

# NKOMAZI ESTUARY

## FLOOD FREQUENCY ANALYSIS: FLOOD MAGNITUDES FOR REQUIRED EXCEEDANCE PROBABILITIES

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**DIRECTORATE HYDROLOGY**

**DEPARTMENT OF WATER AFFAIRS AND  
FORESTRY**

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE : HYDROLOGY

SUBDIRECTORATE : FLOODSTUDIES

## NKOMAZI ESTUARY

CALCULATION OF REQUIRED FLOOD MAGNITUDES

BY



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DATE: 8/5/98

## EXECUTIVE SUMMARY

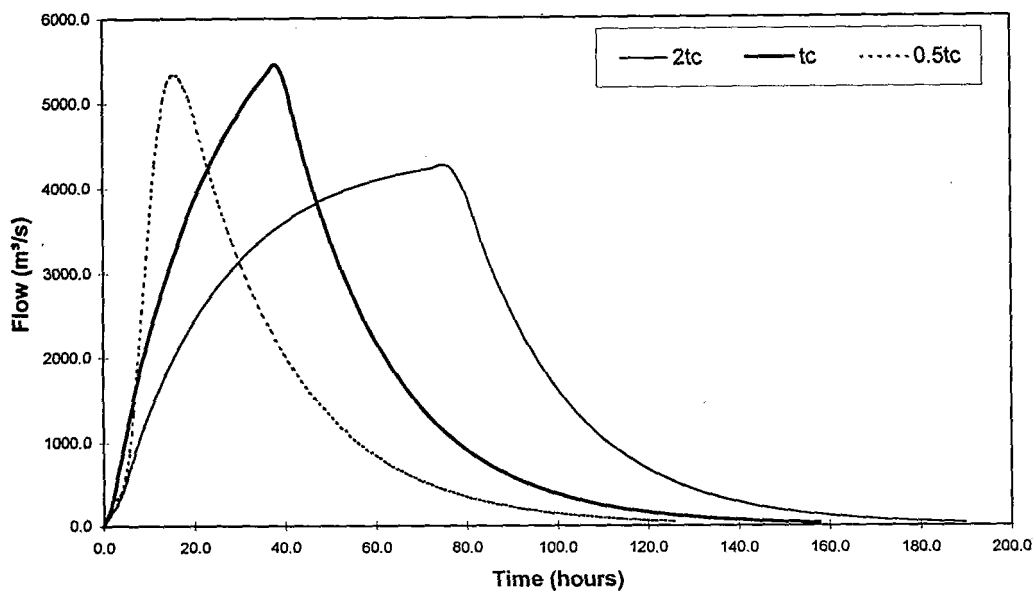
It was requested that the Subdirectorate Flood Studies carry out a detailed flood frequency analysis on the Nkomazi Estuary as part of an estuarine flow requirement (EFR) study undertaken by Ninham Shand Consulting Engineers, Pietermaritzburg.

The Nkomazi Estuary is situated in the upper south coast region (Latitude 30° 11' 52" and Longitude 30° 48' 06").

The 4390 km<sup>2</sup> catchment has a mean annual rainfall of 940 mm and an average slope of 10.5%. The time of concentration is 38 hours.

Results of statistical methods were used to estimate the flood peaks.

**0.5% Exceedance Probability Hydrograph**



**Recommended flood peaks (m<sup>3</sup>/s) :**

STORM DURATION (HOURS)	EXCEEDANCE PROBABILITY (%)							EXTREME FLOODS
	50	20	10	5	2	1	0.5	
19	530	1220	1820	2500	3520	4390	5340	RMF (9680)
38	560	1280	1900	2600	3640	4510	5460	9900
76	450	1010	1500	2040	2850	3520	4260	(7730)

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## LIST OF ABBREVIATIONS AND ACRONYMS

A	Total catchment area (km <sup>2</sup> )
A <sub>e</sub>	Effective catchment area (km <sup>2</sup> )
ARF	Areal reduction factor
C <sub>Y</sub>	Value dependent on catchment steepness (Rational method)
C <sub>P</sub>	Value dependent on soil permeability in catchment (Rational method)
C <sub>V</sub>	Value dependent on vegetation in catchment (Rational method)
CAPA	Catchment parameter method (Mc Pherson, 1983)
DRH	Direct runoff hydrograph (Bauer and Midgley, 1974)
FSL	Full supply level
GEV	General extreme value frequency distribution
K	RMF region
K <sub>e</sub>	Francou-Rodier value
L	Length of longest water course (km)
MAP	Mean annual precipitation (mm)
MIPI	Method of Pitman and Midgley (1972)
PMF	Probable maximum flood (m <sup>3</sup> /s). Calculated by DRH and SUH methods
RMF	Regional maximum flood (m <sup>3</sup> /s). Calculated by TR137 method
S	Average slope of longest watercourse (m/m)
S <sub>A</sub>	Average steepness of the effective catchment area (%)
SEF	Safety evaluation flood (m <sup>3</sup> /s)
SUH	Synthetic unit hydrograph method (Hydrological Research Unit, 1972)
t <sub>c</sub>	Time of concentration

## 1. INTRODUCTION

The Nkomazi Estuary catchment (U1) covers an area of approximately 4390 km<sup>2</sup>, with a mean annual rainfall of 940 mm and an average slope of 10.5%. The time of concentration is 38 hours.

There are no major tributaries to the Nkomazi River.

Umkomaas is the largest town in the catchment and is situated at the estuary. Other towns within the catchment are Ixopo and Bulwer. There are many rural settlements throughout the region.

## 2. THE CATCHMENT

The catchment size was measured by planimeter on the relevant 1:250 000 maps.

*Table 2.1 Most significant catchment characteristics*

Catchment Area (km <sup>2</sup> )	4390
MAP (mm)	940
RMF region	5.4
Soil Permeability	5% Very permeable 65% Permeable 30% Semi-permeable
MIPI flood region	60% 2 and 40% 4
Extreme point rainfall region	3
Veld type zone	50% 5 and 50% 8
Time of concentration t <sub>c</sub> (hours)	38

*Table 2.2 Vegetal cover of the catchment*

VEGETAL COVER	% Catchment
Forest plantation	5
Dense bush	40
Thin bush	20
Cultivated land	20
Grassland	15

The vegetation consists of 15 % Coastal Tropical Forest, 5% Pure Grassveld, 10% False Grassveld, 15% Tropical Bush, 35% Temperate and Transitional Forest and Scrub. See Appendix A for more information on the catchment characteristics.

