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DOCUMENTATION OF THE SEPTEMBER 1987 NATAL FLOODS

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DEPARTMENT OF WATER AFFAIRS

Directorate of Hydrology
Subdirectorate: Flood Studies
and
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DOCUMENTATION OF THE SEPTEMBER 1987 NATAL FLOODS

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Cover: Tugela River showing the failed John Ross bridge
on 30 September 1987

(Photo: L. Bloomfield, Daily News. By courtesy of
J.E. Perry, CSIR, Stellenbosch)

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1. INTRODUCTION

The floods that ravaged the central and southern parts of Natal from 28 to 20 September 1987, were among the most devastating to have occurred in South Africa to date. The destruction of property was the most catastrophic, in that it affected major metropolitan areas. Some 388 people were killed and 140 000 were left homeless. Damage to agriculture, communications, infrastructure and private property amounted to R 400 million (Photos 38, 40, 46 and 47).

The heavy and prolonged rains which fell between the 25 and 30 September were the result of the presence of a cut-off low and a strong onshore easterly air flow. The onshore flow was caused by the ridging of a high pressure system which originated over the Atlantic and moved to the south and then northwards east of the continent.

Following its established practice of gathering relevant hydrological data on extraordinary floods, the Directorate of Hydrology of the Department of Water Affairs carried out an extensive field survey over the flood ravaged region (Fig. 1.1).

Basic information used for the hydrological documentation of the September 1987 floods in Natal were rainfall data collected at 224 observation points (Appendix 1) and flood surveys and records of 106 sites in 59 rivers. Other information used included daily synoptic weather charts, satellite photographs, colour LANDSAT images, aerial photographs, sediment samples, reservoir sedimentation surveys, photographs, videofilms, personal accounts by inhabitants, contact with experts and scientists, daily press reports and technical literature.

This technical report contains the results of hydrological and hydraulic calculations, and analyses based on the above sources. The primary aim of the document is to serve as a data-source, and the interested reader is furnished with relevant flood data for each of the 106 catchments.

These comprise storm rainfall depth, flood peak with approximate return periods and, when possible, the flood volume, runoff percentage and time of peak (Appendix 2).

Additional data included are historical flood peaks, erosion and sedimentation, bridge damage (Appendix 3) and approximate sediment loads.

The effect of the floods on agriculture, economy, ecology, health and infrastructure is not covered by the hydrological documentation and the reader is referred to References (40 to 57) for details on these aspects.

2. THE STORM

2.1 METEOROLOGY

The following has been drawn largely from reports (1), (2) and (3) issued by the Weather Bureau.

2.1.1 Synoptic sequence

Fig. 2.1 (a - f) gives the daily synoptic weather maps issued by the Weather Bureau describing the synoptic situation at 14h00 S.A.S.T from 24 September until 29 September 1987. Satellite photographs for the corresponding time period are shown in Photo 1 (a - f).

On 25 September 1987 an intense anticyclone, or Atlantic high, began to ridge (invade a low pressure area) to the south of South Africa. Ahead of this were two cold fronts, one trailing over the south-eastern Cape and the second located south of the country and moving northwards. A strong warm north-westerly air flow was also evident.

Twenty-four hours later the second front had caught up with the first and the low intensified. The continued ridging of the Atlantic high generated a steep pressure gradient of 10 hPa extending from Port Elizabeth up to Maputo, the consequent advection of cold, moist air resulting in heavy rainfall over the south-eastern areas. The development of a cut-off low in the upper air was evident, with the surface low located over the central interior, and widespread rain fell over the entire country.

By 27 September the pressure gradient had increased to 16 hPa thus continuing the low-level onshore flow of cold, moist air from the east. The upper air cut-off low had moved north-eastwards (1). The rainfall of the 26th and 27th had already exceeded that expected with the passage of a typical cut-off low (2).

On 28 September the system began to weaken, the pressure gradient lessened to 10 hPa but still ensured a strong onshore flow from the surface high-pressure cell now moving eastwards along the 40°S parallel.

The now weakened cut-off low moved eastwards over northern Natal on 29 September with the associated surface low situated to the east of Durban (1). On this day most of the rainfall was recorded in southern Natal, apart from a small area north of Richards Bay. The low-pressure system from the interior brought drier air replacing the westward advection of maritime air. Further to the south the easterly onshore flow continued (2).

Several features associated with this weather system are particularly noteworthy:

(i) Most of the precipitable water below the 850 hPa level was precipitated over the coastal escarpment (2).

(ii) The rainfall over Natal increased as the easterly onshore flow increased. The correlation between wind strength and rainfall levels of 0,975 indicates that the precipitation rate was strongly influenced by the strength of the onshore flow. The rainfall levels were highest and the onshore flow the strongest on the 27th and 28th of September (2).

(iii) The onshore flow from the east was the more important source of precipitation.

(iv) Cut-off lows tend to move off the continent in a south-easterly direction as they develop. In this case the upper air cut-off low moved eastwards probably because of the presence of the blocking high-pressure system (2).

2.1.2 Cut-off low development and its role in historic storm events

Cut-off lows have been recognised for more than 30 years as specific types of low-pressure systems which are strongest in the upper troposphere (500 hPa - 200 hPa) and are associated with strong uplift and the occurrence of widespread rain on their eastern sides. Generally such systems occur 11 times per year (where the lifespan of a system exceeds 2 days) with most occurring in the periods March to May and August to October. In most cases a cut-off low is characterised by widespread rain but this is highly variable ranging from flood-generating falls to light falls indistinguishable from other rain-producing systems that are part of the general circulation (3). The Weather Bureau classifies cut-off lows according to the amount of rainfall over a given area and for a given duration as either Class 1, 2 or 3. The system responsible for the Natal flood of September 1987 would, therefore, be classified as a Class 1 cut-off low (1).

The development of a cut-off low has been variously described but has been seen to resemble the process described as anticyclonic wave disruption, a schematic diagram of which is shown in Fig. 2.2 (2).

An examination of large historic storm events of recent times indicates that cut-off lows have frequently been associated with such storms. The Laingsburg flood of January 1981, for example, the March to May 1981 floods of the south-eastern Cape and the 1971 floods of the Eastern Cape were all the result of weather systems where cut-off lows were part of the synoptic sequence. Other storms of note are the East London storm of August 1970, the Durban storm of December 1977 and the Port Elizabeth storm of September 1968: in all these cases cut-off lows were active (4).

2.2 POINT RAINFALL

2.2.1 Data (type and source)

Point rainfall data was obtained from a number of sources and in varying formats. The sources of data are outlined below:-

(i) Weather Bureau - stations operated by the Weather Bureau provided daily rainfall records throughout the duration of the flood-producing storm. In total, the records of 190 stations were utilised resulting in a fair, but uneven, coverage of the flood survey area (Fig. 2.3). In addition, data was obtained via a number of autographic rainfall stations. Unfortunately malfunction of recording equipment during the storm rendered several of the records unusable resulting in only 3 stations providing data.

(ii) Department of Water Affairs - daily rainfall records were obtained from a total of 22 gauging stations sited either at reservoirs or at sites of evaporation gauging pans. Of these stations 3 recorded total storm rainfall values only whilst the remaining 19 supplied daily rainfall data.

(iii) Municipalities and Universities - the autographic rainfall records of five stations located within the Durban city environs were obtained from the City Engineers' Department. Valuable data on rainfall intensity was supplied by the Borough Engineers' Department in Stanger. Autographic rainfall records for four stations located at the Cedara agricultural research station were made available by the Department of Agricultural Engineering at the University of Natal.

2.2.2 Antecedent rainfall

Antecedent rainfall values for all rainfall stations within the flood survey area, were determined by totalling the rainfall measured over the 14 days preceding the commencement of the storm, that is to say, the period 11 to 25 September 1987. These values are listed in Appendix 1.

Using the data thus obtained isohyets of antecedent rainfall (AP 14) were drawn and are shown in Fig. 2.4. This map clearly shows two areas of high antecedent rainfall. One area extends south of Durban, to some 30 kilometres south of Port Shepstone and encompasses the lower reaches of the Lovu, Mkomazi and Mzimkulu rivers. This area, reaching inland between 25 and 50 kilometres, experienced antecedent rainfall levels ranging from 100 to 140 mm. The second, smaller area lies in the Cathedral Peak region of the Drakensberg and recorded levels in excess of 100 mm. The remainder of the flood study area measured antecedent rainfall levels of between 20 and 60 mm.

If compared with normal September rainfall for a similar period of time (5) it becomes clear that the antecedent levels recorded during the 14 days prior to the September 1987 storm were, in the areas of maximum antecedent rainfall, some three or four times greater than the norm for a comparable period. Elsewhere in the region, except in the area north of Richards Bay towards Hluhluwe where the levels were variable, antecedent rainfall was generally twice that experienced normally.

2.2.3 Distribution in space and time

(i) Spatial distribution

Fig. 2.5 shows the 5-day storm isohyetal map covering the period 25 to 30 September 1987. It can be clearly seen that the main areas of heavy rainfall lie in the coastal belt stretching inland for 50 to

80 kilometres from St. Lucia in the north to Port Shepstone in the south. Isohyets lie parallel to the coastline and thus indicate the direction from which the low-level air mass moved. The topography of Natal was clearly instrumental in determining the spatial distribution of the rainfall, the zones of maximum rainfall were just inland of the immediate coastal strip on the coastal escarpment and correlate with the 300-metre contour level. Further inland the areas of high rainfall to the west of Pietermaritzburg, notably over the middle section of the catchment of the Mkomazi River, are associated with elevations in excess of 1200 metres. In northern Natal the areas of highest rainfall are apparently associated with lower elevations as they are confined to areas below the 100-metre contour level.

The maximum 5-day rainfall of 928 mm was recorded in the Richards Bay area at Langepan (Appendix 1). Other areas of high rainfall were north of Durban in the vicinity of Hazelmere Dam (Site 41) where a 5-day maximum of 790 mm was recorded. In the south of Natal the area to the west and north of Port Shepstone experienced high rainfall with a 5-day maximum of 762 mm at St. Faith's. These storm cells covered extensive areas, the extent of which is outlined in Table 2.1 below. Equivalent data for the storm generated by Cyclone Domoina (1984) is also tabulated (6).

TABLE 2.1: RAINFALL DEPTH AND AREA

Rainfall depth exceeded mm	Area (km^2) Domoina 1984	September 1987
>200	94 000	69 000
>300	69 000	41 000
>400	47 000	25 000
>500	18 500	14 400
>600	9 000	6 300
>700	1 750	1 600
>800	125	510
>900	20	150

Figure 2.6 shows the areas that experienced rainfall higher than 200 mm during the floods of May 1959, January 1984 and September 1987. It is readily apparent that the area affected by the storm of 1959 which resulted in extensive damage to bridges, roads and railways (7) was relatively small when compared to the area affected by the storms of 1984 and 1987. The 1-day maximum of 495 mm was recorded inland of Port Shepstone in the catchment area of the Mzimkulu River on 17 May 1959. Generally, the storm fell on catchments south and west of Port Shepstone with the heaviest rainfall confined to a small geographical area. Rainfall depths exceeding 400 mm covered an area of some 470 km^2 with 12 170 km^2 receiving in excess of 200 mm.

Details of floods prior to that of May 1959 are scarce but it is known that the storm that resulted in heavy flooding in 1856 affected principally the Mgeni catchment but also the Tongati and Mvoti rivers to the north of Durban and the Mlazi and Mkomazi rivers to the south of Durban and these rivers all came down in flood. Durban received

707 mm of rain in 5 days. It was reported that the storm reached as far inland as Pietermaritzburg although the rainfall totals in that area were very much lower, being of the order of 40% of the rainfall recorded in Durban (8). From this it can be deduced that the storm affected an area of at least 7 000 km^2, and possibly as much as 10 000 km^2, where rainfall was in excess of 200 mm.

(ii) Temporal distribution

Generally the areas of maximum rainfall remained static indicating that storm movement was not marked, controlled as it was by the nature of the terrain of the region and the position of the operative weather system. This is in sharp contrast to the 1984 storm generated by Cyclone Domoina where a daily shift in the recorded maximum rainfall was apparent and resembled the anticlockwise movement of the cyclone centre (6).

The majority of the rainfall stations (145 out of 220 stations) recorded the heaviest and most widespread rainfall between 08h00 on 28 September and 08h00 on 29 September. Many stations also reported heavy falls in the 24 hours preceding and following this time (Appendix 1). Although some stations did report that the heaviest rain fell on 28 September (measured at 08h00), it should be noted that in a number of instances a large total was recorded on this day and no rain was reported as having fallen in the preceding days (a weekend) suggesting that in some cases the rainfall values could be the total for several days.

The distribution of the rainfall throughout the 5-day storm was established by examining the records of autographic rainfall stations in the region. Fig 2.7 shows the accumulated rainfall for 5 stations from 25 September to 30 September 1987. Five stations were selected for inclusion namely those at Cedara (15 kilometres north-west of Pietermaritzburg), at the Louis Botha Airport in Durban, at Newcastle, at Dunkeld in Durban and at Stanger. The first three named are all stations operated by the Weather Bureau. An example of the chart of one of these stations is shown in Fig. 2.8. The autographic rainfall record for Dunkeld was supplied by the Durban City Engineers' Department. The rainfall at Stanger was not recorded at an autographic rainfall station but was measured, at varying intervals, at the Stanger Borough Engineers' office from 25 September at 08h00 until 29 September at 08h00 and from this the accumulated rainfall was deduced.

The accumulated rainfall graphs show the pattern of rainfall at one station through time and indicate the variation in rainfall intensity - the steeper the line, the higher the intensity - during the storm. Examination of Fig. 2.8 reveals that a period of high intensity rainfall occurred at all stations on September 26 from approximately 16h00. Periods of intense rainfall were measured at Stanger on 28 September when 58 mm fell in one hour and inland at Cedara on 29 September where maximum intensities reached over 100 mm/hour but only lasted for very short periods of time.

Fig. 2.9a gives the accumulated rainfall graphs for selected stations in Durban, the locations of which are indicated in Fig. 2.9b. The curves are very similar for 26 and 27 September but from then on there is considerable variation. The daily rainfall figures for these stations are given in Table 2.2(a) below.

TABLE 2.2(a) DAILY RAINFALL AT SELECTED STATIONS IN DURBAN

	Daily rainfall (mm)			
	26/9/87	27/9/87	28/9/87	29/9/87
City Eng. Dept.	60	86	145	49
Bluff	70	80	146	39
Phoenix	54	110	175	44
Dunkeld	70	138	209	58
Chatsworth	61	137	255	71

TABLE 2.2(b) 5-DAY RAINFALL AT SELECTED STATIONS IN DURBAN

	Total 5-day rainfall mm	Altitude m.a.s.l
City Eng. Dept.	341	20+
Bluff	338	100
Phoenix	382	160
Dunkeld	477	280
Chatsworth	525	300

There is a good correlation between altitude and higher rainfall totals and intensities as evidenced by the values given in Tables 2.2(b) and 2.3. Other factors must be taken into account, however, such as the positioning of the individual rain gauges which can affect the amount of rainfall collected, and the influence of the urban environment.

TABLE 2.3 RAINFALL INTENSITY AT SELECTED STATIONS IN DURBAN

Station	Maximum rainfall intensity mm/hr														
	Minutes					Hours									
	5	10	15	30	45	1	2	4	6	8	10	12	16	20	24
City Eng. Dept.	48	-	20	18	16	16	12	10	8	8	7	7	7	7	6
Bluff	69	45	40	29	22	17	12	10	9	8	8	8	7	7	6
Phoenix	48	-	31	26	22	19	14	12	11	9	9	9	8	8	7
Dunkeld	55	48	36	25	20	18	15	13	13	11	10	9	9	9	9
Chatsworth	60	-	24	23	21	20	19	17	16	14	13	12	11	12	11

For periods longer than 45 minutes it would seem that Chatsworth generally experienced the highest rainfall intensities with the stations located nearer the coastline recording the lowest.

The role of rainfall intensity is of significance in the generation of streamflow but its precise contribution is difficult to quantify. However, the prolonged occurrence of heavy rainfall particularly over Chatsworth is associated with landslips where arenaceous cohesionless soils underlain by the Natal group of sandstones became saturated and slopes failed (48).

2.2.4 Frequency

Fig. 2.10 shows the area where the maximum 3-day rainfall during the storm of September 1987 exceeded the 3-day 200-year point rainfall indicated by the shaded part of the map. This area measures some 21 740 km^2 which is somewhat less than the area determined for the flood caused by Cyclone Domoina using the same parameters: that area was calculated to have been 32 000 km^2 (6). The use here of the 3-day storm rainfall is valid since the majority of the total precipitation in fact fell during a period of 3 days. The 3-day 200-year point rainfalls have been extracted from Adamson's analysis of Southern African storm rainfall (4).

Fig. 2.11a-h gives frequency curves for a number of selected rainfall gauging stations (see Fig. 2.10 for locations). These were selected on the basis of (a) length of record - 55 years or longer (b) their position - in a high rainfall area and (c) quality of record. All the records of the stations for which rainfall frequency curves have been drawn have been subjected to a gap-filling procedure (9). The stations, of which the records were used, were randomly selected from those which satisfied the criteria specified in (a), (b) and (c).

The graphs are plotted on log-probability paper. There are two graphs per station: Fig. 11 (a) shows the 1-day recorded annual maxima whilst Fig. 11 (b) shows the 3-day recorded annual maxima. Two frequency distributions have been applied namely Log Normal 2-parameter and Log Pearson 3-parameter.

From an examination of the four sets of frequency curves a number of observations can be made: Fig. 2.11 (a) and (b) exhibit a tendency towards extreme rainfall values in the upper regions appearing as outliers to the rest of the more homogeneous data set. The highest 1-day rainfall recorded at this station (Kwa-Mbonambi, 15 km north of Richards Bay) is 525 mm which fell during the September 1987 storm. The recorded maximum 1-day rainfall during Cyclone Domoina at this Station was, at 337mm, the fourth-highest on record. The records of Station 239/133 (at Vaucluse south-west of Pietermaritzburg) shown in Fig. 2.11 (c) and (d) exhibit a similar tendency; as does Station 182/439 (at Ballyclare, 20 km south-west of Port Shepstone) to a lesser degree (Fig. 2.11 (e) and (f)). It can readily be seen that the frequency distributions which are often applied do not fit the data well in the upper regions. It should be noted that at Station 239/133 the highly skewed nature of the data set rendered the Log Pearson 3-parameter distribution inapplicable. Aside from the examples given it should be noted that such a tendency towards high values appearing as outliers is often seen particularly for those stations located in coastal Natal.

The consequence of this is that these commonly used distribution curves may suggest a longer return period for a given rainfall by failing to take cognizance of outliers, thus implying that the recorded rainfall is more extreme, or rare, than in reality. This, in turn, suggests that the area where the 3-day rainfall exceeded the 3-day 200-year value (Fig. 2.10) is, in reality, much smaller.

Pegram and Adamson (41) have suggested, as a result of their exploratory study of storm rainfall over Natal and Kwa-Zulu, that the presence of outliers in the rainfall record is characteristic for this region and is related to the meteorological conditions that prevail namely that periodically large or synoptic scale events are present. Their study of recordings made at 43 rainfall stations and their analysis of outlier proportion to homogeneous data indicates that distance from coast may be significant.

By no means do all rainfall stations in the Natal/Kwa-Zulu region record rainfalls that appear as obvious outliers in their records. Station No. 240/738, for example, located at Durban Heights purification works, the records of which are given in Fig. 2.11 (g) and (h), displays little evidence of this.

2.3 CATCHMENT RAINFALL

2.3.1 Depth

Catchment rainfall has been calculated from point rainfall for all 106 flood peak measurement sites included in this study. The method employed was as follows: firstly, all the previously determined total 5-day storm values (Appendix 1) were plotted on a map of the flood survey area and isohyets of a suitable range added; secondly, the relevant catchment areas were marked and the rainfall depth (or areal catchment rainfall) determined by the measurement of areas bounded by specific isohyets per catchment; and thirdly, a weighted average was calculated in order to arrive at an areal catchment value. These are listed in Appendix 2, Column 19(p). Antecedent rainfall was treated in the same manner and is listed in Appendix 2, Column 20 (AP 14).

Naturally, the accuracy of the calculation of the areal catchment rainfall or rainfall depth is closely linked to the distribution of rain gauges (Fig. 2.3). Density of the network is somewhat variable ranging from one rain gauge per 170 km^2 in the lower reaches of the Mlazi, Msunduze and Mgeni River catchments up to one rain gauge per 2 700 km^2 in parts of the Tugela catchment. On average the network density is approximately 1 per 600 km^2. Therefore, for smaller catchments removed from the centres of population it can be expected that the catchment rainfall is less accurate than for larger catchments.

2.3.2 Areal reduction factors

The storm centred areal reduction factor (ARF) is the ratio of mean rainfall depth and maximum point rainfall depth over an area. Fig. 2.12 gives the ARF curves for the flood of September 1987, for the Domoina flood of January 1984 (6) and, in addition, for the world envelope comprising values for maximum recorded 5-day storms in Asia, Australia and the U.S.A (10). In order to facilitate comparison the flood events must be of a similar duration and this precludes the use here of ARF curves for historical flood events such as the 1959 floods which resulted from storms over southern Natal on 16 and 17 May 1959.

The areal reduction factors were calculated by first establishing the point of maximum precipitation (storm centre) and then by using that as a reference point relating all other areas and rainfall to that point. The calculated areal reduction factors are listed in Table 2.4.

TABLE 2.4 AREAL REDUCTION FACTORS (ARF) FOR STORMS OF 5 DAYS DURATION

Area (km^2)	September 1987	Domoina	World envelope (of storms in the order of the PMP)
0	1.00	1.00	1.00
1 000	0.92	0.82	0.95
2 000	0.84	0.79	0.91
3 000	0.80	0.77	0.88
5 000	0.74	0.74	0.84
10 000	0.69	0.70	0.76
20 000	0.61	0.63	0.67
30 000	0.55	0.59	0.62
40 000	0.50	0.56	0.57
50 000	0.46	0.53	0.54
60 000	0.43	0.50	0.51

The ARF values for both storms are high in comparison with the world envelope value. The 1987 storm generated 92% of the maximum point rainfall over an area of up to 1 000 km^2 whereas the Domoina storm netted 82% thus implying that in the higher ranges the 1987 rainfall was more widespread. At lower levels for areas of 5 000 km^2 or more the September 1987 rainfall more rapidly decreased with increased distance from the point of maximum rainfall and was therefore less widespread than the Domoina rainfall.

2.3.3 Comparison with the PMP

The probable maximum precipitation (PMP) has been calculated for 100 catchments that occur within the boundaries of the flood study area. The concept of the PMP is useful in the assessment of the relative magnitude of rainfall and has been determined by using the PMP curves developed by the Hydrological Research Unit of the University of the Witwatersrand (11).

The established PMP varies in magnitude from 800 mm to 375 mm. In 5 out of a total of 100 catchments the 3-day areal catchment rainfall exceeded the 3-day PMP. These catchments are located along the Msunduse River at Henley Dam, the lower part of the Mgeni catchment downstream of its' confluence with the Msunduse River, and at the Nungwana Dam along the Nungwana River (Table 2.5).

TABLE 2.5 AREAL CATCHMENT RAINFALL > 3-DAY PMP

Site	River	Area (km²)	Areal rainfall (mm) September 1987 3-day rainfall	3-day PMP
18	Nungwana	55	550	500
34	Msunduse	176	553	493
38	Mqeku	257	535	487
39	Mgeni	4 023	412	409
40	Mgeni	4 149	419	407

In many instances the catchment rainfall and the 3-day PMP are similar. Along the Msunduse and Mgeni rivers and the coastal belt extending from the Mlalazi River in the north to Port Shepstone in the south, the catchment rainfall is 80% or more of the 3-day PMP in 19 catchments out of 93 (Table 2.6). This area corresponds well with the region of highest rainfall described in Chapter 2.2.3.

TABLE 2.6 AREAL CATCHMENT RAINFALL > 80% OF 3-DAY PMP

Site	River	Area (km²)	Areal rainfall September 1987 (mm)	3-day PMP (mm)
9	Mzimkulu	6 727	354	390
10	Mtalwume	565	521	546
11	Fafa	196	554	638
12	Mpambonyoni	495	499	546
14	Mkomazi	4 349	393	415
15	Mkomazi	4 375	393	464
19	Lovu	936	461	466
20	Mlazi	105	423	500
22	Mlazi	803	395	496
23	Mlazi	972	412	488
31	Sterk	438	400	483
32	Mgeni	2 519	374	431
33	Mgeni	2 542	375	431
35	Msunduze	284	448	485
36	Msunduze	877	406	466
37	Mgeni	3 455	377	415
41	Mdloti	380	620	768
42	Tongati	236	659	780
43	Mvoti	325	420	483

The flood-producing storm which was generated by Cyclone Domoina during January 1984 resulted in more than 55 catchments out of 83 experiencing rainfalls higher than the 3-day 200-year value. In areas of heaviest rainfall the Domoina rainfall was in the order of the PMP (6).

3. VISUAL DOCUMENTATION

The visual documentation of the September 1987 floods in Natal contained in this report consists of LANDSAT images (contributed by L.A. Randall), aerial photographs and photographs of special and general interest to the reader. Material was obtained from various sources including the South African Transport Services (SATS), SAICCOR (through Mr E. Beesley), CSIR (through Mrs J.E. Perry),the press and the Directorate of Hydrology. Aerial photographs were supplied by the Directorate: Survey Services of the Department of Water Affairs.

3.1 LANDSAT images (L.A. Randall, HRI, Roodeplaat)

LANDSAT is the name given to a series of American satellites first launched in 1972. There are at present two operational satellites orbiting the earth. Two sensors are mounted on each satellite: the high resolution Thematic Mapper and the lower resolution Multispectral Scanner. The data used in this study was obtained from the Multispectral Scanner. Data is collected every 16 days, in the form of digital values for discrete bands in the electromagnetic spectrum. LANDSAT MSS data has 4 bands: three in the visible part of the electromagnetic spectrum and the one in the near-infra-red. The pre- and post-flood images were simultaneously displayed on a image processor as false-colour, contrast enhanced images.

Two LANDSAT scenes cover the catchments. Two images from each scene were obtained in February 1987 before the floods, and two in mid-October 1987 (Table 3.1. below).

TABLE 3.1: LANDSAT IMAGES USED IN THE STUDY

WRS No.	Scene ID	Date
168/81	51075-07112	09/02/1987
	51331-07184	23/10/1987
168/80	51075-07112	09/02/1987
	51331-07182	23/10/1987

The area covered is indicated in Fig. 3.1. Photos 2 to 8 are a selection taken from these scenes. Rivers shown in these photographs are the Mzimkulu, Mzimkulwana, Mtwalume, Mkomazi, Lovu, Mlazi and the Mgeni after the floods. Pre- and postflood scenes are shown for the Mgeni (Midmar to Albert Falls), Mdloti, Mvoti and the Tugela rivers. Interpretation of the images are covered more comprehensively in Chapter 7.1.

3.2 Aerial photography

The scale of the photography is 1:5 000 (dams), 1:10 000 (rivers) and 1:30 000.

Fig.3.1 indicates the river reaches photographed by the Directorate Survey Services. These comprise the Mzimkulu, Mkomazi, Mlazi, Mgeni, Mdloti, Tongati, Mvoti, Tugela, Mhlatuze, Mfolozi (including the slope-area sites on the White and Black Mfolozi) and the Hluhluwe rivers. Most of the coverage is of the river mouths and estuaries. The Mlazi River has coverage from the Nshongweni Dam to the sea, the Mgeni River from the Midmar Dam to the sea, the Mdloti River from Hazelmere Dam to the sea and the Hluhluwe River from Hluhluwe Dam to Lake St. Lucia.

The aerial photographs included in this document are:

- Pre- and post-flood views of the Mkomazi-, Lovu- and Mvoti River mouths taken in July 1985 and on 30 September 1987. Photographs were taken by Aerial Photographic Service (APS) and supplied by Mrs J.E. Perry of the CSIR in Stellenbosch (Photos 9, 10 and 11).

- Views of the Mzimkulu, Mkomazi and Mlazi river mouth systems after the 1959 and 1987 floods (Photos 12,13 and 14).

- Mhlatuze River at Site 80 after the 1977 and 1987 floods (Photo 15).

- Hazelmere Dam in 1978 and after the September 1987 flood. These two photographs clearly indicate the degree of sediment deposition in the delta of the reservoir (Photo 16).

Although many more rivers were photographed (see Fig. 3.1) the above mentioned used in this document are of the most interesting scenes. The other photographs were used as a data source for the study of erosion and scour of the rivers and their immediate area.

3.3 Photographs

The 60 photographs cover slope-area sites, standing waves in rivers, channel characteristics, erosion and sedimentation, damage to bridges and inundation of residential areas. The sources of non-departmental photographs are indicated when applicable.

4. FIELD SURVEY

Fig. 4.1 shows 106 flood peak measurement sites. Site selection was made using a preliminary storm isohyetal map, LANDSAT images, press reports and a ground inspection of the affected areas. The scope of the survey was extended to include bridge damage, floodlines in reservoir basins, dam sedimentation, gauging-weir damage, gauging-weir discharge table extension surveys and erosion and sedimentation in alluvial rivers currently under investigation in northern Natal. Remote sensing surveys such as LANDSAT and aerial photography were carried out as soon as the weather permitted.

Floodpeak measurement surveys were undertaken at slope-area sites, bridges, flow-gauging stations and dams. The survey commenced during October 1987, a few days after the flood, when it became possible to reach most of the sites in the affected area. The initial survey lasting 10 days was carried out by three teams consisting of six or seven people under a person experienced in flood surveys and accompanied by a person who was familiar with the previously delimited region. Follow-up surveys were made in November and December 1987 and February 1988. These teams, along with the hydrological data collectors, gathered the information at 97 of the sites. At the remaining nine sites information was obtained from other sources (Column 22 of Appendix 2). Obstacles that hindered the survey were (6):

- damage to roads which delayed surveys, especially in the rural areas and in Kwa-Zulu
- strongly flowing rivers
- dense bush and trees
- poor flood marks in dense bush and on steep rocky banks
- the presence of crocodiles, hippopotami and leeches in the rivers of Northern Natal and
- cloud cover that delayed remote sensing surveys.

The flood-peak measurement sites comprise 43 slope-area reaches, 44 gauging weirs, 18 dams and one bridge.

4.1 Slope-area surveys (SA)

Number of sites: 43

This includes surveys at gauging stations where the discharge exceeded the capacity of the discharge table, a bridge contraction survey that was combined with the slope-area survey, and erosion and sedimentation surveys.

At the slope-area sites the average number of sections per site was 4, the number of flood marks was 31 and the number of points surveyed per section was 19. The statistics for 40 of these sites are shown in Table 4.1.

At SA sites the field work comprised the survey of the longitudinal flood profile as indicated by the flood marks and between two and five cross-sections perpendicular to the flow. Estimations of the absolute roughness at each section were also made. Photographs of the reach and cross-sections were taken and a sketch was drawn of the site.

TABLE 4.1: STATISTICS OF SURVEYED DATA AT 40 SLOPE-AREA SITES

Site no.	No. of cross-sec.	Length of reach	Mean top width (m)	No. of flood marks (m)	No. of survey point/section	Sediment samples
1	4	383	95	31	15	no
3	4	651	98	13	14	no
9	3	529	250	23	20	no
10	4	418	107	27	15	no
12	4	650	69	32	17	no
14	3	598	155	16	12	no
18a	3	110	29	10	10	no
18c	3	113	36	18	11	no
19	3	343	171	17	17	no
21	3	281	60	16	37	no
22b	3	211	101	18	13	no
27	2	100	52	12	12	no
28	4	168	58	6	16	no
33	5	659	142	27	12	no
35	4	560	120	45	23	no
36	4	394	95	21	12	no
37	4	549	182	44	26	no
38	4	630	96	44	14	no
40	4	696	163	12	19	no
41b	3	217	76	25	13	no
42	4	458	81	38	12	no
43b	5	223	49	44	15	no
44	4	597	179	91	29	no
45	4	416	66	23	15	no
46	3	163	54	30	13	no
52	5	328	62	7	23	no
61	4	1130	216	72	29	no
66	5	506	108	42	12	no
68	4	521	118	34	15	no
73	4	821	220	58	24	no
74	3	248	134	26	23	no
76	4	314	134	24	21	no
79	3	441	158	48	23	no
80	4	480	148	71	28	yes
82	3	254	206	9	17	no
86	4	1235	166	32	20	yes
90	4	823	150	18	33	no
91	4	1087	383	41	26	yes
93	3	153	174	12	16	no
97	4	557	132	63	26	yes

Slope-area surveys were carried out at sites suspected of having high flood discharges. Fourteen of the sites were at or near gauging stations and were surveyed with a view to extending the discharge tables (DT). At seven of the sites a full hydrograph was obtained. At Site 93, the bridge spanning the Nyalazi River, two SA sections were taken since the bridge had poor flood marks on the downstream side at the time of the survey. The flood peak at this site was calculated as shown in Chapter 5.1.5 and (12).

The criteria for a good slope-area survey site are described in (6), (12) and (13).

The cross-sections taken represent post-flood conditions and are fairly representative even in alluvial rivers (6). Cross-section changes during floods are dealt with in Chapter 7.3.

Fig. 4.2 and 4.3 show the plan, flood profile and cross-sections in the Mqeku River (Site 38) and the Mooi River (Site 68). Both are good SA sites each with a slight bend in the reach.The resulting superelevation is clearly revealed in the longitudinal flood profiles in Fig. 4.2 along the left bank between sections 1 and 2, and in Fig. 4.3 along the left bank between sections 1 and 4.In both cases the water slope was uniform.

Various SA reaches are shown in Photos 19-20, 28, 31, 35, 41-42, 44, 50, 52, 54, 58, 63-64 and 69-72.

Sedimentation and erosion surveys were carried out at the Mhlatuze (Site 80), White Mfolozi (Site 86), Black Mfolozi (Site 90), Mfolozi (Site 91) and Mkuze rivers (Site 97).The survey was a normal slope-area survey with sections taken at points that had been established by previous surveys. These sites were selected for their alluvial character after the Domoina floods of January 1984 (6) had changed the geometry of the rivers dramatically. The sites have been regularly surveyed since July 1985 to monitor changes. Site 10 in the Mtwalume River was originally also part of the study but was abandoned in 1986 due to its isolated location. It was, however, also surveyed again in October 1987. The results are discussed in Chapter 7.3.

Soil samples were taken at Sites 80, 86, 91 and 97 in alluvial rivers during August 1987 and October 1987. The results are discussed in Chapter 7.3.

4.2 River flow gauging stations (G)

Number of sites: 44

The field work consisted of the removal of the recorder charts and in certain cases, the survey of flood marks at the station. This was done in order to establish a flood profile and related gauge height if the station was damaged. Slope-area surveys were carried out in the immediate vicinity of 14 of these sites.

Damage to the Departmental flow gauging network was extensive.In the lower reaches of the major rivers no records of the flood exist. Of the 68 stations for which specific flood damage reports (14) were compiled, 34% were destroyed and 18% suffered partial structural damage. The total cost of damage is estimated at R 1,2 million, which is the total annual budget of the Directorate of Hydrology for the Natal region. Photos 17, 30, 50, 51, 66 and 67 show some of the damage incurred at gauging stations.

Of the 44 gauging stations used as flood peak measurement sites the discharge table (DT) was exceeded in 38 cases (see Appendix 2, columns 9 and 22).

Discharge table extension surveys were carried out at 18 gauging stations. These consisted of the survey of a section at the gauging structure up to the highest flood level, and of a section one riverwidth downstream of the gauging structure, and water levels 200 to 300 metres upstream and downstream of the gauging structure. The section downstream was assumed to be typical of the river. If good flood marks were still present, they were then surveyed to provide a true flood profile at a specific high flood level. These results were often combined with slope-area results in the immediate vicinity of the weir. The method of extension is discussed in Chapter 5.1.4. Site 43a, station U4M02 (Photo 51) on the Mvoti River at Greytown is an example of a good DT extension site.

4.3 Dams (D)

Number of sites: 18

This includes two sites (22a and 34b) for which information was received from the Mgeni Water Board and (43).

The work was restricted to the removal of the recorder charts and the establishing of the spillway flood level at Sites 8, 17 and 39. The flood levels for Sites 17 and 39 were obtained from the Dam Safety Office of the Department of Water Affairs. The level at Site 8 was supplied by (35) and confirmed to a certain extent by subsequent visits to the site.

At Sites 18b and 22a (Photos 27 and 28) the outflow peaks were obtained by using slope-area methods. A tentative flood volume has been calculated from daily recordings of the dam level at Site 18b.

Reservoir basin flood profiles were surveyed at Sites 18b (Photo 27) and 41a with the purpose of gaining information on wedge storage. Fig. 4.4 show the survey and flood profile at Site 18b. Chapter 5.1.3 will expand further on the results.

Reservoir sedimentation surveys were carried out in five reservoirs namely at Nshongweni (Site 22a), Henley (Site 34b), Nagle (downstream of Site 32), Hazelmere (Site 41a) and Goedertrouw (Site 77). Photo 16 shows the sediment deposits in the delta of Hazelmere Dam. The results are discussed in Chapter 7.5.

4.4 Bridge contractions (B)

Number of sites: 1

The only site surveyed was Site 30 in the Mgeni River, downstream of Albert Falls Dam.

The survey of flood marks upstream and downstream of the bridge was necessary in order to establish the drop of the water level across the bridge. The sections surveyed were: an approach section (upstream of bridge), a contracted section (underneath the bridge) and a normal section (downstream of the bridge). Photographs were taken, a sketch was drawn of the site and estimates were made of the roughness at each section.

4.5 Other sources of flood peak information

Number of sites: 9

The site number, information and source are listed in Table 4.2 below.

TABLE 4.2: SOURCES OF INFORMATION

Site	Information	Source of data
7	High flood level.	Umzimkulu Post Office, Transkei.
8	High flood level at spillway.	Mr Buhr, Paddock.
15	High flood level, time of peak and stage-time readings that were used for a tentative flood hydrograph. Also supplied were high flood levels for the 1856, 1925, 1959, 1976 and 1987 floods. Photographs for Site 15 and the Lovu River at the N2 before, during and after the 1987 floods were also supplied.	Mr E Beesley , SAICCOR.
17	Outflow peak	Dam Safety Office, Department of Water Affairs.
22a	Dam levels during flood, 1958 hydrographic survey and and capacity tables for 1948, 1958 and 1960.	Umgeni Water Board, Pietermaritzburg and reference (43)
23	Flood peak.	Mr K Legge, Directorate Civil Design, Department of Water Affairs.
34b	Dam levels and plans.	Umgeni Water Board, Pietermaritzburg and reference (43).
39	High flood level and construction plans.	Departmental Resident Engineer, Inanda.
81	High flood levels for 1941 and 1987, and bridge plans.	South African Transport Services.

Data for Nagle Dam were received from the Mgeni Water Board (32) and (43). Mr G. Hulley (31) of Hill, Kaplan, Scott and Associates gave a tentative value of the flood volume and time of peak at Durban for the Mgeni River. Photographs and data on estuaries on the Natal coast were supplied by Mrs J.E. Perry (30) of the CSIR in Stellenbosch.

4.6. Bridge damage survey

This consisted of the survey of the bridge deck level and the upstream and downstream flood levels. Photographs were taken and notes were made of the damage and any other relevant information. The results are discussed in Chapter 7.4 and summarised in Appendix 3.

4.7 Remote sensing surveys

This includes LANDSAT images and aerial photographs. The former were obtained from the Hydrological Research Institute, the latter from the Directorate: Survey Services of the Department of Water Affairs. The areas covered are shown in Fig. 3.1. The interpretation of the images and photographs are described in Chapter 7.

5. FLOOD PEAKS

The main purpose of the flood survey was to gather sufficient data for the calculation of high to extreme peak discharges. The importance of these are twofold:

(i) When associated with the return period or Francou-Rodier coefficient "K", essential information can be provided for design flood calculations.

(ii) If used in conjunction with the maximum flood level recorded at river flow gauging stations an important, if only approximate, point can be provided for the extrapolation of stage-discharge curves. The more extreme a flood peak, the more value it has as a calibration point (6).

5.1 Methods of flood peak calculation

5.1.1 Slope-area (SA)

When using this method the peak discharge was calculated by application of a (i) uniform or (ii) quasi-uniform flow equation utilising the flood profile, cross-sections and roughness.

(i) Uniform flow: the Chezy equation was applied at each cross-section with the local flood profile slope.

(ii) Quasi-uniform flow: the slope-area equation was applied for each sub-reach between two cross-sections. The slope-area equation is based on the Chezy equation, but the change in velocity-head is taken into account i.e. the flow is treated as gradually varied.

These methods were applied according to established departmental standards (12),(13). The representative cross-section (i) and roughness (ii) are, however, mentioned:

(i) Representative cross-section: The cross-sections surveyed after the flood were used for the calculation of the flood peaks. This assumption is discussed in (6).

(ii) Roughness: Estimation of roughness is described fully in (12) and (13).

Absolute roughness (ε) is estimated as follows:

- 1 to 2 times the diameter of the dominant obstacle
- ε_{min} is 0,15R or 0,20m in smooth, sandy simple natural channels (R = hydraulic radius.)
- ε_{max} = water depth were the bush or trees are higher than the maximum water depth.

The Chezy coefficient $C=18 \log(6R/\varepsilon)$ $(m^{0,5}/s)$

Fig. 4.2 and 4.3 illustrate the choice of roughness in various parts of the river channel at two of the sites where the slope-area method was applied. Photos 42 and 59 relate to these sites.

A further aid in estimating the roughness in main channels was the presence of waves in many of the rivers. Photos 17, 19, 24-26, 29-30, 39, 45, 48, 57, 60-62 and 68 illustrate the waves and in two cases (Photos 25-26, 60 and 61) the river bed associated with it. Further reports of surface waves from local inhabitants and videofilms were also of much help. Waves in the Tugela River were said to be 2-3m high at Tugela Ferry. At the John Ross bridge eyewitnesses reported waves of 6-8m in height, though the height is more likely to have been 4-5m. This compares well with the waves that were reported in the Mfolozi and Pongolo rivers during the Domoina floods (6). The waves at fixed obstacles such as weirs, rocks and bridges may have reached up to 5 m (Photos 30 and 57).

Roughness estimation in alluvial rivers is based on the specific energy curve which defines changes in water level that occur if the bed level changes (6),(16-18). Bed forms and their occurrence are discussed in (17) and (19). At Froude number (Fr) = 1,0 the observed waves may have been due to the flow type alternating between sub- and supercritical flow as defined by the specific energy curve (16), and not the bed form. This may have been true at sites where Fr > 0,8.

Photos 20, 28, 31, 35, 41-42, 44, 50, 52, 54, 58-59, 64, 69 and 71-73 illustrate the conditions at some of the slope-area sites.

The results obtained at Sites 18,27,35 and 41 (Appendix 2, Column 10), which are all downstream of dams, indicate the accuracy that can be attained through the slope-area method.

Table 5.1 summarises basic hydraulic data at 40 slope-area sites.

TABLE 5.1: HYDRAULIC PARAMETERS AT 40 SLOPE-AREA SITES

Site no.	Number of cross sections	Catchment area	Peak discharge	Slope flood	Slope 1:50000	Cross-section Area	Cross-section Top width	Main channel-mean values Depth	Main channel-mean values Roughness	Main channel-mean values Velocity	Froude number	Non-dimensional stream power
		CA	Q	Sf	S	A	T	D	E	V	Fr	U
		(km^2)	(m^3/s)	(m/m)	(m/m)	(m^2)	(m)	(m)	(m)	(m/s)		
1	2	3	4	5	6	7	8	9	10	11	12	13
1	4	2 471	850	0.00433	0.00126	276	95	3.9	0.47	3.2	0.66	0,013
3	4	715	1 470	0.00345	0.00507	404	98	7.0	0.48	3.5	0.68	0,012
9	3	6 727	5 600	0.00113	0.00113	1 782	250	10.2	0.44	3.3	0.42	0,004
10	4	565	850	0.00238	0.00333	329	107	3.3	0.30	3.5	0.53	0,006
12	4	379	1 130	0.00570	0.01072	260	69	4.2	0.69	3.9	0.74	0,021
14	3	4 349	6 900	0.00295	0.00323	1 374	155	10.6	0.80	5.1	0.61	0,015
18a	3	55	195	0.01037	0.01524	53	29	3.0	0.50	3.3	0.89	0,033
18c	3	58	140	0.00860	0.01219	50	36	1.9	0.59	2.4	0.81	0,020
19	3	936	1 800	0.00306	0.00185	592	171	4.0	0.47	3.1	0.63	0,009
21	3	417	560	0.00400	0.00387	178	60	5.1	0.44	3.1	0.65	0,012
22b	3	803	1 350	0.01117	0.00500	353	101	4.7	1.55	4.0	0.84	0,043
27	2	972	1 340	0.01329	0.02000	250	52	5.4	1.49	5.5	0.95	0,071
28	4	339	850	0.00530	0.00526	210	58	4.4	0.41	4.1	0.72	0,021
33	5	2 542	3 350	0.00709	0.01524	683	142	5.5	0.91	4.9	0.81	0,034
35	4	284	610	0.00022	0.00219	459	120	4.5	0.10	1.2	0.21	0,001
36	4	877	1 440	0.00212	0.00234	424	95	6.2	0.25	3.5	0.57	0,007
37	4	3 455	4 000	0.00423	0.00258	980	182	6.2	0.95	4.1	0.64	0,017
38	4	257	810	0.00869	0.01250	220	96	2.8	0.54	3.7	0.90	0,031
40	4	4 149	5 100	0.00341	0.00559	1 048	163	7.9	0.67	4.6	0.65	0,015
41b	3	381	1 650	0.00752	0.00909	335	76	5.2	0.64	5.4	0.89	0,039
42	4	236	950	0.00702	0.00667	251	81	3.8	0.45	4.2	0.86	0,028
43b	5	325	400	0.00717	0.00696	113	49	3.5	0.33	3.9	0.99	0,027
44	4	2 473	5 000	0.00172	0.00391	1 273	179	8.6	0.48	3.8	0.50	0,006
45	4	157	1 160	0.00563	0.00762	269	66	5.7	0.79	4.2	0.76	0,023
46	3	28	400	0.00860	0.00667	117	54	3.5	0.54	3.5	0.97	0,029
52	5	1 644	1 230	0.00565	0.00126	282	62	5.3	0.43	4.6	0.84	0,025
61	4	12 862	3 600	0.00215	0.00152	1 107	216	6.5	0.67	3.3	0.52	0,004
66	5	1 186	1 380	0.00750	0.00802	305	108	3.8	0.38	4.4	0.93	0,018
68	4	2 482	2 000	0.00675	0.01014	423	118	4.7	0.68	4.8	0.95	0,017
73	4	28 920	9 400	0.00147	0.00110	2 091	220	10.4	0.43	4.4	0.49	0,003
74	3	583	3 170	0.00100	0.00100	1 014	134	9.9	0.44	3.1	0.40	0,002
76	4	230	950	0.00094	0.00079	525	134	6.1	0.50	1.8	0.33	0,001
79	3	618	3 300	0.00308	0.00228	784	158	6.9	0.33	4.3	0.67	0,008
80	4	2 409	3 600	0.00223	0.00128	886	148	7.6	0.31	4.2	0.59	0,005
82	3	547	4 250	0.00188	0.00085	1 184	206	10.3	0.32	3.7	0.55	0,004
86	4	4 776	2 150	0.00220	0.00152	715	166	5.0	0.47	3.0	0.51	0,004
90	4	3 396	1 740	0.00183	0.00120	649	150	4.9	0.39	2.6	0.44	0,003
91	4	9 216	4 500	0.00079	0.00055	2 144	383	8.2	0.45	2.2	0.33	0,001
93	3	560	1 200	0.00135	0.00056	775	174	11.0	1.86	1.6	0.26	0,001
97	4	2 647	1 060	0.00188	0.00125	453	132	4.1	0.46	2.4	0.45	0,002

Conclusions from Table 5.1 are:

- The flood slope is not always well approximated by the slope taken from 1:50 000 maps. A comparison of the slopes seems to indicate the following (Fig. 5.1):

Slope from 1 : 50 000 map	Flood slope /1:50 000 slope
< 0,0025	> 1
0,0025 - 0,0090	= 1
> 0,0090	< 1

- The maximum mean velocity was 5,5 m/s in the Mgeni River downstream of Howick Falls.

- Critical flow (Fr > 0,8) was approached in 13 cases with Fr = 0,99 at Site 43b on the Mvoti River. The slope of these sites varied between 0,005 and 0,02 with the mean being 0,01.

- Estimated values of the non-dimensional stream power (U), as proposed by White (19), indicate the following:

U	Number of sites	Bed form
> 0,020	13	Antidunes and flat bed."Upper regime".
< 0,011	18	Ripples and dunes."Lower regime". Mostly confined to the northern areas.
0,011 < U < 0,020	8	A mixed bed form nature."Transition zone."

This method of classification of bed form shows a fair agreement with the Fr number. The non-dimensional stream power is defined as:

$$U = VS/Dgr*(gv)^{0,333}$$

where: V = velocity (m/s)
S = slope (m/m)
Dgr = dimensionless grain size = 0,24d
d = mean sediment size (m)
g = gravity constant = 9,81 m/s^2
v = kinematic viscosity = 1,14 * 10^{-6} (m^2/s)

5.1.2 Bridge contraction

The only site where a bridge contraction calculation was applied was Site 30 in the Mgeni River downstream of Albert Falls Dam.The type of flow was a combination of pipe and weir flow. The flood peak was calculated as the sum of the pipe flow under the bridge and the weir flow over the bridge.

The method is explained in more detail in (12) and (13).

5.1.3 Dams

The flood peak inflow into 15 of the 18 dams listed in Appendix 2 was calculated from the recorded dam level, outlet and spillway discharges and the depth-capacity relationship. The basic continuity equation was then applied:

$$I = \theta + \frac{\Delta Vol}{\Delta t} \quad (m^3/s)$$

where
I = inflow peak (m^3/s)
θ = outflow peak (m^3/s)
$\frac{\Delta Vol}{\Delta t}$ = rate of change in the dam storage with time (m^3/s)

Furthermore, horizontal dam levels were assumed although this may not always be true due to wedge storage and surges caused by the sudden inflow of an extraordinary flood. This is especially true for small dams(6).

Table 5.2 below lists the content of 17 reservoirs at various stages of the flood. The content of all the dams with the exception of Goedertrouw, Klipfontein, Hluhluwe and Pongolapoort was either 100% or close to 100% before the flood.

TABLE 5.2: CONTENT OF 17 DAMS DURING THE FLOOD PERIOD

Site no.	Dam	Full Supply Capacity FSC $(*10^6 m^3)$	Dam content (% of FSC) Before flood	At max. inflow	After flood	Maximum during flood
8	Gilbert Eyles	0,34	100,0	---,-	100,0	339,5
16	Umgababa	1,28	104,2	187,9	116,6	195,8
18b	Nungwana	2,18	98,9	113,1+	101,6	113,7
22a	Nshongweni	7,23	103,5	159,2	105,4	162,8
26	Midmar	177,76	97,6	124,4	104,3	125,5
29	Albert Falls	290,72	97,0	132,4	106,9	134,9
--	Nagle	24,60	100,0	---,-	106,2	113,7
34a	Henley	5,51	100,0	125,0	100,0	125,8
41a	Hazelmere	22,29	107,3	150,3	105,7	151,1
49	Spioenkop	274,29	96,9	109,0	101,9	109,8
56	Wagendrift	58,50	93,5	117,7	93,3	118,3
67	Craigie Burn	23,48	97,5	111,1	100,8	111,2
75	Eshowe	0,90	96,9	140,0	100,0	146,4
77	Goedertrouw	315,55	50,0	104,0	100,3	105,5
83	Klipfontein	19,01	63,0	77,3	102,1	105,3
94	Hluhluwe	28,75	61,6	133,9	102,0	133,9
100	Pongolapoort	2 445,97	51,9	53,2	57,3	57,3

Note : At site 18b no continuous records exist, and thus the maximum content during the flood peak inflow may be higher. Only daily readings were taken during the flood. FSC refers to the capacity before the flood.

A survey of the maximum reservoir levels was carried out at Sites 18b (Photo 27), and 41a to determine the extent of a discernable slope in the reservoir and to check the validity of the horizontal dam level assumption. At Site 41a (Hazelmere Dam) no slope could be discerned. Site 18b (Nungwana Dam) did however show a slope of 0,00922 in the upper reaches of the reservoir (Fig 4.4). At 1750 m from the dam wall the slope became zero. No continuous record was, however, kept of levels of the dam during the flood and this survey could not be tested against a theoretical calculation. The indication from the survey is that surge and wedge storage has an effect upon the results obtained for smaller dams like Nungwana.

Table 5.3 lists the approximate theoretical surge wave heights at 15 dams where large to extreme inflows occurred. The surge height was calculated from the wave velocity and continuity equations by assuming a sudden rise of the flow from zero to peak (6), (22):

$$\text{Maximum surge height} = Y_{max} = V \sqrt{\frac{Hw}{g}} \quad (m)$$

where V = mean velocity in the dam during peak inflow = Qi/A (m/s)
Hw = hydraulic depth in the vicinity of the wall = A/W (m)
g = gravity constant (m/s^2)
W = width of the reservoir in the vicinity of the dam wall (m)
A = mean cross-section of the dam = C/L (m^2)
L = length of the dam during peak inflow (m)
C = capacity of the dam at the time of Qi ($10^6 m^3$)
Qi = Peak inflow (m^3/s)

As a rule of thumb surges are negligible if $(Qi/C)10^6 < 10$ (22).

5.1.4 River flow gauging stations (G)

The methods for determining flood peak discharges at gauging stations may be classified as follows:

	Method	Number of sites
(i)	Flow within the calibration limit of the gauging station.	7
(ii)	Log-log extrapolation of the current stage-discharge curve to a point calculated using the weir equation.	12
(iii)	Log-log extrapolation of the current stage-discharge curve to a point calculated by using indirect discharge methods.	5
(iv)	Extension of the stage-discharge curve by using the Chezy equation on a section at the weir as surveyed for this purpose at 18 of the sites.	20

TABLE 5.3: APPROXIMATE THEORETICAL SURGE HEIGHTS

Site Dam	Inflow peak Qi (m^3/s)	Content at Qi C $(*10^6 m^3)$	Qi/C	Length of dam L (m)	Width W (m)	Cross section area A (m^2)	Mean values Velocity V (m/s^2)	Mean values Depth Hw (m)	Theoretical surge height Ymax (m)
8 Gilbert Eyles	700	0,96	733,0	1 950	139	492	1,49	3,54	0,90
18b Nungwana	195	2,46	79,3	2 043	245	1 204	0,16	4,91	0,11
22a Nshongweni	1 500	11,59	129,4	3 725	246	3 111	0,48	12,65	0,54
26 Midmar	1 505	221,10	6,8	8 800	1 090	25 120	0,06	23,05	0,09
29 Albert Falls	2 534	383,50	6,6	14 800	3 120	25 920	0,10	8,31	0,09
-- Nagle	3 960	27,34	144,8	2 730	392	10 025	0,40	25,55	0,65
34a Henley	620	7,11	87,2	3 420	428	2 080	0,30	4,86	0,21
41a Hazelmere	1 826	33,49	54,5	8 000	461	4 186	0,44	9,08	0,42
49 Spioenkop	847	296,20	2,9	20 800	410	14 240	0,06	34,74	0,11
56 Wagendrift	785	68,86	11,4	11 500	287	5 988	0,13	20,86	0,19
67 Craigie Burn	377	25,25	14,9	4 380	562	5 765	0,07	10,25	0,07
77 Goedertrouw	3 911	328,00	11,5	18 200	593	18 020	0,22	30,39	0,39
83 Klipfontein	127	14,64	8,7	8 400	138	1 743	0,07	12,63	0,08
94 Hluhluwe	1 696	38,50	44,1	15 400	448	2 500	0,68	5,58	0,51

Note: Surge calculated for conditions at time of inflow peak.

Although only 18 of the sites were surveyed for the extension of the stage-discharge curve, the method was applied to a further two sites with data taken from the gauging structures plans. The method used to calculate the discharge for the 20 sites of type (iv) was proposed by Venter & Benade in 1981 (15).

Briefly, the procedure is to determine the point of 100% submergence for the gauging structure. The Chezy equation is then applied to the section at the weir, using the criteria for the slope-area method. The valid discharge curve for the gauging structure is then plotted on a graph along with that of the extended section. The transition area is accommodated by using a smooth line fit.

5.1.5 Bridge contraction and slope-area method combination at bridges

This method which is described in (12) is used to estimate the discharge (Q) at bridges where only the upstream high flood level at the bridge is known. At Site 93 on the Nyalazi River it was used to give a first estimate of the discharge and flood levels on the downstream side of the bridge. This flood level was then compared with flood levels surveyed at the slope-area site downstream.

This procedure may be used to estimate the flood peak for those bridges listed in Appendix 3, for which a flood peak is not indicated. The flow at many of these sites was similar to that at Site 30, i.e. pipe and weir flow.

5.2 Results

The calculated peak discharges and related information such as the method of measurement, gauge height, Francou-Rodier "K", return period, accuracy of the measurement and time of peak are listed in Columns 8 to 14 of Appendix 2. Columns 15 and 16 list the previously recorded maximum flood peaks measured or observed at the site and the year of occurrence.

The following is a brief clarification of the information given in each of the columns:

Column 8: The methods of measurement were slope-area calculation (SA), bridge contraction calculation (B), dams (D) and river flow gauging stations (G).

Column 9: Maximum gauge height (GH) at the river flow gauging stations is the height of the recorded flood level above the crest of the lowest notch. In the case of dams the height given refers to the maximum gauge height recorded above the spillway if a particular dam spilled. At slope-area sites and bridge sites the GH is given in brackets and refers to the mean hydraulic depth (Hm) in the main channel. Hm = A/T (A = cross-section area and T = top-width, both referring to the main channel).

Column 10: The flood peak discharge. At dams "I" refers to the peak inflow and θ to the peak outflow.

