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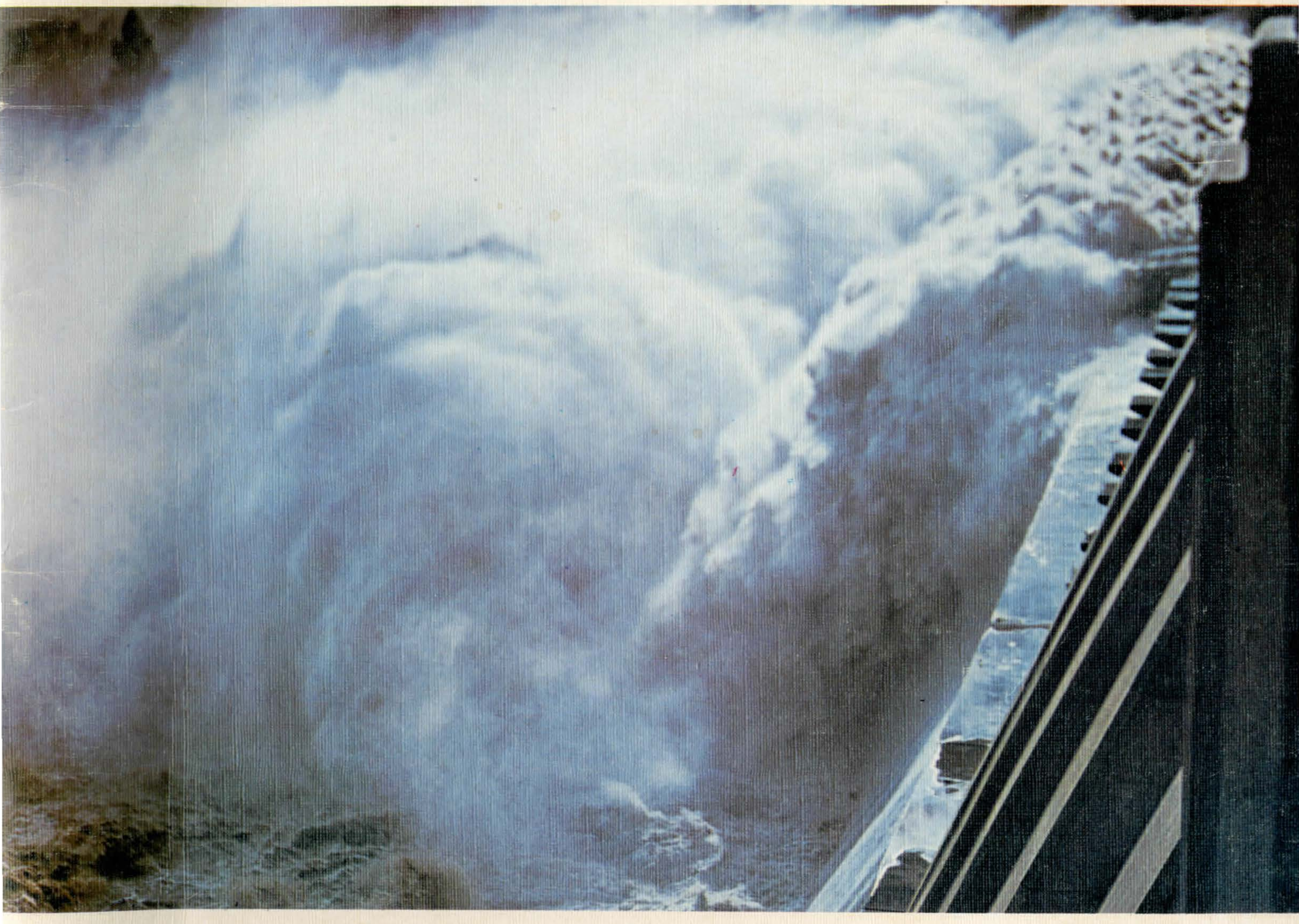
DEPARTMENT OF ENVIRONMENT AFFAIRS

Maximum flood peak discharges in South Africa: An empirical approach

Z P Kovács



DEPARTMENT OF ENVIRONMENT AFFAIRS

Division of Hydrology

Technical Report TR 105

MAXIMUM FLOOD PEAK DISCHARGES IN SOUTH AFRICA : AN EMPIRICAL APPROACH

(REVISED AND IMPROVED EDITION)

by

Z P Kovâcs

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Department of Environment Affairs
Private Bag X313
PRETORIA
0001

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NOTE

The devastating South Western Cape and Karoo floods of 25th January, 1981 occurred after Report TR105 was sent for printing. Provisional flood peak estimates indicate that it is more realistic to include the whole of the Buffels and Touws rivers catchments into maximum flood peak region 2 instead of dividing them into regions 2 and 3 as shown in Fig. 5.

ABSTRACT

Following a brief critical appraisal of currently employed statistical (10 000 year return interval flood peak) and deterministic (probable maximum flood peak or PMF) methods of maximum flood peak determination, the FRANCOU-RODIER empirical approach is introduced. A catalogue of 355 flood peaks recorded in South Africa between 1894 and 1979 is presented and the delimitation of five maximum flood peak regions described. The derivation of regional flood peak envelope curves is discussed in detail and these are recommended as the upper limit of maximum flood peaks that can be reasonably expected.

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1. INTRODUCTION

In recent years during the routine estimation of maximum design flood peaks for dams in South Africa it has become evident that both currently used methods of estimating the very rare or probable maximum flood (PMF) peaks can result in grossly unrealistic figures. Suggested causes for this are :-

(i) Statistical methods rely on the estimation of flood peaks with return periods of $T >> 200$ years based on relatively short records in a range of 15 to 75 years and fitted to a theoretical probability distribution. Such extrapolation can be most unsatisfactory and Adamson [1] has shown that under South African conditions the three most widely used theoretical probability models (the two parameter log-Normal, log-Pearson and Gumbel) can provide estimates of the $T = 1\ 000$ year event that differ on average by a factor of 2,2. Extension of this analysis to the $T = 10\ 000$ year event, generally considered the likely maximum and a statistical equivalent to the PMF, the mean difference between the three statistical models was found to be a factor of 4,5. In three of the fifty estimations the factor of difference was more than 10 whilst only three, situated in the higher rainfall regions, provided estimates that differed by less than 1,5.

(ii) Deterministic methods for the calculation of PMF rely on the estimation of a probable maximum precipitation (PMP) falling on a saturated catchment. Unit-graph principles are then applied. The drawbacks here are that the great number of assumptions employed can become a serious source of cumulative error. Examples of such difficulties are the need for a realistic estimate of PMP, lack of knowledge on suitable areal reduction factors for extreme storms, the influence on flood waves of storm movement and direction, and the need for a viable estimate of total catchment storage consisting of infiltration, surface retention and valley storage. South African experience has shown that the application of the synthetic unit-graph model [2] far too often leads to intuitively unacceptable estimates of PMF. Such estimates are generally much too high.

As a consequence of the above results and experience it is obvious that there is an urgent need for a simple but realistic method for the estimation of maximum design flood peaks in South Africa and further that such a method be based upon an up to date catalogue of observed peaks and upon the use of regional envelope curves. In short a return to the empirical approach, largely neglected over the last few decades.

2. FLOOD PEAK ENVELOPE CURVES AND THE FRANCOU-RODIER METHOD

When maximum recorded flood peaks from a hydrologically homogeneous region are plotted on a log-log scale against catchment area it is generally possible to draw an envelope curve as an upper bound to the points. The algebraic expression for the curve becomes the regional empirical equation, noting that it takes no account of the frequency of the plotted events. The most simple form for such an equation is a straight line defined by $Q = K.A^{x}$, with K and x the regional coefficients.

Prior to the widespread popularity of the PMF concept perhaps the best known empirical approach was that of Creager [3] published in 1941, but based almost exclusively on American data. It is defined by :-

$$Q = 46\ C.A^{(0{,}894A^{-0{,}048})} \qquad \text{(Imperial units)}$$

where 'C' is a regional parameter with maximum $C = 100$. The relationship provides a curve on log-log scales and apart from its awkward algebraic form, this and similar expressions lack physical meaning and as a consequence universal application is not justified.

In 1967 Francou and Rodier revived the much neglected empirical approach in publishing a simple original concept of flood peak envelope curves[4]. They compiled a catalogue of 1 200 maximum recorded flood peaks representing all regions of the world. These had an average return period of ± 100 years and when plotted against corresponding catchment areas on a log-log scale it was found that for hydrologically homogeneous regions-

(i) the envelope curves representing regional upper bounds were straight, and
(ii) that the curves apparently converged towards a single point.

This single point lay at approximately $A = 10^8 km^2$ and $Q = 10^6 m^3/sec$ or that representing the total land surface of the earth excluding deserts and polar ice caps on the one hand whilst $Q = 10^6 m^3/sec$ represents the mean annual discharge of all the rivers on earth.

The equation given by Francou and Rodier for these converging envelope curves can be written as :-

$$Q/_{10^6} = A/_{10^8}{}^{\,1 - 0{,}1K}$$

where K is a regional coefficient. Figure 1 presents the equation graphically. The authors found that practically all 1 200 points lay within an upper envelope curve of $\tan a = 0{,}4$ and a lower one with $\tan a = 1$, where a is the slope of the line. The coefficient K is given by $K = 10(1 - \tan a)$. Francou [5] gives the following notes on the equation :-

(1) The relationship is valid only in the 'flood zone' or where the peak depends both upon storm intensity and basin characteristics. The approximate lower limit of the 'flood zone' corresponds to $A = 10\ km^2$ and $Q = 10\ m^3/sec$ whilst the real upper limit is, of course, the largest single catchment on earth, namely the Amazon with a catchment area near its mouth of $6 x 10^6 km^2$.

(2) In very small catchments, say $A < 1\ km^2$, which for most purposes can be considered truly impermeable, the specific peak discharge depends on storm instensity alone and is given by : $Q = 0{,}278\, i\ (m^3/s/km^2)$, where i is the storm rainfall intensity in *mm/hour*.

In the 'storm zone' a storm of given intensity will plot as a 45^o line and the lower limit of this zone represents an intensity which is just capable of generating a flood. That indicated by Francou[5] is a minimum intensity of $Q = 1\ m^3/s/km^2$. The upper limit of the 'storm zone' should correspond to the world record rainfall for the time of concentration in a catchment of $1\ km^2$. This duration may be taken as 15 minutes for which the world record rainfall is $= 200\ mm\ (i = 800\ mm/hour)$. It should be noted that strictly speaking the intensity lines in the $A < 1\ km^2$ zone do not have constant slope but become slightly steeper with shorter critical duration.

(3) Between the 'storm zone' and the 'flood zone' there lies a transition zone where the envelope curves are supposed to provide a smooth transition between the regional record point rainfall discharge $(Q = 0{,}278\, i\ (m^3/s/km^2))$ and the regional K envelope curve in the 'flood zone'.

Figures 2 and 3 illustrate the soundness of the Francou-Rodier approach, with Figure 2 showing world floods with $K > 5$, data having been taken from references 3, 5, 6, 10, 11, 12, 13 It is obvious that the upper bound to the points is well aligned with the direction of the $K = 6$ line whilst of the few peaks plotted above this line the most notable is that of the Amazon ($K = 6{,}3$). This value is attributable to the particular characteristics of this huge basin - year round high rainfall amounting to 2 000 - 4 000 mm, a considerable portion of the basin inundated in the high flood season, basin shape etc.

Probably one of the most important points to arise from the analysis was noted by Rodier[4] - that the upper envelope of world record peaks has not moved upwards in 30 years illustrating the completeness of the sample and the sufficiency of the method.

For the sake of comparison the highest Creager curve ($C = 100$) is also shown in Figure 2. It's shape seemingly does not fit the data particularly well in catchments smaller than ± 200 km^2 or larger than 20 000 km^2. Figures 3a and b show maximum recorded peaks in Canada, the USSR and tropical Africa at primary gauging sites, data being abstracted from "World Catalogue of very large floods" published in 1976[6]. Again, the general alignment of points agrees very well with the direction of the K lines in all 3 regions. The remarkably close agreement between Canada and the USSR reflects similar climatic and basin features.

In summary : the Francou-Rodier method by virtue of the incorporated physical boundary conditions, is apparently eminently suited for the definition of regional maximum flood peak envelope curves.

3. A CATALOGUE OF MAXIMUM FLOOD PEAKS FOR SOUTH AFRICA

In assembling an up to date South African catalogue of maximum flood peaks the following sources were employed : -

(1) Previous catalogues of the Department of Environment Affairs (DEA)

(a) Hydrographic Surveyor Pretoria. "Measured Large Floods in the Union". Prepared 1931. Contains 102 peaks measured at DEA gauging stations and elsewhere.

(b) Irrigation Department. Pretoria. Professional Paper No. 17. L.A. Mackenzie. Prepared 1951. Contains 164 peaks. Most peaks from (a) are included.

(c) DEA. Division of Hydrological Research. Professional Paper No. 20. D.F. Roberts. 1963. Contains 227 peaks including most of those from (b) above.

(2) Old general and regional files of the Irrigation Department. Pretoria.

(3) General and Régional flood files of the Division of Hydrology. Department of Environment Affairs.

(4) Annual Reports of the Division of Hydrology. DEA.

(5) Monthly summaries of river flow data. Division of Hydrology. DEA. Publications Nos. 8 and 10. Additional unpublished data.

(6) Original river stage charts. Department of Environment Affairs.

(7) Begg. G. "The Estuaries of Natal". Natal Town and Regional Planning Commission. Durban. 1978.

(8) Slope-area and other indirect flood peak surveys carried out and reported since 1967.

(9) Sundry reports, technical notes and dam reports (DEA).

In drawing up the catalogue certain restrictions were adopted :

(a) At any one site only the largest peak was selected for inclusion.

(b) Peaks observed at any site were included only if judged to be sufficiently large in comparison to other maxima in the local area.

(c) If two different surveys or calculations were documented for the same event then either the mean was taken or where sufficient information was available the choice was made after an examination of details.

(d) Peaks obtained from obviously erroneous procedures were excluded from the catalogue.

The catalogue, presented as Appendix I contains 355 peaks and was arranged according to drainage regions (A → X) and within each region according to increasing catchment size. The columns of the catalogue require the following notes :-

Column 1 : Drainage region or station number : Whenever an observation was made in reasonably close proximity to a DEA gauge the station number was used as opposed to the region number only. Sites not included in the analysis are denoted by an asterisk.

Column 2 : Geographical Position : Abstracted from DEA publication No 12. Division of Hydrology. "List of Hydrological Stations". 30/9/1977.

Column 4 : Catchment Area : (A) : For DEA stations this was abstracted from the same source as column 2, otherwise A was taken from various sources but was only roughly checked.

Column 5 : Flood Peak : (Q) : At stations where only a river stage chart was available the peak was obtained from extrapolated discharge tables valid at the time of the event.

Column 9 : Representative Period : (N) : This statistic provides an approximate idea of the total number of station-years available in each region but *N does not indicate the return period of the event.* At DEA stations it represents the length of record available. In the case of historic floods noted by the DWA and other N represents the the number of years that have elapsed between the event and 1980. Brackets indicate approximate values.

Column 10 : Maximum flood peak region number See 4 below.

Column 11 : Method of Measurement. Meaning of symbols :-

GS : From recorded stage and discharge table (DT) of DEA.
SA : Slope-area survey.
FVA : Float velocity/area survey.
BC : Bridge contraction survey.
ID : Inflow to dam.
OD : Outflow from dam.
W : From depth over weir.
U : Unknown.

Column 12 : Reliability Estimate . Meaning of symbols :-

1 : Accuracy ± 10%
2 : " ± 30%
U : " unknown.

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The reliability estimate or rating class was decided upon in each case after consideration of available information on the details of the measurement. For a large number of historical peaks or those estimated after substantial extrapolation of the DT it was not possible to estimate accuracy. Many historical peaks were calculated after slope-area surveys and documentation, sometimes including plotted cross-sections, was available. Despite this it was not justified to state the accuracy of the estimate as classes 1 or 2 because the quality of flood marks, channel stability, roughness and other details were unknown. Yet it is believed that in general peaks rated 'U' are of acceptable accuracy not in the least because of the technical quality of the personnel who carried out the surveys. Further indications regarding the likely quality of the U class peaks are to be found in 5 below.

For the sake of completedness the following statistics have been abstracted from the catalogue. (Events denoted by asterisk are not included)

DATE OF RECORDED MAXIMUM FLOOD PEAK	NO.
prior to 1925	50
1926 - 1950	61
1951 - 1979	180

METHOD OF MEASUREMENT	NO.
At gauging station from DT	164
Other	99
Unknown	28

RATING CLASS OF PEAK ESTIMATE	NO.
'1'	42
'2'	83
Unknown	166

Appendix 2 contains a list of 23 flood peaks observed in South-West Africa, Zimbabwe (Rhodesia) and Malawi. These data, although not used in the analysis provide a useful addition to those available for the Republic.

4. DELIMITATION OF MAXIMUM FLOOD PEAK REGIONS

The reliability of empirical methods of flood peak estimation is most dependent on a realistic delimitation of homogenous flood regions. To this end the three factors considered to play an essential role in the problem are considered separately below.