### 3. INFORMATION TO DATE

#### 3.1 Previous calculations :

No previous calculations could be found on the Nkomazi Estuary.

#### 3.2 Historical floods :

The following historical floods were recorded in the region of gauging station U1H003 with a catchment area of 4375 km<sup>2</sup>.

*Table 3.2 Historical floods*

Hydrological year	Flood peak (m <sup>3</sup> /s)	Source
1855/56	7251	E. Beesley, SAPPI-SAICCOR
1867/68	5823	E. Beesley, SAPPI-SAICCOR
1874/75	4311	Proposed bridge plan
1892/93	≈895	Natal Mercury, Jan 1893
1917/18	3569	Natal Mercury, May 1959
1924/25	6160	E. Beesley, SAPPI-SAICCOR

## 4. FLOOD FREQUENCY ANALYSIS

### 4.1 Statistical analysis :

Three gauging stations were considered for inclusion in the analysis.

Gauging station	Catchment area (km <sup>2</sup> )	Record length (years)
U1H001	3339	4
U1H003/4	4375	25
U1H006	4349	35

After evaluation it was decided to use a combination of U1H003/4 and U1H006's record for the statistical analysis. This combined record will start at hydrological year 1951/52 and end at 1996/97, with thus a total record length of 45 years.

D. van Bladeren extended the discharge tables for U1H003/4 on the 3/11/1992 and for U1H006 on 12/10/1994. These extended discharge tables were used in calculating the combined flow record.

The rainfall intensity and physical characteristics of both U1H003/4 and U1H006's catchment are almost identical to that of the catchment of Nkomazi Estuary. The following formula is therefore applicable to calculate inflow data for Nkomazi Estuary, between 1951 and 1997:

$$Q_{ESTUARY} = Q_{U1H00X} \sqrt{\frac{A_{ESTUARY}}{A_{U1H00X}}}$$

See Appendix E for more information.

### 4.2 MAP and Point Rainfall :

Rainfall data from a total of 15 rainfall gauging stations, in and around the Nkomazi Estuary's catchment, were analysed.

The Thiessen Polygon method was used to calculate the weighted catchment factor for each gauging station.

The daily rainfall files for all the gauging stations in question were downloaded from the *RFDB2* rainfall database.

The *RainCalc2* program (Linström, 1998) was then applied on the daily rainfall data to obtain the point rainfall for all exceedance probabilities.

See Appendix B for more information.

#### 4.3 Deterministic methods :

The Rational and DRH methods were used to estimate the flood peaks. The SUH method was not considered due to the fact that it can only accept one veld type zone as parameter at this stage and further investigation into the development of this method is necessary in order to cater for more than one veld type zone. The DRH method was also developed for only one veld type zone but from past experience it was found to be in order to extrapolate the storm loss coefficient between the two veld type zones in question.

See Appendix C for more information.

#### 4.4 Empirical methods :

The MIPI, MIPI 1/71, CAPA methods and TR137 were used to estimate the flood peaks.

It was found that the PMF generally gives an unrealistically high flood peak for all storm durations, it was considered sufficient to use the RMF as the maximum flood peak.

See Appendix D for more information.

## 5.RESULTS

### 5.1 Estimates of the flood peaks for Nkomazi Estuary:

The estimates, obtained from applying various methods, are given in Table 5.1

**Table 5.1 Summary of the flood peak estimates ( $m^3/s$ ) for the Nkomazi Estuary catchment**

Method	Storm Duration	Exceedance Probability (%)							Extreme Peaks
		50	20	10	5	2	1	0.5	RMF
Statistical	19-76	560	1274	1899	2598	3638	4510	5454	
Rational	19	353	534	687	883	1281	1727	2293	
	38	397	588	749	957	1371	1831	2401	
	76	231	337	430	542	775	1026	1348	
DRH	19	449	743	965	1211	1558	1868	2193	
	38	359	575	738	917	1155	1363	1565	
	76	269	423	543	659	827	961	1107	
MIPI 1/71	19 - 76	283	711	1036	1396	1957	2463	3058	
TR 137	19 - 76					4904	5933	6897	9898
MIPI	19 - 76	333	696	1024	1398	1964	2445	2973	
CAPA	19 - 76	458	710	980	1333	1979	2657	3550	

### 5.2 Representative flood peaks :

By evaluation of the estimates in Table 5.1 it became clear that the deterministic (DET) and empirical (EMP) values are much lower in comparison with the statistical values. It was then considered to use only the statistical results for the representative flood peaks since the EMP and DET methods were developed a long time ago. The proven reliability of D. van Bladeren's extended discharge table also contributed in using the statistical values.

The representative flood peaks are shown in table 5.2.

**Table 5.2 Representative flood peaks ( $m^3/s$ ) for storm duration  $t_c$**

EXCEEDANCE PROBABILITY (%)	50	20	10	5	2	1	0.5
FLOOD PEAKS ( $m^3/s$ )	560	1280	1900	2600	3640	4510	5460

## 6. RECOMMENDATIONS

The variation of flood peaks with storm duration  $\frac{1}{2} t_c$  and  $t_c$  was calculated as follows:

$$Var_{\frac{1}{2}t_c} = \frac{Rational_{\frac{1}{2}t_c}}{Rational_{t_c}}, \quad Var_{2t_c} = \frac{Rational_{2t_c}}{Rational_{t_c}}$$

The DRH method were not included in the above formula due to the fact that it was considered to give too high values for  $\frac{1}{2} t_c$ .

Because storm duration  $\frac{1}{2} t_c$  and  $t_c$  are unknown for the statistical and empirical methods the variation must be corrected as follows:

$$Var^* = \frac{(Var + 1)}{2}$$

The recommended flood peaks and their volumes for the required exceedance probabilities at Nkomazi Estuary are given in Table 6.1 and Table 6.2 respectively.

**Table 6.1 Recommended flood peaks ( $m^3/s$ )**

STORM DURATION (HOURS)	EXCEEDANCE PROBABILITY (%)							EXTREME FLOODS
	50	20	10	5	2	1	0.5	RMF
19	530	1220	1820	2500	3520	4390	5340	(9680)
38	560	1280	1900	2600	3640	4510	5460	9900
76	450	1010	1500	2040	2850	3520	4260	(7730)

**Table 6.2 Recommended flood volumes ( $10^6 m^3$ )**

STORM DURATION (HOURS)	EXCEEDANCE PROBABILITY (%)							EXTREME FLOODS
	50	20	10	5	2	1	0.5	RMF
19	61	140	210	288	406	505	615	1116
38	95	217	324	443	620	768	929	1686
76	126	285	425	579	811	1001	1212	2200

Flood hydrographs for the 0.5 % exceedance probability and their ordinates are given in Figure F.1 and Table F.2 of Appendix F respectively.

