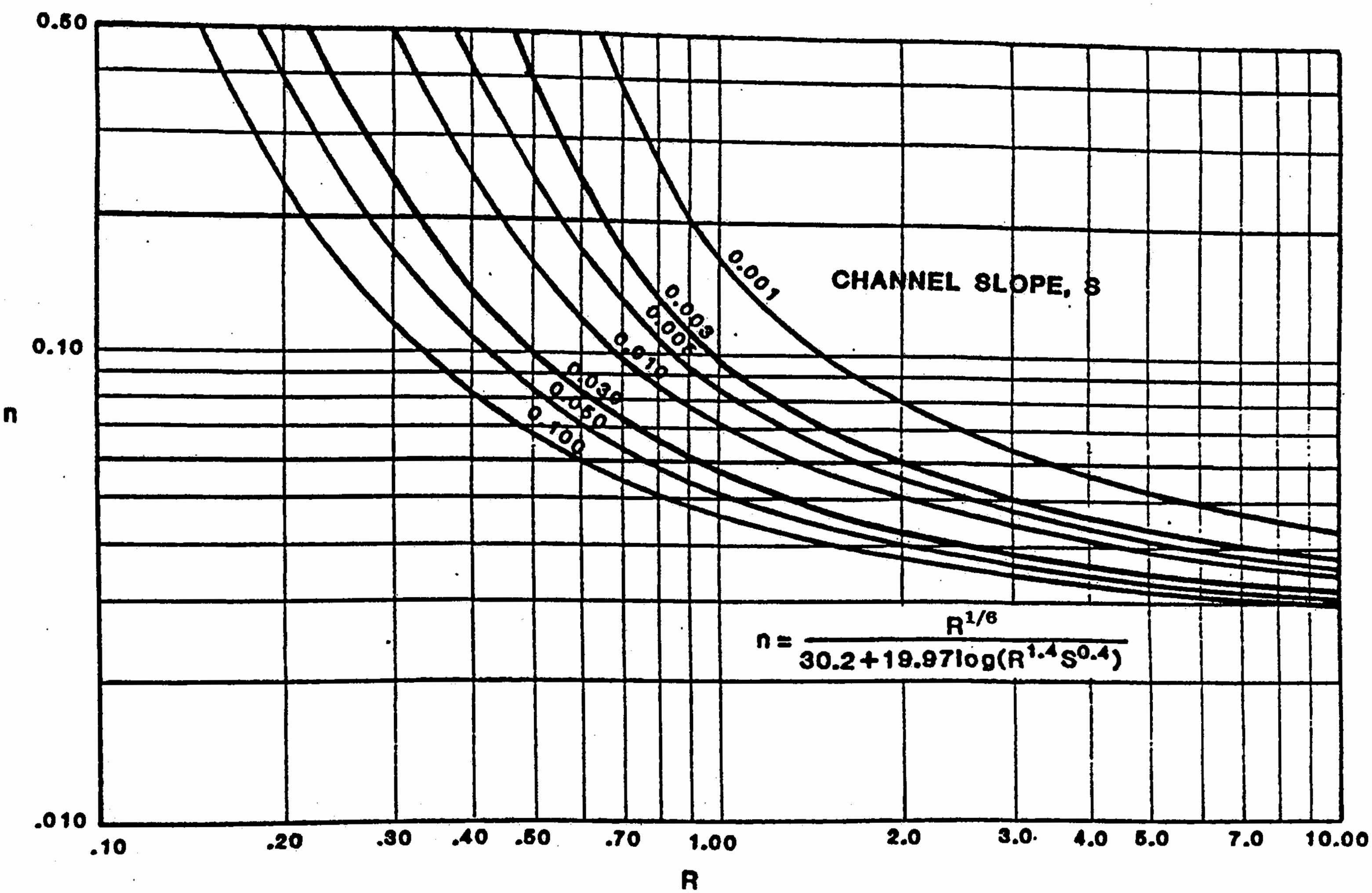
NOTE: THIS IS A REPRODUCTION OF CHART 6 IN HEC-15



Manning's "n" versus hydraulic radius, R, for class B vegetation.

(See Chart F-1f for Vegetation class)

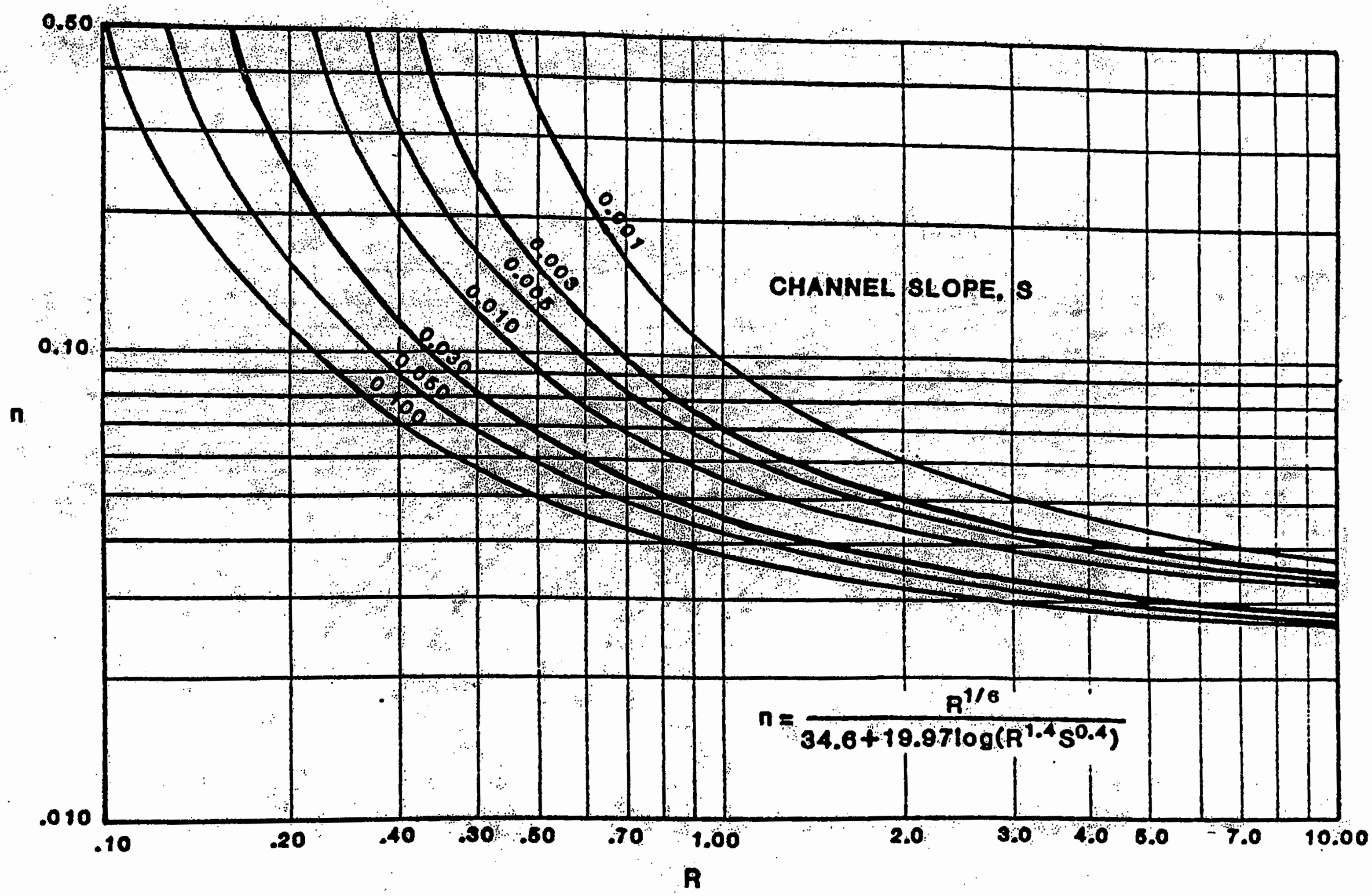
NOTE: THIS IS A REPRODUCTION OF CHART 7 IN HEC-15



Manning's "n" versus hydraulic radius, R, for class C vegetation.