4.1 Statistical comparison of data according to drainage regions

Before embarking on the comparative analysis the catalogue was reviewed with the purpose of achieving a balanced distribution of data within each drainage region. As a result 64 peaks from the total of 355 were excluded from further study. In most cases these were observed at sites adjacent to others where the recorded peak had a higher K value. One such excluded peak, for example, observed on the Bloemspruit in drainage region C, had an uncharacteristically high K and was suspected to be influenced by discharge

TABLE 1 SUMMARY OF USEFUL STATISTICAL INFORMATION OF MAXIMUM FLOOD PEAK RECORDS IN 20 DRAINAGE REGIONS

Drainage region	Area A(Km²)	Number of flood peaks M	A/M	Represen= tative total period NT (years)	NT/M (years)	Parameters calculated from the Francou-Rodier coefficient K: Mean $\overline{K}$	Coeffi= cient of variation CVk	Maximum recorded Km	$\frac{Km}{\overline{K}}$
A	110 000	41	2 680	1 215	30	3,91	0,15	4,83	1,24
B	73 500	15	4 900	405	27	3,63	0,24	4,75	1,31
C	194 000	32	6 060	1 305	41	3,23	0,26	4,25	1,32
D	412 000	30	13 700	919	31	3,35	0,23	4,44	1,33
E	48 500	7	6 930	241	34	3,11	0,19	3,91	1,26
G	25 500	16	1 590	265	17	3,77	0,15	4,84	1,28
H	15 500	15	1 030	306	20	4,01	0,10	4,68	1,17
J	45 500	15	3 030	612	41	3,84	0,15	4,70	1,22
K	7 200	8	900	140	18	3,95	0,11	4,90	1,24
L	34 500	9	3 830	222	25	4,05	0,16	5,02	1,24
M	2 700	6	450	162	27	4,53	0,06	4,90	1,08
N	21 000	7	3 000	254	36	4,20	0,11	5,02	1,20
Q	30 500	13	2 350	389	30	3,95	0,16	4,86	1,23
R	7 900	8	990	196	25	4,48	0,09	5,03	1,12
S	20 500	6	3 420	183	31	3,86	0,13	4,72	1,22
T	46 500	14	3 320	383	27	3,96	0,18	4,86	1,23
U	18 500	11	1 680	272	25	4,38	0,12	4,94	1,13
V	29 000	14	2 070	403	29	3,95	0,16	4,86	1,23
W	60 000	11	5 450	300	27	4,15	0,16	5,10	1,23
X	31 000	13	2 380	219	17	3,75	0,13	4,31	1,15
TOTALS or MEANS	1 234 000	291	4 380	8 391	29				

from a burst dam. These excluded events are marked with an asterisk in Column 1 of the catalogue.

Table 1 provides a summary of relevant statistical information on the 291 selected peaks. A number of columns in the table are further explained as follows :-

Table 1 : Column 5 : Representative Total Period : (NT) : Provides the sum of representative periods for all events in each drainage region and was abstracted from column 9 of the catalogue.

Table 1 : Columns 6-10 : List various statistics derived from the range of K values calculated from all events in a region. Note that in column 7 of the table $CV_k = S_K / \overline{K}$ = coefficient of variation or the standard deviation of the regional K values divided by their mean. Thus CV_K provides a dimensionless measure of the relative dispersion of K in each region.

The conclusions from Table 1 are as follows :-

(a) Region C, D and E, draining into the Atlantic have a low mean K value ($\overline{K}$).

(b) Regions K to W, draining into the Indian Ocean, are characterized by high mean K, with the exception of region S which had very few events and short NT.

(c) The relatively high CV_K values found in regions B, C and D clearly indicate the heterogeneity of flood generating conditions in these regions.

(d) The inequalities in NT values between regions and the mean representative period (NT/M) for the M events in each region should be taken into account in the final regional delimitation.

4.2 Regional Topography

Obviously topographical, geomorphological and geological considerations must be accounted for in the identification of flood regions. General landscape slope as well as the prominent boundaries and position of the catchments were given primary consideration.

4.3 Regional Storm Rainfall Patterns

As a final consideration in the regionalization scheme the storm rainfall pattern over the Republic must be considered. Figure 4 shows the distribution of the 100 year return period one-day storm rainfall over South Africa. It is derived from the recent work of Adamson [7] which presents results for over 2 000 daily rainfall records.

Giving due weight to each of the three essential considerations outlined above, regional flood boundaries for the Republic could now be drawn.

4.4 Proposed Flood Regions

Figure 5 shows the five maximum flood peak regions proposed for South Africa. In addition to the regional boundaries the map also indicates the main drainage network, drainage regions (A - X), dolomitic areas (shaded), the sites of all peaks given in the catalogue (Appendix 1) and the observed maximum Francou-Rodier K value in each drainage region. The flood regions are characterized by the following essential features :

Region 1 : Rainfall régime of the heavy, cyclonic type; mean annual precipitation (MAP) ranges between wide limits but generally increases towards the coast; the topography, with isolated exceptions, is hilly to mountainous.

Region 2 : Fairly high extreme storm rainfall but definitely lower than in region 1; MAP and topography include all types to be found in the Republic.

Region 3 : Moderate values of extreme storm rainfall; MAP fairly high to less than 100 mm; topography, except for parts of the Western Cape and Karoo in addition to the catchment of the upper Orange River, is generally fairly flat.

Region 4 : Moderate to low extreme storm rainfall; MAP moderate to practically nil; topography is flat with isolated and limited exceptions.

Region 5 : As region 4 but extremely flat, desertic or dolomitic.

Employing Figure 5, each catchment listed in the catalogue was given its appropriate flood region number (cf. Column 10, Appendix 1). Obviously as a general rule sites located within a given flood region were accorded the number of that region. However, there were exceptions :-

(1) Some of the larger rivers were classified to other regions than the one which they cross at a particular site. Notably :

- In drainage region A the Crocodile, Mogalakwena and Sand rivers were transposed along their lower reaches from Region 2 to Region 3 on account of the reduction of flood peaks caused by a combination of rather flat, permeable and bushy catchments in addition to a consistent and marked decrease in MAP in a downstream direction. The Limpopo River was 'declassed' to Region 4 because its catchment includes extensive flat and semi-arid areas of Botswana.

- In drainage region B the Olifants River was 'declassed' as shown mainly because of the above mentioned conditions, but also owing to the distinctly reduced extreme storm rainfall in a considerable part of its upper and middle catchment.

- In drainage region D that reach of the Orange River upstream of its confluence with the Vaal was upgraded to flood region 3 because this relatively narrow part of the catchment although geographically belonging to Region 4 comprises only a negligible part of the total catchment area. The lower reaches of the Hartebees and Orange Rivers were degraded from Region 4 to Region 5 as a consequence of the influence of large, very flat and desertic areas in these particular basins.

In each of the above cases the valid flood region number appears along the river reach in question (cf. Figure 5).

TABLE 2 : SUMMARY OF SOME STATISTICAL INFORMATION ON MAXIMUM FLOOD PEAKS ACCORDING TO FLOOD REGIONS

Maximum flood peak Region Number		1	2	3	4	5
Area A (km^2)		165 000	342 000	340 000	250 000	137 000
Number of flood peaks M		80	127	64	16	4
$\frac{A}{M}$		2 060	2 690	5 310	15 600	34 000
Representative total period NT (years)		2 030	3 520	2 180	562	99
$\frac{NT}{M}$ (years)		25	28	34	35	4
$\frac{\text{Number of storms}}{\text{Number of flood peaks}}$		0,46	0,72	0,71	0,83	-
Parameters calculated from the Francou-Rodier "K"	mean $\overline{K}$	4,29	3,87	3,54	2,53	-
	Coeff. of variation CV_k	0,11	0,14	0,15	0,17	-
	Maximum recorded K_m	5,10	4,86	4,44	3,26	2,16
	$\frac{K_m}{\overline{K}}$	1,19	1,26	1,25	1,29	-

(2) Some further detailed adjustments were made. In particular a number of sites in the very flat, largely dolomitic areas of Region 3 were transposed to Region 4. These minor details are not shown in Figure 5.

Table 2 provides a summary of pertinent statistics of the 291 events according to the five established flood regions. This Table contains the same information as Table 1 with the addition of the ratio of the number of storms to the number of flood peaks. The data reveal that the proposed flood regions apparently fulfil the fundamental requirements of regionalization insofar as each region has a distinct mean and maximum K value ($\overline{K}$ and K_{max}) and within each zone the K values are homogenous as illustrated by their low coefficient of variation (CV_K). It is to be noted, however, that as a consequence of the lack of information in Region 4 the statistics attached to the K values therein are less reliable than those provided for Regions 1, 2 and 3. For the same reason it made no sense to calculate $\overline{K}$, CV_K and $K_{max}/\overline{K}$ for Region 5.

It is interesting and reassuring to note that the maximum flood peaks recorded in Zimbabwe (Rhodesia) are characterized by very similar K values as their counterparts in the N and NE Transvaal. These data, given in Appendix 2, and their agreement with adjacent areas of the Republic reflect comparable basin and meteorological characte= ristics.

5. THE ESTABLISHMENT OF REGIONAL MAXIMUM FLOOD PEAK ENVELOPE CURVES

In Figures 6a-e the flood peaks selected for study in each of the proposed flood regions are shown plotted against catchment area on a log-log scale. For Region 5, which had only four selected events, the two non-selected events (see catalogue) are plotted as an addition. An examination of the plots immediately reveals that the cloud of points, especially their upper bounds, tends to follow the direction of the K = constant lines, thereby giving substantial credence to the application of the Francou-Rodier approach to the empirical appraisal of maximum flood peaks in South Africa. Additionally, simultaneous reference to the Figures 6a-e and Column 12 of the catalogue, which attaches an estimate of accuracy to the flood peak, discloses that the peaks of unknown accuracy and particularly those near the regional upper bound, associate very well with those peaks of more definite quality. This points to the fact that the peaks of unknown (U) accuracy lie within a realistic range.

The lower bound of each cloud of points is not so well defined but this is of no consequence given the object of this study. It is to be expected anyway since the catalogue inevitably contains many peaks derived from quite short records and merely serves to convey an impression of the difference between "ordinary" and "rare" floods.

Returning to an examination of the upper bounds of the plotted events suggests a slight tendency towards convexity particularly at the two extremes, in other words, a curved envelope of the Creager type might appear more realistic than the straight K lines. However, the suggested primary cause of the convexity is that there are considerably fewer very small and very large catchments available for analysis than those of a middle range. This point is well illustrated by the following data.

CATCHMENT AREA RANGE (KM^2)	NUMBER OF CATCHMENTS	% OF TOTAL
<10	8	3
$10 - 10^2$	42	14
$10^2 - 10^3$	119	41
$10^3 - 10^4$	91	31
$10^4 - 10^5$	28	10
$>10^5$	3	1

It is clearly evident that the chance of containing the peak with the highest K value is greatest in the mid-range of catchment areas where the majority lie.

The problem now arises as to where exactly to locate the regional envelope curves. It would be straightforward to place them through the point with the highest regional K value, however, such a procedure would not satisfy the natural desire for a certain degree of safety. There would indeed be legitimate fears that an envelope curve so traced stands far too high a risk of being surpassed by a larger event. It is also important to bear in mind that the purpose of this study is to devise an efficient practice for the estimation of the expected limits of maximum peaks. In reality such limits could be closely approximated or reached. If future rare events consistently exceed the envelopes there would be a need to adjust them upwards so some margin of safety must be satisfied by slightly shifting the curve to a higher level. On the other hand, to shift them too far would be to render the whole exercise useless by arriving at an unrealistically high flood peak range.

Figure *7* is an attempt to solve the dilemma and shows the increase of the highest observed K with time from the start of available records (± 1900 to 1980 for regions 1 - 4. It was assumed that the starting value for K was the regional mean (c.f. Table 2). The asymptotic nature of the increase in K with time is obvious with the exception of Region 4 where the number of events available was really too few for this exercise. It should also be noted that the number of events available increased with time but despite this it is striking to note the rapid rise in maximum regional K in the first decades of the century with the considerable growth of available events towards the end of the period (1950 - 1980) making little difference to the asymptotic nature of the diagrams. This bears out Rodier's [4] claim that the envelope of world record peaks did not change in the 30 years preceding 1967.

With the above evidence in support it was concluded that the envelope curves for regions 1 - 3 should not be shifted above the highest regional observed K value by more than $\Delta K = 0{,}1$ to $0{,}2$. In regions 4 and 5 the scarcity of records warrants the adoption of a relatively higher increment, say $\Delta K = 0{,}3$ to $0{,}4$. The regionally recommended K values thus become:

REGION	1	2	3	4	5
K - ENVELOPE	5,25	5,00	4,60	3,60	2,50

These values are shown plotted in Figure 7, and the envelope curves in Figures 6a-e together with the regional K values. The recommended valid range of the curves is indicated by a continuous line whilst the transition to the "storm zone" is shown by a dashed line and is tentative. This transition is based on the principles expressed by Francou (cf. Figure 1) and on 15 to 60 minute extreme point rainfalls recorded or analysed in South Africa (8, 9).

To conclude this part of the study one cannot but pay some consideration to the likely range of return periods associated with the upper envelope of observed maximum events and a comparison of these return periods with those derived from probabalistic techniques. In Table 2, the "representative total period" (NT) of all records in each region was listed. Strictly 'NT' cannot be said to be the return period of the largest regional peak ($K = K_{max}$) since the recorded peaks are not entirely independent and the period of record in years (N) assigned to each event is arbitary and most probably somewhat short. The lack of independence between events is confirmed by the ratio of the number of storms to the number of flood peaks, as shown in Table 2.

The above considerations should have the opposite influence on NT. It is felt therefore that the NT values of Table 2 are at least in a comparable range with the unknown true return period of the peak with the largest regional K value. Furthermore, it is reasonable to infer that within each region, at least in the range characterized by the peaks which approach the regional envelope curve in terms of their associated K values, that the return period of the peak with the nth greatest K is $T \simeq NT/n$.

Using these assumptions the values given in Table 3a were computed, that is the return period of each regional K_{max} peak and 10th largest K-peak. The availability of data limited the exercise to a study of regions 1-3 whilst an arbitary 1 000 km^2 catchment was chosen for the Francou-Rodier equation.

TABLE 3a

Region	No. of flood peaks	K_{max}	10th largest K	'NT' years	$0,1\ NT$ years	A km^2	Q_{NT} (m^3/s)	$Q_{0,1\ NT}$ (m^3/s)	$\frac{Q_{NT}}{Q_{0,1\ NT}}$
1	80	5,10	4,86	2 030	203	1 000	3 550	2 690	1,32
2	127	4,86	4,68	3 520	352	1 000	2 690	2 190	1,23
3	64	4,44	4,17	2 180	218	1 000	1 660	1 220	1,36

The primary conclusion of the exercise, as shown in the final column of the table, is that a peak with a return period in the range of T = 200 - 300 years is only about 30% smaller than the maximum ever recorded in the region for the same catchment area. If the actual recommended regional K-envelopes were used it would be found that the T = 200-300 year event is about 65% of the likely upper limit of peaks. As a consequence it is not suprising how quickly the upper limit for a regional K value is approximated during the span of available historic data.

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It now becomes pertinent to compare the above $Q_{NT}/Q_{0,1NT}$ ratio with a similar relationship derived from a probabilistic approach. Table 3b is based on the work of Adamson[1] using the Log-Normal and Extreme Value Type 2 probability models and shows the $Q_T/Q_{0,1T}$ ratio.

TABLE 3b

Probability Model	$Q_T/Q_{0,1T}$						
	T (YEARS)						
	20	50	100	200	500	1 000	10 000
LN2	5,00	3,14	2,71*	2,43	2,18	2,05	1,84
EV2	4,43	2,69	2,35	2,13	1,95	1,87	1,75

(* eg. Q_{100} *is 2,71 times greater than* Q_{10} *according to the LN2 model*).

These data show that for the 50 records analysed the $Q_T/Q_{0,1T}$ ratio is much greater than the figure calculated as $Q_T/Q_{0,1NT}$ even at the $T = 10\ 000$ year level (1,8 *vs* 1,3). In fact it is apparent from the data in Table 3b that a ratio of 1,3 would only be reached at an astronomical return period which does not accord with the physical reality as shown in Table 3a of a physical upper limit being approximated quite quickly in historical terms and with a return period in the range of 1 000 - 5 000 years attached to it. (cf. Table 3a, column 5). Although based on some very particular assumptions this comparative exercise does call to account the use of probabilistic approaches to the estimation of probable maximum flood. This is especially so for South African annual flood peak maxima where outliers (outlier : a much larger peak than the next largest in the ranked data) can unduely affect the parameters and therefore the fit of probabilistic models giving rise to thoroughly unreasonable results. Outliers in fact point to a mixed distribution for flood peak data which represents a mixture of catchment and meteorological flood generating conditions. Such a mixed model is sketched in Figure 8 and illustrates how currently employed approaches can significantly underestimate peaks in the vital mid-range, that is $20 < T < 200$ years.

6. SOME GENERAL NOTES

1. The five recommended envelope curves provide for each region the upper limit of maximum peaks that can be reasonbly expected.