Column 11: The Francou-Rodier "K". At dams the "K" refers to the inflow (I) peak.

$$Q = 10^6 (A_e/10^8)^{1-0,1K} \ (m^3/s)$$

A_e = effective catchment area (km^2)

Column 12: The return period of the flood peak (T) was determined using the Regional Maximum Flood (RMF) and, if available, the recorded annual maximum floods at gauging stations where records were at least 15 years in length. For return periods of 20 years or less the return period of the flood peak was obtained from the flood frequency distribution curve at the gauging station. The distributions used were the log-normal Type 2 and log Pearson Type 3. For return periods of 20 years or more the return period was calculated using the Q_T/RMF ratio. The return periods for the various Q_T/RMF ratios are listed in Table 5.4, extracted from Reference (23). The RMF is calculated by using the Francou-Rodier envelope "Ke" shown in Figure 5.4.

TABLE 5.4: Q_T/RMF RATIOS FOR DIFFERENT CATCHMENT AREAS IN NATAL (23)

Region	Return Period T (years)	Effective catchment area, A_e (km^2)							
		<10	30	100	300	1 000	3 000	10 000	30 000
5,6	50	0,537	0,508	0,474	0,503	0,535	0,570	0,607	-----
	100	0,668	0,645	0,617	0,640	0,668	0,695	0,724	-----
	200	0,803	0,788	0,769	0,784	0,803	0,821	0,838	-----
5,4	50	0,447	0,416	0,380	0,411	0,447	0,482	0,523	-----
	100	0,556	0,525	0,492	0,523	0,556	0,588	0,623	-----
	200	0,661	0,635	0,607	0,633	0,661	0,687	0,716	-----
5,2	50	0,447	0,416	0,380	0,411	0,447	0,482	0,526	0,566
	100	0,556	0,528	0,494	0,524	0,556	0,588	0,626	0,660
	200	0,676	0,650	0,624	0,650	0,676	0,701	0,733	0,758
5,0	50	0,447	0,416	0,380	0,411	0,447	0,482	0,525	0,567
	100	0,550	0,521	0,488	0,517	0,550	0,582	0,619	0,657
	200	0,661	0,636	0,608	0,633	0,661	0,687	0,718	0,748

In some instances, for return periods of between 20 and 50 years, the return period was taken as the mean of the two methods. The return periods are classified as:

- < 20 years (if calculated using the RMF)
- 20 - 50 years
- 50 -200 years and
- >200 years

Fig. 5.3 shows approximate return period isolines associated with the flood.

Column 13: The accuracy of each flood peak was determined by the quality of the measurement, criteria for the establishment of which are described in Chapter 5.1, (12) and (13). The rating symbols for accuracy are :

Rating	Error in peak discharge
1	less than 10%
2	less than 30%
u	accuracy unknown

Column 14: The time of peak was obtained from the hydrographs, if available, at the gauging stations and dams. At other sites the time of peak was supplied by eyewitnesses and by the sources mentioned in Chapter 4.5.

Columns 15 & 16: Previous maximum peaks and the dates of occurrence at the sites were obtained from the records of the gauging stations, previous flood surveys and historical peaks gleaned from departmental files and reports.

Columns 17-21: Flood volume, storm rainfall, antecedent rainfall and runoff %, refer to Chapters 2 and 6.

Column 22: Valid stage-discharge table (DT) limits at the time of the flood, and other notes.

5.3 Evaluation of results

5.3.1 Accuracy of flood peaks

The criteria for evaluating the accuracy of the measured flood peaks are detailed in (6),(12),(13) and (15).

Table 5.5 summarises the accuracy ratings for the various methods.

TABLE 5.5: SUMMARY OF FLOOD PEAK DISCHARGE ACCURACY RATINGS

Method		Number of of measure-ments	Number of ratings 1	2	u	Number of flood peaks with T > 50 years
Slope-area	(SA)	43	24	18	1	14
Bridge contraction	(B)	1	0	1	0	1
Flow gauging weir	(G)	44	15	25	4	5
Dam	(D)	18	11	6	1	5
Total		106	50	50	6	25
% of total			47	47	6	24

At gauging stations where extended stage discharge relationships were used (Method iv, section 5.1.5) the accuracy ratings were as follows:

Accuracy rating	Number of stations
"1"	6 (30%)
"2"	12 (60%)
"u"	2 (10%)

The results listed in Table 5.6 compare favourably with those obtained for the floods in the South Western Cape in 1981 (12) and Domoina in 1984 (6). In the case of the 1987 Natal floods the indirect measurements accounted for 56 % of the flood peaks with a return period of 50 years or more. Indirect flood peak discharge measurements are thus indispensible for the documentation of large to extreme floods.

Furthermore, it is significant that the slope-area surveys yielded better accuracies than the gauging structures. It should, however, be borne in mind that the measuring capacity of 37 of the gauging structures was exceeded. Thus many qualify as an indirect discharge measurement depending on the method used to extend the discharge calibration of the gauging structure (Chapter 5.1.4).

Generally, although some sites are rated as "2" or even "u", the values of the flood peaks are deemed to be good if viewed in total. Only 6 % of the peaks were rated as being of unknown accuracy.

5.3.2 Reduction of flood peak by dams

The reduction is expressed as the ratio of outflow peak to inflow peak, Qo/Qi. Table 5.6 relates the reduction to the Full Supply Capacity (FSC), initial dam content (% of the FSC) and flood volume.

TABLE 5.6: FLOOD PEAK REDUCTION AT DAMS

Site no.	Dam name	Dam content FSC $10^6 m^3$)	Dam content Before flood (% of FSC)	Flood Volume / FSL	Q_O / Q_I
16	Umgababa	1,28	104,18	10,73	0,78
18b	Nungwana	2,18	98,94	14,46	0,72
22a	Nshongweni	7,23	103,50	12,68	0,95
26	Midmar	177,76	97,64	0,94	0,74
29	Albert Falls	290,72	97,01	1,14	0,72
--	Nagle	24,51	100,00	24,35	0,85
34a	Henley	5,69	100,00	8,00	0,98
41a	Hazelmere	22,29	107,29	7,06	0,91
49	Spioenkop	274,29	96,91	0,41	0,76
56	Wagendrift	58,50	93,51	1,55	0,88
67	Craigie Burn	23,48	97,46	1,24	0,97
75	Eshowe	0,90	96,89	5,99	0,91
77	Goedertrouw	315,55	50,03	0,73	0,15
83	Klipfontein	19,01	63,02	0,56	0,24
94	Hluhluwe	28,75	61,59	2,33	0,69

Note: Inflow at all the dams was uncontrolled.

Conclusions:

- The flood volume/FSC ratio should be < 1.0 if the reduction is to be 25% or more.
- The shape and surface area of a reservoir plays a major part in the reduction of the flood peak by the storage that is available.

- In dams with an initial content of 100% or more, flood peak reduction was, at best, 22% with the mean at 7%.

- In dams with an initial content of 60% or less, flood peak reduction was 30% to 85%.

5.3.3 Flood peak times

Figure 5.5 shows the time of peak plotted against the distance of the site from the source, for a few rivers where this information was available.

The general pattern of flood peak times derived from Figure 5.5 is that flooding commenced in the north and then progressed southwards to the central and southern parts of Natal. The Hluhluwe River was the last to be affected by flooding indicating an isolated late period of intense rain (on 29 September) in northern Natal. Most of the rivers however reached their flood peak on 29 September 1987 between 02h00 and 18h00.

The Mgeni River is the most interesting since the indications are that the flood peak first occurred in the lower reaches before occurring in the upper reaches (compare the flood peak times for the sites at Midmar Dam with those at Inanda and Durban). The heaviest rain first fell in the lower coastal area before it occurred in the catchments further upstream. The flood peaks were mainly the result of rainfall on the intermediate catchments between the various sites.

The general conclusions are that the times of peak were mainly determined by the pattern and movement of the storm rainfall and the slope of the river. In the case of the Mgeni River the storm movement had an attenuating effect on the flood peaks in the lower reaches (55). This is the opposite of what happened during the Domoina floods of 1984 (6), where the storm moved in a downstream direction, in the Pongolo and Mfolozi Rivers.

5.3.4 Flood peaks in perspective

Table 5.7 lists five of the highest flood peaks on record together with the September 1987 flood peak at 20 sites.

The Klip River at Ladysmith has a history of flooding dating back to 1886, and the values listed in Table 5.9 are only those for the most severe floods. Floods similar to the September 1987 floods occurred again in February 1988 and 1989 at Ladysmith. The peaks for the April 1856 floods in the Mdloti and Tongati Rivers should be assumed to refer to their total catchments areas of 527 km^2 and 436 km^2 respectively.

The 1856 floods cannot be validated because of a lack of data. The major source of information (10) only refers to the rise in water level in four of the rivers without any reference to the location of the sites. Data for the peak at the Mkomazi River (29) is accurate within limits. The magnitudes of the calculated 1856 peaks are, however, supported by the total 5-day rainfalls for the 1856 storm and the 1987 storm around Durban of 707 mm and 525 mm respectively. Data for the other historical peaks were gathered from old departmental files and from (6), (7), (23-29).

TABLE 5.7: PREVIOUS HIGH TO EXTREME PEAKS AT SELECTED STATIONS ON RECORD

River	Catchment (km²)	Period under review	Previous peaks (m³/s) and year of occurrence (chronological sequence)					Flood peak 1987 (m³/s)
Mtamvuna	715	1951-1987	292 (1955)	2 270 (1959)	322 (1976)	730 (1978)	486 (1985)	1 470
Mzimkulu	3 643	1932-1987	2 240 (1939)	1 010 (1940)	1 250 (1943)	1 060 (1956)	3 800 (1959)	3 720
Mzimkulu	6 727	1925-1987		? (1925)	6 000 (1931)	6 520 (1959)	? (1976)	5 600
Mtwalume	565	1917-1987	? (1917)	? (1925)	991 (1959)	? (1976)	1 000 (1985)	850
Fafa	196	1959-1987				991 (1959)	1 000 (1985)	950
Mpambanyoni	495	1917-1987	? (1917)	? (1925)	1 230 (1959)	? (1976)	830 (1985)	1 130
Mkomazi	4 350	1856-1987	7 000 (1856)	6 130 (1868)	6 260 (1925)	6 230 (1959)	2 140 (1976)	6 900
Lovu	936	1917-1987	1 500 (1917)	1 300 (1943)	1 700 (1959)	1 900 (1976)	830 (1985)	1 800
Mlazi	800	1856-1987	? (1856)	990 (1917)	? (1925)	1 400 (1959)	? (1976)	1 420
Mgeni	4 200	1856-1987	6 600 (1856)	5 700 (1917)	538 (1943)	821 (1976)	596 (1985)	5 100
Mdloti	380	1856-1987	>1 830 (1856)	? (1925)	? (1935)	426 (1976)		1 830
Tongati	236	1856-1987	>2 100 (1856)	2 100 (1918)	970 (1953)	1 050 (1978)	850 (1985)	950
Mvoti	2 470	1856-1987	3 400 (1856)	2 200 (1913)	1 300 (1932)	932 (1943)	3 000 (1974)	5 000
Klip	1 644	1886-1987	1 800 (1886)	1 260 (1918)	1 800 (1923)	902 (1925)	834 (1975)	1 230
Tugela	12 862	1930-1987	3 250 (1930)	5 100 (1943)	4 080 (1955)	3 690 (1974)	3 500 (1978)	3 600
Tugela	28 920	1925-1987	15 100 (1925)	4 700 (1967)	4 090 (1974)	4 870 (1978)	5 720 (1984)	9 400
Mhlatuze	2 400	1941-1987	3 200 (1941)	1 420 (1963)	2 080 (1977)	2 400 (1984)	1 750 (1985)	3 600
Mfolozi	9 250	1905-1987	4 530 (1918)	5 600 (1957)	8 500 (1963)	3 000 (1977)	16 000 (1984)	4 500
Mkuze	2 543	1925-1987	1 500 (1925)	1 950 (1963)	1 100 (1974)	805 (1977)	5 500 (1984)	1 000
Pongolo	5 800	1925-1987	5 850 (?)	4 130 (1928)	3 010 (1957)	3 400 (1963)	9 200 (1984)	721

It is evident from Table 5.7 that high to extreme floods occur more often than is generally assumed. The Mkomazi River has had 5 floods exceeding 6 000 m^3/s in the past 130 years. This suggests that a flood peak of 6 000 m^3/s may occur roughly every 30 years. The same argument may be applied to the other rivers.

During the preparation of this report it was found that the recalculation of some historical peaks using the Chezy equation showed possible overestimations of these peaks. A tentative recalculation yielded the following results at three sites where sufficient information was available:

River	Catchment area (km^2)	Historical peak calculation result and date (m^3/s)		Recalculation using Chezy equation 1988 (m^3/s)
Mtamvuna	715	2 266	(1959)	1 500
Mlazi	972	2 265	(1959)	1 400
Mvoti	2 470	2 200	(1913)	1 210

These overestimations may have resulted from the low Manning "n" values used at the time.

As regards the Francou-Rodier "K" coefficient, no peak had a K-value that exceeded the valid regional K-values. The highest K-value was recorded at Site 82 in the Nseleni River (5,49) where the regional K_e is 5,6.

In the aftermath of the September 1987 floods in Natal and the floods in the Orange Free State and the northern Cape of February and March 1988, the regional boundaries for "K_e" were revised (23) and are shown in Fig. 5.4.

5.3.5 Flood frequency analysis and related problems

In Table 5.8 the return periods of the September 1987 flood peaks were calculated by (i) statistical analyses of recorded annual maximum peaks: (log normal 2-parameter, LN2, and log Pearson 3-parameter, LP3, distributions) and (ii) from Q_T/RMF ratios as described in TR 137 (23). The symbols for the respective return periods are T_{LN2}, T_{LP3} and T_{RMF}. Only those sites where T_{RMF} was 20 years or longer were considered.

The results are a confirmation of earlier findings (6), (27), (36), (41), (52) and (55), i.e. that currently used frequency distributions are applicable only if the sample populations are not mixed. In cases where outliers are included in the record the return periods are generally far too long i.e. the flood peak magnitude associated with a given T is underestimated. This is particularly true in the $20 < T < 200$-year frequency range.

In Fig. 5.6.1(a) and 5.6.2(a) examples are shown of the LN2 and LP3 distributions calculated for a mixed population of annual maximum flood peak records. Fig. 5.6.1(b) and 5.6.2(b) are for the same sites as above, with the difference that the historical peaks of 1856, 1868, 1917 and 1925 are included. The frequency distributions however, have not been drawn. The inclusion of the historical peaks would seem to support a distribution having an S-shape as proposed by Kovacs (45) and by Hulley and Beaumont (55).

TABLE 5.8: COMPARISON OF RETURN PERIOD ESTIMATES

Site	River	Catchment area CA. (km^2)	Record length N	Francou-Rodier "K" K_e	RMF TR137 (m^3/s)	Flood peak Sept. 1987 Qp (m^3/s)	Qp/RMF	Return period of September 1987 flood (yrs)		
								T_{RMF}	T_{LN2}	T_{LP3}
3	Mtamvuna	715	36	5,2	3 389	1 470	0,43	40	150	45
4	Mzimkulu	545	39	5,0	2 335	900	0,39	45	90	50
13	Mkomazi	1 744	25	5,0	4 176	2 770	0,66	190	1 000	200
14	Mkomazi	4 349	35	5,4	9 855	6 900	0,70	210	400	80
24	Mgeni	299	27	5,0	1 729	395	0,23	25	200	80
25	Mpofana	360	33	5,0	1 897	503	0,27	25	1 000	200
28	Karkloof	339	33	5,0	1 841	850	0,46	65	500	65
29	Mgeni	1 644	23	5,2	5 054	1 820	0,36	70	400	100
31	Sterk	438	27	5,2	2 679	667	0,25	25	110	55
32	Mgeni	2 519	33	5,2	6 203	3 960	0,64	140	10 000	200
34	Msunduze	176	27	5,0	1 327	495	0,37	45	50	55
39	Mgeni	4 023	52	5,4	9 508	5 500	0,58	90	>10 000	500
42	Tongati	236	25	5,4	2 580	950	0,37	40	80	50
43	Mvoti	316	24	5,2	2 290	394	0,17	30	3 000	--
50	Little Tugela	782	26	5,0	2 796	812	0,29	25	16	15
52	Klip	1 644	17	5,0	4 055	1 230	0,30	25	13	19
61	Tugela	12 862	61	5,0	11 341	3 600	0,32	25	14	14
62	Mooi	260	15	5,0	1 612	375	0,23	25	70	35
63	Klein Mooi	188	15	5,0	1 371	397	0,29	30	50	50
65	Mooi	937	37	5,0	3 061	1 480	0,48	60	1 100	120
73	Tugela	28 920	31	5,2	20 016	9 400	0,47	35	70	100
74	Matigulu	583	22	5,6	4 976	3 170	0,64	95	45	40
78	Mfuluzone	45	39	5,6	1 612	790	0,49	55	130	130
80	Mhlatuze	2 409	27	5,6	9 290	3 600	0,39	30	28	28

Note: The frequency analyses did not not include historical peaks.

Fig. 5.6.3 (a and b) are the frequency distributions of two sites with a single population. Note the similarity between these plots (Fig. 5.6) and those of the annual maximum 1-day and 3-day storm rainfall distribution shown in Fig. 2.11a-h.

It is therefore clear that Natal, with the exception of the Drakensberg regions and surroundings, is characterized by a mixed population annual maximum flood peak series.

6. FLOOD VOLUMES

6.1 Flood hydrographs - river gauging stations

A total of 36 hydrographs have been drawn from data recorded at river flow gauging stations (Fig. 6.1). Of these 36 stations only 7 were able to record the full magnitude of the flood. This situation has arisen due to the fact that most gauging stations are calibrated only in the low and medium flow range. Consequently the measuring capacity of many of the weirs was exceeded during the passage of the flood. The flow records of these remaining 29 stations were therefore incomplete and required manual computation in order to provide a complete flow record and thus facilitate the drawing of hydrographs.

Several techniques were employed and are described as follows:

(i) Tacheometric survey of the river banks and river bed in the immediate vicinity of the gauging weir and, by application of the slope-area method, with consequent extension of the discharge table into the high-flow region (14 stations). Consult chapters 5.1.4 and 5.1.5.

(ii) Log-log extrapolation of currently employed discharge tables using historical flood peaks determined by the slope-area method (12 stations). See chapter 5.1.4.

(iii) Combination of existing discharge tables and previous tacheometric surveys in order to extend the current discharge table (3 stations).

Examination of the hydrographs in Fig. 6.1 reveals considerable variation in shape. Factors such as the temporal and spatial distribution of rainfall and catchment characteristics will influence its form to a greater or lesser extent. Detailed information on these variables is necessary if the degree of contribution is to be assessed and quantified.

A number of hydrographs exhibit a smaller initial peak occurring in most cases on 28 September 1987 between 12h00 and 18h00. Site 12 on the Mpambanyoni River, Site 13 on the Mkomazi River and Site 55 on the Ncibidwane River recorded such peaks. Catchment response of this nature may well be the result of variation in rainfall intensity combined with catchment shapes that are rather elongated. The paucity of autographic rain gauges in the region precludes an accurate assessment.

Different rivers can produce characteristic hydrograph shapes, for example, hydrographs for sites along the Mgeni River (Site 24 and 32) have a flatter peak and broader profile than those of sites along the Black Mfolozi River which show a narrow, sharper peak (Site 88 and 89).

In the Buffels and Slang river catchments at Sites 69, 70 and 72 the descending limb is unusually flat, that is to say, it exhibits a slow trend towards returning to base-flow conditions after the occurrence of the peak. These sites are located in an area that received low rainfall during the storm, i.e. in the order of 100 - 140 mm, and experienced fairly dry antecedent conditions (Appendix 2, Columns 19 and 20). Comparison with a hydrograph of the flood experienced as a result of Cyclone Domoina at Site 69 indicates that this shape is characteristic for the region suggesting that local catchment conditions are of particular significance. The presence of marshlands along much of the Slang River and its tributaries, especially in the upper half of the catchment, suggests conditions likely to delay interflow and hence result in a hydrograph such as that shown.

6.2 Flood hydrographs - Dams

Flood hydrographs for 12 dams operated by the Department of Water Affairs are shown in Fig. 6.2 (1-12).

The graphs show both the calculated inflow and the measured outflow (10). No outflow occurred at the Pongolapoort Dam (Fig. 6.2, Site 100). Several of the hydrographs exhibit a large measure of oscillation. Surging is a possible cause although it is more probable that variation in rainfall intensity was responsible, particularly in the smaller catchments such as that of the Umgababa Dam (Fig.6.2, Site 16).

6.3 Flood volumes and runoff factors.

The flood volumes of the hydrographs have been determined as the volume from the start of increase of flow until a time (t) after the peak determined by the following formula (6):

$$t = 0.8\,A^{0.2} = \text{time} \quad \text{(days)}$$

where A = catchment area (km^2)

The flood volumes for hydrographs at 56 river and dam gauging stations are listed in Appendix 2, Column 17 ($10^6 m^3$). Columns 18 - 21 of Appendix 2 contain additional data relevant to flood volumes. Column 18 gives the flood volume as a depth (mm) which has been determined by dividing the flood volume by the catchment area and converting to millimetres. Columns 19 and 20 contain the areal storm rainfall (for the period 25 to 30 September 1987) and the antecedent rainfall. The methods of calculation for these have already been outlined in Chapter 2.3.1. Column 21 gives the runoff percentage (pv/p*100): this was derived by dividing the flood volume as a depth by the areal rainfall and converting to a percentage. This represents storm losses whereby, for example,a runoff percentage of 10% indicates that 10% of the precipitation depth was available for runoff and therefore contributed to the measured flood volume, and 90% was lost in the hydrological system through such agencies as evaporation, plant interception and soil profile storage. Thus, catchment characteristics such as the type and extent of the vegetal cover, soil characteristics and antecedent rainfall are of great significance.

Fig. 6.3 is a plot of total storm rainfall (p) against the runoff percentage for all 48 stations for which hydrographs have been drawn. The result is a little disappointing as, contrary to expectation, it did not reveal any real trends as regards the relationship between vegetation characteristics, storm rainfall and antecedent rainfall (or, incidently, any other catchment parameter such as size or average slope). A similar exercise carried out using data relating to the flood caused by Cyclone Domoina indicated a clear relationship between these variables. The approximate lower limit of runoff percentage is, however, similar for both floods (compare with Fig. 6.3 of (6)). Nevertheless, certain observations may be made on the result illustrated by Fig. 6.3:

(i) It would seem that a minimum level of total storm rainfall of 50 - 100mm was necessary before runoff commenced.

(ii) Several stations feature anomalously on the diagram. This could be the result of inaccuracies in discharge tables associated with these gauging structures or of the often poor distribution of rain gauges which may result in the inaccurate determination of catchment rainfall.

At Site 92 (W3M14), on the Mpate River, for example, a runoff percentage of 74% was calculated which is unusually high considering the wholly afforested nature of the catchment. In this case the rainfall may not be representative in such a small catchment as this.

Runoff percentages for Sites 10 (U8M02), 11 (U8M01) and 12 (U8M03) range from 25% up to 50%. The antecedent rainfall levels associated with these stations are extremely high and, in catchments such as these containing large areas of cultivation and little afforestation, high runoff (and low loss) would be expected.

7. EROSION AND SEDIMENTATION

This chapter briefly outlines some observations on erosion and sedimentation. The section on LANDSAT image interpretation was contributed by L. A. Randall of the Hydrological Research Institute of the Department of Water Affairs. River channel course changes, channel stability and erosion, sediment loads, erosion at bridges and reservoir sedimentation will be discussed at selected sites.

7.1 Interpretation of LANDSAT images (L A Randall)

Visual interpretation of Landsat multispectral scanner (MSS) data was carried out on pre- and post-flood images for selected rivers: Mgeni, Mzimkulu, Mkomazi, Mdloti, Mvoti, Tugela, Mooi and Mhlatuze.

In false-colour images natural vegetation appears as a red-brown colour. Healthy, well-watered vegetation with a good aerial cover appears as bright red, and as the condition and cover deteriorates, the colour changes to red-brown and white. Recent sediment deposits also appear as white. Water appears as black or, with increasing turbidity, blue.

Visual interpretation was carried out by assessing catchment conditions along the river, measuring river width by counting the number of pixels and locating areas of erosion and deposition.

7.1.1 Mzimkulu River

This catchment covers 3 643 km^2 (at station T5M01 at Mzimkulu). It originates in the foothills of the Drakensberg, and its highest point is at 2 734 m. Forested areas occur in the western and central parts of the catchment. The river flows through the Transkei before entering the sea at Port Shepstone. See Fig. 7.1 and Photo 2.

(a) Catchment conditions

The edge of the images was near Dan Thai Lodge in the Underberg district. The catchment conditions appeared to be reasonably good on the slopes and hills, but poorer in the valley bottoms. The catchment appeared to be slightly degraded in parts of the Transkei.

(b) River widening

Significant widening of the river did not take place until the confluence with the Mpumulwane River where the width increased from 80 m to 160 m. At Mount Hermon it again increased to nearly 400 m. Inundation of the irrigated areas downstream occurred, creating an island. The river narrowed after this before widening to 320 m near Melrose. At Strangers Rest, the valley narrowed and the river was about 80 m wide at this point. After the confluence with the Bisi River, the river widened from 300 m to 480 m. Huge sandbanks formed after the Umkanyara Spruit confluence which effectively reduced the river width to 80 m. At the Oribi Flats, sand banks dimimished slightly although the river was still narrow (160 - 240 m). The river widened to 360 m at the confluence with the Mzimkulwana River and again at Port Shepstone.

(c) Sediment deposits

The first signs of erosion and deposition occurred at Pitout Falls, and after the confluence with the Bisi River. Sedimentation was found in the Tungwa River, as well as sand bars after the confluence. Sand bars stretching across the width of the river occurred after the confluence with the Umkanyara Spruit, and again at Gibraltar and Sunnyside. Deposition occurred after the confluence with the Mzimkulwana River. The sand bar at Port Shepstone, seen in the pre-flood image, was washed out to sea.

7.1.2 Mkomazi River

The catchment area above Station U1M03 comprises 4 375 km^2. It originates in the foothills of the Drakensberg near the Ngaqamadola Pass. Forests are found in the western and central parts of the catchment. The Mkomazi River passes through parts of KwaZulu. However, the only urban area it passes through is Umkomaas, at its outlet to the sea. The altitude in the catchment ranges from sea level to 3 314 m at Giant's Castle. See Fig. 7.1 and Photo 3.

(a) Catchment conditions

The edge of the image was at Brookland on the border of the districts of Mpendle, Underberg and Polela. The catchment appeared to be quite degraded throughout Polela but vegetation cover improved near Hill Top.

(b) River width

At Brookland the river was only 80 m wide. At KwaSambane it widened to 240 m and at Mdutshini, the inundation of the river banks led to the formation of an island. At KwaGengeshe the river width increased to 480 m and at Riverbank and Hella Hella to 560 m. At Otto's Kop and Greenvale, two islands were formed when the banks were inundated. The river width increased to 640 m. Comparison of the river course on the image with that on the 1: 250 000 maps (1976 and 1971) indicates that the course has changed considerably since the 1970's. However, this did not occur during these floods as the pre-flood images attest. River width varied between 160 and 480 m downstream of Greenvale. At Magabeni Water Works, inundation of the meander took place, almost cutting off the hill.

(c) Sediment deposits

The first signs of increased turbidity occurred after the confluence with the Elands River. Where the river widens at Hella Hella, increased turbidity was also observed. Large sand banks were distinguished between Greenvale and Hill Top and also after the confluence with the Mtungwane River. As the river gradient drops, the number of sediment deposits increased. As in the Mzimkulu River, the sand bar at the mouth of the river was washed away.

7.1.3 Mgeni River catchment

The catchment above the Inanda gauging weir (U2M15) covers 4 023 km^2. It is a mountainous catchment ranging in altitude from 1 687 m down to sea level. Three major dams are found in the catchment: Midmar, Albert Falls and Nagle. The major centres of population are Pietermaritzburg and Durban as well as parts of KwaZulu. Forested areas occur throughout the catchment. See Fig. 7.1 and Photos 4, 5 and 6.

(a) Catchment conditions

The interpretation of catchment conditions was based on vegetative cover. The catchment appeared to be in a good condition although areas of low vegetative cover were found in parts of KwaZulu. Poor cover and possible erosion was apparent in the Valley of a Thousand Hills and in the Msunduze catchment (U203).

(b) River widening

River widening occurred all along the course of the river, but particularly downstream of confluences and dams. Downstream of Nagle Dam, the river widened to 160 m and after the confluences with the Msunduze, Sikelekelheni, Mqeku and the Mkhelekeine tributaries, the river widened briefly to over 300 m in width. The Inanda Dam, which was low in the pre-flood image, widened to nearly 1 km.

Due to the river gradients and the steep channels, the river was highly erosive, as indicated by the loss of riverine vegetation in the post-flood image and by erosion within the channel. The latter feature was especially noticeable near the Msunduze confluence. Inundation of adjacent land was observed, in particular, above and below the Mgeni-Msunduze confluence and the Mgeni Island, in Durban. In general, all the riverine vegetation apparent on the pre-flood image of the Mgeni river had been removed by the floods.

(c) Sediment deposits

In general, two types of sedimentation took place: on the inside of river bends and at confluences. The first type was found near Salvo, just upstream of Inanda Dam and between Inanda Dam and the outlet to the sea at Durban. The second type was observed at the confluences with the Mkabela River, which runs through the Valley of a Thousand Hills, sometimes indicating sources of erosion. For example, in the pre-flood image of Midmar Dam, the water appeared to be black indicating that it was clear; in the post-flood image the water was a light blue colour suggesting that it was very turbid, except for a clear plume from the Mpofana and Mgeni rivers. This implies that most of the sediment was from Mphophomeni township and agricultural land on the southern banks of the dam. This entered the dam via the uGqishi and Nguku rivers. All the dams downstream of Midmar were very turbid, whilst the vleis and farm dams upstream were clearer.

7.1.4 Mdloti River - Hazelmere Dam

Sedimentation took place before and after the peak and large sand banks were formed. As a result the dam was very turbid. See Fig. 7.1 and Photo 7.

7.1.5 Mvoti River catchment

The Mvoti catchment covers 2 600 km^2 and originates west of Greytown. It ranges in altitude from 1 594 m down to sea level. Greytown and the virtual conurbation of Stanger/Melville/Groutville are the two major urban areas in the catchment. Forested areas are found in the western third of the catchment, KwaZulu areas in the central third and a coastal zone in the eastern third. See Fig. 7.1 and Photos 7 and 8.

(a) Catchment conditions

The Mvoti vlei and Merthley Dam appeared to be clear in the post-flood image and the catchments in good condition. The river was barely perceptible as it passed through the Mvoti vleis. However as it left the vleis, the turbidity increased. In a similar manner, the dams to the east and south of Greytown were more turbid than in the pre-flood images or to the western dams. The catchment conditions deteriorated as the river entered KwaZulu. After the confluence with the Mtize River, catchment conditions improved. Just after the confluence with the Dabango River, the southern bank appears to have collapsed. Catchment conditions deteriorated again after the Dabango confluence. The worst vegetation cover appeared to be on the south side of the river near Rio Grande.

(b) River widening

The river was about 80 m wide as it left the Mvoti vleis. At the confluence with the Mbalana River it widened to 160 m. At the Makeni confluence it doubled in width, and at the Faye confluence it was 480 m wide. The presence of sediment deposits after the Mapumulo confluence narrowed the river to 80 m but at the confluence with the Hlimbula River, the Mvoti widened to 320 m. After the confluences with the Nsuze and Dabango the river widened to 480 m before narrowing slightly to 240 m. As the river entered the coastal plain, it maintained an average width of about 240 m although the presence of large sandbanks effectively narrowed it. The banks, especially near Melville and Groutville, filled the valley bottom (1,14 km) to a width of 900 m.

(c) Sediment deposits

Increased turbidity and the deposition of sandbanks occurred at most confluences. At times these deposits stretched across the full width of the river, for instance at the Mtize, Makeni and the Dabango confluences, and between Dabango and Melville. All along the coastal plain sand banks were formed as the flow decreased.

7.1.6 Confluence of the Tugela and Mooi rivers

In the pre-flood image the Tugela River was a green colour. This indicated that it was probably carrying red soils. In the post-flood image it was a sky-blue colour suggesting that the water was turbid. According to the colour on the image, the Mooi River was much clearer than the Tugela. The presence of sediments on the inside of the bends indicate that it had already dropped most of its sediment load prior to entering the Tugela River. The Mooi River was 160 m at the confluence compared to the Tugela, which was 240 - 320 m wide. At the confluence, catchment conditions appeared to be moderately good. See Fig. 7.1 and Photo 8.

7.1.7 Mhlatuze River catchment

The catchment covers 2 408 km^2 (at Station W1M09) and its source is at Mount Babanango (1 608 masl). Forested areas are found in the central and coastal zones, whilst the major centres of population are Melmoth, Empangeni and Richards Bay. Most of the catchment lies within KwaZulu. See Fig. 7.1 .

(a) Catchment conditions

Vegetation cover appeared to be in a reasonable condition in the upper reaches of the Mhlatuze.

(b) River widening

The river only became discernable at the confluence with the Gologodo River at Riversmeet. Its width was approximately 80 m until just south of Spelonk where it doubled in width.

(c) Sediment deposits

South of Spelonk and west of Llangwe, sandbanks were noted on the post-flood image. Goedertrouw Dam was turbid along its entire length. Comparison to the pre-flood image showed that only the upstream half of the dam was turbid. In the agricultural areas below the dam sandbanks were formed along the length of the river.

7.1.8 Conclusions

Analysis of LANDSAT imagery provided a synoptic view of catchments affected by the Natal floods of September 1987.

Since the scenes were adjacent, the images were comparable in terms of acquisition date. One problem with the data was that the pre- and post-flood images were not taken at the same time of the year.

The turbidity of the rivers and dams, in conjunction with the evidence of deposition within the flood plains suggests that a considerable amount of erosion took place within all the catchments. The Mgeni, Mkomazi and Mvoti catchments showed the greatest amount of sediment production.

The maximum river width was found in the Mvoti, where sediment and river combined to a width of 1,14 km. The Mhlatuze, on the other hand, achieved a maximum width of 160 m. The river width is attributable to not only the topography but also the amount of rainfall. The isohyets of the flood indicated that the maximum rainfalls were at the headwaters of the Msunduze and Mlazi, or further down the catchment as in the case of the Nseleni, Mzimkulu and Mkomazi.

7.2 River course changes

River course changes are generally not problematic along undisturbed reaches. The problems only arise when, in the design of civil engineering structures, the natural high-flood course of the river has been ignored.

Two bridges that failed due to changes of the river course during high floods were the Edendale bridge across the Msunduze River (Photo 37) and the N2 bridge across the Mdloti River (Photo 49). In both instances the approaches of the bridges were severely breached.

These approaches were constructed across the natural high flood channel of the river. This obstruction of the channel coupled with contraction at the bridge greatly increased the flow velocities at the approaches and through the bridge itself (increasing the waterhead upstream of the bridge). The result was scouring of the approaches that commenced at the bridge itself and then progressed along the approaches until the river had re-established its natural high-flood channel configuration.

At the Mdloti River bridge the natural high-flood channel to the north was blocked by the construction of the approach. Chapter 7.4 will deal with the damage observed at selected bridges.

The changes of river courses that were witnessed during the Domoina floods of 1984 on the Mfolozi flats were repeated, fortunately to a lesser extent, in September 1987. During the 1984 floods the Mfoloze River reverted to its old course before it joined the Msunduzi River at its mouth at St. Lucia. The capacity of the rerouted Mfolozi River channel is 1 100 m^3/s, the peak flows during the floods of 1984 and September 1987 were 16 000 m^3/s and 4 500 m^3/s respectively.

Photo 10 shows the change in the course of the Lovu River upstream of the N2 road crossing at Scottsburgh. The shift to the south has cut off the old channel from the river: this is typical of a river flowing through a well developed alluvial flood plain. The movement of the main thalweg is approximately 300 m to the south.

Photo 15 is a sequence of aerial photographs of the Mhlatuze River at Site 80 after the floods of February 1977 and September 1987. It is evident from these photographs that the river is increasing the radius of the bend on which the gauging weir and the bridge is located. This has major implications for both structures if the scouring were to be repeated during future floods. The weir may be cut off from the river, as was the case at W1M05 (Site 78) on the Mfuluzone River (Photo 66) where the weir was buried under rocks and sand and the river made a new channel on its right side. Weirs W1M05 and W1M09 are both sited on bends in rivers. The bridge at W1M09 may have its right approach and abutment jeopardized if the scour continues. Surface geology at these sites indicate only a clay soil profile for the right bank of the river. Photos 67 and 70 show the condition of the right bank at the weir and the slope-area site.

7.3 River cross-section changes

7.3.1 Changes in cross-section geometry of natural rivers (erosion) (Fig. 7.1.1 to 7.1.9) show the cross-section changes at various sites which were observed after the floods, and at four sites the condition one year later. Table 7.1 lists the erosion and sedimentation observed at five sites surveyed prior to the September 1987 floods. The dates of the comparative sections are given in the table.

Table 7.2 shows the response of four of the monitored rivers to the September 1987 floods and their condition one year after the floods. These rivers were surveyed in August 1987, October 1987 and August 1988.

From Tables 7.1 and 7.2 it appears that river channel adjustment in post-flood sections is mainly lateral. The lateral adjustment varied from 54% (Site 80) to 134% (Site 44) in the rivers which experienced their most extreme floods in recent times. Sites in northern Natal did not show large increases in their lateral dimensions due to the degree of scour caused by the Domoina floods of 1984 (6). The lateral scour in 1987 was around 2-3% in most cases. The Mfolozi River flood peak of 4 500 m^3/s was well within the limit of the river's current channel and thus aggregation is dominant in this case (see Photo 73). Site 3 on the Mtamvuna River showed a narrowing of the main channel when compared to 1959 sections. This may be attributable to the nature of the river banks. This is also the only site surveyed that showed a significant scour of the river bed (2,77 m).

TABLE 7.1: RESPONSE OF RIVER CHANNELS TO THE SEPTEMBER 1987 FLOODS

Flood data	Mtamvuna	Mtwalume	Mkomazi	Mvoti	Black Mfolozi
Site no.	3	10	15	44	90
Catchment area (km^2)	715	565	4 375	2 473	3 396
Flood peak (m^3/s)	1 470	850	6 900	5 000	1 740
Rainfall volume ($10^6 m^3$)	170	350	1 810	1 240	890
Approximate flood volume ($10^6 m^3$)	62	97	920	620	222
Average channel data					
Date of comparative survey (month & year)	6/1959	8/1986	-/1985	3/1913	8/1987
Increase of mean channel width (m)	- 7,6	1,3	61	59	2,4
% increase of the channel width	- 18	2	88	13	2
Post flood channel width(m)	35	64	130	103	109
Change in bed level(m)	-2,77	-0,15	0,4	10,27	-0,16
Area scoured in a section (m^2)	118	24	251	271	44
Area filled in a section (m^2)	19	4	33	16	9
Nett scour or fill (m^2)	- 99	- 20	-218	- 255	- 35

Lateral erosion as observed by local inhabitants along the Tugela River was 30 m (14%) at Site 61 (see Photo 58), and 50 m (23%) at Site 73.

TABLE 7.2: RESPONSE OF FOUR MONITORED RIVERS TO THE SEPTEMBER 1987 FLOODS AND RECOVERY ONE YEAR LATER

Flood data	Mhlatuze	White Mfolozi	Mfolozi	Mkuze
Site no.	80	86	91	97
Catchment area (km^2)	2 409	4 776	9 216	2 647
Flood peak (m^3/s)	3 600	2 150	4 500	1 060
Rainfall volume (10^6m^3)	1 050	1 180	2 530	436
Approximate flood volume (10^6m^3)	409	236	583	174
Average channel data				
Date of comparative survey (month/year)	8/1987	8/1987	8/1987	8/1987
Increase of mean channel width (m)	26	3	5	2
Post flood channel width (m)	75	115	152	102
% increase of the channel width	54	3	3	2
Change in bed level (m)	0,45	-0,02	0,10	0,19
Area scoured in a section (m^2)	96	82	85	36
Area filled in a section (m^2)	28	82	186	13
Nett scour or fill (m^2)	- 68	0	+101	-23
Mean sediment diameter (mm)	0,27	0,60	0,35	0,42
Recovery of the river channels one year later(survey 8/1988), relative to the post September 1987 flood survey				
Increase of bed level (m)	-0,48	0,06	0,05	-0,04
Area scoured in a section(m^2)	94	67	46	15
Area filled in a section (m^2)	8	50	58	15
Nett scour or fill (m^2)	- 86	- 17	12	0

7.3.2 Lateral erosion in estuaries

Table 7.3 is derived from data taken from aerial photographs of four estuaries (Photos 9-11 and 48). Conclusions for the surveyed sites outlined above may be assumed to be valid for these river estuaries. Lateral erosion at the estuaries varied from 73% to 213%. On the Mkomazi River the lateral scour upstream was 88% compared to the 73% average at the estuary. The Mvoti experienced lateral scour of 134% at the upstream site and 213% at the estuary.

TABLE 7.3: COMPARISON OF PRE- AND POST-FLOOD CHANNEL WIDTHS IN FOUR ESTUARIES

Flow parameters		Mkomazi	Lovu	Mgeni	Mvoti
Catchment area	(km^2)	4 390	940	4 432	2 829
Flood peak	(m^3/s)	6 900	1 800	5 300	5 400
Flood volume	($10^6 m^3$)	920	223	850	708
Storm volume	($10^6 m^3$)	1 810	447	1 890	1 420

For the position of width measurement, distances given are measured from the mouth(m). Points of reference such as bridges are also indicated.

	Mkomazi	Lovu	Mgeni	Mvoti
Pos. no. 1.	Mouth	Mouth	Mouth d/s of bridge	Mouth
Pre-flood	96	180	188	168
Post-flood	192	225	385	510
Pos. no. 2.	480 m (island)	400 m at bridge	530m island	1 000m
Pre-flood	198	126	84	84
Post-flood	240	246	305	297
Pos. no. 3.	1 300m	1 200m u/s of N2	1 250m u/s of island	2 200m
Pre-flood	93	33	74	54
Post-flood	207	75	160	150
Pos. no. 4.	2 000m d/s of N2	------	1 930m d/s of Connaught	-----
Pre-flood	90	-----	48	-----
Post-flood	186	-----	155	-----
Mean values				
Pre-flood channel width (m)	119	113	99	102
Increase of channel width (m)	87	69	153	217
% channel width increase	73	61	154	213
Maximum width inundated in reach (m)	354	915	410	1 140
Maximum % increase in flow width	197	710	314	1 018

7.3.3 September 1987 channel erosion vs April 1856 and May 1959.

During the April 1856 floods the Mgeni River channel widened from 62 m to 215 m. This represents an increase in width of 239%. If the rainfall for the Durban area in April 1856 is compared with that of September 1987, the flood volume in 1856 can be estimated to have been around 1 $150*10^6 m^3$ if similar runoff factors are applied as those of 1987 when the flood volume was 850 $*10^6 m^3$. The lateral scour in 1856 was 85% more than that observed in 1987. The Mgeni River was reportedly scoured in depth to such an extent that boulders and rock were exposed. At the Mvoti River the channel width increased by about 300% in 1856 (9).

Photos 12 and 13 show the relative condition of the Mzimkulu- and Mkomazi rivers after the 1959 and 1987 floods. From these scenes it is clear that both rivers suffered more extensive scour in 1987. The flood peaks in both rivers were approximately similar in 1959 and 1987 but the 1987 floods had a larger flood volume. For the Mkomazi River the flood volume in 1987 was 920 $*10^6 m^3$ and in 1959 the volume was 306 $*10^6 m^3$. The mean channel width in the Mzimkulu River after the 1959 flood was 70 m and in 1987 it was 94 m. For the Mkomazi River the post-flood (1959) width was 63 m and in 1987 it was 91 m.

Photo 14 shows the condition of the Mlazi Canal after the 1959 and 1987 floods. It is evident that the outlet suffered more damage and scour during the September 1987 flood (Photo 29).

7.3.4 Conclusions on channel erosion

From Tables 7.1, 7.2 and 7.3 it is obvious that rivers adjust mainly in a lateral direction if floods exceed the channel capacity. Bed scour in unrestricted natural channels is relatively minor if the banks are erodible. If banks show a resistance to scour, then bed scour along with a rise in water level will accomodate the increased flow. Photos 9-11, 21-22, 36, 41, 42, 45, 53, 58, 67, 70 and 72 show bank erosion and lateral scour at various sites.

From the observations on channel erosion the following conclusions may be made :

- Lateral erosion is the main source of channel enlargements.

- Erosion of the channels may also be the largest source of sediment discharge in rivers that have not suffered a large flood in recent times.

- Flood volume is the major control for lateral and general scour of a river channel.

- A higher flood peak may however increase the rate at which scour is occurring.

- Time scales for scour are short.

7.3.5 Sediment load volume due to channel erosion

Table 7.4 gives rough estimates of the sediment volume discharged in rivers resulting from channel erosion during the September 1987 floods.

The Tugela ($42,78 x 10^6 m^3$), Mkomazi ($19,6 * 10^6 m^3$), Mgeni ($16,7 * 10^6 m^3$) and the Mvoti ($11,8 * 10^6 m^3$) rivers had the largest volume of soil scoured from their channels. These values are only approximations and are based on the length of the reach in which scour was observed.

In the Mgeni River scour was only evident downstream of Nagle Dam. Photos 35, 41, 44-45, 47-48 show the conditions of the Mgeni River downstream of Nagle Dam. Conditions upsteam of Nagle Dam indicate relatively little scour (Photo 31). Most of the sediment for the upper reaches of the Mgeni originated from the catchment itself in the form of surface erosion, gully erosion and landslides (Photos 32 and 34).

TABLE 7.4: SEDIMENT VOLUMES DISCHARGED IN RIVERS AS A RESULT OF CHANNEL EROSION

Site	River	Catchment area (km^2)	Flood volume ($10^6 m^3$)	Surveyed sediment volume scoured at measurement point ($10^3 m^3$)	Total surveyed sediment volume derived from channel erosion for upstream catchment ($10^6 m^3$)	Adjusted total surveyed sediment volume derived from channel erosion for upstream catchment (see note below) ($10^6 m^3$)	% Sediment per volume of water from channel erosion (%)
3	Mtamvuna	715	62	99	1,98	1,29	2,08
10	Mtwalume	565	97	20	0,85	0,55	0,57
15	Mkomazi	4 375	920	218	30,10	19,60	2,12
	Lovu	940	223	138	9,32	6,06	2,72
	Mgeni	4 432	850	604	25,70	16,70	1,96
44	Mvoti	2 473	620	255	18,10	11,80	1,90
74	Tugela	28 920	1 440	213	79,21	42,78	1,75
80	Mhlatuze	2 409	297	68	1,87	1,22	0,41
90	Black Mfolozi	3 396	222	35	2,89	1,88	0,85
97	Mkuze	2 647	174	23	2,21	1,44	0,83

Note: The surveyed sediment volumes were adjusted using a voids ratio of 0,54 (silty sand). This made provision for the voids present in the scoured bank material.

The severe erosion in the sugar-cane fields (Photo 55), and the landslides (Photo 56) observed in the lower Mvoti River valley were also evident in the Tugela River valley in the areas around Site 73.

Sediment concentrations (of sediment resulting from channel erosion) averaged between 0,5% and 2,7% of the water volume with the mean being 1,49%. When compared to the rough estimates of total sediment concentration calculated at the dams (Chapter 7.5), this means that 60% of the discharged sediment is derived from erosion of the river channels, which is similar to what was observed for the Sacremento River in the USA (37). This 60% is, however, only an averaged value for the various sediment concentrations (Site 34b Henley Dam was excluded).

Table 7.5 shows the suspended sediment (silt and clay) concentrations observed at some sites during the flood. The mean suspended load for normal low flows are for conditions before and after the flood. It is evident that the suspended sediment loads may increase more than 10 times during extreme floods.

TABLE 7.5: SUSPENDED SEDIMENT LOADS

Site	River	Suspended sediment concentration (% of volume) Mean load at at low flows	 Mean load	 Peak load	Maximum % increase of load at peak above normal
1	Mzimvubu	0,0032	0,0149	0,0383	1 096
2	Mtamvuna	0,0007	0,0126	0,0364	5 100
8	Mzimkulwana	0,0126	0,0186	0,0305	142
10	Mtwalume	0,0018	0,0185	0,0351	53
11	Fafa	0,0150	0,0302	0,0758	405
12	Mpambanyoni	0,0081	0,0556	0,1031	1 173
18b	Nungwana	0,0101	0,0128	0,0155	53
20	Mlazi	0,0008	0,0082	0,0155	1 838
21	Mlazi	0,0035	0,0340	0,0645	1 743
26	Mgeni	0,0009	0,0023	0,0038	322
32	Mgeni	0,0045	0,0159	0,0273	507
36	Msunduze	0,0124	0,0416	0,0707	470
41	Mdloti	0,0236	0,0441	0,0647	174
51	Tugela	0,0044	0,0269	0,0493	1 020
52	Klip	0,0191	0,0653	0,1115	484
61	Tugela	0,0028	0,0159	0,0289	932
73	Tugela	0,0009	0,0153	0,0297	3 200
80	Mhlatuze	0,0005	0,0234	0,0464	9 180
85	White Mfolozi	0,0037	0,0078	0,0119	222
89	Black Mfolozi	0,0056	0,0102	0,0148	164

7.3.6 Post-flood recovery of scoured channels

The recovery of the rivers is currently being monitored. Fig. 7.2.5-6 and 7.2.8-9 show the recovery at four of the monitored sites. The results shown in Table 7.2 indicate further scour at Sites 80 and 86. This is mainly due to the scour of the material that was still collapsing into the channel during the survey in October 1987. The floods that followed in February 1988 scoured away this material as well as causing further scour to the bases of the steep river banks. The increased bed level observed during the October 1987 survey proves to a certain extent that collapsed material was still in the channel.

Prior to the September 1987 floods all the rivers monitored after the Domoina floods (1984) showed a decrease in channel dimensions. This recovery of the channel, though modest, could rather be described as an adjustment of the river channel to carry low flows more efficiently. The scour observed at the rivers in 1987 was mostly in the main channel.

Observations made at the old South Coast road bridge crossing the Mkomazi River showed a marked decrease in the main channel width of the river during long periods of low flow. These observations, started in 1875, showed that the river had a width of 50 m before the 1959 floods. After the 1959 floods the width was 90 m. In 1961 this width was 55 m and decreased even further to 17 m in 1985. After the floods of 1987 the width was 90 m (30).

The recovery of the channel is a function of the sediment supply from the catchment, hydrological conditions, vegetational recovery and long enough time scales (38). The recovery observed at the Mfolozi River and at other rivers where the river channels narrowed during periods of low flows suggests that rivers adjust their widths as the flow varies by river bank and flood plain formation. The pattern indicating the long time scales is well illustrated by the observation at the Mkomazi River.

7.3.7 Bed sediment

Table 7.6 shows the basic bed sediment properties of the monitored sites. Fig. 7.3 shows the grading curve envelopes for the sediment. It was observed that the coarser material was mostly deposited in the faster flowing and deeper sections of the main channel and along outer bends.This distribution was valid for the samples taken both before and after the floods.

It is evident that the pre-flood envelopes are narrower and have a more uniform grading. This is due to the washing out of the fines and the more constant low discharges that were present at the sites during pre-flood surveys. The post-flood sediment is more a mixture of sediment from the catchment and the river channel and thus has a broader envelope and a non-uniform grading. The range of the post-flood fineness modulus (FM-indicates the distribution of sediment grain size) is also indicative of the distribution of the sediment grading.

TABLE 7.6: SEDIMENT ANALYSIS AND GRADING

River	Site no.	Sample date	Mean sediment diameter (mm) Range	Mean sediment diameter (mm) Mean	FM-fineness modulus Range	FM-fineness modulus Mean	Relative density RD
Mhlatuze	80						
Section 1		8/1987	0,37-0,41	0,39	1,8-1,9	1,9	2,65
		10/1987	0,13-0,31	0,22	0,4-1,6	1,3	2,67
Section 2		8/1987	0,31-0,42	0,37	1,6-2,0	1,9	2,66
		10/1987	0,24-0,42	0,33	1,2-2,1	1,6	2,65
White Mfolozi	86						
Section 1		8/1987	0,40-0,46	0,43	1,9-2,1	2,0	2,69
		10/1987	0,26-0,89	0,58	1,1-1,7	1,4	2,65
Section 4		8/1987	0,34-0,42	0,38	1,6-2,0	1,8	2,69
		10/1987	0,31-0,94	0,63	1,3-1,8	1,5	2,67
Mfolozi	91						
Section 1		8/1987	0,10-0,46	0,28	0,2-2,0	1,2	2,65
		10/1987	0,06-0,80	0,43	0,8-1,6	0,9	2,62
Mkuze	97						
Section 1		8/1987	0,31-0,47	0,39	1,4-2,2	1,9	2,69
		10/1987	0,29-0,46	0,38	1,5-2,2	1,9	2,67
Section 4		8/1987	0,27-0,39	0,33	1,3-1,9	1,8	2,66
		10/1987	0,46-0,49	0,48	2,2-2,3	2,2	2,70

7.4 Erosion at bridges

Appendix 3 lists the damage the high flood level relative to the deck, the return period category and the peak (if calculated) at 31 bridges.

Damage at the bridges can be categorised as follows:

- Scour of abutment and approach fills = 12 (Photos 65, 75 and 76)
- Breach and scour of approaches = 14 (Photos 18, 33, 37 and 49)
- Damage or loss of main structure = 8 (Photos 18,26,37,49 and 62)

Failure or damage of the bridges was caused by

- Scour and breaching of approach or abutment fill (inadequate protection).
- Scour of piers and piles.
- Loading by debris and water of main structure.
- Alteration of river courses.

Refer to (44) and (53) for a more detailed description of some of the failures that occurred.

7.5 Dam sedimentation

Table 7.7 lists the sedimentation surveyed in four dams after the September 1987 floods. A first approximation of the sediment concentration was calculated by using the Brune curve (16). The use of the Churchill curve was not possible due to short retention times (16).

No sedimentation was surveyed at Nagle Dam downstream of Site 32. The diversion weir upstream of Nagle Dam (built to divert floods and silt) lost 42% of its original capacity due to sedimentation. The original capacity of 2,046 * $10^6 m^3$ was reduced to 1,183 * $10^6 m^3$ and the weir was very effective in diverting sediment past the reservoir.

In Photo 16 (a and b) the sedimentation of the delta at Hazelmere Dam on the Mdloti River during the September 1987 flood, is clearly shown relative to the conditions in 1978. The end of the delta that was previously at Section 10 in 1978, was moved to Section 7 (Sections are shown in Photo 16a). The delta silted up for a distance of 1 000m.

Table 7.8 shows similar analyses to those in Table 7.7 for other reservoirs during the 1981 floods in the South-Western Cape and the 1984 floods in Natal. The Brune curve was used on the data collected at these sites for uniformity of calculation. It is important to note that Tables 7.7 and 7.8 are only a first approximation of the sediment volumes. The consolidation of the sediment in the reservoir is not yet satisfactory for a more accurate assessment (16).

From Tables 7.7 and 7.8 it is clear that sediment concentrations were generally higher for the 1987 floods than for the 1984 floods in Natal. A possible explanation is the time of year that these floods occurred. The 1984 floods occurred in the second half of the rainy season and therefore the catchments had a good vegetal cover, whereas the 1987 flood occurred at the start of the rainy season.

It is also noted that the dams in the higher and smaller catchments show a low concentration of sediment in relation to the other dams. This is true for the 1984 and 1987 floods in Natal if the values for the Klipfontein Dam (1984) and Henley Dam (1987) are considered.

The sediment concentrations for the 1981 floods compare well to those for the 1987 floods even though the catchments are totally different. These tables and sediment concentration may aid designers to evaluate the possible loss of capacity in a reservoir due to extreme floods.

From Tables 7.4, 7.5 and 7.7 the average total sediment load was 2,49% of the flood volume. Scour of the river channels contributed 60% of the sediment and catchment erosion 40%.

TABLE 7.7: SEDIMENTATION IN FOUR RESERVOIRS

Dam	Nshongweni	Henley	Hazelmere	Goedertrouw
River	Mlazi	Msunduze	Mdloti	Mhlatuze
Station number	U6R01	U2R05	U3R01	W1R01
Catchment area (km^2)	803	238	381	1 273
Original capacity (10^6m^3) and date	12,061(1927)	5,867(1960)	23,901(1975)	317,860(1982)
Capacity before floods (10^6m^3) and date	7,232(1960)	5,512(1983)	22,914(1979)	315,420(1984)
Capacity after floods (10^6m^3) and date	5,208(1987)	5,407(1987)	19,223(1987)	304,105(1987)
Total surveyed sediment volume in reservoir below the full supply level (FSL) (10^6m^3)	6,853	0,460	4,678	13,755
Total surveyed sediment volume in reservoir including deposits above FSL (10^6m^3)	8,119	0,461	5,950	13,809
Total surveyed sediment volume below FSL as a percentage of original capacity (%)	56,82	7,84	19,57	4,33
Sediment surveyed volume below FSL since previous survey (10^6m^3)	2,024	0,105	3,691	11,315
Total surveyed sediment volume in reservoir since previous survey including deposits above FSL (10^6m^3)	2,654	0,106	4,963	11,369
Surveyed sediment volume below FSL since previous survey as a percentage of total sedimentation (%)	29,53	22,83	78,90	82,26
Inflow peak (m^3/s)	1 416	620	1 826	3 759
Total inflow (10^6m^3)	91,7	45,4	157,0	230,2
Surveyed sediment volume below FSL since previous surveys as a percentage of the total inflow (%)	2,25	0,23	2,35	4,92
Total surveyed sediment volume since previous survey including deposits above FSL as a percentage of total inflow (%)	2,95	0,23	3,16	4,94
Mean velocity in reservoir during peak (m/s)	0,48	0,30	0,44	0,22
Mean retention time (seconds)	4 821	8 890	12 549	81 273
Sedimentation index, Churchill (m/s^2)	10 043	29 634	28 520	369 424
Capacity/Inflow ratio	0,079	0,121	0,146	1,37
Percentage sediment trapped in reservoir using the Brune curve (%)	84	89	92	100
Total surveyed sediment volume - Brune (10^6m^3)	3,160	0,119	5,395	11,369
Adjusted sediment volume (see note below) (10^6m^3)	1,928	0,073	3,290	7,390
Mean sediment concentration - Brune (%)	2,10	0,16	2,10	3,21

Note: Total sediment volume adjusted using a voids ratio of 0,39 (sand). This compensated for the lack of consolidation and voids present in the deposits.