## 7. REFERENCES

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**APPENDICES**

APPENDIX A  
Catchment Characteristics

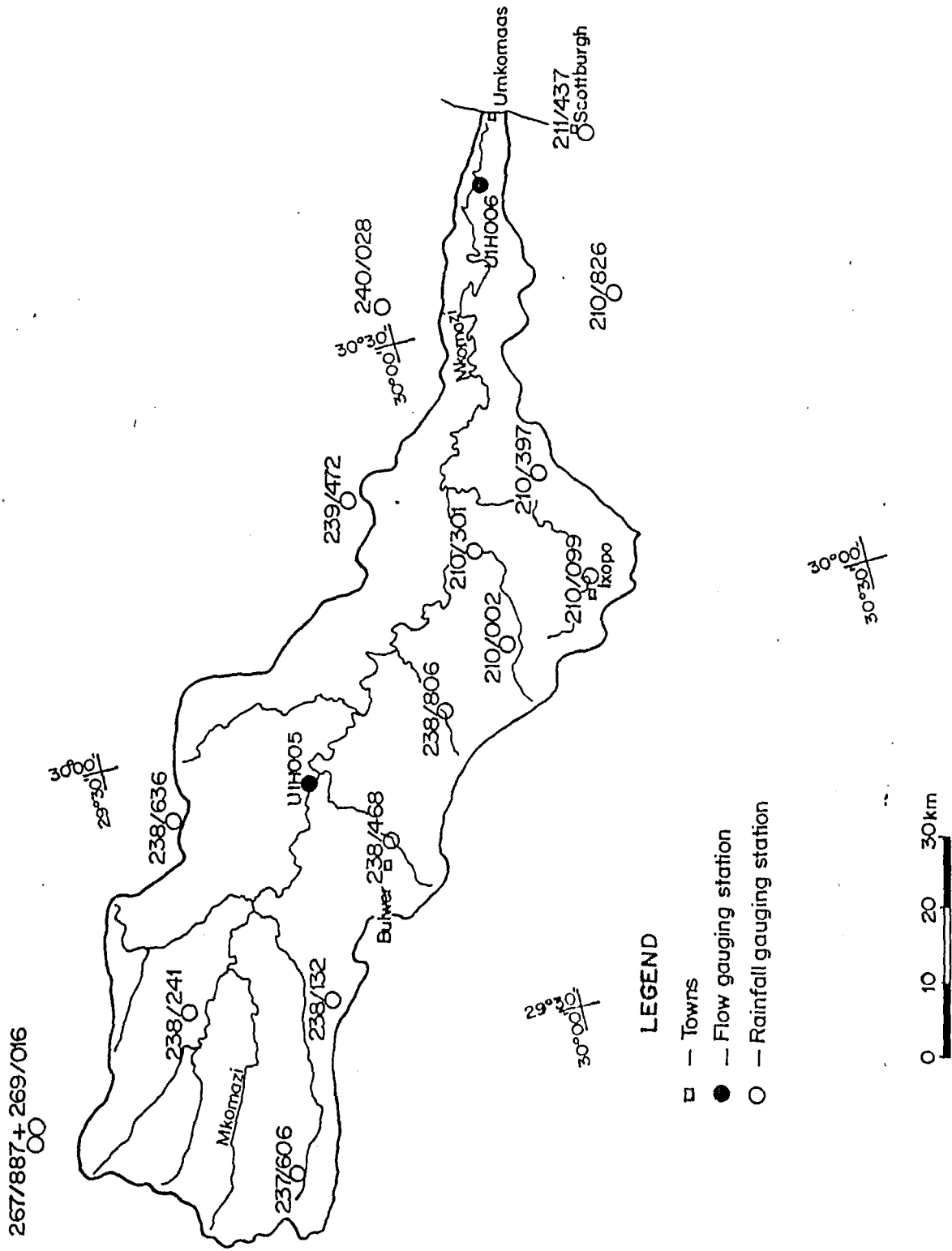


FIGURE A.1 NKOMAZI ESTUARY CATCHMENT

Table A.1

## Catchment Characteristics and information

IDENTIFICATION OF SITE			
Drainage Region: U1910		Latitude: 30° 11' 52"	
Station no.:		Longitude: 30° 48' 06"	
Watercourse: Nkomazi River		Altitude at site: 0.0 m.a.s.l.	
Place: Estuary		Maximum Altitude: 3344 m.a.s.l.	
CATCHMENT CHARACTERISTICS			
<b>Catchment Area:</b>			
Total: $A = 4390 \text{ km}^2$	$A_i = 0 \text{ km}^3$	Dolomitic Area: $A_d = 0 \text{ km}^2$	
Ineffective:	$A_e = 4390 \text{ km}^2$	Reduction factor: $k = 0.31$	
Effective:	$S_A = 10.39 \%$	Flood peak reduction coefficient: $f_d = 1.00$	
Mean steepness of $A_e$		Mean steepness of $A_e$ as used in CAPA: 13.18 %	
Veld type zones (max. of two)	5	8	(HRU 1/72 fig.F1)
Relative Weight (%)	50	50	
<b>Watercourse:</b>			
Longest Watercourse:			
Natural channel	$L_1 = 272 \text{ km}$		
Overland	$L_2 = 0.0 \text{ km}$		
Total length	$L = 272 \text{ km}$		
Distance from site to centre of catchment	$L_c = 150 \text{ km}$		
Mean Slope:			
Mean slope of $L_1$	$S_1 = 0.005165$		
Mean slope of $L_2$	$S_2 = 0.000000$		
Mean slope of $L$	$S = 0.005165$		
<b>Rainfall:</b>			
Mean Annual Rainfall	MAP = 942 mm	Rainfall region: Coastal (C) or Inland (I)	
Extreme point rainfall region	3 (HRU 1/72 fig.C3)	Winter (W) or Summer (S)	
<b>Time of concentration:</b>			
<b>TYPE OF FLOW</b>			<b>where</b>
<b>TIME OF CONCENTRATION (hours)</b>			$A_e = 4390$ to calculate $\tau$
Natural channel	$t_{c1} = \tau [0.87 * L_1^2 / (1000 * S_1)]^{0.385}$	37.75	$\tau = 1.0$ correction to factor depending on $A$
Overland	$t_{c2} = 0.6 * [r * L_2 / (S_2)^{0.5}]^{0.467}$	0.00	$r = 0.20$ roughness factor
Artificial channel	$t_{c1a} = 0.278 * \Sigma (l_i / v_i)$		$l_i =$ length of a uniform reach $v_i =$ velocity in a uniform reach
			<b>Typical values of r</b>
Pavement	0.02	Average grass	0.4
Bare soil	0.1	Cultivated land	0.4
Poor grass	0.3	Dense grass	0.8
GENERAL			
RMF region	5.4	Francou-Rodier K	5.4
			TR137 - Kovacs (1988)
MIPI Flood regions - max. of 3	2	4	
Relative proportion (%)	60%	40%	0%
			Pitman and Midgley (1971)
Roberts "K" (Transvaal)			

