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CROSS-SECTION CHANGES IN THE MFLOLOZI RIVERS: EROSION AND SEDIMENTATION.

P.R. Bracher and Z.P. Kovács
Department of Water Affairs 1985.

Abstract

In the alluvial valleys of the White Mfolozi, Black Mfolozi and Mfolozi rivers 12 cross-sections were surveyed after the February 1977 floods at three sites with the purpose of flood peak estimation. The sections were resurveyed in March 1984 after the Domoina floods. In March 1985 the sections were again resurveyed and in the Mfolozi River piezometer cone penetration testing (CUPT) was carried out to obtain information on the deepest scour line during the Domoina flood. The lateral and vertical cross-section changes are compared and related to flood regime, potential catchment erosion, unit stream power and to other conditions. The results are significant enough to justify systematic monitoring of cross-sectional changes in alluvial rivers.

CROSS-SECTION CHANGES IN THE MFOLOZI RIVERS : EROSION AND SEDIMENTATION

by : P.R. Bracher and Z. Kovács, Department of Water Affairs, Pretoria.

INTRODUCTION

After the February 1977 flood which had been the last appreciable event before the Domoina deluge, slope-area surveys were carried out at three sites in the alluvial valleys of the Mfolozi rivers with the aim of flood peak determination, see Sites 1, 2 and 3 in Figure 1. These sites were resurveyed after Domoina (February and March 1984) with the dual aim of flood peak determination and checking of cross-section changes. The discovery of substantial cross-section enlargements has called attention to the need of regular monitoring of erodible river reaches and spot-checking of the deepest scour profile.

Due to the great number and complexity of processes and factors which influence river channel stability, theoretical and model studies alone are unable to predict the behaviour of alluvial rivers. In many problems prototype measurements may furnish the most reliable basic information or facilitate the solution of practical problems.

In the following an attempt is made to interpret the results of field surveys and search answers to questions such as the

- relative importance of vertical and lateral section changes
- representativeness of surveyed (post-flood) sections for flood peak calculations
- relation of surveyed scour to catchment erosion potential and other parameters.

The moderate flood of February 1985 in the Mfolozi rivers has been a fortunate occasion to implement the regular monitoring of section changes and supply further information for the study.

Though this study refers to fairly straight natural reaches, valuable additional information was obtained at two bridges and in the short intermediate reach in the Mfolozi River near Mtubatuba (Site 4 in Figure 1).

DESCRIPTION OF THE SITES AND THEIR CATCHMENTS

Site 1 : Black Mfolozi River in the Umfolozi Game Reserve

(Figures 1, 4 and 12, Photo's 1, 7 and 8)

This river reach has a straight plan with steep banks rising fairly sharply from the sandy river bed which follows a braided pattern during low flows. The right bank flattens off to a wide flood plain. This gave the sections an asymmetrical shape during the Domoina flood (Figure 4). The left bank exhibits rocky outcrops. The vegetation along the banks is thick Zululand bush. In the 700 m long reach four sections were surveyed (Photo 1).

Site 2 : White Mfolozi River in the Umfolozi Game Reserve

(Figures 1, 5 and 13, Photo's 2, 9 and 10)

This river reach is very straight and uniform, both banks are steep. The river bed is sandy and at low flows it has a braided pattern. There are no rocky outcrops. The vegetation is similar to Site 1. It is slightly thicker on the left bank inside the Umfolozi Game Reserve. The four sections were surveyed in a 1 300 m long reach (Photo 2).

Site 3 : Mfolozi River 6 km upstream of the N2 bridge crossing.

(Figures 1, 6 and 14, Photo's 3, 4, 11 - 16)

This is an 1 300 m long fairly straight reach. Its upstream end is just downstream of a curve. The vegetation of the banks is short grass with only isolated bushes. The comparison of aerial photographs taken in 1969 and 1984 (Photo's 3 and 4) shows the great changes caused by the Domoina flood. The most striking of these is the disappearance of the cultivated flood plains and the braided low water channel pattern. The flood plains were either washed away or covered by deposits. Four sections were surveyed.

Site 4 : Mfolozi River between the N2 and SAR bridges near Mtubatuba

(Figures 1 and 11, Photo's 5, 6, 17 - 20)

This straight reach is about 1 500 m long. Its upstream and downstream ends are at the N2 road bridge and the SAR bridge respectively. Both bridges were destroyed by Domoina. The comparison of aerial photographs taken in 1970 and 1984 (Photo's 5 and 6) shows the great changes, which are essentially the same as at Site 3, caused by the Domoina flood. The vegetation of the banks is similar to Site 3. The sudden widening of the flood plain downstream of the SAR bridge marks the beginning of the Mfolozi Flats.