TABLE 7.8: SEDIMENTATION IN RESERVOIRS FOR THE 1984 DOMOINA FLOODS AND THE JANUARY 1981 FLOODS IN SOUTH-WESTERN CAPE

Dam	Goedertrouw	Klipfontein	Hluhluwe	Pongolapoort	Pietersfont.	Prins River	Floriskraal
River	Mhlatuze	W. Mfolozi	Hluhluwe	Pongolo	Keisie	Prins	Buffels
Station no.	W1R01	W2R02	W3R01	W4R01	H3R02	J1R01	J1R03
Catchment area (km^2)	1 273	340	516	7 831	166	757	4 001
Capacity before flood (10^{6}m^3)	317,86	18,99	29,66	2 500,91	2,50	2,39	58,47
Total surveyed sediment volume since previous survey (10^6 m^3)	2,44	0,02	2,52	55,66	0,54	1,26	9,22
Date of survey before flood	1982	1983	1978	1973	1979	1979	1977
Date of flood	1/1984	1/1984	1/1984	1/1984	1/1981	1/1981	1/1981
Inflow peak (m^3/s)	1 900	1 090	2 940	13 000	---	1 030	5 740
Outflow peak (m^3/s)	0	980	1 800	1 480	576	1 030	4 620
Flood inflow volume (10^{6}m^3)	153	102	126	2 105	19	59	145
Capacity/Inflow volume ratio	2,08	0,19	0,25	1,19	0,13	0,04	0,40
% sediment trapped -Brune curve	100	91	92	98	90	73	96
Total surveyed sediment volume (10^{6}m^3)	2,44	0,02	2,74	56,80	0,60	1,73	9,60
Adjusted total sediment volume (see note below Table 7.7) (10^{6}m^3)	1,49	0,01	1,67	34,65	0,37	1,06	5,86
Sediment concentration % - Brune curve	0,97	0,01	1,33	1,65	1,93	1,79	4,04

8. CONCLUSIONS AND SUMMARY OF RESULTS

Survey

- Rainfall at 224 points.
- Flood measurements in 59 rivers.
- Flood peaks at 106 sites.
- Reservoir basin flood level survey at two sites.
- Erosion surveys at four monitored sites.
- Bridge damage survey at 31 bridges.
- Sedimentation surveys at five dams.

Rainfall

- The flood-generating storm was the result of an upper air cut-off low combined with an anticyclonic pressure system.
- The main area of precipitation was the coastal belt stretching inland some 50 to 80 kilometres.
- The heaviest and most widespread rain fell between 28 September (08h00) and 29 September (08h00).
- The derived areal reduction factors indicate that the storm of September 1987 - up to 5 000 km^2 - produced a higher percentage of the maximum point rainfall than did the storm resulting from Cyclone Domoina. Over 5 000 km^2 the Domoina rainfall was higher.
- The areas where the catchment rainfall was 80% or more of the 3-day PMP correspond to the regions of high rainfall.

Flood peaks

- The valid Francou-Rodier "K_e" was not exceeded at any of the sites.
- In terms of "K" the largest peaks were:

Site	River	Catchment area (km^2)	Flood peak (m^3/s)	Francou-Rodier "K"
14	Mkomazi	4 349	6 900	5,05
39	Mgeni	4 023	5 500	4,86
41a	Mdloti	380	1 830	4,95
44	Mvoti	2 473	5 000	5,01
45	Nonoti	157	1 160	4,94
46	Zinkwazi	28	400	4,81
74	Matigulu	583	3 170	5,23
77	Mhlatuze	1 273	3 760	5,05
78	Mfuluzone	45	790	5,11
79	Mfule	618	3 300	5,24
82	Nseleni	547	4 250	5,49

- The maximum mean velocity was 5,5 m/s at Site 27 on the Mgeni River downstream of Howick.

- Surface waves of between 2 and 5 m were observed.

- The flood peaks of the September 1987 flood were the highest on record at 34 sites (Appendix 2).

- At 25 sites the return period of the flood peak was 50 years or more.

Flood volumes and runoff factors

- At the Mkomazi River the flood volume was $920*10^6 m^3$ (Site 15), with a runoff percentage of 51%. At the Mgeni River the flood volume was $850*10^6 m^3$ with a runoff percentage of 48%.

- A plot of the runoff percentage against the storm rainfall revealed that between 50 and 100 mm of rain was necessary before runoff began.

- The often poor distribution of rain gauges, and inaccuracies in weir calibration curves may be responsible for the lack of a significant relationship between runoff percentage, storm and antecedent rainfall and catchment characteristics.

Erosion and sedimentation

- LANDSAT imagery is useful when assessing the global effect of extreme floods in catchments and rivers.

- Changes in river courses during extreme floods need more consideration when designing civil engineering structures.

- Lateral erosion of up to 134% were measured in natural river channels and 213% in estuaries.

- Vertical erosion was minor in undisturbed river channels.

- Channel erosion contributed 60% of the sediment load in rivers that have not experienced an extreme flood in recent time.

- Suspended sediment loads may increase more than tenfold during floods.

- Goedertrouw Dam had the largest sediment volume deposited in a reservoir.

- The capacity of Nshongweni Dam has decreased by 57% since its construction.

- The average sediment load was 2,5% of the flood volume.

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FIG. 1.1 AREA OF FLOOD DOCUMENTATION

a

b

c

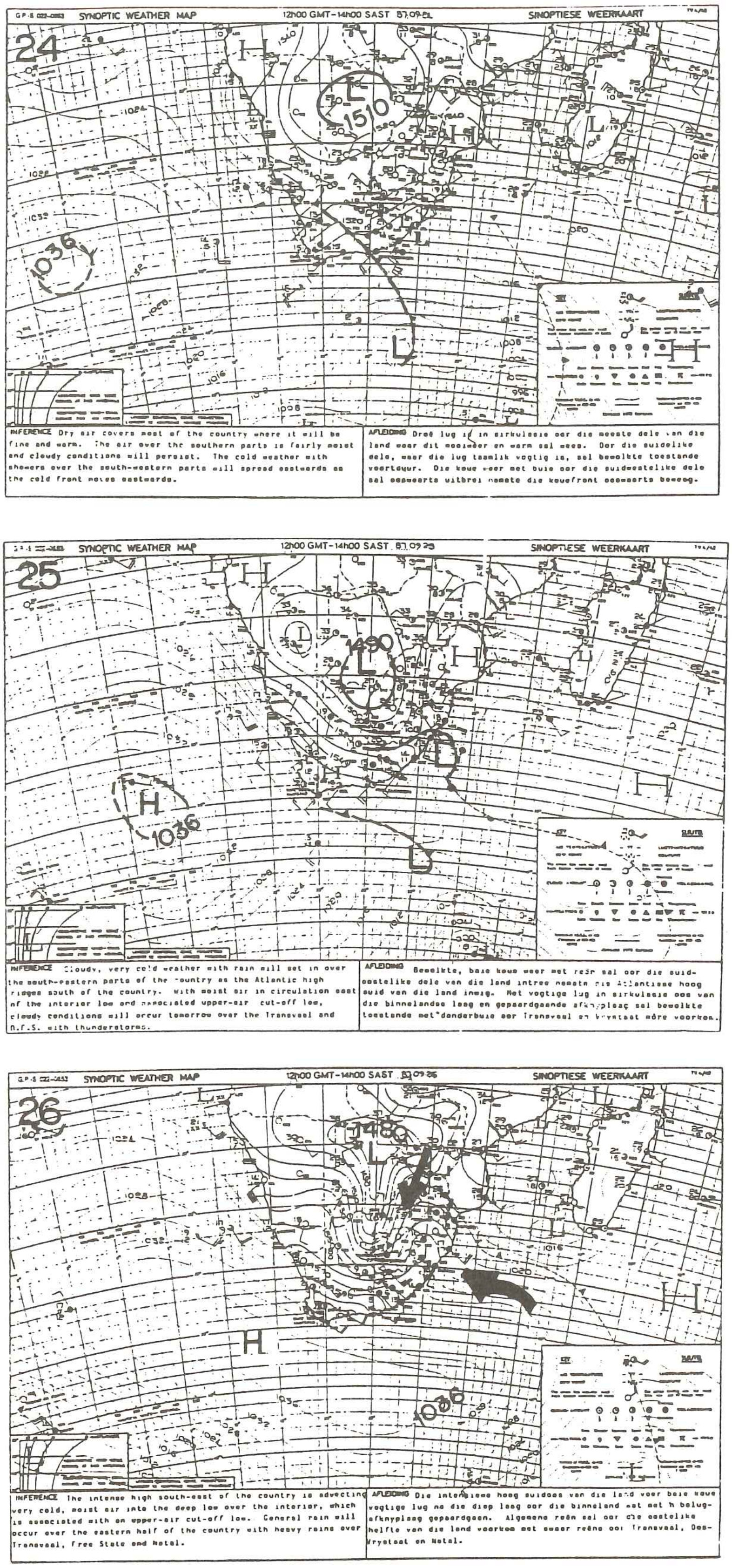
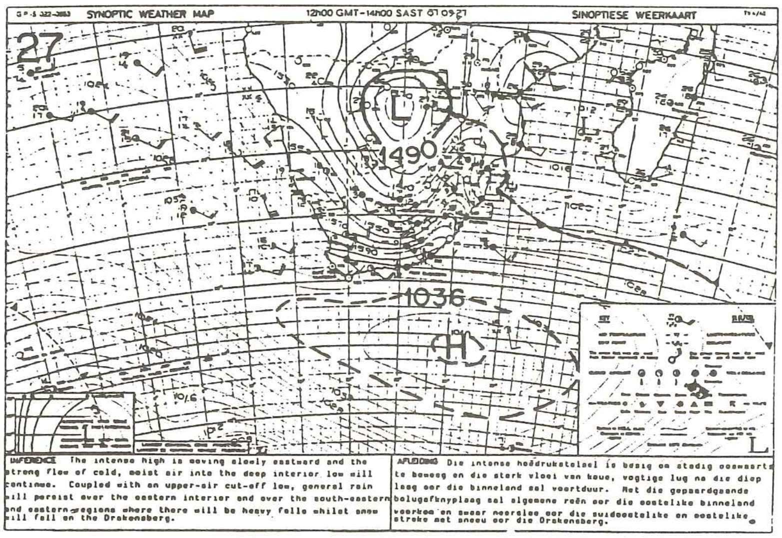
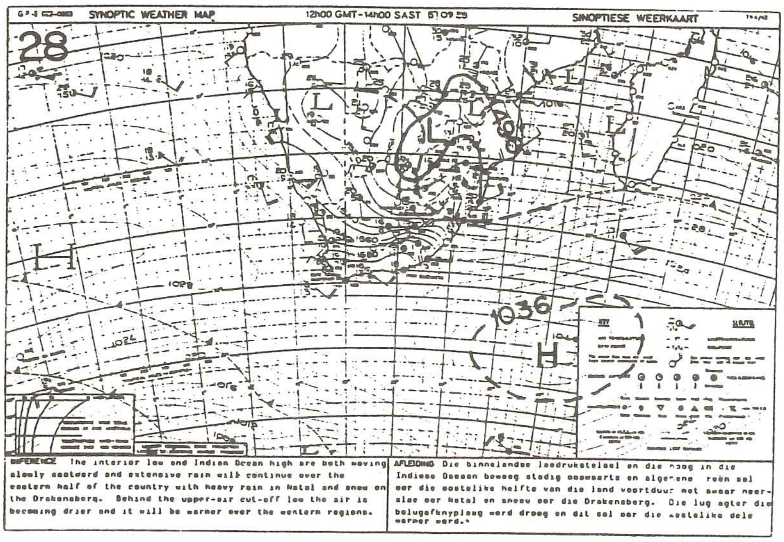


FIG. 2.1 (a–c) DAILY SYNOPTIC CHARTS

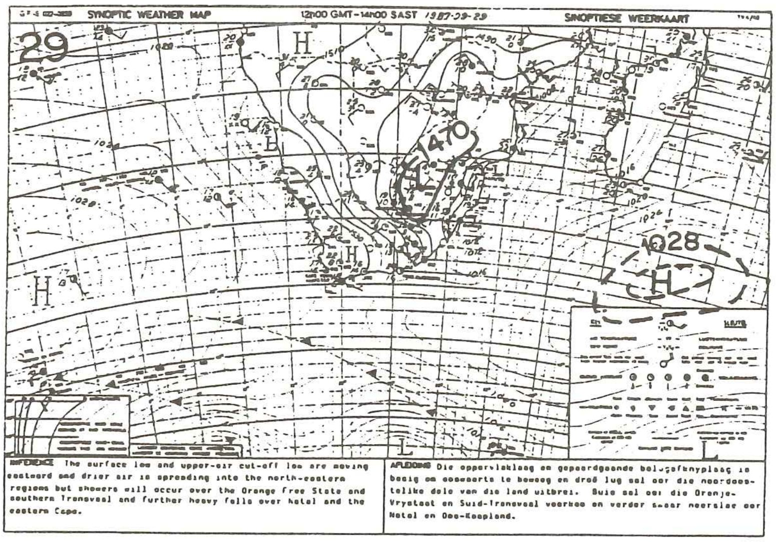
(24th–26th September 1987)



d

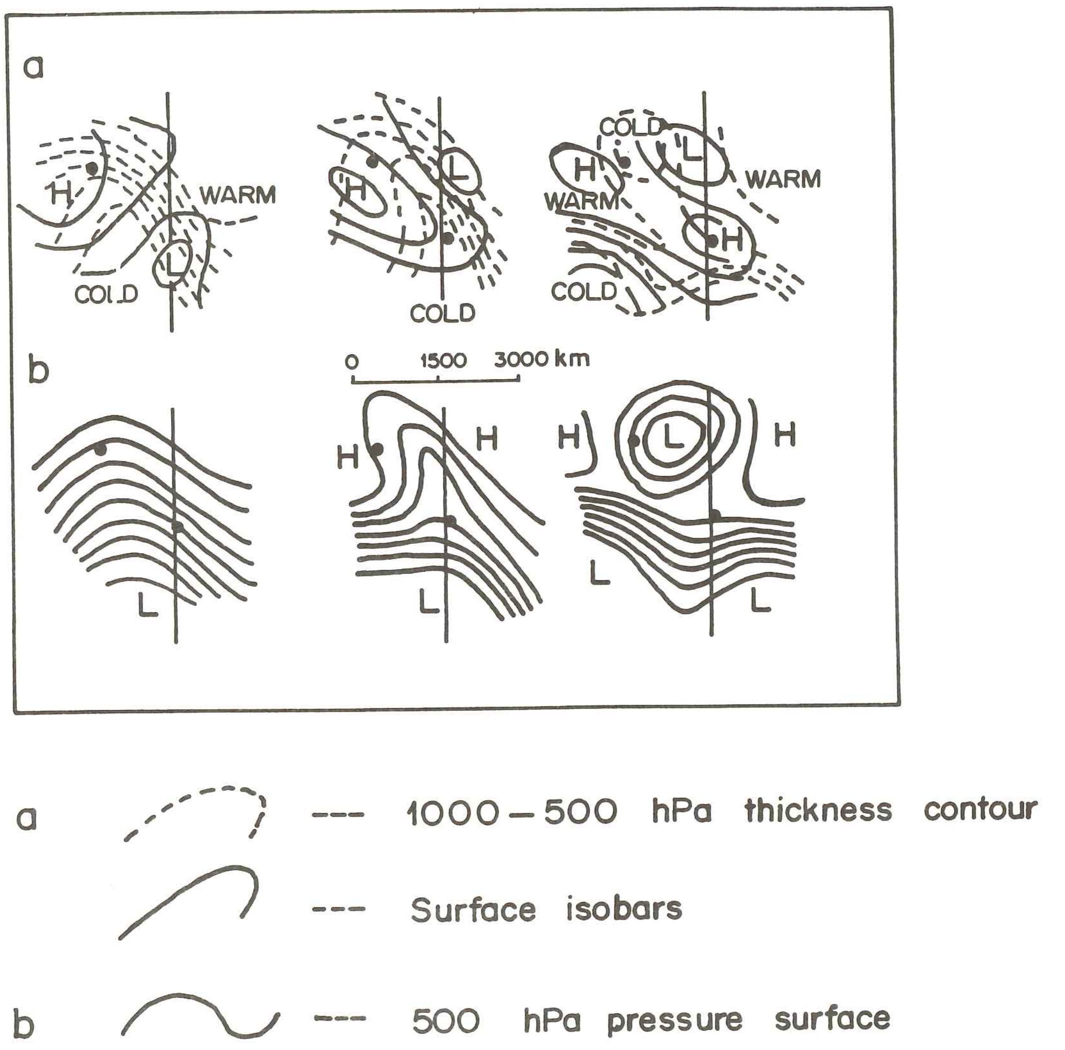


e



f

FIG. 2.1 (d–f) DAILY SYNOPTIC CHARTS (27th–29th September 1987)



REFERENCE (2)

FIG. 2.2 ANTICYCLONIC WAVE DISRUPTION

FIG. 2.3 RAINFALL OBSERVATION POINTS

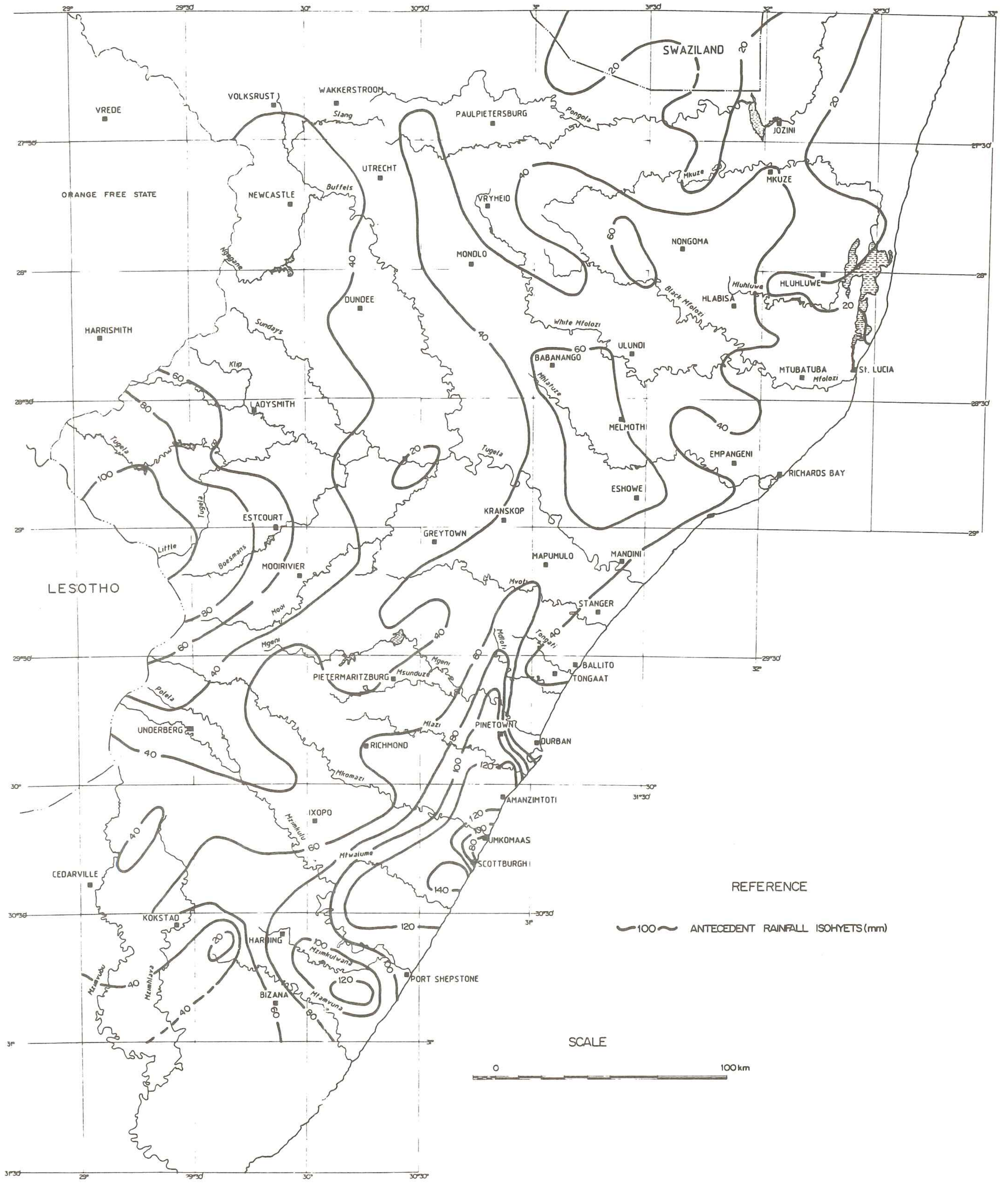


FIG. 2.4 14-DAY ANTECEDENT RAINFALL, 11th – 25th SEPTEMBER 1987 (08h00)

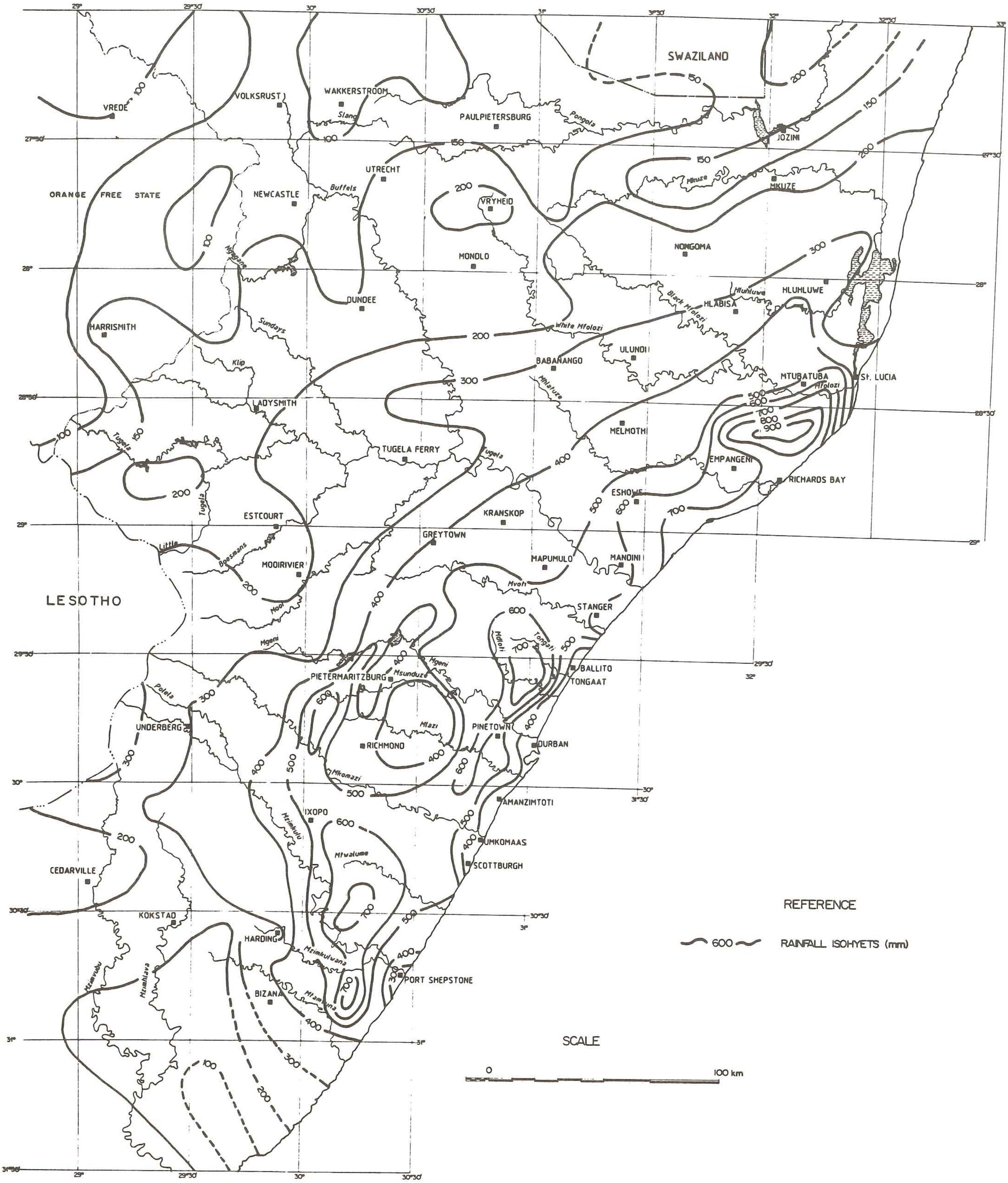


FIG. 2.5 ISOHYETAL MAP OF STORM RAINFALL, 25th – 30th SEPTEMBER 1987 (08h00)