2. Conditions that may justify the lowering of the regional envelope curves are :-

   (a) Unusually flat catchment, wide flood plain, pans etc.

   (b) Very permeable surfaces - dolomitic areas+

   (c) Afforestation and indigenous forest.

   (d) Consistent and marked decrease in MAP in a downstream direction in catchments larger than ± 10 000 km².

Such conditions do occur in each of the proposed regions but the reduction of the *K* envelope should not be more than one which brings it to the same value as that of the subsequent region. For example for any catchment in Region 2 the reduction cannot exceed $\Delta K = 0,4$ or the difference between the *K* values of regions 2 and 3.

For interests sake Figure 9 shows the change in maximum recorded *K* along the Orange and Tugela rivers. Along the former *K* is fairly constant in the wetter and steep upper catchment but beyond Aliwal North the value is gradually reduced as the effects of decreasing MAP and the influence of a flatter catchment become apparent. The opposite case is shown for the Tugela where *K* increases in a downstream direction reflecting the fact that the river flows from a drier to a wetter region and that the catchment slope remains steep.

3. Catchments on or about the boundaries of the proposed flood regions can be accorded an average *K* value or where particularly justified the higher of the two values.

4. The flood catalogue presented in Appendix 1 will be periodically updated as further data become available. Depending on future floods a slight increase in regional *K* values (say 0,1 to 0,15) or minor adjustments of regional boundaries may be warranted.

7. ACKNOWLEDGEMENTS

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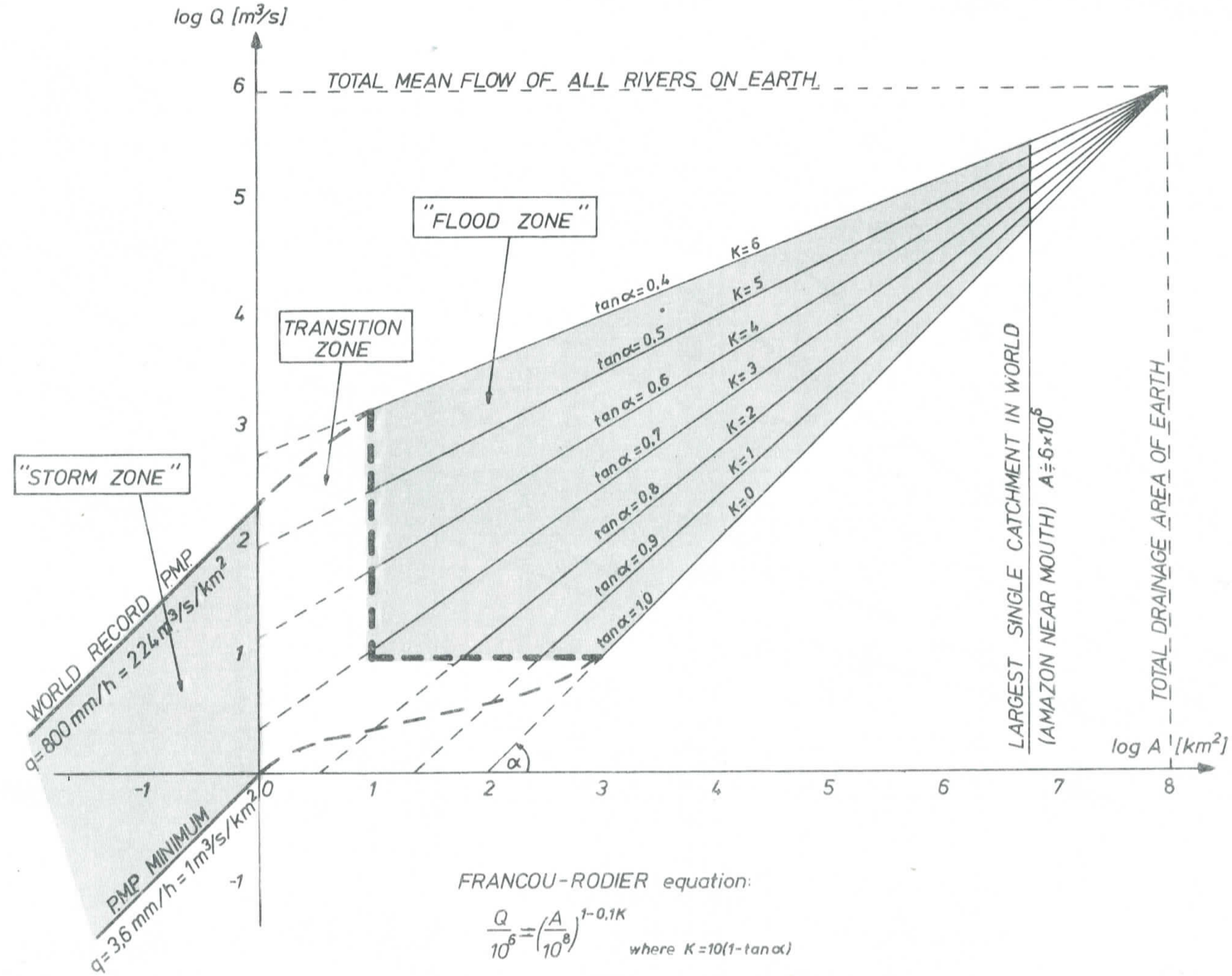

FIGURE 1. PRINCIPLE OF THE FRANCOU-RODIER EQUATION.

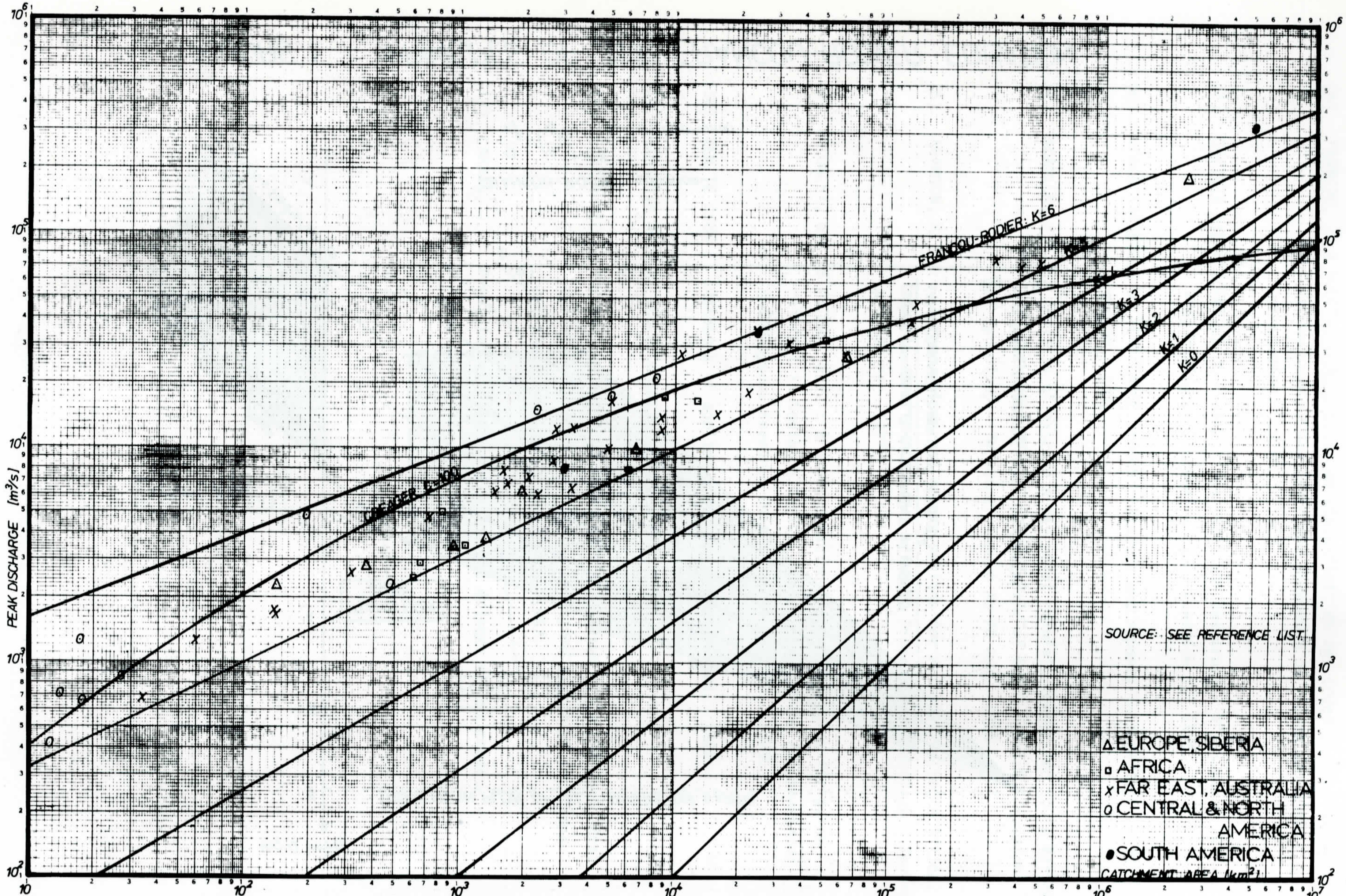

FIGURE 2. MAXIMUM RECORDED FLOOD PEAKS IN THE WORLD (FRANCOU-RODIER K > 5)

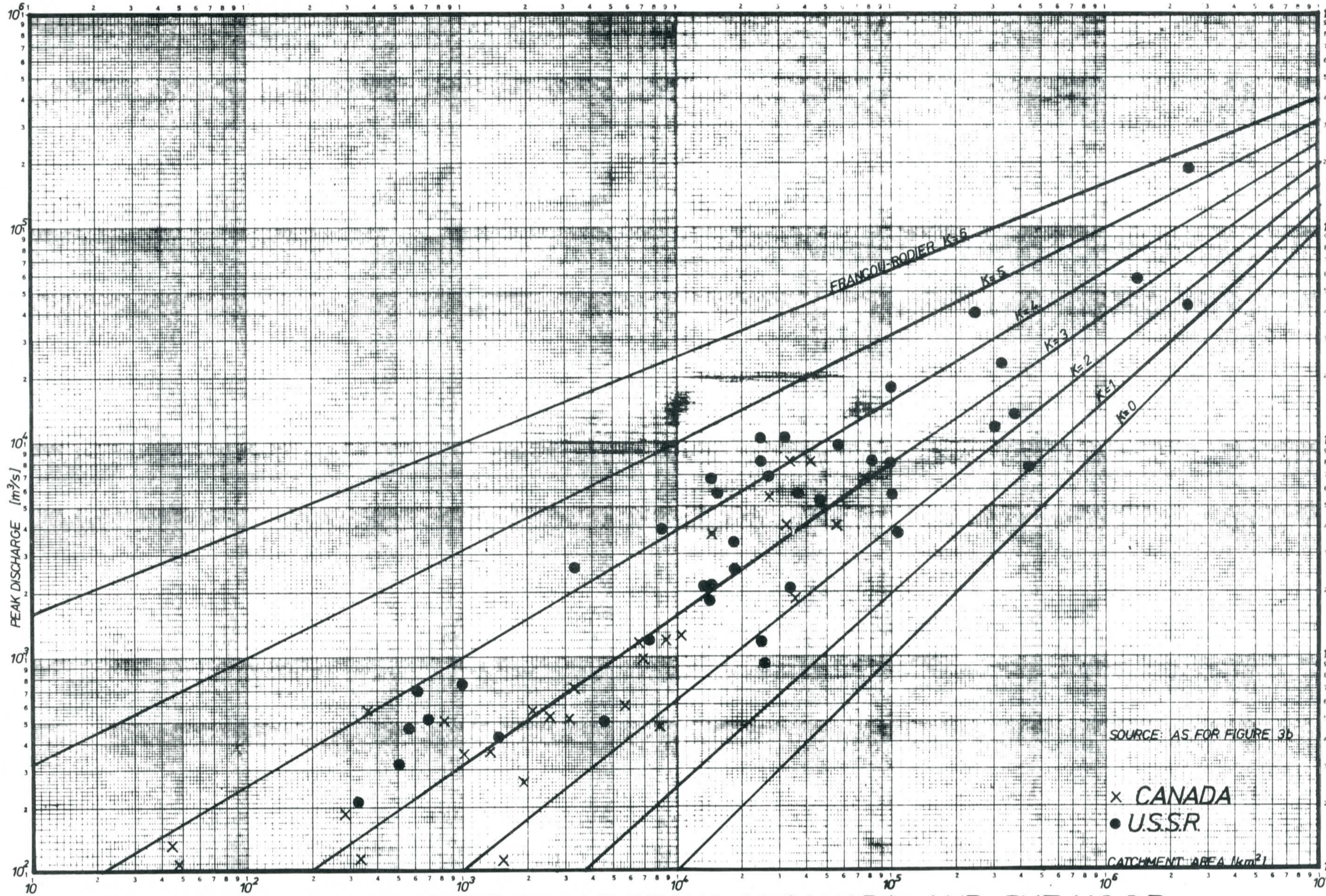

FIGURE 3a MAXIMUM RECORDED FLOOD PEAKS IN CANADA AND THE U.S.S.R.