The catchments (Figure 1, reference (1)).

The headwaters of the Black- and White Mfolozi rivers are situated near Vryheid at an altitude of about 1 500 m. The upper catchment of the Black Mfolozi is distinctly steep. Approximately two-thirds of the catchment at Sites 3 and 4 consists of soils with high runoff potential. This figure is about 80% for the Black Mfolozi catchment. The dominant veld-types are various false-grassveld types, thornveld and Zululand thornveld. Under normal climatic conditions these veld-types do not facilitate quick runoff. After prolonged droughts, however, considerable parts of the catchments, especially in Kwa-Zulu, become bare and denuded, mainly due to overgrazing. The result is high runoff and potential soil erosion. The Mfolozi catchment is affected by cyclones and tropical depressions and, as proved by Domoina, it can even be visited by tropical cyclones. Consequently, high storm-rainfall figures, in South African context, are not uncommon. The flood regime is of the extreme type i.e., years of drought or moderate floods are interrupted by extreme floods. Table 1 is a summary of a few relevant physical catchment parameters.

TABLE 1 : PHYSICAL FEATURES OF THE MFOLOZI CATCHMENTS

	Area A (km^2)	River length L (km)	Shape factor $L/\sqrt{A}$	Average slope %	MAP (mm)	1-day, 100 yr rainfall (mm)	Mean annual flood peak (m^3/s)
Black Mfolozi at Site 1	3 396	196	3,37	1·5	870	230	600
White Mfolozi at Site 2	4 776	292	4,23	10	820	220	500
Mfolozi between Sites 1, 2 and 4	1 076	106	3,23	3	840	270	1 000
Mfolozi at Site 4	9 248	398	4,14	11	840	230	1 000

SURVEYS

Cross-sections

At each site four cross-sections were surveyed. The shape of cross-sections was obtained, on the average, from 20 points. The flood levels were obtained from a great number of flood marks surveyed along the reaches. In the survey of sections standard tacheometric technics were employed by using a Kern theodolite and a levelling staff. The 1977 and 1984 surveys were matched with the help of bench marks, aerial photographs and photographs.

Maximum (deepest) scour profile

(Figures 2 and 3, Photo's 14 - 16)

This is the deepest profile which was scoured during the Domoina flood. It was determined only in the Mfolozi River, in sections 3 and 4 at Site 3. The method employed was the Piezometer Cone Penetration Testing (CUPT) developed by Jones and Rust (2). The piezometer used in the CUPT testing is similar to the standard 35 mm diameter electrical cone but in addition has a pore pressure sensor. This allows simultaneous measurement of penetration resistance and excess pore pressure generated during penetration.

By correlating the CUPT data with independent soil classification tests the authors of the method were able to draw up a chart relating penetration resistance and pore pressure to soil type (Figure 2). Figure 3 illustrates an example of a test hole at Site 3 and the associated maximum scour depth.

RESULTS

(Note : In comparing survey results from 1977, 1984 and 1985, these refer to conditions observed after the respective floods).

1. Comparison of the 1977 and 1984 sections at Sites 1, 2 and 3

(i) Graphical and visual comparison

Black Mfolozi (Figure 4) : Both the lateral and vertical enlargement of the sections are rather small. Scour is dominant below the 1977 flood level (HFL 1977). Photo's 7 and 8 show little sediment deposition. The general shape of both sets of sections is similar, except the addition in 1984 of a wide flat flood plain along the right bank.

White Mfolozi (Figure 5) : The same applies as in the Black Mfolozi, but with more pronounced lateral scour and sedimentation (Photo's 9 and 10).

Mfolozi (Figure 6) : The widening of the channel was large, its deepening was moderate. Sediment deposition took place mainly above HFL 1977. As the 1977 survey was not extended above that level, nothing certain can be said above the relative magnitude of erosion and deposition between HFL 1977 and HFL 1984. It appears that, on the whole, the two processes were in balance. Photo's 4, 11 and 13 show extensive depositions. These, however, were generally shallow, except in zones of stagnant waters, such as at tributary mouths. Noticeable is the lateral shifting of the channel. In section 1 the gravity centre of the 1984 section was shifted to the left by about 60 m, in section 4, it was shifted to the right by the same distance. The shifting was evidently caused by the disturbing effect of the river curve situated immediately upstream of the reach.

