NATIONAL WATER AND SOIL CONSERVATION ORGANISATION

# METRIC VERSION
# OF
# TECHNICAL MEMORANDUM No.61

## A METHOD FOR ESTIMATING DESIGN PEAK DISCHARGE

# METRIC VERSION OF TECHNICAL MEMORANDUM NO. 61

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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 the metric version of TM61. 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.

# 2. FORMULA

The TM61 formula is

$$Q_p = 0.0139\ C\ R\ S\ A^{3/4} \qquad (1)$$

where $Q_p$ = 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.

## 3.3 $W_S$

$W_S$ is a slope factor, and its determination requires data on the 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.

## 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).<br>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<br>Average shortgrazed catchments<br>30% of area in long grass, scrub or bush | | 0.5 |
| | 60% of area in long grass, scrub or bush<br>100% of area in long grass, scrub or bush | | 0.4 |

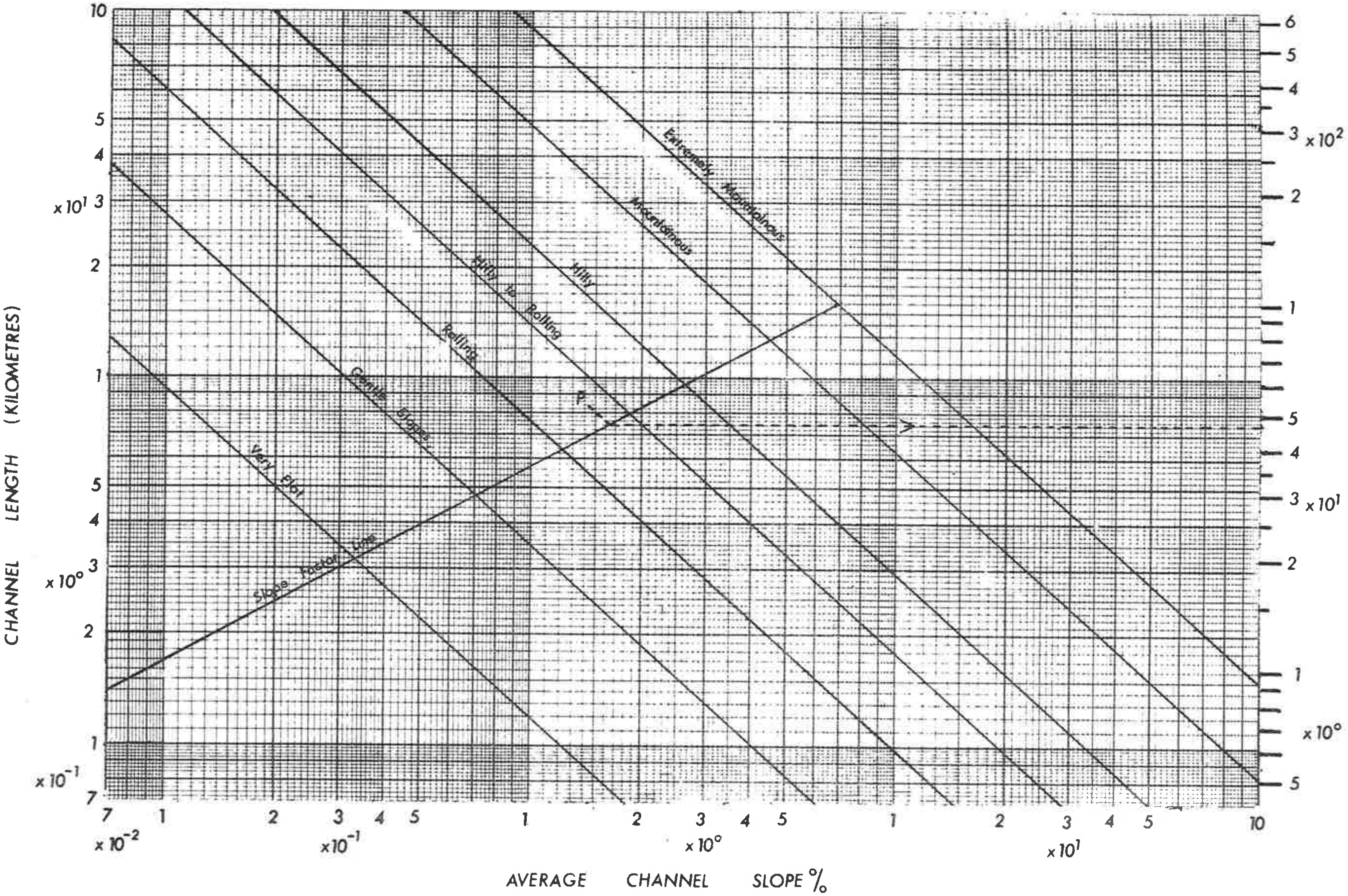


FIG.1 SLOPE FACTOR ESTIMATION

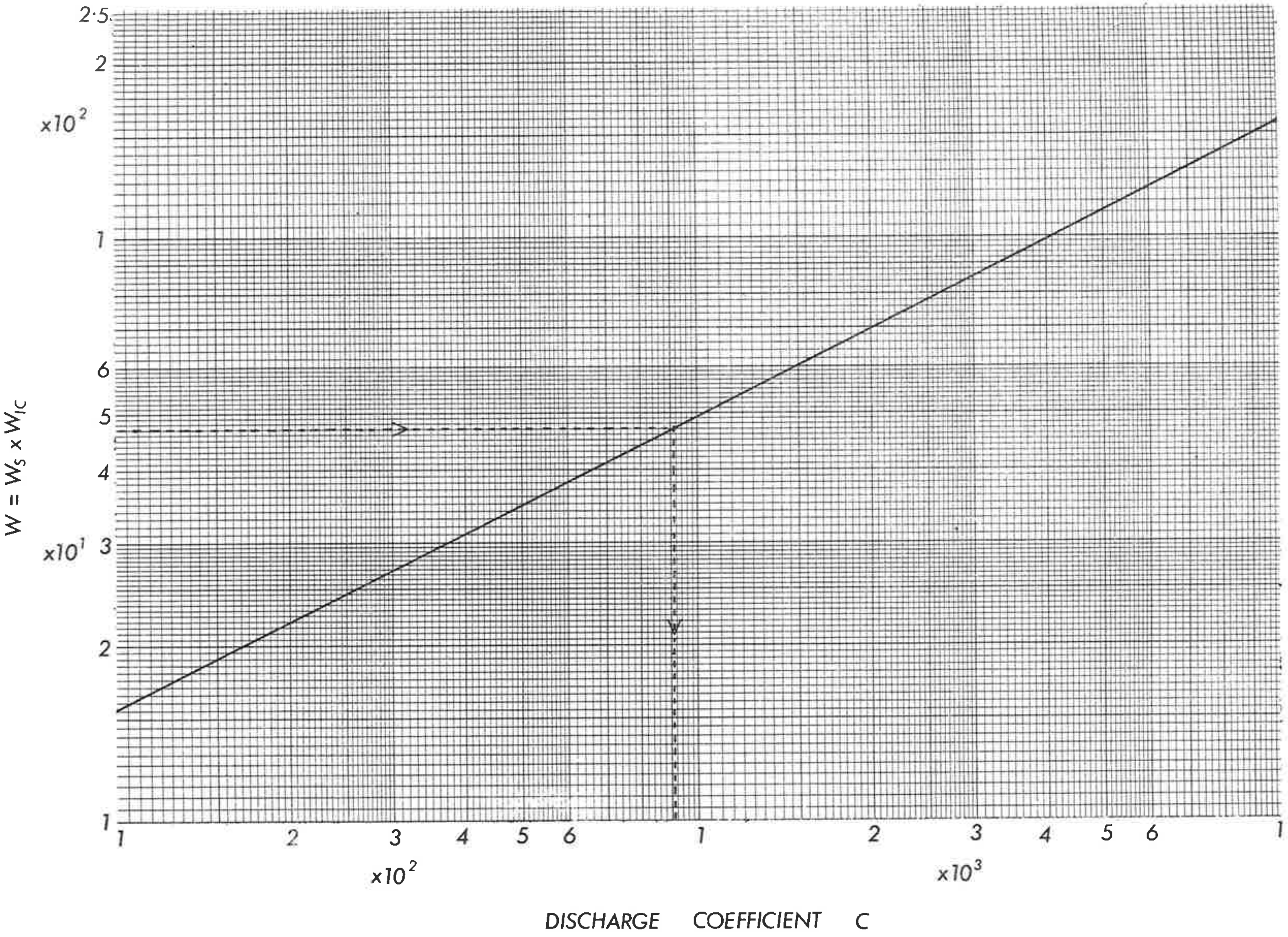


FIG. 2 **CONVERSION CHART W — C**

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 Draft Code of Practice on Design of Bridge Waterways (1974). 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.

