A method for estimating design peak discharge

(Technical Memorandum No. 61)

Planning and Technical Services
Water and Soil Division
Ministry of Works and Development

Wellington 1980

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This publication presents an empirical method for estimating a design flood peak discharge in an ungauged New Zealand catchment.

It is emphasised that this is not a new revision of the method, which is still in its 3rd revised (1964) form, metric version, with only minor modifications.

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CONTENTS

TABLES AND FIGURES

1. INTRODUCTION

Technical Memorandum No. 61 (TM61) is an empirical method for estimating a design flood peak discharge in an ungauged New Zealand catchment.

This publication presents a reprint of the metric version of TM61 (October 1975). It is emphasised that this is not a new revision of the method; the method is presented in its 3rd revision form (1964) with only minor modifications. Further clarification of various points and reference to more recent rainfall records are included.

2. FORMULA

The TM61 formula is:

$$Qp = 0.0139\ C\ R\ S\ A^{3/4} \tag{1}$$

where Qp = estimate of the design peak discharge, in m^3/s
C = a coefficient which depends on the physiography of the catchment
R = a rainfall factor which depends on the design storm
S = a catchment shape factor
and A = catchment area, in km^2.

The derivation of C, R and S is described in sections 3, 4 and 5, respectively.

3. THE COEFFICIENT C

3.1 General Procedure

The coefficient C for the catchment is derived by the following procedure:

(a) Select from Table 1 a value for W_{IC} representative of the catchment.

(b) Determine a value for W_S from Figure 1.

(c) Obtain W, which is the product of the W_{IC} and W_S values.

(d) Convert W to a value for C using Figure 2.

3.2 W_{IC}

The W_{IC} factor is intended to account for the effects of infiltration and ground surface and cover characteristics on runoff. The selection of a value from Table 1 for the factor must take into consideration the moisture condition of the catchment for the design storm. As the return period of the design storm is increased the catchment is more likely to be saturated, and a higher W_{IC} value should be chosen accordingly.

NOTE: Care should be taken when using W_{IC} values of 0.4 and 0.5 for pumice soil. Pumice can be very absorbent when wet. However, high runoff from pumice catchments has been observed after dry conditions and also when the catchment is saturated. Careful judgement based on local knowledge should be made when choosing a value for W_{IC} for these catchments.

TABLE 1

VALUES FOR W_{IC}

Soils	Ground Surface-Cover		W_{IC}
Impervious soils (such as clay soils with poor structure e.g. northern yellow brown earths). Any soil, if saturated, is included in this group.	Urban Catchments	high density development	1.8
		moderate to low density development	1.5
	Mainly bare surfaces		1.2
	Average shortgrazed catchments		1.1
	30% of area in long grass, scrub or bush		1.0
	60% of area in long grass, scrub or bush		0.9
	100% of area in long grass, scrub or bush		0.8
Moderately absorbent soils (such as medium textured soils with good structure e.g. southern yellow brown earths).	Urban Catchments	high density development	1.7
		moderate to low density development	1.3
	Mainly bare surfaces		1.1
	Average shortgrazed catchments		1.0
	30% of area in long grass, scrub or bush		0.9
	60% of area in long grass, scrub or bush		0.8
	100% of area in long grass, scrub or bush		0.7
Absorbent soil (such as deep yellow brown sands and pumice soils).	Urban Catchments	high density development	1.5
		moderate to low density·development	1.2
	Mainly bare surfaces		1.0
	Average shortgrazed catchments		0.9
	30% of area in long grass, scrub or bush		0.8
	60% of area in long grass, scrub or bush		0.7
	100% of area in long grass, scrub or bush		0.6
Very absorbent pumice soil.	Mainly bare surfaces Average shortgrazed catchments 30% of area in long grass, scrub or bush		0.5
	60% of area in long grass, scrub or bush 100% of area in long grass, scrub or bush		0.4