(ii) Numerical comparison

This is shown in Table 2 where some of the principal flow parameters of the Domoina flood (3) are compared with parameters expressing the enlargement of the 1984 sections relative to the 1977 ones. The latter parameters are explained in Figure 7.

TABLE 2 COMPARISON OF FLOW PARAMETERS AND SECTION ENLARGEMENTS CAUSED BY THE DOMOINA FLOOD.

	Item No.	Parameter		Unit	Black Mfolozi (Site 1)	White Mfolozi (Site 2)	Mfolozi (Site 3)
MEAN FLOW PARAMETERS	1	Catchment area	A	km^2	3396	4776	9218
	2	Storm rainfall) depth		mm	580	445	500
	3	over catchment) volume		$10^6 m^3$	1970	2130	4610
	4	Slope of water surface	S	m/m	0,0012	0,0010	0,00056
	5	Mean velocity	v	m/s	3,6	3,1	2,8
	6	Flood peak	Q	m^3/s	10000	6500	16000
	7	Stream power: ρgQS		$10^3 kgms^{-3}$	120	65	89
MEAN SECTION PARAMETERS	8	Increase of wet cross-section: $\Delta a = a_{1984} - a_{1977}$		m^2	3060	1820	5290
	9	Area of scoured section below level HFL 1977	a_s	m^2	130	190	880
	10	$a_s/\Delta a$		-	0,04	0,10	0,17
	11	Water level rise: ΔHFL = HFL 1984 - HFL 1977		m	11,1	8,4	9,8
	12	Maximum scour depth	y	m	1,1	1,3	2,0
	13	y/ΔHFL		-	0,10	0,15	0,20
	14	Scour width at level HFL 1977		m	17	35	95
	15	Median sediment diameter		mm	0,12	0,39	0,40

Conclusions :

- Increased flood discharges were mainly accomodated by rising water level. Relative to the great increase of wet cross sections the scoured areas were small to moderate (items 8-10).

- In absolute and relative terms the smallest erosion took place in the Black Mfolozi notwithstanding the steepest slope, highest velocity and greatest stream power. The greater stability of this river reach is perhaps due to

(a) more stable banks because of dense vegetation and rocky outcrops,

(b) the channel had been adjusted to higher floods than the White Mfolozi (Figure 8) because of steeper, less elongated and more impermeable catchment and higher storm rainfalls (Table 1),

(c) sediment transport must have been extremely high during Domoina owing to severe land erosion, particularly in the upper catchment (Consult the pre-Domoina LANDSAT IMAGE : photo 54 in reference (3)). This is supported by the small median sediment diameter obtained from a spot-sample (item 15). Increased sediment transport, in turn, consumes more energy. This could be an important reason for the small scour in spite of high stream power (items 7, 9, 10 and 12).

- In absolute and relative terms the biggest scour was experienced at Site 3 in the Mfolozi, despite the smallest slope and velocity. The big scour was caused by the presence of more erodible river banks i.e., lateral scour could progress with relative ease.

- Lateral scour was at each site far more important than vertical scour (items 12 and 14).

- The storm rainfall volume was a better indicator for channel erosion than any other flow parameter. The stream power was not indicative for scour.

2. Maximum scour profiles during Domoina in the Mfolozi River at Site 3

Figures 9 and 10 show the 1977 and 1984 surveyed profiles and the maximum scour profile during Domoina in sections 3 and 4. As mentioned earlier, the latter profiles were obtained by the CUPT method. A comparison of the three profiles reveals that:

- The scoured area between the 1984 profile and the maximum scour line was less than 10% of the wet cross section associated with HFL 1984. The maximum depth of the maximum scour line below the 1984 profile was about 4 m in section 3 and 3 m in section 4.

- In both sections the maximum depth of the maximum scour line lies near to the deepest part of the 1977 profile, rather than to the deepest part of the 1984 section. This means that the deepest scour during Domoina had to occur relatively early in the flood when the previous profile (= the 1977 one) still exerted a leading role on the flow pattern. Another implication is that the lateral scour had to take place mainly during the subsequent flood stages. It thus follows that the maximum scour profile did not correspond to one given point in time, but to different moments.