(See Chart F-1f for Vegetation class)

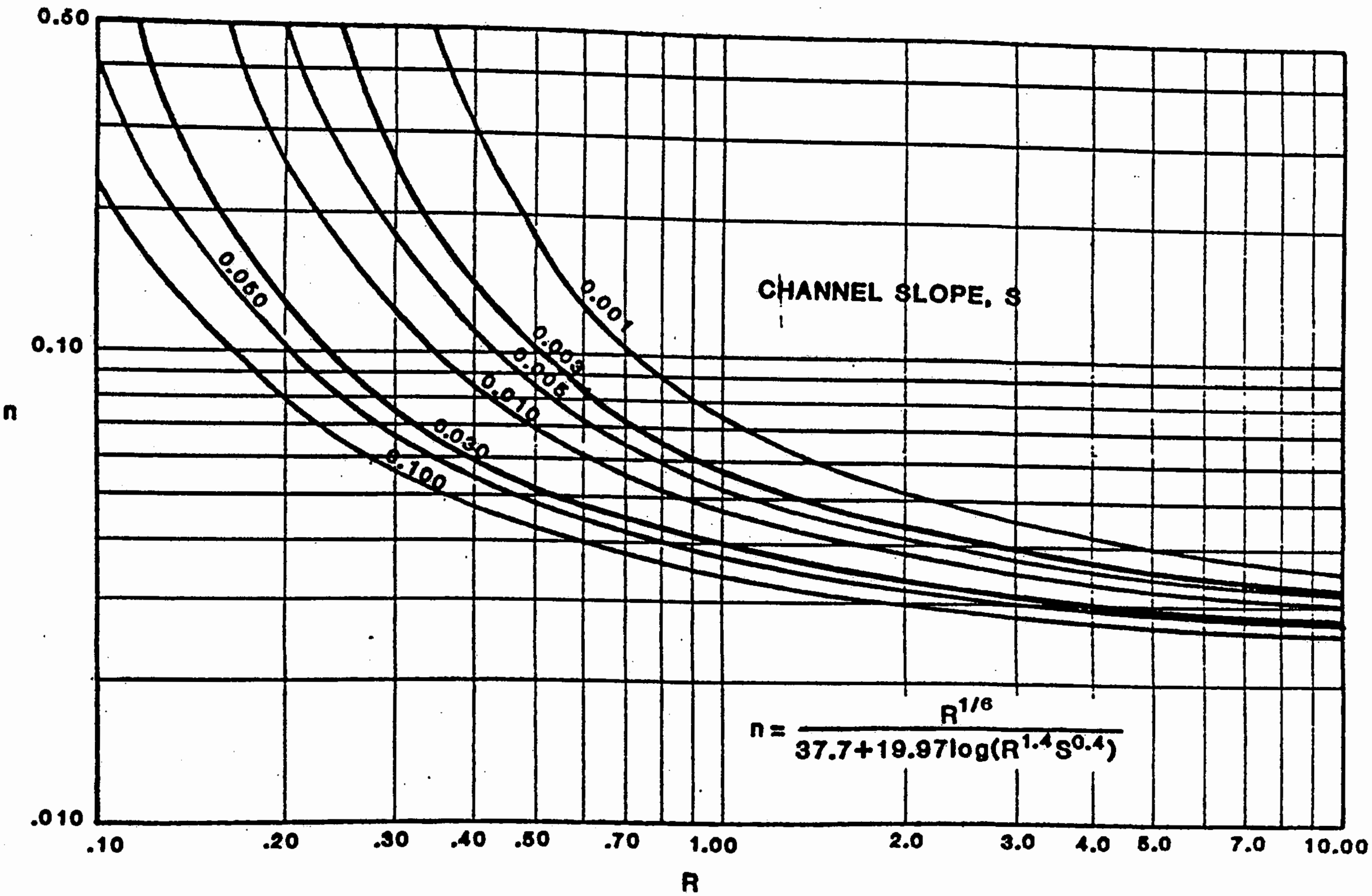
NOTE: THIS IS A REPRODUCTION OF CHART 8 IN HEC-15



Manning's "n" versus hydraulic radius, R, for class D vegetation.

(See Chart F-1f for Vegetation class)

NOTE: THIS IS A REPRODUCTION OF CHART 9 IN HEC-15



Manning's "n" versus hydraulic radius, R, for class E vegetation.

(See Chart F-1f for Vegetation class)

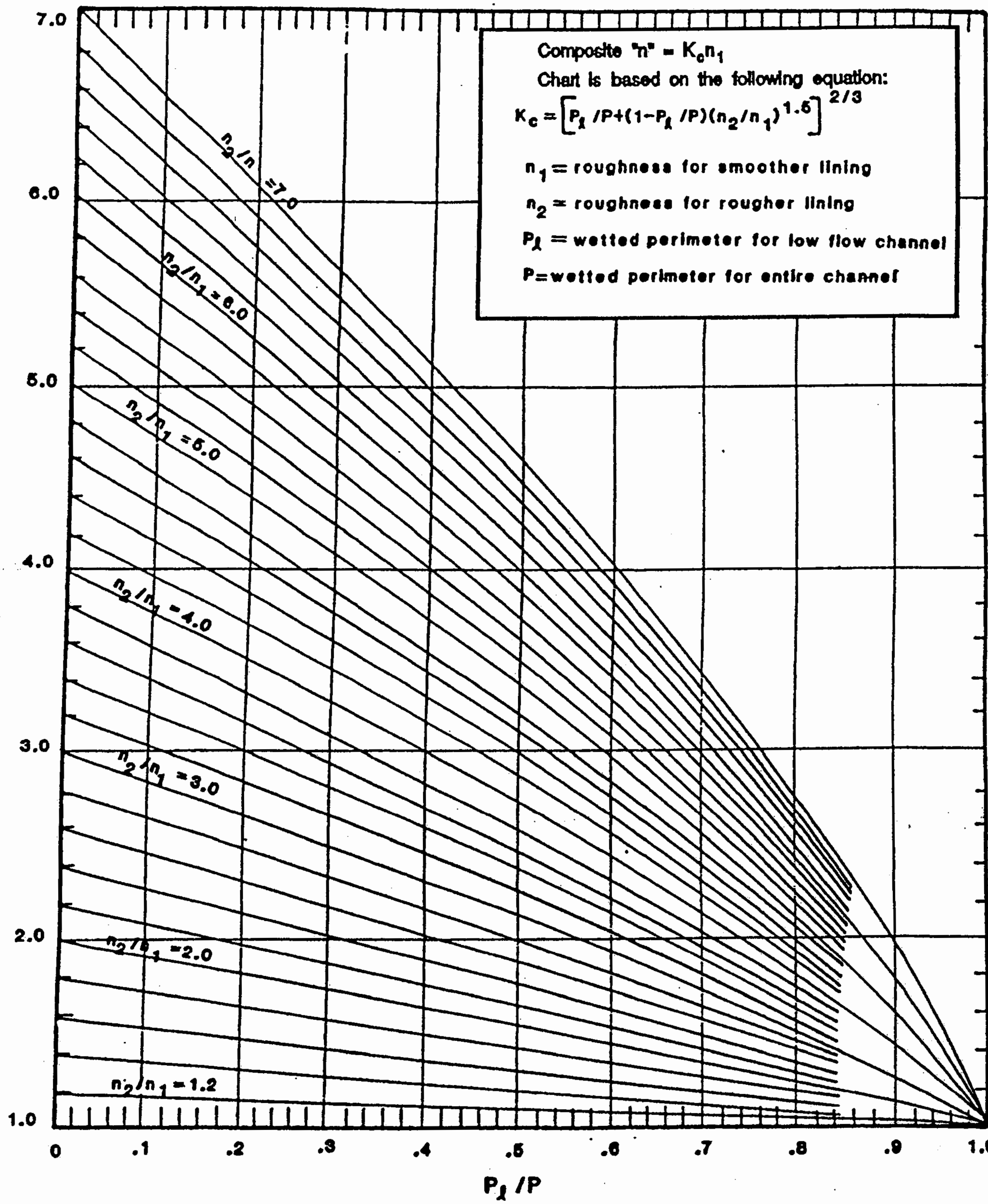
NOTE: THIS IS A REPRODUCTION OF TABLE 1 IN HEC-15

Classification of Vegetal Covers as to Degree of Retardance.