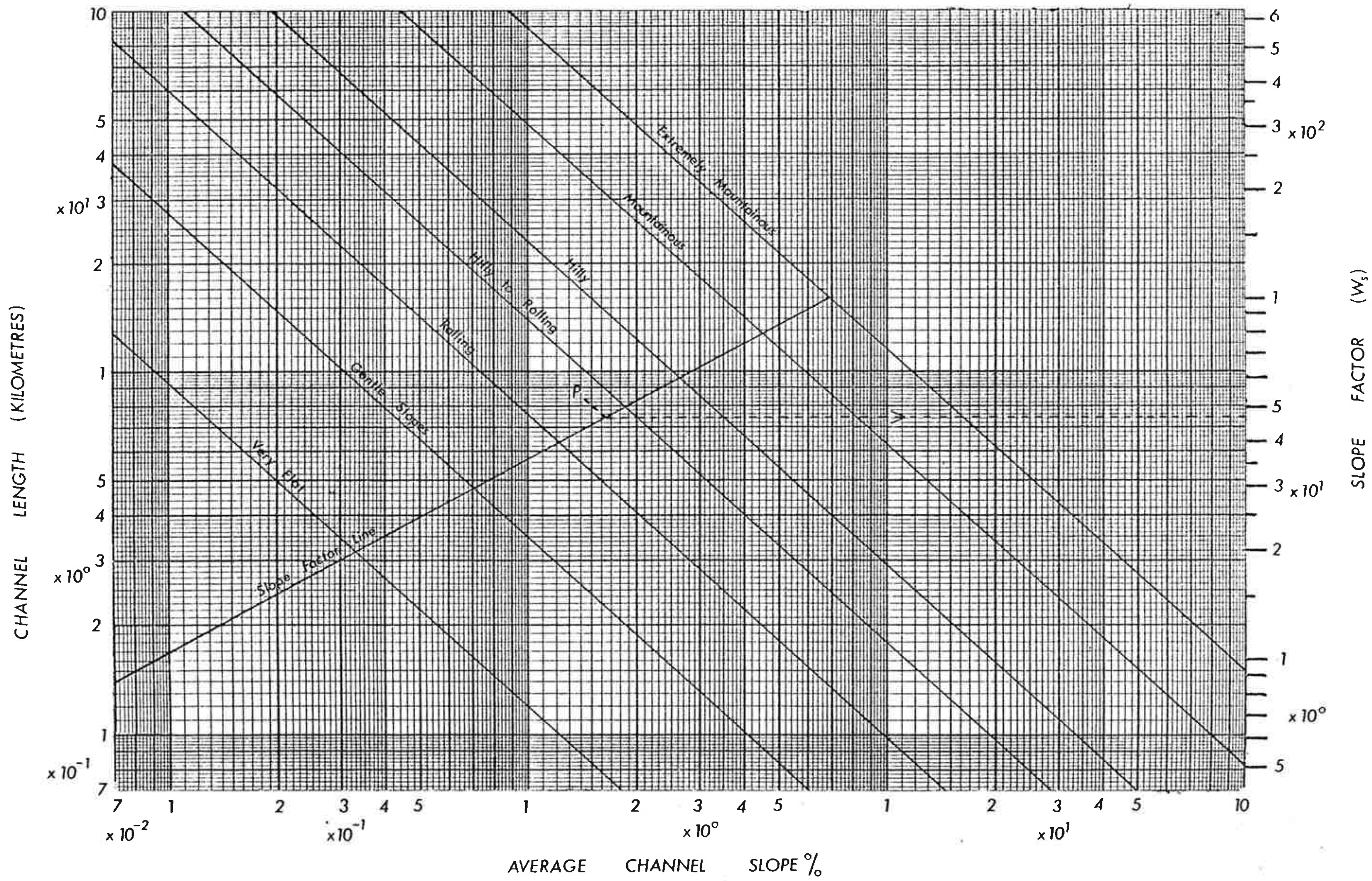

FIG.1 SLOPE FACTOR ESTIMATION

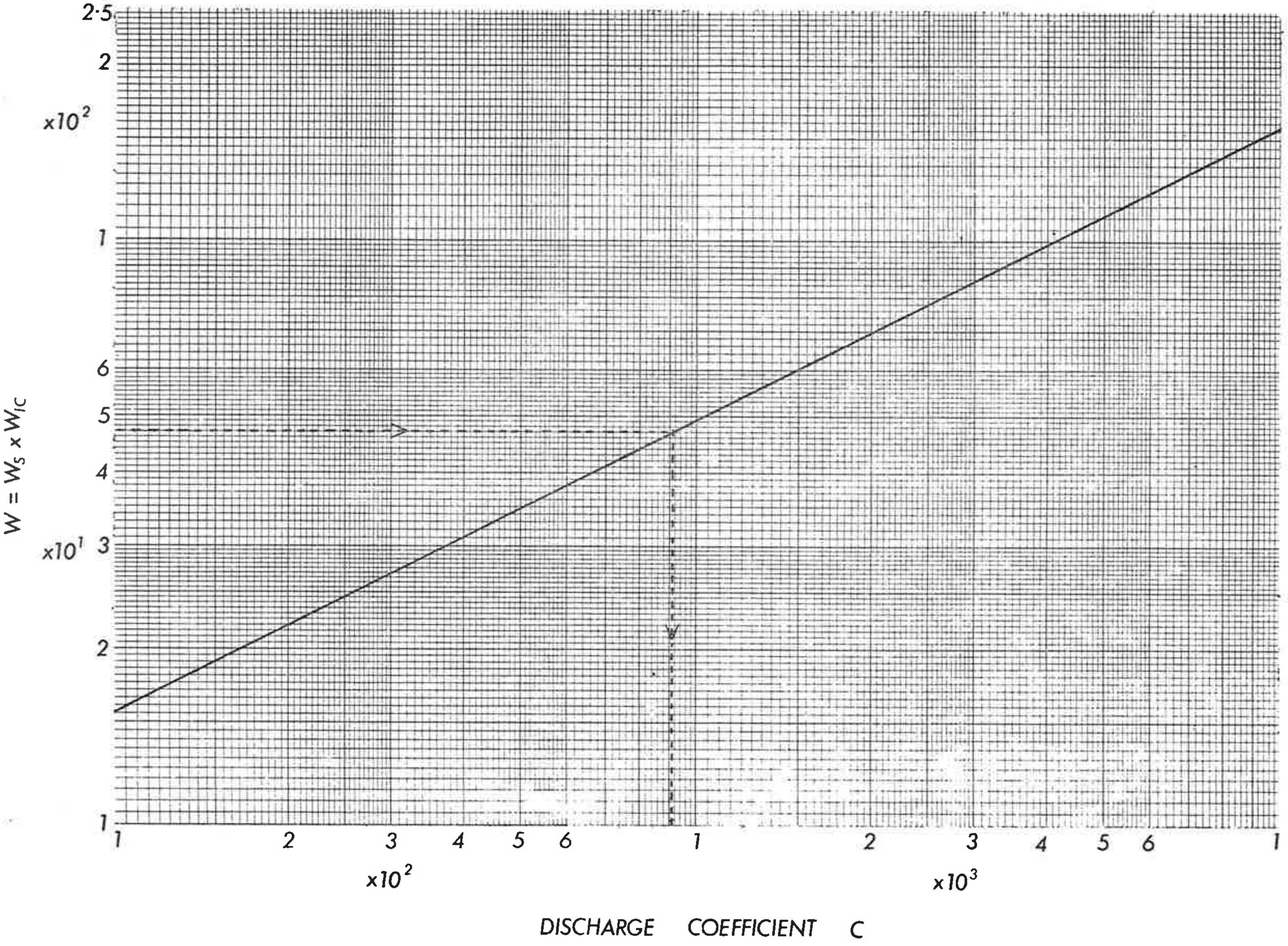

FIG. 2 **CONVERSION CHART W — C**

3.3 W_S

W_S is a slope factor, and its determination requires data on the horizontal length and slope of the main channel extended up to the catchment boundary. Methods of calculating the average channel slope are given in Appendix A.

To determine W_S, define the point on Figure 1 corresponding to the channel length in kilometres and the average channel slope in percent. From this point draw a line parallel to the topography lines to intersect the slope factor line. W_S is then the right-hand ordinate that corresponds to the intersection point on the slope factor line.

When there are insufficient data to calculate the average channel slope, W_S can still be determined by assessing the topography of the catchment. W_S corresponds to the point on the slope factor line that represents the average catchment topography. Because of the subjectivity in this approach, it is advisable to make a slightly conservative estimate of the topographical characteristics.

4. THE RAINFALL FACTOR R

4.1 General

The rainfall factor R is given by

$$R = \frac{\text{design rainfall depth}}{\text{standard rainfall depth}} \qquad (2)$$

The design rainfall depth depends on:

(a) the return period of the design storm; and

(b) the duration of the design storm.

Both these points are elaborated upon below.

4.2 Return Period

It is assumed that the design storm has a return period the same as that of the design flood. For practical purposes this assumption is the most reasonable one to make.

The choice of return period must take into account several factors, which include: the expected life of the structure involved; the general economic consequences of the failure of the structure; and the loss of life and livelihood that might result. Information on the return period is available in many hydrological texts, including the "Code of Practice for the Design of Bridge Waterways" (Civil Division, MWD, 1976). Many bridges are designed for the 50, 100 or 200-year peak discharge. Small culverts are often designed for the 10 or 20-year peak discharge and a check made that larger floods can be passed by heading up.

4.3 Duration

If the rainfall in an impervious catchment is temporally and spatially uniform, the peak of the outflow hydrograph is not attained until the whole of the catchment is contributing to the flow at the outlet. Therefore, the duration of the design storm for a catchment is usually taken as being equal to the time for water to travel from the farthest point on the catchment to the outlet. This travel time is known as the time of concentration. The recommended measure of the time of concentration is the fairly constant minimum value for the time of rise of the flood hydrograph that results from short duration rainfall excess.