In Photo 12 the erosion of a steep sand bank at Site 3 is shown. The sand bank was deposited by earlier large floods. The loose sand at the base of the steep face bears withness to lateral channel erosion during flood recession when the saturated banks collapse because of increased weight and decreased frictional strength. Consequently, the top width of the surveyed 1984 sections is wider than the unknown top width during flood peak. Prototype and model studies carried out for the San Dieguito River in California by Howard H Chang led to the same conclusion (4).

To sum up, it appears that the wet river cross section was deeper but narrower during the Domoina flood peak than at the time of the post-Domoina survey (February-March 1984). It seems therefore admissible to assume that the surveyed sections were fairly representative for flood peak calculations. During the flood recession sediment was deposited over those parts of the sections where the velocity was low or stagnant water was characteristic. These deposits, however, were responsible but for a minor reduction, say less than 3%, of the cross-section.

The above conclusions were obtained for a straight, sandy river reach with erodible banks. It is obvious that in constricted sections, where the river bed is erodible but the banks are not (bridges) the general scoured section during flood peak ought to be larger than the one given by post-flood survey.

3. Comparison of sections in the Mfolozi River near Mtubatuba (Site 4)

(Figure 11, Photo's 5, 6, 17 - 20)

Figure 11 shows 10 channel profiles surveyed in four sections between 1927 and 1984.

Section A lies at the N2 road bridge site. It had been surveyed 3 times:

- Before the July 1963 flood when natural flow conditions prevailed (5).
- After the July 1963 flood. This flood occurred during the early stages of the construction of the road bridge which was washed away by Domoina. The flood peak was ± 8 500 m^3/s, the second largest on record. This profile also represents mainly natural flow conditions (5).
- After Domoina. This profile represents constricted conditions.

The conclusion from Figure 11 is essentially the same as for the natural sections of Site 3 i.e., the lateral channel scour was dominant. The 1984 section was only ± 2m deeper than the pre-July 1963 one, but it was 150 to 200 m wider at bottom level.

The deepest general scour profile during Domoina ought to have been considerably below the surveyed profile.

Section 1 and 2 were surveyed in 1963 and 1984 between the two bridges. The 1984 sections show aggradation on the left bank. The channel bottom levels are not very different.

Section B lies at the SAR bridge which was built in 1929 and was destroyed by Domoina. The previous bridge was destroyed during the March 1925 flood. The three profiles were surveyed parallel to the crossing and represent essentially natural conditions as the flow was not significantly contracted by the structure. These profiles are a remarkable proof for the stable nature of the river bed level and the overwhelming importance of lateral scour (6).

4. Comparison of the 1984 and 1985 sections at Sites 1, 2 and 3

Figures 12 to 14 reveal that the moderate flood of February 1985 (Q_{max} $\sim$1 000 m^3/s) did not cause perceptible changes in the large sections scoured by Domoina. The difference between the two sets of profiles can mainly be attributed to slight differences in the position of the surveyed sections.

Though this result seems to be contrary to the expection that small floods tend to fill up sections eroded by large floods, it, in fact, supports the earlier made conclusion in respect of the remarkable stability of channel bed levels. It is also an indication that large sections scoured by extreme floods would require quite large floods, thus long periods, for narrowing by sediment deposits.

Sediment samples taken from the surface of the channel bed at Site 2 and 3 (two samples at each site) indicated definitely smaller median diameters that the post-Domoina samples : 0,12 mm vs 0,39 mm in the White Mfolozi and 0,10 mm vs 0,40 mm in the Mfolozi.

SUMMARY

Principal conclusions

1. In straight natural reaches of the alluvial valleys of the Mfolozi rivers large floods are accommodated, in addition to rising water level, mainly by channel widening. Vertical general scour was moderate or negligible.

2. In two sections of the Mfolozi (Site 3) the result of CUPT tests seem to indicate that the deepest vertical scour had occurred during the rising flood phase and the widest eroded profile was established during the falling flood phase. Hence it may be assumed that the post-flood surveyed sections were fairly representative for flood peak calculations.

3. The narrowing of wide sections eroded by Domoina would require fairly large floods i.e., long periods.

4. Besides the erodibility of the river channel perimeter, the scoured area of sections seemed to depend also on the total storm rainfall volume and sediment concentration conditioned by land erosion. It showed no relation to slope, velocity and stream power.

5. The considerable lateral channel erosion caused by Domoina has two practical implications for erosion defence :

   (i) In river reaches where bank erosion would cause great danger or economical loss, the banks, particularly at their base, should be properly protected.

   (ii) At bridges the protection of piers and abutments should be generally based on the same scour depth.