Retardance Class	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30") (76 cm)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36") (91 cm)
B	Kudzu	Very dense growth, uncut
	Bermuda grass	Good stand, tall (average 12") (30 cm)
	Native grass mixture (little bluestem, bluestem, blue gamma, and other long and short midwest grasses)..........	Good stand, unmowed
	Weeping lovegrass	Good stand, tall (average 24") (61 cm)
	Lespedeza sericea	Good stand, not woody, tall (average 19") (48 cm)
	Alfalfa	Good stand, uncut (average 11") (28 cm)
	Weeping lovegrass	Good stand, unmowed (average 13") (33 cm)
	Kudzu	Dense growth, uncut
	Blue gamma	Good stand, uncut (average 13") (28 cm)
C	Crabgrass	Fair stand, uncut (10 to 48") (25 to 120 cm)
	Bermuda grass	Good stand, mowed (average 6") (15 cm)
	Common lespedeza	Good stand, uncut (average 11") (28 cm)
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)....	Good stand, uncut (6 to 8 inches) (15 to 20 cm)
	Centipedegrass..............	Very dense cover (average 6 inches) (15 cm)
	Kentucky bluegrass..........	Good stand, headed (6 to 12 inches (15 to 30 cm)
D	Bermuda grass...............	Good stand, cut to 2.5-inch height (6 cm)
	Common lespedeza	Excellent stand, uncut (average 4.5") (11 cm)
	Buffalo grass	Good stand, uncut (3 to 6 inches (8 to 15 cm)
	Grass-legume mixture--fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza)...............	Good stand, uncut (4 to 5 inches) (10 to 13 cm)
	Lespedeza sericea	After cutting to 2-inch height (5 cm) Very good stand before cutting
E	Bermuda grass	Good stand, cut to 1.5 inch height (4 cm)
	Bermuda grass	Burned stubble

NOTE: Covers classified have been tested in experimental channels. Covers were green and generally uniform.

NOTE: THIS IS A REPRODUCTION OF CHART 25 IN HEC-15



COMPOSITE "n" VALUES	CHART "F-2"

CHANNEL REACH I.D.	SURFACE DESCRIPTION OR PORTION OF CHANNEL	TYPICAL MANNING BASE "n" VALUE (i)	"n" VALUE ADJUSTMENT FACTORS (ii)						ADJUSTED MANNING "n" VALUE (iii)
		n_0	n_1	n_2	n_3	n_4	m	D	n
ZZ	EXAMPLE	0.030	0.003	0.010	0.004	0.001	1.05	1.000	0.050

(I) SEE TABLE "F-1", TABLE "F-2", OR CHART "F-1" FOR SELECTION. (II) SEE TABLE "F-3" FOR SELECTION IF APPLICABLE. (III) $n = (n_0 + n_1 + n_2 + n_3 + n_4)mD$

MANNING "n" VALUE WORKSHEET

TABLE "F-4"

CHANNEL REACH I.D.	ADJUSTED MANNING "n" VALUE			"n" VALUE WETTED PERIMETER			ADJUSTMENT FACTOR FROM CHART "F-2" (K_c)	COMPOSITE MANNING "n" VALUE ("n" = $K_c n_1$) (n)
	ROUGHER LINING (n_2)	SMOOTHER LINING (n_1)	"n" VALUE RATIO n_2/n_1	LOW FLOW CHANNEL (P_ℓ)	ENTIRE CHANNEL (P)	"P" VALUE RATIO P_ℓ/P		
EXAMPLE	0.060	0.030	2.0	10	50	0.20	1.82	0.055

COMPOSITE MANNING "n" VALUE WORKSHEET

TABLE "F-5"

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APPENDIX "G"
STREET FLOW AND INLET CAPACITY CHARTS

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APPENDIX "G"
STREET FLOW AND INLET CAPACITY CHARTS

Street and inlet flow criteria were presented in Section VII. In this Appendix, capacity information is provided which is in accordance with such criteria.

1. **Street Inundation Limits** The street inundation limits presented in Section VII are graphically shown in Figure "G-1". It may be observed that the inundation limits selected allow for maximum usage of local streets to convey storm runoff, which streets usually precede stormwater storage facilities, and have limited traffic usage. For collector, commercial, and industrial streets, however, traffic needs do not allow for extensive use of streets for stormwater, and a storm drainage sewer or channel is usually required. Although arterial roads have more stormwater conveyance capacity due to their width, they should not receive direct runoff except where drainage fee applications apply. In this way, arterial roads convey small amounts of runoff from side collector streets and limited direct runoff from adjacent property.

2. **Flow Capacity Charts** Design aids are provided for the solution of both standard and unique project conditions.

   a. **Standard Conditions** When streets, gutters, and inlets conform with July 1992 City/County street standards with street cross slopes at 2%, the condition is said to be standard. The paragraphs below explain procedures and use of figures pertaining to standard conditions.

   HEC-12 procedures allow for gutter slopes that are different from street slopes, but do not allow for a 1/4-inch drop from edge of pavement to lip of gutter, and non-vertical curb faces. In order to simplify the analysis process, the gutter shape was modified as shown in Figure "G-2". Using this modification of standard conditions, HEC-12 procedures, and the inundation limits shown in Figure "G-1", the inundation limits shown in Figure "G-3" were determined.

   In addition to street inundation limits and flow depths, it would be helpful to know allowed street capacities. This may be theoretically calculated, but experience has shown that actual capacity is less than theoretical capacity. This occurs because of flow expansion and contraction at curb openings and gutter irregularities, intersections, and locations with debris. There is a further reduction of flow capacity where street parking of cars is allowed. Application of capacity reduction factors which are applied to theoretical capacity is often a requirement. Figure "G-4" shows the reduction factors required for use by Maricopa County. (UD&FCD reduction factors are even more restrictive.) Also shown are the reduction factors required per this manual, which is essentially the Maricopa County curves except for modifications that result in constant street capacity as slopes increase beyond a certain point. Both the UD&FCD and Maricopa County reduction factors result in decreased flow capacity as slope increases.

Applying required reduction factors shown in Figure "G-4" to the street inundation limits shown in Figure "G-3" allows preparation of curves which show maximum allowed half street flows. These are shown in Figure "G-5". The benefit of these curves is that they allow a designer to quickly determine how far a street may have adequate conveyance capacity before removal of runoff is required. This helps locate inlets and other storm drainage facilities that are required.

The next question may be, "Now that the allowed flow capacity of the street is reached, what size and type of inlet is required, how much runoff will be intercepted, and how much will flow past the inlet and continue on?" This question can usually be answered directly from figures and a table presented herein. Inlet types are shown in Figure "G-6", of which only type (b) and (c) are normally allowed per standards. For inlet types which conform to City/County standards, use of HEC-12 procedures and Figure "G-5" allows calculation of inlet capacities at maximum allowed street flow depths. The results are shown on Figures "G-7A"through "G-7D" and Table "G-1".

Note that while street flow capacities are reduced per Figure "G-4" to account for flow obstructions, the flow depth remains the same as it would be for the theoretical street flow; that is, with allowed street flow under backwater conditions or with theoretical street flow without backwater, depths are the same. Therefore, the inlet capacities shown, which were calculated based upon theoretical flow conditions, should be appropriate.

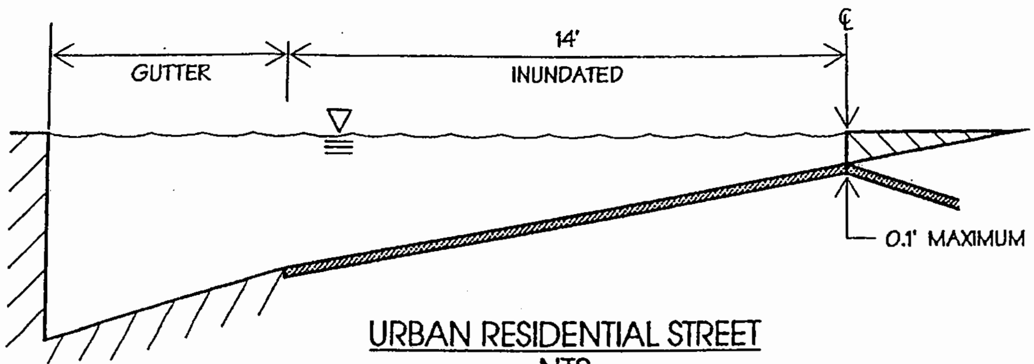
A typical use of these figures would be as follows:

i) Determine by hydrological procedures and Figure "G-5" the probable location where allowable street capacity is reached and an inlet is required; and