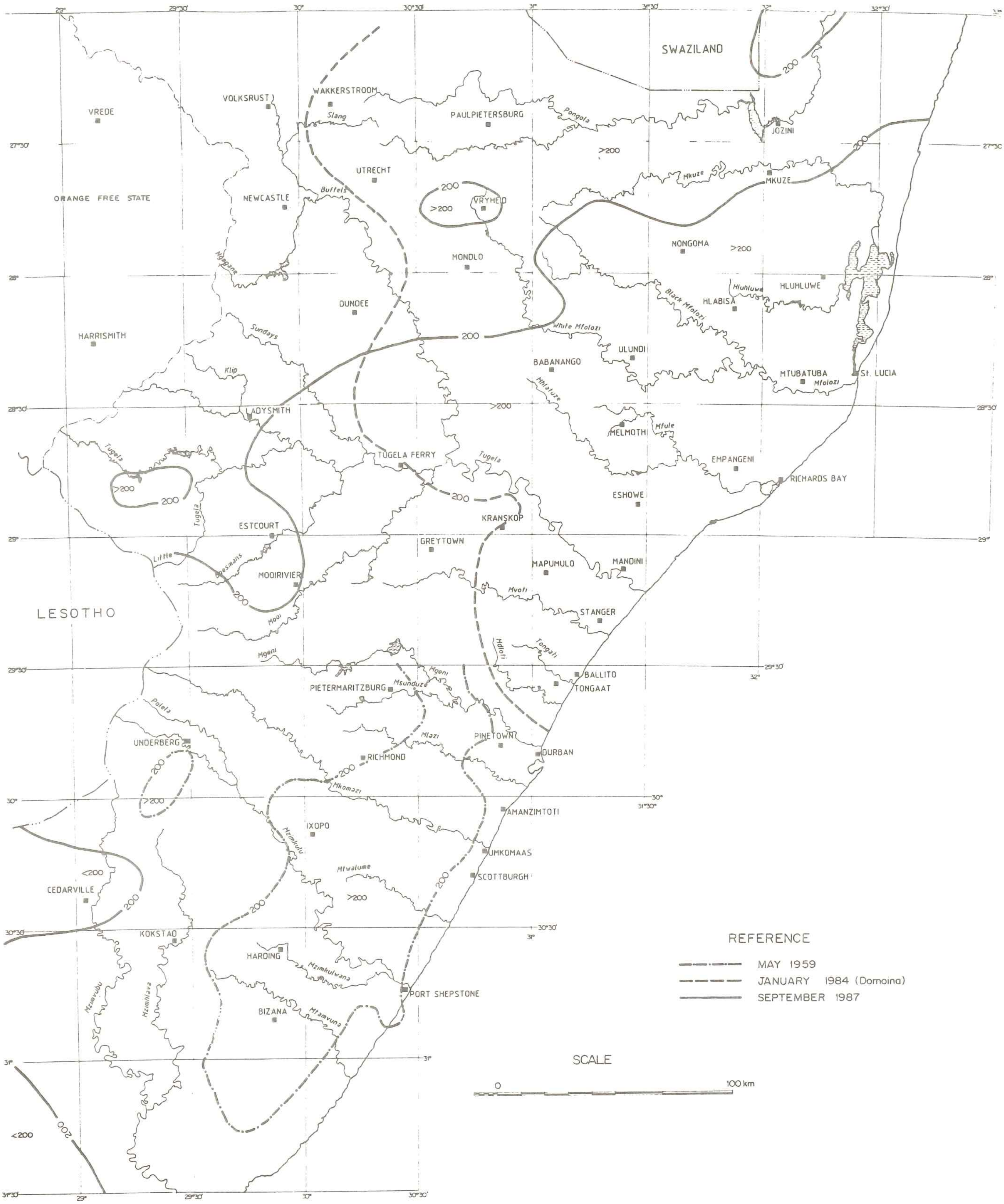


FIG. 2.6 COMPARISON OF AREAS THAT EXPERIENCED >200mm RAINFALL DURING THE STORMS OF 1959, 1984 AND 1987

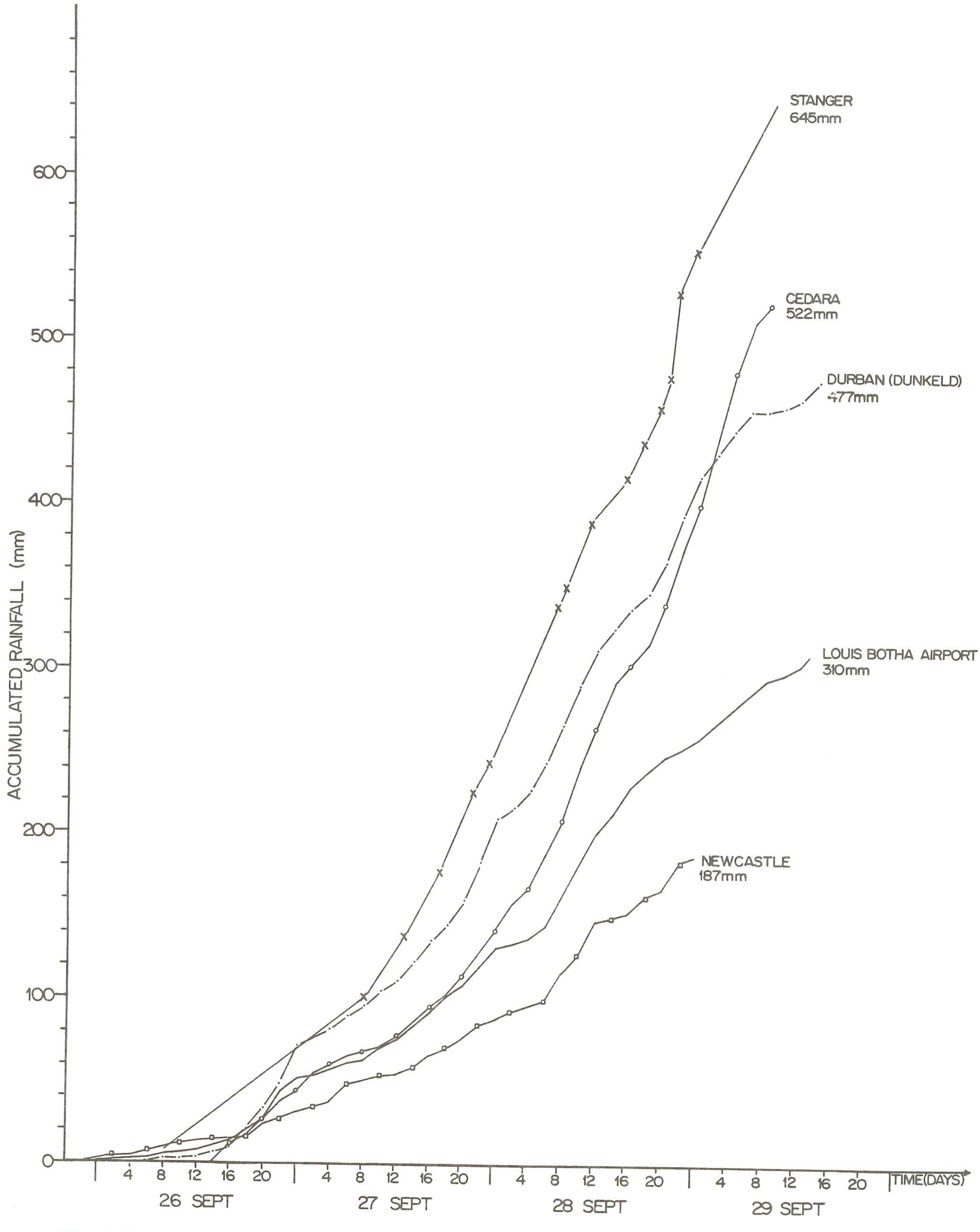


FIG. 2.7 ACCUMULATED RAINFALL AT SELECTED STATIONS

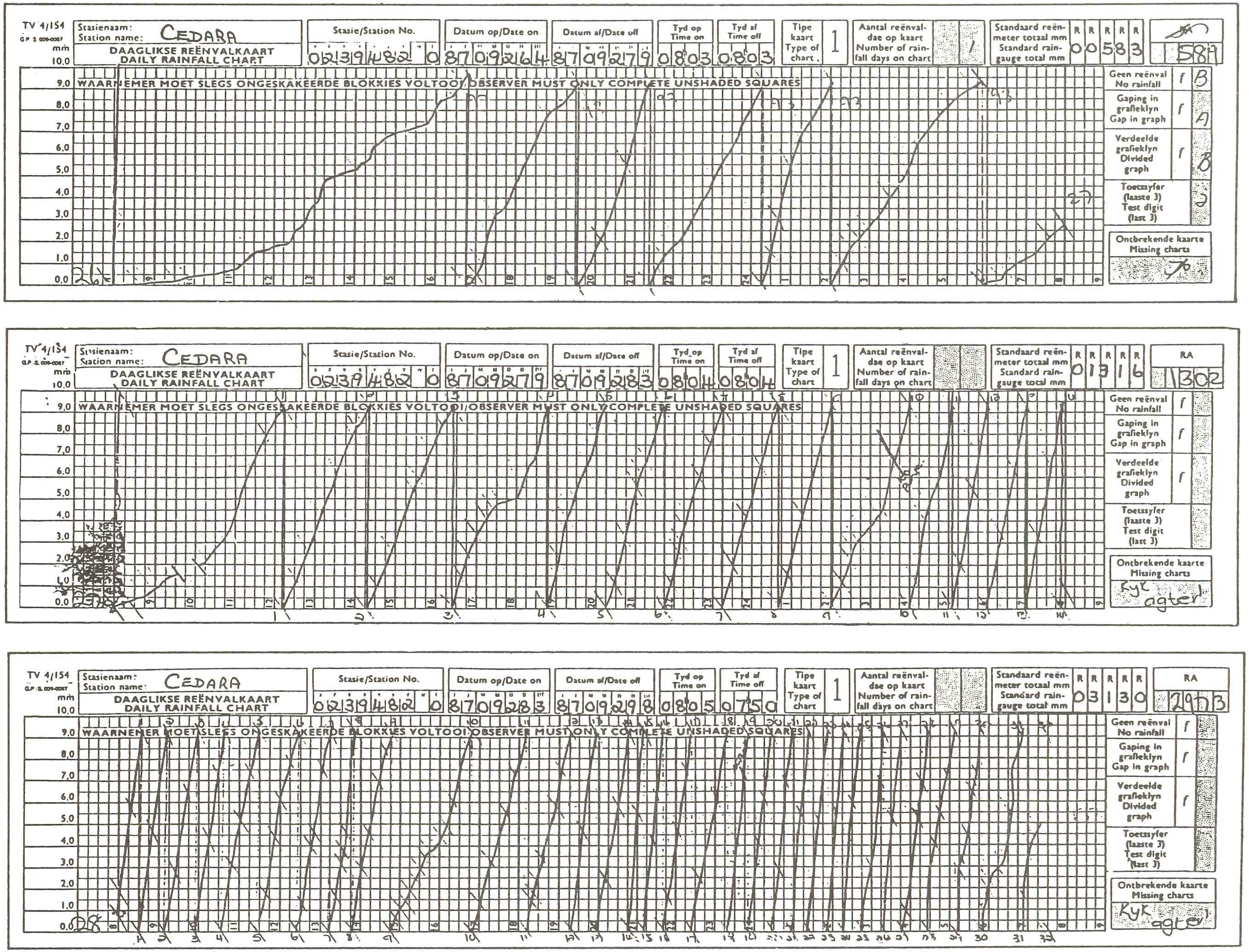


FIG. 2.8 AUTOGRAPHIC RAINFALL RECORD : CEDARA 26th–29th September, 1987

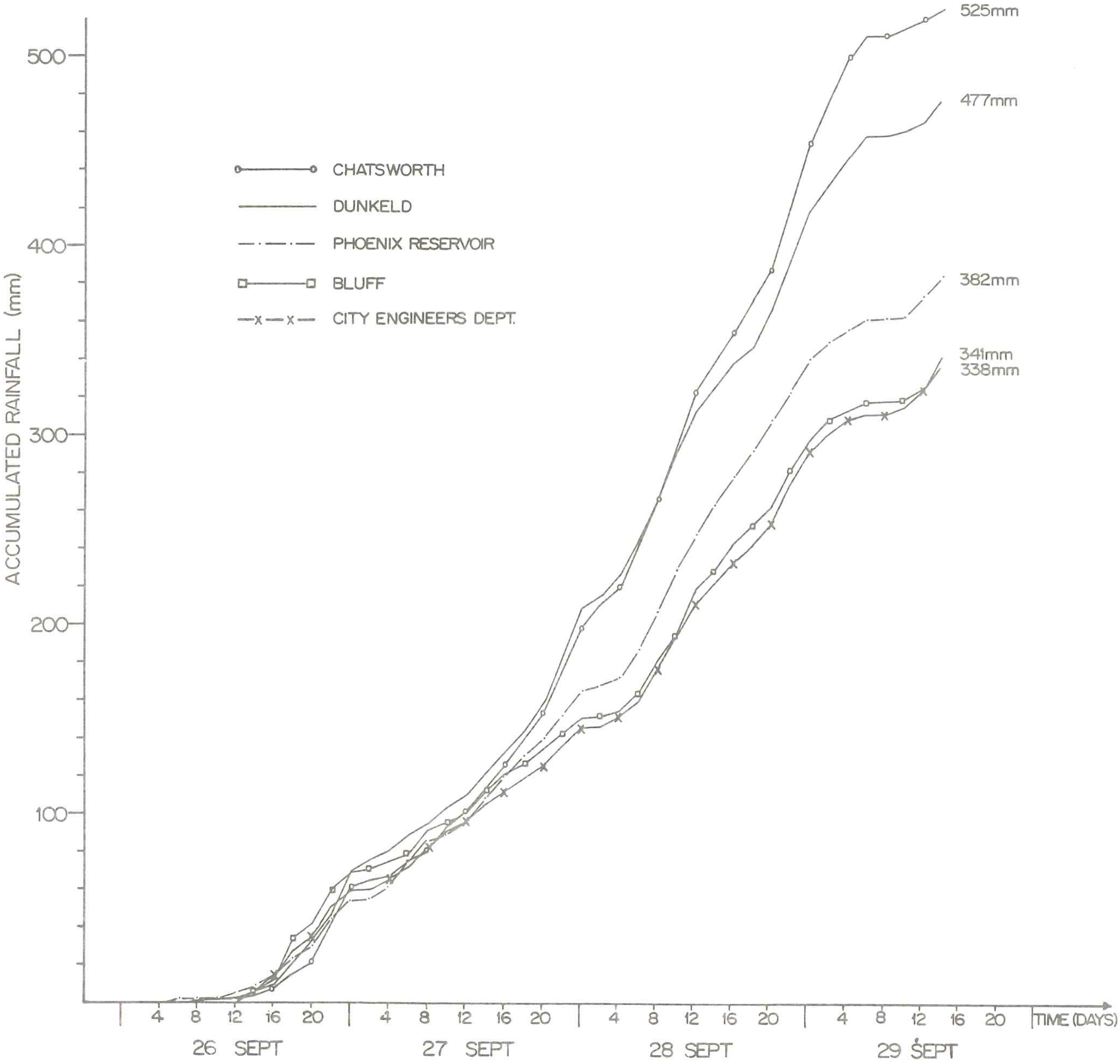


FIG. 2.9a ACCUMULATED RAINFALL FOR SELECTED STATIONS IN DURBAN

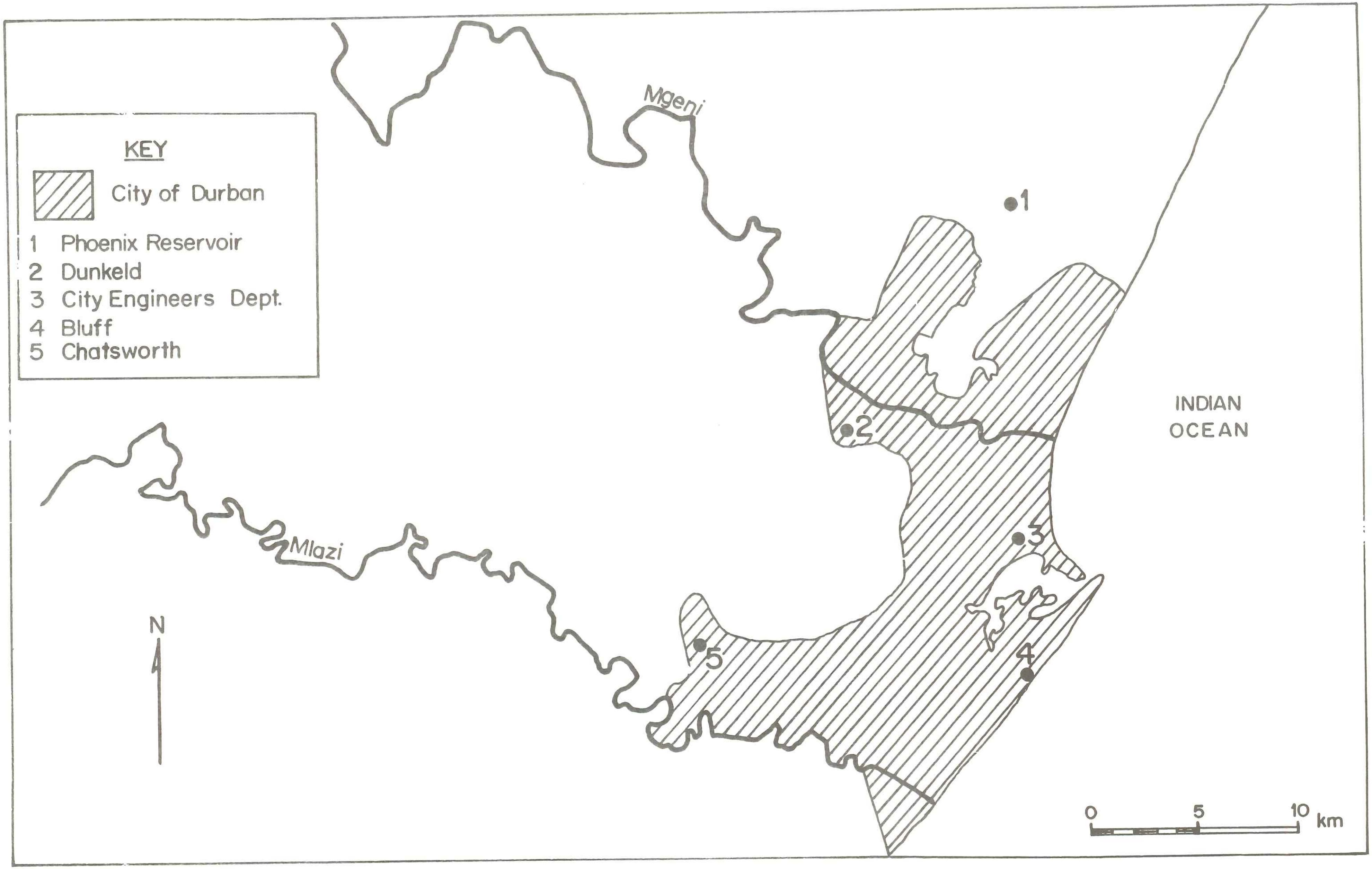


FIG. 2.9b LOCATION OF SELECTED RAINFALL STATIONS IN DURBAN

FIG. 2.10 AREA WHERE THE 3-DAY RAINFALL DURING THE STORM OF SEPTEMBER 1987 EXCEEDED THE 3-DAY 200 YEAR POINT RAINFALL

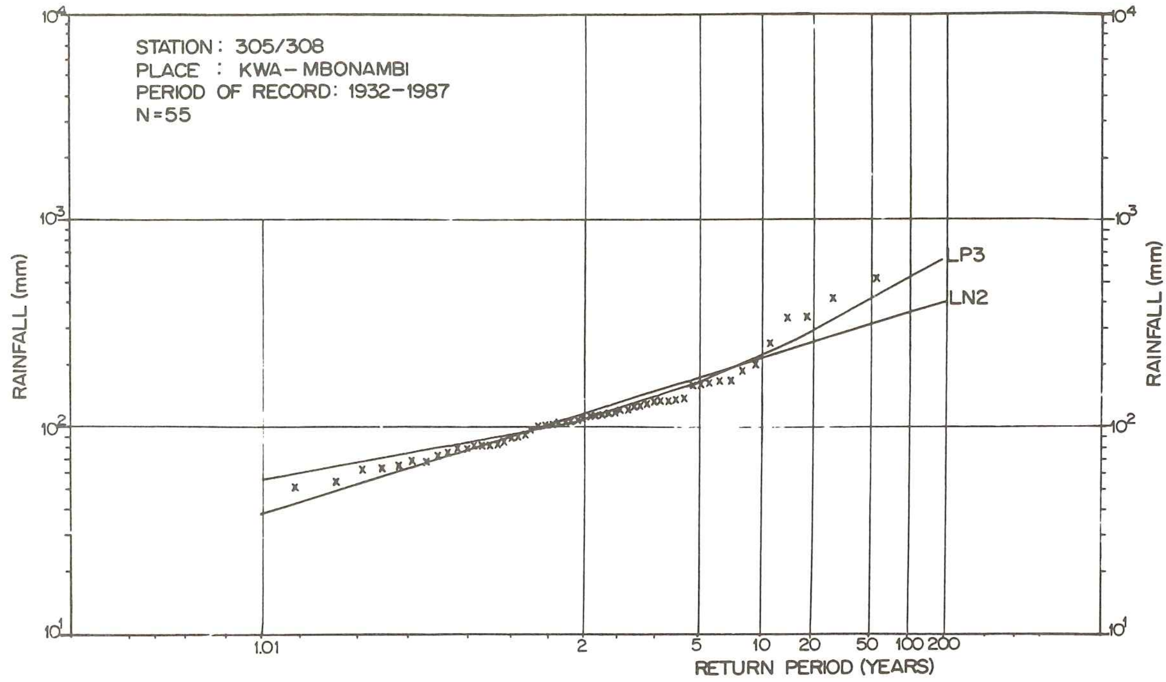


FIG. 2.11a ANNUAL MAXIMUM 1-DAY RAINFALL

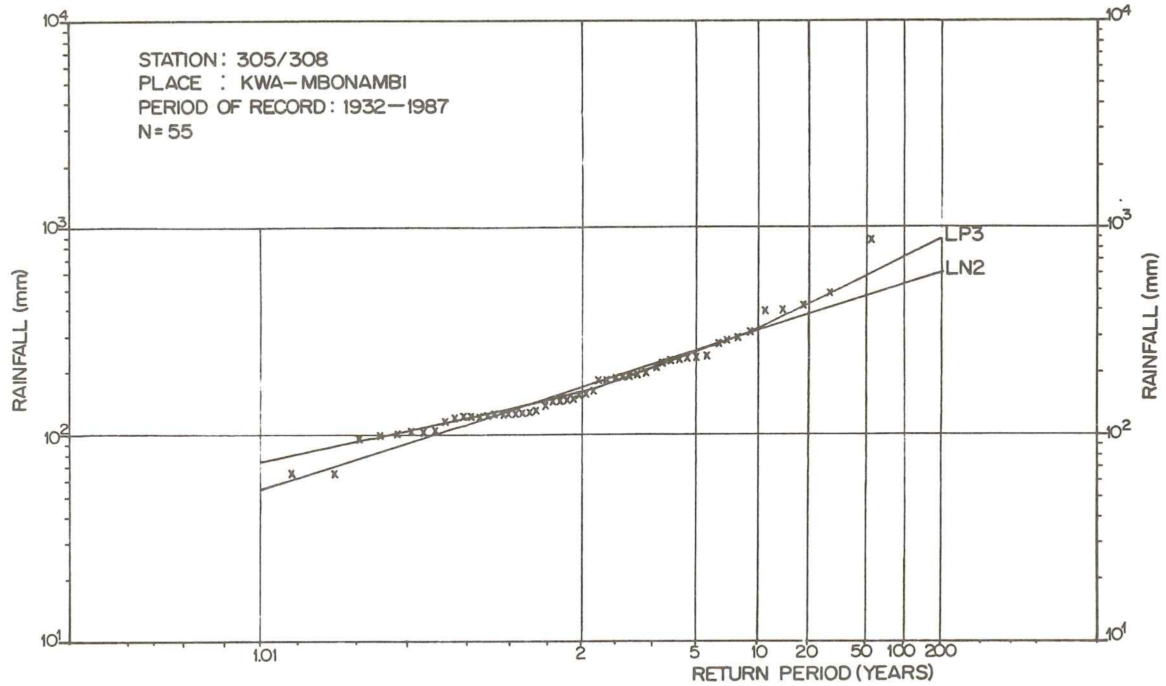


FIG. 2.11b ANNUAL MAXIMUM 3-DAY RAINFALL

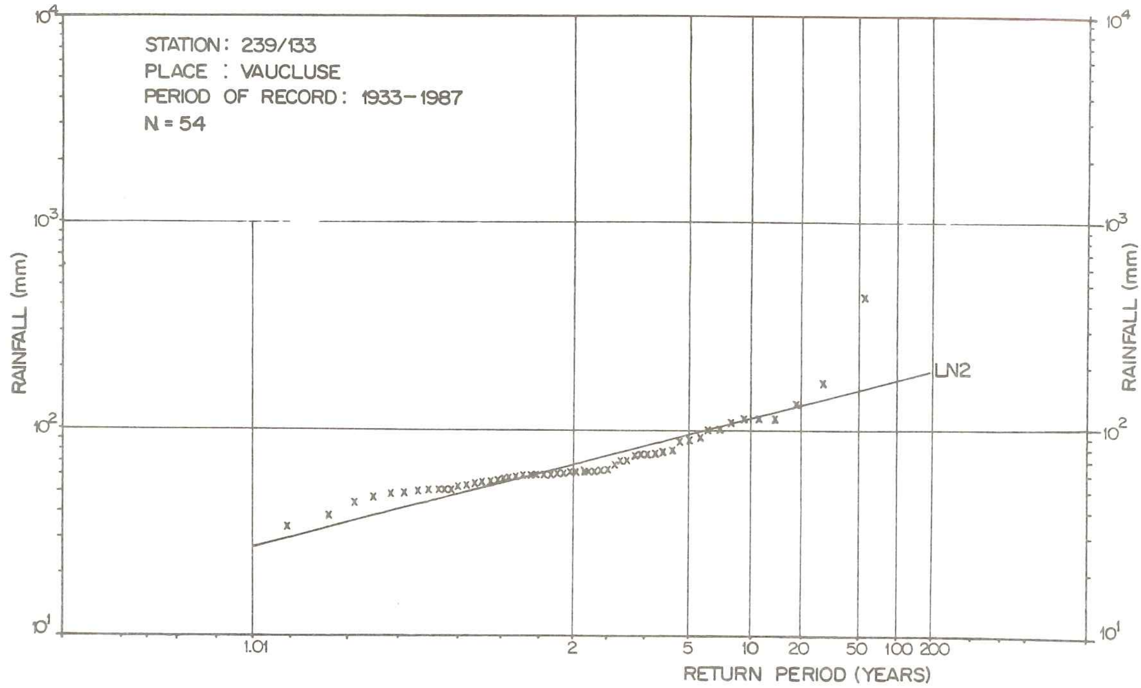


FIG. 2.11c ANNUAL MAXIMUM 1-DAY RAINFALL

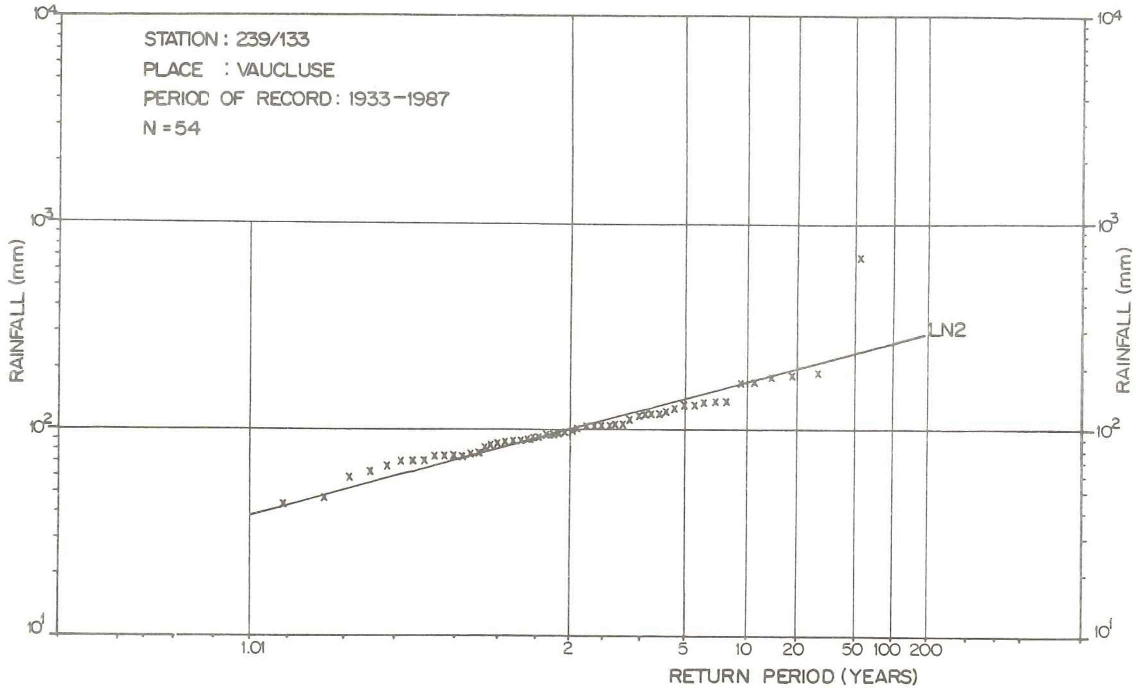


FIG. 2.11d ANNUAL MAXIMUM 3-DAY RAINFALL

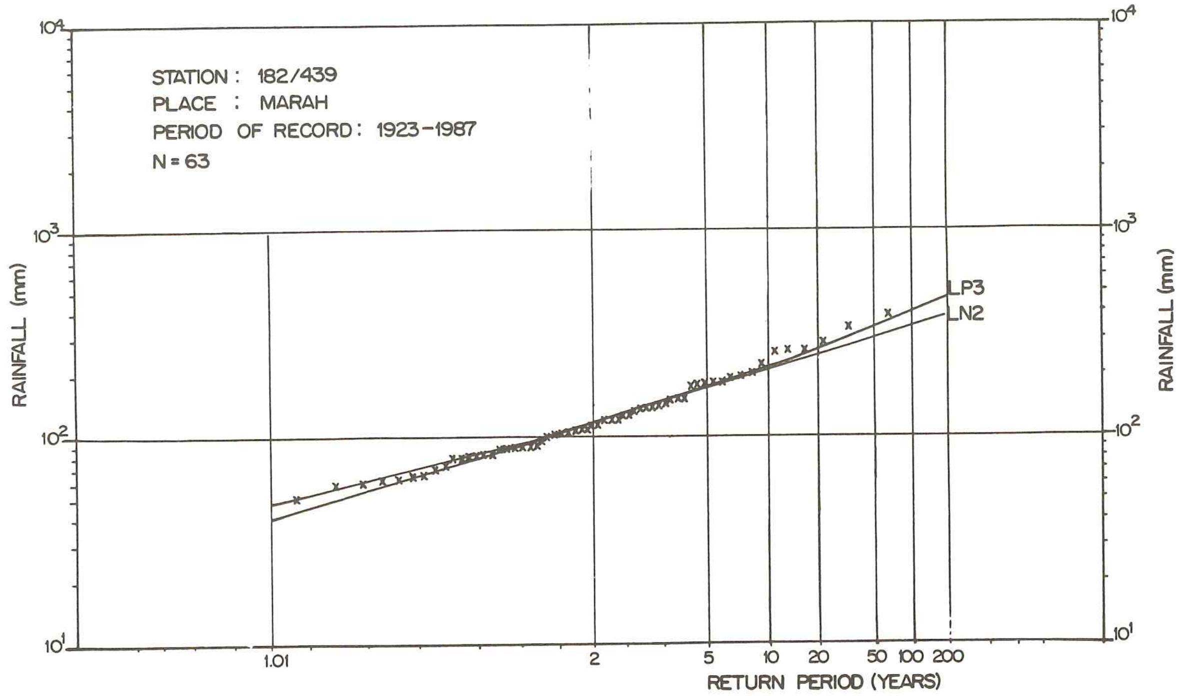


FIG. 2.11e ANNUAL MAXIMUM 1-DAY RAINFALL

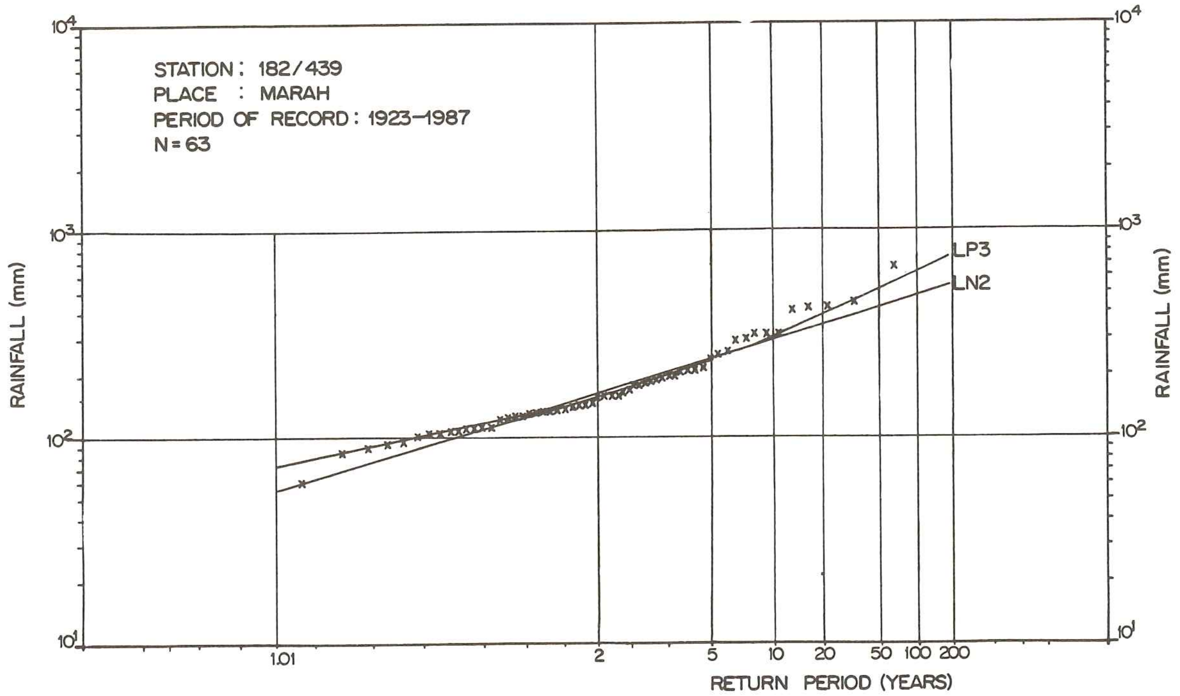


FIG. 2.11f ANNUAL MAXIMUM 3-DAY RAINFALL

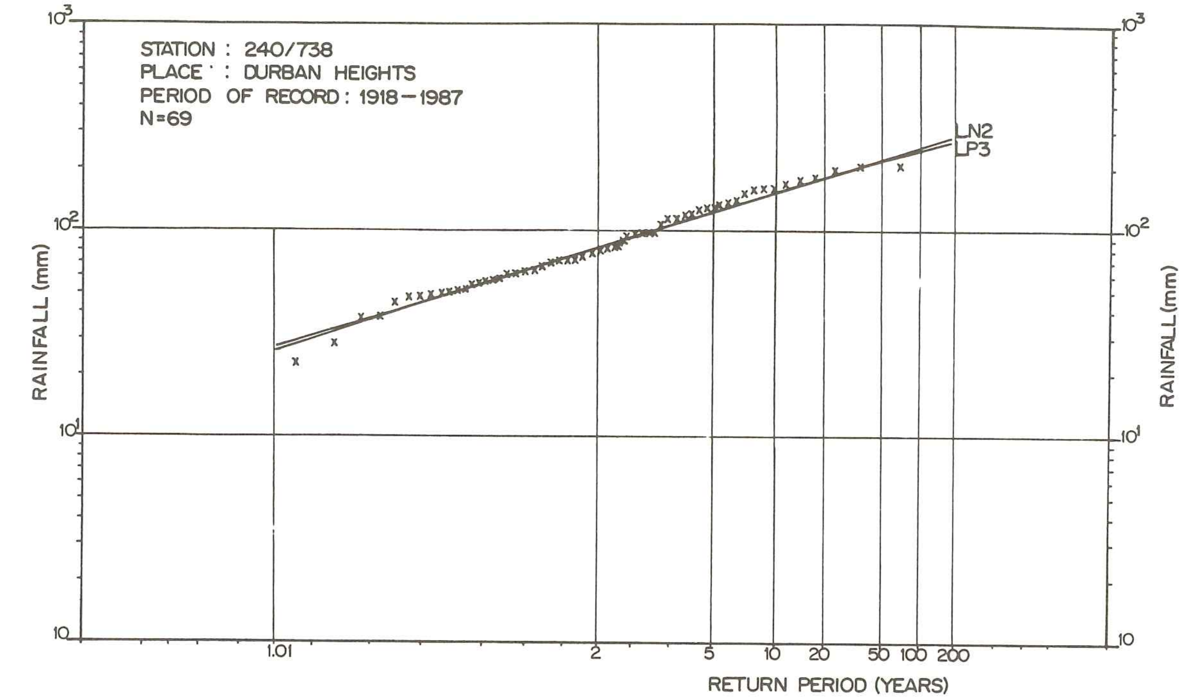


FIG. 2.11g ANNUAL MAXIMUM 1-DAY RAINFALL

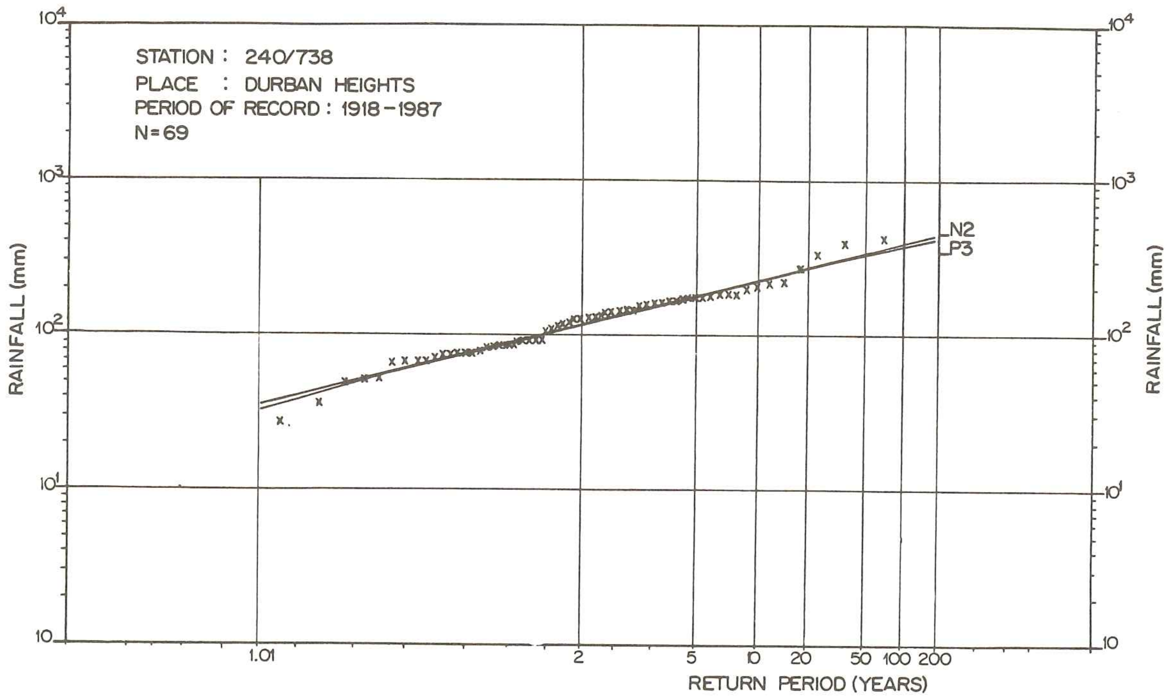


FIG. 2.11h ANNUAL MAXIMUM 3-DAY RAINFALL

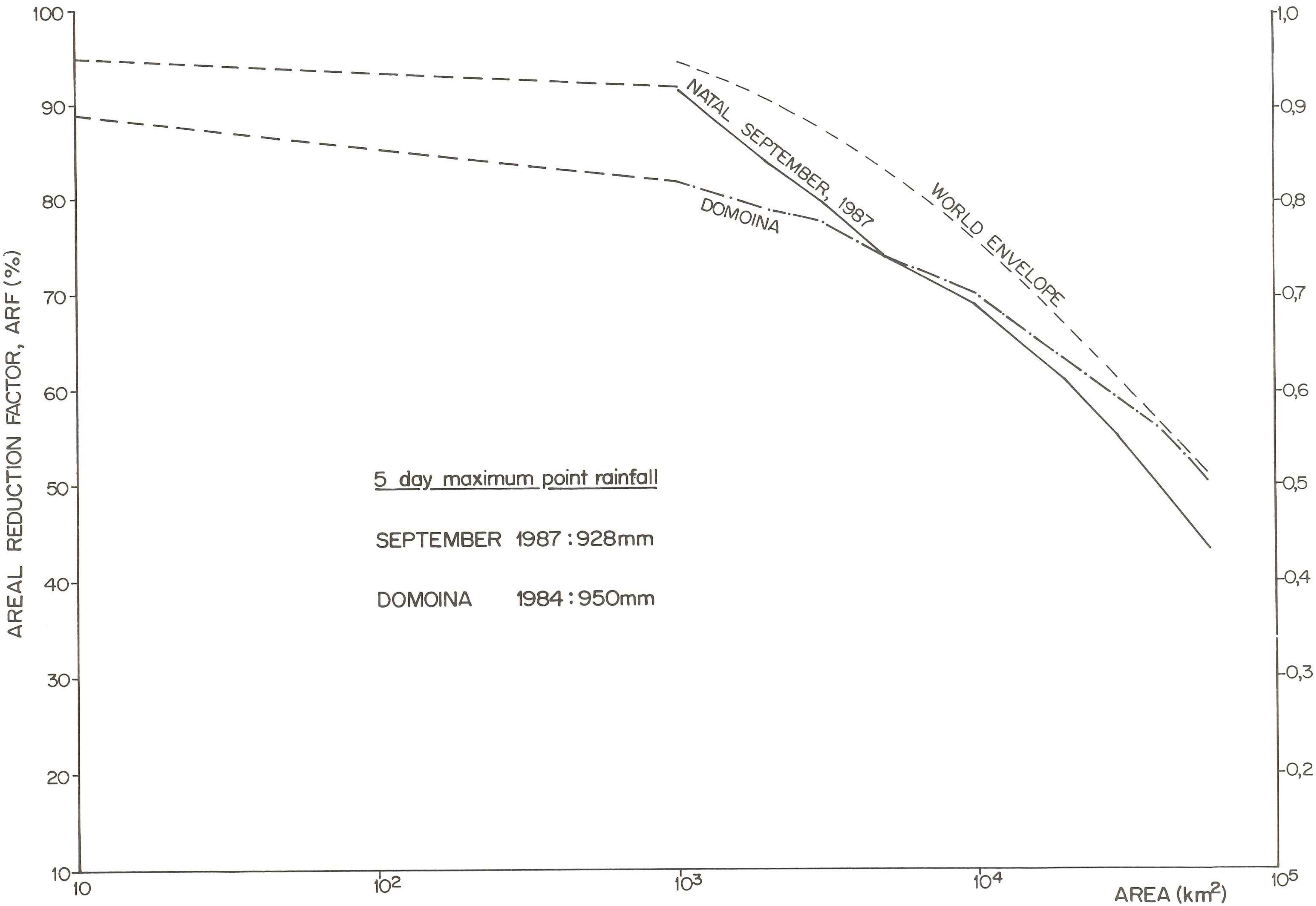


FIG. 2.12 AREAL REDUCTION OF 5-DAY MAXIMUM POINT RAINFALL

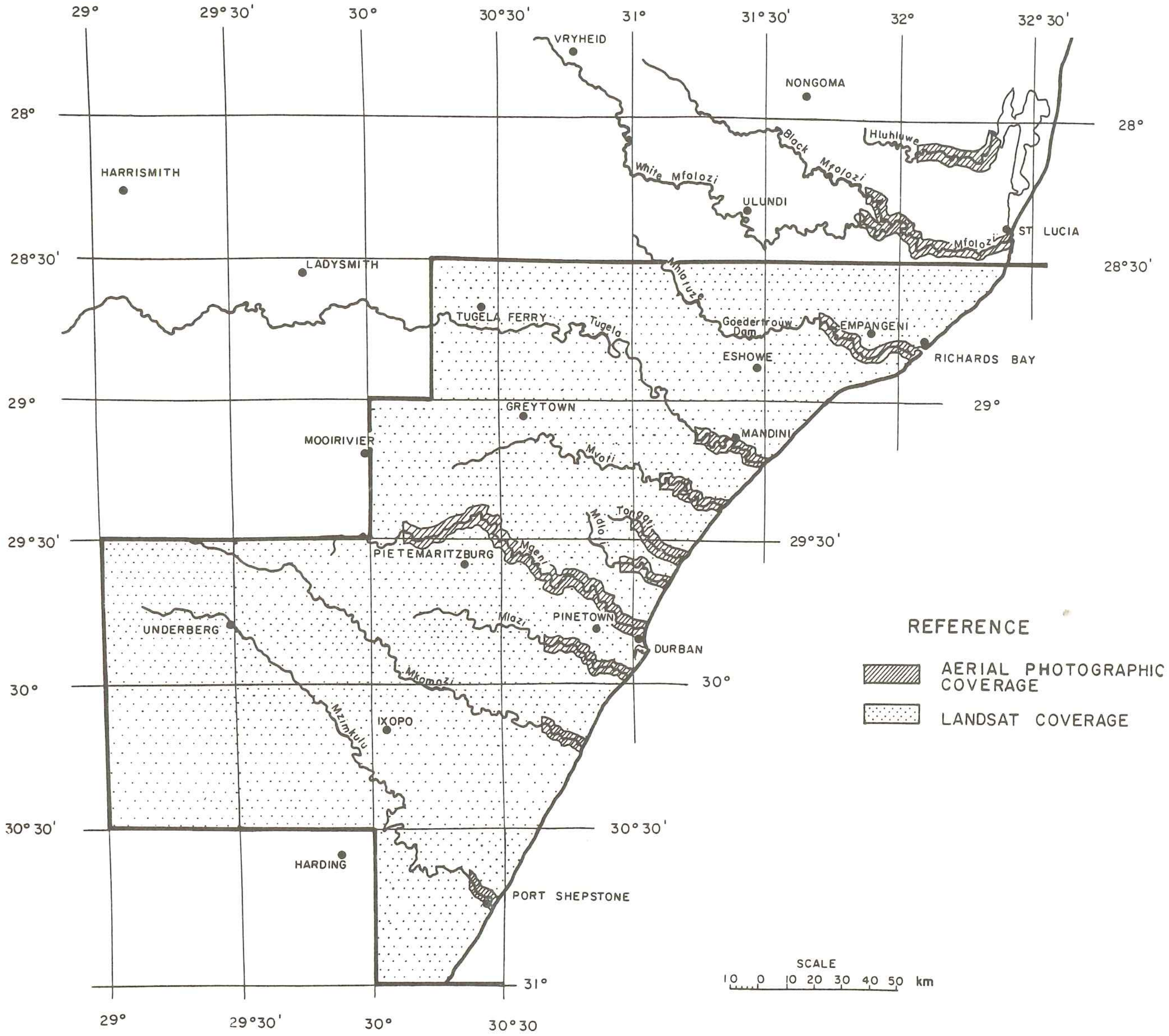


FIG. 3.1 AREA COVERED BY LANDSAT AND AERIAL PHOTOGRAPHY

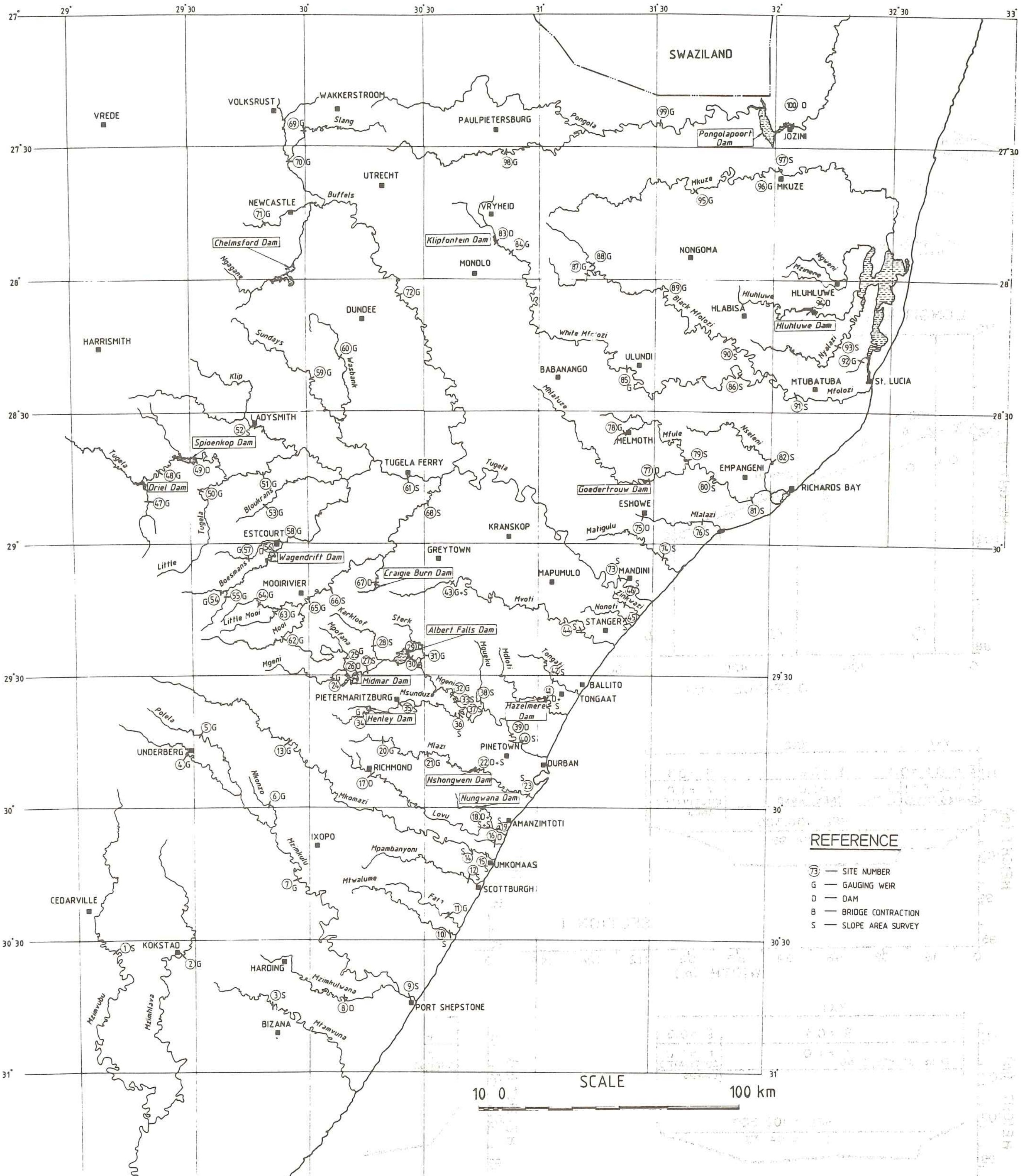


FIG.4.1. FLOOD PEAK MEASUREMENT SITES

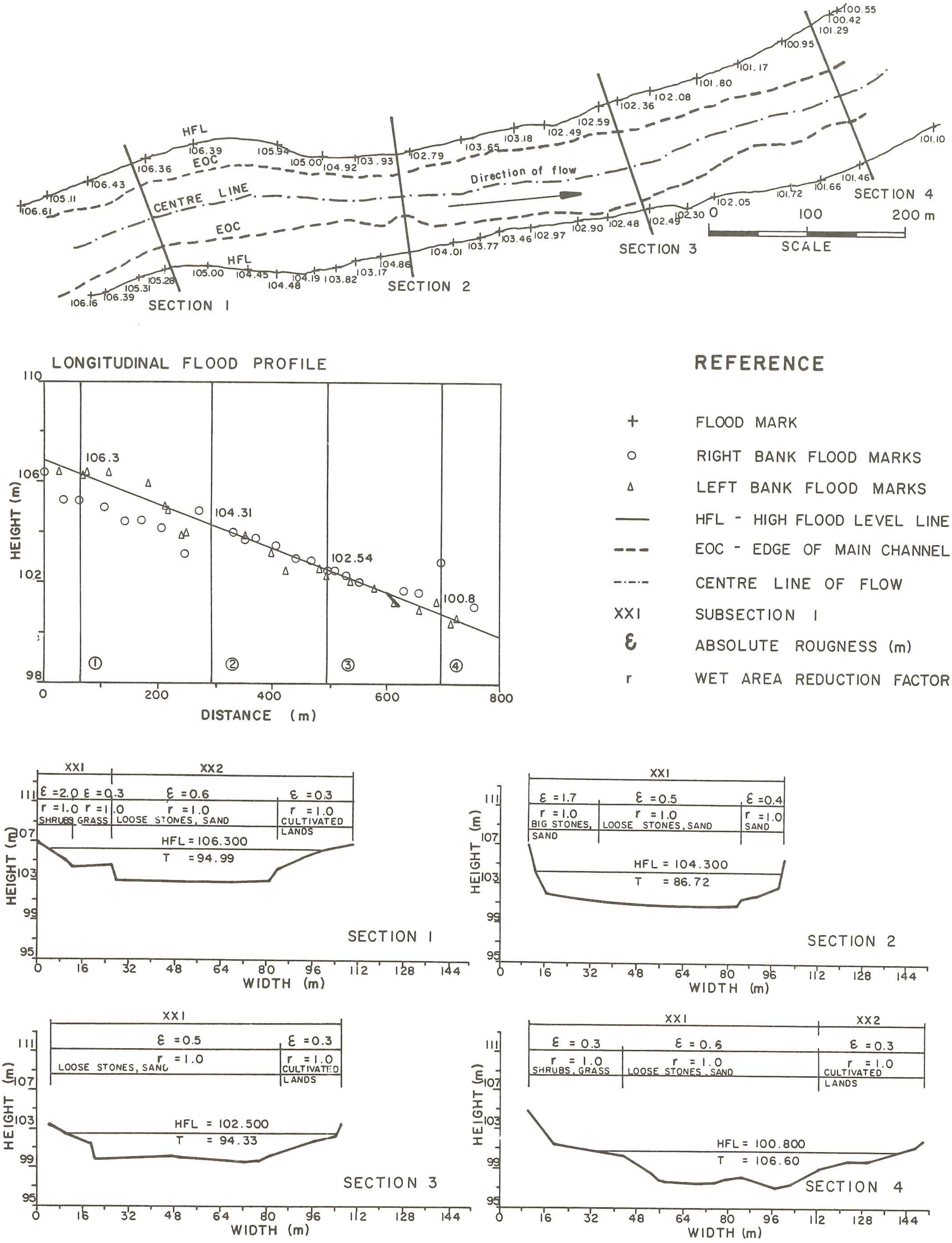


FIG. 4.2 SLOPE - AREA SURVEY AT SITE 37 - MQEKU RIVER

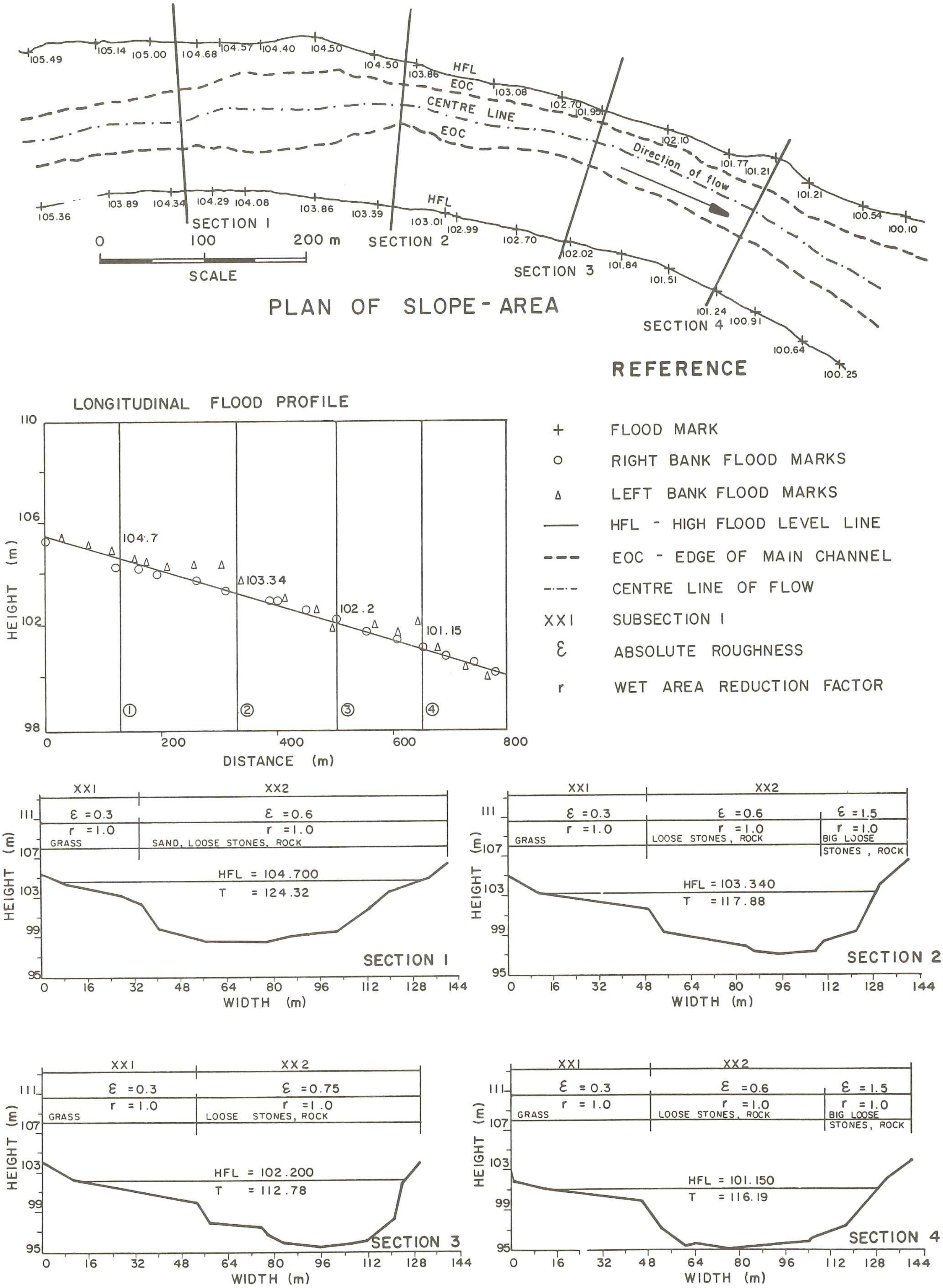


FIG. 4.3 SLOPE - AREA SURVEY AT SITE 68 - MOOI RIVER

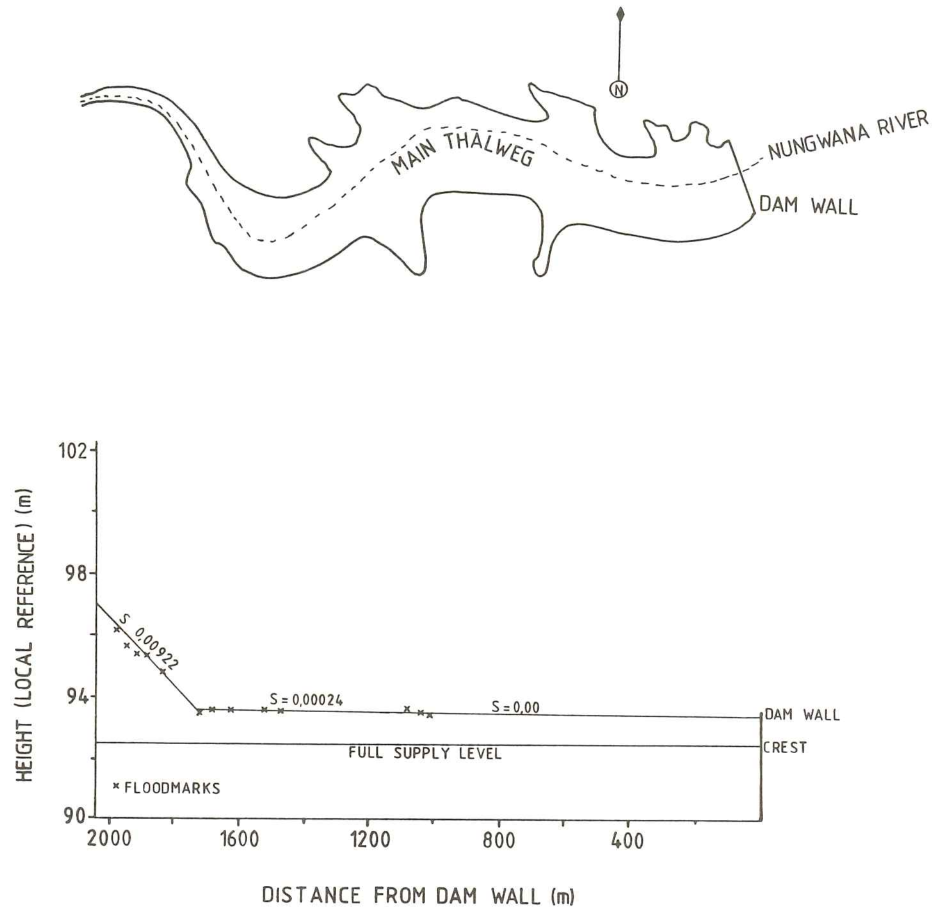


FIG 4.4 RESERVOIR BASIN FLOOD LINE SURVEY AT SITE 18b NUNGWANA DAM

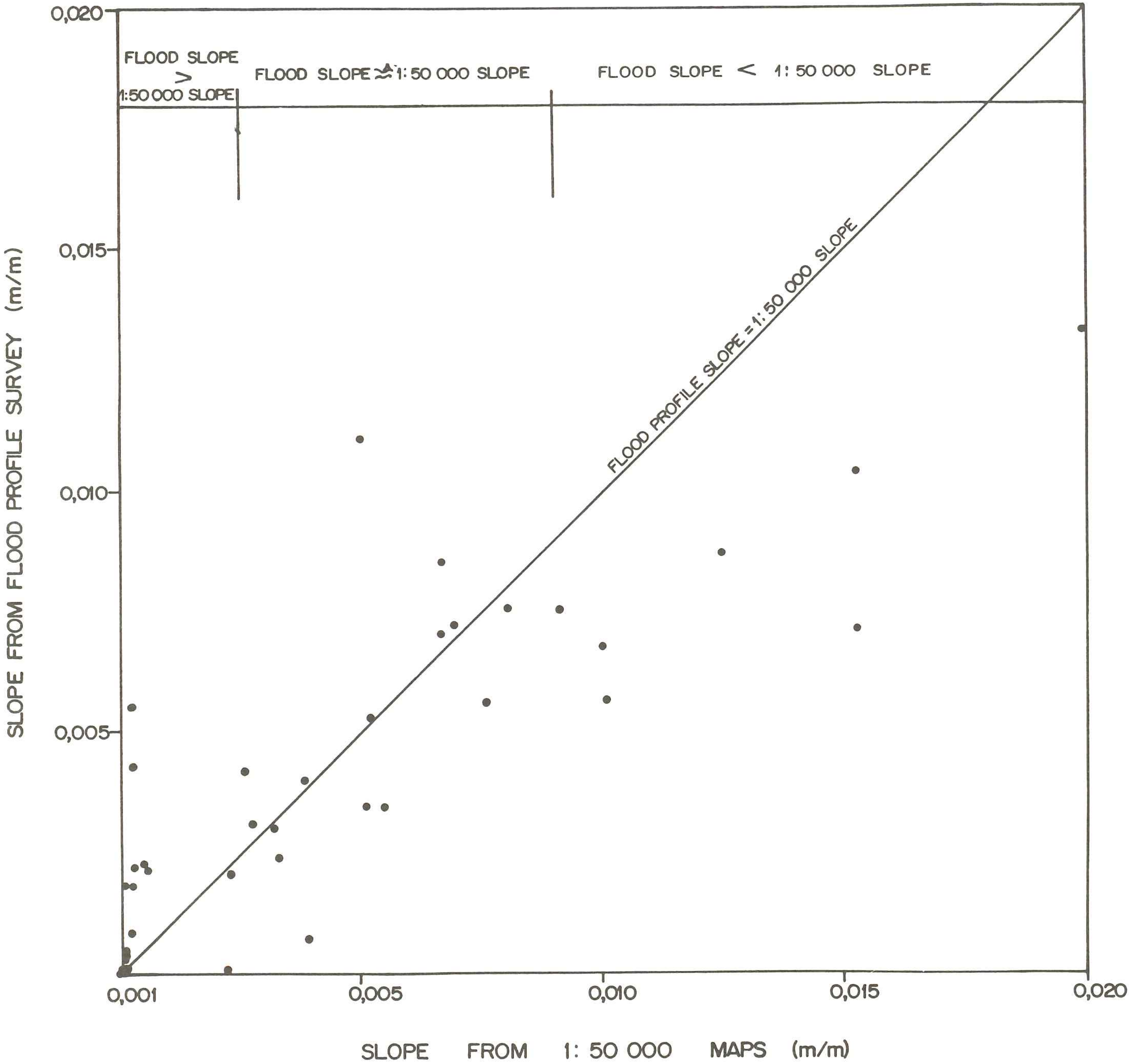
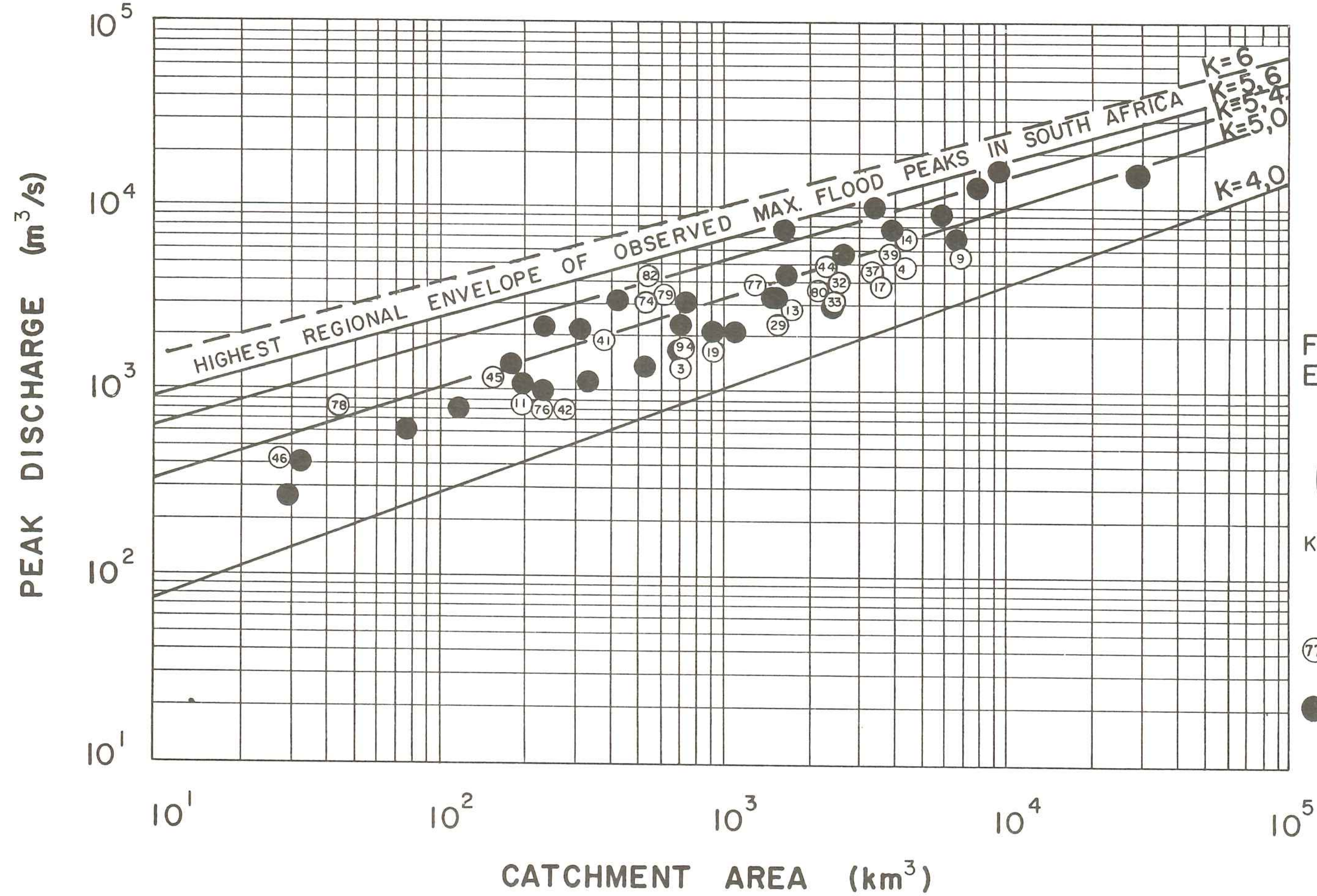


FIG. 5.1 FLOOD SLOPE vs SLOPE FROM 1:50000 SCALE MAPS



NOTE:

FRANCOU-RODIER EQUATION:

$$\left(\frac{Q}{10^6}\right) = \left(\frac{A}{10^8}\right)^{1-0,1K}$$

K = FRANCOU-RODIER COEFFICIENT

SYMBOLS:

(77) 1987 FLOOD SITE NO.

● PREVIOUS FLOOD PEAKS RECORDED IN REGIONS T, U, V AND W WITH K > 4,5

FIG. 5.2 MAXIMUM FLOOD PEAK DISCARGES WITH K>4,5 IN NATAL

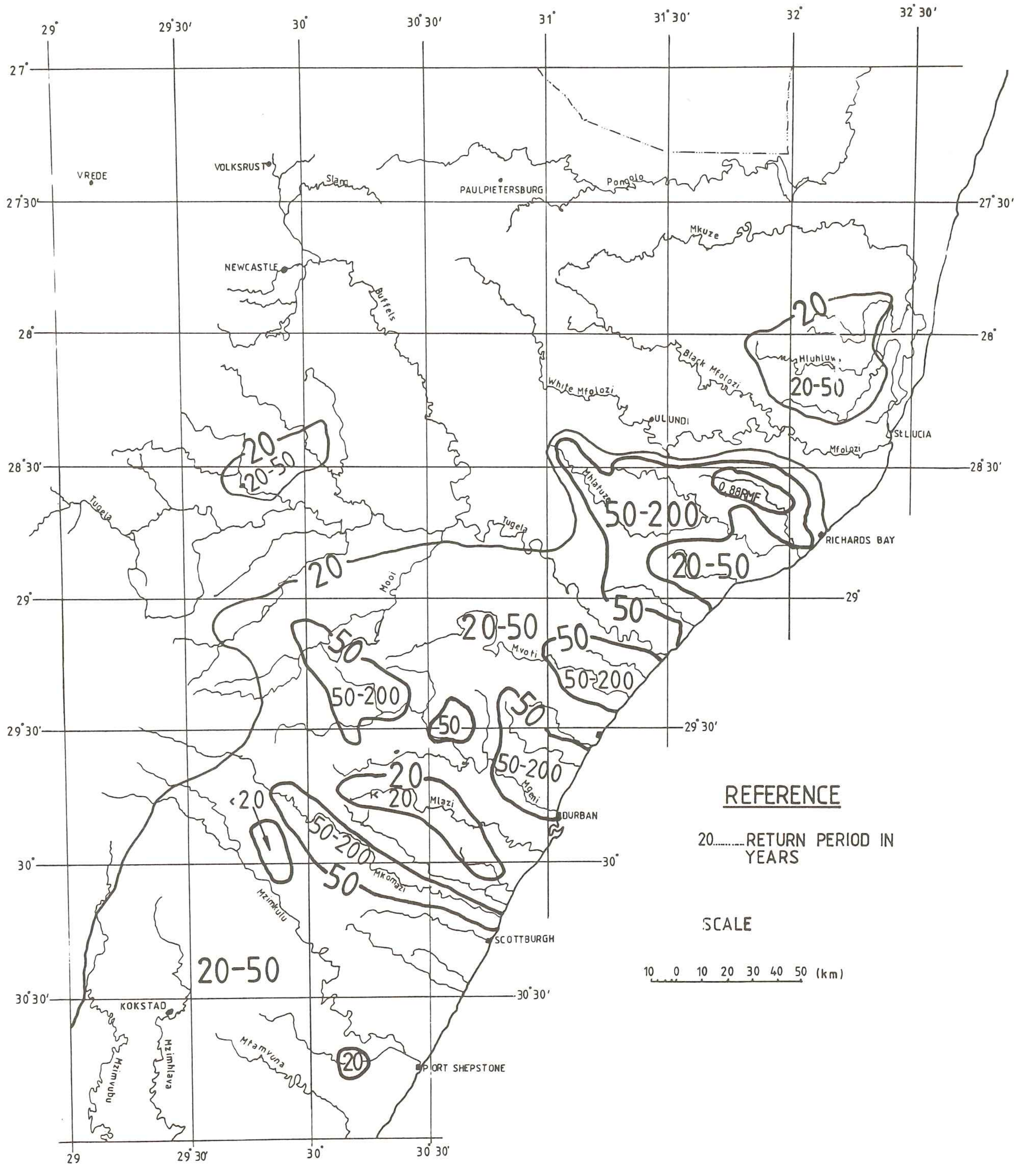


FIG.5.3 APPROXIMATE RETURN PERIOD ISOLINES FOR THE SEPTEMBER 1987 FLOOD

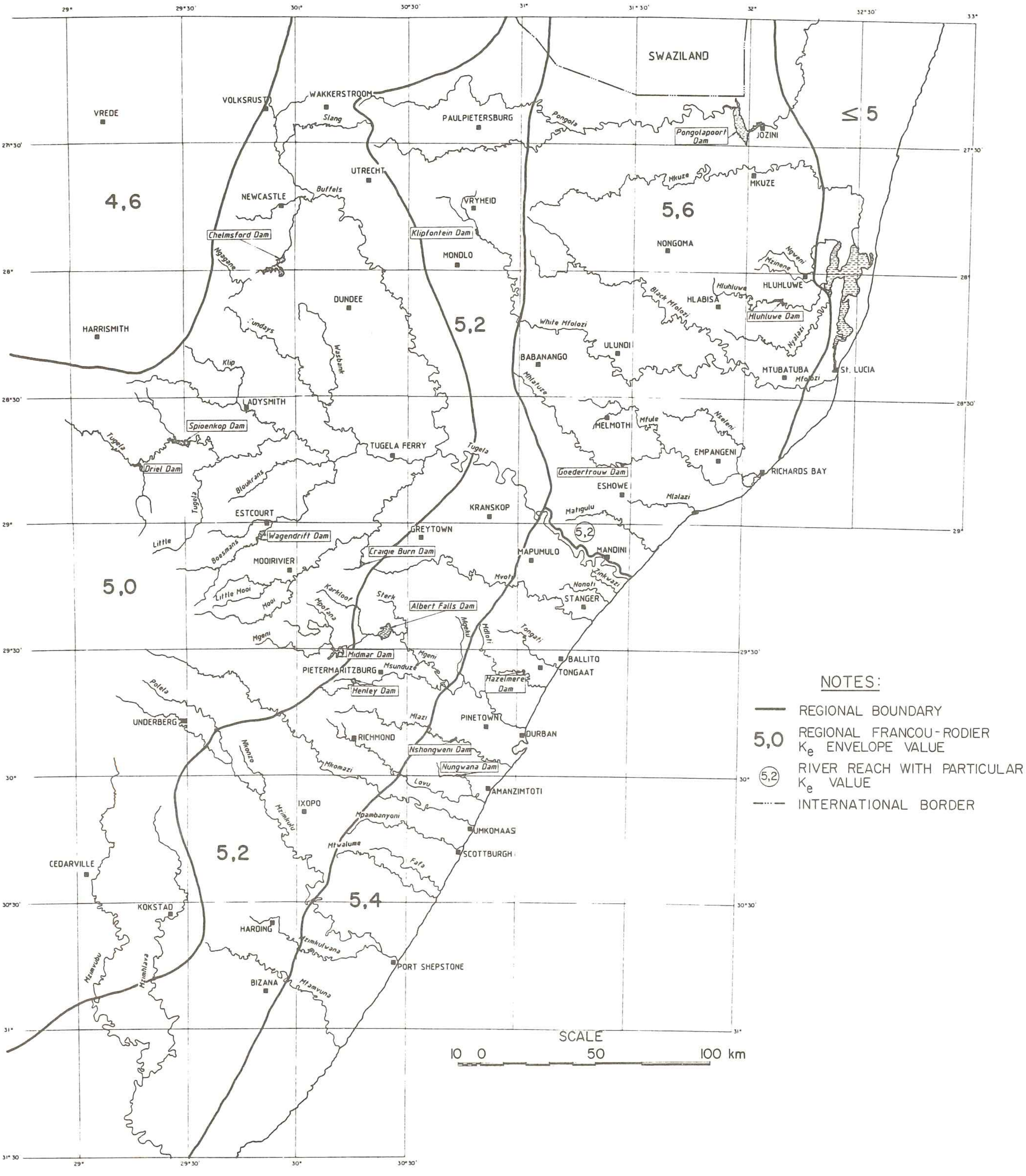


FIG. 5.4 MAXIMUM FLOOD PEAK REGIONS IN NATAL (REF 23)

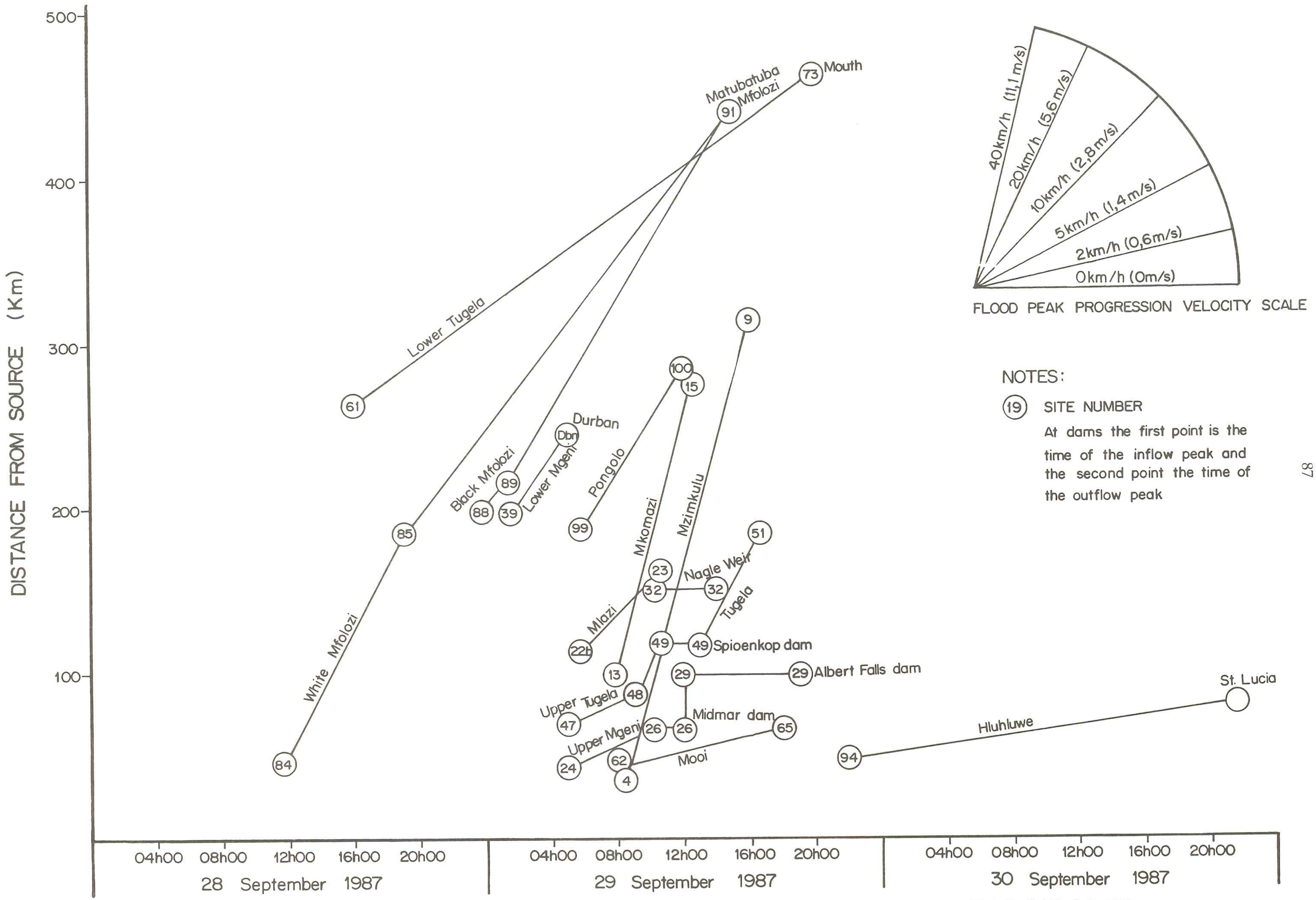


FIG. 5.5 FLOOD PEAK TIME VS DISTANCE DIAGRAMS

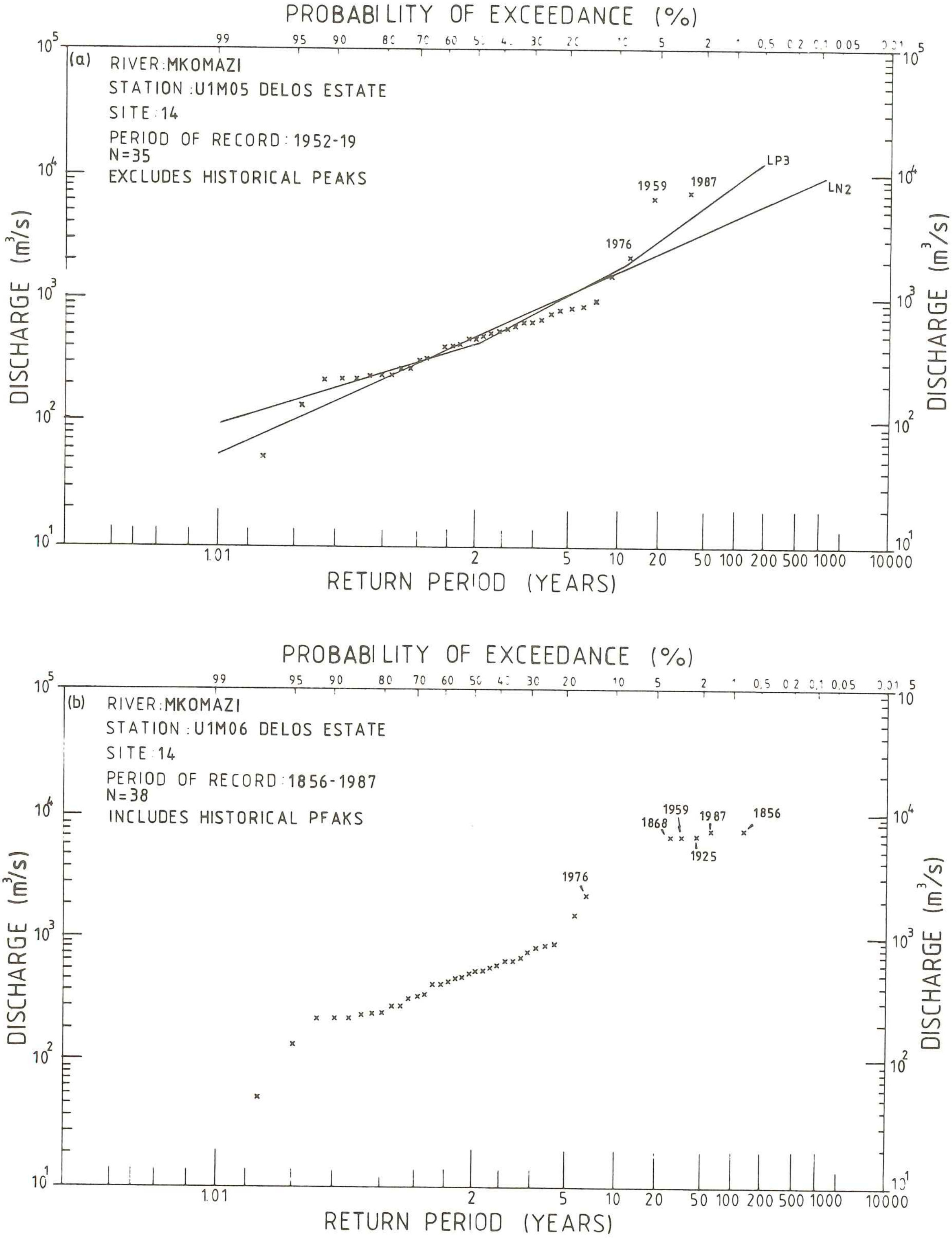


FIG.5.6.1 FREQUENCY ANALYSIS OF ANNUAL MAXIMUM FLOOD PEAKS

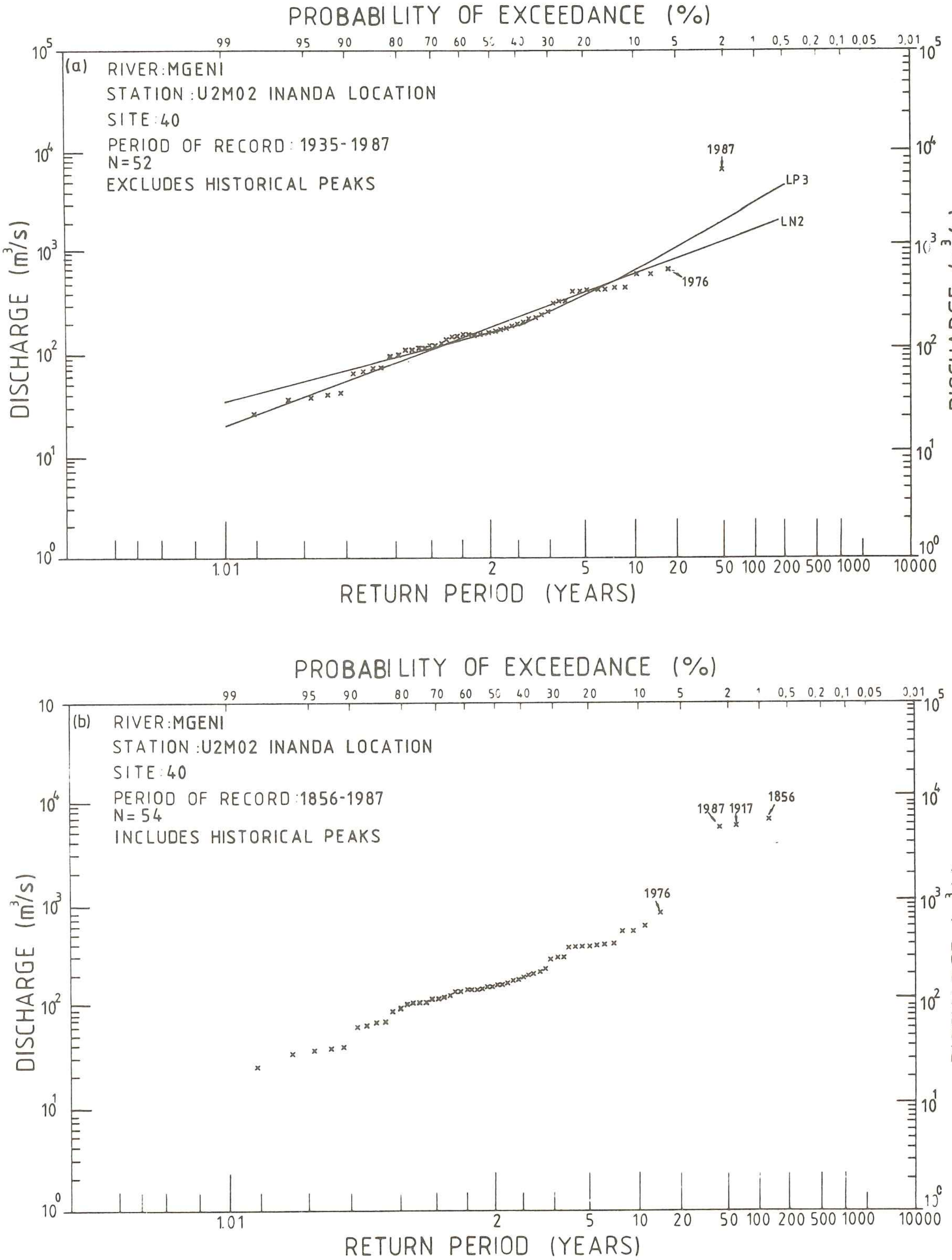
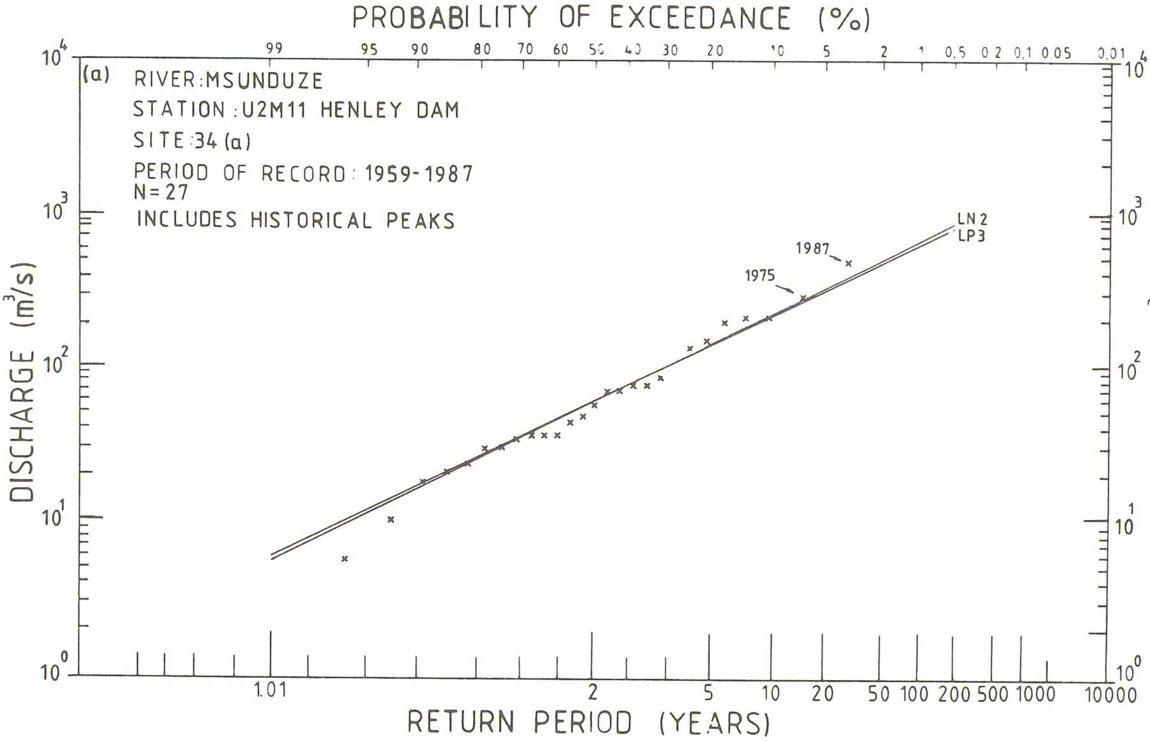