Comment : The above results obtained from only a few observations justify the regular monitoring of alluvial river cross-sections. This has already begun in five Natal rivers where the position of 20 cross-sections have been permanently marked. Besides the regular re-surveying, more spot-check data should be required on maximum scour depths during floods.

ACKNOWLEDGEMENTS

The permission of the Director General of Water Affairs to present this paper is gratefully acknowledged. Thank are due to the staff of the Subdirectorate Flood Studies and the Howick Hydro Regional Office, both belonging to the Directorate of Hydrology of the Department of Water Affairs, for the surveys. The permission given by Mr E. Rust to quote from his investigations into subsoil probing is also acknowledged.

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6. PERSONAL COMMUNICATION with Mr J Szombati of the South African Railways.

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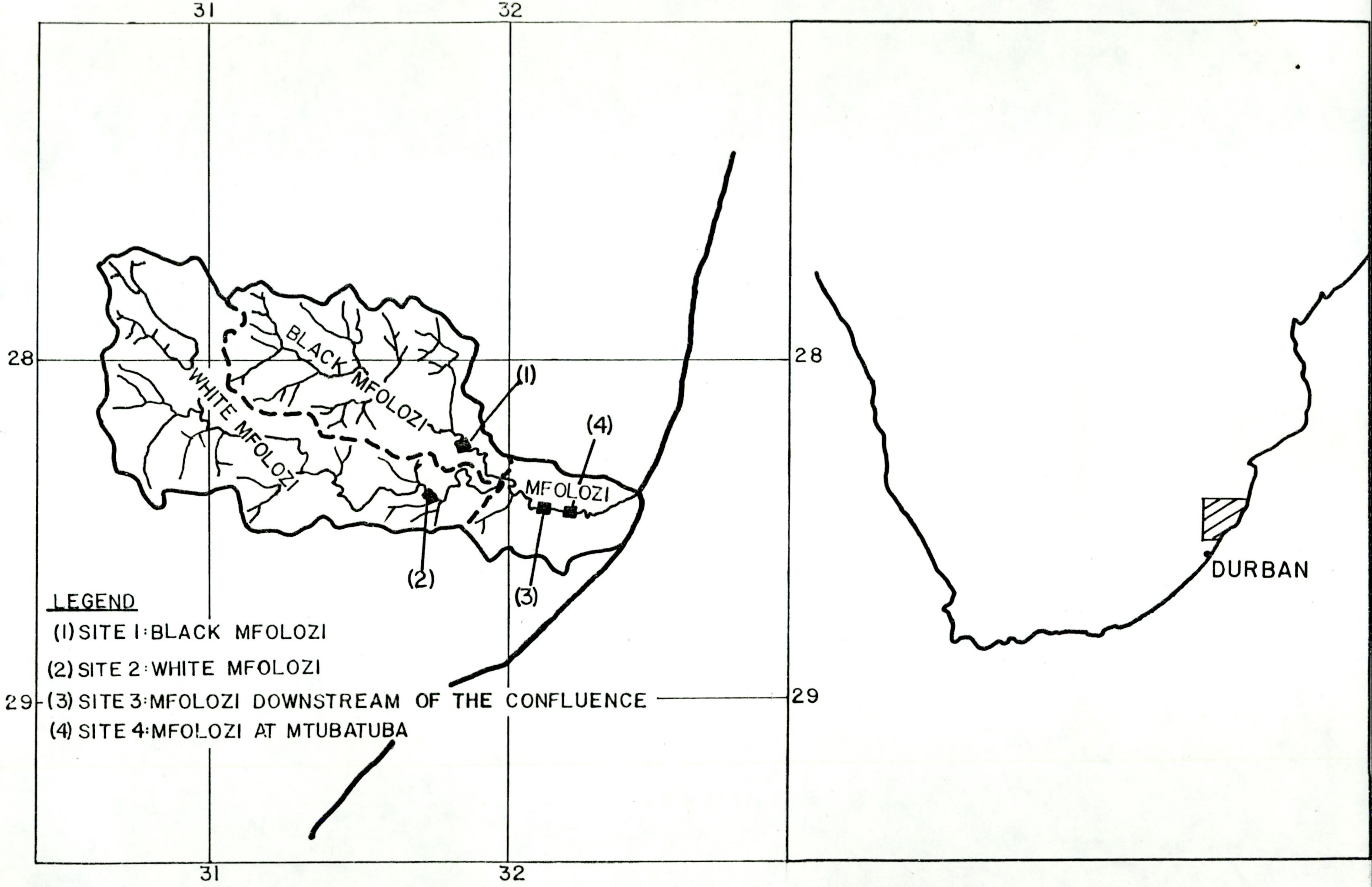