For an ungauged catchment the formulae and nomogram in Appendix B may be used to estimate the time of concentration. The estimates from these sources will vary because: different interpretations of the time of concentration are involved; not all the sources are suited to the same conditions; and the sources do not account for the tendency of the time of concentration to decrease with increasing rainfall intensity.

The chosen value for the time of concentration should be the one considered the most reasonable for the catchment and for the design storm. It should *not* be arrived at by simply averaging the results from the formulae and nomogram in Appendix B. A useful check on the chosen value is to convert it to an average flow velocity (using the maximum flow length) and then compare this velocity value with those pertaining to nearby, gauged catchments of similar size and topography.

The rainfall factor R may sometimes prove insensitive to different storm durations. In these cases it will not be necessary to estimate the time of concentration.

4.4 Design Rainfall Depth

Robertson (1963) has presented rainfall depth-duration-frequency data in map form for the whole of New Zealand and in detailed tabular form for 46 pluviometer stations. Similar, up-to-date data are available from the Meteorological Office for individual pluviometer stations. From the data the rainfall depth, corresponding to the selected duration and return period of the design storm, can be calculated by the method described by Robertson (1963).

It is preferable to use the more precise pluviometer data when calculating the rainfall depth. The importance of the structure involved may necessitate the processing of data for a pluviometer not covered by Robertson (1963) into depth-duration-frequency form. If no pluviometer is located within reasonable distance of the catchment it will be necessary to use the data given in map form.

NOTE: Data are available in map and tabular form from the Water and Soil Division, MWD (Tomlinson, 1980) and the Meteorological Service (Coulter and Hessell, 1980).

4.5 Standard Rainfall Depth

The value on the standard curve in Figures 3a, 3b corresponding to the design storm duration is the standard rainfall depth. The standard curve is proportional to the rainfall depth-duration relationships existing at Kelburn, but has been set so that 76 mm corresponds to the 1-hour duration.