FIG.5.6.2 FREQUENCY ANALYSIS OF ANNUAL MAXIMUM FLOOD PEAKS



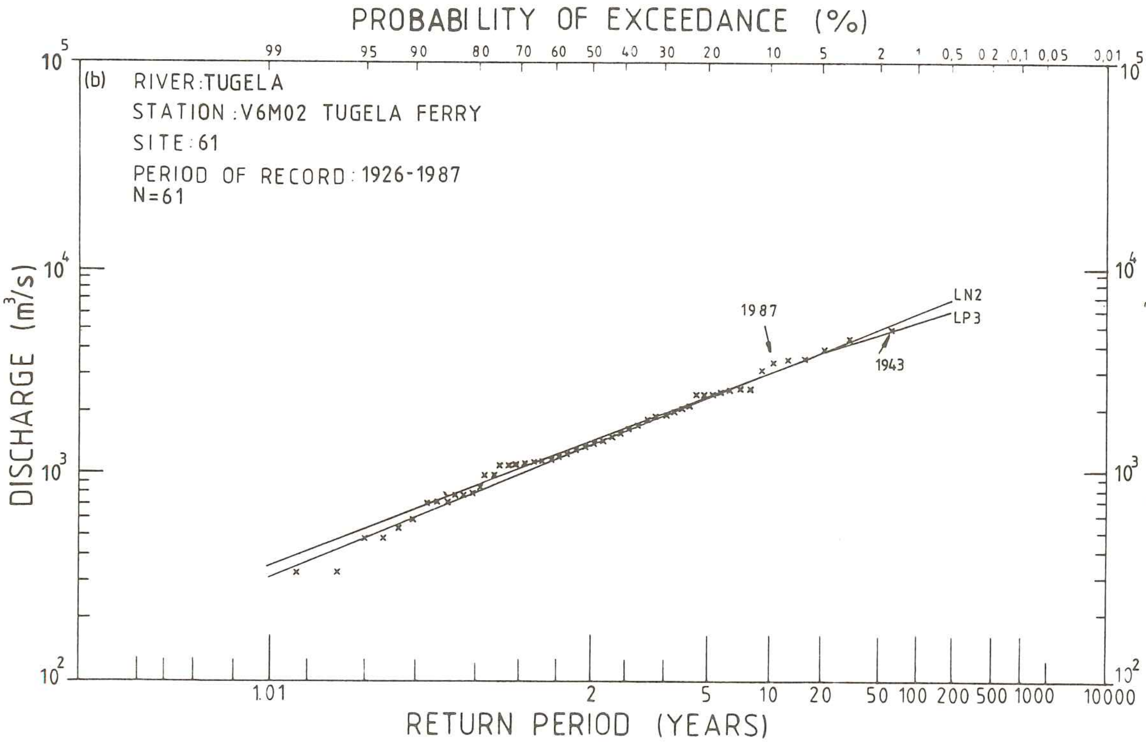


FIG.5.6.3 FREQUENCY ANALYSIS OF ANNUAL MAXIMUM FLOOD PEAKS

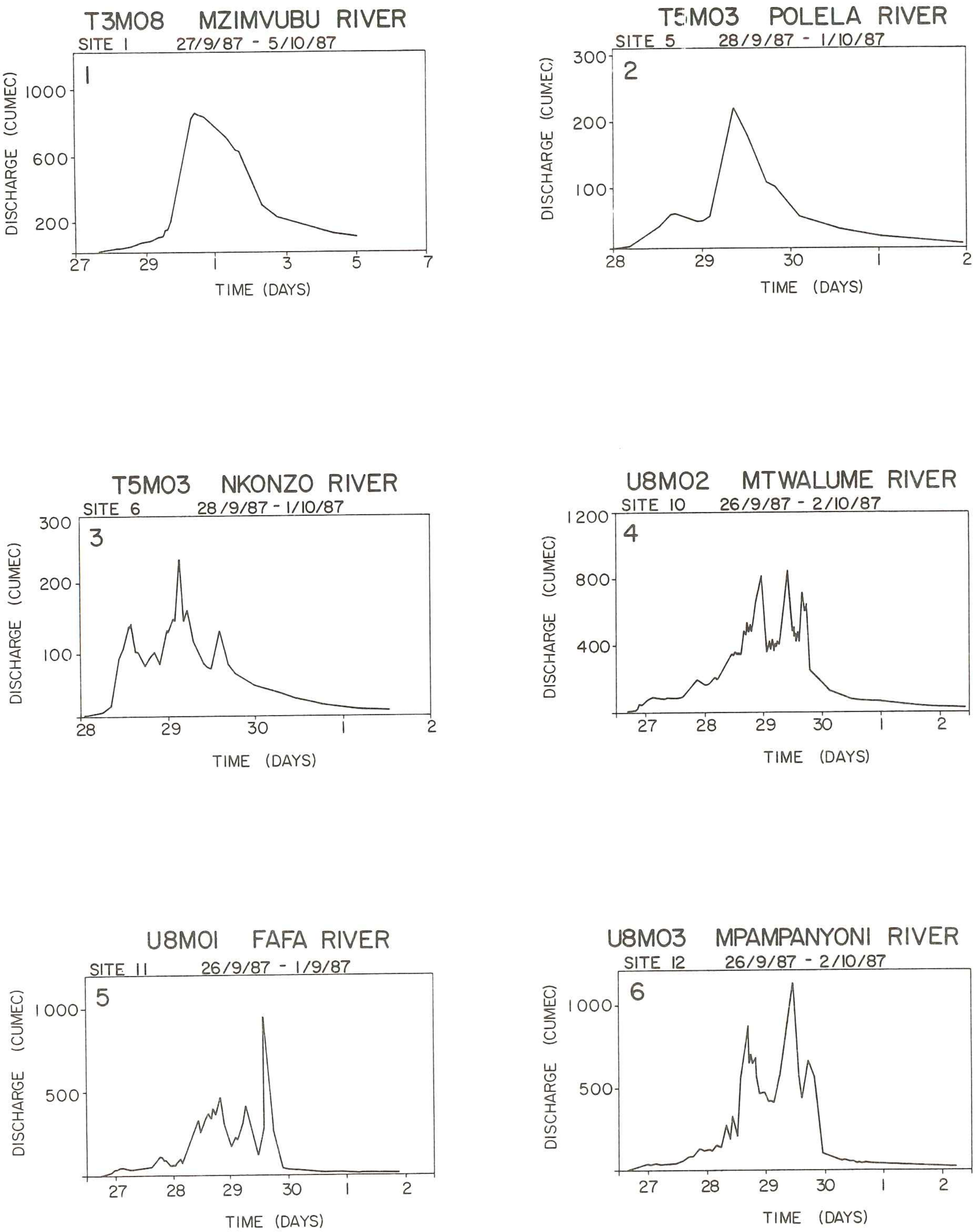


FIG. 6.1 (1-6) FLOOD HYDROGRAPHS AT RIVER GAUGING STATIONS

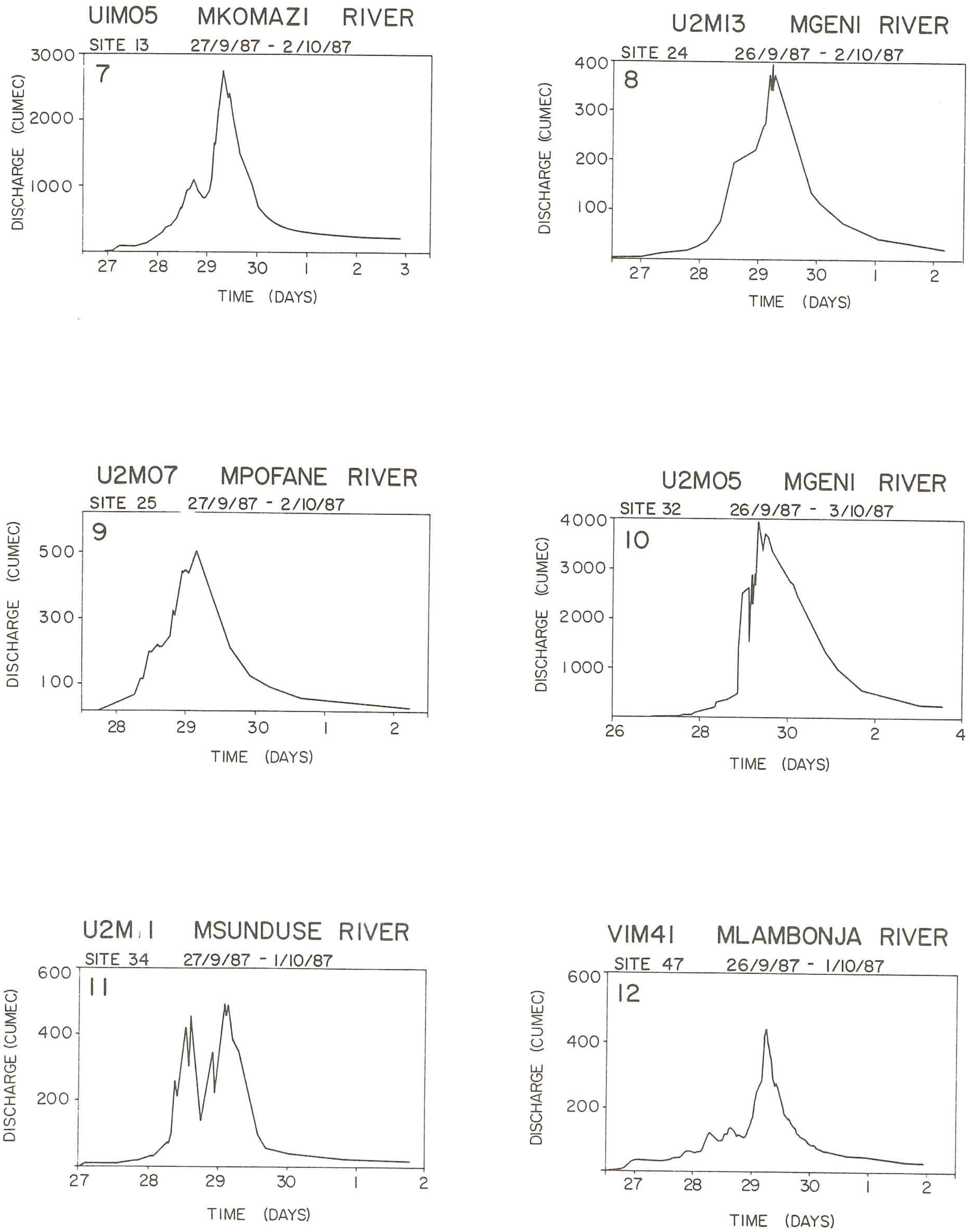


FIG. 6.1 (7 - 12) FLOOD HYDROGRPHS AT RIVER GAUGING STATIONS

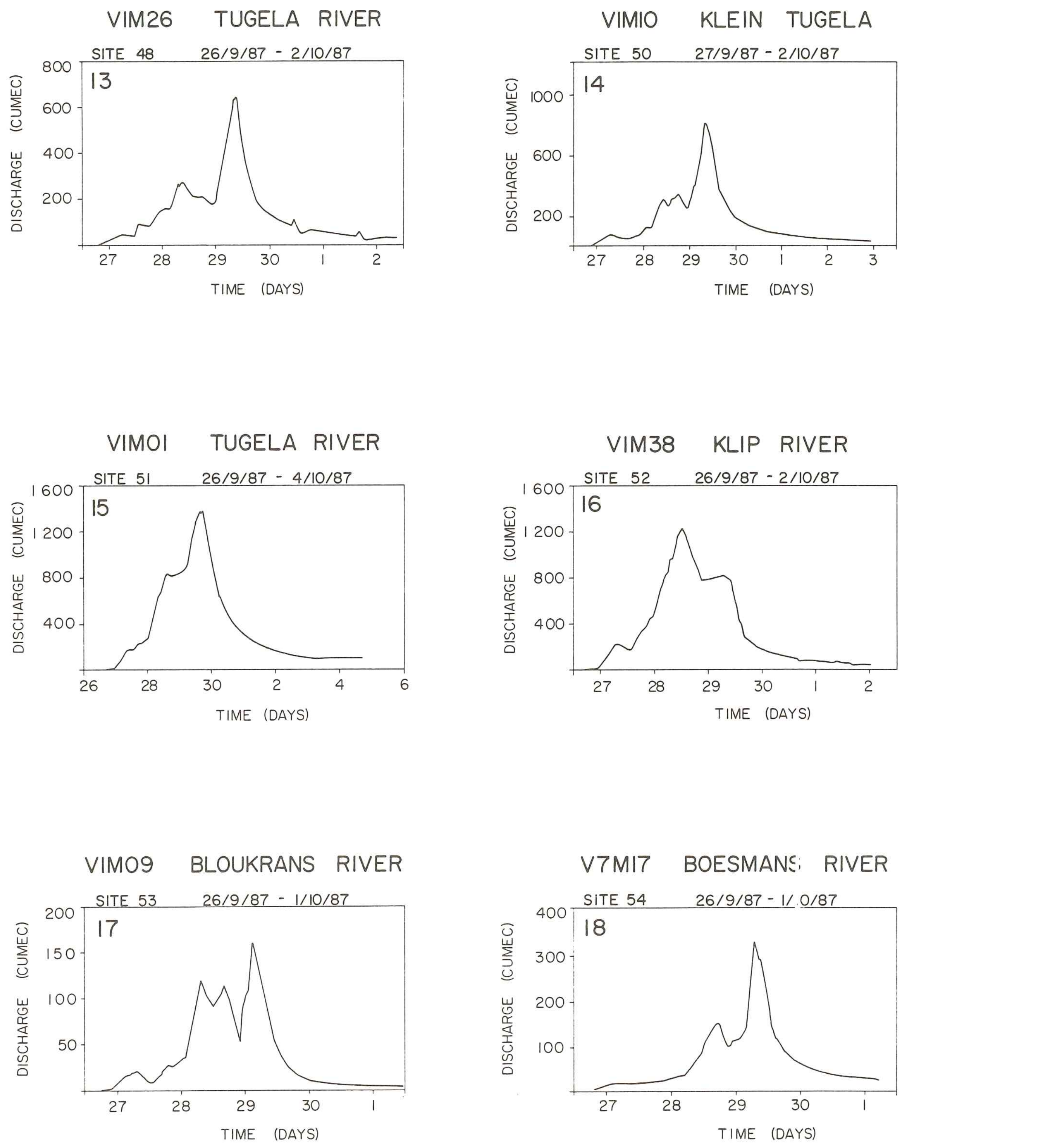


FIG. 6.1 (13 - 18) FLOOD HYDROGRAPHS AT RIVER GAUGING STATIONS

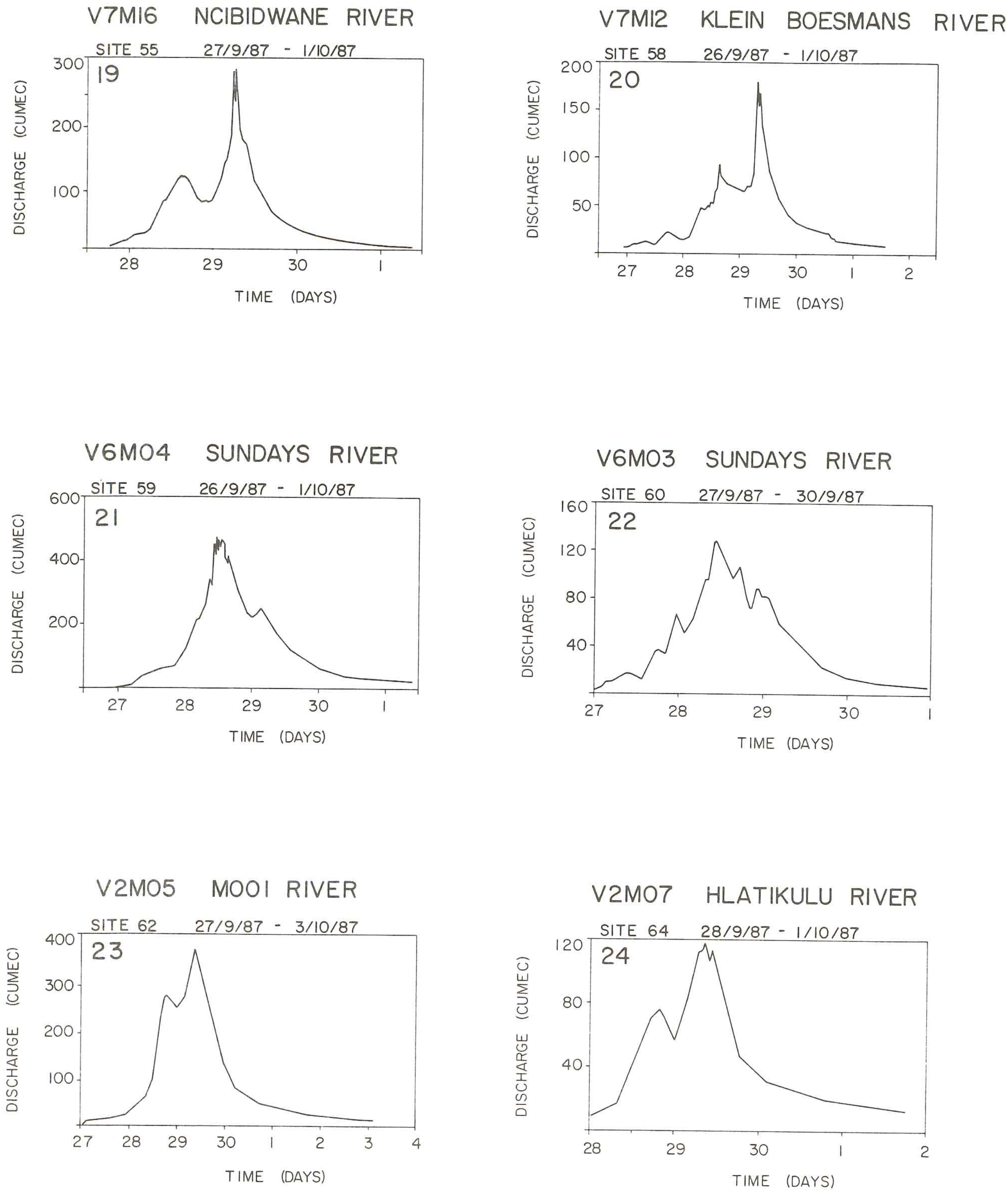


FIG. 6.1 (19-24) FLOOD HYDROGRAPHS AT RIVER GAUGING STATIONS

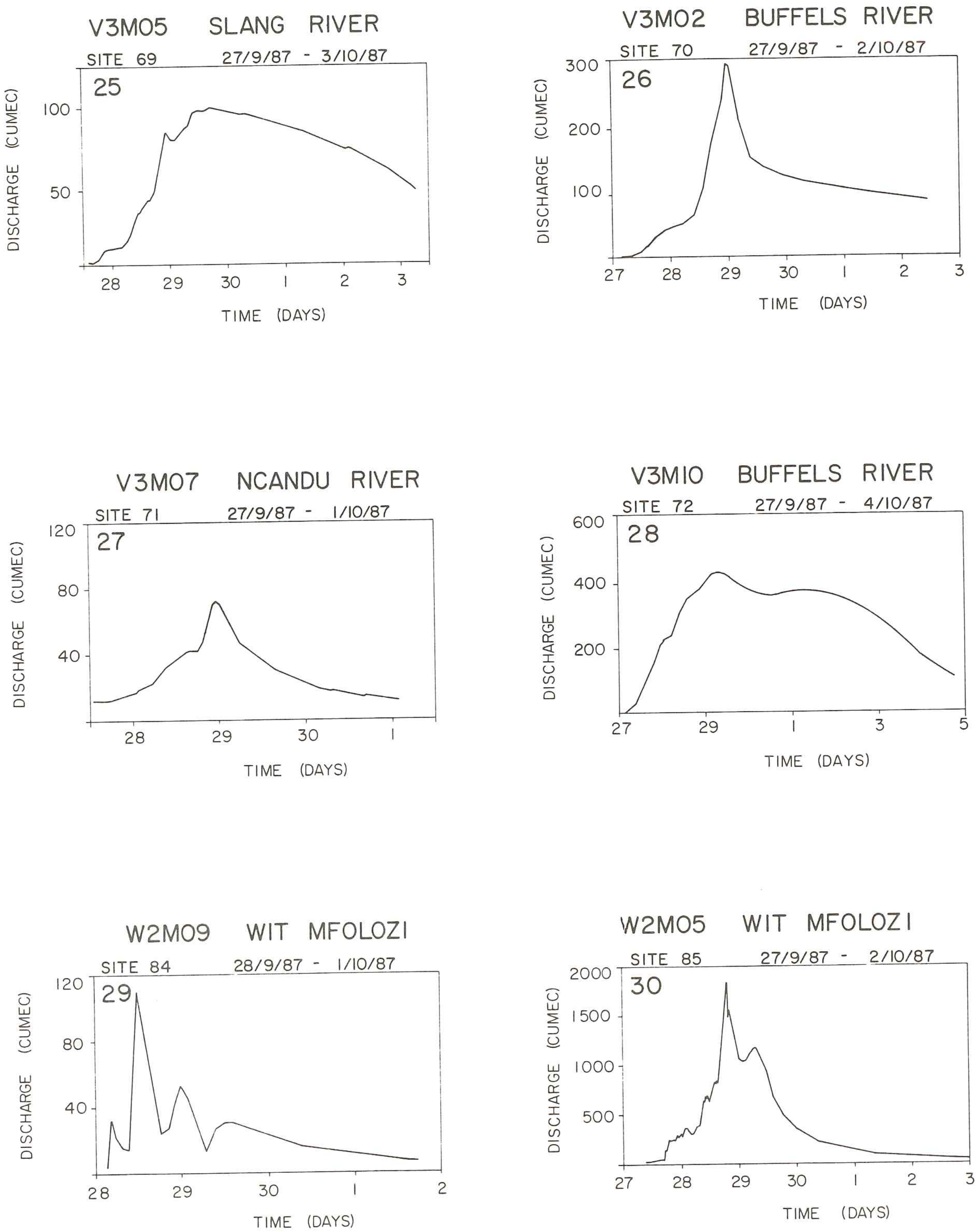


FIG. 6.1 (25 - 30) FLOOD HYDROGRAPHS AT RIVER GAUGING STATIONS

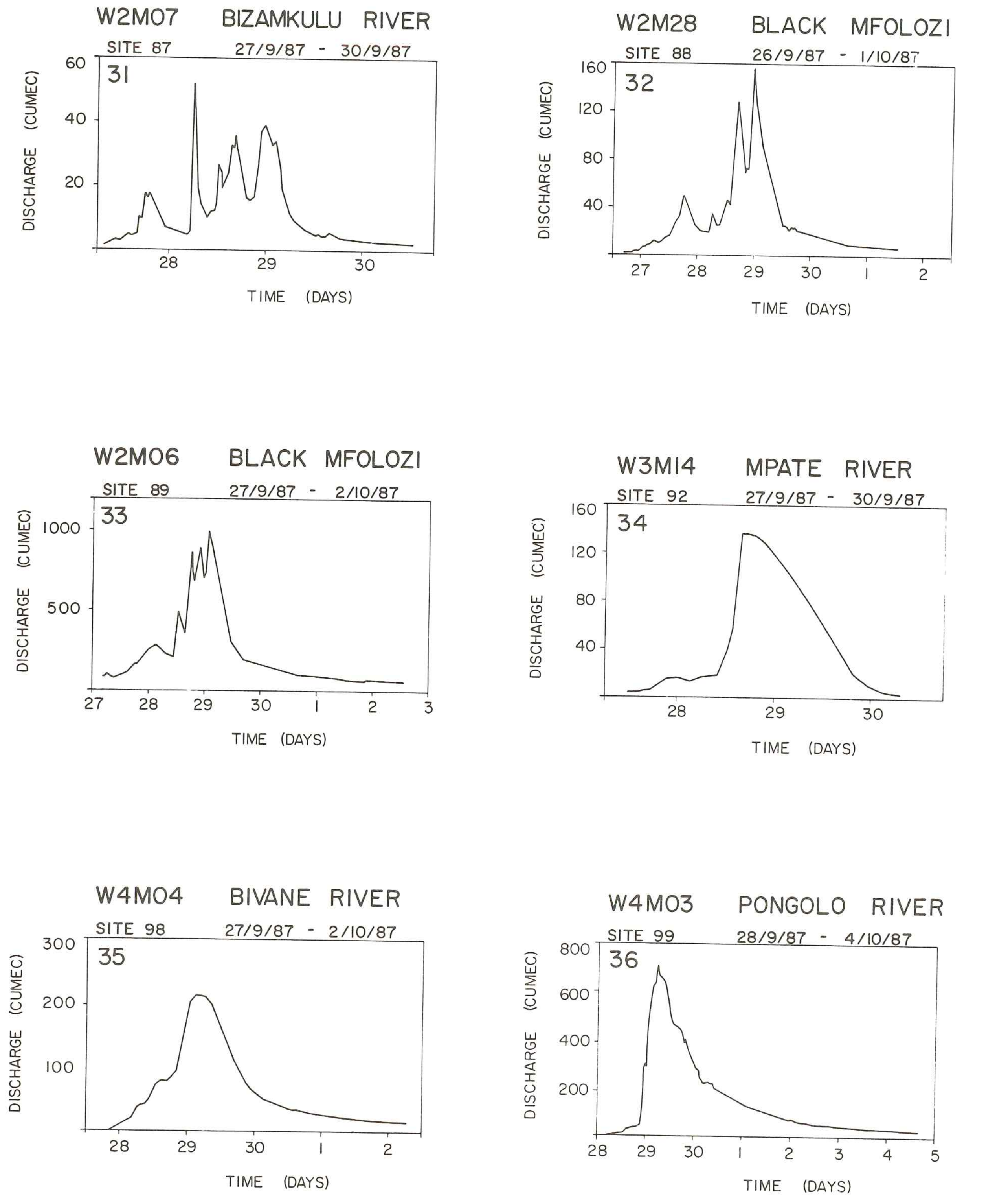


FIG. 6.1 (31 - 36) FLOOD HYDROGRAPHS AT RIVER GAUGING STATIONS

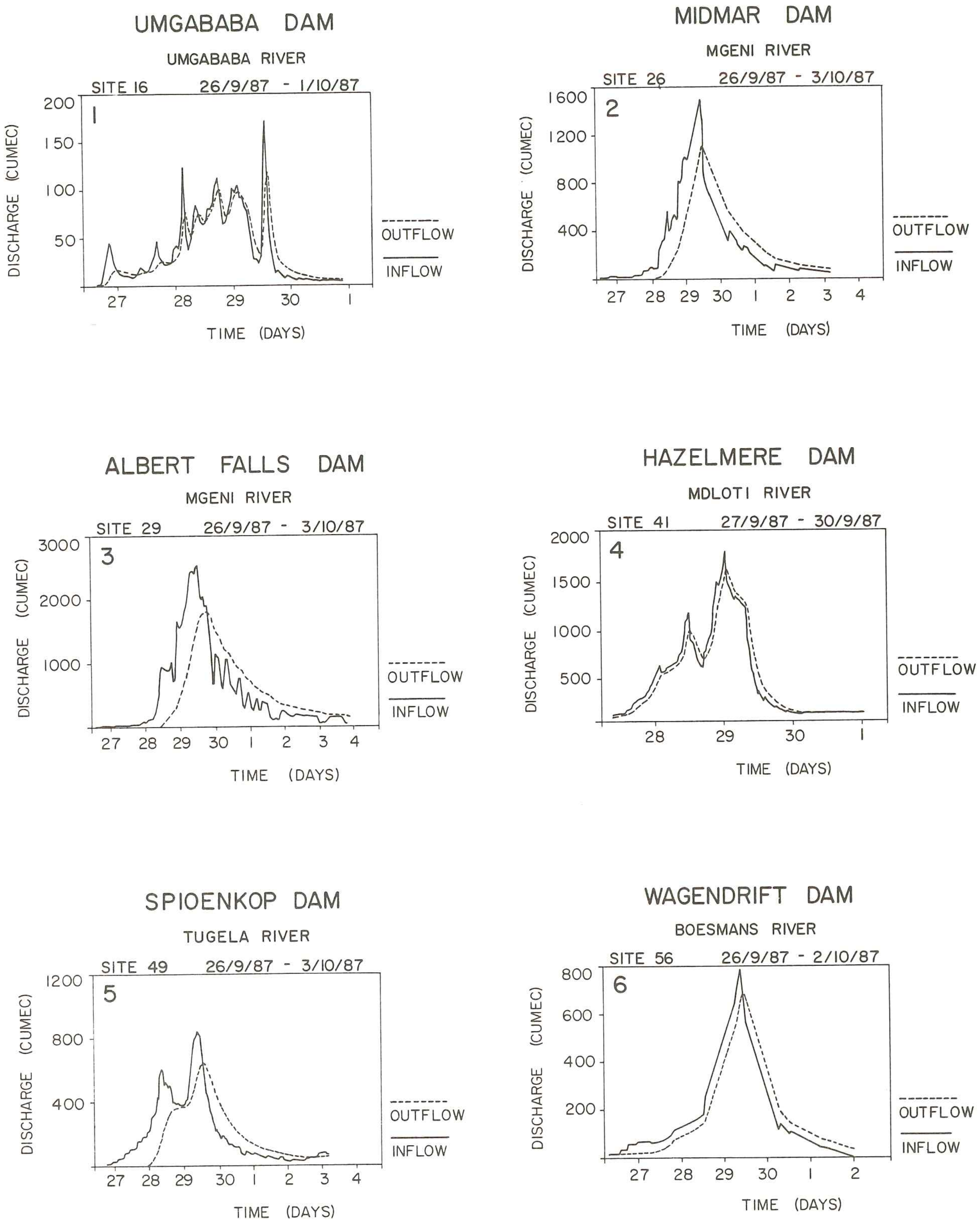


FIG. 6.2 (1-6) FLOOD HYDROGRAPHS AT DAMS

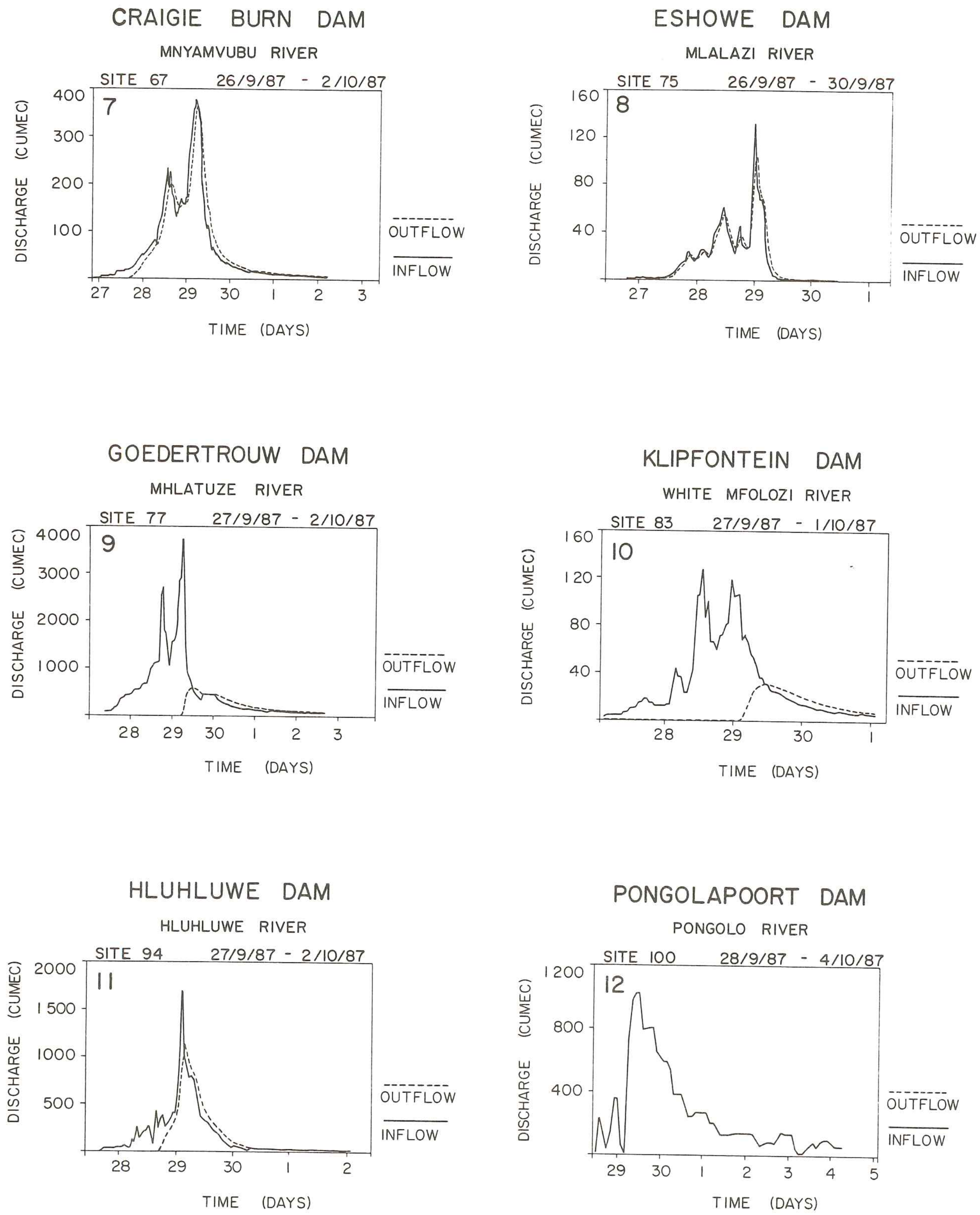


FIG. 6.2 (7 - 12) FLOOD HYDROGRAPHS AT DAMS

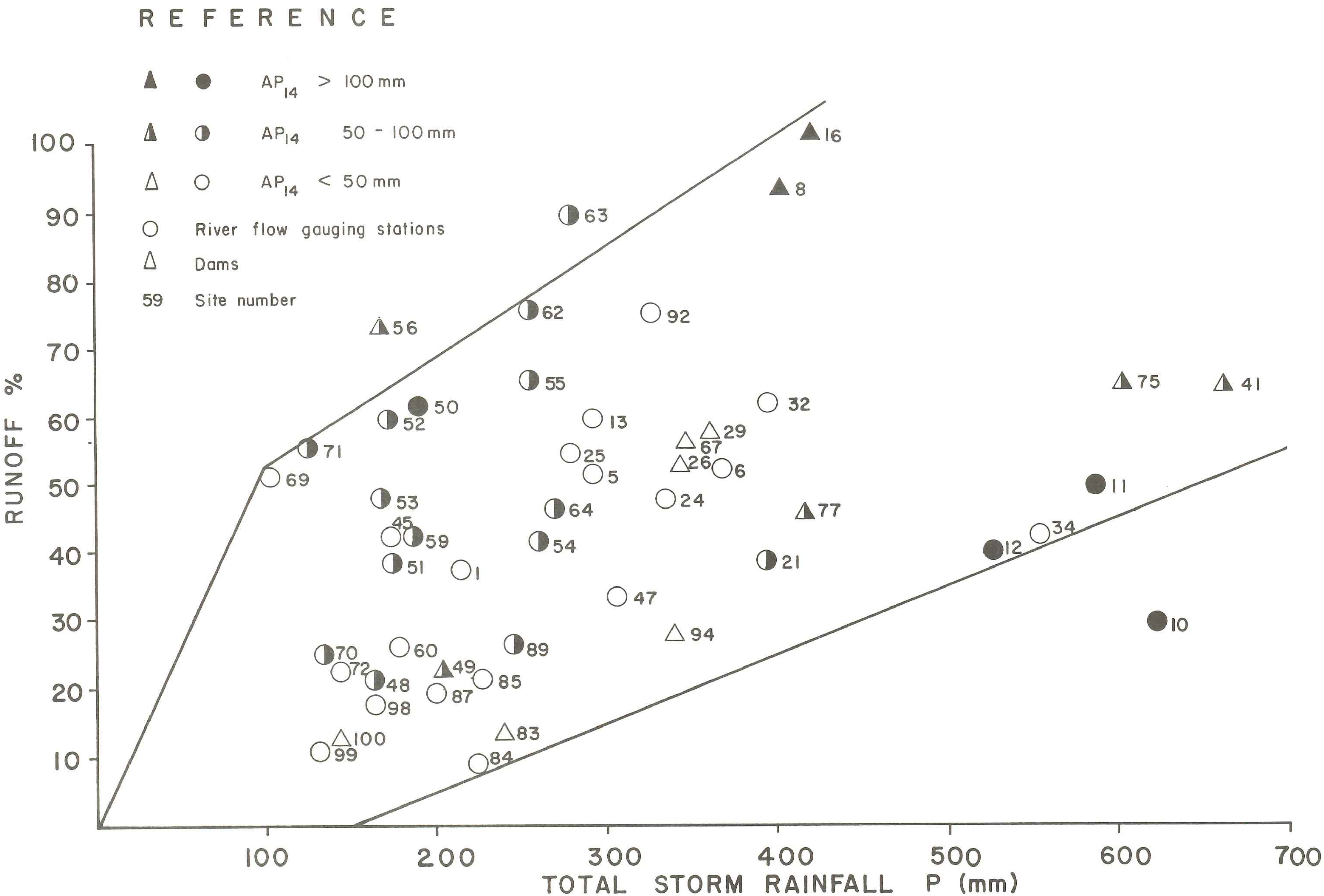


FIG. 6.3 RUNOFF % VERSUS STORM RAINFALL

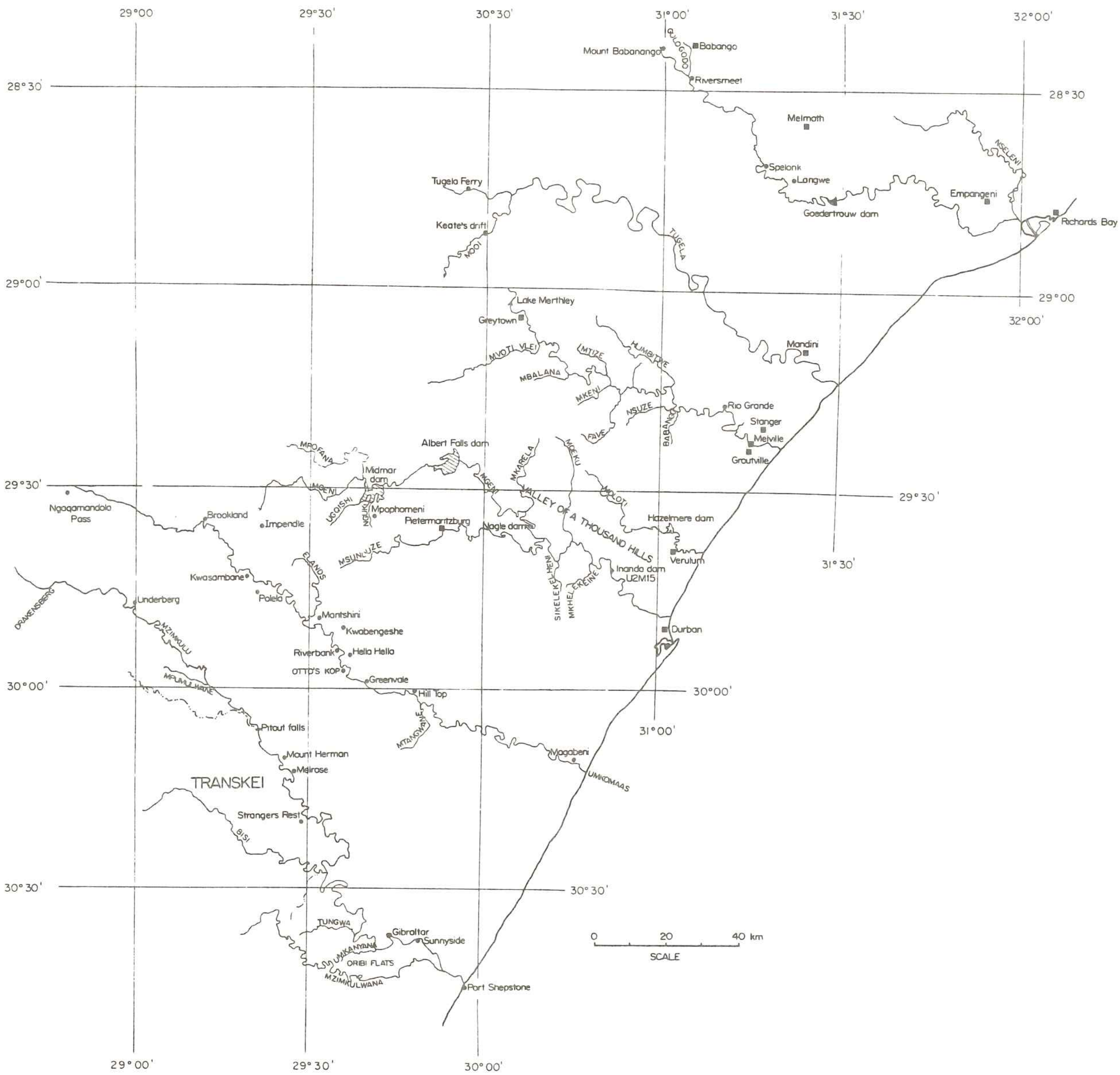
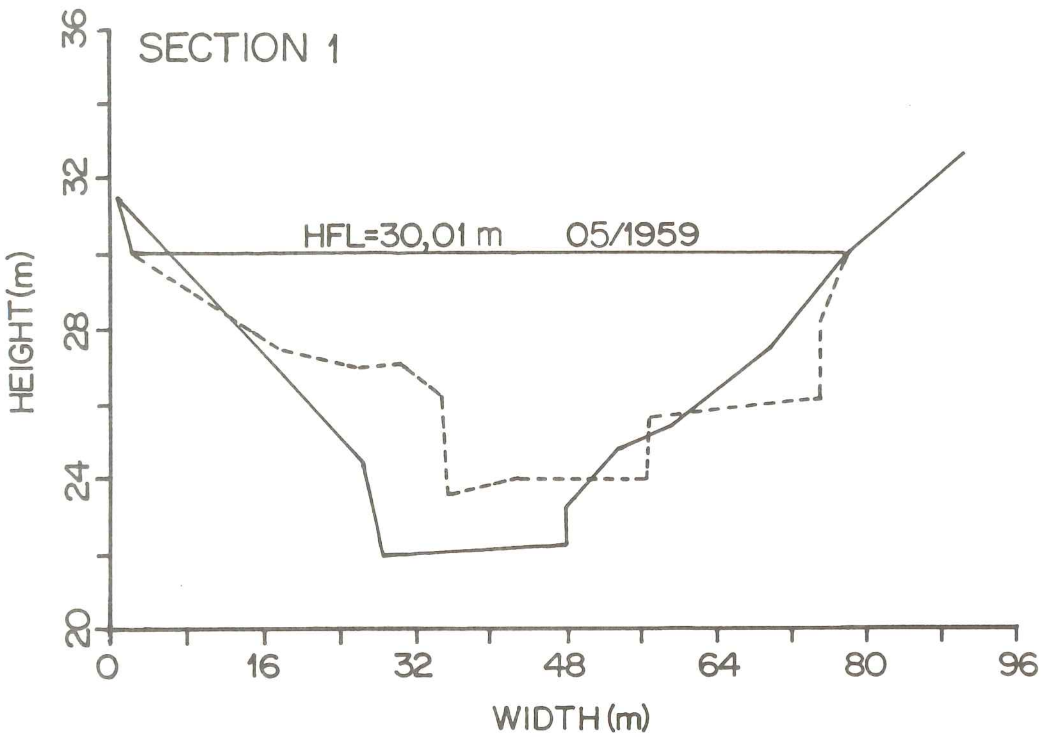


FIG. 7.1 LANDSAT REFERENCE MAP



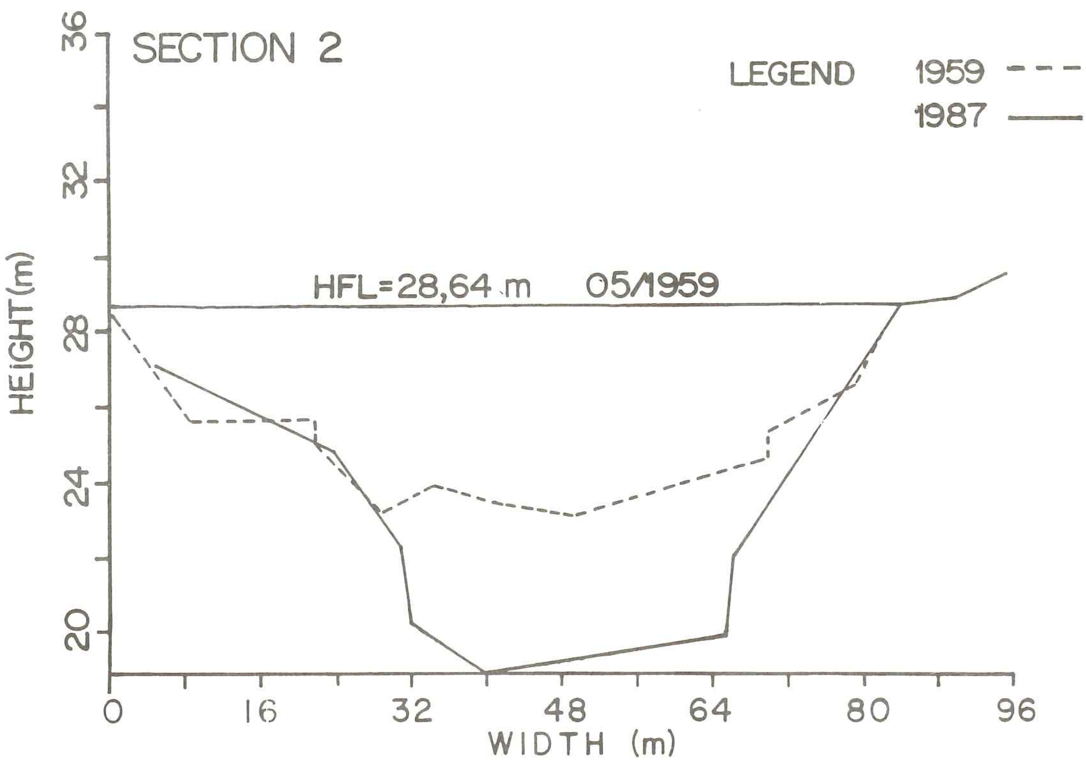
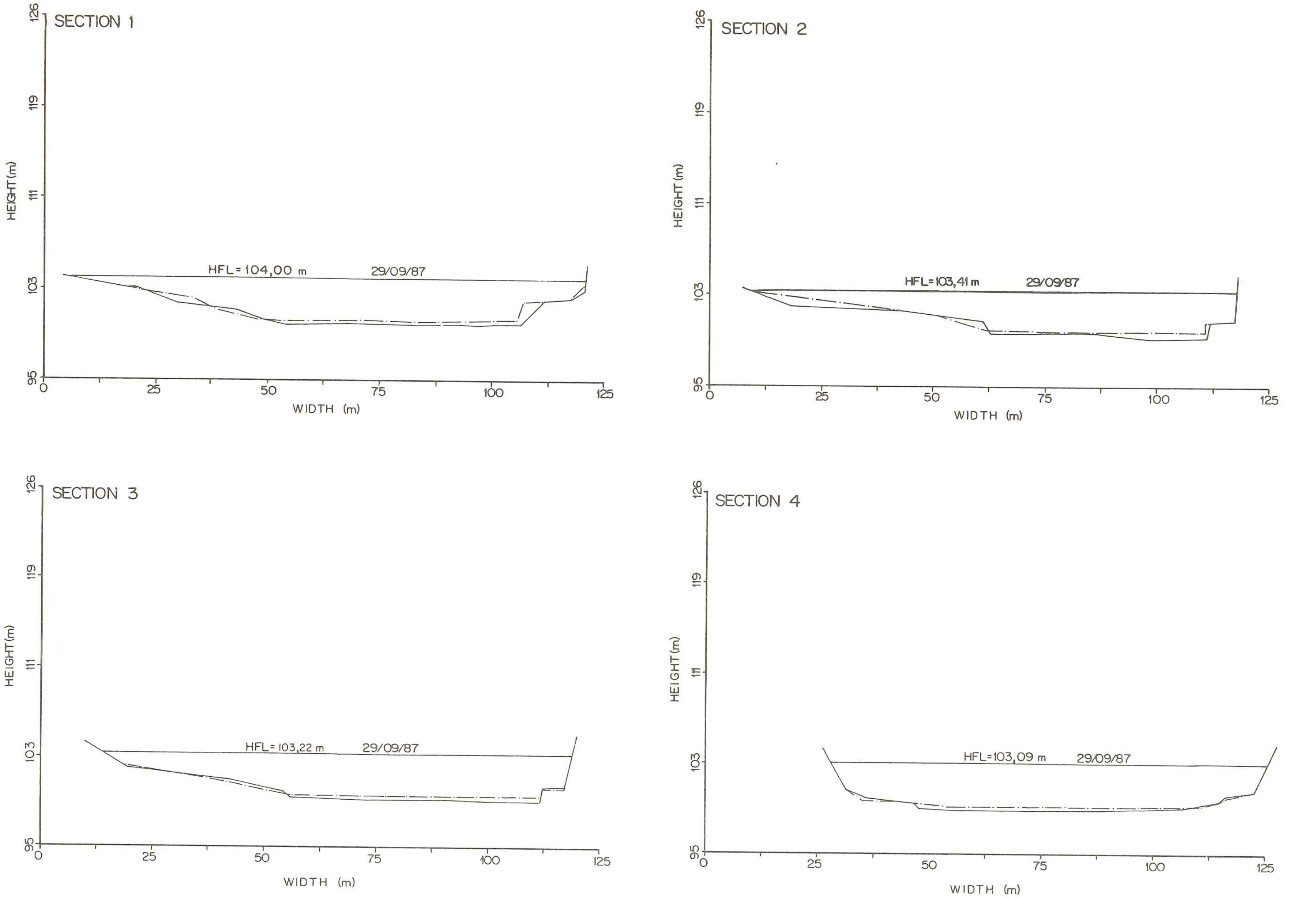