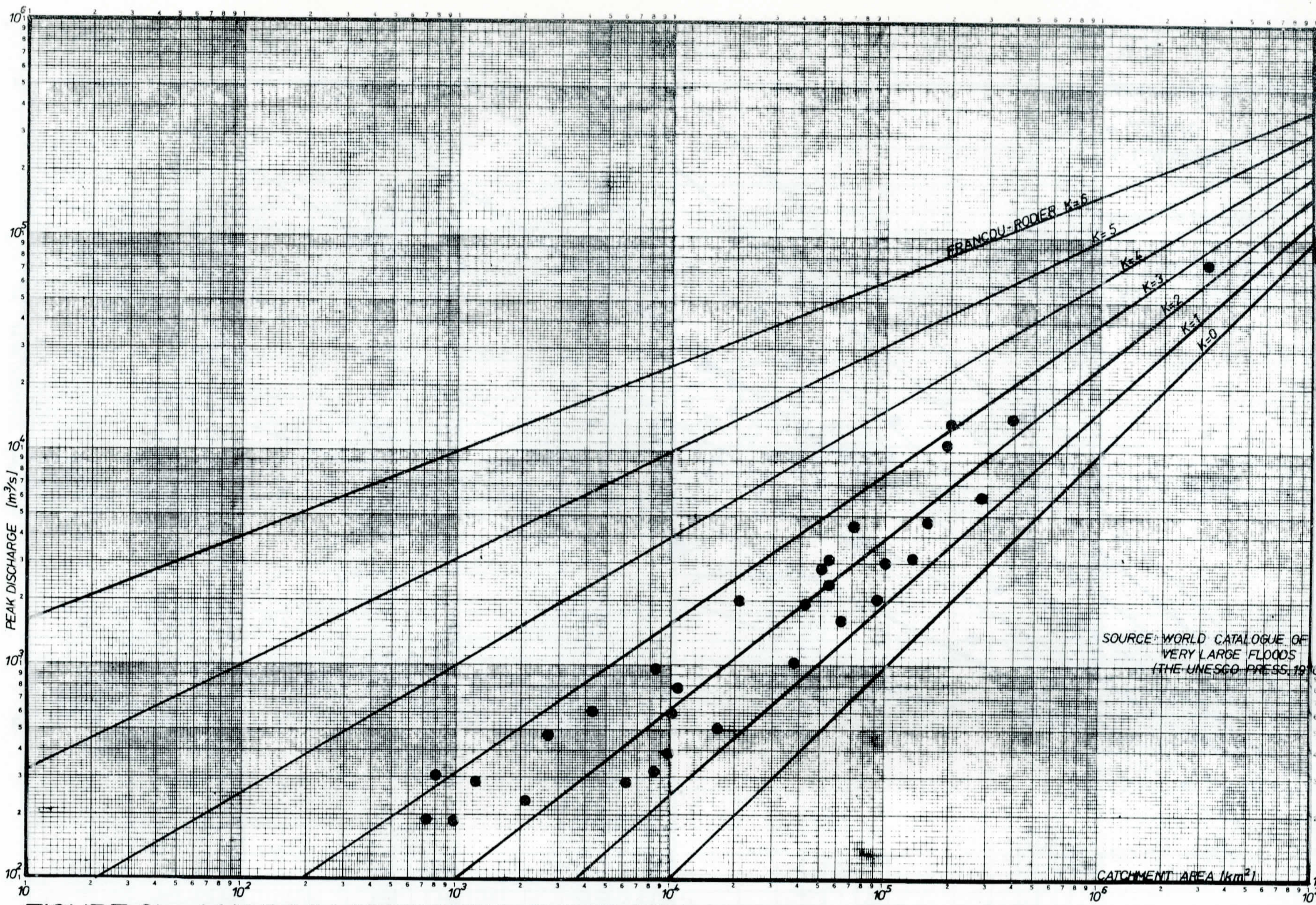

FIGURE 3b. MAXIMUM RECORDED FLOOD PEAKS IN TROPICAL AFRICA

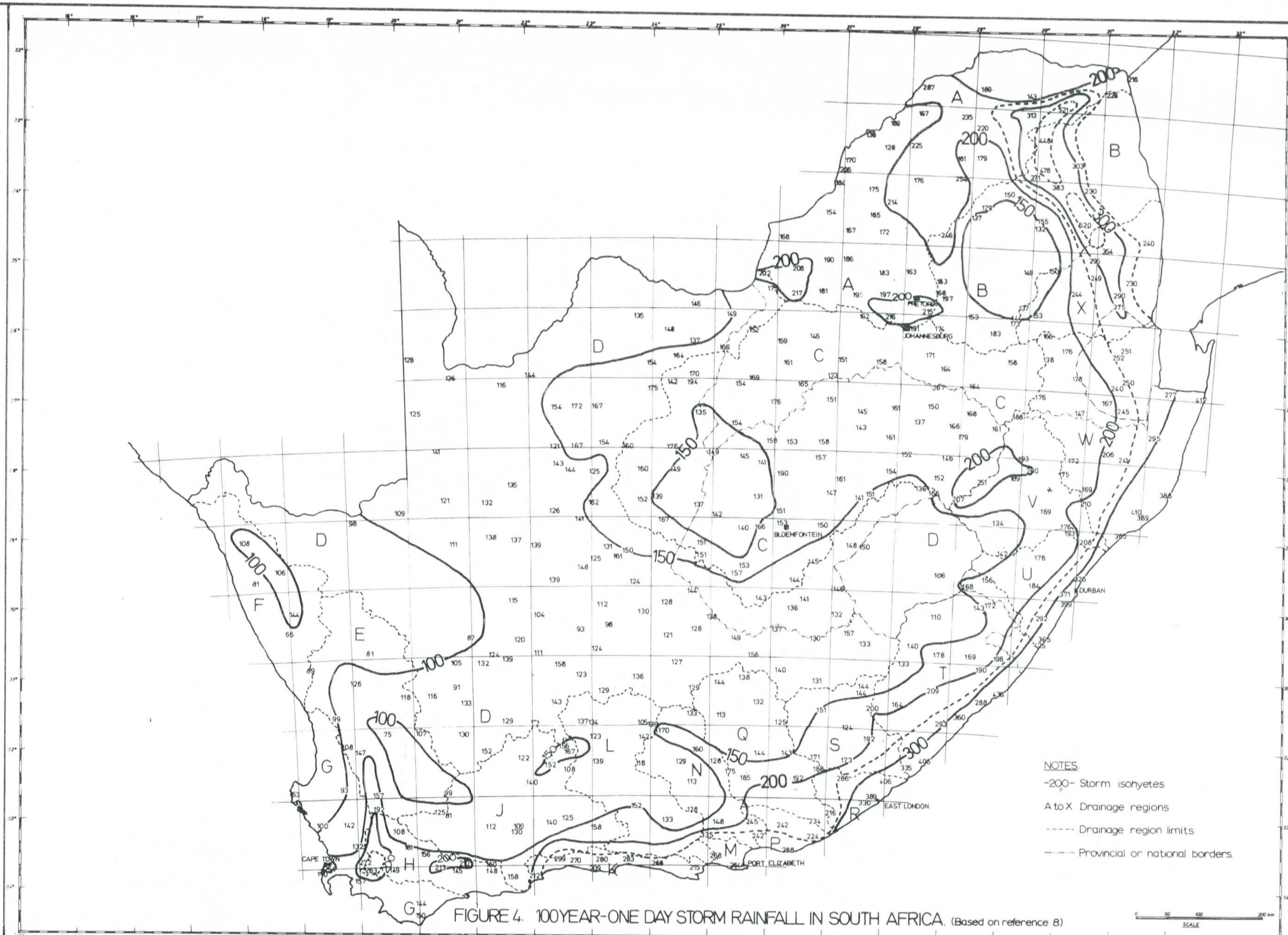

FIGURE 4. 100YEAR-ONE DAY STORM RAINFALL IN SOUTH AFRICA. (Based on reference 8)

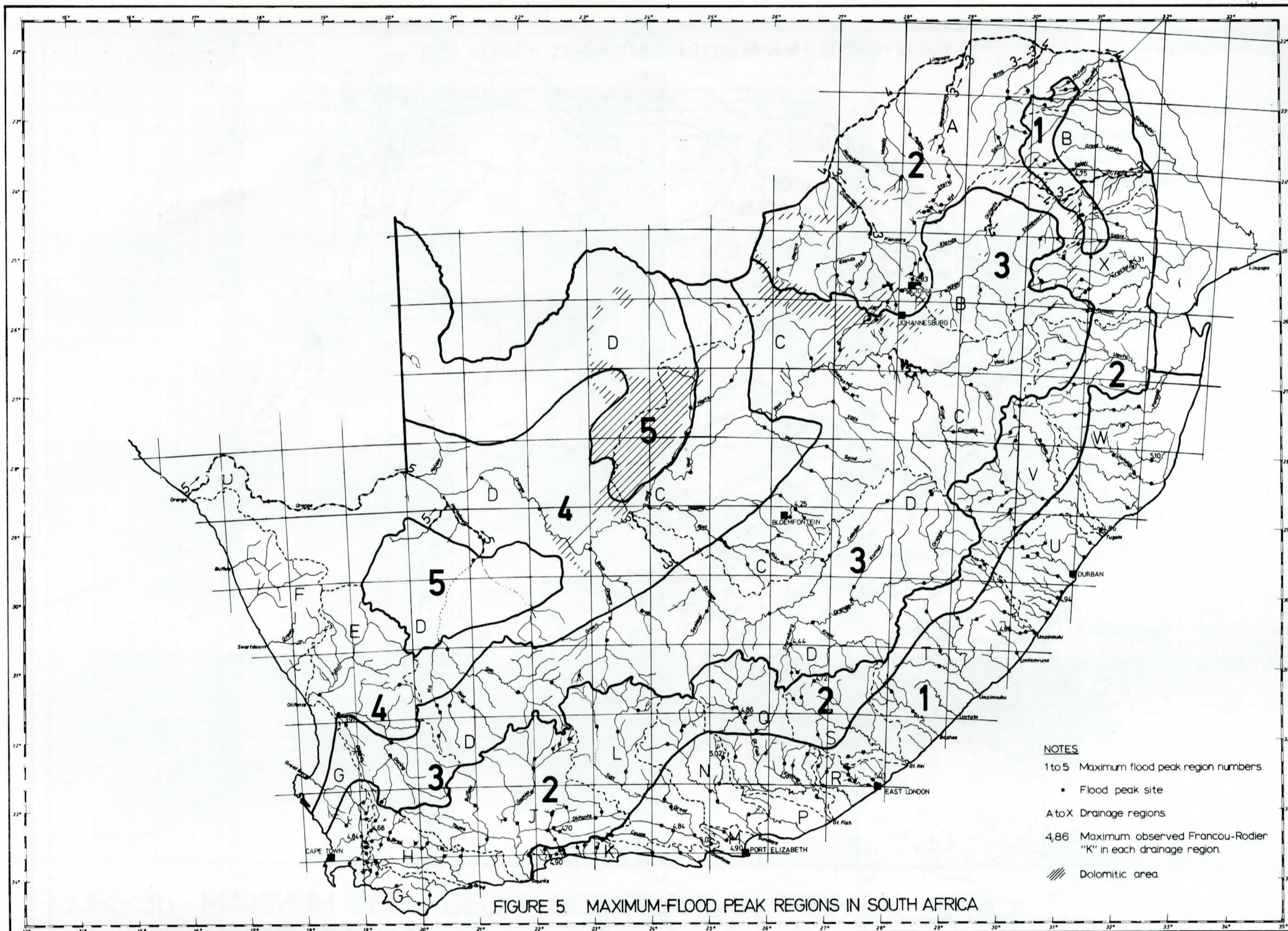

FIGURE 5. MAXIMUM-FLOOD PEAK REGIONS IN SOUTH AFRICA

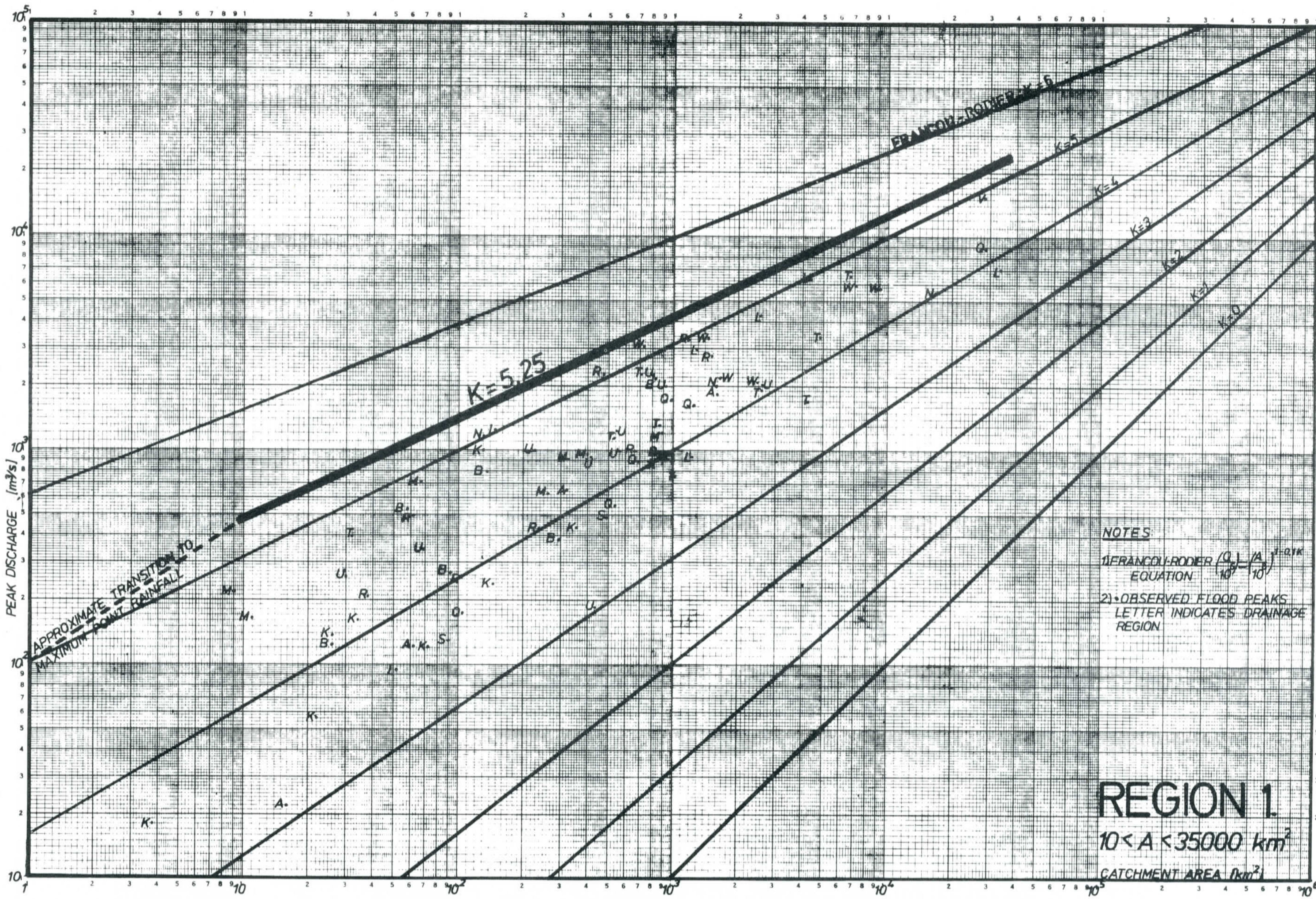

FIGURE 6a. ENVELOPE OF MAXIMUM PEAK DISCHARGES.

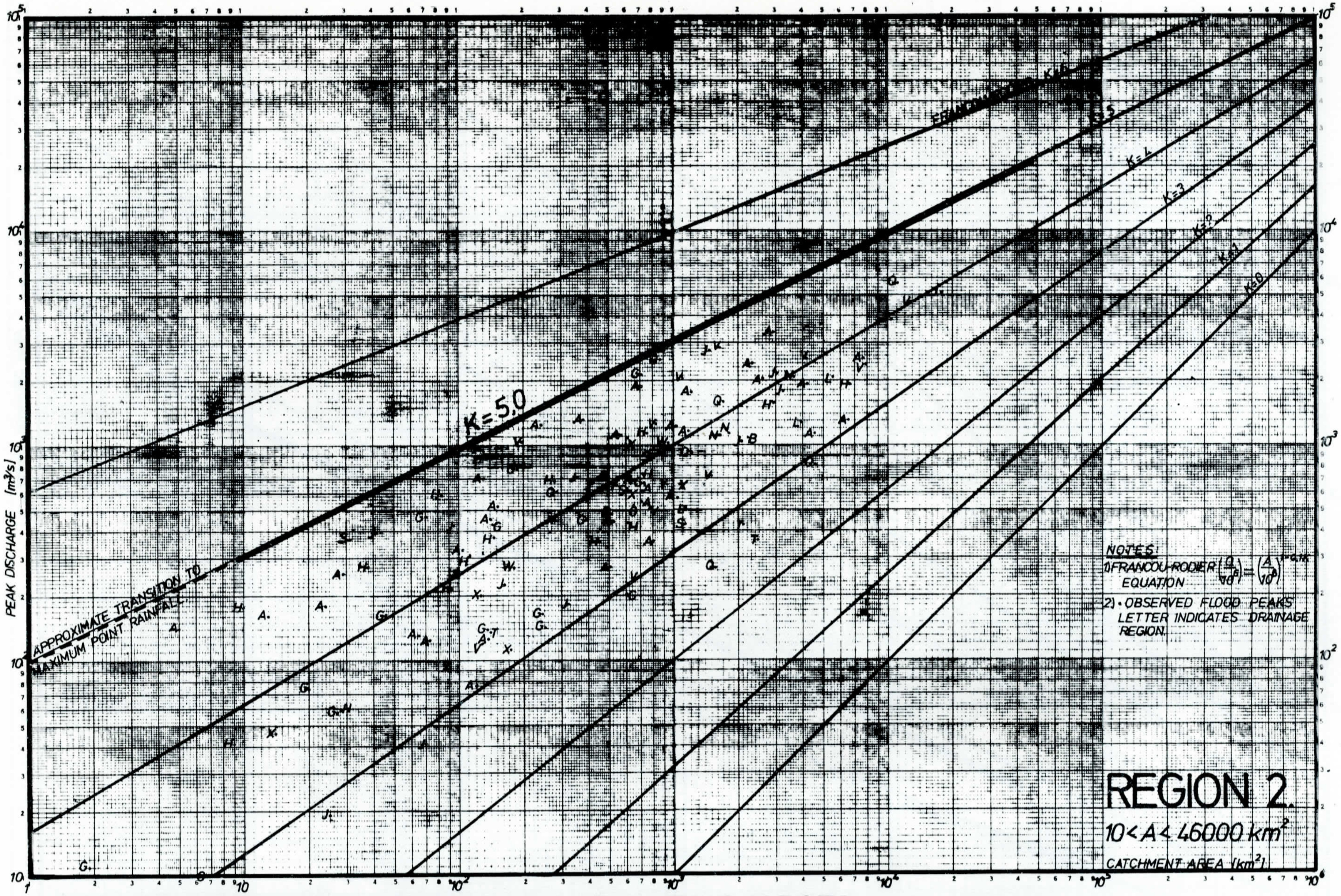

FIGURE 6b. ENVELOPE OF MAXIMUM PEAK DISCHARGES.