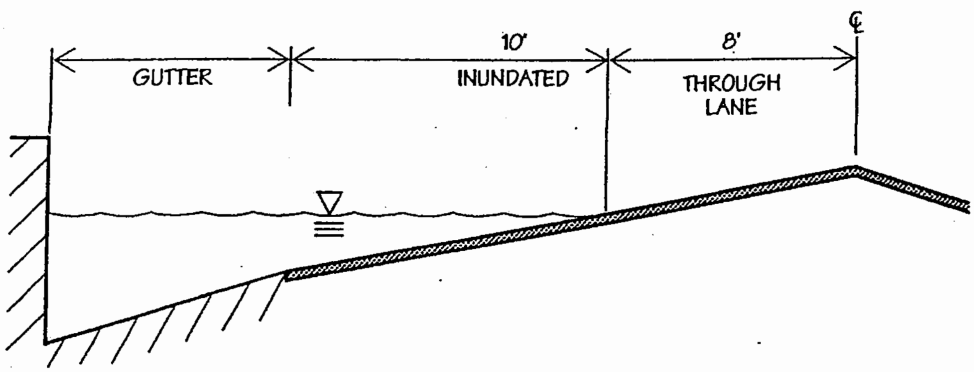
ii) Select an appropriate inlet per Figure "G-7" (or Table "G-1" if in a sump application), and determine interception capacity. The balance of runoff, if any, overflows the inlet and is added to additional contributing runoff downstream. One then goes back to step (i) above and repeats the process until all runoff is accounted for.

b. <u>Non-Standard Conditions</u> For projects that involve conditions that are not standard as defined above, specific calculations will be required. Figure "G-8" may be used to calculate theoretical street capacity, which must be reduced per Figure "G-4". Once allowable street flow capacities are determined, HEC-12 procedures must be used to calculate inlet capacities, where required.

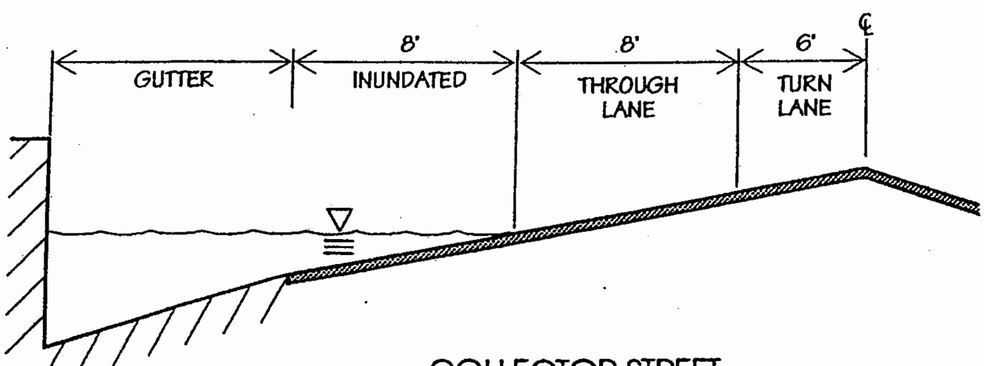
An inlet interception capacity worksheet is provided on Table "G-2".