## 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.

## 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.

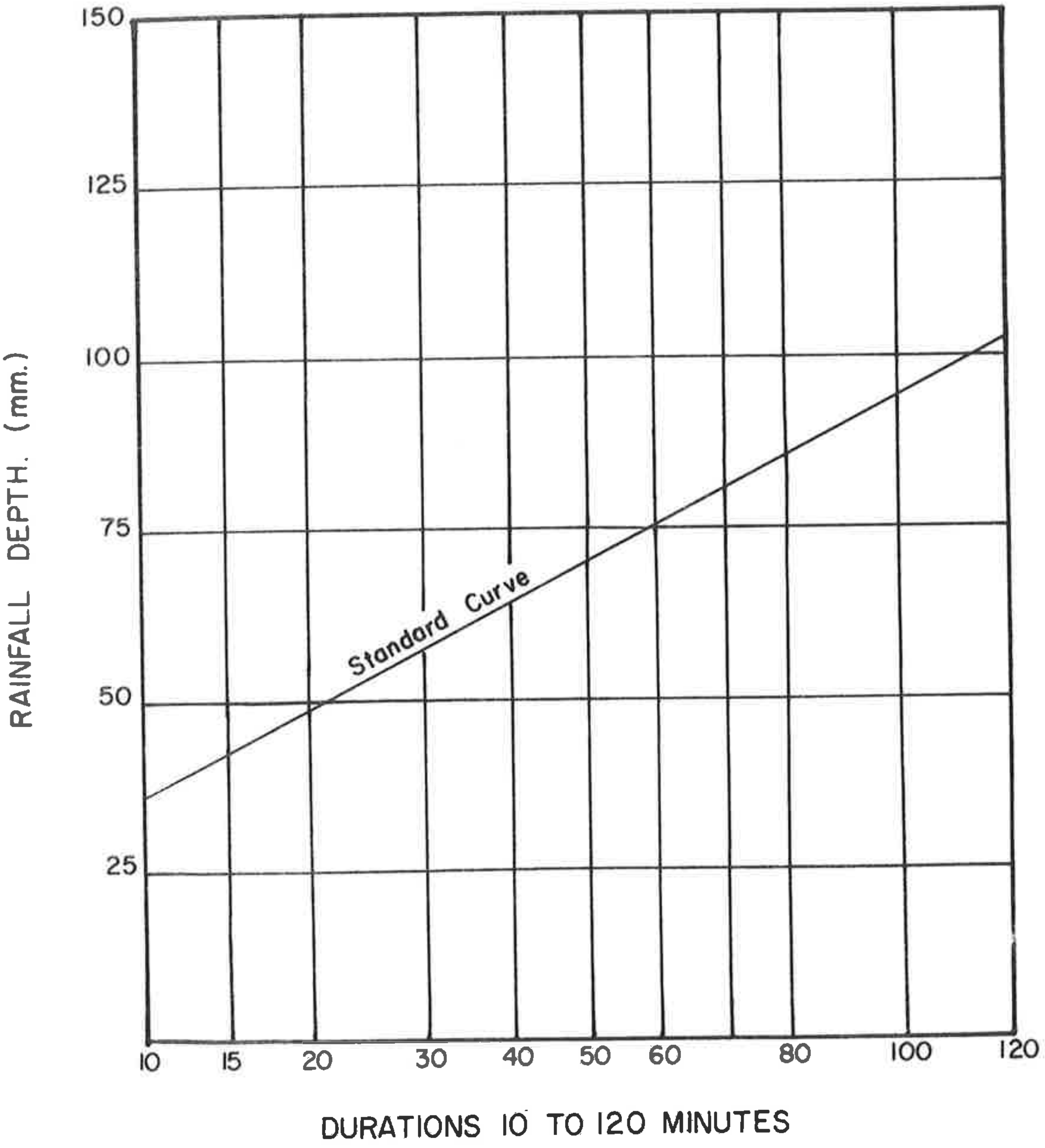


FIG.3A. STANDARD DEPTH — DURATION DIAGRAM.