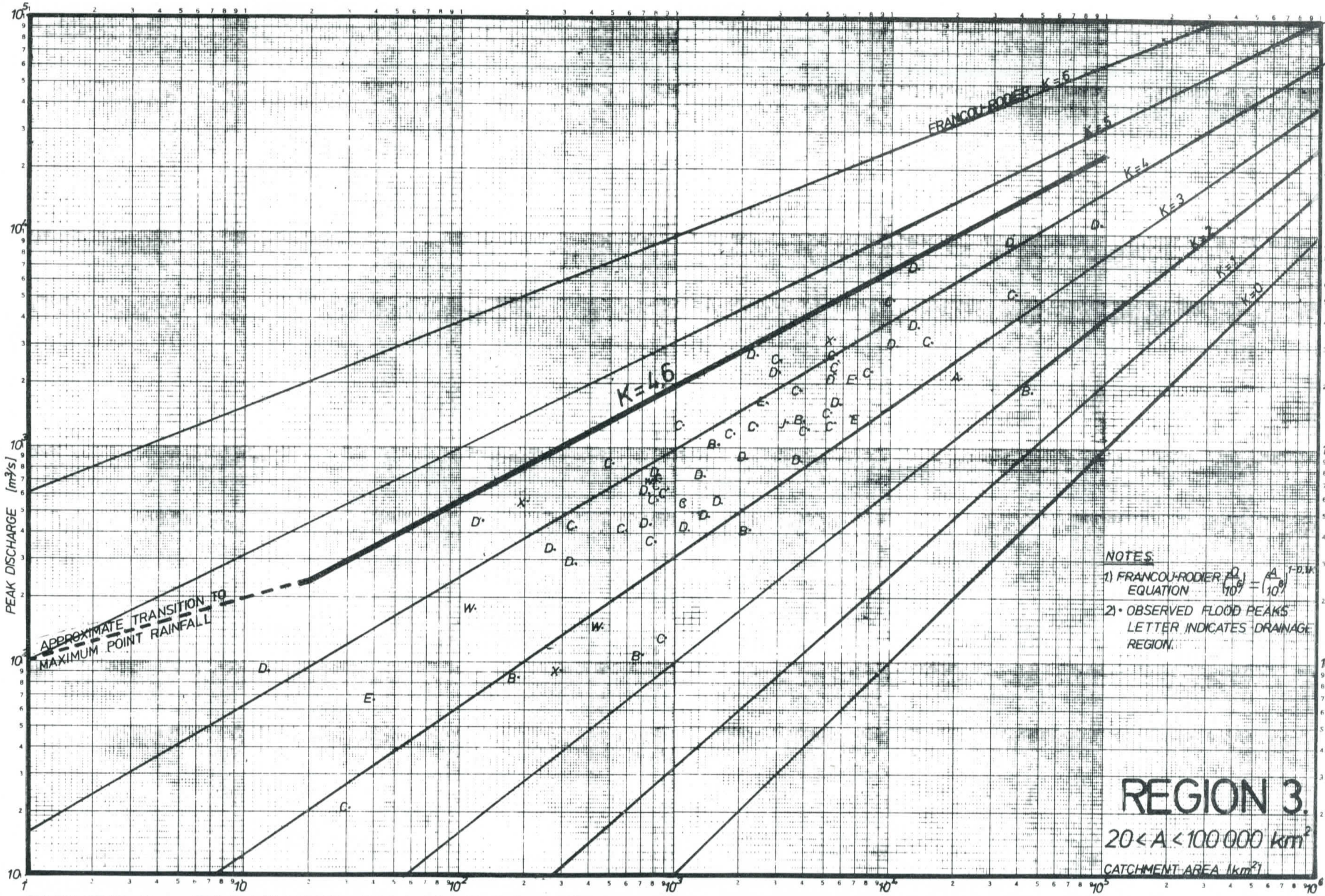

FIGURE 6c. ENVELOPE OF MAXIMUM PEAK DISCHARGES.

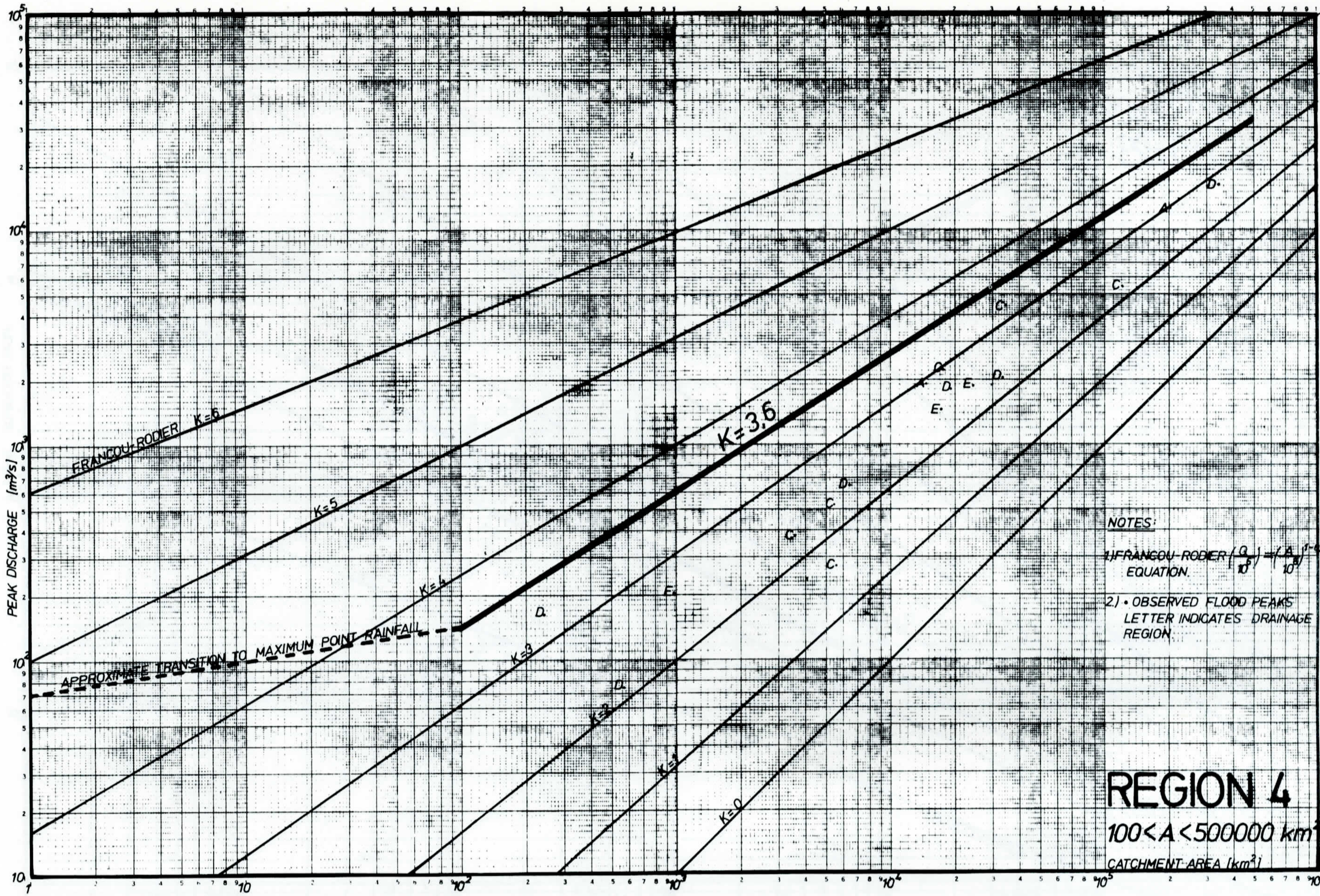

FIGURE 6d. ENVELOPE OF MAXIMUM PEAK DISCHARGES.

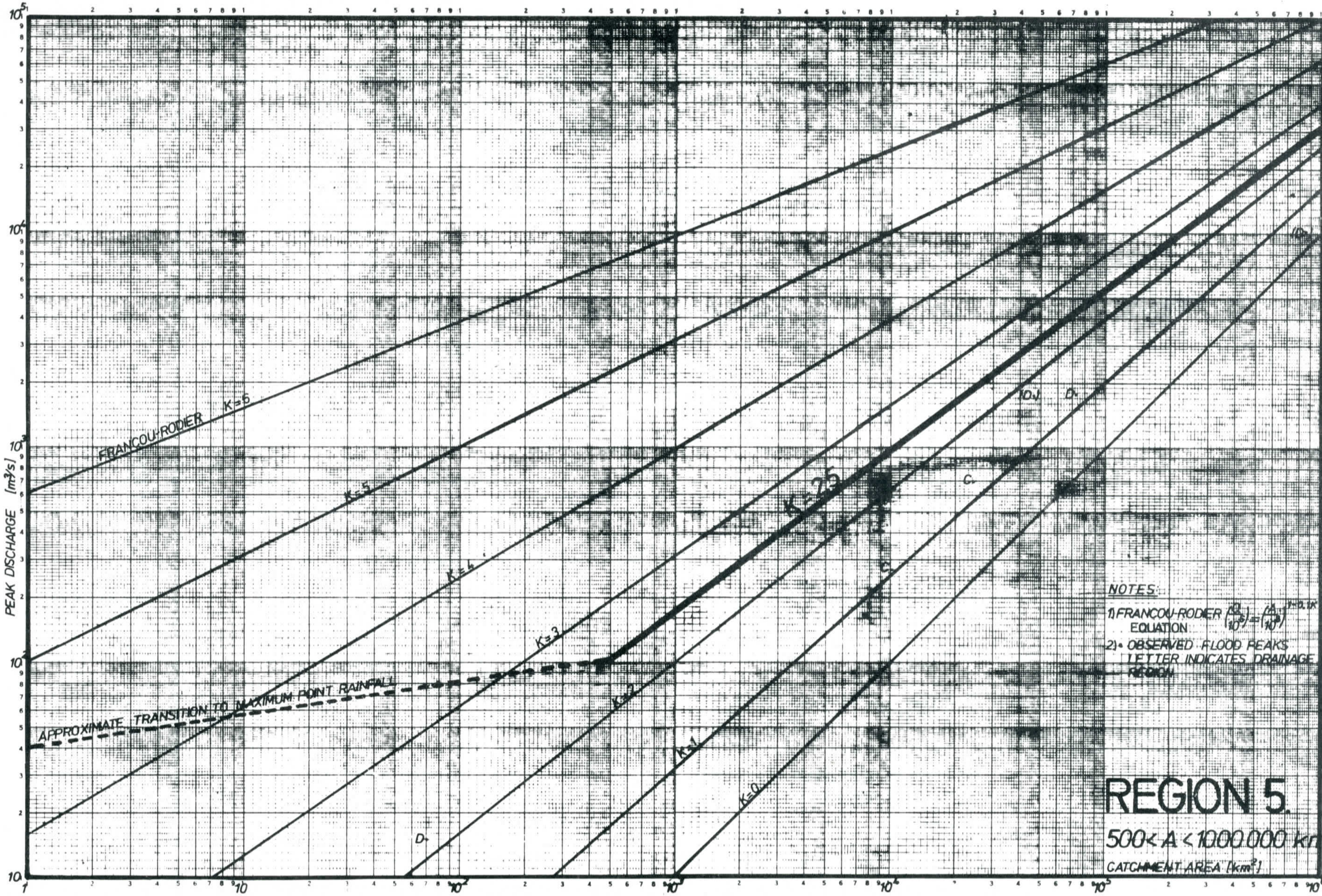

FIGURE 6e. ENVELOPE OF MAXIMUM PEAK DISCHARGES

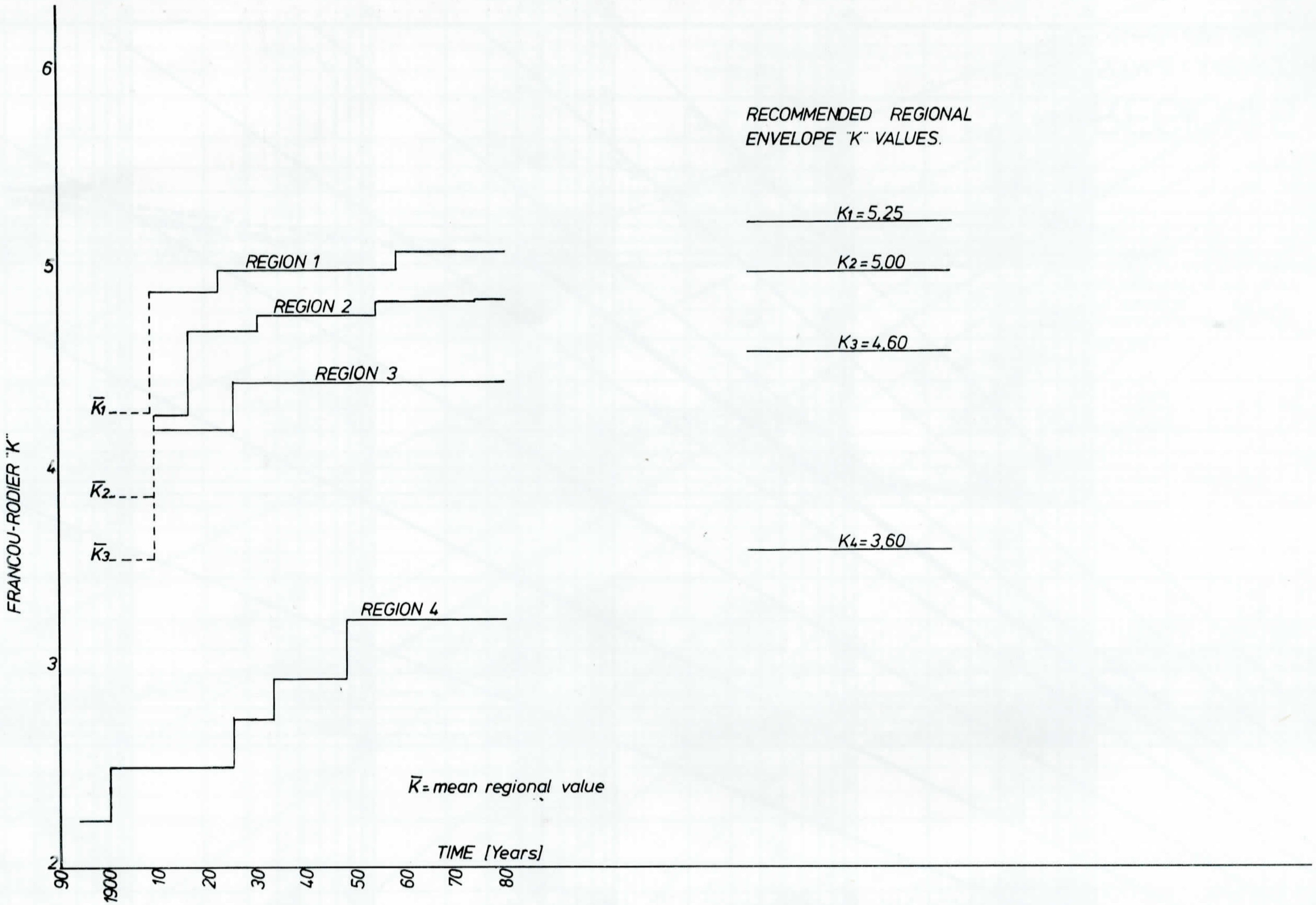

FIGURE 7. INCREASE OF MAXIMUM RECORDED "K" WITH TIME.

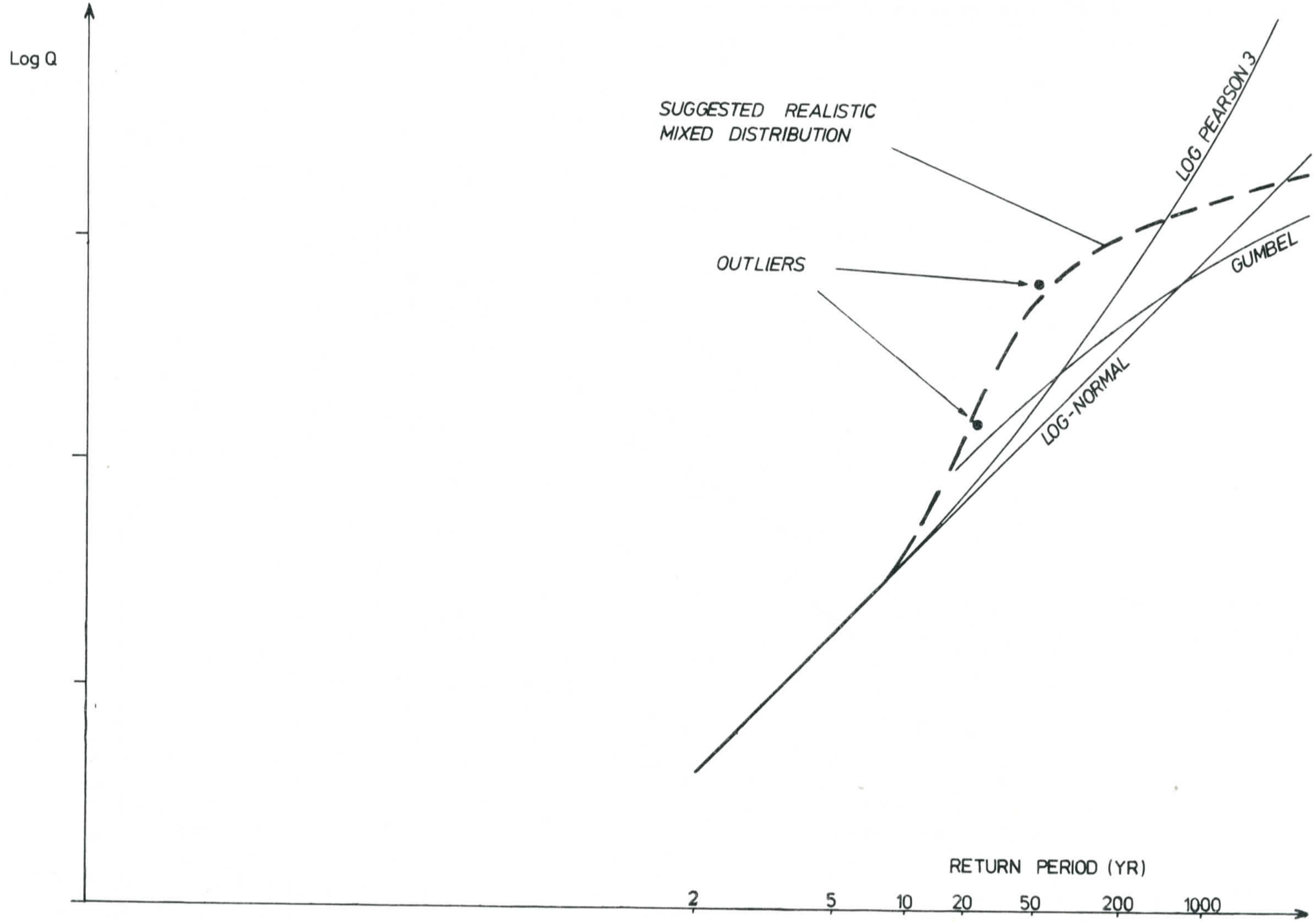

FIGURE 8. CHARACTERISTIC APPEARANCE OF FREQUENCY DISTRIBUTIONS OF ANNUAL FLOOD PEAK SERIES CONTAINING OUTLIERS.