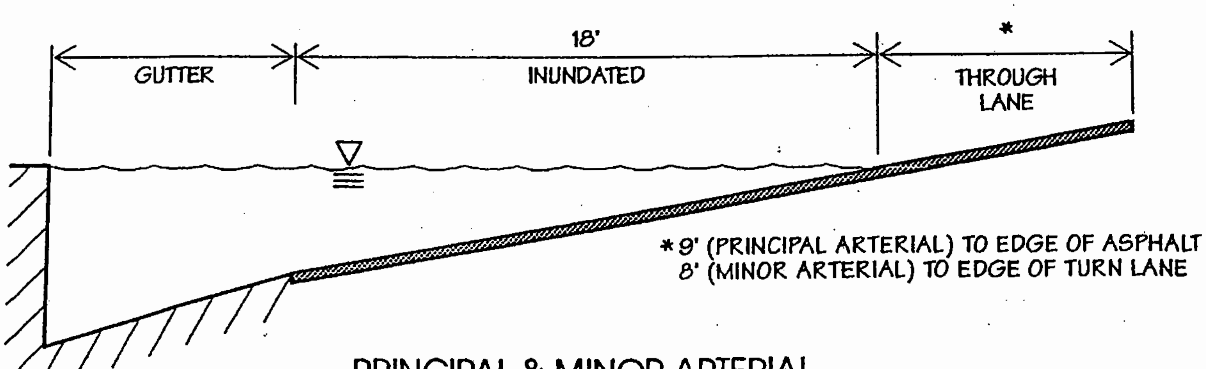
URBAN RESIDENTIAL STREET
NTS



URBAN RESIDENTIAL COLLECTOR, COMMERCIAL & INDUSTRIAL STREETS
NTS



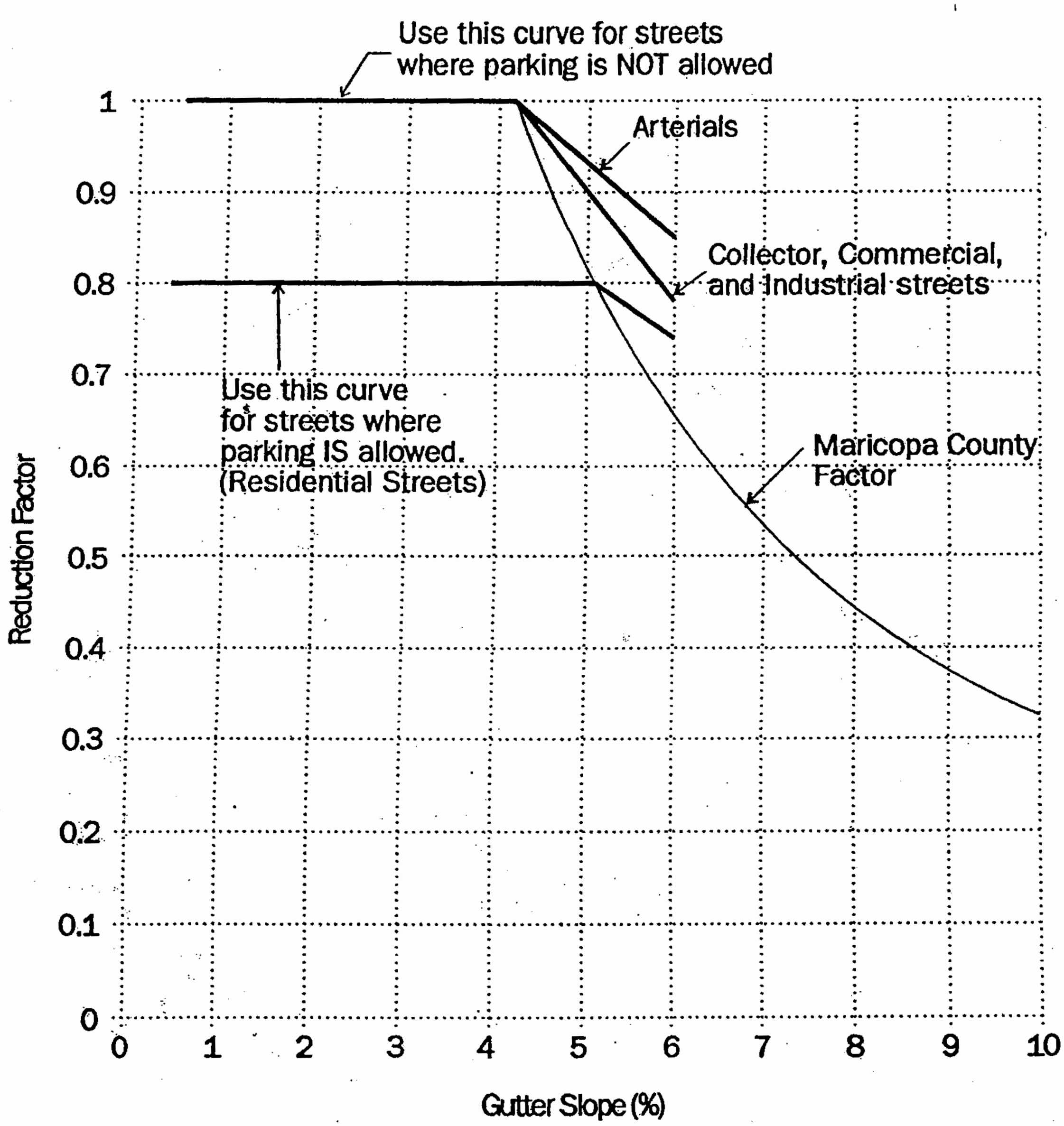
COLLECTOR STREET
NTS



PRINCIPAL & MINOR ARTERIAL
NTS

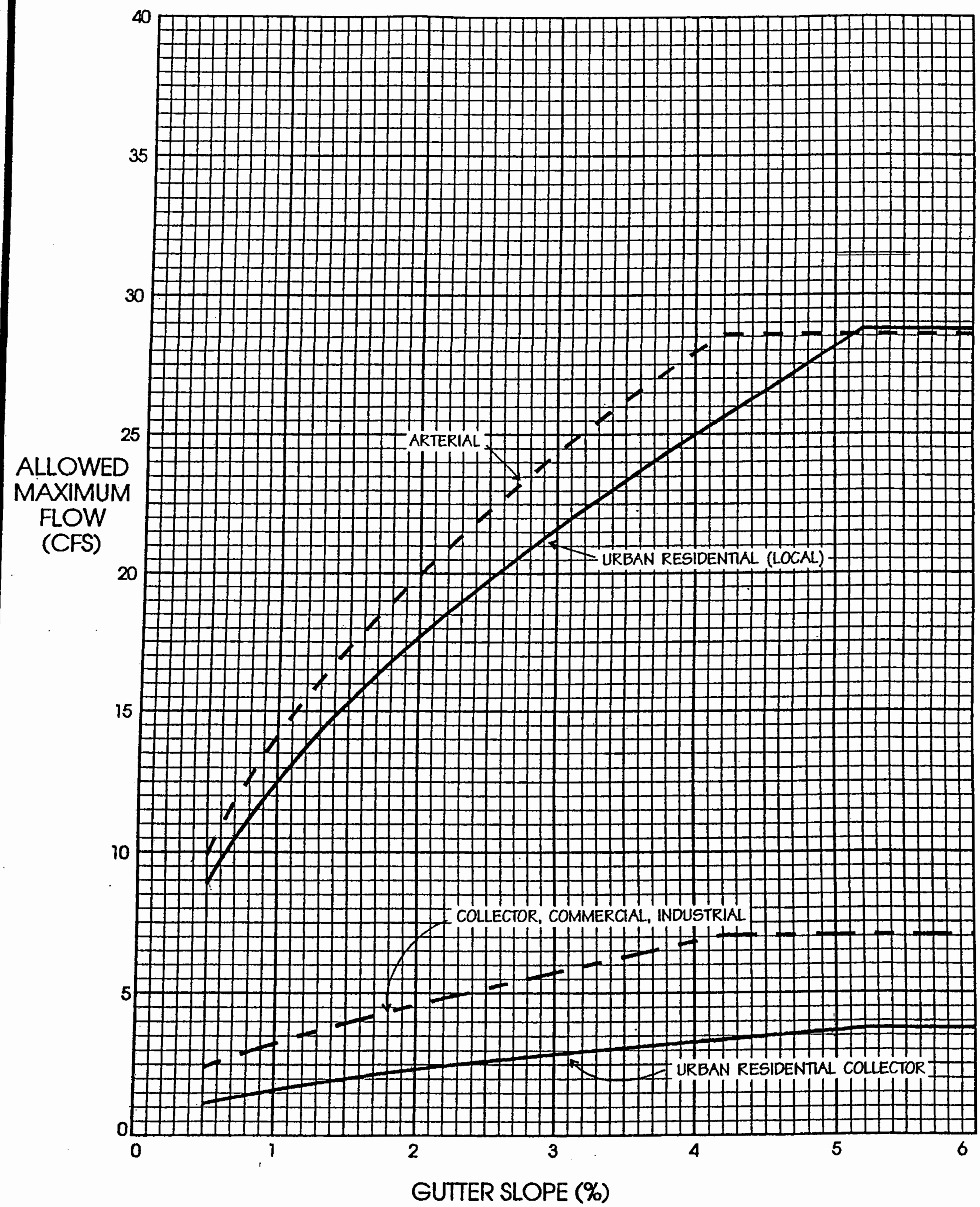
STREET INUNDATION LIMITS FOR THE 2-YEAR STORM (SEE CITY/COUNTY STD. STREET SECTIONS, 7/92)	**FIGURE "G-1"**

Reduction factors required per this manual are based upon Maricopa County's, except that reductions at greater slopes are adjusted so that resultant street flow capacities do not decrease as slope increases, but at least remain constant (See Figure G-5).



GUTTER CAPACITY REDUCTION FACTORS

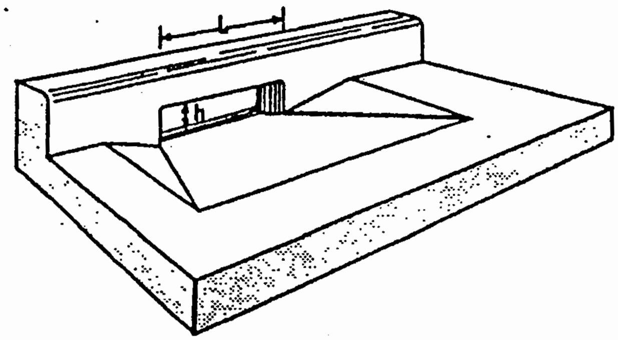
FIGURE G-4



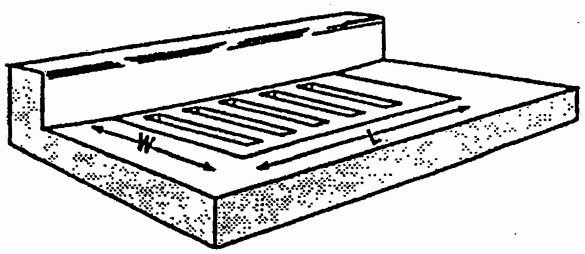
MAXIMUM HALF STREET FLOWS (Sx=2%, n=0.016)
(Based upon Figures G-3 and G-4)

FIGURE "G-5"

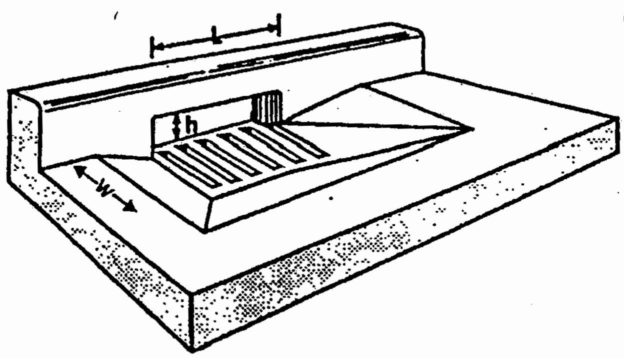
MODIFIED FROM DRAINAGE DESIGN MANUAL FOR MARICOPA COUNTY, VOL-II



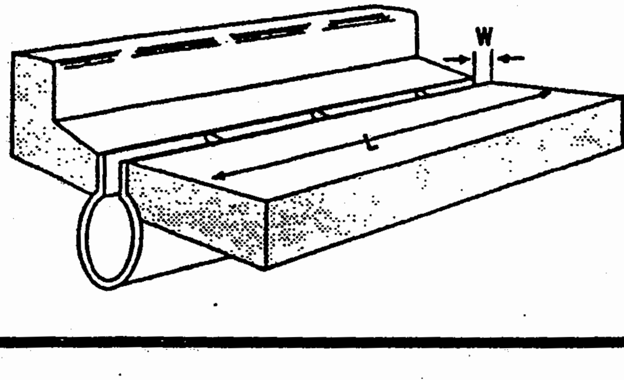
(a) Curb Opening Catch Basin Inlet
Clogging Factor = 80% of HEC-12



(b) Grated Catch Basin Inlet
- P = 2w + L
- Clogging Factor
  - On grade - 50% of HEC-12
  - Sag or Sump - 0% of HEC-12 (i.e., not allowed)



(c) Combination Catch Basin Inlet
- P = 2w + L
- Clogging Factor
  - On grade
    Grate @ 100% of HEC-12
    Curb Opening @ 0% of HEC-12
  - Sag or Sump [<0.5' depth]
    Grate @ 100% of HEC-12
    Curb Opening @ 0% of HEC-12
  - Sag or Sump [1.0' depth]
    Grate @ 50%of HEC-12
    Curb Opening @100% of HEC-12