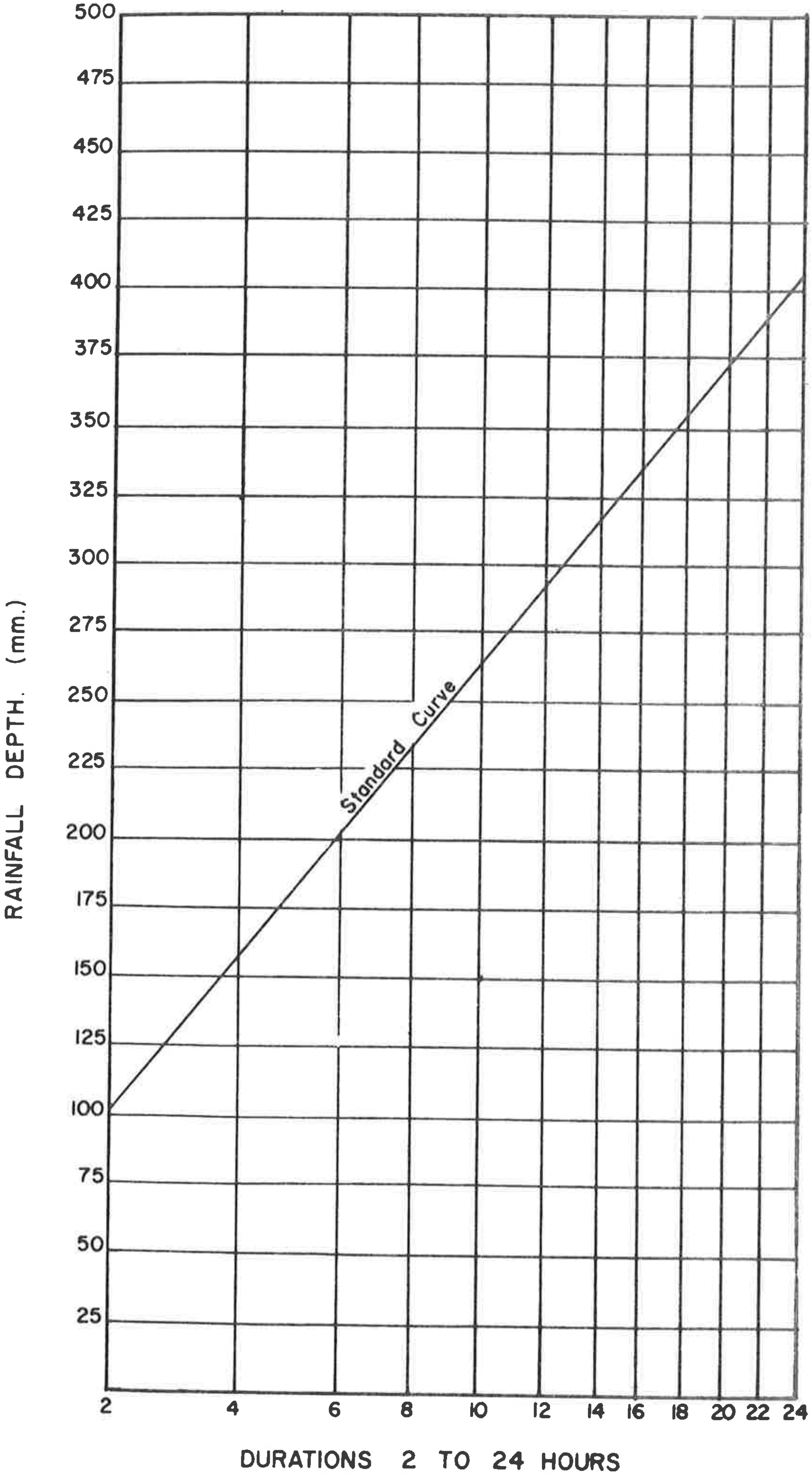


FIG. 3B. STANDARD DEPTH — DURATION DIAGRAM.