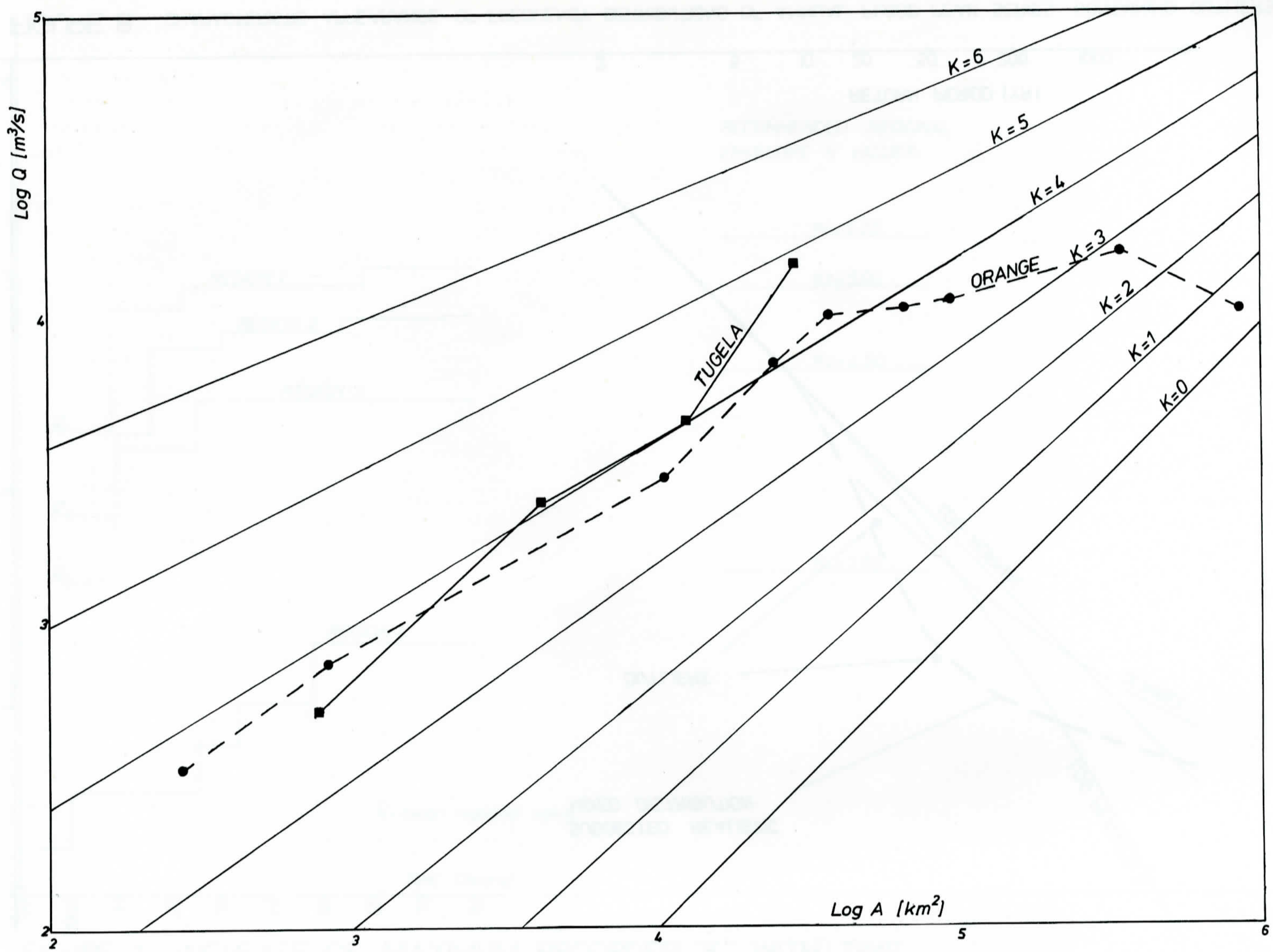

FIGURE 9. CHANGE OF K ALONG THE ORANGE AND TUGELA RIVERS.

APPENDIX 1 CATALOGUE OF MAXIMUM PEAK DISCHARGES RECORDED IN SOUTH AFRICA

Drainage Region or Station Number	Geographic position Lat. Long.	River	Catchment Area A(km²)	Flood Peak Q (m³/s)	Q/A	Francou-Rodier K	Date of Peak Y M D	Representative Period N(year)	Maximum flood peak region	Method of measurement	Reliability	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
A2	25 46 28 13	Waterkloofspruit	5	141	28,2	4,73	35 12	45	2	U	U	Pretoria Country Club
A2*	25 42 28 12	Noordspruit	8	65	8,13	4,10	78 01 28	2	2	BC	1	Pretoria, Voortrekker Rd
A2M24	26 09 27 36	Brandvlei	13	160	12,3	4,49	70 12 27	16	2	GS	U	
A9M06	23 02 30 17	Livhungwa	16	22	1,38	3,15	77 02 09	17	1	GS	1	
A2M38*	25 44 27 13	Waterkloof Onder	17	46	2,42	3,59	79 02 19	9	2	GS	1	
A2*	25 42 28 12	Suidspruit	20	196	9,80	4,47	78 01 28	2	2	BC	1	Pretoria, Wonderboom Suid
A7	23 29 29 55	Dwars	24	179	7,46	4,34	58 01 04	22	2	SA	U	Soekmekaar
A2	25 42 28 12	Noord en Suidspruit	29	252	8,69	4,50	78 01 28	2	2	BC	1	Pretoria, Wonderboom Suid
A2*	25 41 28 17	Hartbeespruit	33	222	6,73	4,36	"	2	2	BC	1	Road P2-5
A2*	25 46 28 17	Moreletaspruit	49	171	3,49	4,03	"	2	2	BC	1	Pretoria, Military Rd
A9M03	22 54 30 32	Tshinane	62	122	1,97	3,70	67 02 01	9	1	GS	2	
A2M47	26 04 27 58	Klein Jukskei	65	130	2,00	3,72	77 02 01	10	2	GS	2	
A2*	25 46 28 17	Moreletaspruit	69	258	3,74	4,18	78 01 28	2	2	BC	1	Pretoria, Lynnwood Rd
A6M10*	24 35 28 39	Badseloop	70	43	0,61	2,91	75 02 22	14	2	GS	1	
A6M11	24 46 28 21	Groot-Nyl	73	123	1,68	3,63	78 01 05	12	2	GS	U	
A2*	25 44 28 18	Moreletaspruit	83	361	4,35	4,34	78 01 28	2	2	BC	2	Pretoria, Silverton
A8	22 55 29 55	Marandanyombe	104	326	3,13	4,17	58 01 04	22	2	SA	U	Wylliespoort
A2M51*	26 02 27 51	Krokodil	109	195	1,79	3,78	76 01 16	7	2	GS	2	
A6M12	24 40 28 29	Olifantspruit	120	76	0,63	3,04	75 01 12	14	2	GS	U	
A2M29*	25 39 28 23	Edenvalespruit	129	104	0,81	3,24	67 01 21	18	2	SA	2	
A6	23 44 28 36	Wydhoekspruit	130	700	5,38	4,64	75 12 25	5	2	BC	2	Road 694
A2M04	24 52 28 16	Plat	137	126	0,92	3,35	09 01 09	43	2	GS	2	
A2M16*	25 45 27 29	Sterkstroom	140	397	2,84	4,19	28 12 12	7	2	GS	U	

NOTES:

Col 1: events marked with * were excluded from analysis

Col 7: K= co-efficient in the Francou-Rodier equation

Col 10: See Figure 5

Col 11 & 12: Symbols are explained in Chapter 3

Col 13: cf = confluence

(1)	(2)	(3)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
A2M07	25 44 28 10	Apies	142	454	3,20	4,28	09 01 09	46	2	GS	2	
A2M28	25 39 28 18	Hartbeespruit	156	520	3,33	4,34	78 01 28	18	2	BC	2	Road S620
A6M06*	24 42 28 25	Klein Nyl	168	94	0,56	3,03	76 02 11	31	2	GS	1	
A2	25 45 28 22	Pienaars	243	1 250	5,14	4,83	78 01 28	75	2	BC	2	Road N4
A2R02*	25 37 28 11	Apies	315	535	1,70	4,05	"	(20)	2	OD	2	Bon Accord Dam
A9M04	22 46 30 32	Mutale	320	650	2,03	4,20	72 01 29	15	1	GS	U	
A2M27*	25 41 28 21	Pienaars	350	1 340	3,83	4,73	78 01 28	75	2	BC	2	Road P 2-5
A7	23 27 29 44	Dwars	381	1 308	3,43	4,68	58 01 04	22	2	SA	U	Bandolierkop
A6*	23 36 28 30	Klein Galakwin	400	700	1,75	4,16	75 12 25	5	2	BC	2	Road 694
A2M03	25 46 27 16	Hex	495	709	1,43	4,06	14 12 17	25	2	GS	U	
A4M08	24 13 27 59	Sterkstroom	504	270	0,54	3,26	67 01 21	22	2	GS	U	
A2M32	25 38 27 01	Selons	522	440	0,84	3,65	67 01 20	17	2	SA	2	
A7	23 02 29 35	Dorps	570	1 103	1,94	4,36	58 01 04	22	2	SA	U	Mara
A9M05*	23 05 30 11	Luvuvhu	611	712	1,17	3,96	47 12 28	7	1	GS	U	
A2	25 27 28 16	Apies	650	682	1,05	3,90	78 01 28	20	2	SA	1	Hammanskraal
A2R09*	25 37 28 22	Pienaars	684	1 510	2,21	4,54	"	22	2	ID	2	Roodeplaat Dam
A2R07	25 29 26 41	Elands	704	541	0,77	3,66	76 03 20	(14)	2	OD	1	
A6	24 14 28 47	Sterk	707	1 879	2,66	4,71	46 02 02	34	2	U	U	"Rooiwal"
A6M02	24 41 28 38	Nyl	738	646	0,88	3,78	41 12	29	2	U	U	
A2M05	25 50 28 08	Hennops	808	359	0,44	3,24	09 01 22	46	2	GS	U	
A2M06	25 23 28 19	Pienaars	1 028	1 218	1,18	4,16	14 02 26	75	2	GS	2	
A4M04	24 09 27 29	Matlabas	1 046	566	0,54	3,48	67 01 22	18	2	GS	U	
A3M01	25 32 26 06	Klein Marico	1 165	1 159	0,99	4,05	?	(60)	2	U	U	
A2M02	25 44 27 51	Magalies	1 207	1 758	1,46	4,40	?	(76)	2	U	U	
A9	22 54 30 41	Luvuvhu	1 600	1 830	1,14	4,29	76 01 31	4	1	BC	2	Road P98-1
A5M05	23 37 28 09	Palala	2 331	2 400	1,03	4,34	69 12 08	13	2	GS	U	
A4	24 11 28 00	Mokolo	2 603	2 023	0,78	4,12	43	37	2	SA	U	"Klipspruit"
A2M01	25 44 27 52	Krokodil	2 909	3 323	1,14	4,54	18 02 15	76	2	GS	U	
A3	25 02 26 25	Groot Marico	4 170	1 933	0,46	3,80	?	(60)	2	U	U	"Nooitgedacht"
A2M20	25 19 27 28	Elands	4 558	1 123	0,25	3,21	67 02 28	19	2	U	U	
A9*	22 25 31 13	Luvuvhu	5 110	2 877	0,56	4,08	76 01 31	4	1	BC	2	Road H1-8
A6	23 50 28 37	Mogalakwena	6 550	1 304	0,20	3,10	46 02	(34)	2	U	U	"Gadashill"
A7M01	22 54 29 37	Sand	7 703	2 550	0,33	3,70	58 01 04	33	2	SA	U	Waterpoort
A3M07*	24 52 26 27	Groot Marico	8 685	2 465	0,28	3,58	?	(60)	2	U	U	
A6M09	22 36 28 53	Mogalakwena	14 733	1 900	0,13	2,90	67 02 04	20	3	GS	U	
A2M25	24 56 27 33	Krokodil	21 349	2 124	0,10	2 72	67 02 07	21	3	GS	2	
A7M04	22 13 29 59	Limpopo	201 000	12 550	0,06	2,95	33 01	47	4	SA	U	Beit Bridge

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
B8	23 55 30 14	Tamara	26	123	4,73	4,06	60 11 09	(20)	1	U	U	Agatha-Letaba road
B7M02	24 05 30 16	Ngwabitsi	58	530	9,14	4,75	56 02 17	32	1	GS	U	
B6M03	24 41 30 49	Treur	92	269	2,92	4,09	67 04 16	18	1	GS	U	
B7M01	24 33 31 02	Klaserie	137	793	5,79	4,71	39 02 05	40	1	GS	U	
B4M05	25 02 30 13	Waterval	188	85	0,45	2,89	61 12 06	18	3	GS	1	
B8M14	23 53 30 05	Great Letaba	294	380	1,29	3,82	72 01 29	10	1	GS	U	
B6M01	24 40 30 48	Blyde	518	477	0,92	3,72	15 02 13	58	2	GS	2	
B4M04	25 01 30 27	Dorps	701	108	0,15	2,30	66 02 02	14	3	GS	1	
B7M08	24 00 30 40	Selati	832	2 153	2,59	4,75	58 01 05	24	1	SA	U	
B8M09	23 53 30 22	Great Letaba	861	973	1,13	4,05	60 12 20	20	1	GS	U	
B2M01	25 48 28 46	Bronkhorstspruit	1 594	1 028	0,64	3,77	36 05 24	47	3	GS	U	
B6M05	24 31 30 50	Blyde	2 204	1 079	0,49	3,63	60 02 02	20	2	GS	U	
B4M03	25 02 24 52	Steelpoort	2 240	411	0,18	2,72	55 12 31	15	3	GS	U	
B1M01	25 48 29 20	Olifants	3 989	1 327	0,33	3,46	09 03 03	47	3	GS	U	
B7M07	24 11 30 49	Olifants	46 583	1 813	0,04	1,77	58 01 05	22	3	SA	U	
C2M26*	26 14 27 40	Middelvleispruit	26	8	0,31	2,26	77 03 10	20	3	GS	2	
C2M28	26 15 27 36	Rietfonteinspruit	31	21	0,68	2,81	76 02 12	22	3	GS	2	
C5*	29 07 26 13	Bloemspruit	36	451	12,5	4,81	?	(70)	3	U	U	Bloemfontein
C2M23*	26 24 27 45	Wonderfonteinspruit	83	19	0,23	2,24	78 01 28	23	3	GS	2	
C5M07	29 09 26 19	Renosterspruit	348	422	2,21	3,82	25 03 22	31	3	GS	U	
C5M11*	29 48 26 20	Ruigtespruit	348	198	0,57	3,22	48 03 15	15	3	GS	U	
C2	26 55 27 43	Kromellenboog	518	850	1,64	4,19	36 11	44	3	SA	2	Wolwehoek
C5M08	29 49 26 13	Riet	593	410	0,69	3,52	33 12 13	28	3	GS	U	
C8M03	27 51 28 58	Cornelis	806	365	0,45	3,25	56 12 26	26	3	GS	2	
C2M14	26 49 27 55	Taaibosspruit	825	574	0,70	3,62	36 11	44	3	GS	U	
C2M65	27 22 26 21	Leeudoringspruit	860	720	0,84	3,80	76 01 14	9	3	GS	U	
C7M03	27 22 27 17	Heuningspruit	914	130	0,14	2,29	58 01 30	48	3	GS	1	
C5R01	29 25 26 08	Kaffir	922	649	0,70	3,67	48 03 18	47	3	OD	2	Tierpoort Dam
C1M06	26 47 29 33	Blesbokspruit	1 094	1 280	1,17	4,17	75 02 15	16	3	GS	2	
C2	26 44 27 07	Loop	1 096	539	0,49	3,41	?	(50)	3	U	U	Potchefstroom
C5M03*	29 10 26 34	Modder	1 650	1 161	0,70	3,86	48 03 13	35	3	GS	U	
C5M10	29 51 25 39	Kromellenboogspruit	1 849	1 167	0,63	3,80	"	16	3	GS	U	
C5M12	29 40 25 59	Riet	2 372	1 274	0,54	3,74	66 01 22	32	3	GS	U	
C5M05	29 02 26 25	Modder	3 088	2 563	0,83	4,25	?	(80)	3	U	U	