FIG. 7.2.1 A GENERAL COMPARISON OF CROSS SECTION GEOMETRY AT SITE 3, MTAMVUNA RIVER, FOR THE 1959 AND 1987 FLOODS



LEGEND

FIG. 7.2.2 COMPARISON OF CROSS SECTION CHANGES AT SITE 10, MTWALUME RIVER BETWEEN 08/1986 AND 10/1987

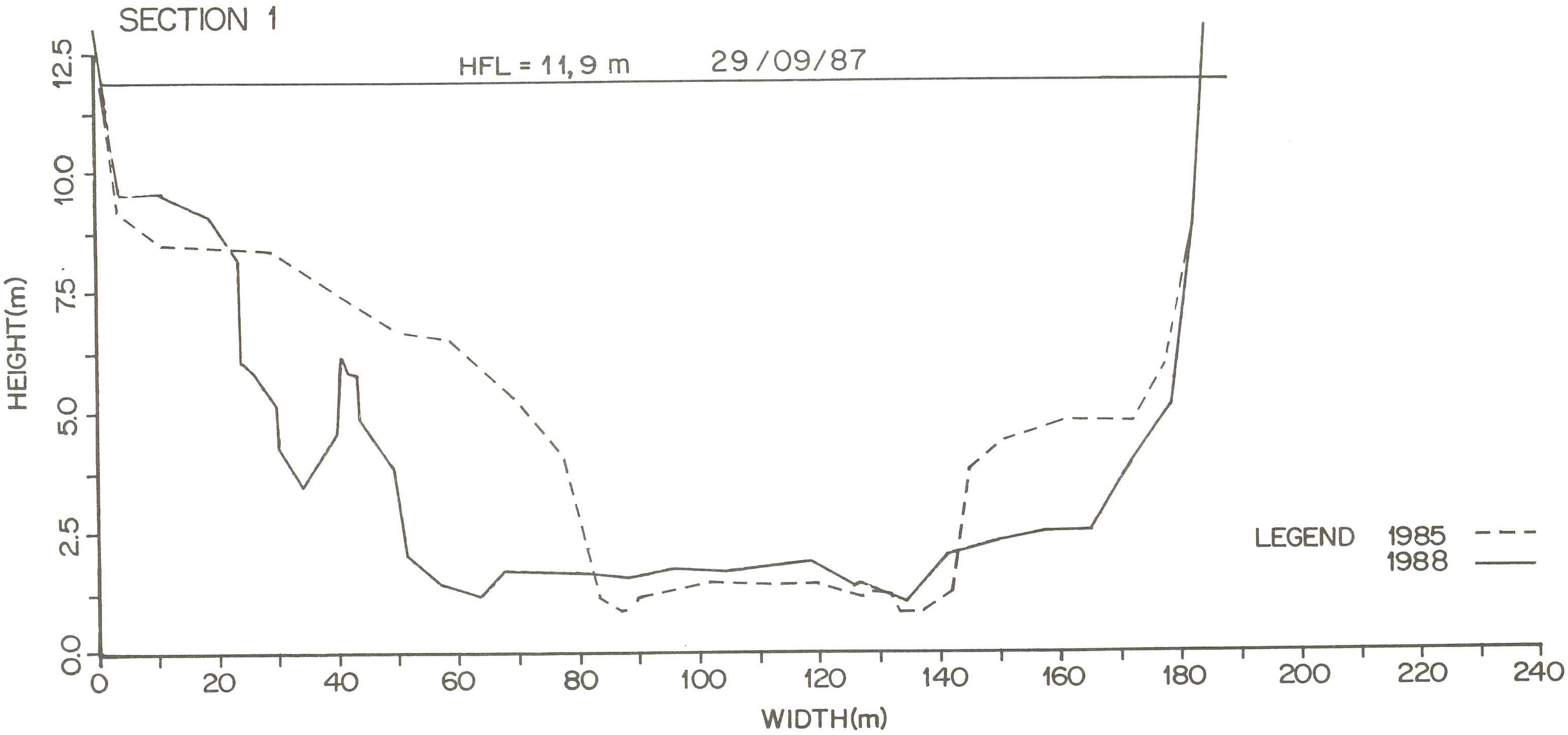


FIG. 7.2.3 COMPARISON OF CROSS SECTION CHANGES AT SITE 15, MKOMAZI RIVER, BETWEEN 1985 AND 1988

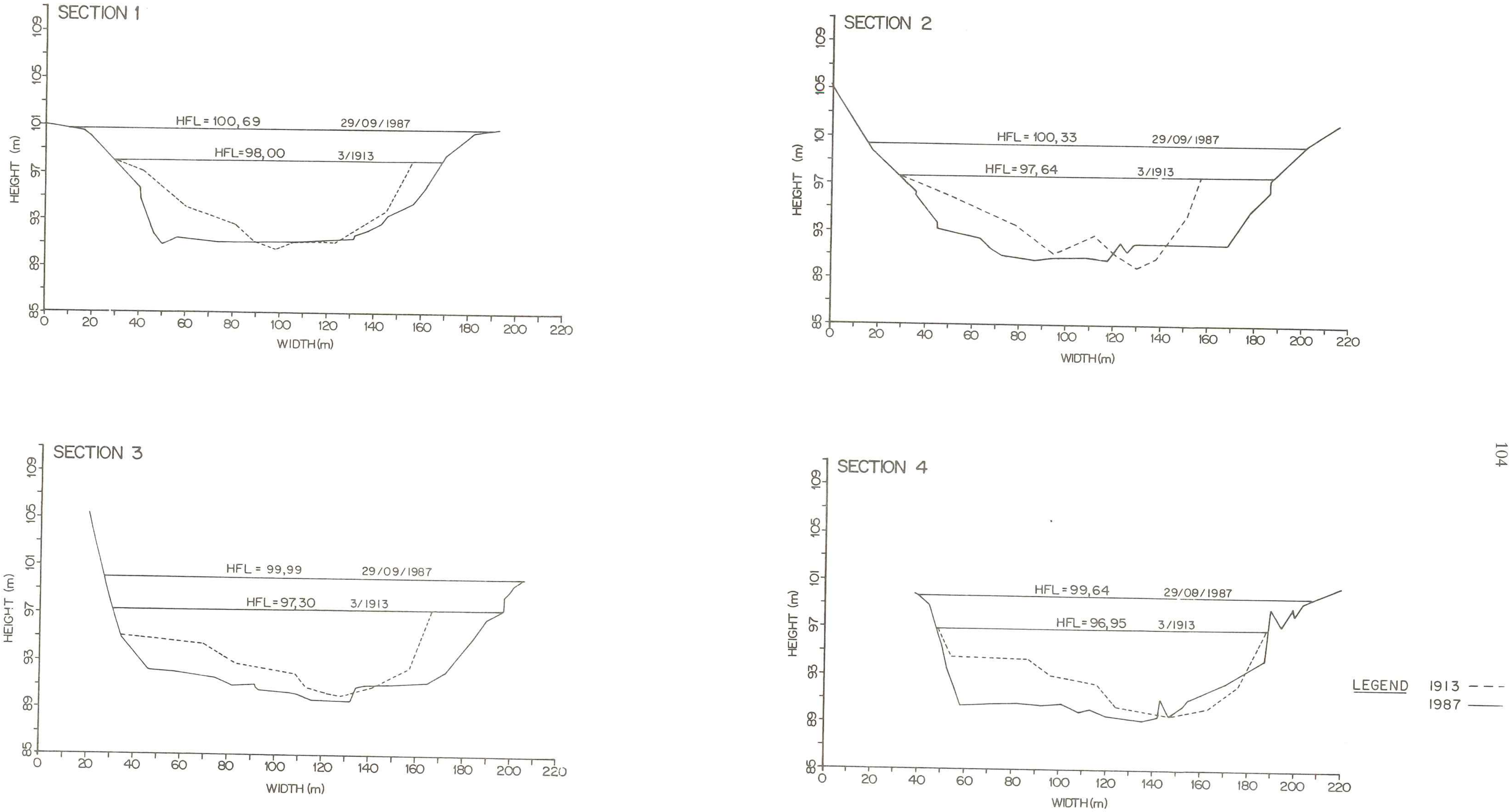


FIG. 7.2.4 A GENERAL COMPARISON OF CROSS SECTION GEOMETRY AT SITE 44, MVOTI RIVER FOR THE 1913 AND 1987 FLOOD

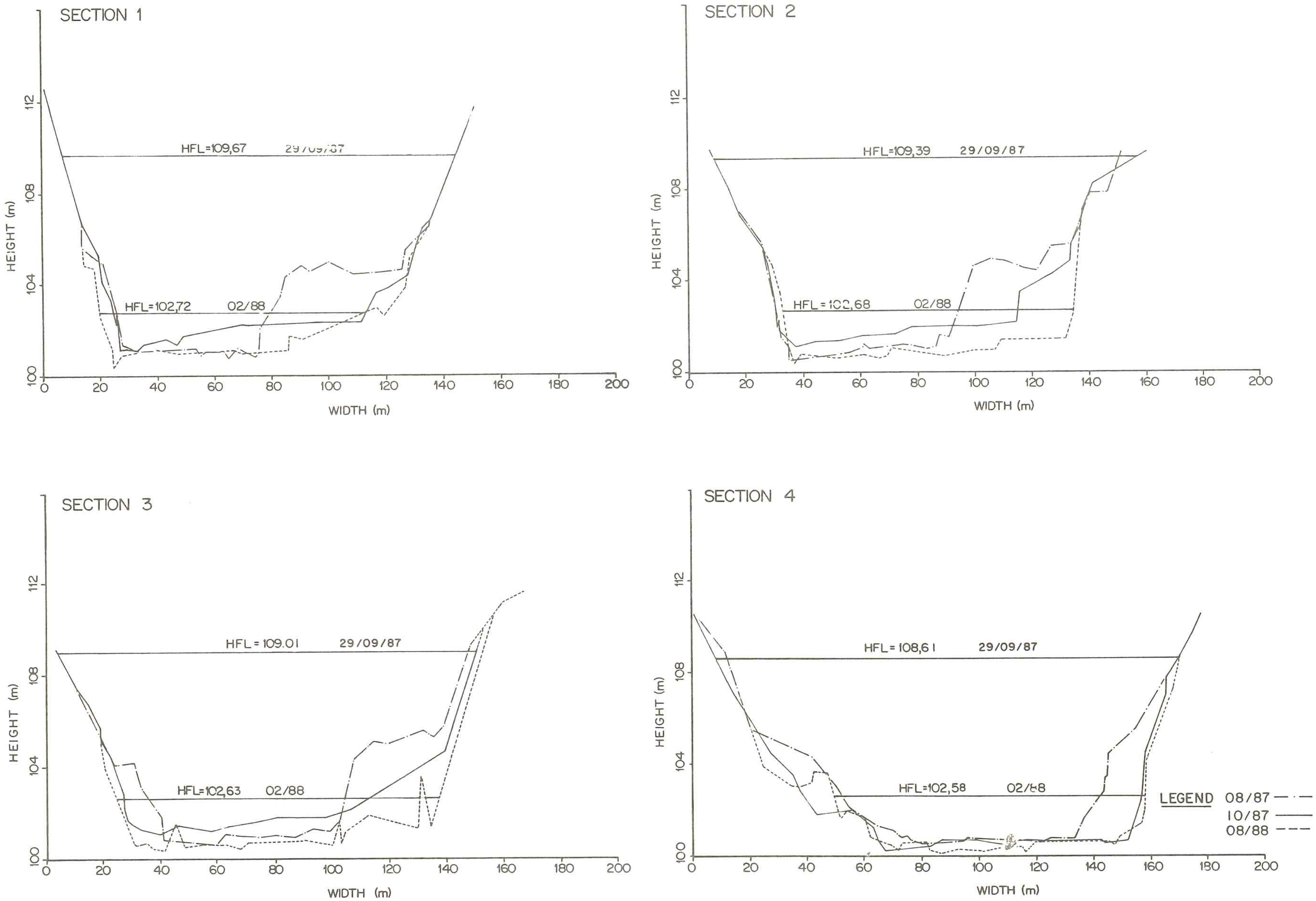


FIG. 7.2.5 COMPARISON OF CROSS SECTION CHANGES AT SITE 80, MHLATUZE RIVER BETWEEN 08/1987, 10/1987 AND 08/1988

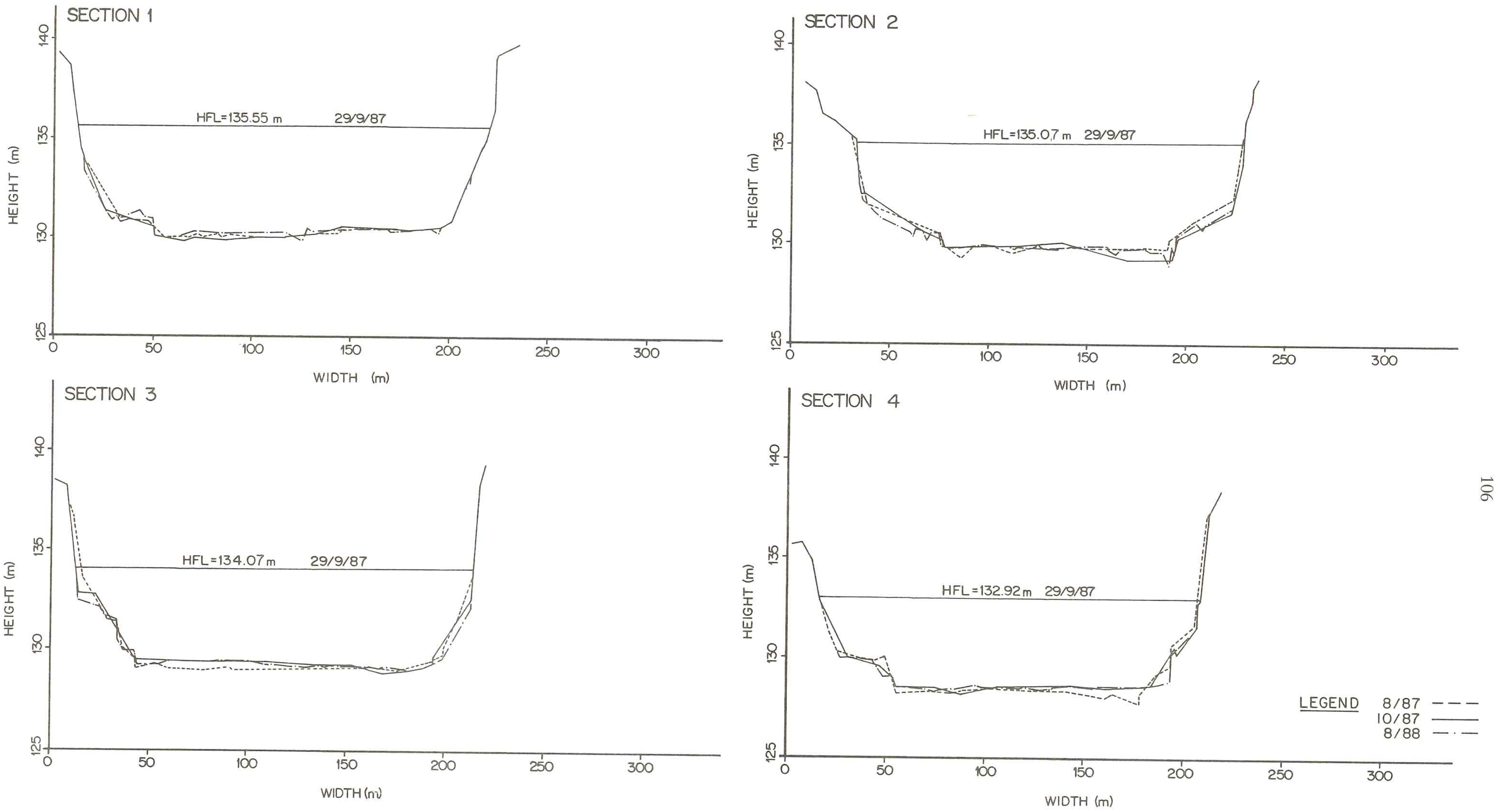


FIG. 7.2.6 COMPARISON OF CROSS SECTION CHANGES AT SITE 86, WHITE MFOLOZI RIVER, BETWEEN 08/1987, 10/1987 AND 08/1988

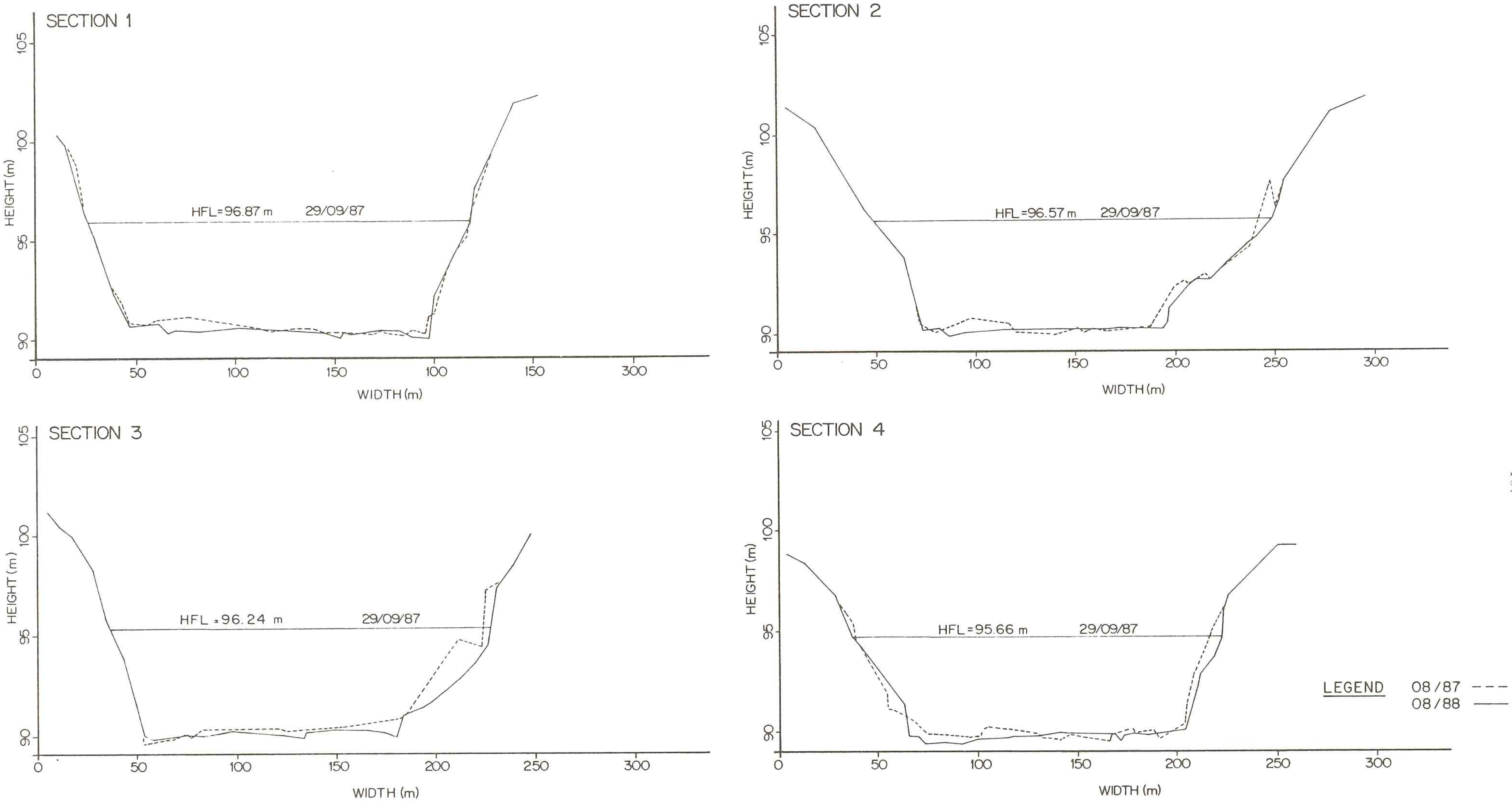


FIG. 7.2.7 COMPARISON OF CROSS SECTION CHANGES AT SITE 98, BLACK MFOLOZI RIVER BETWEEN 09/1987 AND 08/1988

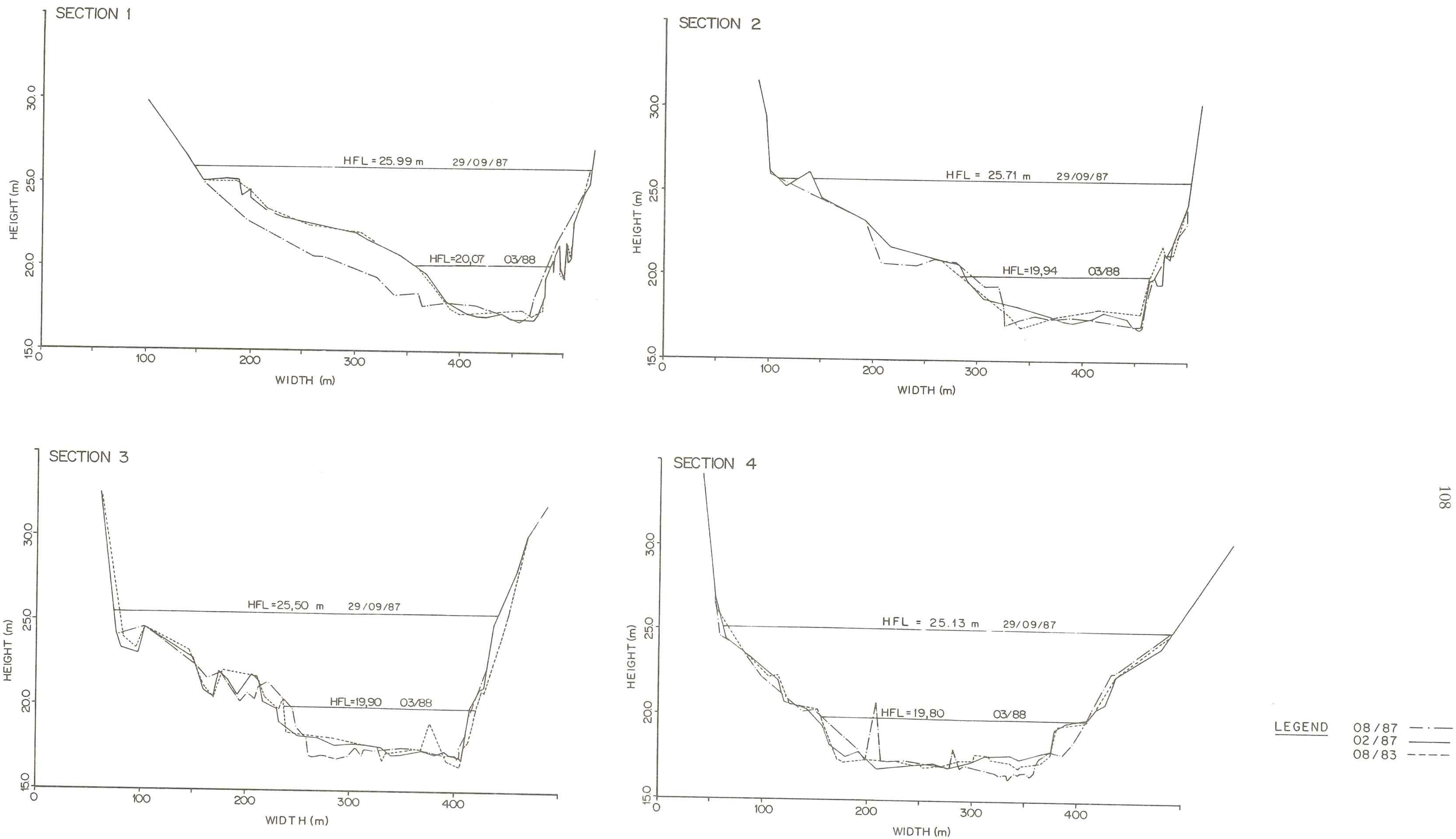


FIG. 7.2.8 COMPARISON OF CROSS SECTION CHANGES AT SITE 91, MFOLOZI RIVER BETWEEN 08/1987 02/1988 AND 08/1988

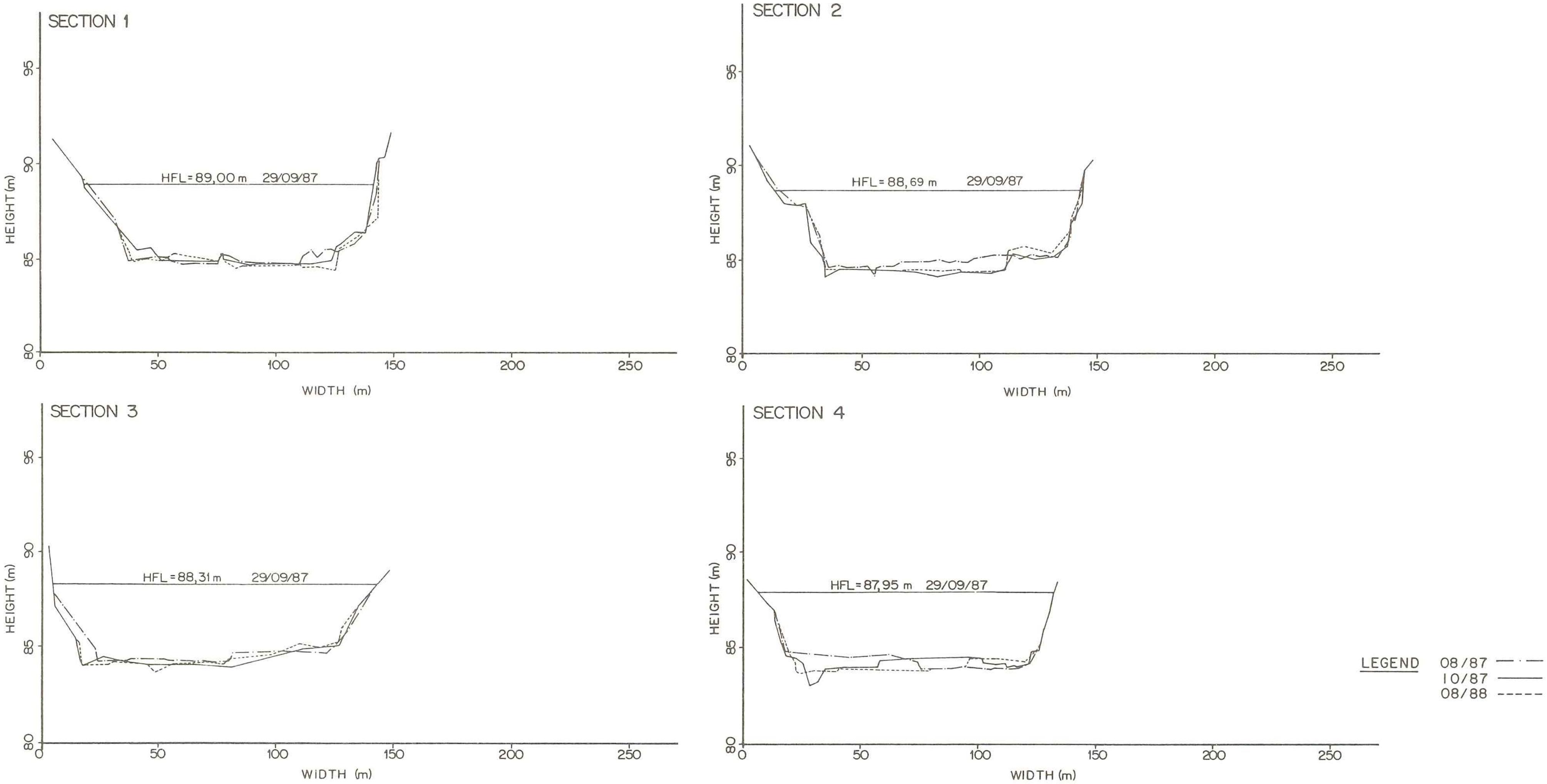


FIG. 7.2.9 COMPARISON OF CROSS SECTION CHANGES AT SITE 97, MKUZE RIVER BETWEEN 08/1987, 10/1987 AND 08/1988

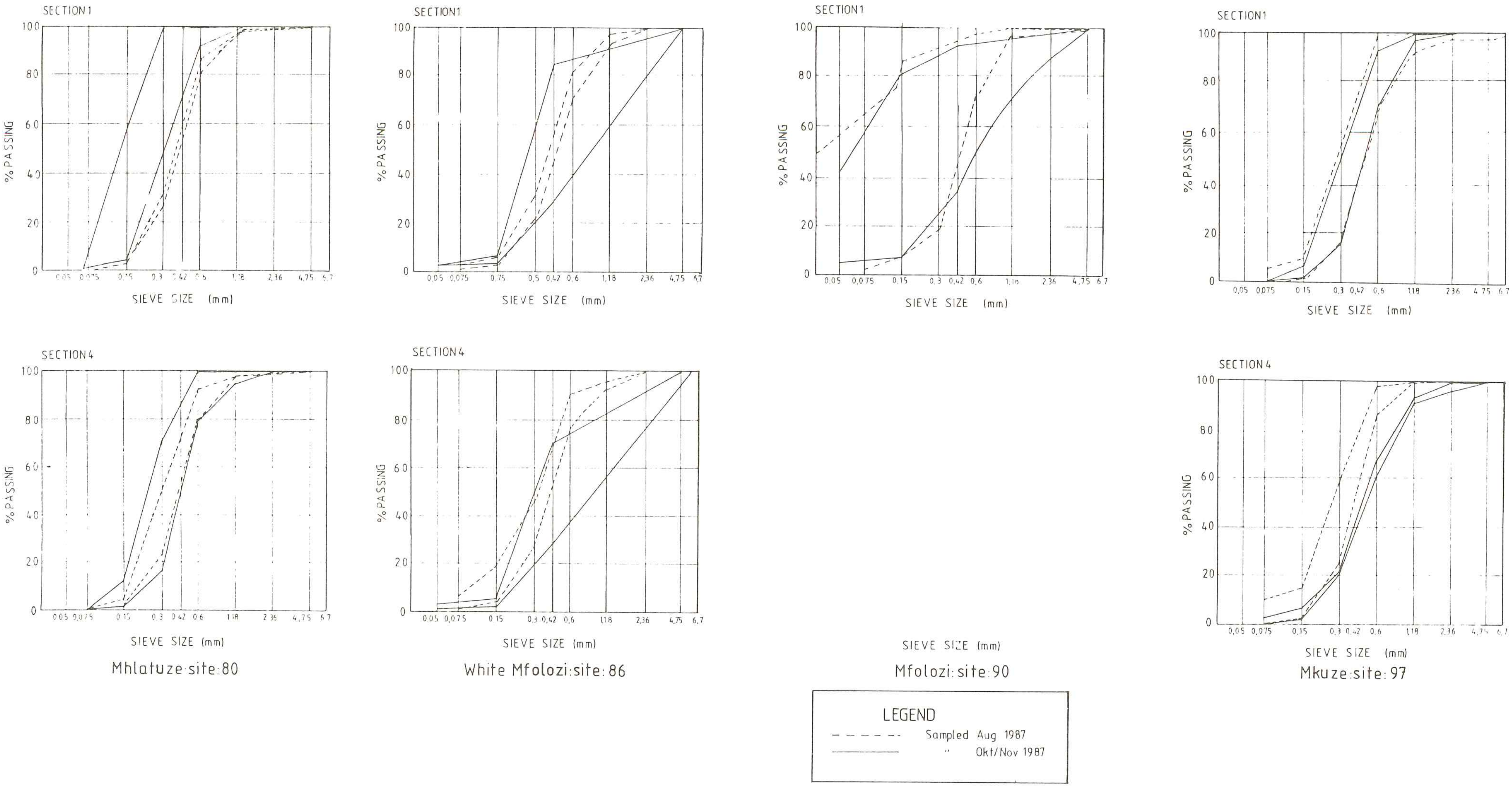
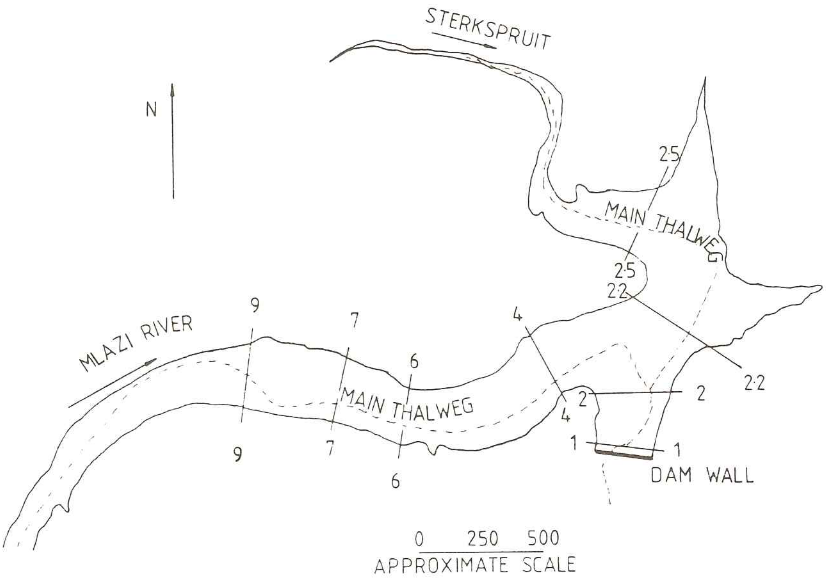
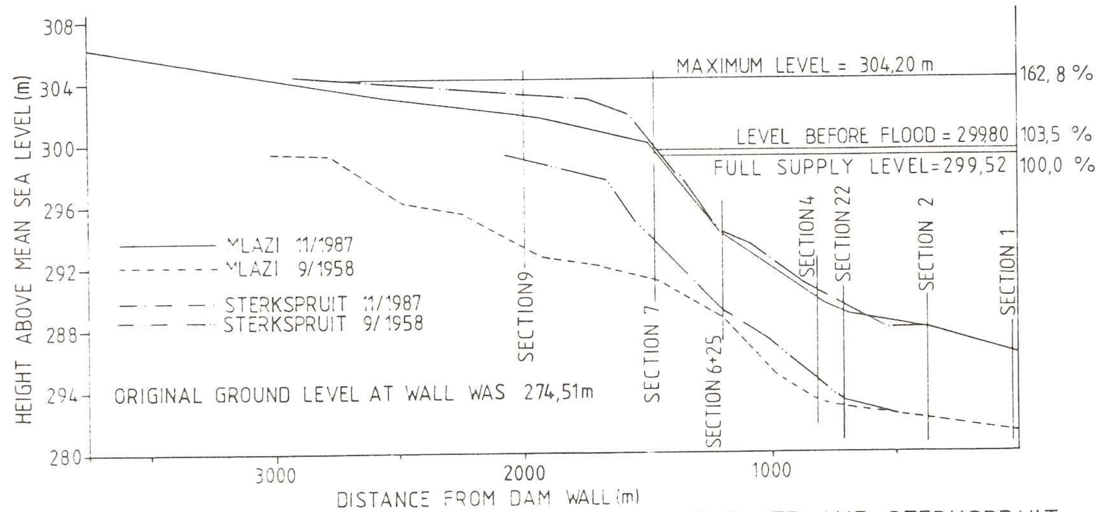


FIG: 7·3 SEDIMENT GRADING ENVELOPE CURVES AT ALLUVIAL RIVERS



PLAN OF SECTIONS



LONGITUDINAL SECTION ALONG CHANNEL-MLAZI RIVER AND STERKSPRUIT

FIG.7·4·1 NSHONGWENI DAM: PLAN AND LONGITUDINAL SECTION

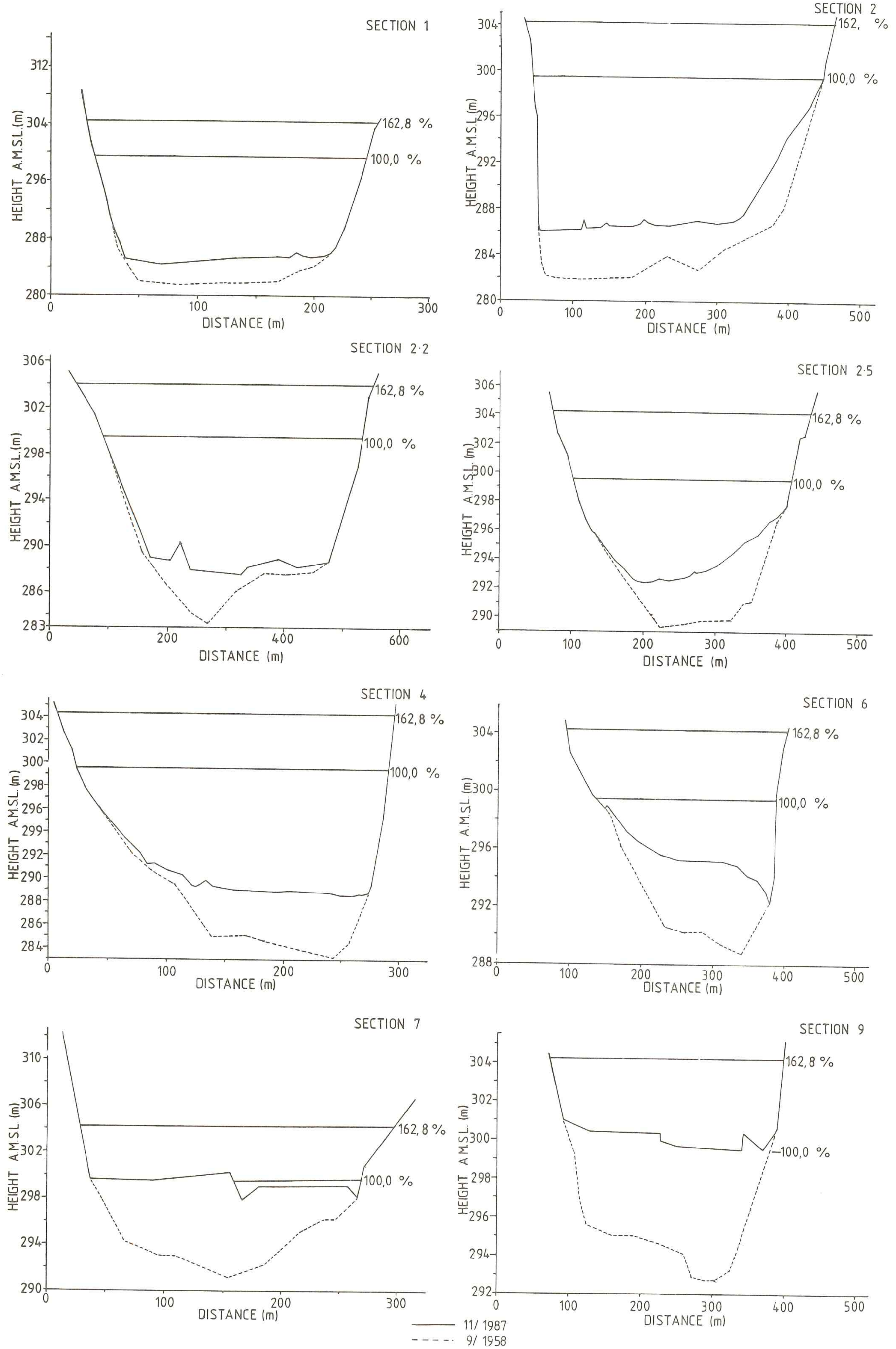
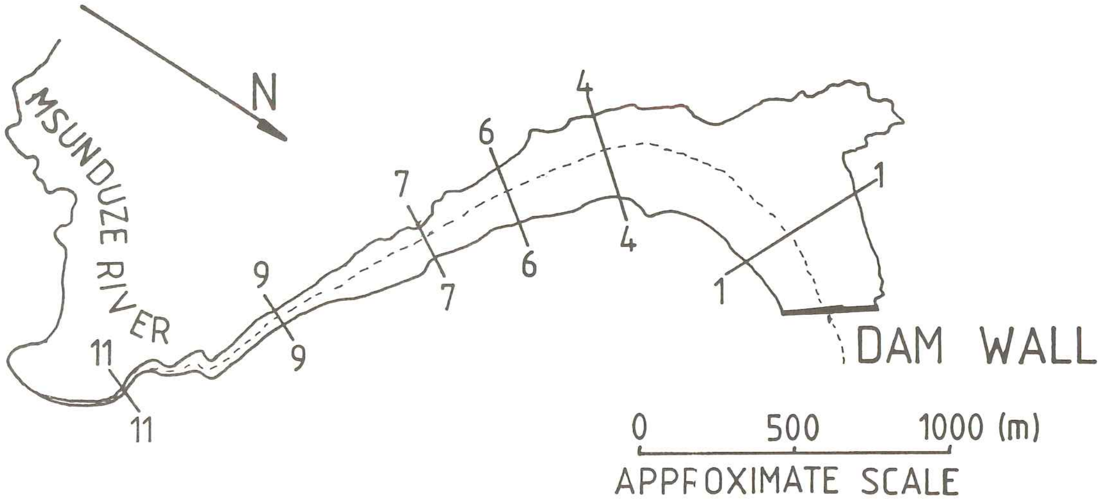
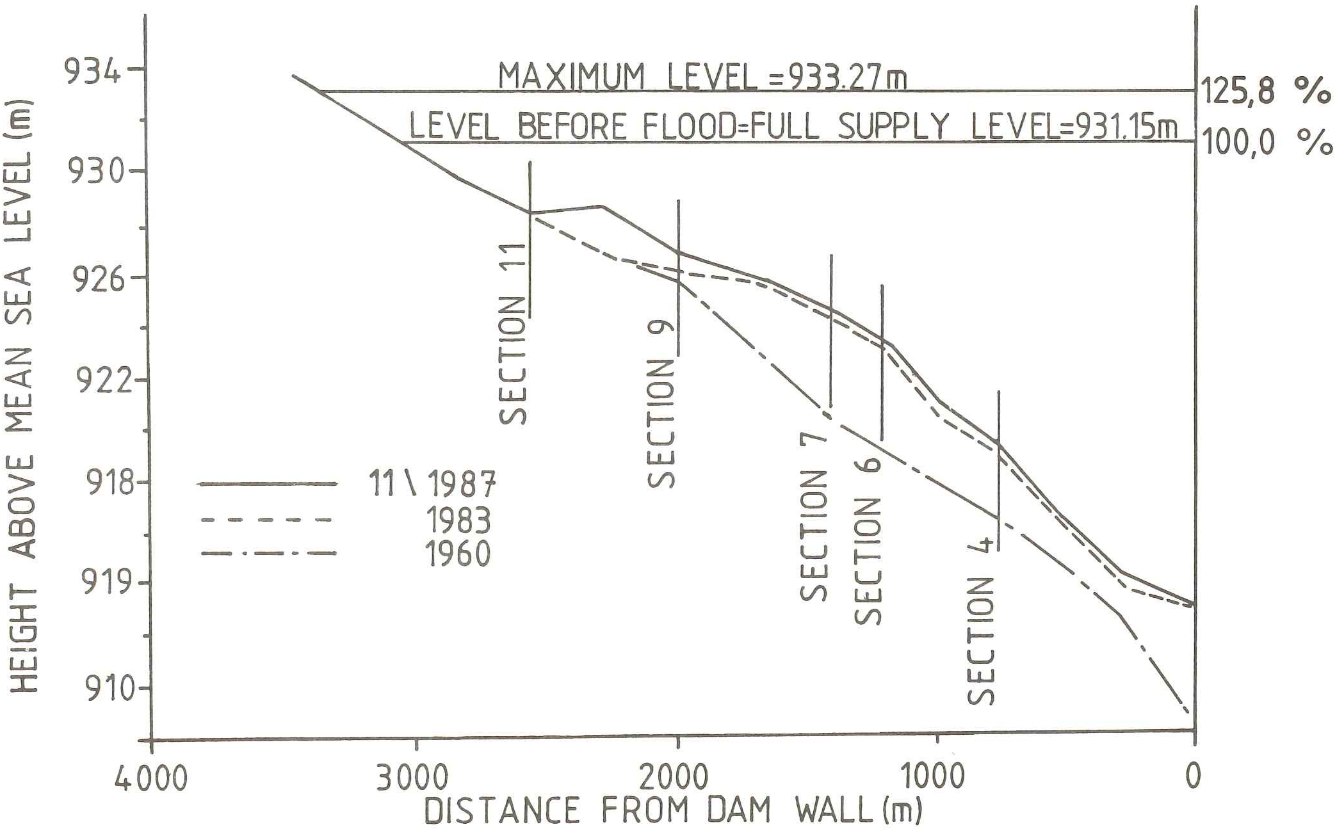


FIG: 7.4.2. NSHONGWENI DAM: CROSS SECTIONS



PLAN OF SECTIONS



LONGITUDINAL SECTIONS ALONG CHANNEL

FIG: 7.4.3 HENLEY DAM: PLAN AND LONGITUDINAL SECTIONS

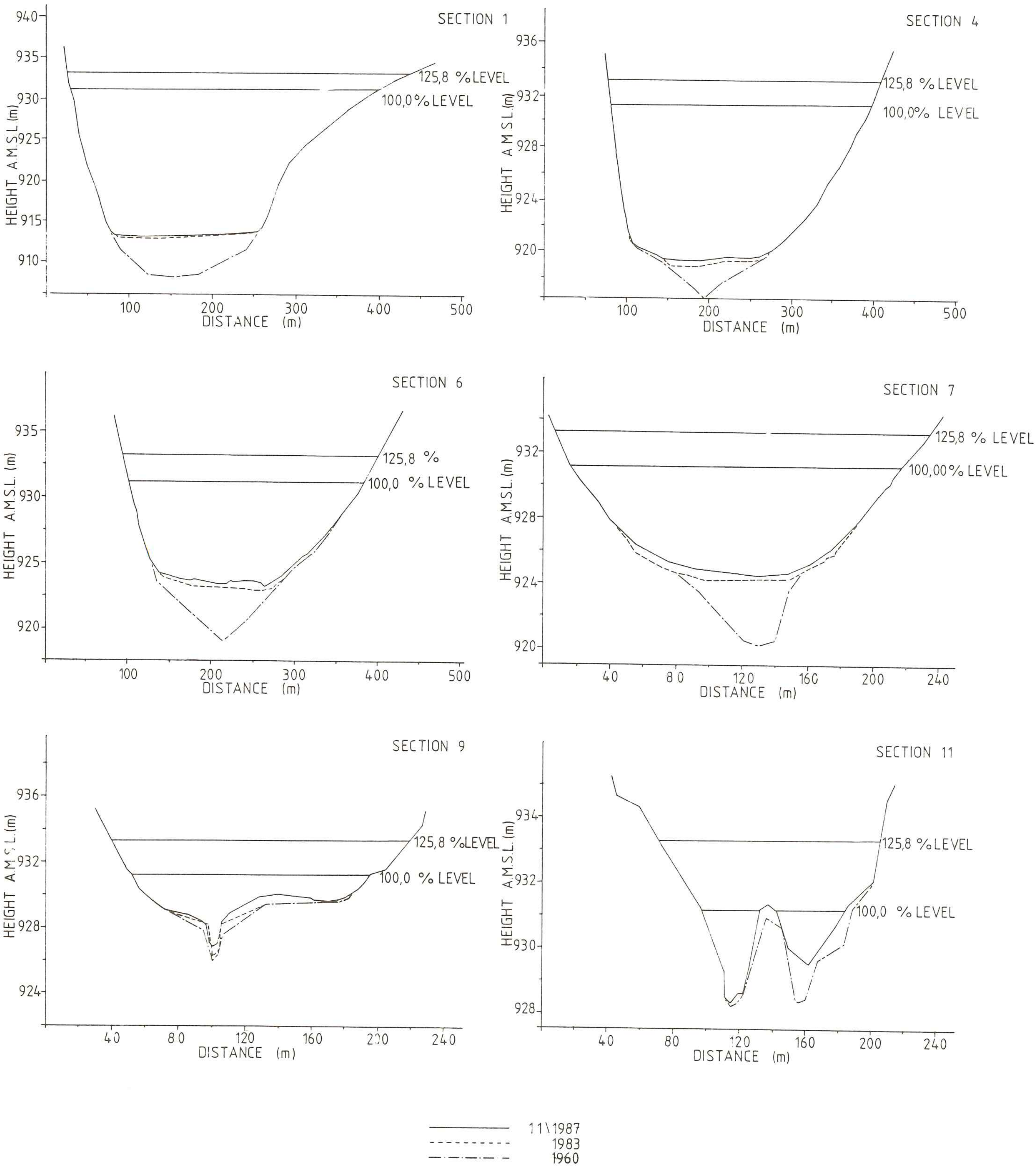
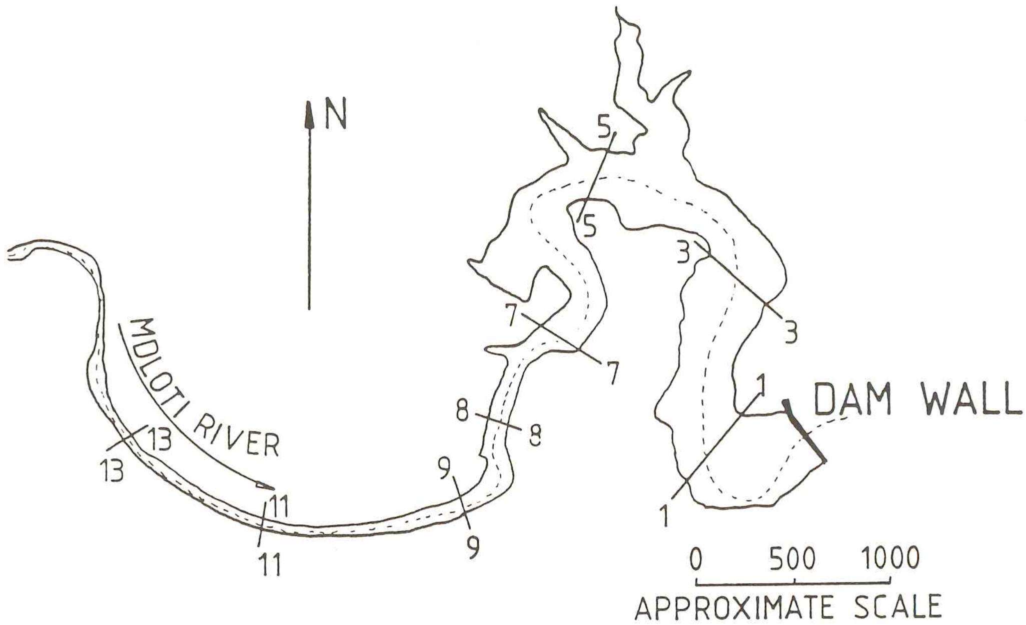
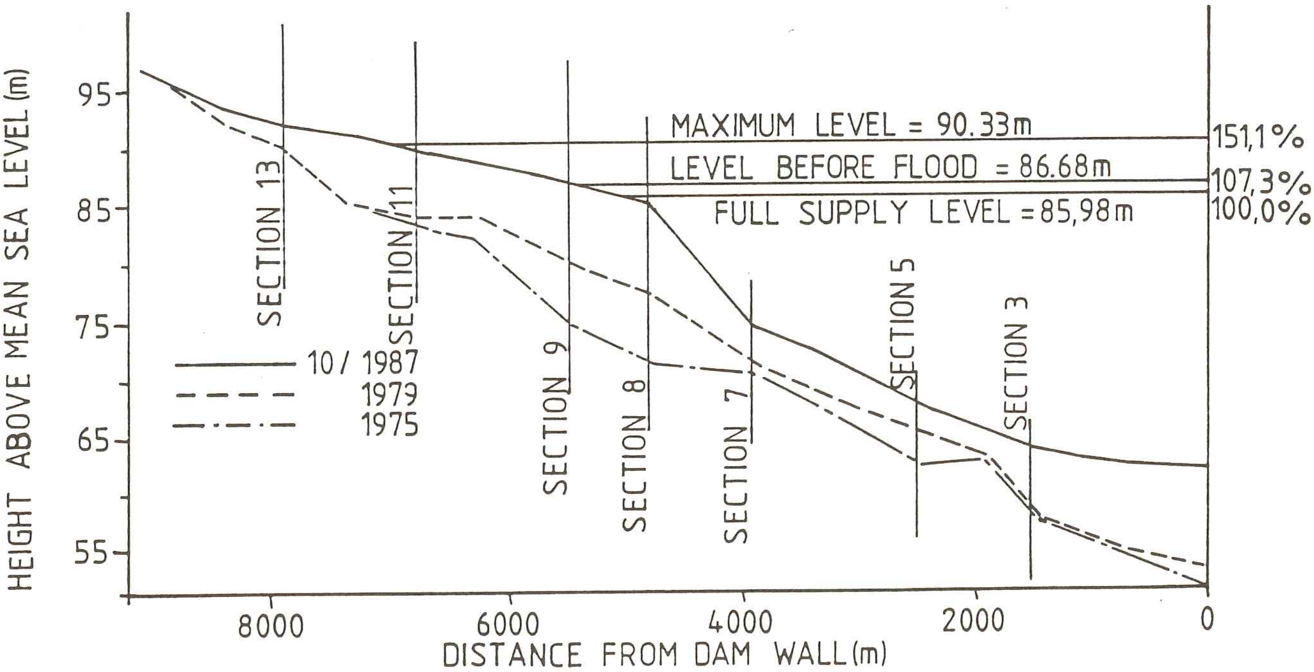


FIG.7.4.4. HENLEY DAM: CROSS SECTIONS



PLAN OF SECTIONS



LONGITUDINAL SECTIONS ALONG CHANNEL

FIG: 7.4.5 HAZELMERE DAM: PLAN AND LONGITUDINAL SECTIONS

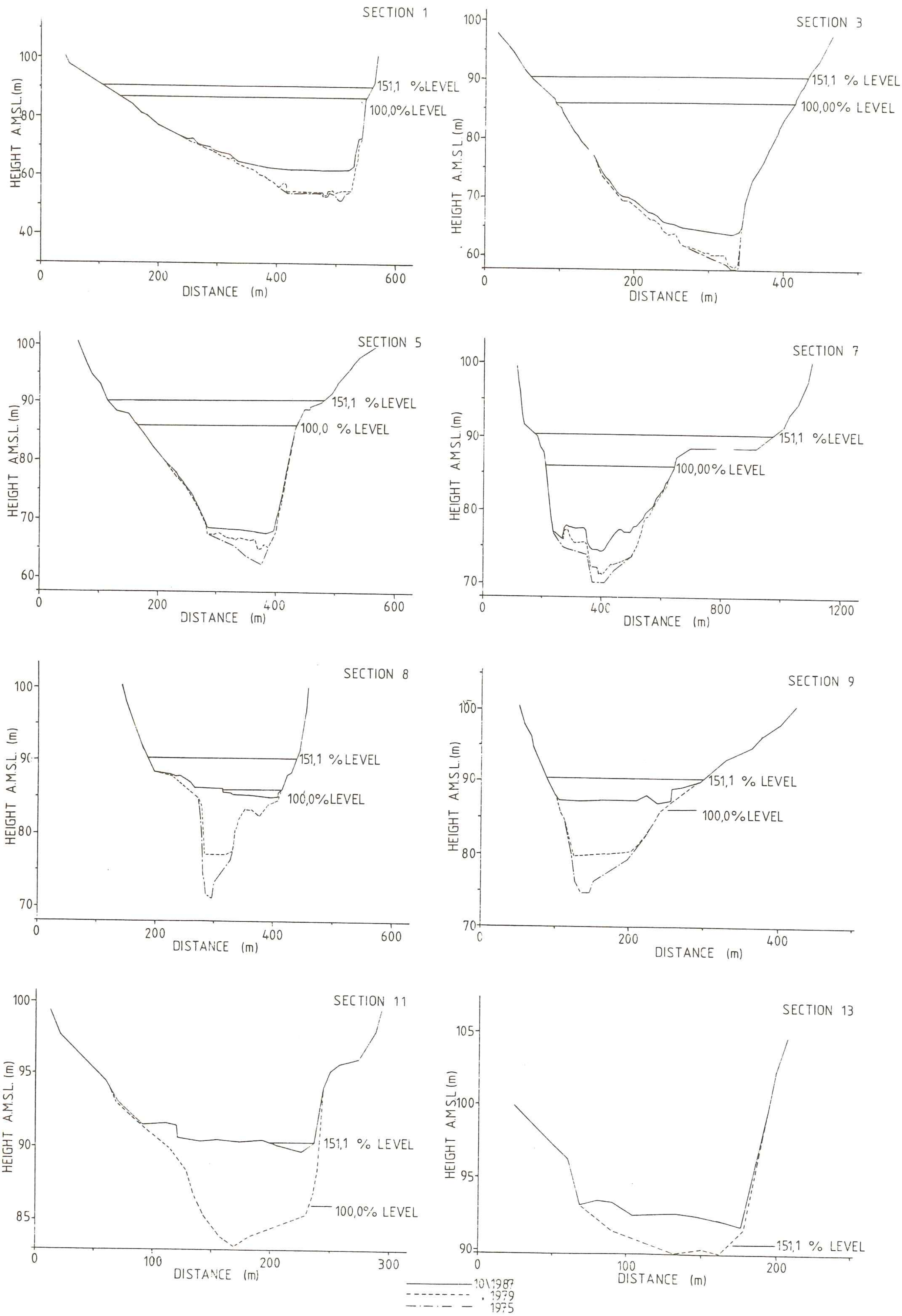
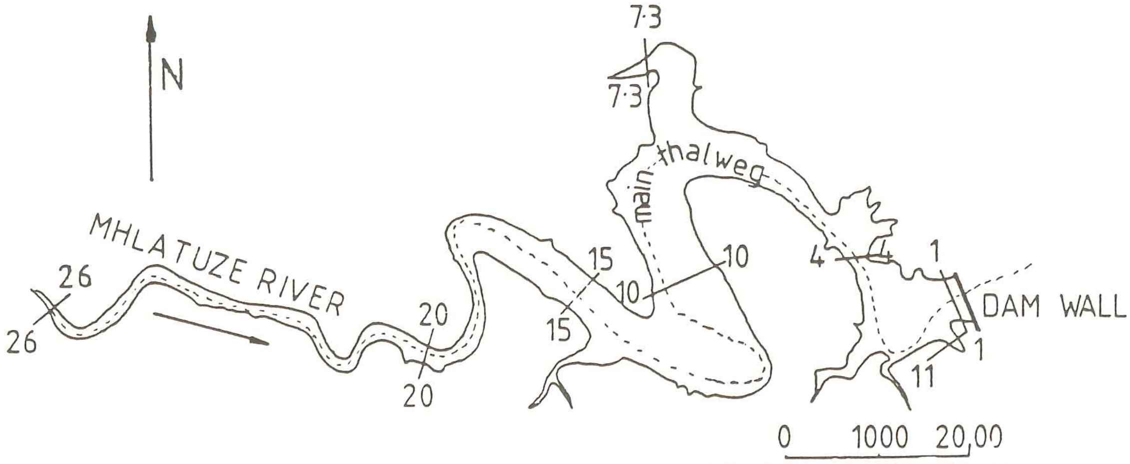
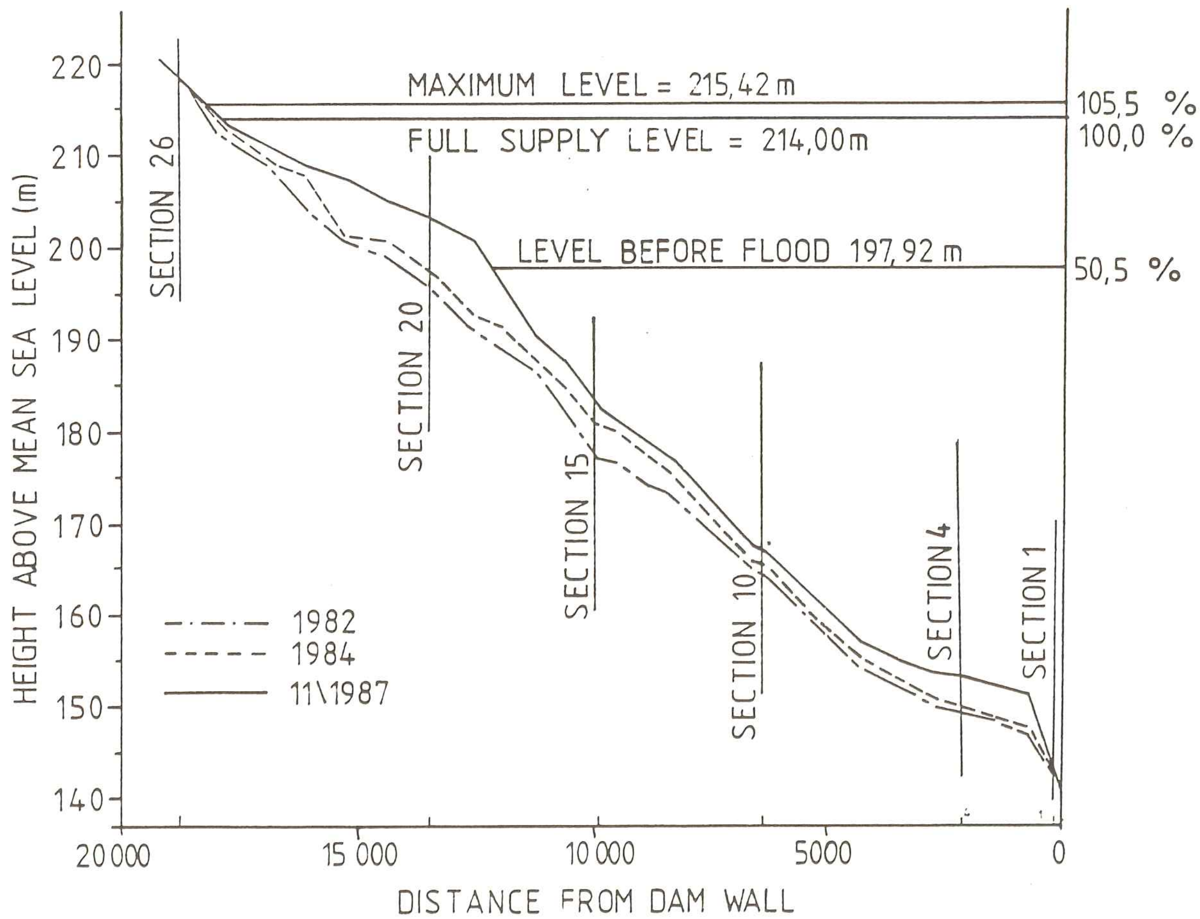