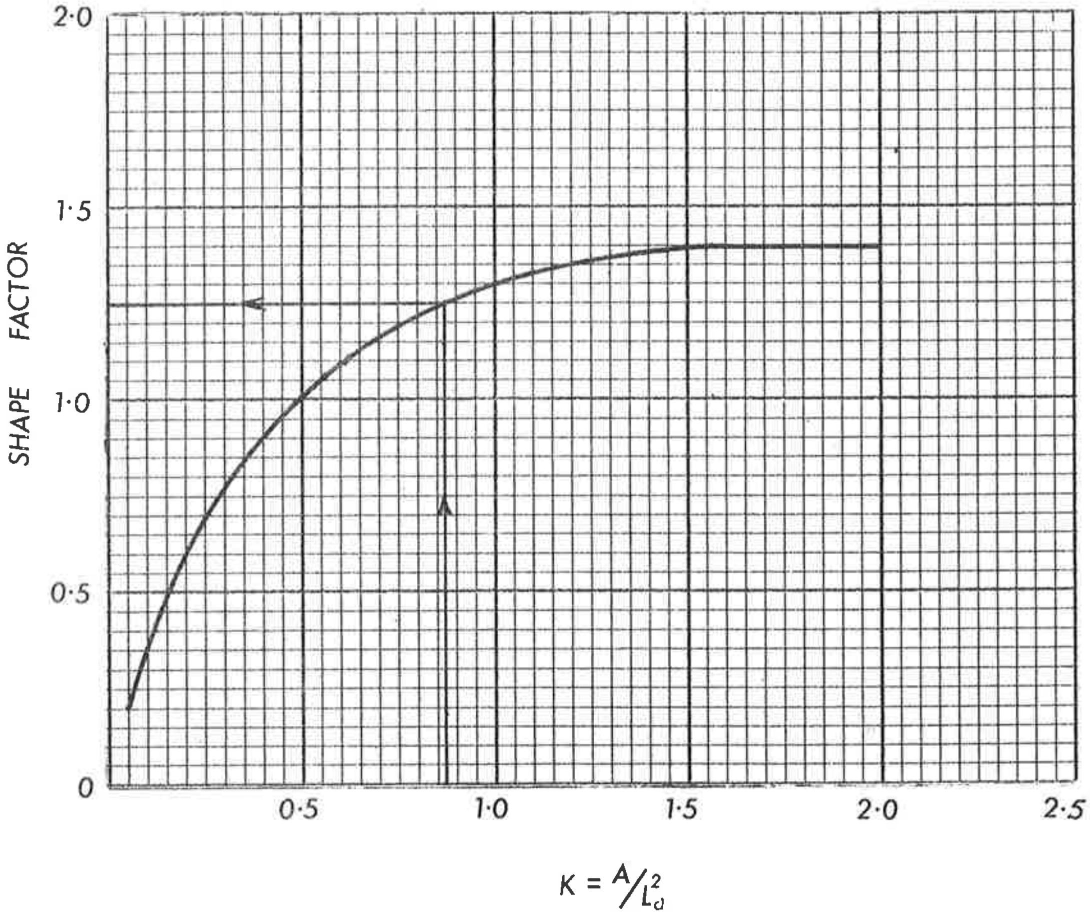


FIG.4 **SHAPE FACTOR**

## 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.

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.

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

## REFERENCES

Robertson, N. G., 1963: *The frequency of high intensity rainfalls in New Zealand.* New Zealand Meteorological Service, Miscellaneous Publication No. 118.

Taylor, A. B., Schwarz, H. E., 1952: *Unit hydrograph lag and peak flow related to basin characteristics.* Transactions of American Geophysical Union, Vol. 33, No. 2, pp.235-246.

Technical Memorandum No. 61, 3rd Revision, 1964: *Provisional standard for empirical estimation of flood discharges.* Water and Soil Division, Ministry of Works.

Water and Soil Division, MWD, 1974: *Draft code of practice on design of bridge waterways.* Planning and Technical Services, January, 42 pp.

# APPENDIX A

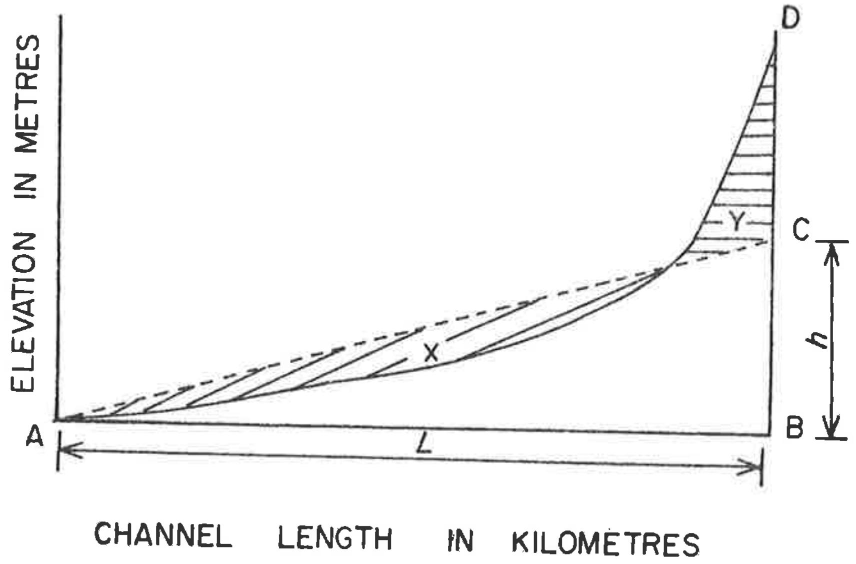
## CALCULATION OF THE AVERAGE CHANNEL SLOPE