**APPENDIX B**  
Storm Rainfall

## Storm Rainfall

The position of each station is plotted on the catchment map. See Figure A.1.

The following stations were selected on reliability of the data, location and record length.

**Table B.1 Rainfall gauging stations**

Station no.	Name	Latitude	Longitude	Record (years)
210/002	Summerford	30° 02'	30° 01'	66
210/099	Ixopo – Pol	30° 09'	30° 04'	44
210/301	Stae Braes	30° 01'	30° 11'	50
210/397	Leenane	30° 07'	30° 14'	28
210/826	Sawoti	30° 16'	30° 28'	65
211/437	Scottburgh – Mun	30° 17'	30° 45'	46
237/606	Sanipas – Pol	29° 36'	29° 21'	27
238/132	The Duffryn	29° 42'	29° 35'	71
238/241	Fairview	29° 31'	29° 39'	16
238/468	Bulwer – Tnk	29° 48'	29° 46'	68
238/636	Impendle – Pol	29° 36'	29° 52'	64
238/806	Emerald Dale	29° 56'	29° 57'	35
239/472	Richmond – Pol	29° 52'	30° 16'	57
240/028	Mid Illovo – Pol	29° 58'	30° 31'	20
267/886+	Giants Castle	29°17 '	29°30 '	45
268/016		29°16 '	29°31 '	

Annual daily rainfall for each gauging station was extracted from the *RFDB2* database on the mainframe. The *RainCalc2* program (Linström, 1998) analysed all the rainfall files with their represented catchment sizes, as calculated by the Thiessen Polygon method, to give the point rainfall as well as the MAP for the Nkomazi Estuary catchment.

**Table B.2 Estimated point rainfall (mm) for the Nkomazi Estuary catchment**

Storm duration	Probability of exceedance (%)						
	50	20	10	5	2	1	0.5
$\frac{1}{2} t_c$	69	95	112	129	151	169	187
$t_c$	75	101	118	135	156	173	189
$2 t_c$	85	113	132	149	172	189	207

APPENDIX C  
Deterministic Methods

## Deterministic Methods

The Rational (Pitman and Midgley, 1971) and DRH (Bauer and Midgley, 1974) methods were used to estimate flood peaks for Nkomazi Estuary. The storm rainfalls calculated in Appendix B, Table B.2, were used.

Storm durations  $\frac{1}{2} t_c$ ,  $t_c$  and  $2 t_c$  were used to calculate flood peaks for different probabilities of exceedance.

The info needed to apply these methods can be found in Table A.1

**Table C.1** *Estimated flood peaks ( $m^3/s$ ) using the Rational method*

Duration	Probability of exceedance (%)						
	50	20	10	5	2	1	0.5
$\frac{1}{2} t_c$	353	534	687	883	1281	1727	2293
$t_c$	397	588	749	957	1371	1831	2401
$2 t_c$	231	337	430	542	775	1026	1348

See Table C.4 for more information on the Rational Method.

The extrapolation of storm loss coefficients for veld type zone 5 and 8 to form combined storm loss coefficients used in the DRH method are summarised in table C.2

**Table C.2** *Combined storm loss coefficients used in the DRH method*

Duration	Probability of exceedance (%)						
	50	20	10	5	2	1	0.5
$\frac{1}{2} t_c$	0.203	0.244	0.269	0.293	0.322	0.345	0.366
$t_c$	0.213	0.253	0.278	0.302	0.329	0.350	0.368
$2 t_c$	0.229	0.271	0.298	0.320	0.348	0.368	0.387

**Table C.3** *Estimated flood peaks ( $m^3/s$ ) using the DRH method*

Duration	Probability of exceedance (%)						
	50	20	10	5	2	1	0.5
$\frac{1}{2} t_c$	449	743	965	1211	1558	1868	2193
$t_c$	359	575	738	917	1155	1363	1565
$2 t_c$	269	423	543	659	827	961	1107

Table C.4

**RATIONAL METHOD**

**IDENTIFICATION OF SITE**

Watercourse	Nkomazi River
Farm	Estuary

Latitude	30° 11' 52"
Longitude	30° 48' 06"

Drainage Region	U1910
Station no.	

**CATCHMENT CHARACTERISTICS**

Catchment Area:	Total: A = 4390 km <sup>2</sup>	Effective: Ae = 4390 km <sup>2</sup>
Areal weighting factors: $\alpha + \beta + \gamma = 1$		Dolomitic: Ad = km <sup>2</sup>
$\alpha$ (Rural)	$\beta$ (Urban)	$\gamma$ (Lakes)
1.00		

Longest Watercourse	L = 272 km
Mean Slope of L	S = 0.0 %
Mean Annual Rainfall	MAP = 942 mm
Time of concentration	t <sub>c</sub> = 38.0 hours

Steepness Y (%)	%A	Soil Permeability	%A	Vegetation	%A	Occupation	%A
Grid method: < 1		Very Permeable (A)	5	Forest Plantation	5	Lawns, Parks	40
mean slope: 1 - 3		Permeable (B)	65	Dense Bush & Wood	40	Residential	10
n = 3 - 10		Semi-Permeable (C)	30	Thin Bush	20	Industrial	15
60	10 - 30	Impermeable (D)		Cultivated land	20	Business	25
Y = 30 - 50				Grassland	15	Streets	10
10.4	> 50			Bare surface			
If Y = 0, C <sub>v</sub> is determined by a formulae, otherwise weighted areas are used.		C <sub>p</sub> = 0.126		C <sub>v</sub> = 0.112		C <sub>2</sub> vir T ≤ 20	
						C <sub>2</sub> vir 20 < T ≤ 50	
						C <sub>2</sub> vir T > 50	