FIG: 7·4·6 _ HAZELMERE DAM : CROSS SECTIONS



PLAN OF SECTIONS



LONGITUDINAL SECTION ALONG CHANNEL

FIG:7.4.7. GOEDERTROUW DAM: PLAN AND LONGITUDINAL SECTION

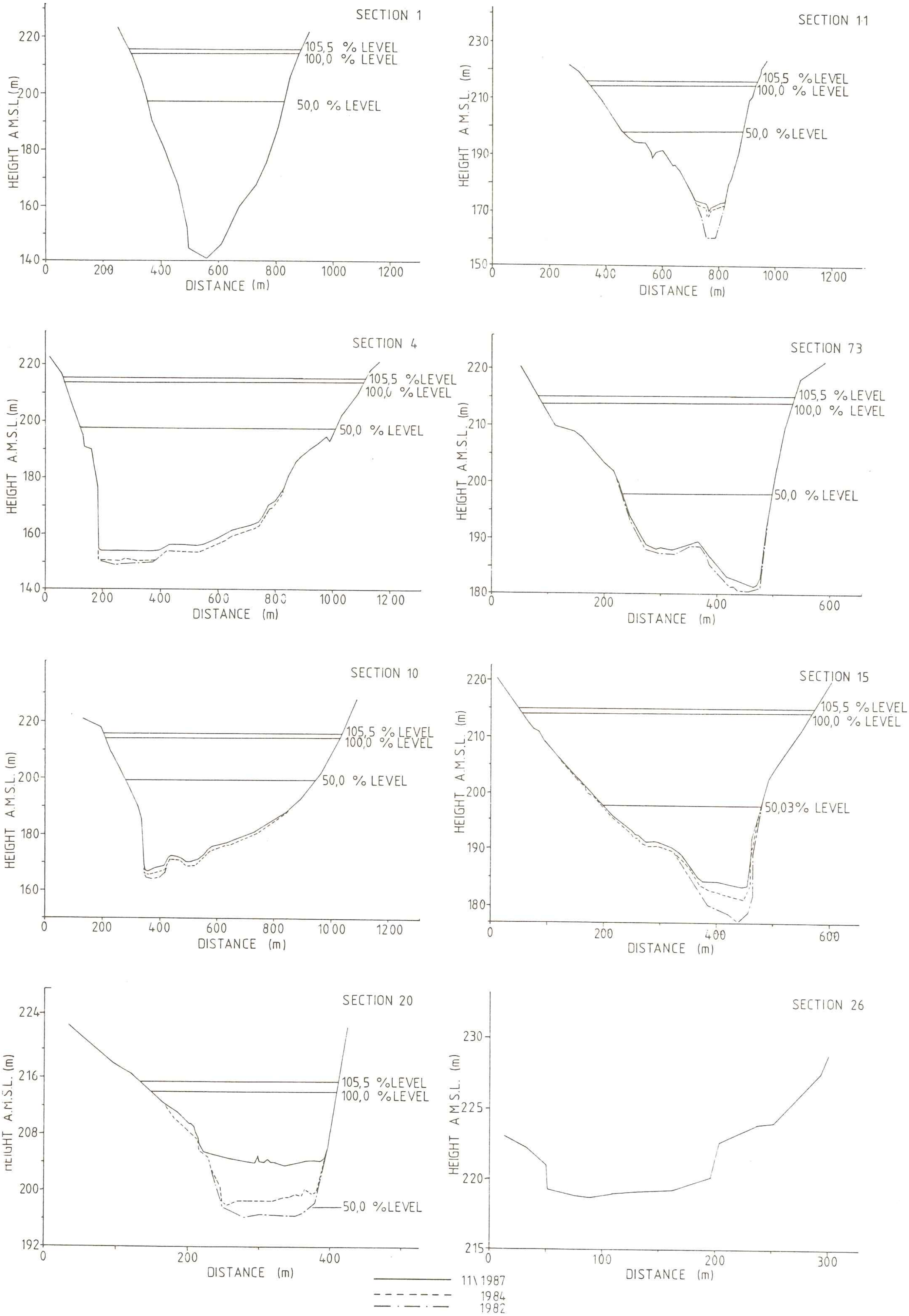
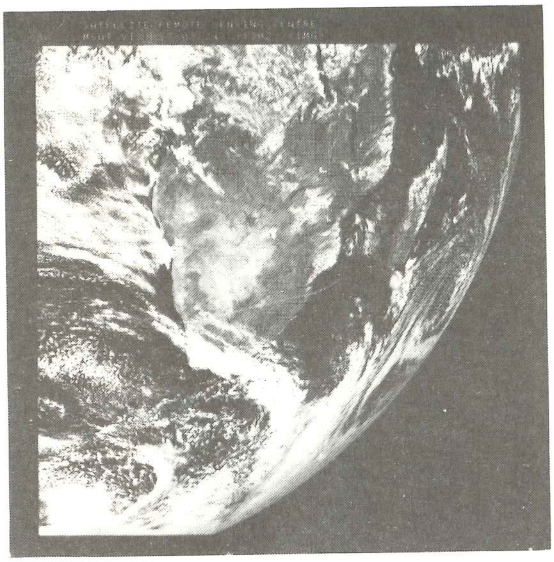
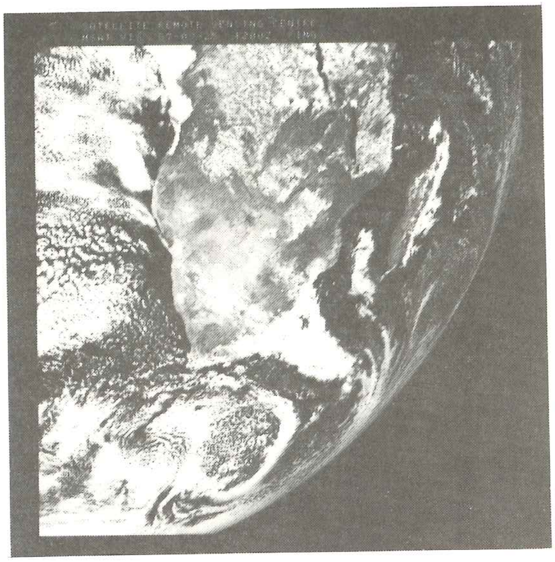


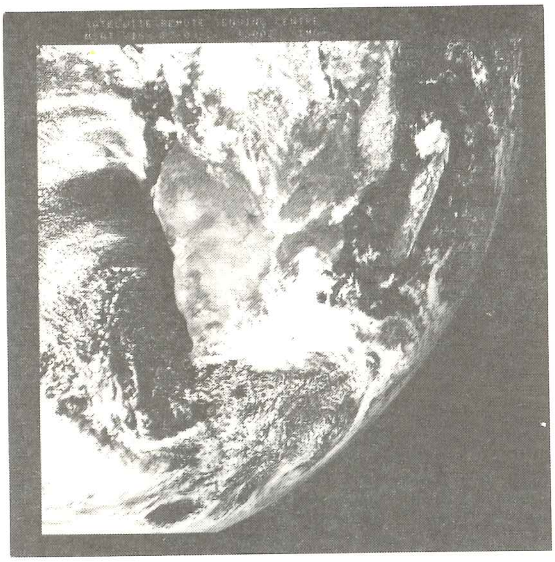
FIG: 7.4.8 GOEDERTROUW DAM



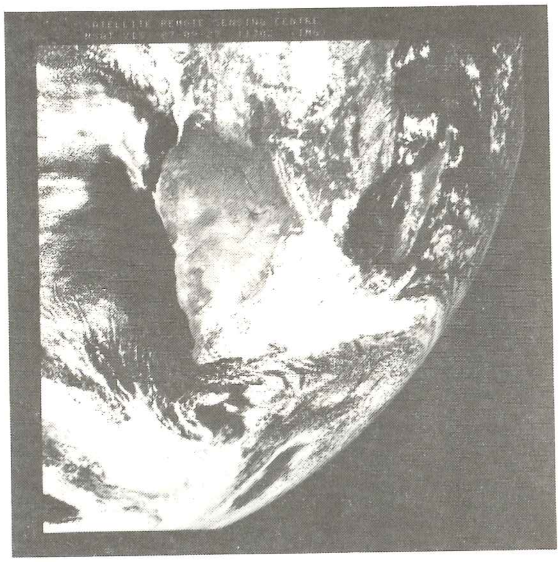
(a) 24th September, 1987



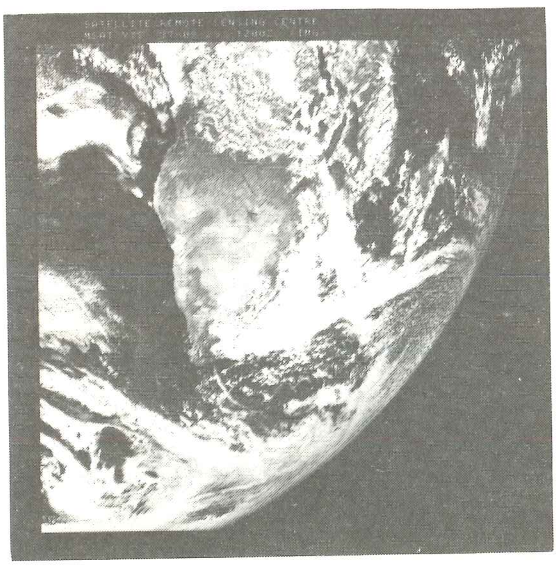
(b) 25th September, 1987



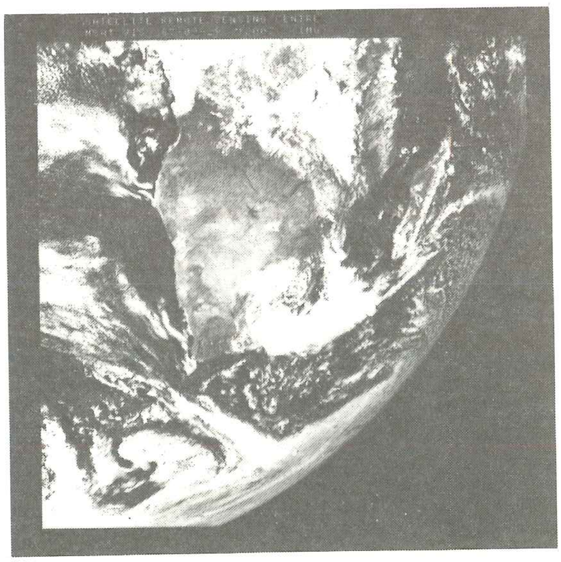
(c) 26th September, 1987



(d) 27th September, 1987



(e) 28th September, 1987

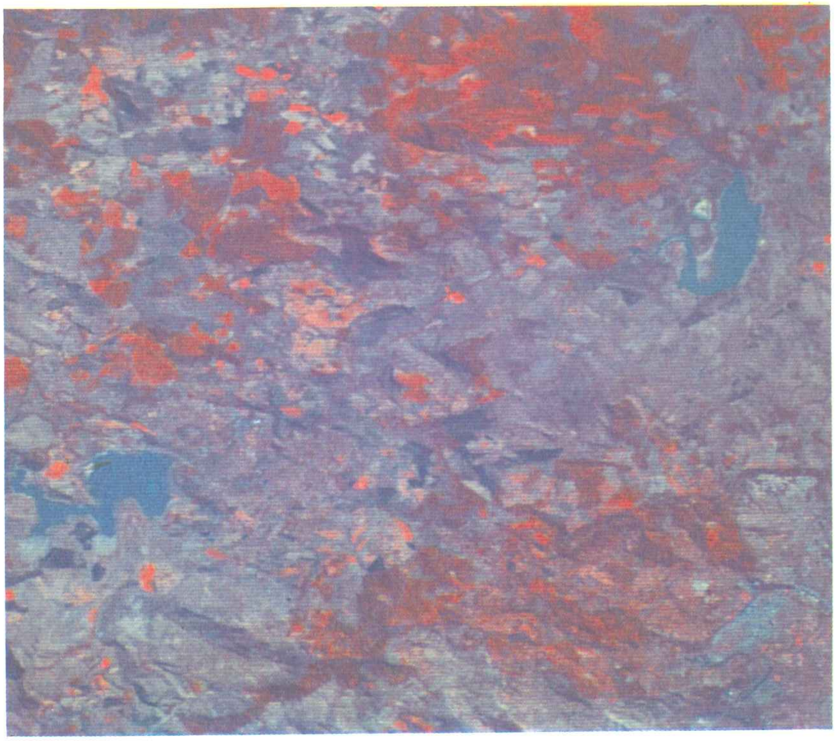


(f) 29th September, 1987

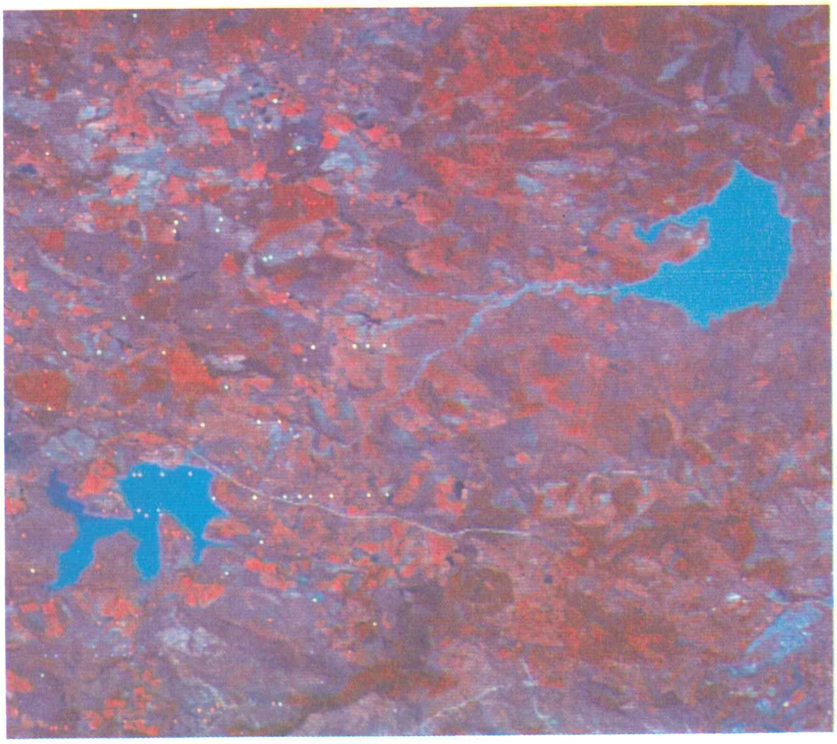
1 (a-f). SATELLITE PHOTOGRAPHS (AT 12h00 S.A.S.T.)

2. LANDSAT image of the Mzimkulu- and Mzimkulwana rivers, October 1987. The Mtwalume River may be seen faintly at the top of this image (Hydrological Research Institute - HRI)

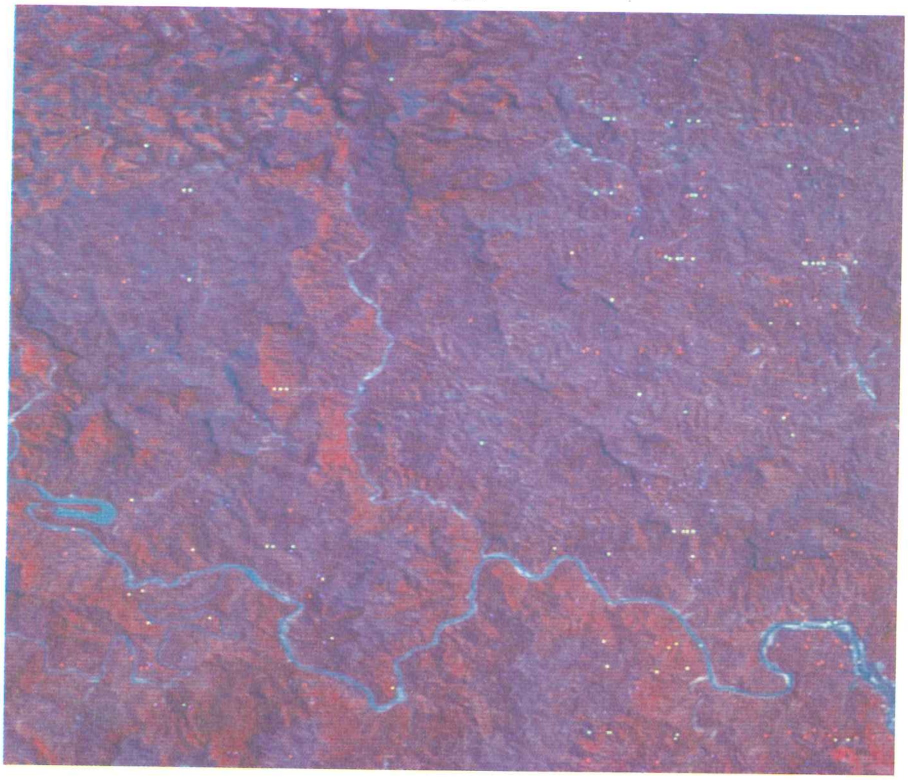
3. LANDSAT image of the Mkomazi- Lovu- and Mlazi rivers, October 1987 (HRI)



4. (a) LANDSAT image of the Mgeni River prior to the September 1987 floods. Midmar Dam (left) and Albert Falls Dam (right) are clearly shown in the image (HRI)

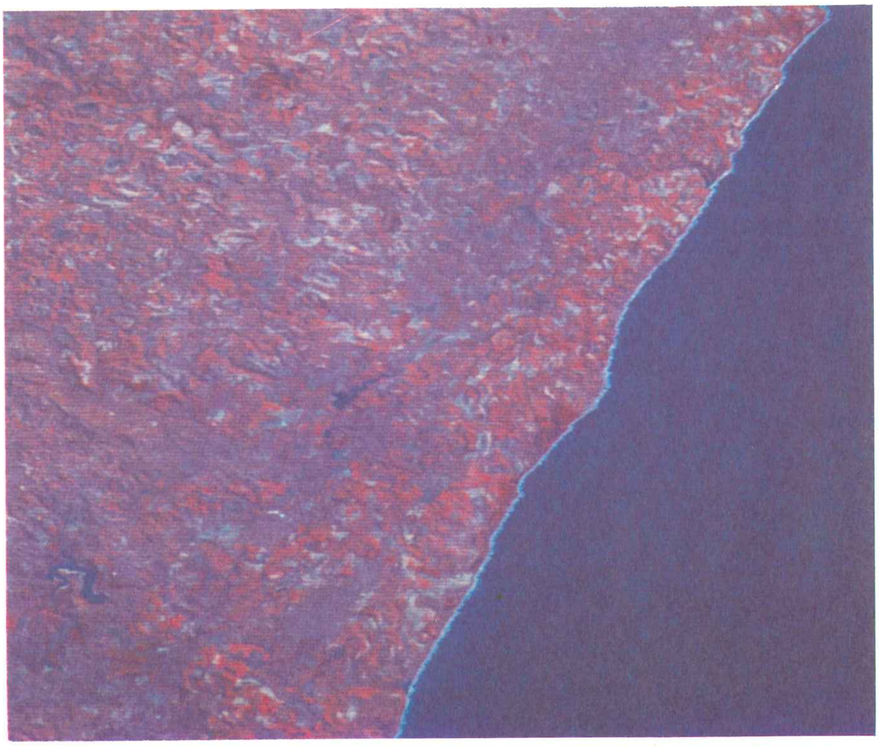


4. (b) LANDSAT image of the Mgeni River, October 1987. The lighter blue colour of the Midmar- and Albert Falls dams indicate the increased turbidity of the water (HRI)

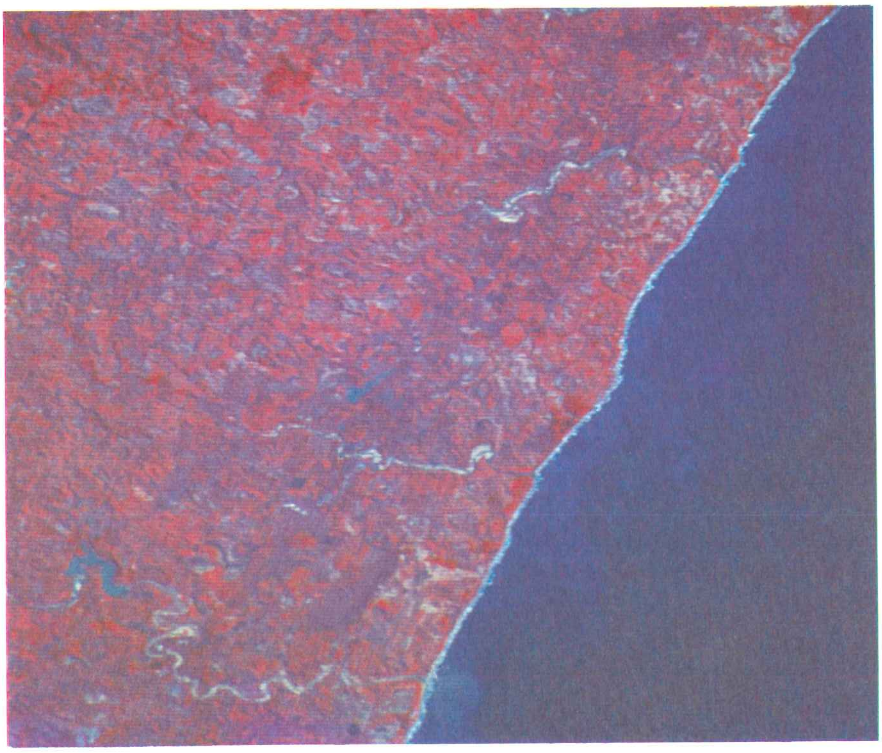


5. LANDSAT image of the Mgeni River between Nagle- and Inanda dams, October 1987. The Msunduze River is seen flowing in to the Mgeni just downstream of Nagle Dam. The Mqeku River is clearly shown flowing in from the North in the centre of the image (HRI)

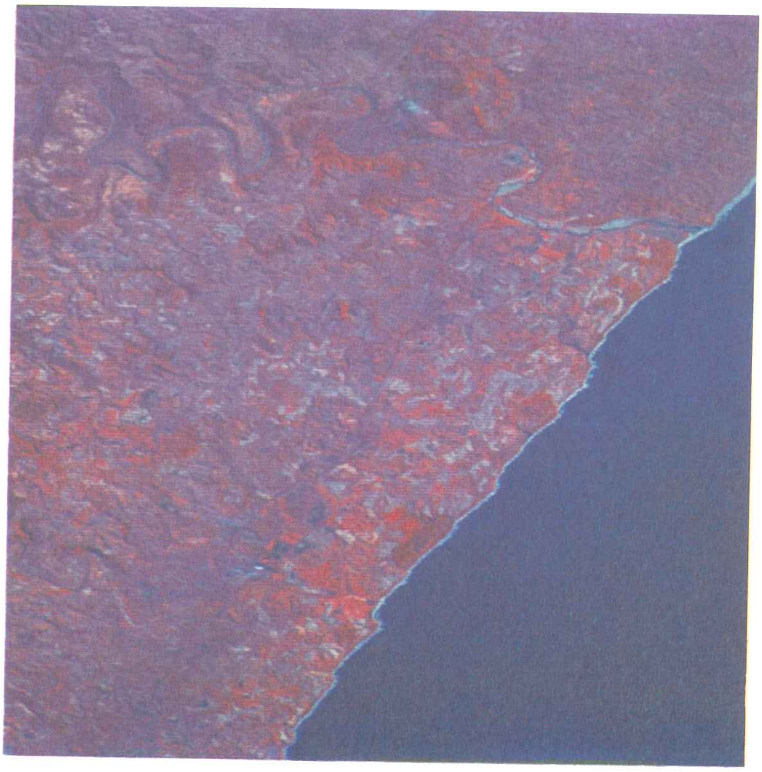
6. LANDSAT image of the Mgeni River between Inanda Dam and the Indian Ocean, October 1987. The removal of the island in the Mgeni River mouth is clear, even at this small scale. The Mlazi River is seen to the South of Durban Harbour (HRI)



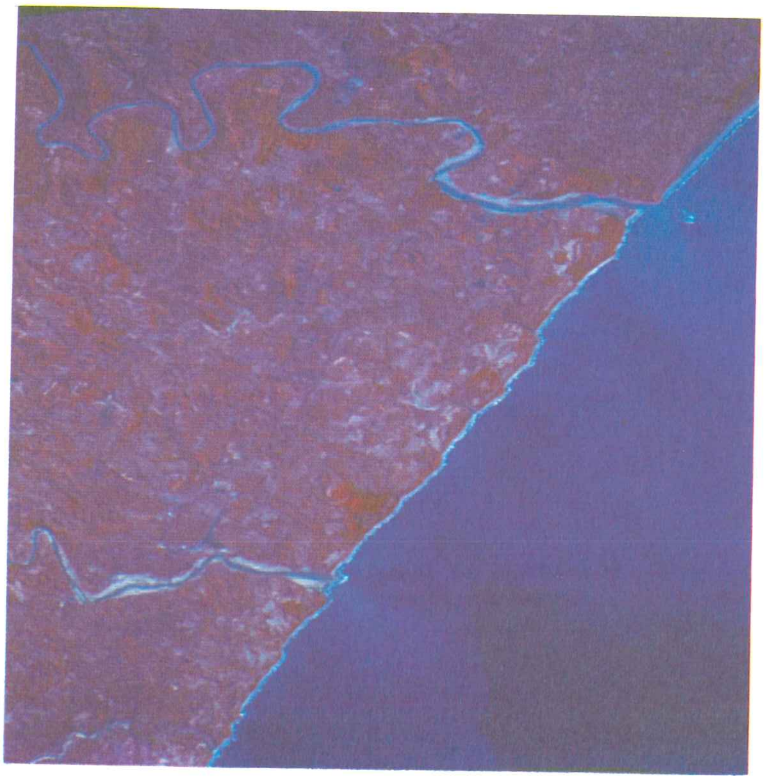
7. (a) LANDSAT image of the Mdloti- and Mvoti rivers prior to the September 1987 floods (HRI)



7. (b) LANDSAT image of the Mdloti- and Mvoti rivers, October 1987 (HRI)



8. (a) LANDSAT image of the Mvoti- and Tugela rivers prior to the September 1987 floods (HRI)



8. (b) LANDSAT image of the Mvoti- and Tugela rivers, October 1987. The enlargement of the river channels are very clear for both rivers and also a large turbid area in the sea (HRI)

9. (a) Mkomazi River mouth: Pre-flood aerial view, 10 July 1985 (Photograph by C.J.H. Armstrong, Aerial Photographic Service. Supplied by J.E. Perry, CSIR, Stellenbosch)

9. (b) Mkomazi River mouth: Post flood aerial view, 30 September 1987 (C.J.H. Armstrong)

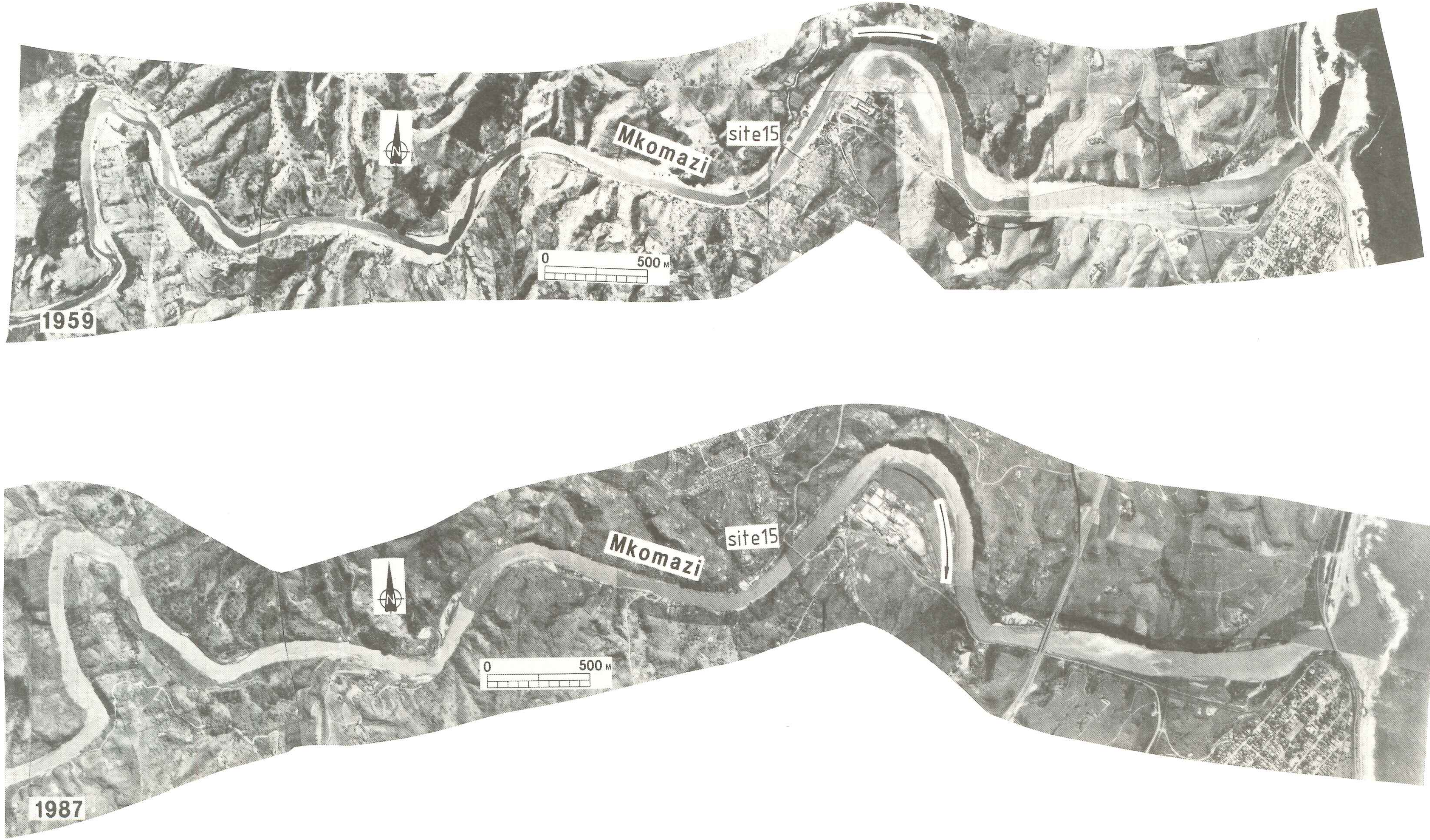
10. (a) Lovu River mouth: Pre-flood aerial view, 10 July 1985 (C.J.H. Armstrong)

10. (b) Lovu River mouth: Post flood aerial view, 30 September 1987 (C.J.H. Armstrong)

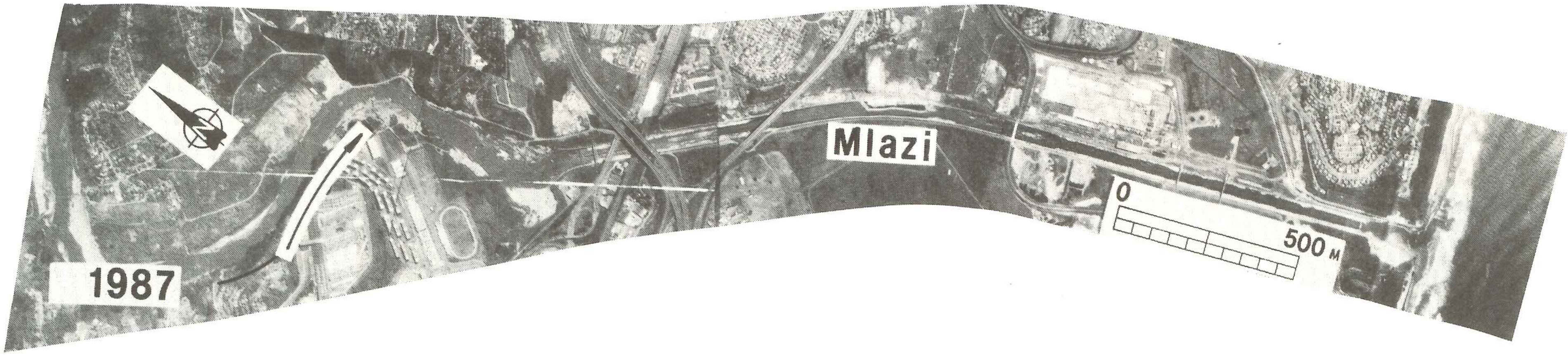
11. (a) Mvoti River mouth: Pre-flood aerial view, 17 July 1985 (C.J.H. Armstrong)

11. (b) Mvoti River mouth: Post flood aerial view, 30 September 1987 (C.J.H. Armstrong)

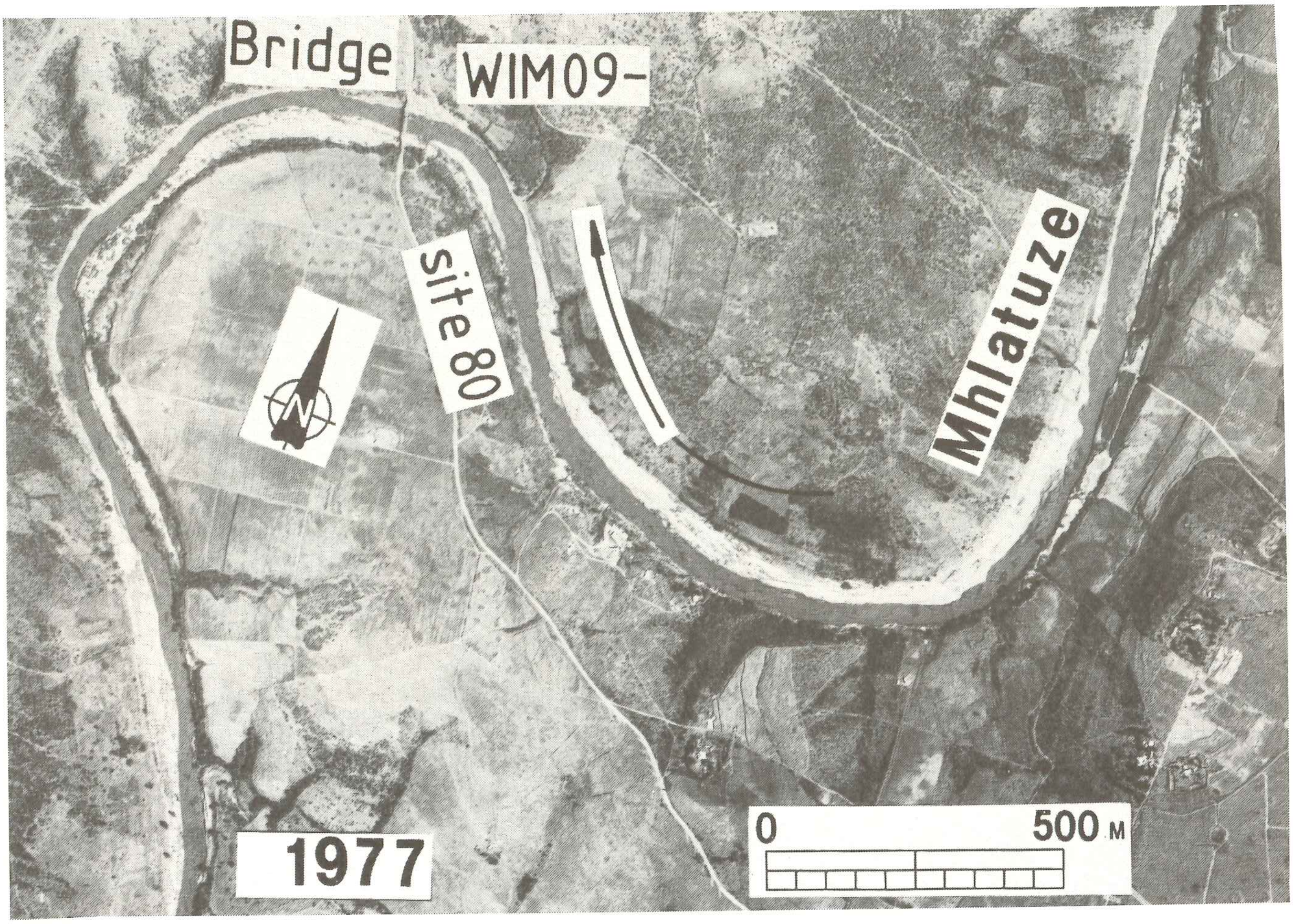
12. Mzimkulu River: aerial photographs taken of Site 9 after the 1959 and 1987 floods

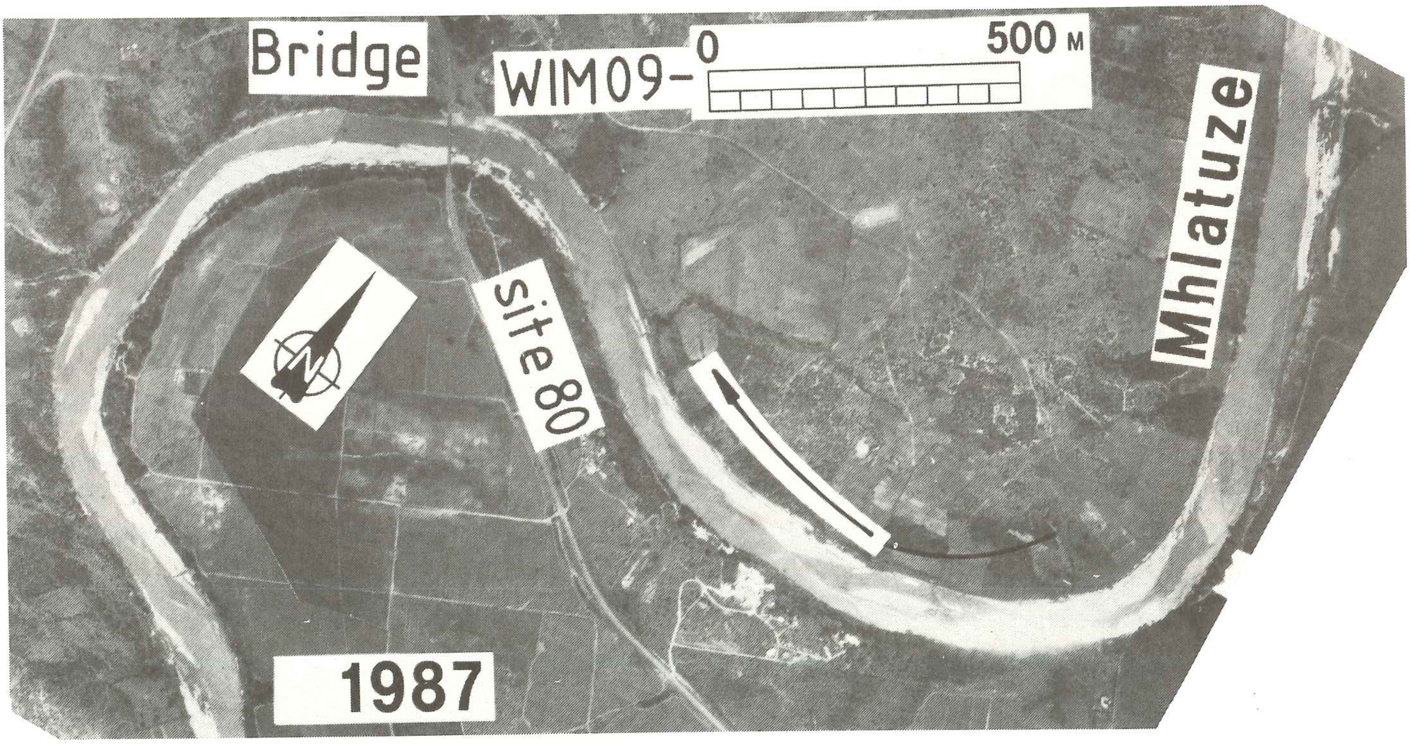


13. Mkomazi River: aerial photographs taken of Site 15 after the 1959 and 1987 floods

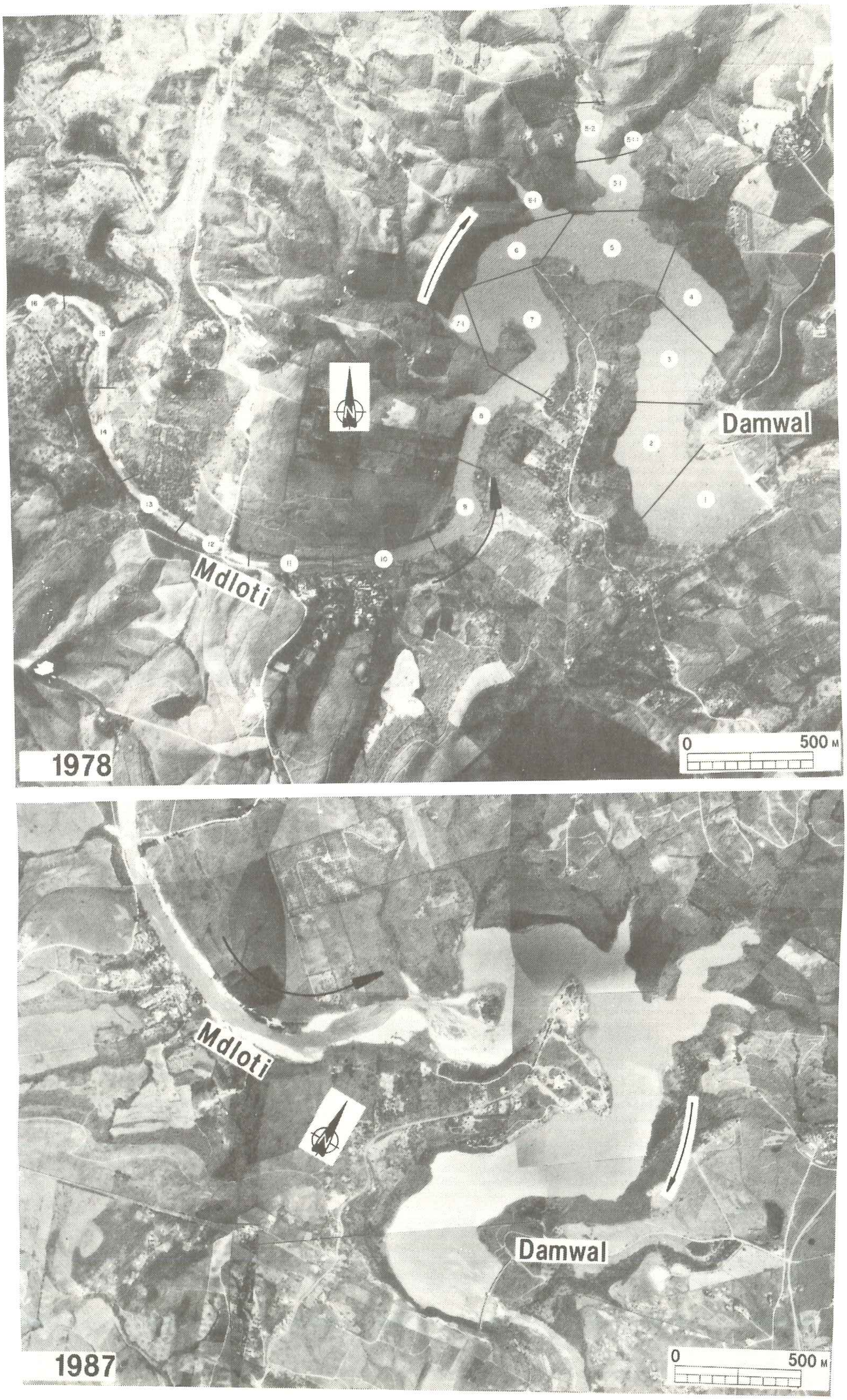


14. Mlazi River: aerial photographs taken of the Umlaas canal after the 1959 and 1987 floods (Site 23)



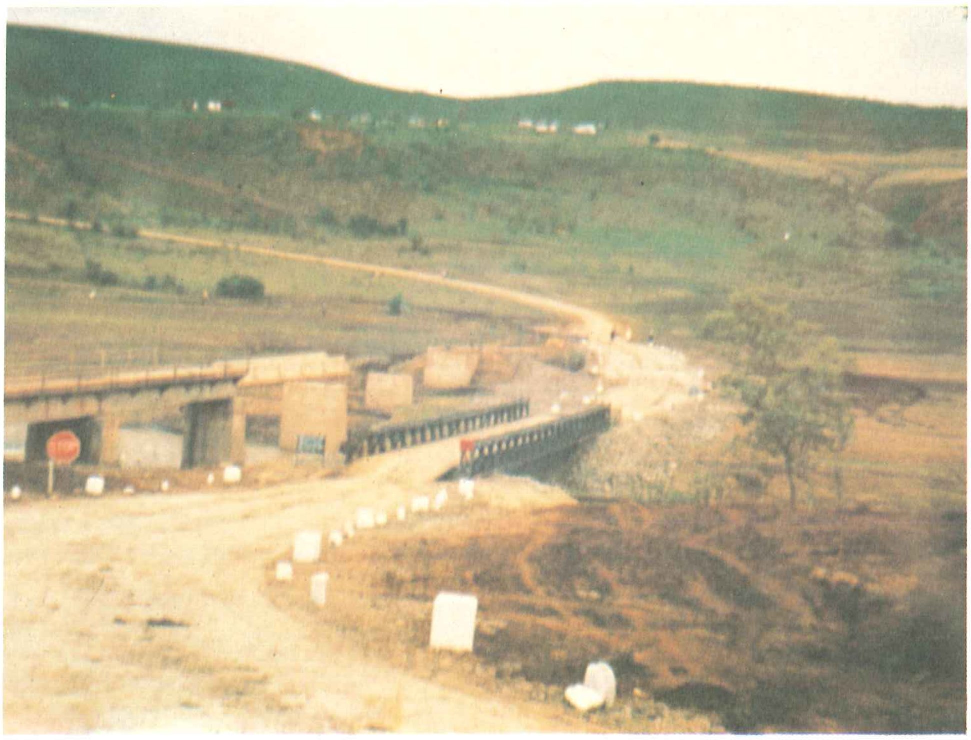


15. Mhlatuze River: aerial photographs taken of Site 80 after the 1977 and 1987 floods



16. Mdloti River: aerial photographs taken of Hazelmere Dam in 1978 and after the 1987 floods (Site 41a)

17. Mzimvubu River: Site 1, gauging station T3M08 during peak at 07h30 on 30 September 1987

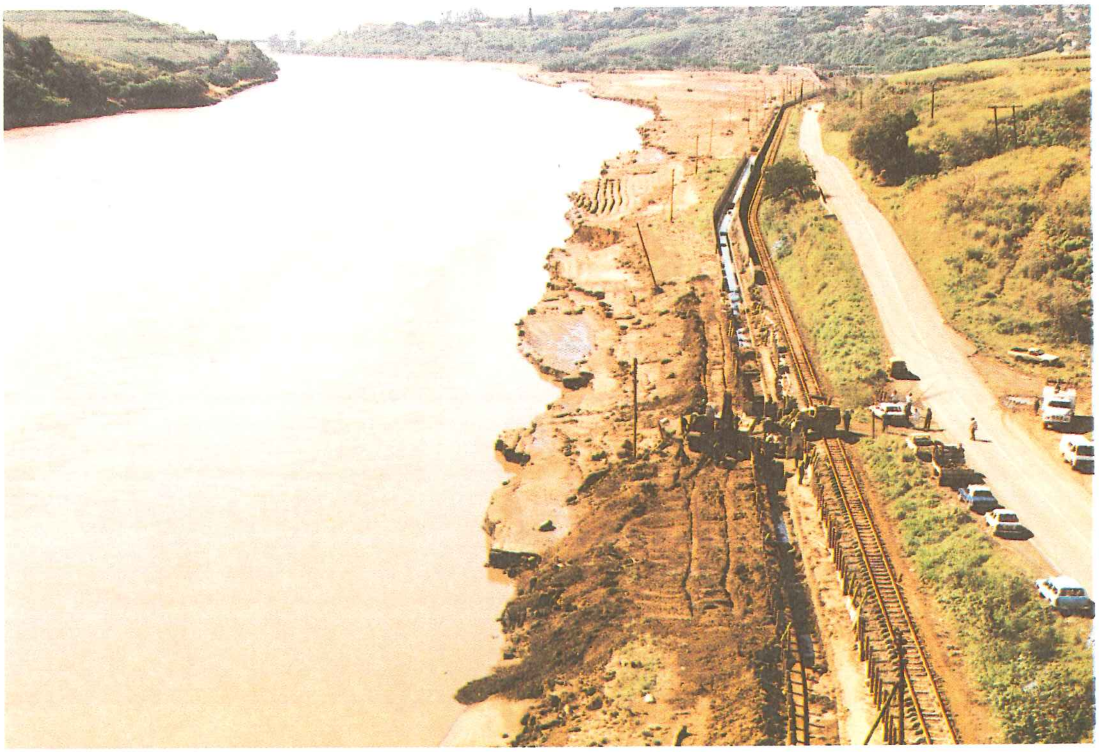


18. Mtamvuna River: upstream of Site 3, bridge at Gundrift, deck on south side washed away

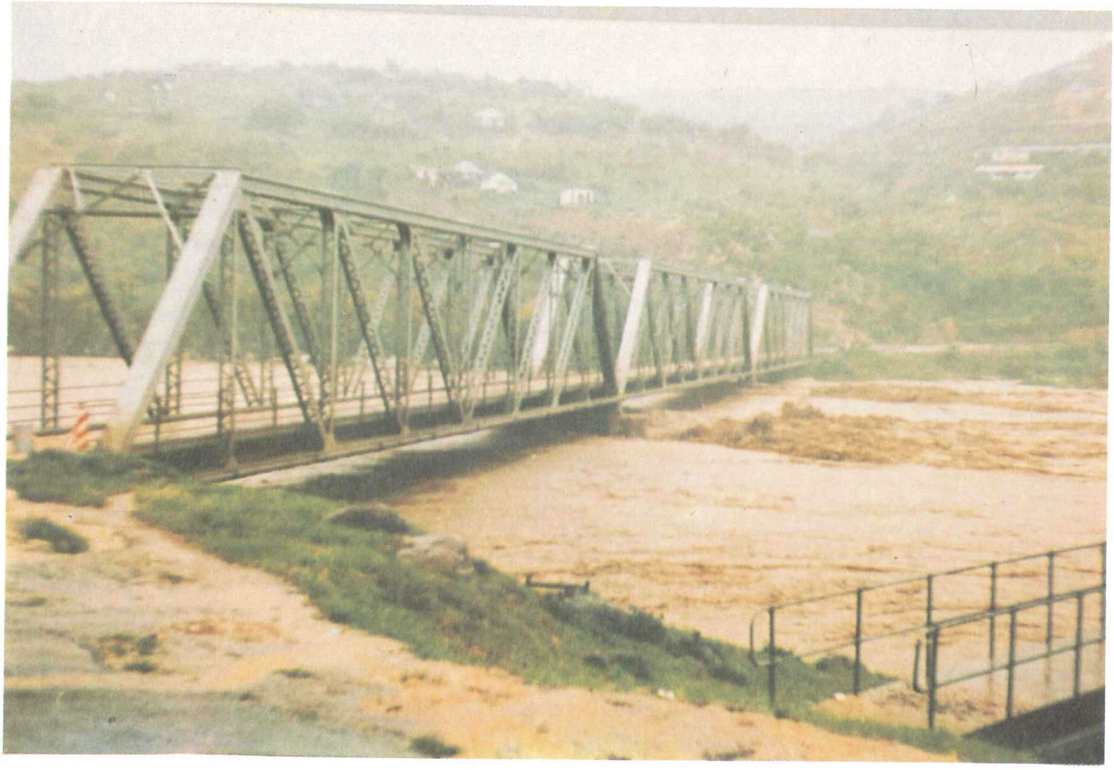
19. Mtwalume River: Site 10, slope-area site during rising flood on 29 September 1987

20. Mpambanyoni River: Site 12, looking downstream at slope-area site. Representative roughness = 0,7 m

21. Mkomazi River: downstream of Site 15 on 29 May 1986
(Photograph E. Beesley, SAICCOR)

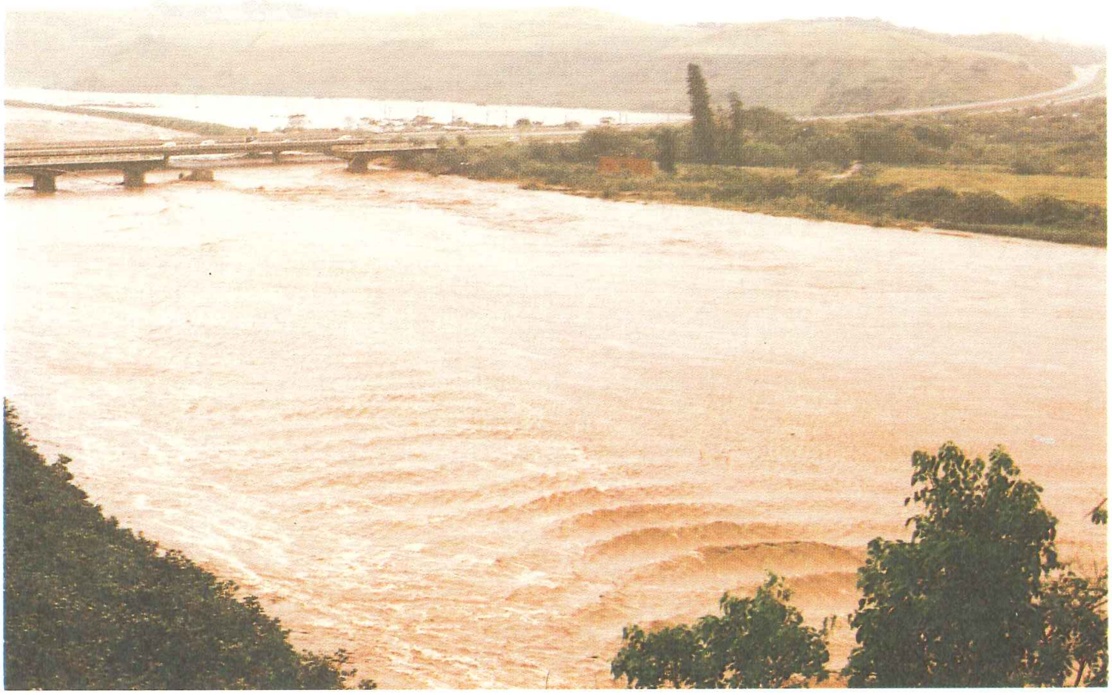


22. Mkomazi River: downstream of Site 15 on 4 October 1987
(E. Beesley)



23. Mkomazi River: Site 15, during flood peak on 29 September 1987 at 12h30 (E. Beesley)

24. Mkomazi River: downstream of Site 15, at Railbridge crossing the river mouth. Photograph taken shortly before flood peak on 29 September 1987 at 11h45 (E. Beesley)



25. Lovu River: downstream of Site 19, looking upstream during flood peak on 29 September 1987 at 08h00. Note the waves on right side of channel on the sand bed seen in photo 26 below (E. Beesley)

26. Lovu River: downstream of Site 19, looking upstream after the flood had receeded (E. Beesley)

27. Nungwana Dam: Site 18b, reservoir basin flood line survey

28. Mlazi River: Site 22b, slope-area site, 300m down stream of Nshongweni Dam. Representative roughness = 1.5 m

29. Mlazi River: Site 23, canal during receding flood on 29 September 1987 (Photograph by Aerial Photographic Service, courtesy J.E. Perry, CSIR, Stellenbosch)

30. Mgeni River: at U2M01 upstream of Howick Falls, during peak. The weir is located below the wave in the foreground indicating critical to super- critical flow

31. Mgeni River: Site 27, downstream of Howick Falls.
Representative roughness = 1,5 m

32. Landslide in the Karkloof river valley downstream of the Karkloof Falls

33. Single carriage bridge downstream of Albert Falls Dam, on the Mgeni River. Although both approaches were breached, the main structure did not suffer any significant damage

34. Typical gully erosion on rural road in the Mgeni River catchment at Nagle Dam

35. Mgeni River: Site 33, downstream of Nagle Dam showing sections of an excellent slope-area site. Representative roughness = 0,9 m

36. Msunduze River: bank erosion in Pietermaritzburg

37. Msunduze River: Edendale bridge in Pietermaritzburg, failed due to river course change

38. Damage to main tennis court in Pietermaritzburg, flooded by the Msunduze River

39. Msunduze River in flood in Pietermaritzburg
(Natal Witness)

40. Sobantu township in Pietermaritzburg area flooded by
the Msunduze River (Natal Witness)

41. Mgeni River: Site 37, downstream of confluence with Msunduze River, viewed from right bank, looking downstream. Representative roughness = 0,9 m

42. Mqeku River: Site 38, cross section 3 viewed from right bank. This is a excellent slope-area site. Representative roughness = 0,5 m

43. Mgeni River: Inanda Dam, Site 39, during receding flood (Photograph by personnel at Inanda)

44. Mgeni River: Site 40, slope-area site downstream of Inanda Dam, looking upstream from right bank. Representative roughness = 0,7 m

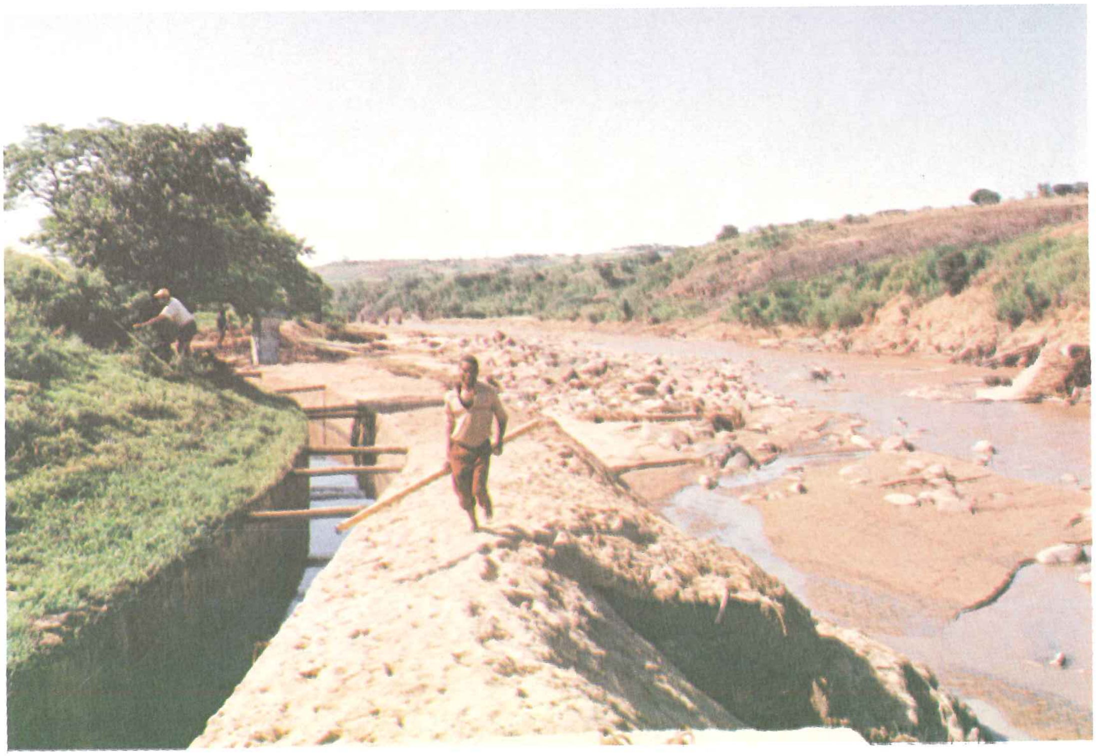
45. Mgeni River in Durban North showing bank erosion at Riverside road (Photograph by South African Transport Services - SATS)

46. Aerial view along the N2, looking south, of Mgeni River flooding the Durban North area (SATS)

47. Damaged factory premises adjacent to the Mgeni River. Damage due to collapse of river banks. Deposition in factory was approximately 2m deep