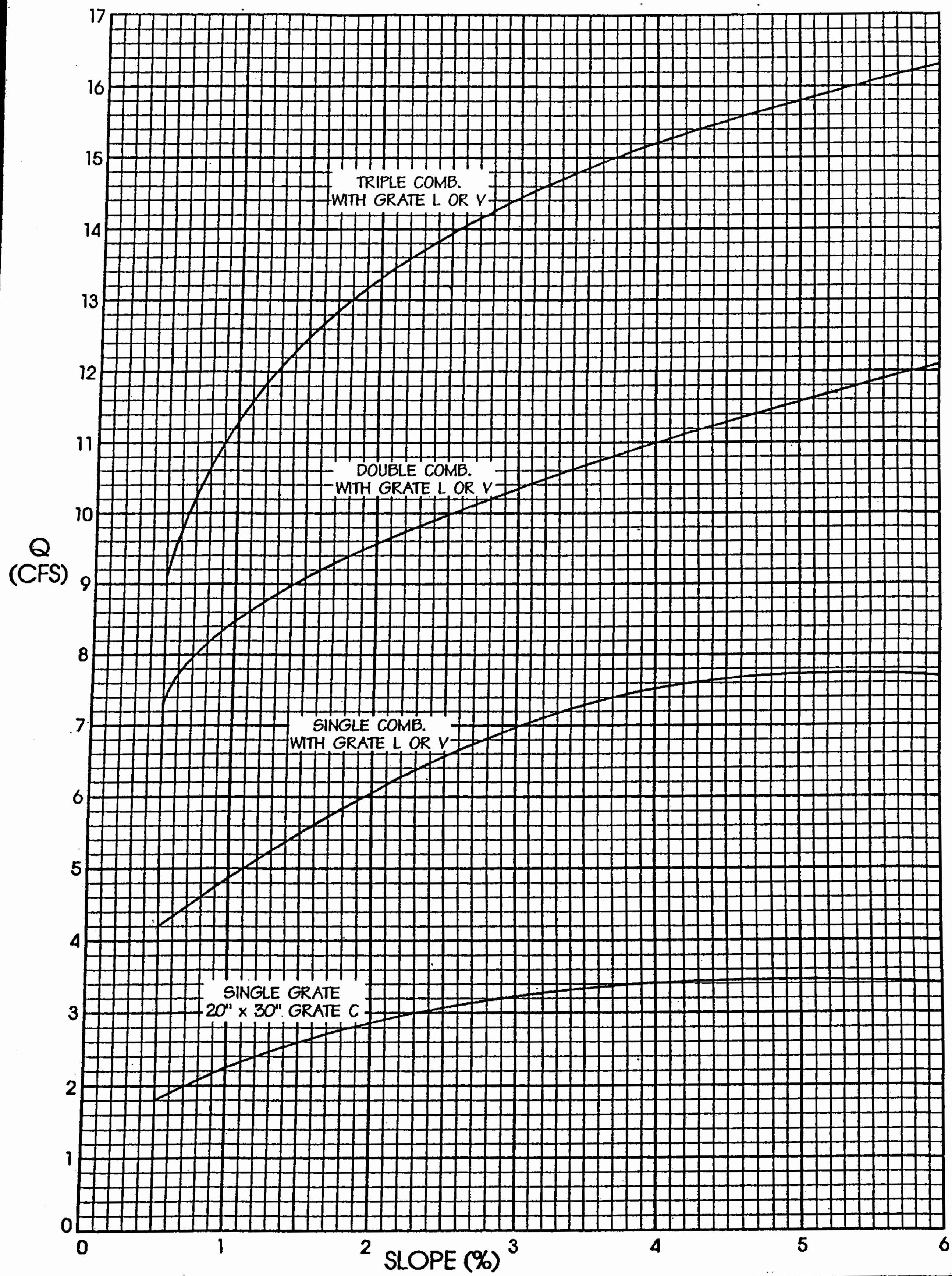


(c) Slotted Drain Catch Basin Inlet
Clogging Factor = 80% of HEC-12
(not allowed in sag or sump condition)

CATCH BASIN INLET TYPES

FIGURE G-6

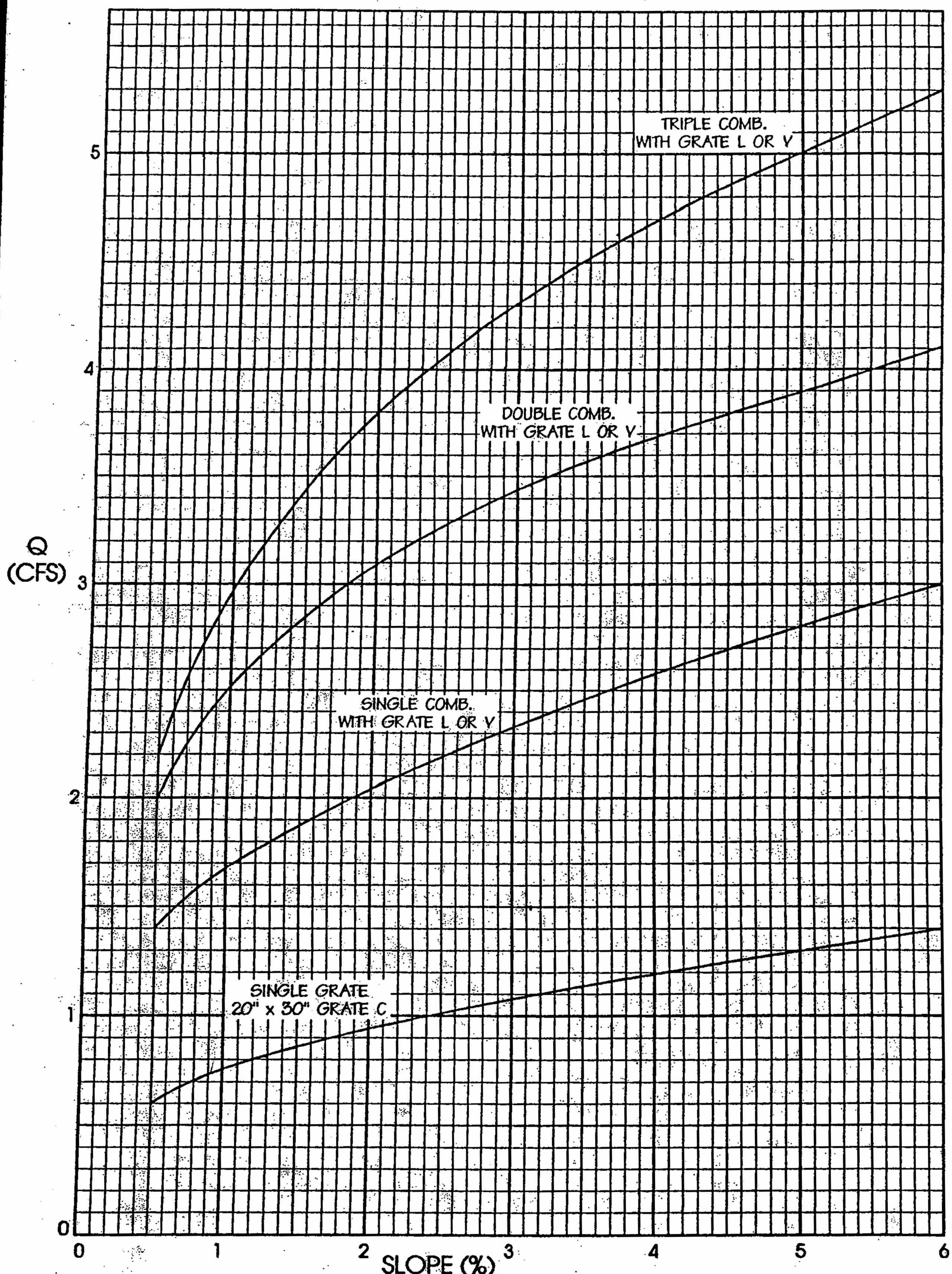
INLET CAPACITIES PROVIDED ARE BASED UPON FIGURE "G-4", MAXIMUM ALLOWED FLOW CONDITIONS, SMF ENGINEERING CORP.'S HEC-12 SOFTWARE, CLOGGING FACTORS PRESENTED IN SECTION VI, AND CITY\COUNTY STANDARD INLETS.