Dolomitic Areas and Forest Plantations must always be considered as "very permeable"

**STORM RAINFALL**

Probability of exceedence (%)	STORM DURATION (AS MULTIPLES OF t <sub>c</sub> ) IN HOURS											
	1/2 t <sub>c</sub> = 19.0			t <sub>c</sub> = 38.0			2 t <sub>c</sub> = 76.0			3 t <sub>c</sub> = 114.0		
	P(mm)	ARF	I=ARF*P/D	P(mm)	ARF	I=ARF*P/D	P(mm)	ARF	I=ARF*P/D	P(mm)	ARF	I=ARF*P/D
50	69	0.84	3.059	75	0.87	1.722	85	0.89	1.001			0.91
20	95	0.84	4.212	101	0.87	2.319	113	0.89	1.331			0.91
10	112	0.84	4.965	118	0.87	2.710	132	0.89	1.554			0.91
5	129	0.84	5.719	135	0.87	3.100	149	0.89	1.754			0.91
2	151	0.84	6.694	156	0.87	3.582	172	0.89	2.025			0.91
1	169	0.84	7.492	173	0.87	3.972	189	0.89	2.225			0.91
0.5	187	0.84	8.290	189	0.87	4.340	207	0.89	2.437			0.91
PMP		0.84			0.87			0.89				0.91

**RUNOFF COEFFICIENT**

Probability of exceedence		50	20	10	5	2	1	0.5
Rural:	C <sub>1</sub>	0.189	0.208	0.227	0.253	0.314	0.378	0.453
Urban:	C <sub>2</sub>							
Combined:	C	0.189	0.208	0.227	0.253	0.314	0.378	0.453
C adjusted for upstream dams		0.189	0.208	0.227	0.253	0.314	0.378	0.453
C adjusted for Ad		0.189	0.208	0.227	0.253	0.314	0.378	0.453

The adjustment for upstream dams has not been introduced into the spreadsheet, yet

**PEAK DISCHARGE**

Probability of exceedence		50	20	10	5	2	1	0.5
Q (m <sup>3</sup> /s)	1/2 t <sub>c</sub>	353	534	687	883	1281	1727	2293
	1 t <sub>c</sub>	397	588	749	957	1371	1831	2401
	2 t <sub>c</sub>	231	337	430	542	775	1026	1348
	3 t <sub>c</sub>							

**RECOMMENDED VALUES OF RUNOFF COEFFICIENTS C<sub>1</sub> & C<sub>2</sub> (for hand calculations)**

RURAL: C <sub>1</sub> = fr (C <sub>v</sub> + C <sub>p</sub> + C <sub>v</sub> )				M.A.P. (mm)		
Component	Category			<600	600 - 900	>900
C <sub>v</sub> Steepness in %	Y < 3	1.5		0.01	0.03	0.05
	3 - 10	6.5		0.06	0.08	0.11
	10 - 30 or Y = 20			0.12	0.16	0.20
	30 - 50	40		0.22	0.26	0.30
	Y ≥ 50	≥ 50		0.26	0.30	0.34
C <sub>p</sub> Permeability of soil	Very Permeable (A)			0.03	0.04	0.05
	Permeable (B)			0.06	0.08	0.10
	Semi-Permeable (C)			0.12	0.16	0.20
	Impermeable (D)			0.21	0.26	0.30
C <sub>v</sub> Vegetation	Dense Bush, Forest			0.03	0.04	0.05
	Thin Bush, Cultivated Land			0.07	0.11	0.15
	Grass Land			0.17	0.21	0.25
	Bare Surface			0.26	0.28	0.30

URBAN: C <sub>2</sub> for T ≤ 20		
Occupation	Runoff Coefficient	%A
Lawns		40
sandy, flat < 2%	0.05 - 0.10	0.163
sandy, steep > 7%	0.15 - 0.20	20
heavy soil, flat < 2%	0.13 - 0.17	20
heavy soil, steep > 7%	0.25 - 0.35	
Residential		10
single family area	0.30 - 0.50	10
apartment dwelling	0.50 - 0.70	0.400
Industrial		15
light areas	0.50 - 0.80	10
heavy areas	0.60 - 0.90	5
Business		25
downtown neighbourhood	0.70 - 0.95	20
Streets	0.50 - 0.70	5
	0.70 - 0.95	10
URBAN: C <sub>2</sub> for 20 < T ≤ 50		
Lawns	0.35 - 0.50	40
Other	0.70 - 1.00	60
URBAN: C <sub>2</sub> for T > 50		
	1.00	100
		1.000

Probability of exceedence	50	20	10	5	2	1	0.5
fr	0.50	0.55	0.60	0.67	0.83	1.00	1.20

RAM condition: C<sub>1</sub> = C<sub>v</sub> + C<sub>pmax</sub> + C<sub>vmax</sub>

Department of Water Affairs and Forestry  
 Directorate of Hydrology: Flood Studies Subdirectorate

Calculated by:  
 C. R. Linström

Date:  
 May-98

**APPENDIX D**  
Empirical Methods

## Empirical Methods

The MIPI (Pitman and Midgley, 1971), CAPA (McPherson, 1983) and MIPI 1/71 methods (Midgley, 1972) and TR137 (Kovács, 1988) were used to estimate flood peaks for Nkomazi Estuary.