48. Aerial view of the Mgeni River mouth on 29 September 1987, during receding flood. The last remnants of the island are still visible between the two bridges (Aerial Photographic Services)

49. Mdloti River: the N2 bridge failed due to the river reverting to its' northern channel during the flood (SATS)



50. Tongati River: Site 42, at U3M01. The destroyed gauging tower may be seen on the right side of the photograph. The slope-area site is viewed from the left bank, looking downstream. Representative roughness = 0,4 m

51. Mvoti River: Site 43a, at station U4M02

52. Mvoti River: Site 43b, which is an excellent slope-area site viewed from right bank looking upstream. Representative roughness = 0,3 m

53. Mvoti River: lateral bank erosion on the outside of a bend, destroyed the road

54. Mvoti River: Site 44, slope-area site at Wellvale near Stanger, viewed from left bank looking upstream. Representative roughness = 0,5 m

55. General soil and gully erosion in the sugar cane fields, in the Mvoti River valley

56. Slip in road cut along the road between Kranskop and Mapumulo

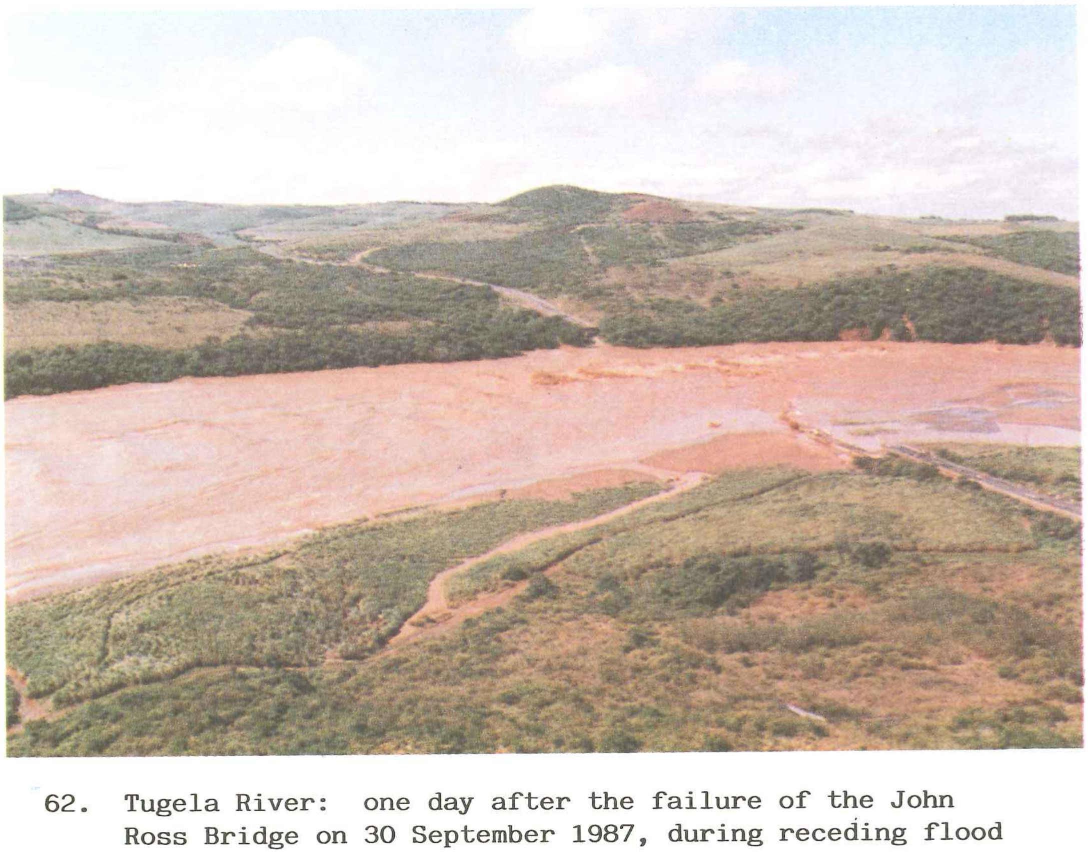
57. Little Boesmans River: Site 58, at station V7M12 during flood peak

58. Tugela River: Site 61, at Tugela Ferry showing severe erosion and scour of the river bank. Representative roughness = 0,7 m

59. Mooi River: Site 68, at Keates Drift, view of cross section 3 from left bank, of an excellent slope-area site. Representative roughness = 0,7 m

60. Tugela River: at old road bridge near Mandini viewed from left bank during peak. Waves and turbulence are caused by the rocky river bed, see photo 61 below (SATS)

61. Tugela River: at old road bridge near Mandini viewed from left bank looking upstream



62. Tugela River: one day after the failure of the John Ross Bridge on 30 September 1987, during receding flood (SATS)

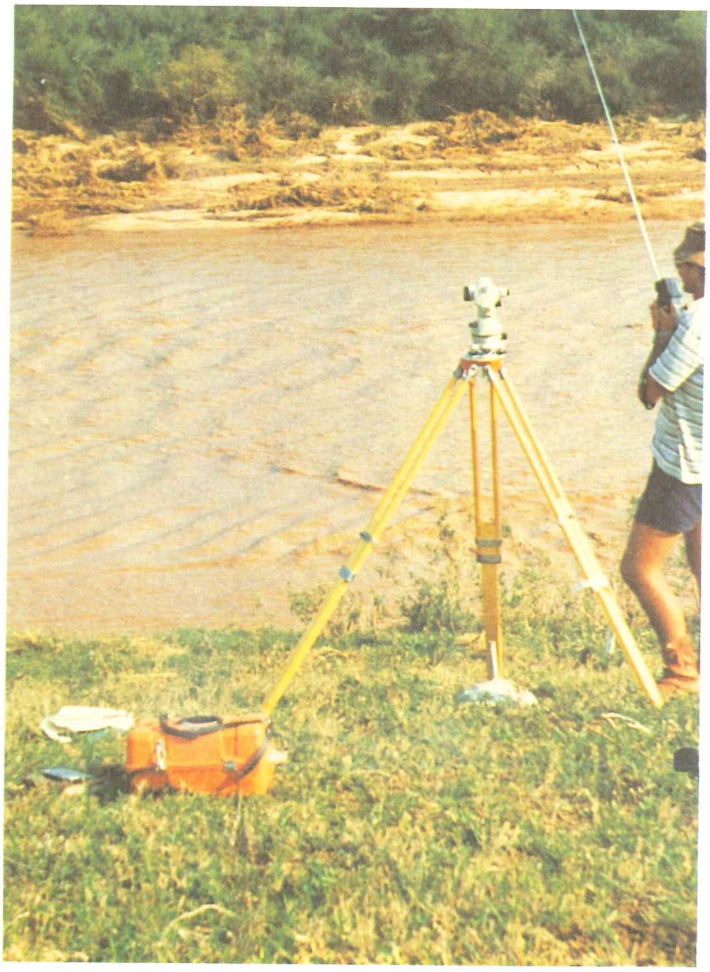
63. Tugela River mouth on 30 September 1987 (SATS)

64. Matigulu River: Site 74, view of slope-area site from right bank, looking downstream. Representative roughness = 0,4 m

65. Nyezane River: bridge on N2 viewed from right bank. The asphalt surface in the foreground was carried intact off the road surface

66. Mfulozone River: Site 78, gauging station W1M05 destroyed due to river course change

67. Mhlatuze River: Site 80, destroyed gauging station W1M09 and extensive scour of the right bank



68. Mhlatuze River: Site 80, showing surface waves during receding flow

69. Mhlatuze River: Site 80. Deposition of sediment on right bank along the inside of a mild inner bend. Representative roughness = 0,3 m

70. Mhlatuze River: Site 80, extensive scour of right bank at cross section 4 along an outer bend

71. Nseleni River: Site 82, viewed from the left bank. Note the dense vegetation on the right bank where roughness = water depth. Representative roughness = 0,3 m

72. White Mfolozi River: Site 86, in the Mfolozi Game Reserve, viewed from left bank at cross section 3. Note the continued collapse of river banks even though the high flood level was only 25% of total bank height. Representative roughness = 0,5 m

73. Mfolozi River: Site 91. Significant deposition of sediment occured on the floodplains and river banks. Representative roughness = 0,4 m

74. Nyalazi River: Site 93. Note debris trapped under the 13,2 m high bridge deck

75. Mzinene River: Scour of approaches along the downstream side of the N2 bridge, between Hluhluwe and Mkuze. The flow was 0,3 m deep over the bridge deck

76. Typical scour behind the wingwalls on the downstream side of the N2 bridge crossing the Ncemane River

APPENDIX 1: DAILY RAINFALL DATA

RAIN GAUGE				AP_{14}	RAINFALL AT 8 AM (mm)						TOTAL RAIN PS
					SEPTEMBER						
NO.	LAT.	LONG.	PLACE	(mm)	25	26	27	28	29	30	(mm)
126/082	31°52'	28°03'	NKOBONGO	120		19	20	39	53	29	160
127/078	39°48'	28°33'	BITYI	32				108	13	133	122
197	31°47'	28°37'	QUNU	43		18	75	40	30	21	184
298	31°58'	28°40'	ELLIOTDALE	41		14	87	55	69	29	254
406	31°46'	28°44'	CEZU	75		17	89	66	66	35	273
426	31°36'	28°45'	OWEN	35		15	56	34	80	15	200
438	31°48'	28°45	MQANDULI	50		17	84	63	68	41	273
833	32°53'	28°58'	WILO	64		20	30	50	223	26	349
128/040	31°40'	29°02'	NGQELENI	38		19	19	61	40	53	192
055	31°55'	29°02'	KWAAIMAN	113		45	39	31	101	43	259
129/007	31°37'	29°31'	PORT ST. JOHNS	100		13	80	61	56	33	243
151/604	31°04'	28°21'	MACLEAR	34				100	19	19	138
152/054	31°24'	28°32'	MHLAHLANE	76		25	69	59	34	50	237
259	31°19'	28°39'	BELE	43		18	59	29	10	19	135
468	31°18'	28°46'	TSOLO	24		38	39	23	12	16	128
475	31°25'	28°46'	NGADU HEIGHTS	61		45	53	20	14	31	163
792	31°12'	28°57'	BENCUTI	99		58	79	66	28	49	280
154/354	31°24'	29°42'	NTSUBANE	-				26	12	22	60
179/713	30°53'	28°54'	AMANZAMNYAMA	40		40	40	40	48	69	237
180/030	31°00'	29°01'	PAPANE	35		40	40	39	0	19	138
305	30°35'	29°11'	DEEMOUNT	54		34	33	67	89	0	223
577	30°37'	29°20'	HILLENDALE	55			31	33	31	112	207
181/275	30°35'	29°40'	ELANDSDRIFT	17				139			139
277	30°37'	29°40'	IMPETYNE	17				160			160
423	30°33'	29°45	BORDER	73		9	47	133	105		294
181/426	30°36'	29°45'	WEZA	72		7	47	51	99	123	327
604	30°34'	29°51'	GLENORA	85			43	51	107	87	288
182/013	30°43'	30°01'	EUREKA	111		35	105	103	136	93	472
197	30°47'	30°07'	IZINGOLWENI	-			100	102	164	104	470
331	30°31'	30°12'	ST. FAITHS	122		19	85	203	352	103	762
430	30°40'	30°15'	MINNEHAHA	91		10	89	155	236	121	611
439	30°49'	30°15'	MARAH	133		12	191	283	186	83	755
535	30°55'	30°18'	BUSHY VALES	87			100	96	92	123	411
621	30°51'	30°21'	MARGATE AIRPORT	99			148	71	140	114	473
710	30°50'	30°24'	UVONGO	100			86	61	80	60	287
730	30°40'	30°25'	THE VALLEYS	108			97	103	157	74	431
881	30°41'	30°30'	SOUTHPORT	113		10	40	88	129	56	323
206/738	30°18'	28°25'	AVONDALE	73		20	40	12	59	25	156
208/083	30°23'	29°03'	CEDARVILLE	48			29	26	65	55	175
406	30°16'	29°41'	THE MEADOWS	31			35	28	75	36	174
631	30°01'	29°22'	EVATT	47		45	40	85	74	27	271
635	30°05'	29°22'	BEN LOMOND	41			25	100	151	50	326
733	30°13'	29°25'	FLITWICK GRANGE	45			36	57	139	52	284
209/139	30°19'	29°35'	MPUR	77				117	195	70	382
270	30°30'	29°39'	LANGGEWACHT	74					177	73	250
651	30°21'	29°52'	MIDDELWATER	68				144	187	60	391
210/002	30°02	30°01'	SUMMERFORD	40			65	116	294	48	523
768	30°18'	30°26'	TANHURST EST.	132			78	125	233	181	617
826	30°16'	30°28'	SAWOTI	136			75	145	252	100	572
211/289	30°19'	30°40'	UMZINTO	146				242	225	71	538
211/437	30°17'	30°45'	SCOTTBURGH	75				124	168	55	347
663	30°03'	30°53'	AMANZIMTOTI	134				178	134	52	364

RAIN GAUGE				AP_{14}	RAINFALL AT 8 AM (mm) SEPTEMBER						TOTAL RAIN PS
NO.	LAT.	LONG.	PLACE	(mm)	25	26	27	28	29	30	(mm)
237/405	29°45'	29°14'	DRAKENSBERG GARD. HOT.	32			48	58	182	18	306
731	29°41'	29°25'	COBHAM	43		9	49	70	121	41	290
837	29°57'	29°28'	COLEFORD	15			38	72	160	33	303
238/045	29°45'	29°32'	HIMEVILLE	35				124	153	36	313
442	29°52'	29°45'	SARNIA	35			43	88	155	36	322
468	29°48'	29°46'	BULWER	42			41	92	169	30	332
636	29°36'	29°52'	IMPENDELE	45			43	88	195	15	341
239/002	29°32'	30°01'	DARGLE	42				98	163	19	280
133	29°43'	30°05'	VAUCLUSE	17			18	225	435	11	689
472	29°52'	30°16'	RICHMOND	62				135	257	22	414
U2E02	29°32'	30°17'	CEDARA	33			61	125	320	11	517
U2R01	29°30'	30°12'	MIDMAR DAM	21							367
518	29°38'	30°18'	EDENDALE	32				130	212	7	349
577	29°37'	30°20'	PIETERMARITZBURG	45			54	88	229	7	378
585	29°45'	30°20'	BAYNESFIELD EST.	43			40	107	247	11	405
240/022	29°52'	30°31'	ESTON	65			47	80	212	13	352
028	29°58'	30°31'	MID-ILLOVO	71			100	80	270	17	467
U2E05	29°31'	30°33'	WINDY HILL	43		13	72	128	292		505
073	29°43'	30°33'	CAMPERDOWN	52				152	227	9	388
284	29°44'	30°40'	INCHANGA	72		12	58	84	226	11	391
389	29°59'	30°43'	UMBUMBULU	131			89	176	332	19	618
404	29°44'	30°44'	BOTHA'S HILL	91				225	296	7	528
564	29°54'	30°49'	INTAKE WEIR	108			85	185	252	14	536
586	29°46'	30°50'	KLOOF	118			91	190	333	17	631
683	29°53'	30°53'	QUEENSBURG	113			86	181	242	18	527
716	29°56'	30°54'	UMLAAS WATER WORKS	126		12	70	159	207	17	465
240/732	20°48'	30°55'	DURBAN HEIGHTS	45			78	135	181	15	409
891	29°51'	31°00'	DURBAN-BOT. GARDENS	54			87	110	148	24	369
241/019	29°49'	31°01'	DURBAN-COWIE RD	51			77	111	137	23	348
U3R01	29°36'	31°03'	HAZELMERE DAM	34							790
U3E01	29°42'	31°03'	MOUNT EDGECOMBE	59			101	140	164	27	432
131	29°41'	31°05'	BLACKBURN	49				170	162	21	353
302	29°32'	31°11'	FRASERS	28			89	156	188	28	461
267/693	29°03'	29°24'	MONKS COWL	93		8	46	31	97		182
789	29°09'	29°27'	INJASUTI COTTAGE	103			49	91	144	10	294
887	29°17'	29°30'	GIANTS CASTLE	83		16	46	42	143	8	255
268/199	29°19'	29°37'	HIGHMOOR	77			44	67	175		286
359	29°29'	29°42'	CYPRUS	34		12	36	58	166	9	281
V7R01	29°02'	29°52'	WAGENDRIFT DAM	72			31	39	82		152
V2R01	29°10'	30°17'	CRAIGIEBURN DAM	30							337
269/611	29°11'	30°21'	RIETVLEI	39		6	41	86	204		337
712	29°22'	30°24'	CLAN SINDICATE	44		10	65	83	297	9	464
U2E06	29°26'	30°26'	ALBERT FALLS DAM	31			49	50	234		333
270/021	29°21'	30°31'	NEW HANOVER	33				140	219		359
119	29°29'	30°34'	WINDY HILL	44		11	72	91	335	11	520
282	29°12'	30°40'	MISTLEY ESTATE	45	190			325			515
271/099	29°09'	31°04'	MAPUMULO	60				272	209		481
U3E03	29°27'	31°12'	SHAKA'S KRAAL	32			82	180	174	21	457
420	29°30'	31°14'	UMHLATI BEACH	27				204	159	27	390
500	29°20'	31°17'	STANGER	32				349	317	12	678
702	29°12'	31°24'	NEWARK	35		8	80	220	254		562
299/357	28°57'	29°12'	CATHEDRAL PEAK-HOTEL	112			42	39	86	7	174

RAIN GAUGE				AP_{14}	RAINFALL AT 8 AM (mm) SEPTEMBER						TOTAL RAIN PS
NO.	LAT.	LONG.	PLACE	(mm)	25	26	27	28	29	30	(mm)
V1R02	28°46'	29°18'	DRIEL DAM	108			63	74	120		257
V1R01	28°41'	29°31'	SPIOENKOP DAM	78			36	70	50		156
300/067	28°37'	29°33'	ROSELEIGH	65			41	73	55		169
345	28°45'	29°42'	RIVERSIDE	52			37	79	68		184
554	28°44'	29°49'	COLENSO	57				153	80		233
301/692	28°32'	30°24'	ENHLANHLENI	39		11	70	105	121		307
795	28°45'	30°27'	TUGELA FERRY	18				100	100		200
302/628	28°58'	30°51'	KRANSKOP	42		62	64	62	254		442
687	28°57'	30°53'	DOUGVALE	42		7	53	161	292		473
699	28°39'	30°54'	QUDENI	32		39	80	85	144		348
303/695	28°35'	31°24'	MELMOTH	41				238	161	26	425
W1E12	28°35'	31°24'	MELMOTH	60				201	203	26	430
W1E10	28°53'	31°28'	ESHOWE	65		10	93	244	290	6	637
W1R01	28°46'	31°29'	GOEDERTROUW DAM	63			42	159	315	6	522
304/426	28°36'	31°45'	NTAMBANANA	23		20	20	140	275	11	466
593	28°53'	31°50'	PORT DURNFORD	50		32	94	131	353	16	626
727	28°37'	31°50'	CWAKA	57		16	124	169	501	80	890
736	28°46'	31°55'	EMPANGENI	26				191	401	13	605
305/037	28°37'	32°02'	FAIRVIEW	29			70	125	260	13	468
W1E09	28°46'	32°05'	RICHARDS BAY	21			122	180	395	21	718
308	28°38'	32°11'	KWA-MBONAMBI	32		18	208	142	525	7	900
336	28°36'	32°12'	LANGEPAN	34		15	189	136	577	11	928
334/008	28°08'	29°31'	BACHELORS HOME	35			24	63	25		112
825	28°15'	29°58'	BALBROGIE	44		10	49	90	47		196
335/091	28°01'	30°04'	DANNHAUSER	47		10	35	51	37		133
169	28°19'	30°06'	WASBANK	41				130	56		186
215	28°05'	30°08'	HATTINGSPRUIT	48				113	33		146
250	28°10'	30°09'	GLENCOE	33				125	50		175
400	28°10'	30°14'	DUNDEE	-				126	45		171
337/006	28°06'	31°01'	GOEDGELOOF	43			38	45	82	12	177
143	28°23'	31°05'	BABANANGO	66		11	47	89	119		266
431	28°11'	31°15'	SURPRISE STORE	49		9	42	82	85		218
795	28°15'	31°27'	MAHLABATINI	54			70	70	216	8	364
338/524	28°14'	31°48'	MBHUZANA	48		8	31	79	180	23	321
668	28°08'	31°53'	HLABISA	58				199	116		315
714	28°24'	31°54'	MAKHAMISA	31		30	82	332	12		456
339/065	28°05'	32°03'	HLUHLUWE GAME RES.	18		12	48	114	124	10	308
W3R01	28°07'	32°11'	HLUHLUWE DAM	23			28	113	300	13	454
352	28°22'	32°12'	KANGELA	28		7	39	100	249	5	400
415	28°25'	32°14'	HILL FARM	23		7	59	117	341	14	538
441	28°21'	32°15'	DUKUDUKU	34				157	251	12	420
523	28°13'	32°18'	NYALAZI	20		6	28	66	166	11	277
538	28°28'	32°18'	ULDA	24		17	115	119	449	12	712
681	28°21'	32°23'	ST. LUCIA ESTUARY	25		12	62	76	169	7	326
W3E01	28°12'	32°25'	CHARTERS CREEK	23			22	72	60	9	163
734	28°14'	32°25'	MAKAKATANA	20		6	33	89	137	10	275
756	28°06'	32°26'	FANIESEILAND	16		7	16	65	125	6	219
340/010	28°10'	32°31'	MEERSIG	16		21	41	55	110		227
369/117	27°57	29°04'	HERITAGE	37			22	47	32		101
145	27°55'	29°05'	HOPEDALE	37			30	55	34	8	127
496	27°46'	29°17'	DRIEBULT	45			34	39	38		111
505	27°55'	29°17'	VERKYKERSKOP	53		23	25	25	33		106
785	27°35'	29°27'	TYGERFONTEIN	29			59	22	40		121

RAIN GAUGE				AP_{14}	RAINFALL AT 8 AM (mm) SEPTEMBER						TOTAL RAIN PS
NO.	LAT.	LONG.	PLACE	(mm)	25	26	27	28	29	30	(mm)
370/101	27°41'	29°34'	MEMEL	46				57	37		94
486	27°36'	29°47'	LOSKOP	49			35	40	72		147
509	27°59'	29°47'	NORMANDIEN	57		17	51	80	42		190
807	27°57'	29°57'	CHELMSFORD DAM	53		8	36	70	45		159
371/437	27°47'	30°15'	WATERVAL	40			40	58	64		162
579	27°39'	30°20'	UTRECHT	23			43	50	62		155
706	27°46'	30°24'	WAAIHOEK	37			44	47	63		154
372/056	27°56'	30°32'	KINGSLEY	45			38	23	36		157
296	27°56'	30°40'	KANDASPUNT	50			28	74	47		199
361	27°31'	30°43'	MARTHINUS DRIFT	22			34	43	58		135
496	27°46'	30°47'	VRYHEID	40			60	81	118		259
W2R01	27°51'	30°49'	KLIPFONTEIN DAM	34			28	63	92		183
602	27°32'	30°51'	EERSTELING	28			24	46	59	10	139
852	27°42'	30°59'	HLOBANE	43				59	78		137
373/329	27°59'	31°11'	VLAKFONTEIN	35			32	41	81		154
485	27°35'	31°17'	LOUWSBURG	32					157		157
680	27°50'	31°23'	NGOMI	63		13	46	56	102	34	251
374/242	27°32'	31°39'	MAGUDU	24			29	45	83		157
264	27°54'	31°39'	NONGOMA	50		37	37	37	135		246
402	27°42'	31°44'	ZILVERHOUT	17			10	41	80		131
375/124	27°34'	32°05'	UBOMBO	38				40	160		200
366	27°36'	32°13'	MKUZI GAME RES.	17				57	105		162
688	27°58'	32°23'	FALSE BAY	28			8	175	·128	9	320
405/295	27°25'	29°10'	VREDE	22			24	9	31		64
380	27°20'	29°13'	CLOCOLAN	65			40	44	18		102
596	27°26'	29°20'	ROME	20		6	21	26	21		74
736	27°16'	29°25'	SKOONHEID	12		8	20	0	34		62
834	27°24'	29°28'	TWEEDEGELUK	32			24	16	28		68
876	27°06'	29°30'	VARKENSPRUIT	37			30	19	15		64
406/221	27°11'	29°38'	PAARDEKOPPLAAS	28			32	18	23		73
607	27°07'	29°51'	RIETPOORT	38			30	30	42		102
658	27°28'	29°52'	LANGSNEK	58		10	59	50	69		188
682	27°22'	29°53'	VOLKSRUST	32			32	38	62		132
407/148	27°28'	30°05'	BARROWFIELD	40			39	48			87
418	27°28'	30°14'	GROENVLEI	-		17	35	52			104
639	27°09'	30°22'	GROOT RIETVLEI	32		9	22	18	42		91
730	27°10'	30°25'	DIRKIESDORP	29		10	15	11	40		76
408/027	27°27'	30°31'	KEMPLUST	44			79	63			142
798	27°18'	30°57'	ZAAIPLAATS	27		9	11	31	56		107
409/096	27°06'	31°04'	MAHAMBA	21		31	17	22	45	15	130
375	27°15'	31°13'	BERGPLAATS	7		14	24	19	93		150
862	27°22'	31°29'	RHEBOKFONTEIN	33		21	30	57			108
410/203	27°23'	31°37'	PONGOLA	13				60	58		118
679	27°19'	31°53'	GOLLEL	20				25	100	50	175
782	27°02'	31°57'	NSOKO	6		29	26	16	15		86
878	27°08'	32°00'	INGWAVUMA	35		17	20	48	120	10	215
W4R01	27°25'	32°04'	PONGOLAPOORT DAM	24				51	102		153
411/116	27°26'	32°04'	PONGOLAPOORT DAM	23				51	102		153
412/052	27°22'	32°32'	MSELENI	6		10	45	129			184
103	27°13'	32°34'	NGUTSHANA	11					146		146
180	27°30'	32°36'	MBAZWANE	11		20	50	10	150		230
485	27°05'	32°47'	MANGUZI	16			43	126			169

NOTES: Weather Bureau stations: six - digit numbers
Departmental reservoir gauging stations: W4R01
Departmental evaporation gauging stations: U2E02

APPENDIX 2. SUMMARY OF RAINFALL AND FLOOD DATA AT MEASUREMENT SITES

MEASUREMENT SITE							FLOOD PEAK									FLOOD VOLUME		RAINFALL		Run-off	REMARKS
No	Drainage region or Station No	Geographic position Lat.	Geographic position Long.	River	Place (farm, road, bridge, dam)	Catchment area A (km²)	Method of measurement	Max gauge height (m)	Discharge Q (m³/s)	Fr.-Rodier K	Return period T (yr)	Accuracy rating	Time of peak M D H	Previous max. peak m³/s	Previous max. peak year	Ω (10⁶m³)	Pv (mm)	Storm 25-30 Sep (08h) p̄ (mm)	Antecedent (14 days) AP_{14} (mm)	Pv/p̄ (%)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	T3M08	30.34	29.09	Mzimvubu	Inungi	2471	SA	4,58	850	3,34	20-50	2	09.30.11	360	1976	190	77	215	45	36	(9) DT limit = 1,55 m
2	T3M04	30.34	29.25	Mzimhlava	Kokstad	1029	G	4,32	750	3,73	20-50	2	09.29.12	760	1959			252	52		(9) DT limit = 0,77 m
3	T4M01	30.44	29.50	Mtamvuna	Mtamvuna	715	SA	3,79	1470	4,50	20-50	1	09.29	2270	1959			241	48		(9) DT limit = 3,89 m
4	T5M04	29.46	29.28	Mzimkulu	F.P. 160	545	G	3,95	900	4,21	20-50	1	09.29.08	650	1976			310	35		(9) DT limit = 3,35 m
5	T5M03	29.45	29.32	Polela	EH2 Himeville	140	G	2,84	218	3,75	20-50	1	09.29.09	135	1959	20	145	292	40	50	(9) DT limit = 2,43 m
6	T5M05	29.59	29.51	Nkonzo	Kleinhoek	100	G	3,54	241	3,97	10	1	09.29.04	400	1959	19	187	368	38	51	(9) DT limit = 4,26 m (15+16) Catchment area = 32 km²
7	T5M07	30.15	29.56	Mzimkulu	Bezweni	3586	G	12,01	3720	4,53	≈50	u	09.29.15	3800	1959			342	41		(9) DT limit = 1,82 m
8	T5R01	30.43	30.09	Mzimkulwana	Gilbert Eyles	427	D	2,3	Θ: 688	4,11	20	2	09.29	905	1959	158	370	402	103	92	(17) Over Estimated
9	T5	30.42	30.24	Mzimkulu	Esperanza	6727	SA	(7,68)	5600	4,60	20-50	2	09.29.16	6520	1959			373	58		
10	U8M02	30.28	30.36	Mtwalume	Comptonsdale	565	SA	3,52	850	4,15	20	1	09.29.10	1000	1985	97	172	619	132	28	
11	U8M01	30.24	30.36	Fafa	Cowick	196	G	5,61	950	4,70	20-50	2	09.29.16	1000	1985	55	282	584	130	48	(15+16) Catchment area = 225 km²
12	U8M03	30.17	30.42	Mpambanyoni	Umbelli Belli	495	SA	5,18	1130	4,45	20-30	1	09.29.11	1230	1959	100	202	525	102	38	
13	U1M05	29.44	29.54	Mkomazi	Lot 93.1821	1744	G	5,26	2770	4,63	50-200	1	09.29.08	1000	1976	295	169	293	44	58	(9) DT limit = 1,37 m
14	U1M06	30.10	30.42	Mkomazi	Delos Estate	4349	SA	9,85	6900	5,05	50-200	2	09.29.12	6230	1959			414	50		(9) DT limit = 1,52 m
15	U1	30.11	30.46	Mkomazi	SAICCOR	4375	SA	(7,86)	6900	5,04	50-200	2	09.29.13	7000	1856	920	210	414	50	51	(15+16+17) Data E Beesley
16	U7R01	30.09	30.49	Umgababa	Umgababa	31	D	3,18	I: 170 Θ: 133	4,21	≈20	2	09.29.14 09.29.14			14	442	421	110	100	
17	U7	29.52	30.15	Lovu	Beaulieu	114	D	1,50	Θ: 350	4,18	20-50	1	09.29.12					405	57		
18a	U7	30.01	30.45	Nungwana	Umlazi location	55	SA	(1,94)	195	4,07	≈20	1	09.29					593	110		
b	U7R02	30.00	30.45	Nungwana	Nungwana	58	D	0,95	I: 133 Θ: 133	3,78	<20	u	09.29.08			32	543	593	110	92	
c	U7	30.00	30.45	Nungwana	Nungwana	58	SA	(1,79)	140	3,82	<20	1	09.29					593	110		
19	U7M02	30.05	30.49	Lovu	Lower Illovo	936	SA	6,26	1800	4,54	20-50	2	09.29	2000	1976			475	86		

NOTE:

Col. 8 : G = river gauging station D = dam SA = slope area B = Bridge contraction
Col. 9 : figures in brackets indicate mean depth of main channel
Col. 10 : I = inflow peak Θ = outflow peak
Col. 13 : (1) = error less than ±10% (2) = error less than 30% (u) = unknown accuracy

SUMMARY OF RAINFALL AND FLOOD DATA AT MEASUREMENT SITES

MEASUREMENT SITE							FLOOD PEAK									FLOOD VOLUME		RAINFALL		Run-off	REMARKS
No	Drainage region or Station No	Geographic position Lat.	Long.	River	Place (farm, road, bridge, dam)	Catchment area A (km^2)	Method of measurement	Max gauge height (m)	Discharge Q (m^3/s)	Fr.-Rodier K	Return period T (yr)	Accuracy rating	Time of peak M D H	Previous max. peak m^3/s	year	Ω ($10^6 m^3$)	Pv (mm)	Storm 25-30 Sep (08^h) $\bar{p}$ (mm)	Antecedent (14 days) AP_{14} (mm)	Run-off $\frac{Pv}{\bar{p}}$ (%)	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
20	U6M02	29.45	30.19	Mlazi	Nooitgedacht	105	G	2,96	173	3,71	<20	u	09.29	26	1982			445	56		(9) DT limit = 0,75 m
21	U6M03	29.48	30.31	Mlazi	Umlaas	417	SA	4,09	560	3,96	≈20	1	09.29.06	18	1985	60	144	393	60	37	(9) DT limit = 2,00 m
22a	U6R01	29.53	30.44	Mlazi	Nshongweni	803	D	4,50	I: 1420 θ: 1350	4,45	20-50	2	09.29.05 09.29.06	1400	1959	92	114	415	70	28	
b	U6	29.52	30.44	Mlazi	Umlazi	803	SA	(3,57)	1350	4,37	20-50	2	09.29.06					415	70		
23	U6	29.58	30.59	Mlazi	Mlazi canal	972	SA		1430	4,32	20-50	1	09.29.10	1500	1959			434	79		
24	U2M13	29.31	30.06	Mgeni	Petrus Stroom	299	G	3,67	395	3,84	20-50	2	09.29.05	175	1964	46	155	335	45	46	(9) DT limit = 1,24 m
25	U2M07	29.27	30.09	Mpofana	Weltevreden	360	G	3,07	503	3,94	20-50	2	09.29.03	82	1964	54	149	280	36	53	(9) DT limit = 2,16 m
26	U2R01	29.30	30.12	Mgeni	Midmar	928	D	2,75	I: 1500 θ: 1120	4,39	50-200	1	09.29.10 09.29.12			167	180	346	38	52	
27	U2	29.29	30.15	Mgeni	Howick	972	SA	(4,87)	1340	4,27	20-50	1	09.29	124	1959			354	36		
28	U2M06	29.23	30.17	Karkloof	Shafton	339	SA	4,00	850	4,39	≈50	2	09.29	374	1957			354	30		(9) DT limit = 1,24 m
29	U2R03	29.26	30.26	Mgeni	Albert Falls	1644	D	4,22	I: 2530 θ: 1820	4,57	50-200	1	09.29.12 09.29.19			332	202	363	35	56	
30	U2	29.27	30.27	Mgeni	P - 6	1724	B	(6,66)	2210	4,43	≈ 50	2	09.29					365	35		
31	U2M12	29.26	30.30	Sterk	Groothoek	438	G	4,38	667	4,07	20-50	2	09.29.06	445	1976			421	42		(9) DT limit = 0,99 m
32	U2M05	29.35	30.36	Mgeni	Nagle Dam	2519	G	4,92	3960	4,78	50-200	2	09.29.08	615	1976	599	238	394	37	60	(9) DT limit = 2,10 m
33	U2	29.36	30.38	Mgeni	Inanda location	2542	SA	(4,85)	3350	4,61	50-200	1	09.29.08					395	38		
34a	U2M11	29.39	30.16	Msunduze	Henley Dam	176	G	3,85	495	4,26	20-50	2	09.29.02	296	1975	40	227	553	45	41	(9) DT limit = 1,05 m
b	U2R05	29.38	30.16	Msunduze	Henley	238	D	2,10	I: 620 θ: 607	4,29	20-50	1	09.29.04 09.29.04			45	191	513	43	37	
35	U2	29.38	30.22	Msunduze	Pietermaritz-burg	284	SA	(3,85)	610	4,20	20-50	1	09.29	595	1947			472	42		
36	U2M22	29.39	30.38	Msunduze	Inanda Location	877	SA	(4,46)	1440	4,38	20-50	1	09.29					427	45		(9) DT limit = 0,69 m
37	U2	29.39	30.41	Mgeni	Inanda Location	3455	SA	(5,38)	4000	4,63	≈50	2	09.29					397	39		
38	U2	29.36	30.45	Mqeku	Inanda Location	257	SA	(2,51)	810	4,47	20-50	1	09.27					550	57		

NOTE:

Col. 8 : G = river gauging station D = dam SA = slope area B = Bridge contraction

Col. 10 : I = inflow peak θ = outflow peak

Col. 13 : (1) = error less than ±10% (2) = error less than 30% (u) = unknown accuracy

Col. 9 : figures in brackets indicate mean depth of main channel

SUMMARY OF RAINFALL AND FLOOD DATA AT MEASUREMENT SITES

MEASUREMENT SITE							FLOOD PEAK									FLOOD VOLUME		RAINFALL		Run-off	REMARKS
No	Drainage region or Station No	Geographic position Lat.	Geographic position Long.	River	Place (farm, road, bridge, dam)	Catchment area A (km²)	Method of measurement	Max gauge height (m)	Discharge Q (m³/s)	Fr.- Rodier K	Return period T (yr)	Accuracy rating	Time of peak M D H	Previous max. peak m³/s	Previous max. peak year	Ω (10⁶m³)	Pv (mm)	Storm 25-30 Sep (08h) p̄ (mm)	Antecedent (14 days) AP₁₄ (mm)	Pv/p̄ (%)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
39	U2M15	29.42	30.49	Mgeni	Inanda	4023	D		Θ: 5500	4,86	50-200	2	09.29.02	821	1976			418	42		
40	U2	29.45	30.54	Mgeni	Inanda location	4149	SA	(6,54)	5100	4,77	50-200	1	09.29	5700	1917	850	205	427	43	48	(15+16) Catchment area = 4260 km² (17) Estimate G Hulley
41a	U3R01	29.36	31.03	Mdloti	Hazelmere	380	D	4,35	I: 1830 Θ: 1660	4,95	50-200	1	09.29.01 09.29.01	426	1976	157	413	653	64	63	
b	U3R01W	29.36	31.03	Mdloti	Hazelmere	381	SA	5,38	1650	4,87	50-200	1	09.29					653	64		(9) DT limit = 1,24 m
42	U3M01	29.32	31.06	Tongati	Rietkuil	236	SA	4,15	950	4,63	20-50	2	09.29	2100	1917			694	47		(9) DT limit = 0,36 m
43a	U4M02	29.10	30.38	Mvoti	Mistley	316	G	4,90	394	3,81	20-50	1	09.28.21	45	1976			442	42		(9) DT limit = 1,09 m
b	U4	29.10	30.38	Mvoti	Mistley	325	SA	(1,84)	400	3,81	≈20	1	09.28					442	42		
44	U4	29.20	31.11	Mvoti	Wellvale	2473	SA	(7,16)	5000	5,01	50-200	1	09.29	3000	1974			501	48		
45	U5	29.17	31.23	Nonoti	Chatelope	157	SA	(4,48)	1160	4,94	50-200	1	09.29					570	40		
46	U5	29.14	31.23	Zinkwazi	Ellendale	28	SA	(3,18)	400	4,81	50-200	1	09.25					580	36		
47	V1M41	28.49	29.19	Mlambonja	Kleine Rivier	434	G	3,23	442	3,74	6	2	09.29.06	860	1973	43	99	305	35	32	(9) DT limit = 1,00 m
48	V1M26	28.43	29.23	Tugela	Kleine Waterval	1894	G	2,79	645	3,24	3	1	09.29.09	1400	1979	65	34	165	100	20	(9) DT limit = 3,07 m
49	V1R01	28.41	29.31	Tugela	Spioenkop	2452	D	1,70	I: 847 Θ: 647	3,34	15	1	09.29.10 09.29.14			111	45	205	85	22	
50	V1M10	28.49	29.33	Little Tugela	Winterton	782	G	2,28	812	3,95	15	2	09.29.08	980	1979	89	114	190	102	60	(9) DT limit = 1,52 m
51	V1M01	28.44	29.49	Tugela	Colenso	4176	G	6,78	1386	3,47	15	2	09.29.15	3400	1976	269	64	175	92	37	(9) DT limit = 2,30 m
52	V1M38	28.34	29.45	Klip	Ladysmith	1644	SA	4,76	1230	3,92	20	1	09.28	2200	1923	163	99	172	58	58	(9) DT limit = 2,04 m
53	V1M09	28.54	29.46	Bloukrans	Frere	196	G	1,90	162	3,36	4	1	09.29.03	499	1966	16	80	170	85	47	(9) DT limit = 1,36 m
54	V7M17	29.11	29.39	Boesmans	Drakensberg	276	G	3,37	332	3,74	20	2	09.29.07	206	1985	28	103	260	90	40	(9) DT limit = 1,30 m
55	V7M16	29.11	29.38	Ncibidwane	Drakensberg	121	G	2,75	293	4,03	20-50	2	09.29.06	136	1981	20	163	255	85	64	(9) DT limit = 0,99 m
56	V7R01	29.02	29.52	Boesmans	Wagendrift	744	D	2,01	I: 785 Θ: 687	3,95	20-50	1	09.29.10 09.29.12	894	1930	91	122	168	95	72	
57	V7M18	29.04	29.45	Klein Boesmans	Craig	119	G	3,14	107	3,30	15	2	09.29	147	1978			190	89		(9) DT limit = 1,10 m

NOTE:

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Col. 10 : I = inflow peak Θ = outflow peak
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Col. 9 : figures in brackets indicate mean depth of main channel

SUMMARY OF RAINFALL AND FLOOD DATA AT MEASUREMENT SITES

MEASUREMENT SITE						FLOOD PEAK									FLOOD VOLUME		RAINFALL		Run-off	
No	Drainage region or Station No	Geographic position: Lat.	Geographic position: Long.	River	Place (farm, road, bridge, dam)	Catchment area A (km²)	Method of measurement	Max gauge height (m)	Discharge Q (m³/s)	Fr.-Rodier K	Return period T (yr)	Accuracy rating	Time of peak M D H	Previous max. peak m³/s	Previous max. peak year	Ω (10⁶m³)	Pv (mm)	Storm 25-30 Sep (08h) p̄ (mm)	Antecedent (14 days) AP_{14} (mm)	Pv/p̄ (%)	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
58	V7M12	29.00	29.53	Klein Boesmans	Estcourt	196	G	2,17	180	3,44	20-50	2	09.29.07	1047	1930	15	76	185	87	41	(9) DT limit = 1,09 m
59	V6M04	28.24	30.01	Sundays	Klein Fontein	657	G	2,78	474	3,59	25	2	09.28.11	391	1972	47	72	175	45	41	(9) DT limit = 1,30 m
60	V6M03	28.19	30.09	Wasbank	Kuikvlei	312	G	1,61	128	2,93	3	2	09.28.10	423	1978	14	45	180	42	25	(9) DT limit = 0,75 m
61	V6M02	28.45	30.27	Tugela	Tugela Ferry	12862	SA	5,88	3600	3,72	14	1	09.28.16	4830	1943	1 039	81	197	65	41	(9) DT limit = 3,49 m
62	V2M05	29.22	29.53	Mooi	Avon	260	G	2,88	375	3,87	20-50	2	09.29.09	193	1974	49	189	255	50	74	(9) DT limit = 1,40 m
63	V2M06	29.16	29.52	Klein Mooi	Dartington	188	G	5,56	397	4,06	20-50	2	09.28.22	204	1976	46	247	280	55	88	(9) DT limit = 0,75 m
64	V2M07	29.14	29.47	Hlatikulu	Broadmoor	109	G	2,03	118	3,41	<20	2	09.29.08	35	1976	13	122	270	70	45	(9) DT limit = 1,00 m
65	V2M02	29.13	30.00	Mooi	Mooirivier	937	G	7,88	1480	4,37	50-200	2	09.29.18	651	1956			234	53		(9) DT limit = 1,56 m
66	V2	29.09	30.06	Mooi	Riverside	1186	SA	(2,84)	1380	4,19	50	1	09.29					233	51		
67	V2R01	29.10	30.17	Mnyamvubu	Craigie Burn	152	D	1,20	I: 377 Θ: 367	4,12	20-50	1	09.29.05 09.29.06			29	191	350	35	55	
68	V2	28.52	30.31	Mooi	Etembeni Mission	2482	SA	(4,79)	2000	4,14	50	1	09.29.09					260	40		
69	V3M05	27.26	29.59	Slang	Vlakdrift	676	G	3,11	99	2,25	3	1	09.29.18	400	1984	34	50	100	35	50	(9) DT limit = 5,09 m
70	V3M02	27.36	29.57	Buffels	Schurwepoort	1518	G	3,03	297	2,68	5	2	09.28.23	716	1963	49	32	135	50	24	(9) DT limit = 1,00 m
71	V3M07	27.51	29.51	Ncandu	Rust	129	G	1,45	72	2,97	4	1	09.28.23	300	1969	9	67	125	55	54	(9) DT'limit = 1,06 m
72	V3M10	28.04	30.23	Buffels	Tayside	5887	G	5,83	428	2,04	5	1	09.29.08	1190	1984	191	32	142	44	23	(9) DT limit = 6,00 m
73	V5M02	29.08	31.21	Tugela	Mandini	28920	SA	7,13	9400	4,27	20-50	1	09.29.20	15100	1925	2 437	84	159	51	53	(9) DT limit = 3,80 m
74	W1	29.05	31.33	Matigulu	Dunn's Reserve	583	SA	(8,56)	3170	5,23	50-200	2	09.29	950	1984			580	61		(15+16) Catchment area = 573 km²
75	W1R02	28.52	31.27	Mlalazi	Eshowe	14	D	1,15	I: 132 Θ: 121	4,34	<20	2	09.29.00 09.29.01	31	1984	5	377	600	65	63	
76	W1	28.55	31.41	Mlalazi	Native Reserve	230	SA	(3,98)	950	4,64	20	2	09.29					605	62		
77	W1R01	28.46	31.29	Mhlatuze	Goedertrouw	1273	D	1,42	I: 3760 Θ: 590	5,05	50-200	1	09.29.05 09.29.10	1900	1984	230	181	414	60	44	
78	W1M05	28.34	31.24	Mfuluzone	Golden reef	45	G	5,37	790	5,11	50-200	u	09.29	185	1973			425	58		(9) DT limit = 2,16 m

NOTE:

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Col. 10 : I = inflow peak; Θ = outflow peak

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Col. 9 : figures in brackets indicate mean depth of main channel

SUMMARY OF RAINFALL AND FLOOD DATA AT MEASUREMENT SITES

MEASUREMENT SITE							FLOOD PEAK									FLOOD VOLUME		RAINFALL		Run-off	REMARKS
No	Drainage region or Station No	Geographic position Lat.	Geographic position Long.	River	Place (farm, road, bridge, dam)	Catchment area A (km²)	Method of measurement	Max gauge height (m)	Discharge Q (m³/s)	Francou-Rodier K	Return period T (yr)	Accuracy rating	Time of peak M D H	Previous max. peak m³/s	Previous max. peak year	Ω (10⁶m³)	Pv (mm)	Storm 25-30 Sep (08h) p̄ (mm)	Antecedent (14 days) AP_{14} (mm)	Pv/p̄ (%)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
79	W1	28.42	31.39	Mfule	Mfule Estate	618	SA	(5,03)	3300	5,24	50-200	2	09.29					439	52		
80	W1M09	28.45	31.45	Mhlatuze	Riverview	2409	SA	(6,08)	3600	4,71	20-50	2	09.29	2400	1984			436	56		(9) DT limit = 3,34 m
81	W1	28.51	31.55	Mhlatuze	Felixton	2767	SA	(8,65)	4000	4,74	20-50	3	09.29	3450	1941			466	54		
82	W1	28.41	32.01	Nseleni	Nseleni	547	SA	(8,40)	4250	5,49	0,88RMF	2	09.29	3350	1984			582	37		
83	W2R01	27.51	30.49	White Mfolozi	Klipfontein	340	D	0,33	I: 127 θ: 31	2,88	<10	1	09.28.12 09.29.11	1090	1984	11	31	241	38	13	
84	W2M09	27.54	30.53	White Mfolozi	Doornhoek	432	G	1,79	110	2,62	3	1	09.28.12	1050	1984	8	18	224	40	8	(9) D limit = 2,60 m
85	W2M05	28.20	31.23	White Mfolozi	Overvloed	3939	G	3,87	1840	3,79	7	2	09.28.19	7500	1984	180	46	227	42	20	(9) DT limit = 1,30 m
86	W2	28.24	31.43	White Mfolozi	Game Reserve	4776	SA	(3,27)	2150	3,83	15	2	09.29	6500	1984			247	48		
87	W2M07	27.58	31.12	Bizamkulu	Ekuhlengeni	78	G	1,45	52	2,99	3	1	09.28.06	580	1984	3	40	220	35	18	(9) DT limit = 1,06 m
88	W2M28	27.56	31.12	Black Mfolozi	Ekuhlengeni	324	G	2,08	156	3,07	3	1	09.29.00	2180	1984	13	39	220	46	18	(9) DT limit = 1,67 m
89	W2M06	28.04	31.33	Black Mfolozi	Native Reserve No.12	1648	G	4,65	995	3,72	7	2	09.29.01	7500	1984	104	63	246	50	25	(9) DT limit = 1,52 m
90	W2	28.16	31.51	Black Mfolozi	Game Reserve	3396	SA	(4,33)	1740	3,83	10	2	09.29	10000	1984			262	52		
91	W2	28.27	32.06	Mfolozi	Native Reserve No.5	9216	SA	(5,60)	4500	4,18	8	2	09.29.15	16000	1984			275	49		
92	W3M14	28.20	32.22	Mpate	Mpate Forest Reserve	48	G	3,69	137	3,89	10	u	09.28	106	1984	12	242	326	23	74	(9) DT limit = 0,25 m
93	W3	28.15	32.17	Nyalazi	Bantu Reserve	560	SA	(5,85)	1200	4,44	20	2	09.29					433	31		
94	W3R01	28.07	32.11	Hluhluwe	Hluhluwe	734	D	2,43	I: 1696 θ: 1174	4,60	20	1	09.29.02 09.29.03	3060	1963	67	91	341	35	27	
95	W3M01	27.41	31.40	Mkuze	Rietboklaagte	1467	G	3,17	740	3,52	8	1	09.29	3320	1963			170	40		(9) DT limit = 5,48 m
96	W3M08	27.37	31.58	Mkuze	Doornhoek	2571	G	4,78	1000	3,46	7	2	09.29					155	35		(9) DT limit = 1,12 m
97	W3	27.26	32.01	Mkuze	Morgenstond	2647	SA	(3,47)	1060	3,50	<10	1	09.29	5500	1984			165	34		
98	W4M04	27.32	30.52	Bivane	Pivaansbad	948	G	1,69	218	2,71	3	2	09.29.03	1019	1963	26	28	165	40	17	(9) DT limit = 0,90 m
99	W4M03	27.25	31.31	Pongolo	Grootdraai	5788	G	1,28	721	2,59	3	1	09.29.06	9200	1984	87	15	133	31	11	(9) DT limit = 3,07 m
100	W4R01	27.25	32.04	Pongolo	Pongolapoort	7830	D		I: 1026 θ: 0	2,72	3	2	09.29.12	13000	1984	132	17	141	28	12	

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Col. 13: (1) = error less than ±10 % (2) = error less than 30 % (u) = unknown accuracy
Col. 9: figures in brackets indicate mean depth of main channel

APPENDIX 3 : SUMMARY OF BRIDGE DAMAGE SURVEY

Site no.	Lat.	Long.	River	Place or route no.	Catchment Area (km^2)	HFL relative to deck (m)	Flood Peak (m^3/s)	Return Period (Years)	Damage and General notes
1	2	3	4	5	6	7	8	9	10
1	30.44	29.50	Mtamvuna	Gundrift (Harding to Bizane)	715	0,00	1470	20-50	Three of five spans destroyed. Central pier dislodged. Both approaches washed away. Founded on rock. Failure due to debris loading and deck dislodgement. Reach is straight.
2	30.43	30.27	Mzimkulu	Port Shepstone to Batstone Drift	6740	4,0(-)	5600	20-50	Bridge and approaches completely destroyed and washed away. Founded on gumpole piles in sand. Failure due to debris and water loading. Piers failed due to scour. Straight reach of river.
3	30.17	30.45	Mpambanyoni	Scottsburgh	560	4,07(-)	1130	20-50	Two piers and deck washed away. Approaches intact. Founded on piles in sand. Failure due to scour of piles.
4	30.01	30.15	Mkomazi	R56 Richmond to Ixopo	3340	1,50(+)		50-200	Approaches washed away. Abutments undermined on upstream side and moved from vertical. The deck also shifted. Founded on rock. Failure due to scour.
5	30.49	30.49	Mkomazi	Railbridge (Umkomaas)	4300	10,0(-)	7000	50-200	Northern approach breached.
6	30.06	30.51	Lovu	Illovo	940	1,80(-)	1800	20-50	One pier washed away. Three deck spans lost. Founded on sand. Failure due to scour of piles supporting pier.
7	29.26	30.26	Mgeni	Railbridge (Albert Falls)	1650	0,2(-)	1820	50-200	Approaches breached and eight spans washed away.
8	29.27	30.27	Mgeni	P.6 (Albert Falls)	1724	2,94(+)	2210	50	Southern approach breached for 15 m.
9	29.40	31.11	Mdloti	N2	525	3,59(-)		50-200	Northern pier and deck washed away. Northern approach breached for 100 m. The northern abutment remained intact. Founded in sand. Failure due to river reverting to northern channel.
10	29.04	30.54	Cubhu (Tributary of Mvoti)	R74 (Kranskop to Mapumulo)	38	2,37(-)		20-50	Abutment fill scoured. Road surface damaged by road runoff. Bridge sited in bend.

NOTE:

(7) HFL = High flood level on upstream side of bridge

(9) Return period read off from Fig. 5.3

(8) Flood peaks are only given for those sites at which flood peak measurements were carried out.

APPENDIX 3 : SUMMARY OF BRIDGE DAMAGE SURVEY

Site no.	Lat.	Long.	River	Place or route no.	Catchment Area (km²)	HFL relative to deck (m)	Flood Peak (m³/s)	Return Period (Years)	Damage and General notes
1	2	3	4	5	6	7	8	9	10
11	29.20	31.18	Mvoti	Railbridge (Stanger)	2820	4,0(-)	5000	50-200	Northern approach breached. Bridge sited in bend.
12	29.21	31.19	Mvoti	N2 (Stanger)	2820	0,90(-)	5000	50-200	Southern approach breached for 50 m. Bridge sited in bend.
13	28.52	30.31	Mooi	R33 (Keate's Drift)	2480	0,60(+)	2000	50	Approaches breached.
14	29.09	30.25	Tugela	N2 (John Ross)	28980	8,40(-)	9400	20-50	Lost all piers and spans except those next to the abutments. Failed at 17h10 on 29/9/1987, 3 hours before peak. Flood level at failure was 11,5 m below the deck. Founded on piles in sand. Failure due to scour.
15	29.05	31.33	Matigulu	N2	583	2,73(-)	3170	50-200	South side embankment fill extensively scoured on the outside of the bend in the river. Little scour on north side. Structure intact.
16	29.38	30.38	Msunduze	Pietermaritzburg (Edendale bridge)	280		600	20-50	South side approach breached and abutment washed away. Failure due to scour as river changed course. Founded on piles.
17	28.59	31.34	Nyezane	R68 (Eshowe to Ginginlovu)	47	1,00(-)		20-50	Leftbank abutment scoured on downstream side to under road shoulder.
18	28.48	31.30		Culvert (Eshowe to Goedertrouw)	2	Flow was 1,5 m in Culvert		50-200	Culvert collapsed on downstream side. Failure due to regressive scour of road fill.
19	28.58	31.38	Nyezane	N2	96	1,36(+)		20-50	Railings damaged. Both abutments scoured on downstream side. South abutment scoured on both sides. An asphalt slab 40x8 m was carried intact for ±20 m downstream.
20	28.55	31.45	Mlalazi	N2	411	0,49(+)		20	Road surface damaged on north side. Old bridge 10 m upstream protected the N2 bridge. At the old bridge the approaces at the abutments were breached.

NOTE:

(7) HFL = High flood level on upstream side of bridge

(8) Flood peaks are only given for those sites at which flood peak measurements were carried out.

(9) Return period read off from Fig. 5.3

APPENDIX 3 : SUMMARY OF BRIDGE DAMAGE SURVEY

Site no.	Lat.	Long.	River	Place or route no.	Catchment Area (km^2)	HFL relative to deck (m)	Flood Peak (m^3/s)	Return Period (Years)	Damage and General notes
1	2	3	4	5	6	7	8	9	10
21	28.52	31.42	Ibati	N2	16	1,90(-)		20-50	Downstream abutment fill scoured on both sides. The north abutment fill was scoured on the upstream side.
22	28.42	31.39	Mfule	R34	620	0,50(+)	3300	50-200	Both approaches were breached for a distance of 30 m.
23	28.51	31.54	Mhlatuze	N2 (Empangeni)	2767	4,0(-)	4000	20-50	Abutment fill breached on south side on the outside of bend in river.
24	28.51	31.55	Mhlatuze	Felixton (Railbridge)	2767	6,05(-)	4000	20-5C	South side approach breached for 12-15 m, at slight bend in the river.
25	28.42	32.01	Nseleni	N2 (Empangeni to Matubatuba)	712	1,2(+)	4250	0,88RMF	Railing damaged due to debris loading on both sides of the bridge.
26	28.27	32.09	Mfolozi	N2 (Matubatuba)	9248	9,2(-)	4500	10	No damage to main bridge. Temporary bridge downstream lost both approaches and flow was 0,5 m over temporary bridge.
27	28.15	32.17	Nyalazi	N2 (Hluhluwe to Matubatuba)	560	1,40(+)	1200	20	Negligible scour at all abutment fills.
28	28.08	32.16	Hluhluwe	N2 (Hluhluwe to Matubatuba)	828	1,00(-)		20	South abutment scoured on both upstream and downstream sides. The south abutment is located on a long fill that covers the flood plain.
29	28.04	32.15	Ncemane	N2 (Mkuze to Hluhluwe)	53	0,66(+)		20	Both abutment fills scoured to under road shoulders on upstream side. Surface scour of downstream fill.
30	28.01	32.14	Mzinene	N2 (Mkuze to Hluhluwe)	150	0,30(+)		20	Both abutment fills scoured on upstream and downstream sides. Asphalt damaged on road shoulders.
31	27.57	32.13	Ngweni	N2 (Mkuze to Hluhluwe)	97	0,31(-) flow was 0,15(+) on south side		20-50	Scour of south abutment fill on upstream side on the outside of the bend in the river.

NOTE:

(7) HFL = High flood level on upstream side of bridge

(9) Return period read off from Fig. 5.3

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