MAXIMUM INLET CAPACITIES: ON-GRADE
URBAN RESIDENTIAL (LOCAL)

FIGURE "G-7a"

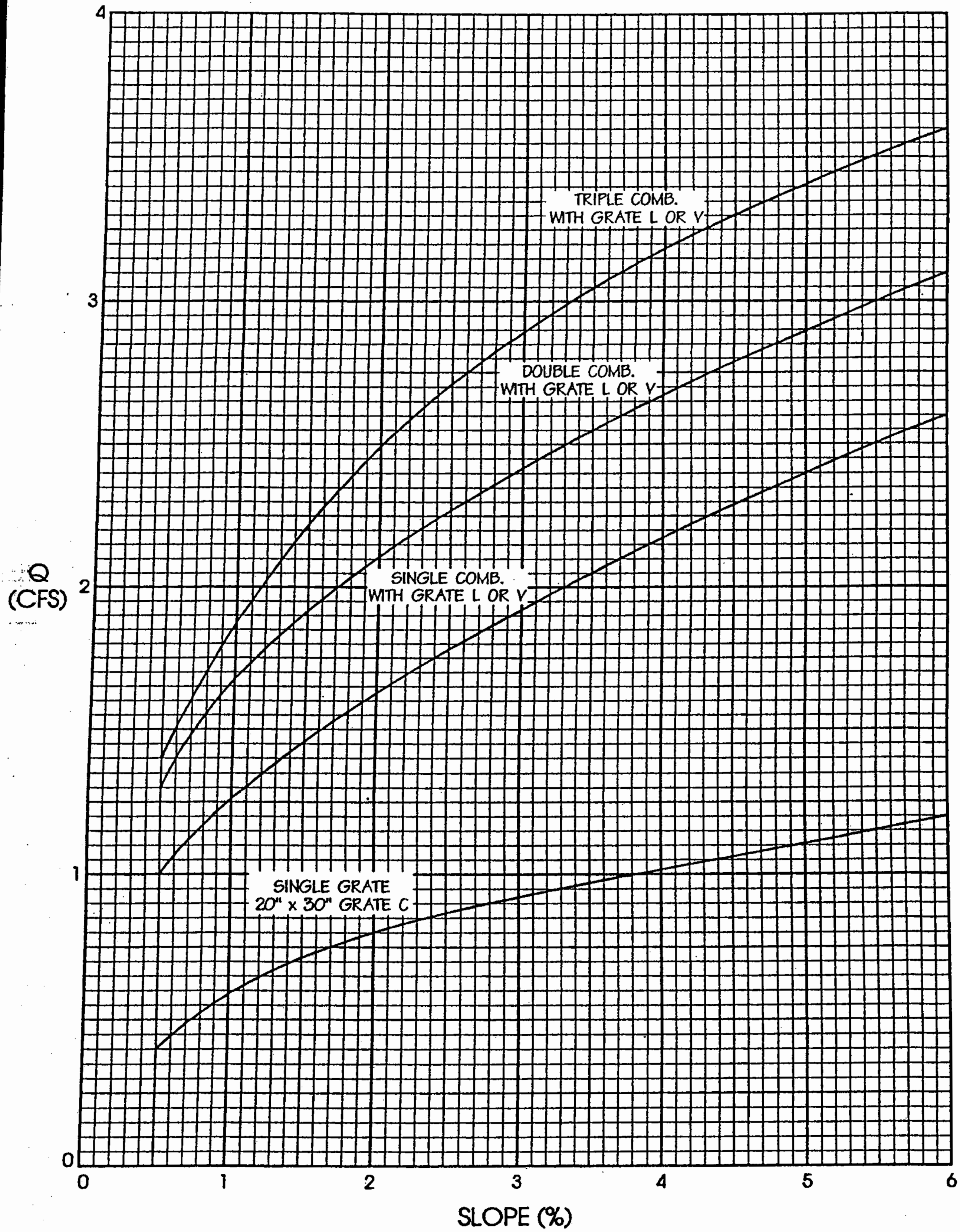
INLET CAPACITIES PROVIDED ARE BASED UPON FIGURE "G-4", MAXIMUM ALLOWED FLOW CONDITIONS, SMF ENGINEERING CORP.'S HEC-12 SOFTWARE, CLOGGING FACTORS PRESENTED IN SECTION VI, AND CITY\COUNTY STANDARD INLETS.



MAXIMUM INLET CAPACITIES: ON-GRADE
RESIDENTIAL COLLECTOR, COMMERCIAL, INDUSTRIAL

FIGURE "G-7b"

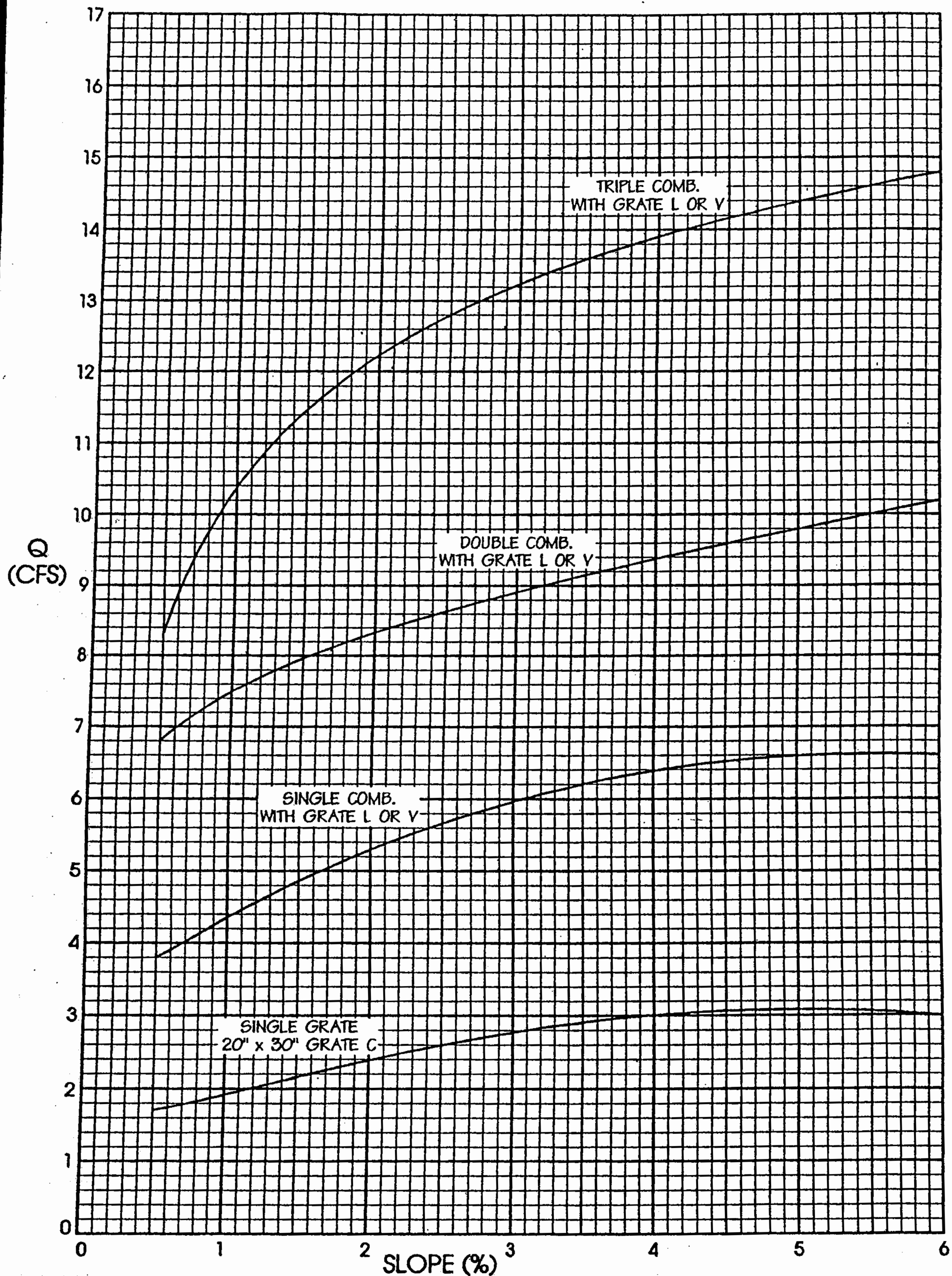
INLET CAPACITIES PROVIDED ARE BASED UPON FIGURE "G-4", MAXIMUM ALLOWED FLOW CONDITIONS, SMF ENGINEERING CORP.'S HEC-12 SOFTWARE, CLOGGING FACTORS PRESENTED IN SECTION VI, AND CITY\COUNTY STANDARD INLETS.