Two methods are described below for calculating the average slope of the main channel. Both require the plotting of the longitudinal profile of the main channel from the catchment outlet up to the catchment boundary.

The first method is quick and gives consistent results. The second method gives a more representative value for the average slope. It is a modification of the Taylor-Schwarz (1952) method. With judicious choice of the points representing changes in slope the modified method is considered more flexible and accurate than the original one.

### 1. 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

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

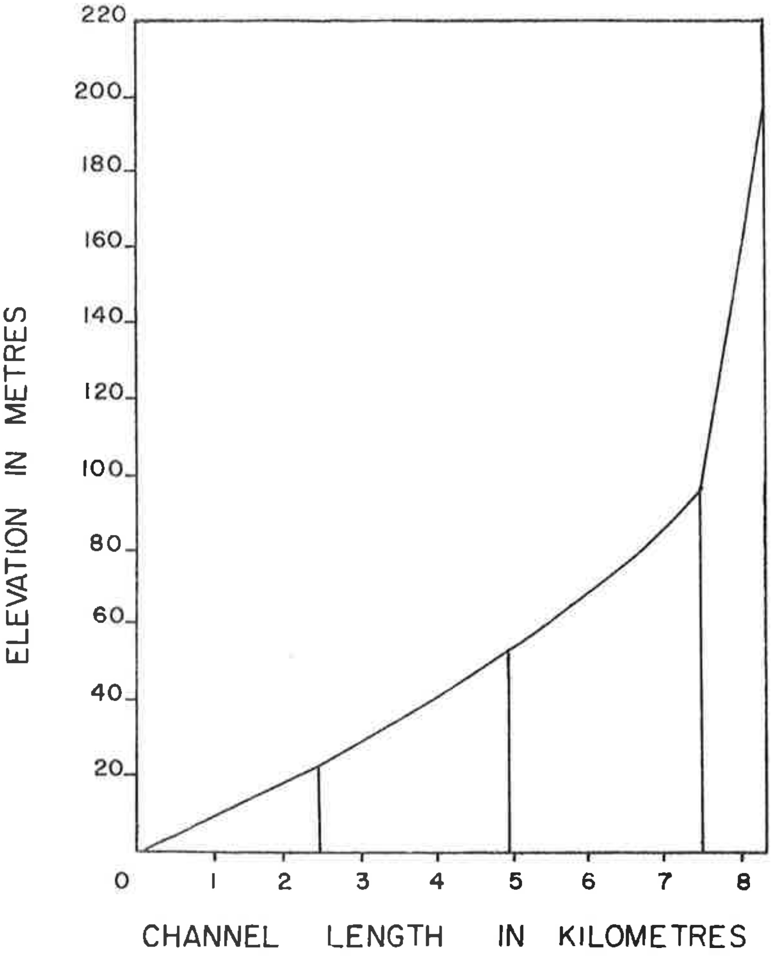
## 2. MODIFIED TAYLOR-SCHWARZ METHOD

The average slope is calculated by the formula

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

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.

Example



For a main channel with a longitudinal profile as shown above, the average channel slope is calculated as follows. Four reaches are considered.