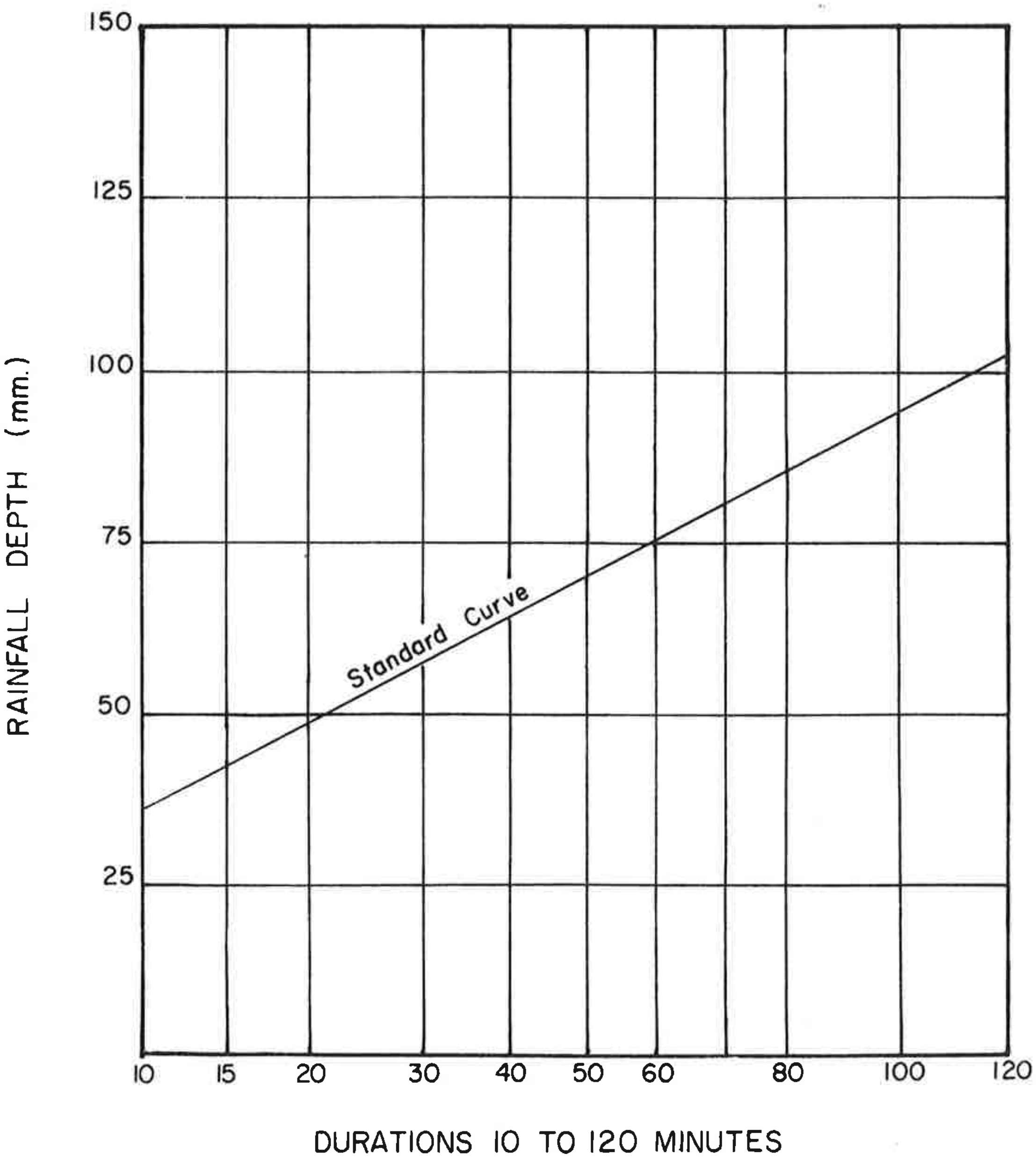

FIG.3A. STANDARD DEPTH — DURATION DIAGRAM

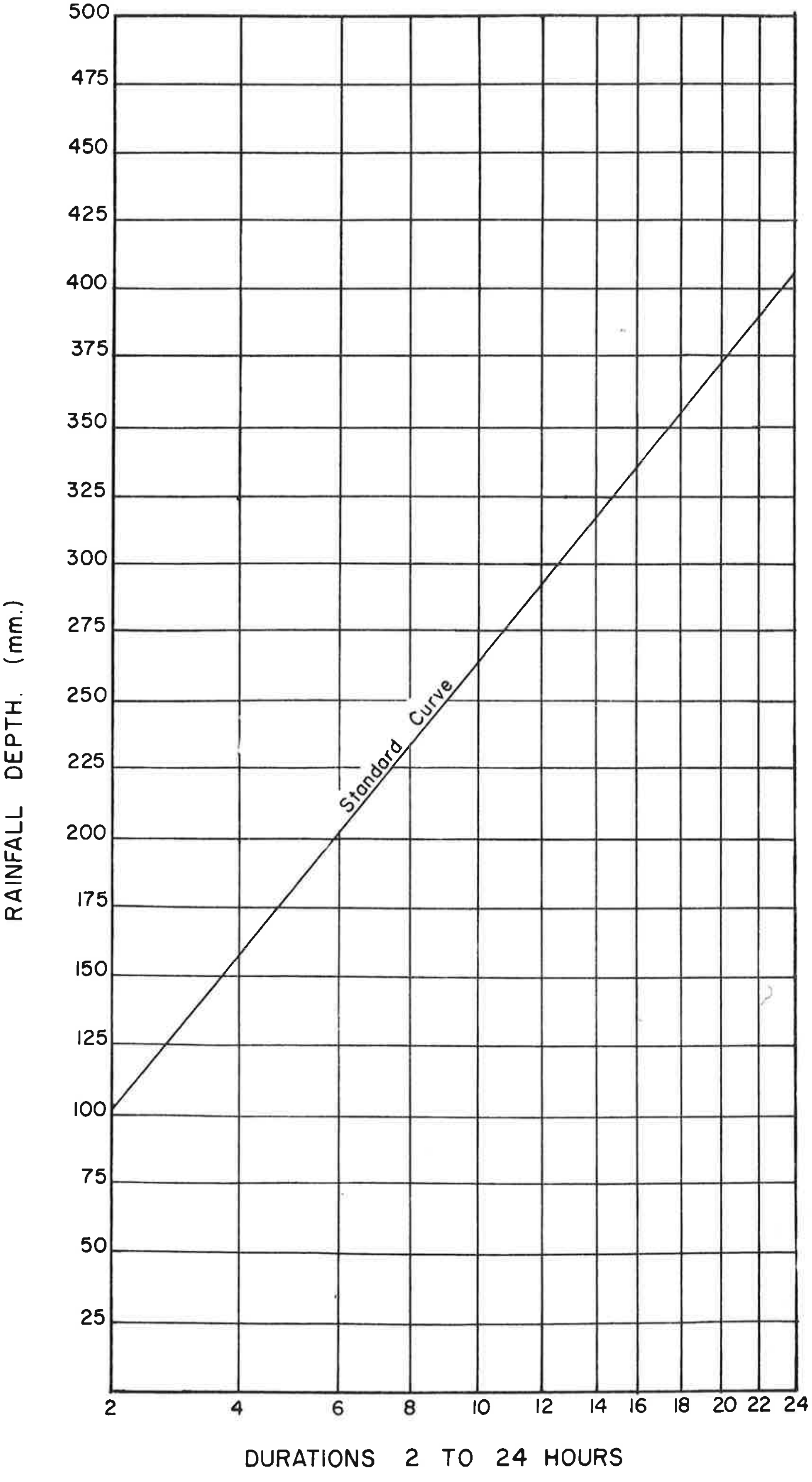

FIG. 3B. STANDARD DEPTH — DURATION DIAGRAM.

5. THE SHAPE FACTOR S

The effect of catchment shape on the peak discharge is allowed for by the shape factor S, which is determined from Figure 4. The abscissa value, the dimensionless number K, is calculated from

$$K = \frac{A}{L_d^2} \qquad (3)$$

where A is the catchment area in square kilometres and L_d is the *direct* length in kilometres from the farthest point on the catchment