MAXIMUM INLET CAPACITIES: ON-GRADE
COLLECTOR STREET (3000-8000 ADT)

FIGURE "G-7c"

INLET CAPACITIES PROVIDED ARE BASED UPON FIGURE "G-4", MAXIMUM ALLOWED FLOW CONDITIONS, SMF ENGINEERING CORP.'S HEC-12 SOFTWARE, CLOGGING FACTORS PRESENTED IN SECTION VI, AND CITY\COUNTY STANDARD INLETS.

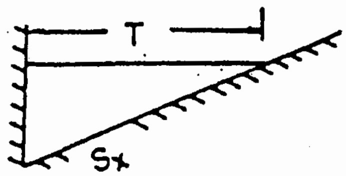


MAXIMUM INLET CAPACITIES: ON-GRADE

PRINCIPAL AND MINOR ARTERIAL

FIGURE "G-7d"

REPRODUCED FROM FHWA HEC-12, CHART 3, 1984



$$Q_t = \left(\frac{0.56}{n}\right) S_x^{1.67}\, S^{0.5}\, T^{2.67}$$

Example: Given:

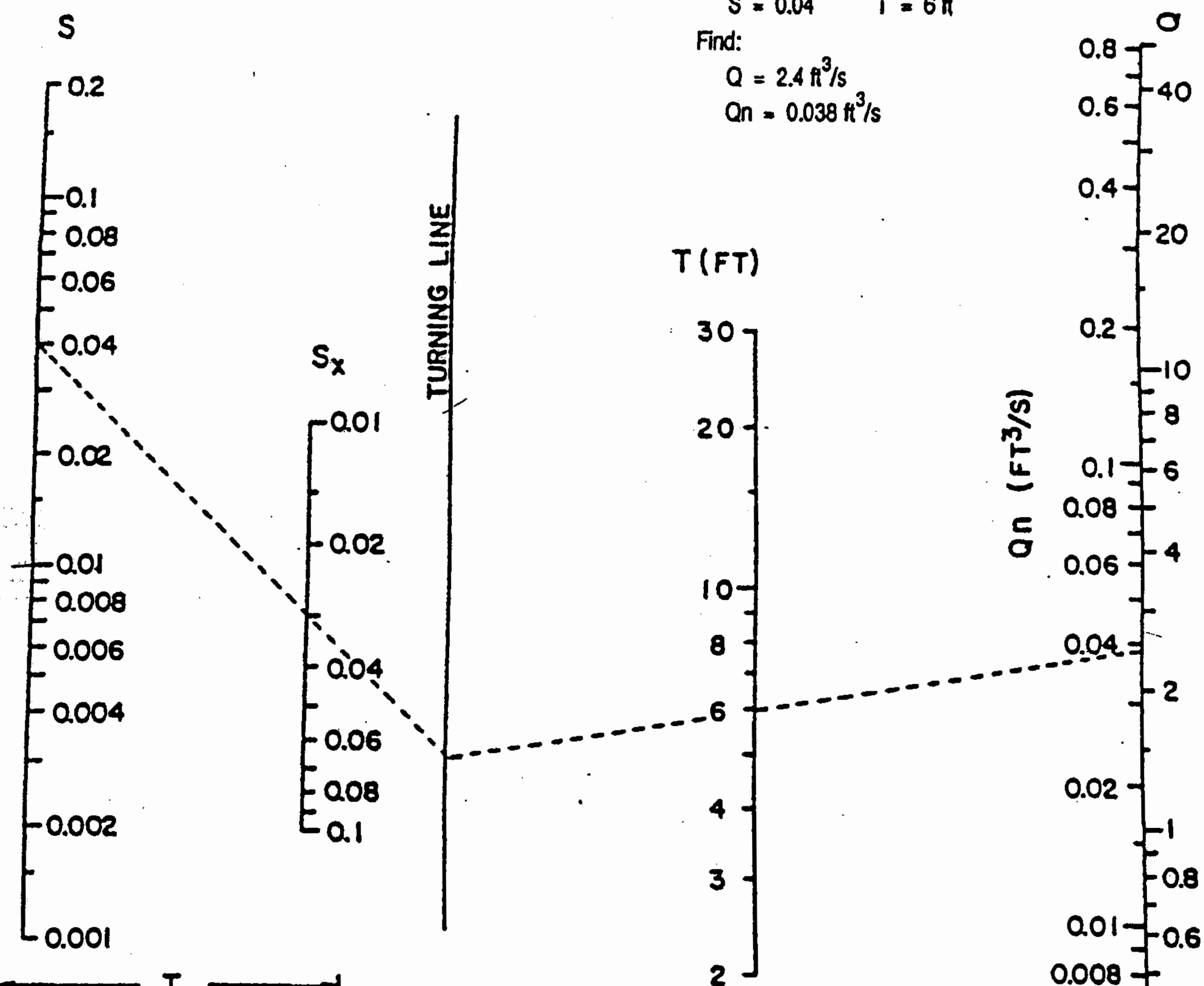
n = 0.016 S_x = 0.03

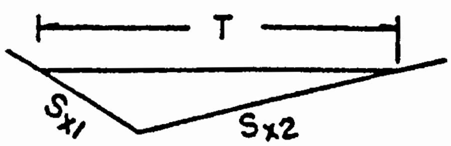
S = 0.04   T = 6 ft

Find:

Q = 2.4 ft^3/s

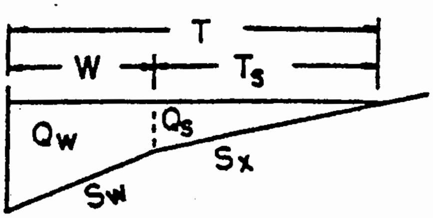
Qn = 0.038 ft^3/s





1) For V-shape, use the nomograph with

$$S_x = \frac{S_{x1} S_{x2}}{(S_{x1} + S_{x2})}$$



2) To determine discharge in gutter with composite cross slopes, find Q_s using T_s and S_x. Then, use Figure 3.23 (page 3-38) to find Eo. The total discharge is $Q = \frac{Q_s}{(1 - E_o)}$, and $Q_w = Q - Q_s$.

NOMOGRAPH FOR TRIANGULAR GUTTERS	FIGURE G-8

ROAD TYPE	COMBINATION INLET CAPACITY (CFS)					
	SINGLE		DOUBLE		TRIPLE	
	2-YR	100-YR	2-YR	100-YR	2-YR	100-YR
Urban Residential (local)	6.4	13	9.5	22	12.7	31
Residential Collector, Commercial and Industrial Streets	3.2	13	4.9	22	6.5	31
Collector Streets (3000 - 8000 ADT)	2.7	13	4.0	22	5.3	31
Principal and Minor Arterials	6.0	13	9.0	22	12.0	31

Inlet capacities shown above are based upon: 1) use of non-curved vane grates (similar to HEC-12 P-1⅞-4 grates; 2) HEC-12 procedures; 3) clogging factors per Section VI; and 4) City/County standard inlets with 2-inch radius on curb face and type C grates. Capacities shown for 2-year storms are based upon depths allowed by maximum street inundation per Figure "G-3". The 100-year capacities are based upon a ponded depth of 1.0 foot. Note that only combination inlets are allowed in sag or sump conditions.

MAXIMUM INLET CAPACITIES: SUMP OR SAG CONDITION — **TABLE "G-1"**

INLET I.D.	STREET SLOPE %	CONDITION		INLET TYPE				INLET CAPACITY[1] (CFS)	SURFACE FLOW TO INLET[2] (CFS)	FLOW INTERCEPTED BY INLET[3] (CFS)	FLOW WHICH BYPASSES INLET (CFS)	FLOW GOES TO INLET:
		ON GRADE	IN SUMP	SGL GRATE	COMBINATION SGL	COMBINATION DBL	COMBINATION TPL					
EXAMPLE	1 %	X				X		8.5	12.5	8.5	3.5	ZZZ

(1) FOR ON GRADE INLETS WITH STANDARD CONDITIONS (SEE "G-2-a") AND TYPE L OR V GRATE, USE FIGURE "G-7". USE TABLE "G-1" FOR INLETS IN A SAG. FOR NON-STANDARD CONDITIONS, INLET CAPACITIES MUST BE CALCULATED.
(2) FLOW MAY NOT EXCEED INUNDATION LIMITS. FOR "STANDARD" CONDITIONS, LIMITS ARE PROVIDED IN FIGURE "G-5".
(3) FLOW INTERCEPTED SHALL BE LESSER OF SURFACE FLOW OR INLET CAPACITY.

INLET INTERCEPTION WORKSHEET | **TABLE "G-2"**

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