The info needed to apply these methods can be found in Table A.1

**Table D.1** *Estimated flood peaks (m<sup>3</sup>/s) using Empirical methods*

Method	Probability of exceedance (%)							RMF
	50	20	10	5	2	1	0.5	
CAPA	458	710	980	1333	1979	2657	3550	
MIPI	333	696	1024	1398	1964	2445	2973	
MIPI 1/71	283	711	1036	1396	1957	2463	3058	
TR 137					4904	5933	6897	9898

APPENDIX E  
Statistical analysis

## Statistical analysis

**Table E.1 Annual maximum flood peaks for Nkomazi Estuary**

Hydrological year	Q (m <sup>3</sup> /s) U1H003 (A=4375 km <sup>2</sup> )	Q (m <sup>3</sup> /s) U1H006 (A=4349 km <sup>2</sup> )	Q (m <sup>3</sup> /s) Combined Record (A=4390 km <sup>2</sup> )
Historical Record			
1855/56	7251		7263
1867/68	5823		5833
1874/75	4311		4318
1892/93	895		897
1917/18	3569		3575
1924/25	6160		6171
Continuous Record			
1951/52	26		26
1952/53	481		482
1953/54	451		452
1954/55	572		573
1955/56	745		746
1956/57	1053		1055
1957/58	665		666
1958/59	3980		3987
1959/60	297		298
1960/61	1474		1477
1961/62	578		579
1962/63		579	582
1963/64		1463	1470
1964/65		740	743
1965/66		611	614
1966/67		644	647
1967/68		157	158
1968/69		196	197
1969/70		387	389
1970/71		679	682
1971/72		633	636
1972/73		323	325
1973/74		1524	1531
1974/75		1222	1228
1975/76		2859	2872
1976/77		217	218
1977/78		220	221
1978/79		240	241
1979/80		146	147
1980/81		441	443
1981/82		301	302
1982/83		54	54
1983/84		237	238
1984/85		1079	1084
1985/86		413	415
1986/87	6828		6840
1987/88	529		530
1988/89		861	865
1989/90		2618	2630
1990/91		1029	1034
1991/92		157	158
1992/93		-	-
1993/94		1603	1611
1994/95		597	600
1995/96		2280	2291
1996/97		1463	1470

## Nkomazi Estuary Flow record

Table E.2: Information about available record

	Continuous	Historical	Combined
Record Length ( years )	46	-	-
Additional Record Length ( years )		96	-
Equivalent Record Length ( years )		-	142
Peaks higher than threshold <sub>max</sub> (Qstoch)	7	5	12
Valid peaks between thresholds	38	-	38
Valid peaks lower than threshold <sub>min</sub> (outliers)	-	-	-
Zero flows	-	-	-
Missing data ( gaps in record )	1	91	92
Censored data ( low + zero + missing )	1	-	92

Table E.3: Statistical properties

	Untransformed data	Log-transformed data
Median	647.0285193	
Mean	882.3	2.7242
s	1183.3	0.4464
g	3.5808	-0.3277

Table E.4: Results of fitted distributions

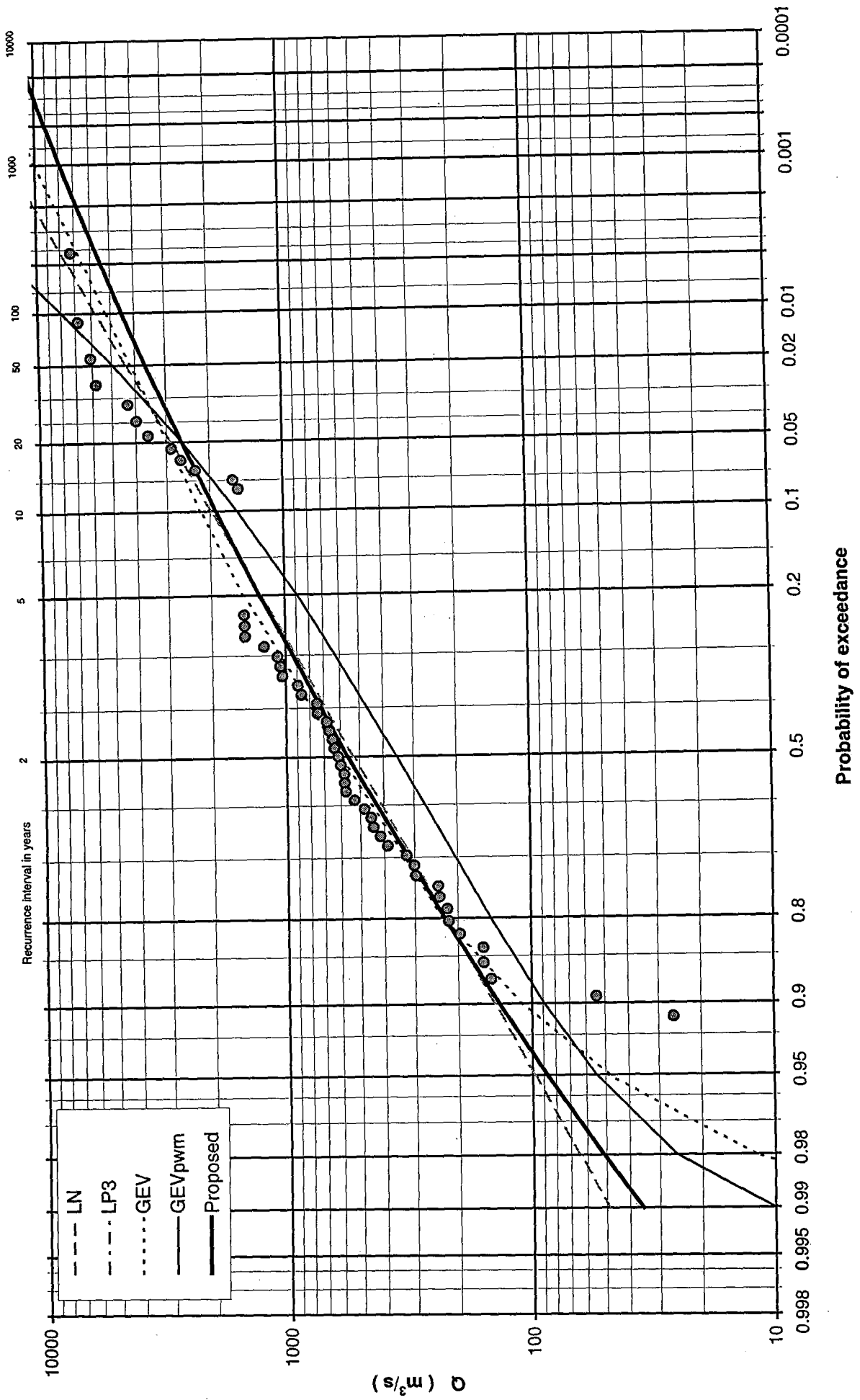
HHP	Exceed. Prob.	LN		LPIII		GEV <sub>PARAM</sub>		GEV <sub>MM</sub>	GEV <sub>PWM</sub>	Proposed
		WT	Q (m <sup>3</sup> /s)	WT	Q (m <sup>3</sup> /s)	WT	Par.	Q (m <sup>3</sup> /s)	Q (m <sup>3</sup> /s)	Q (m <sup>3</sup> /s)
2	0.50	0.00	530	0.05	560	0.38	k	597	352	560
5	0.20	0.84	1259	0.85	1274	1.75	-0.202	1480	892	1274
10	0.10	1.28	1979	1.24	1899	2.85	E(y)	2187	1555	1899
20	0.05	1.64	2874	1.55	2598	4.07	1.166	2973	2595	2598
50	0.02	2.05	4376	1.87	3638	5.93	var(y)	4176	4950	3638
100	0.01	2.33	5792	2.08	4510	7.58	0.137	5237	7974	4510
200	0.005	2.58	7485	2.27	5454	9.47	k	6454	12777	5454
500	0.002	2.88	10213	2.48	6810	12.40	-0.670	8345	23726	6810
1000	0.001	3.09	12701	2.63	7916	15.01	α	10025	37823	7916
2000	0.0005	3.29	15604	2.76	9089	18.01	0.282	11956	60243	9089
5000	0.0002	3.54	20171	2.93	10742	22.67	μ	14961	111374	10742
10000	0.0001	3.72	24253	3.04	12071	26.81	0.282	17632	177225	12071