to the outlet. The S value is the ordinate on the curve in Figure 4 that corresponds to the K value.

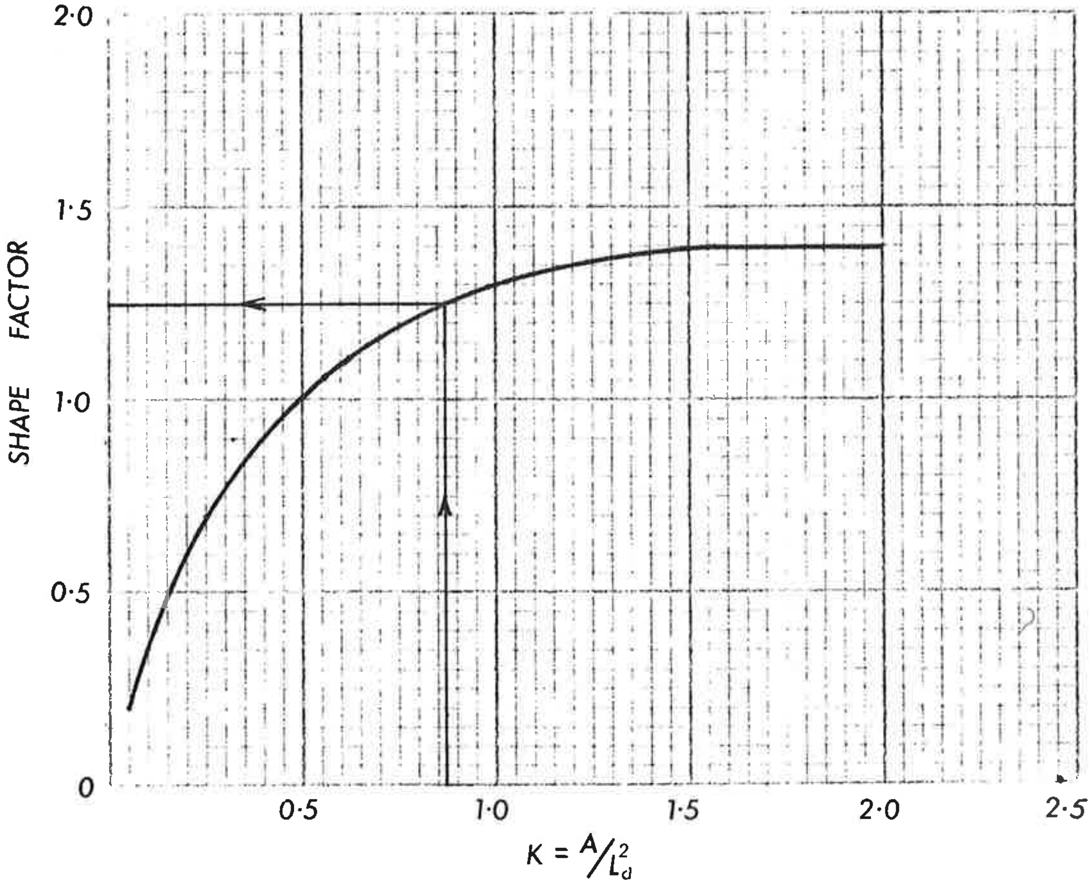

FIG.4 **SHAPE FACTOR**

6. APPLICATION

The application of TM61 requires reasonable spatial uniformity in the physiography and the rainfall characteristics of the catchment concerned. Thus, while the method is generally applicable to small catchments there are limitations on its use for large catchments. The recommended upper limit on the size of the catchment to which the method should be applied is 1000 km^2.