C2M01	26 39 27 05	Mooi	3 595	377	0,10	2,30	?	(80)	4	U	U	
C1	26 50 29 48	Vaal	3 781	1 861	0,49	3,83	?	(80)	3	U	U	
C1M02	27 10 29 14	Klip	4 152	1 218	0,29	3,35	23 01 29	57	3	GS	2	
C5M04*	28 51 26 11	Modder	4 939	3 201	0,65	4,21	20 03 03	28	3	U	U	
C7M01	27 16 27 10	Renoster	5 227	1 487	0,28	3,40	34 01 03	25	3	GS	2	
C3	26 46 25 33	Harts	5 450	521	0,10	2,30	76 01 19	4	4	BC	2	Road 117-1
C4M03	28 07 26 55	Sand	5 547	1 306	0,24	3,22	52 12 18	14	3	GS	2	
C4M01	28 28 26 40	Groot Vet	5 590	2 762	0,49	3,98	25 03	24	3	GS	U	
C2M02	26 51 26 39	Skoonspruit	5 594	272	0,05	1,62	15 02 18	17	4	GS	U	
C6M01	27 27 26 59	Vals	5 674	2 561	0,45	3,90	24 11 05	67	3	GS	U	
C1M01	26 56 29 16	Vaal	8 193	2 287	0,28	3,54	11 01 12	75	3	GS	1	
C3R01*	27 10 25 20	Harts	9 219	648	0,07	2,10	76 01 19	45	4	OD	1	Schweizer Reneke Dam
C3M04	27 34 24 42	Dry Harts	10 204	280	0,03	1,10	29 03 05	23	5	GS	U	
C5R02	29 30 25 13	Riet	10 268	4 880	0,48	4,20	74 03 02	42	3	OD	1	Kalkfontein Dam
C8M01	27 16 28 29	Wilge	15 673	3 121	0,20	3,41	57 09 27	66	3	GS	2	
C4M02	27 50 25 55	Vet	17 599	2 210	0,13	2,93	34 01	46	4	FVA	2	
C3M07	27 55 24 37	Harts	24 097	698	0,03	1,28	76 01 21	22	5	SA	1	
C5	29 02 24 00	Riet	34 616	4 416	0,13	3,20	74 03 03	27	4	SA	2	
C1R01	26 53 28 07	Vaal	38 505	5 475	0,14	3,38	57 09 27	57	3	ID	2	Vaaldam
C2M07*	27 01 26 42	Vaal	63 437	6 999	0,11	3,26	94 02	86	3	U	U	
C9M03	28 31 24 42	Vaal	120 902	5 411	0,04	2,23	"	86	4	U	U	

D1	31 23 26 29	Spioenkop	13	90	6,92	4,12	?	(60)	3	U	U	NE of Molteno
D4M03	26 43 20 02	Swartbas	70	15	0,21	2,16	47 04 26	7	5	GS	U	
D6	31 26 22 46	Meltonwoldspruit	127	453	3,57	4,33	61 03 27	19	3	ID	1	Aspeling Dam
D7	28 32 21 12	Donkerhoekspruit	241	163	0,68	3,26	48 04 17	32	4	U	U	S of Upington
D1M08	28 47 28 37	Madibamatso	277	337	1,22	3,75	57 09 12	4	3	GS	U	
D1M04	31 24 26 22	Stormbergspruit	348	283	0,81	3,50	28 12 10	44	3	GS	2	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
D5M08*	32 14 20 22	Vis	354	114	0,32	2,77	39 04 01	14	3	GS	U	
D4M02	26 06 25 17	Mareetsane	566	75	0,13	2,13	28 01 13	34	4	GS	U	
D2M04	29 45 26 52	Rietspruit	762	439	0,58	3,44	41 02 16	13	3	GS	U	
D5M09	31 31 22 19	Brak	766	611	0,80	3,72	41 02 04	11	3	GS	U	
D1M19	29 01 28 33	Madibamatso	847	740	0,87	3,83	64 10 19	6	3	GS	2	
D5	31 55 20 24	Vis	1 153	411	0,36	3,14	57	23	3	U	U	"Leeuwkloof"
D3	30 12 24 43	Hondeblaf	1 365	738	0,54	3,56	74 03 03	(13)	3	SA	2	"Carbonaatjies kraal"
D2M03	29 32 27 08	Leeuw	1 424	473	0,33	3,14	48 03 03	19	3	GS	U	
D5M03*	31 49 20 22	Vis	1 509	425	0,28	3,01	27 07 16	33	3	SA	2	
D5M11	31 49 20 35	Renoster	1 658	550	0,33	3,18	61 03 26	22	3	GS	1	
D5	31 52 20 59	Klein Riet	2 129	889	0,42	3.47	61 03 26	19	3	U	U	"Plattekraal"
D1M01	31 00 26 20	Stormbergspruit	2 397	2 691	1,12	4,44	25 03 22	68	3	GS	U	
D1M06	30 10 27 24	Kornetspruit	3 014	2 274	0,75	4,15	66 01 22	21	3	GS	U	
D2M05	28 53 27 54	Caledon	3 857	861	0,22	3,06	51 10 28	14	3	GS	U	
D5M15*	31 46 20 48	Riet	5 399	666	0,12	2,56	61 03 26	22	3	GS	U	
D3	30 31 24 58	Seekoei	5 430	2 438	0,45	3,87	74 03 01	(13)	3	SA	2	Petrusville-Colesberg road
D5M04	31 39 21 46	Sak	5 839	1 601	0,27	3,40	61 03 27	51	3	GS	2	
D6M02	30 08 23 34	Brak	6 440	647	0,10	2,39	31 12 31	16	4	GS	U	
D6*	30 56 23 14	Ongers	8 249	3 173	0,38	3,88	61 03 27	19	3	U	U	"Daggafontein"
D1M05	30 03 28 31	Orange	10 758	3 002	0,28	3,64	67 02 01	33	3	GS	U	
D6R02	30 37 23 18	Ongers	13 394	6 940	0,52	4,43	61 03 28	58	3	ID	2	Smartt Syndicate Dam
D2M01	29 43 26 59	Caledon	13 421	3 683	0,27	3,71	34 01 03	59	3	U	U	
D5M04	31 01 20 35	Sak	19 099	1 813	0,09	2,63	61 03 28	19	4	GS	2	
D1M09*	30 20 27 21	Orange	24 752	7 015	0,28	4,03	67 02 01	22	3	SA	2	
D6	29 36 23 00	Brak	33 792	2 039	0,06	2,25	74 03 05	6	4	SA	1	Prieska-Douglas road
D1M03	30 41 26 43	Orange	37 075	10 031	0,27	4,17	34 01 03	66	3	GS	U	
D5*	29 43 21 04	Sak	46 231	1 756	0,04	1,74	61 03 31	19	5	U	U	"Jagdrift"
D3M02*	30 32 26 00	Orange	65 615	10 647	0,16	3,80	67 02 02	24	3	GS	U	
D5R01	29 24 21 12	Hartebees	72 335	1 785	0,02	1,25	61 04 01	47	5	ID	2	Rooiberg Dam
D3M03	29 39 24 12	Orange	94 765	11 160	0,12	3,54	25 03 24	67	3	SA	2	
D7M08	29 02 22 11	Orange	342 967	16 232	0,05	2,74	25 03 26	55	4	SA	2	
D8M03*	28 45 17 44	Orange	850 530	10 227	0,01	0,39	25 03	55	5	SA	2	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
E2M06	33 09 19 22	Kruis	40	67	1,68	3,48	45 06 21	41	3	GS	U	
E4M01	31 29 19 47	Oorlogskloof	970	204	0,21	2,64	25 06 19	21	4	W	U	
E1M01	32 03 18 49	Olifants	2 659	1 643	0,62	3,91	"	31	3	GS	U	
E2M04	32 19 19 35	Tankwa	6 426	1 416	0,22	3,20	"	19	3	SA	2	
E2M02	32 30 19 32	Doring	6 903	2 124	0,31	3,58	25 06 17	57	3	GS	U	
E3	31 35 18 24	Sout (or Hol)	17 167	1 473	0,09	2,48	61 04 10	19	4	U	U	Upstream of cf Olifants River
E2M03	31 51 18 41	Doring	24 044	1 898	0,08	2,48	57 07 15	53	4	GS	U	
F5M01*	30 50 18 07	Swart Doring	2 349	47	0,02	0,65	67 06 13	11	4	GS	1	
G1M15	33 49 19 04	Kasteelkloof	1,9	11	5,79	3,58	76 07 25	13	2	GS	1	
G1M18*	33 49 19 03	Bakkerskloof	3,4	13	3,82	3,46	"	11	2	GS	2	
G4M10	34 11 19 08	Jakkals	6,7	10	1,49	3,03	74 10 01	11	2	GS	1	
G2M08	33 59 18 57	Jonkershoek	20	74	3,70	3,83	55 02 18	29	2	GS	1	
G1M11	33 23 19 06	Watervals	27	57	2,11	3,54	64 08 09	13	2	GS	1	
G1M03	33 54 19 05	Franschhoek	46	164	3,57	4,03	77 08 19	28	2	GS	U	
G1M04	33 56 19 04	Berg	70	466	6,66	4,59	51 06 27	18	2	GS	U	
G2	34 05 18 47	Kuils	137	139	1,01	3,42	45 07 08	35	2	SA	2	near Sarepta railway station
G4M03	34 12 18 59	Palmiet	144	426	2,96	4,23	54 05 19	24	2	GS	1	
G1M02	33 08 19 04	Vier en twintig	187	771	4,12	4,57	"	19	2	GS	U	
G2M12	33 28 18 44	Diep	244	164	0,67	3,26	74 07 05	11	2	GS	1	
G4M14	34 14 19 13	Bot	252	141	0,56	3,12	74 08 21	9	2	GS	2	
G1M08	33 19 19 05	Klein Berg	395	453	1,15	3,81	67 06 10	16	2	GS	U	
G4M06	34 24 19 36	Klein	600	203	0,34	2,93	74 08 22	11	2	GS	1	
G5M05	34 34 20 07	Kars	658	530	0,81	3,68	57 10 03	7	2	GS	1	
G1M07	33 38 18 59	Berg	713	2 126	2,98	4,84	54 05 18	19	2	GS	U	
G5	34 42 19 55	Nuwejaars	730	664	0,91	3,81	78 07 25	2	2	SA	2	"South Bush"
H7M05	33 59 20 26	Hermitage	9	41	4,56	3,77	71 04 04	17	2	GS	1	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
H4	33 47 19 56	Droog Kloof	10	176	17,6	4,64	29 09 05	51	2	SA	U	Robertson
H7M04	33 55 20 43	Huis	28	59	2,11	3,55	54 08 27	24	2	GS	2	
H6M08	34 04 19 04	Riviersonderend	38	270	7,11	4,44	73 07 04	11	2	GS	2	
H1M07	33 34 19 09	Wit	84	587	6,99	4,68	53 04 18	20	2	GS	U	
H3M03	33 54 20 22	Groot	93	213	2,29	3,91	47 09 15	14	2	GS	U	
H1M18	33 44 19 10	Molenaars	113	309	2,73	4,10	73 08 04	6	2	GS	1	
H1M12	33 46 19 20	Holsloot	146	375	2,57	4,13	74 08 09	11	2	GS	U	
H6M01	34 02 19 13	Riviersonderend	280	680	2,43	4,30	64 05 26	14	2	GS	U	
H7M03	34 00 20 40	Buffeljags	450	359	0,80	3,56	62 08 21	17	2	GS	U	
H3M01	33 47 20 07	Kingna	611	439	0,72	3,56	34 10 11	22	2	GS	U	
H2M03	33 36 19 31	Hex	718	737	1,03	3,91	57 07 14	46	2	GS	U	
H1M06	33 25 19 16	Breë	753	1 135	1,51	4,26	55 08 03	20	2	GS	U	
H4M06	33 43 19 28	Breë	2 942	1 583	0,54	3,82	57 07 04	23	2	GS	U	
H5M02	33 54 20 01	Breë	6 684	1 910	0,29	3,49	57 07 15	10	2	GS	U	
J2M06	33 30 21 30	Wilgehout	25	19	0,76	2,78	63 12 07	19	2	GS	1	
J2	32 28 22 19	Klein Sand	41	394	9,61	4,67	48 01 28	32	2	SA	2	28km SW of Beaufort West
J3M15	33 26 22 15	Klein Leroux	70	41	0,59	2,87	76 05 30	9	2	GS	2	
J2*	32 25 22 27	Stols	73	416	5,70	4,49	48 01 29	32	2	SA	1	12km SW of Beaufort West
J3M05	33 47 22 19	Klip	95	425	4,47	4,40	31 12 31	21	2	GS	U	
J3M14*	33 25 22 15	Grobbelaars	151	46	0,30	2,55	76 11 05	10	2	GS	1	
J2	32 21 22 36	Damspruit	163	227	1,39	3,70	18 03 14	62	2	OD	1	Beaufort West Town Dam
J1M06	33 46 21 09	Brand	323	181	0,56	3,18	54 08 27	22	2	GS	U	
J2	32 21 22 35	Gamka	355	708	1,99	4,22	41 04 06	39	2	BC	2	near Beaufort West
J3M03	33 20 22 32	Groot	426	667	1,57	4,09	28 01 08	46	2	GS	U	
J3M01	33 40 22 25	Kammanassie	1 484	2 756	1,86	4,70	16 05 04	64	2	GS	U	
J2R02	32 37 22 00	Leeu	2 088	1 044	0,50	3,63	74 02 22	60	2	OD	1	Leeugamka Dam
J3M02	33 23 23 07	Traka	3 039	2 125	0,70	4,08	21 12 29	68	2	SA	U	
J2	32 46 21 58	Gamka	3 237	1 785	0,55	3,88	"	58	2	SA	U	Fraserburg Road
J1M02	33 15 20 58	Buffels	3 328	1 326	0,40	3,57	25 06 18	6	2	GS	U	
J3M04*	33 29 23 02	Olifants	4 305	1 062	0,25	3,19	53 02 22	57	2	GS	2	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
J3*	33 37 22 14	Olifants	6 410	1 700	0,27	3,40	32 01 01	48	2	W	U	
J2M01*	33 05 21 56	Gamka	10 292	2 720	0,26	3,57	21 12 29	58	2	SA	2	"Klipfontein"
J3	33 39 22 11	Olifants	10 295	3 824	0,37	3,94	32 01 01	48	2	W	U	near Oudtshoorn
J2M03	33 33 21 41	Gamka	17 815	5 099	0,29	3,89	21 12 29	58	2	SA	U	upstream of cf Kammanassie River
K3M02*	33 56 22 28	Rooi	1,0	5	5,00	3,37	64 09 16	12	1	GS	1	
K1M02	33 56 22 08	Beneke	3,8	18	4,74	3,61	"	17	1	GS	1	
K4M02	33 53 22 50	Karatara	22	56	2,55	3,61	77 05 08	16	1	GS	1	
K8M01	33 59 24 01	Kruis	26	136	5,23	4,13	64 09 16	16	1	GS	2	
K3M04	33 57 22 25	Malgas	34	160	4,71	4,13	"	15	1	GS	2	
K4M03	33 55 22 43	Diep	72	120	1,67	3,62	"	15	1	GS	1	
K2M02	34 02 22 13	Groot Brak	131	1 000	7,63	4,90	"	16	1	GS	U	
K5M02*	33 54 23 02	Knysna	133	130	0,98	3,39	67 04 12	10	1	GS	2	
K3M03	34 00 22 21	Maalgate	145	237	1,63	3,79	63 03 29	13	1	GS	U	
K6M01*	33 48 23 08	Keurbooms	165	64	0,39	2,75	62 08 22	12	1	GS	1	
K9R01	34 00 24 30	Krom	357	434	1,22	3,83	71 08 22	32	1	OD	1	Churchill Dam
L8M02	33 44 23 18	Haarlemspruit	52	94	1,81	3,59	71 08 22	4	1	GS	2	
L9R01	33 52 25 02	Loerie	147	1 250	8,50	5,02	77 05 08	10	1	OD	1	Loerie Dam
L2M03	31 56 23 47	Buffels	1 145	510	0,45	3,37	63 01 27	15	2	GS	1	
L8	33 35 24 10	Baviaanskloof	1 217	924	0,76	3,83	32 01 01	(30)	1	SA	U	upstream of cf Cougha River
L6M01	33 12 24 14	Heuningklip	1 290	2 957	2,29	4,83	50 03 15	30	1	U	U	
L8	33 40 24 23	Cougha	2 538	4 249	1,67	4,84	32 01 01	48	1	SA	U	upstream of cf Baviaanskloof River
L1M01	32 10 23 03	Salt	3 938	1 292	0,33	3,44	28 03 28	28	2	GS	2	
L2M04	32 14 23 25	Buffels	5 584	2 068	0,37	3,69	61 03 27	9	2	GS	2	
L2*	32 50 23 32	Buffels	9 893	2 691	0,27	3,58	61 03 28	19	2	U	U	"Middelerf"
L7M02*	33 19 24 21	Groot	25 730	4 390	0,17	3,43	71 08 23	52	1	GS	U	
L9	33 43 24 40	Gamtoos	33 800	7 082	0,21	3,81	32 01 02	48	1	SA	2	"Mistkraal"
M2	33 59 25 39	Shark	9	218	24,2	4,80	68 09 01	12	1	SA	2	Port Elizabeth
M2	33 59 25 37	Humewood	11	164	14,9	4,56	"	12	1	SA	2	"
M2	33 58 25 37	Baakens	67	707	10,6	4,90	08 11 16	72	1	SA	U	"
M1R01	33 41 25 16	Swartkops	261	623	2,39	4,26	71 08 22	42	1	OD	1	Groendal Dam