Distributions used to calculate the estimated flood peak: LPIII

Figure E.1 : Graph of fitted distributions

### STATISTICAL ANALYSIS AT Nkomazi Estuary ( Nkomazi River )

STATIONS USED: U1H003/4, U1H006; RECORD LENGTH: 45 years



APPENDIX F  
Hydrographs

## Hydrographs

The hydrograph for the 1 and 2 % exceedance probabilities can be obtained by using the following formula on the ordinates of the 0.5 % hydrograph.

$$Volume_{(T, D)} = Volume_{(200, D)} \left( \frac{Q_{(T, D)}}{Q_{(200, D)}} \right) \text{ where } T = \text{Return period}$$
$$D = \text{Storm duration}$$

**Figure F.1** 0.5 % Exceedance probability flood hydrographs for Nkomazi Estuary

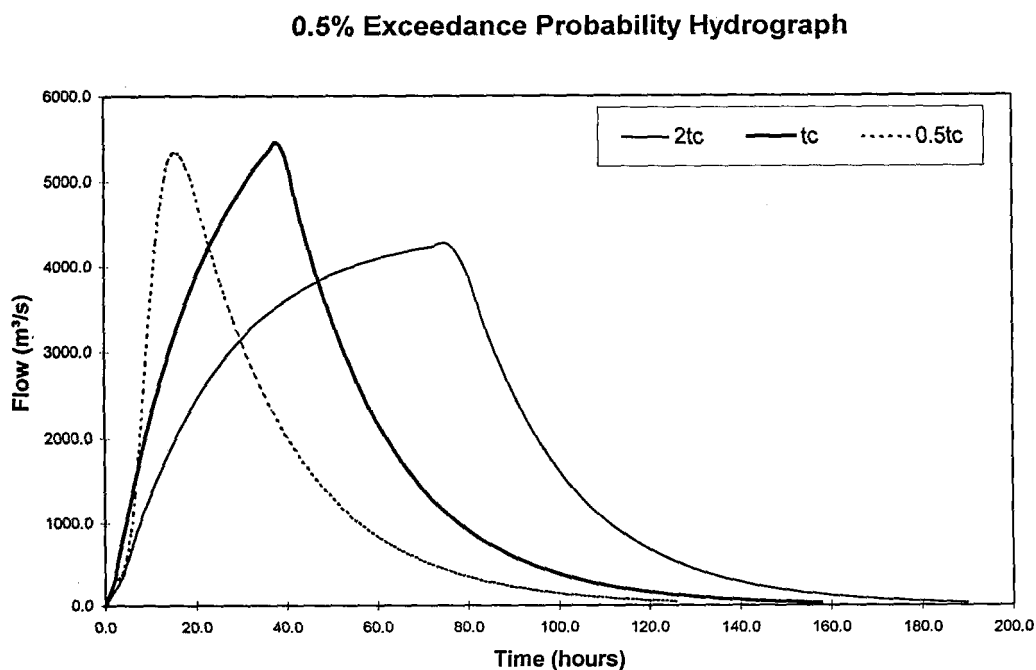


Table F.1.1 Ordinates of hydrographs

$\frac{1}{2} t_c$		$t_c$		$2 t_c$	
Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)
0.0	0.0	0.0	0.0	0.0	0.0
1.0	128.9	1.9	275.3	3.8	349.5
1.9	280.8	3.8	796.3	7.6	976.0
2.9	319.5	5.7	1275.7	11.4	1506.4
3.8	391.6	7.6	1716.7	15.2	1955.3
4.8	576.3	9.5	2122.5	19.0	2335.3
5.7	902.3	11.4	2495.8	22.8	2657.0
6.7	1362.2	13.3	2839.3	26.6	2929.2
7.6	1925.1	15.2	3155.3	30.4	3159.7
8.6	2547.2	17.1	3446.1	34.2	3354.8
9.5	3180.4	19.0	3713.6	38.0	3520.0
10.5	3779.1	20.9	3959.7	41.8	3659.8
11.4	4305.2	22.8	4186.2	45.6	3778.1
12.4	4731.5	24.7	4394.5	49.4	3878.3
13.3	5043.5	26.6	4586.2	53.2	3963.1
14.3	5239.5	28.5	4762.5	57.0	4034.8
15.2	5329.3	30.4	4924.8	60.8	4095.6
16.2	5331.7	32.3	5074.0	64.6	4147.0
17.1	5269.9	34.2	5211.4	68.4	4190.5
18.1	5166.9	36.1	5337.7	72.2	4227.4
19.0	5037.9	38.0	5454.0	76.0	4258.6
20.0	4866.6	39.9	5285.7	79.8	3935.5
20.9	4668.0	41.8	4863.1	83.6	3331.3
21.9	4477.5	43.7	4474.2	87.4	2819.9
22.8	4294.7	45.6	4116.5	91.2	2387.0
23.8	4119.5	47.5	3787.3	95.0	2020.5
24.7	3951.4	49.4	3484.5	98.8	1710.3
25.7	3790.1	51.3	3205.9	102.6	1447.8
26.6	3635.4	53.2	2949.6	106.4	1225.5
27.6	3487.1	55.1	2713.8	110.2	1037.4
28.5	3344.8	57.0	2496.8	114.0	878.1
29.5	3208.3	58.9	2297.1	117.8	743.3
30.4	3077.3	60.8	2113.5	121.6	629.2
31.4	2951.7	62.7	1944.5	125.4	532.6
32.3	2831.3	64.6	1789.0	129.2	450.8
33.3	2715.7	66.5	1646.0	133.0	381.6
34.2	2604.9	68.4	1514.4	136.8	323.0
35.2	2498.6	70.3	1393.3	140.6	273.4
36.1	2396.6	72.2	1281.9	144.4	231.5
37.1	2298.8	74.1	1179.4	148.2	195.9
38.0	2205.0	76.0	1085.1	152.0	165.9
39.0	2115.0	77.9	998.3	155.8	140.4
39.9	2028.7	79.8	918.5	159.6	118.8
40.9	1945.9	81.7	845.1	163.4	100.6
41.8	1866.5	83.6	777.5	167.2	85.2
42.8	1790.3	85.5	715.3	171.0	72.1
43.7	1717.3	87.4	658.1	174.8	61.0
44.7	1647.2	89.3	605.5	178.6	51.6
45.6	1579.9	91.2	557.1	182.4	43.7