The maps presented by Robertson (1963) are based on rainfall intensities recorded at elevations less than 600 m. The maps should therefore not be used for catchments above this elevation. Furthermore, according to Robertson (1963) the rainfall values taken from the maps will be least reliable where the orographic influence on rainfall is greatest. Hence the maps should be used cautiously for the catchments in Taranaki and the West Coast of the South Island.

NOTE: The division of a catchment into sub-catchments for the purpose of discharge estimation may be warranted, but only when obvious physiographical boundaries exist within the catchment. Because rainfall decreases in intensity with increasing catchment area for a given return period, the whole catchment area should be used in determining the design rainfall depth for the sub-catchment. If this is not done and the design depths are based instead on the corresponding sub-catchment areas, then when the computed floods for the sub-catchments are routed to the catchment outlet the resulting return period of the flood will be greater than that of its components.

The combining of the computed floods for the sub-catchments and their transference down stream may require the use of a channel routing technique or some other account being taken of channel routing effects.

Finally, the chosen values for certain TM61 parameters such as W_S and W_{IC} have an important bearing on the design discharge estimate. It is therefore recommended that information on these parameter values for the region concerned should be sought from the appropriate local agencies, e.g. catchment and regional water boards, and district water and soil offices of the Ministry of Works and Development. These agencies may also be able to assist with expected values for times of concentration (or average flow velocities) and with rainfall data.

NOTE: The accuracy of TM61 may be gauged from recent reports written by Waugh (1972) and Ogle (1978).

NOTE: There is some evidence (Waugh 1972) that TM61 may under-estimate design peak discharges for small catchments in the Northland and Auckland regions. It is suggested that for catchments in these regions with areas between 2.5 and 25 km² the TM61 formula could be amended to

$$Q_p = 0.0109 \text{ CRSA}$$

where the symbols and their derivation are as for TM61.

An example of the use of TM61 is given in Appendix C.

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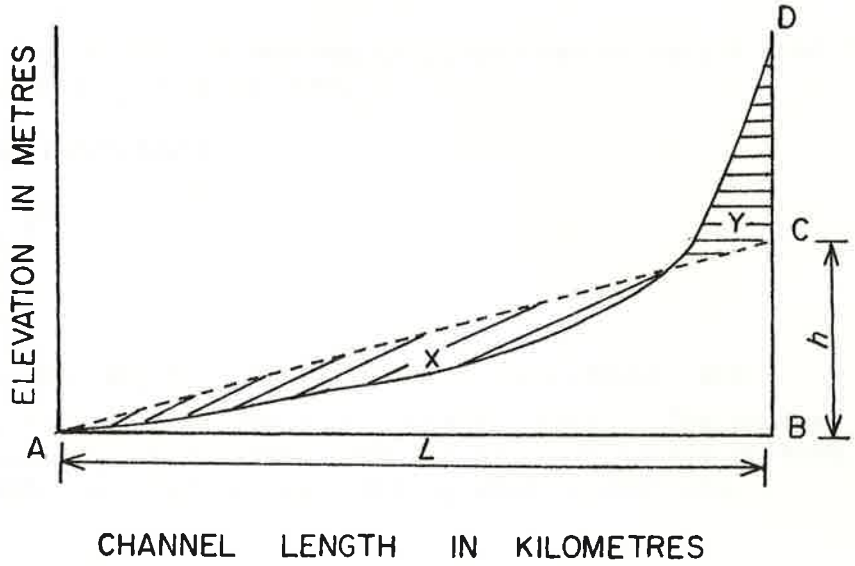
APPENDIX A

CALCULATION OF THE AVERAGE CHANNEL SLOPE

An example of the calculation of the average channel slope using the "Equal Area" method is given below. This method is simple, and has in practice been found to give results largely independent of the user.

EQUAL-AREA METHOD

Assume a longitudinal profile as shown below.



The method involves the calculation of the slope of the hypothetical line AC, which is so positioned that the enclosed areas above and below it, i.e. areas X and Y, are equal. The procedure is to planimeter the total area under the longitudinal profile. This area, A_d, equals the area of the triangle ABC. Thus

$$A_d = \frac{1}{2} AB \times BC$$

$$= \frac{1}{2} L \times h$$

$$\therefore \quad h = \frac{2A_d}{L}$$

Hence the average slope S_a is given by

$$S_a = \frac{h}{L} = \frac{2A_d}{L^2}$$

When the units for elevation and length in the diagram above are used

$$S_a = \frac{2A_d}{1000L^2} \quad m/m$$

Several other methods of calculating the average channel slope are available, such as the Taylor-Schwarz, Modified Taylor-Schwarz, and the method described in "Australian Rainfall and Runoff 1977" which is another modification of the original Taylor-Schwarz.

These have, however, proved inconsistent in recent practice, with the two Taylor-Schwarz methods giving low values for steep slopes and the Australian variation giving high values on all slopes.

The methods are listed below:

(a) Taylor-Schwarz (1952)

$$S_a = \left[\frac{n}{\Sigma \frac{1}{\sqrt{s_i}}} \right]^2$$

where n is the number of reaches of equal channel length that the channel is divided into.