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
M1MO4	33 48 25 18	Elands	400	960	2,40	4,41	71 08 22	15	1	GS	U	
M1	33 46 25 23	Swartkops	898	1 218	1,36	4,23	"	9	1	SA	2	Uitenhage
N3	32 28 25 14	Blyde	130	1 165	8,96	5,02	22 01 11	58	1	SA	2	near Pearston
N4	33 26 25 42	Coerney	324	902	2,78	4,45	79 07 21	1	1	SA	2	"Swanepoelskraal"
N3MO1	32 59 25 11	Vogel	1 597	1 983	1,24	4,37	41 10 30	19	1	GS	U	
N1MO7	32 25 24 17	Camdebo	1 669	1 103	0,66	3,81	32 01 01	20	2	SA	U	
N1MO2	32 10 24 33	Gats	1 811	1 137	0,63	3,79	before1923	(60)	2	SA	U	
N1RO1	32 14 24 32	Sundays	3 681	2 074	0,56	3,95	32 01 01	48	2	ID	2	Vanryneveldspas Dam
N2MO5*	33 05 25 01	Sundays	13 419	3 751	0,28	3,74	41 10 31	39	1	GS	2	
N2RO1	33 13 25 09	Sundays	16 826	5 403	0,32	3,99	32 01 01	48	1	ID	2	Mentz Dam
Q9	32 45 26 28	Gola	105	173	1,65	3,71	71 08 21	9	1	OD	1	"Endwell"
Q3MO2	32 05 25 35	Jenkinsspruit	289	606	2,10	4,19	33 12 22	6	2	GS	2	
Q9M11	32 34 26 41	Kat	539	555	1,03	3,82	53 10 22	36	1	GS	U	
Q6MO1	32 34 25 57	Baviaans	694	895	1,29	4,09	32 01 01	19	1	GS	U	
Q3MO4	32 02 25 31	Pauls	873	2 500	3,09	4,86	74 03	54	2	SA	2	"Spitzekop"
Q8MO1	32 38 25 26	Little Fish	980	1 708	1,74	4,48	32 01 01	21	1	SA	U	
Q1MO9	31 32 25 04	Kleinbrak	1 211	920	0,76	3,82	74 03 01	21	2	SA	2	
Q9MO2	32 43 26 18	Koonap	1 245	1 606	1,29	4,30	74 03 03	44	1	SA	2	
Q1MO6	31 35 25 32	Teebus	1 577	267	0,17	2,56	31 12 31	20	2	GS	U	
Q2MO1	31 55 25 25	Great Fish	1 702	1 558	0,92	4,11	32 01 01	48	2	GS	U	
Q4MO1	32 14 25 48	Tarka	4 508	802	0,18	2,88	21 02 19	10	2	GS	2	
Q1MO1*	31 54 25 29	Great Fish	9 091	2 640	0,29	3,62	74 03 01	62	2	SA	2	
Q3	32 08 25 37	Great Fish	11 032	5 697	0,52	4,33	"	(62)	2	SA	2	Cradock
Q9MO6	33 10 26 50	Great Fish	28 937	8 727	0,30	4,18	74 03 05	39	1	SA	2	
R2	32 45 27 18	Buffalo	38	207	5,45	4,26	22 11 05	(26)	1	OD	1	Maden Dam
R2MO8	32 46 27 22	Quencwe	61	496	8,13	4,68	71 08 21	28	1	GS	U	
R2MO7*	32 47 27 23	Zele	82	259	3,16	4,11	54 10 23	22	1	GS	U	
R2MO9	32 55 27 23	Ngqokweni	103	255	2,48	4,00	48 04 20	23	1	GS	U	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
R2M11*	32 56 27 29	Yellowwoods	197	283	1,44	3,78	70 12 07	18	1	GS	U	
R1M01	32 46 26 52	Tyume	238	430	1,81	4,01	70 08 27	52	1	GS	U	
R2M05*	32 52 27 23	Buffalo	411	1 048	2,55	4,47	70 08 28	33	1	GS	1	
R3R01	32 54 27 48	Nahoon	473	2 266	4,79	5,03	"	14	1	OD	1	Nahoon Dam
R1M02	32 50 27 00	Keiskamma	665	994	1,49	4,20	48 04 19	12	1	GS	U	
R2R03	32 59 27 44	Buffalo	1 176	3 258	2,77	4,95	70 08 28	11	1	OD	1	Bridle Drift Dam
R1M13	33 01 26 57	Keiskamma	1 515	2 750	1,82	4,69	70 08 27	30	1	GS	U	
S3	31 32 26 46	Kleinvlei	31	365	11,8	4,72	?	(60)	2	U	U	E of Sterkstroom
S6M01	32 35 27 22	Kubusi	90	129	1,43	3,57	48 04 19	33	1	GS	1	
S6M02	32 35 27 38	Kubusi	491	483	0,98	3,75	"	33	1	GS	2	
S3R01	32 17 26 51	Klipplaat	603	635	1,05	3,87	76 03 20	23	2	OD	1	Waterdown Dam
S3M02	31 45 26 35	Klaas Smits	796	906	1,14	4,03	50 05 18	17	2	GS	U	
S2M01	31 47 27 25	Indwe	1 139	428	0,38	3,19	62 02 10	17	2	GS	U	
T5	29 59 29 48	Nkonzo	32	396	12,4	4,76	59 05 17	31	1	SA	U	Creighton
T5M03	29 45 29 32	Polela	140	136	0,97	3,40	"	31	2	SA	U	
T5R01*	30 43 30 09	Mzimkulvana	427	907	2,12	4,33	"	21	1	OD	1	Gilbert Eyles Dam
T5M06	30 42 30 16	Mzimkulvana	534	1 133	2,12	4,41	"	21	1	U	U	
T5M04	29 46 29 28	Mzimkulu	545	651	1,19	3,95	76 03 05	31	2	SA	U	
T4M01	30 44 29 49	Mtamvuma	715	2 266	3,17	4,86	59 05 18	29	1	SA	U	
T5M02	30 24 29 54	Bisi	867	1 303	1,50	4,30	59 05 17	46	1	SA	2	
T1M01	31 40 28 06	Xuka	956	907	0,95	3,94	"	13	1	SA	U	
T3M04	30 34 29 26	Mzimhlava	1 029	759	0,74	3,74	59 05 18	33	1	GS	U	
T4*	31 03 30 11	Mtamvuma	1 557	3 173	2,04	4,80	"	21	1	SA	2	near Port Edward
T3M02	30 29 28 37	Kinira	2 101	425	0,20	2,79	59 05 19	31	2	GS	U	
T3M08	30 34 29 09	Mzimvubu	2 471	360	0,15	2,53	76 03 22	14	2	GS	2	
T3M05	31 02 28 53	Tina	2 597	1 900	0,73	4,07	76 03 21	10	1	GS	U	
T5M07*	30 15 29 57	Mzimkulu	3 586	3 796	1,06	4,55	59 05 17	49	1	SA	2	
T3M06	31 14 28 51	Tsitsa	4 268	1 699	0,40	3,66	76 03 21	20	1	SA	2	
T1M04	31 55 28 27	Bashee	4 828	3 400	0,70	4,27	59 05 17	24	1	SA	2	
T5	30 42 30 25	Mzimkulu	6 630	6 515	0,98	4,77	59 05 18	49	1	SA	U	Port Shepstone

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
U2M10	29 37 30 14	Msindusaan	30	255	8,50	4,49	24 12 29	10	1	U	U	
U2	29 36 30 24	Dorpspruit	69	340	4,93	4,37	47 01 14	33	1	SA	U	Pietermaritzburg
U8	30 26 30 37	Ifafa	225	992	4,41	4,68	59 05 17	21	1	SA	U	near mouth
U2M07*	29 27 30 09	Mpofana	358	82	0,23	2,50	64 01 27	16	1	GS	2	
U3	29 33 31 11	Tongati	415	934	2,25	4,37	53	27	1	U	U	near mouth
U2M12	29 26 30 30	Sterk	438	185	0,42	3,03	61 02 10	10	1	GS	2	
U2*	29 36 30 24	Msindusi	469	977	2,08	4,35	47 01 14	33	1	SA	U	Pietermaritzburg
U8	30 17 30 45	Mpambanyoni	548	1 228	2,24	4,47	59 05 17	21	1	U	U	near mouth
U8	30 28 30 36	Mtvalume	565	992	1,76	4,28	"	21	1	SA	U	South Coast road
U6	29 53 30 44	Mlazi	803	2 224	2,77	4,79	"	21	1	OD	1	Shongweni Dam
U7M02	30 05 30 49	Lovu	936	2 000	2,14	4,63	76 03 21	23	1	U	U	
U4M01	29 21 31 14	Mvoti	2 600	2 022	0,78	4,12	13 03	67	1	SA	U	
U1M03	30 11 30 46	Mkomanzi	4 375	6 230	1,42	4,94	59 05 17	18	1	SA	U	
V1M22	28 59 29 15	Mazongwaan VI	0,62	7,9	12,7	3,78	66 02 03	16	2	GS	2	
V3M07	27 51 29 51	Ncandu	129	120	0,93	3,34	75 02 21	20	2	GS	2	
V1M09*	28 54 29 46	Bloukrans	196	119	0,61	3,12	64 11 05	19	2	GS	1	
V7M12	29 00 29 53	Little Bushmans	196	1 047	5,34	4,78	30 03 08	50	2	SA	U	
V3M05	27 26 29 59	Slang	676	240	0,36	3,00	67 01 20	26	2	GS	U	
V1M10	28 49 29 33	Little Tugela	782	510	0,65	3,55	18	(10)	2	U	U	
V3R01	27 57 29 57	Ngagane	830	1 271	1,53	4,30	67 02	15	2	ID	2	Chelmsford Dam
V2M02	29 13 29 59	Mooi	937	654	0,70	3,67	56 12 23	25	2	GS	U	
V7	28 57 29 55	Bushmans	1 100	2 029	1,84	4,57	30 03 08	50	2	SA	U	"Elmwood"
V3M02	27 36 29 56	Buffels	1 518	716	0,47	3,47	63 07 05	18	2	GS	U	
V1M38	28 34 29 45	Klip	1 644	2 832	1,72	4,67	23 02 12	57	2	SA	U	
V2M01*	28 59 30 22	Mooi	2 033	992	0,49	3,60	51 01 11	24	2	GS	U	
V1M01	28 44 29 49	Tugela	4 176	2 533	0,61	4,07	23 02 12	(10)	2	FVA	2	
V3M01	28 15 30 30	Buffels	7 930	2 380	0,30	3,60	39 02 08	18	2	U	U	
V6M02	28 45 30 26	Tugela	12 862	4 614	0,36	4,00	43 04 25	33	2	GS	U	
V5M02	29 10 31 24	Tugela	28 490	15 100	0,53	4,86	25 03	55	1	SA	U	
W5M08	26 29 30 38	Bonnie Brook	119	178	1,50	3,67	60 12 03	23	3	GS	U	
W5M06	27 07 30 50	Swartwater	180	270	1,50	3,73	71 11 06	21	2	GS	U	
W5M04	26 45 30 28	Ngwempisi	460	144	0,31	2,80	55 03 06	26	3	GS	2	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
W3R01	28 07 32 11	Hluhluwe	734	3 060	4,17	5,10	63 07 04	(23)	1	SA,FVA	2	Hluhluwe Dam
W5M05	26 50 30 44	Hlelo	804	709	0,88	3,82	51 12 20	26	3	GS	U	
W4M04	27 32 30 52	Bivane	948	1 019	1,07	4,04	63 07 04	26	2	GS	U	
W3M01	27 40 31 40	Mkuze	1 467	3 320	2,26	4,87	"	52	1	GS	U	
W2M06	28 04 31 33	Black Mfolozi	1 648	2 195	1,33	4,44	63 07 05	17	1	GS	U	
W1	28 49 31 51	Mhlatuze	2 479	2 075	0,84	4,17	77 02 07	3	1	SA	2	
W2M03*	28 20 31 52	White Mfolozi	5 136	3 966	0,77	4,40	57 10 03	10	1	GS	U	
W4M03*	27 25 31 31	Pongolo	5 788	3 404	0,59	4,18	63 07 04	30	1	GS	2	
W4M02	27 21 31 55	Pongolo	7 081	5 850	0,83	4,62	?	(60)	1	GS	U	
W2	28 27 32 12	Mfolozi	9 265	5 660	0,61	4,43	57 10 03	23	1	U	U	Mtubatuba
X2M19*	25 16 30 34	Research Trib I	0,26	1,2	4,62	3,10	68 11 09	14	2	GS	1	
X2M26	25 17 30 35	Research	14	46	3,29	3,67	72 01 17	9	2	GS	1	
X2M12	25 40 30 16	Dawson'sspruit	91	92	1,01	3,32	74 02 07	20	2	GS	2	
X2M01	25 17 31 00	White	103	258	2,50	4,01	39 02 05	19	2	GS	2	
X2M10	25 37 30 53	Noordkaap	126	200	1,59	3,72	67 02 18	28	2	GS	2	
X3M01	25 05 30 47	Sabie	174	112	0,64	3,14	58 01 06	29	2	GS	1	
X2M08*	25 47 30 56	Queens	180	125	0,69	3,21	75 12 22	28	2	GS	1	
X1	26 02 30 24	Buffelspruit	205	560	2,73	4,28	76 01 15	4	3	BC	2	Road P11-1
X2M09	25 44 30 59	Suidkaap	280	443	1,58	3,96	51 12 14	18	2	GS	2	
X1M07	26 01 31 05	Mtsoli	297	92	0,31	2,70	60 02 08	11	3	GS	U	
X2M11*	25 39 30 17	Elands	402	143	0,36	2,87	62 11 17	22	2	GS	2	
X1M06	25 47 31 24	Mlumati	614	609	0,98	3,83	56 03 20	14	2	GS	U	
X2M18	25 17 31 38	Mbyamiti	618	1 082	1,75	4,31	72 03 26	16	2	GS	U	
X3M06	25 02 31 08	Sabie	766	890	1,16	4,04	60 02 02	12	1	GS	U	
X3M08	24 46 31 23	Sand	1 064	658	0,62	3,60	71 01 21	4	2	GS	U	
X1M01	26 02 31 00	Komati	5 499	3 416	0,62	4,21	09 01 29	35	3	GS	2	

APPENDIX 2 MAXIMUM FLOOD PEAK DISCHARGES RECORDED IN SWA, ZIMBABWE AND MALAWI

COUNTRY	RIVER	SITE	Catch= ment area A (km^2)	Flood peak Q(m^3/)	Q/A (m^3 / s/km^2)	Francou-Rodier K	Date of peak YR Mo D	Method of measure= ment	Reliability rating	REMARKS
SWA	Vis	Hardapdam	13 900	6 150	2,26	4,27	72 03	ID	1	NW of Mariental
ZIMBABWE	Avondale Vlei		28	354	12,6	4,73	45 02	U	U	near Salisbury
	Mpako	Chinisa Dip Tank	44	383	8,70	4,62	46 01 12	SA	2	N of Kyle Dam
	Dassura	Hydro Station D.4	73	318	4,36	4,30	41 01	GS	U	30 Km N of Salisbury
	Munendi	1,6 Km of Umtilikwe	130	1 400	10,8	5,15	46 01 12	SA	2	N of Kyle Dam
	Umtilikwe	Fort Victoria-Birchenough road	844	2 490	2,95	4,87	46 01 12	SA	2	N of Kyle Dam
	Umniati	Dyke G/W	2 410	2 270	0,94	4,27	53 01	SA	2	85 Km NE of Gwelo
	Shashani	Hydro Station B86	2 770	3 300	1,19	4,56	72 01	several	1	near Botswana Border
	Umniati	Salisbury-Que Que road	5 880	5 660	0,96	4,69	53 01	several	1	
	Zambezi	Kariba Dam	663 000	16 142	0,024	1,77	58 03 05	OD	1	
MALAWI	Nkata	Nkata Bay	13	147	11,3	4,44	57 01 11	U	U	
	Naperi	Blantyre	21	136	6,48	4,21	52 01 08	U	U	
	Tangadzi	Milole	49	388	7,92	4,59	53 02 05	U	U	
	Litchenya	Mini Mini	73	340	4,66	4,35	56 04 05	U	U	
	Domasi	Domasi	78	320	4,10	4,28	61 12 15	U	U	
	Ruo	Swazi Estate	202	850	4,21	4,40	60 01 66	U	U	
	Nkula	Chitala/Benga	210	652	3,10	4,39	57 02 07	U	U	
	Remero	Deep Bay/KA	246	416	1,69	3,97	55 01 04	U	U	
	Rivi Rivi	Balaka	777	599	0,77	3,69	61 03 08	U	U	
	Tuchila	Chionde	1 400	708	0,51	3,51	52 02 15	U	U	
	N Rukuru	Mwankenja	1 950	680	0,35	3,27	62 03 27	U	U	
	Luweya	Zayuka	2 330	666	0,29	3,14	61 04 28	U	U	
	Ruo	Sankulani	4 840	5 524	1,14	4,77	56 04 06	U	U	

NOTE: SYMBOLS USED ARE THE SAME AS IN APPENDIX 1