**Table F.1.3 Ordinates of hydrographs - CONTINUED**

$\frac{1}{2} t_c$		$t_c$		$2 t_c$	
Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)
94.1	188.7	188.1	7.9	376.2	0.0
95.0	181.0	190.0	7.3	380.0	0.0
96.0	173.6	191.9	6.7	383.8	0.0
96.9	166.5	193.8	6.2	387.6	0.0
97.9	159.7	195.7	5.7	391.4	0.0
98.8	153.2	197.6	5.2	395.2	0.0
99.8	147.0	199.5	4.8	399.0	0.0
100.7	141.0	201.4	4.4	402.8	0.0
101.7	135.2	203.3	4.1	406.6	0.0
102.6	129.7	205.2	3.8	410.4	0.0
103.6	124.4	207.1	3.5	414.2	0.0
104.5	119.3	209.0	3.2	418.0	0.0
105.5	114.5	210.9	2.9	421.8	0.0
106.4	109.8	212.8	2.7	425.6	0.0
107.4	105.3	214.7	2.5	429.4	0.0
108.3	101.0	216.6	2.3	433.2	0.0
109.3	96.9	218.5	2.1	437.0	0.0
110.2	92.9	220.4	1.9	440.8	0.0
111.2	89.1	222.3	1.8	444.6	0.0
112.1	85.5	224.2	1.6	448.4	0.0
113.1	82.0	226.1	1.5	452.2	0.0
114.0	78.7	228.0	1.4	456.0	0.0
115.0	75.5	229.9	1.3	459.8	0.0
115.9	72.4	231.8	1.2	463.6	0.0
116.9	69.4	233.7	1.1	467.4	0.0
117.8	66.6	235.6	1.0	471.2	0.0
118.8	63.9	237.5	0.9	475.0	0.0
119.7	61.3	239.4	0.8	478.8	0.0
120.7	58.8	241.3	0.8	482.6	0.0
121.6	56.4	243.2	0.7	486.4	0.0
122.6	54.1	245.1	0.7	490.2	0.0
123.5	51.9	247.0	0.6	494.0	0.0
124.5	49.7	248.9	0.6	497.8	0.0
125.4	47.7	250.8	0.5	501.6	0.0
126.4	45.8	252.7	0.5	505.4	0.0

Table F.1.2 Ordinates of hydrographs - CONTINUED

$\frac{1}{2} t_c$		$t_c$		$2 t_c$	
Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)	Time (hour)	Flow (m <sup>3</sup> /s)
46.6	1515.5	93.1	512.6	186.2	37.0
47.5	1453.6	95.0	471.6	190.0	31.3
48.5	1394.3	96.9	433.9	193.8	26.5
49.4	1337.4	98.8	399.2	197.6	22.4
50.4	1282.8	100.7	367.3	201.4	19.0
51.3	1230.5	102.6	337.9	205.2	16.1
52.3	1180.2	104.5	310.9	209.0	13.6
53.2	1132.1	106.4	286.0	212.8	11.5
54.2	1085.9	108.3	263.2	216.6	9.8
55.1	1041.6	110.2	242.1	220.4	8.3
56.1	999.1	112.1	222.8	224.2	7.0
57.0	958.3	114.0	204.9	228.0	5.9
58.0	919.2	115.9	188.6	231.8	5.0
58.9	881.7	117.8	173.5	235.6	4.2
59.9	845.7	119.7	159.6	239.4	3.6
60.8	811.2	121.6	146.9	243.2	3.0
61.8	778.1	123.5	135.1	247.0	2.6
62.7	746.3	125.4	124.3	250.8	2.2
63.7	715.9	127.3	114.4	254.6	1.8
64.6	686.6	129.2	105.2	258.4	1.6
65.6	658.6	131.1	96.8	262.2	1.3
66.5	631.7	133.0	89.1	266.0	1.1
67.5	606.0	134.9	81.9	269.8	0.9
68.4	581.2	136.8	75.4	273.6	0.8
69.4	557.5	138.7	69.4	277.4	0.7
70.3	534.8	140.6	63.8	281.2	0.6
71.3	512.9	142.5	58.7	285.0	0.5
72.2	492.0	144.4	54.0	288.8	0.4
73.2	471.9	146.3	49.7	292.6	0.3
74.1	452.7	148.2	45.7	296.4	0.3
75.1	434.2	150.1	42.1	300.2	0.2
76.0	416.5	152.0	38.7	304.0	0.2
77.0	399.5	153.9	35.6	307.8	0.2
77.9	383.2	155.8	32.8	311.6	0.2
78.9	367.5	157.7	30.1	315.4	0.1
79.8	352.5	159.6	27.7	319.2	0.1
80.8	338.1	161.5	25.5	323.0	0.1
81.7	324.3	163.4	23.5	326.8	0.1
82.7	311.1	165.3	21.6	330.6	0.1
83.6	298.4	167.2	19.9	334.4	0.1
84.6	286.2	169.1	18.3	338.2	0.0
85.5	274.6	171.0	16.8	342.0	0.0
86.5	263.3	172.9	15.5	345.8	0.0
87.4	252.6	174.8	14.2	349.6	0.0
88.4	242.3	176.7	13.1	353.4	0.0
89.3	232.4	178.6	12.1	357.2	0.0
90.3	222.9	180.5	11.1	361.0	0.0
91.2	213.8	182.4	10.2	364.8	0.0
92.2	205.1	184.3	9.4	368.6	0.0
93.1	196.7	186.2	8.6	372.4	0.0