(b) Modified Taylor-Schwarz

$$S_a = \left[\frac{\Sigma l_i}{\Sigma \frac{l_i}{\sqrt{s_i}}} \right]^2$$

where l_i is the length of a reach of the main channel and

s_i is the slope of the corresponding reach. The reaches are chosen so that within each the slope is fairly uniform. The method is improved by choosing equal elevations.

(c) Method described in Ward et al. (1977), p 82.

$$S_a = \left[\frac{\Sigma \left(l_i \sqrt{s_i} \right)}{\Sigma l_i} \right]^2$$

using equal elevations.

APPENDIX B

TIME OF CONCENTRATION FORMULAE

1. RAMSER-KIRPICH

$$T_c = 0.0195\ L^{0.77}\ S_a^{-0.385}$$

where T_c = time of concentration, in minutes
S_a = average channel slope, in m/m
L = flow length from the farthest point on the catchment to the outlet, in m.

2. BRANSBY-WILLIAMS

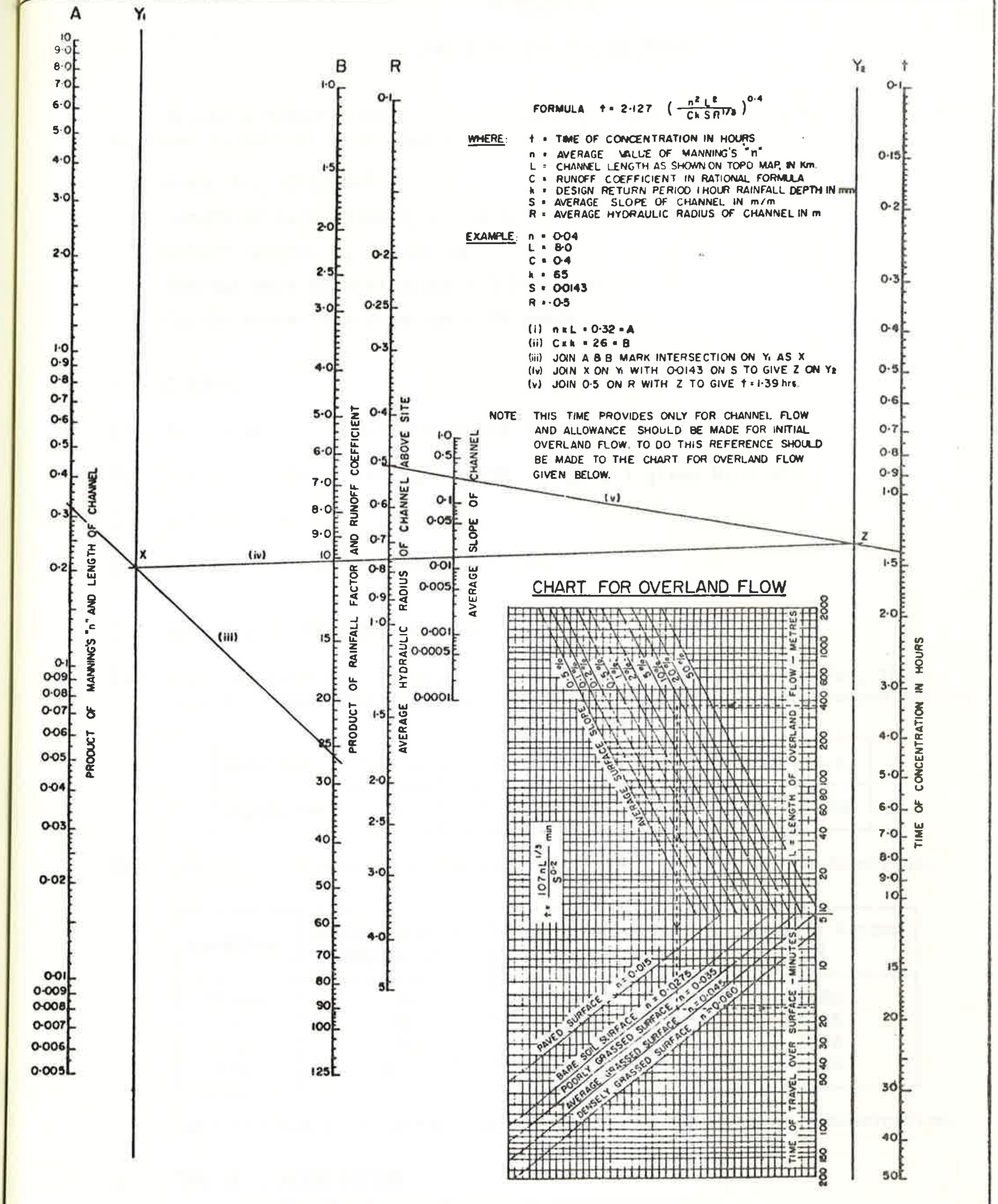
$$T_c = \frac{0.953L^{1.2}}{A^{0.1}\ H^{0.2}}$$

where T_c = time of concentration, in hours
L = maximum flow length, in km
A = catchment area, in km^2
H = the difference in elevation between the highest and lowest points on the main channel, in m.

3. U.S. SOIL CONSERVATION SERVICE

$$T_c = \left(\frac{0.87L^3}{H}\right)^{0.385}$$

where T_c = time of concentration, in hours
L = maximum flow length, in km
H = the difference in elevation between the highest and lowest points on the main channel, in m.