| Elevation metres | Δ Elevation | Length ($l_i$) metres | Slope ($S_i$) m/m | $\sqrt{S_i}$ | $\frac{l_i}{\sqrt{S_i}}$ |
|---|---|---|---|---|---|
| 0 | | | | | |
| 23.8 | 23.8 | 2420 | 0.00984 | 0.09920 | 24396 |
| 53.3 | 29.5 | 2509 | 0.01176 | 0.10844 | 23136 |
| 96.0 | 42.7 | 2565 | 0.01665 | 0.12903 | 19878 |
| 203.4 | 107.4 | 862 | 0.1246 | 0.35299 | 2442 |
| | | 8357 | | | 69852 |

$$S_a = \left[\frac{8357}{69852}\right]^2 = 0.0143 \text{ m/m}$$

For the same channel the Equal-Area method gave

$$S_a = \frac{2 \times 438.85}{1000 \times 8.357^2} = 0.0126 \text{ m/m.}$$

## 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

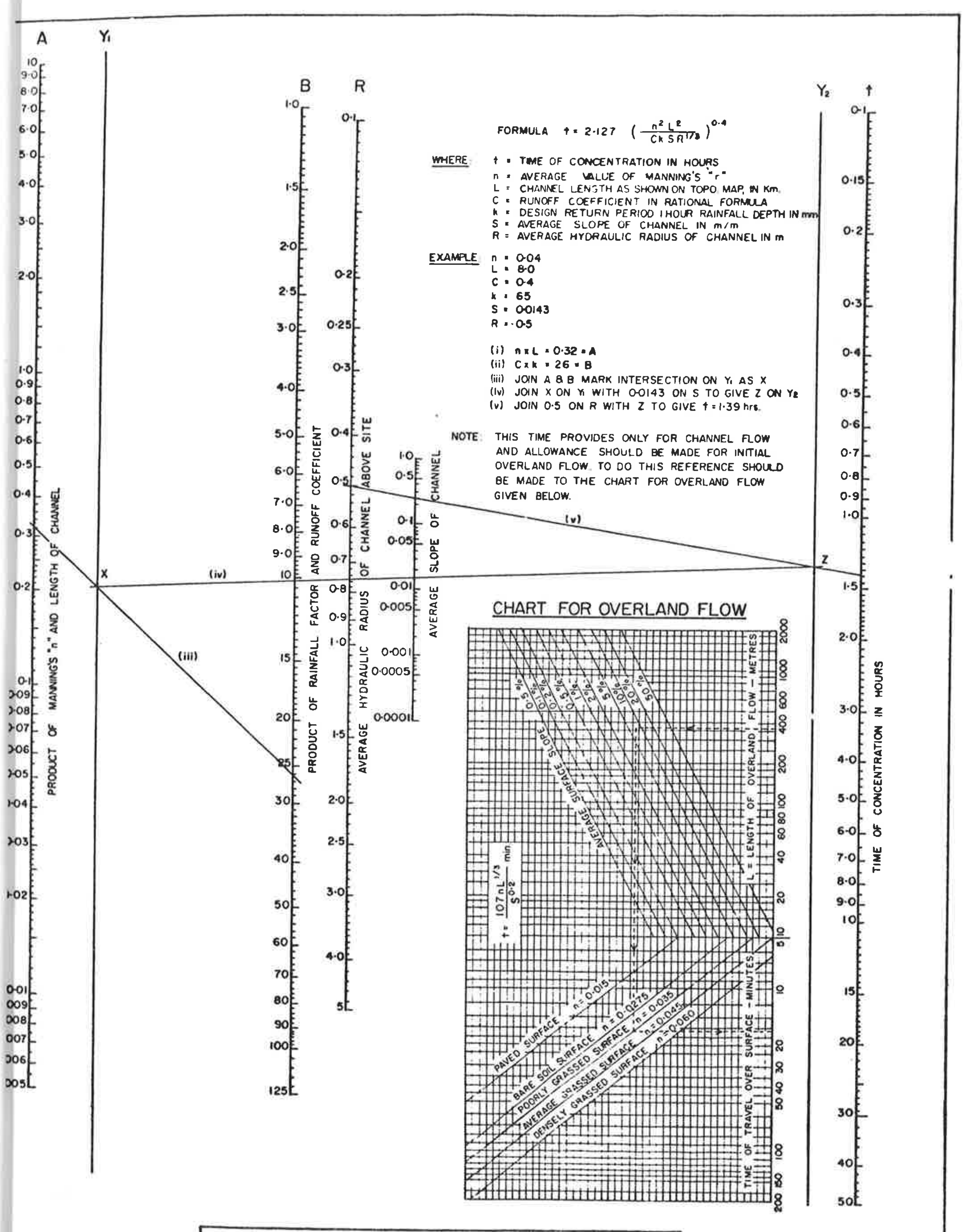
$$T_c = \frac{0.953L^{1.2}}{A^{0.1}\, H^{0.2}}$$

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 "r"
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.

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

## 5. S VALUE

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

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