FORMULA $t = 2{\cdot}127 \left(\frac{n^2 L^2}{C k S R^{1/3}} \right)^{0{\cdot}4}$

WHERE:
t = TIME OF CONCENTRATION IN HOURS
n = AVERAGE VALUE OF MANNING'S "n"
L = CHANNEL LENGTH AS SHOWN ON TOPO MAP, IN Km.
C = RUNOFF COEFFICIENT IN RATIONAL FORMULA
k = DESIGN RETURN PERIOD 1 HOUR RAINFALL DEPTH IN mm
S = AVERAGE SLOPE OF CHANNEL IN m/m
R = AVERAGE HYDRAULIC RADIUS OF CHANNEL IN m

EXAMPLE:
n = 0·04
L = 8·0
C = 0·4
k = 65
S = 0·0143
R = ·0·5

(i) n x L = 0·32 = A
(ii) C x k = 26 = B
(iii) JOIN A & B MARK INTERSECTION ON Y₁ AS X
(iv) JOIN X ON Y₁ WITH 0·0143 ON S TO GIVE Z ON Y₂
(v) JOIN 0·5 ON R WITH Z TO GIVE t = 1·39 hrs.

NOTE: THIS TIME PROVIDES ONLY FOR CHANNEL FLOW AND ALLOWANCE SHOULD BE MADE FOR INITIAL OVERLAND FLOW. TO DO THIS REFERENCE SHOULD BE MADE TO THE CHART FOR OVERLAND FLOW GIVEN BELOW.

CHART TO DETERMINE THE TIME OF
CONCENTRATION OF A CATCHMENT

P.W.D. 159529

APPENDIX C

EXAMPLE OF THE USE OF TM61

Assume a hypothetical catchment with a main channel longitudinal profile as shown in section 2 in Appendix A, and with

Area, $A = 33.62 \text{ km}^2$

Length of main channel, $L = 8.357$ km

Direct length, $L_d = 6.20$ km

Average main channel slope = 0.0143 m/m

Design storm return period = 20 years.

1. C VALUE

(a) For saturated conditions, Table 1 gives $W_{IC} = 1.0$.

(b) For $L = 8.357$ km and $S_a = 1.43\%$, Figure 1 gives $W_S = 47$.

(c) $W = W_{IC} \times W_S = 1.0 \times 47 = 47$.

(d) For $W = 47$, Figure 2 gives $C = 910$.

2. RAINFALL DEPTH-DURATION DATA

(a) From the rainfall intensities recorded at a nearby pluviometer, the following depth-duration data are obtained for the 20-year return period:

Duration	10 min	20 min	30 min	1 hr	2 hr	6 hr
Depth, mm	20	35	49	65	76	104

(b) Examine whether R is insensitive to different design storm durations.

Duration	Design Rainfall Depth, mm	Standard Rainfall Depth, mm	Rainfall Factor R
30 min	49	61	0.80
1 hr	65	76	0.85
2 hr	76	103	0.74
6 hr	104	193	0.54

The variation in R warrants an estimation of the time of concentration.

3. TIME OF CONCENTRATION

(a) **Ramser-Kirpich**

$$T_c = 0.0195 \times 8357^{0.77} \times 0.0143^{-0.385}$$

$$= 105 \text{ min } (1.75 \text{ hrs})$$

$$\therefore \text{ Average flow velocity, } \overline{v} = \frac{8357}{105 \times 60} = 1.33 \text{ m/s.}$$

(b) Bransby-Williams

$$T_c = \frac{0.953 \times 8.357^{1.2}}{33.62^{0.1} \times 203.4^{0.2}}$$

$$= 2.96 \text{ hrs}$$

$$\therefore \bar{v} = \frac{8357}{2.96 \times 3600} = 0.78 \text{ m/s.}$$

(c) U.S. Soil Conservation Service

$$T_c = \left[\frac{0.87 \times 8.357^3}{203.4}\right]^{0.385}$$

$$= 1.42 \text{ hrs}$$

$$\therefore \bar{v} = \frac{8357}{1.42 \times 3600} = 1.64 \text{ m/s.}$$

(d) PWD 159529

As shown in the example with the nomogram,

T_c = 1.39 hrs (channel flow) + 0.28 hrs (overland flow)

$$= 1.67 \text{ hrs}$$

$$\therefore \bar{v} = \frac{8357}{1.67 \times 3600} = 1.39 \text{ m/s.}$$

(e) A time of concentration of 1.40 hrs appears reasonable for the catchment and the design storm - accept this figure.

4. R VALUE

From the depth-duration data of the nearby pluviometer, a rainfall depth of 71 mm is obtained for the design storm of 1.4 hrs duration and 20-year return period.

It is assumed that this rainfall depth is the same as that which would occur at a central point in the catchment. Because of the possible error in this assumption in this instance, the point rainfall value of 71 mm is not reduced according to Figure 6 in Robertson (1963) before it is taken as being a representative value for the whole catchment area.

Thus $R = \frac{71 \text{ mm}}{88 \text{ mm}} = 0.81.$

5. S VALUE

(a) $K = \frac{33.62}{6.2^2} = 0.87.$

(b) For K = 0.87, Figure 4 gives S = 1.25.

6. DESIGN DISCHARGE ESTIMATE

$$Q_p = 0.0139\ C\ R\ S\ A^{3/4}$$

$$= 0.0139 \times 910 \times 0.81 \times 1.25 \times 33.62^{3/4}$$

$$= 178.8\ m^3/s.$$