FIGURE I LOCATION OF SITES IN THE MFOLOZI CATCHMENT

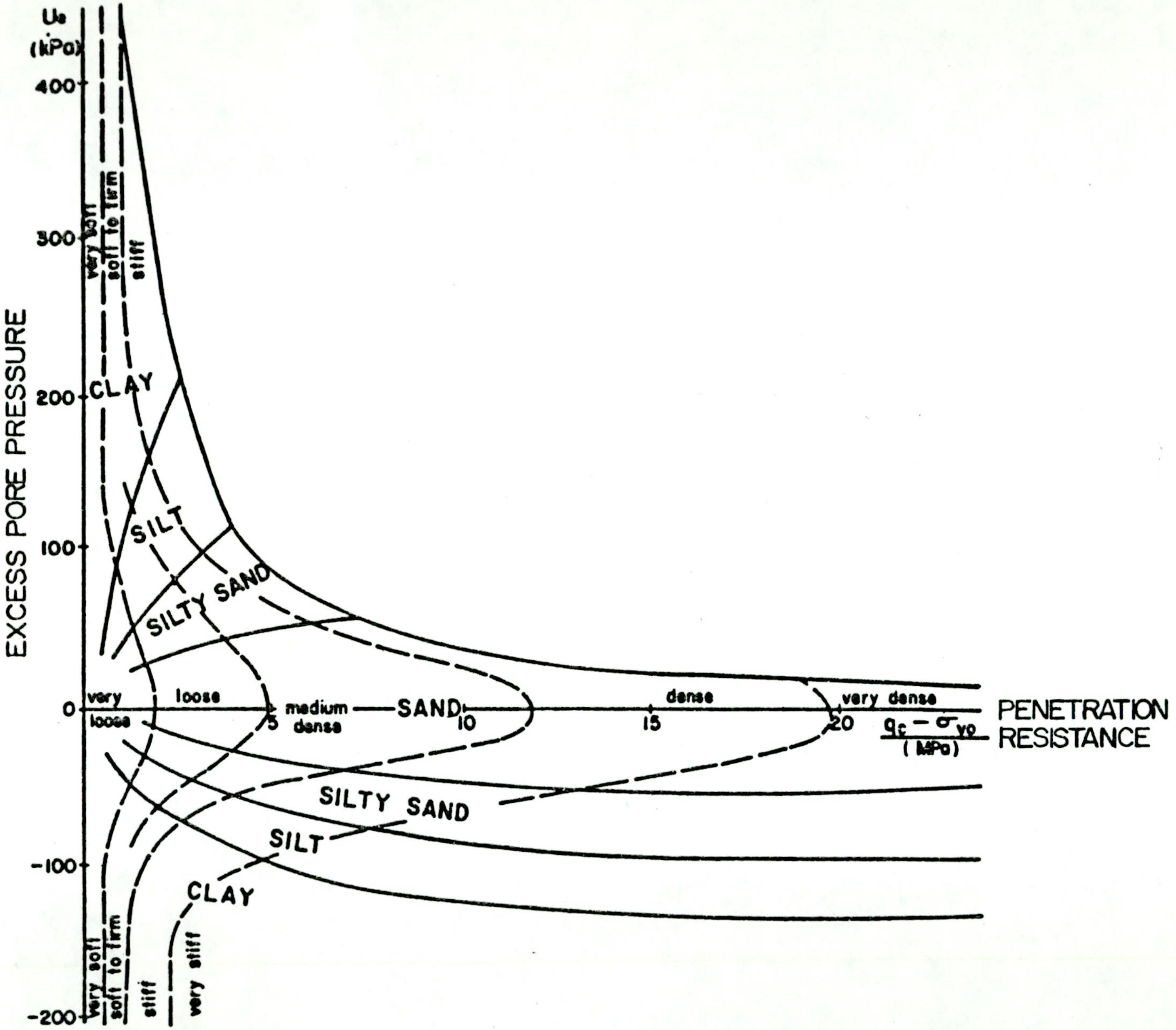


FIGURE 2. PIEZOMETER PROBE (CUPT) SOIL IDENTIFICATION CHART.

MFOLOZI RIVER
SITE 3, SECTION 3

DATE: 22/03/85

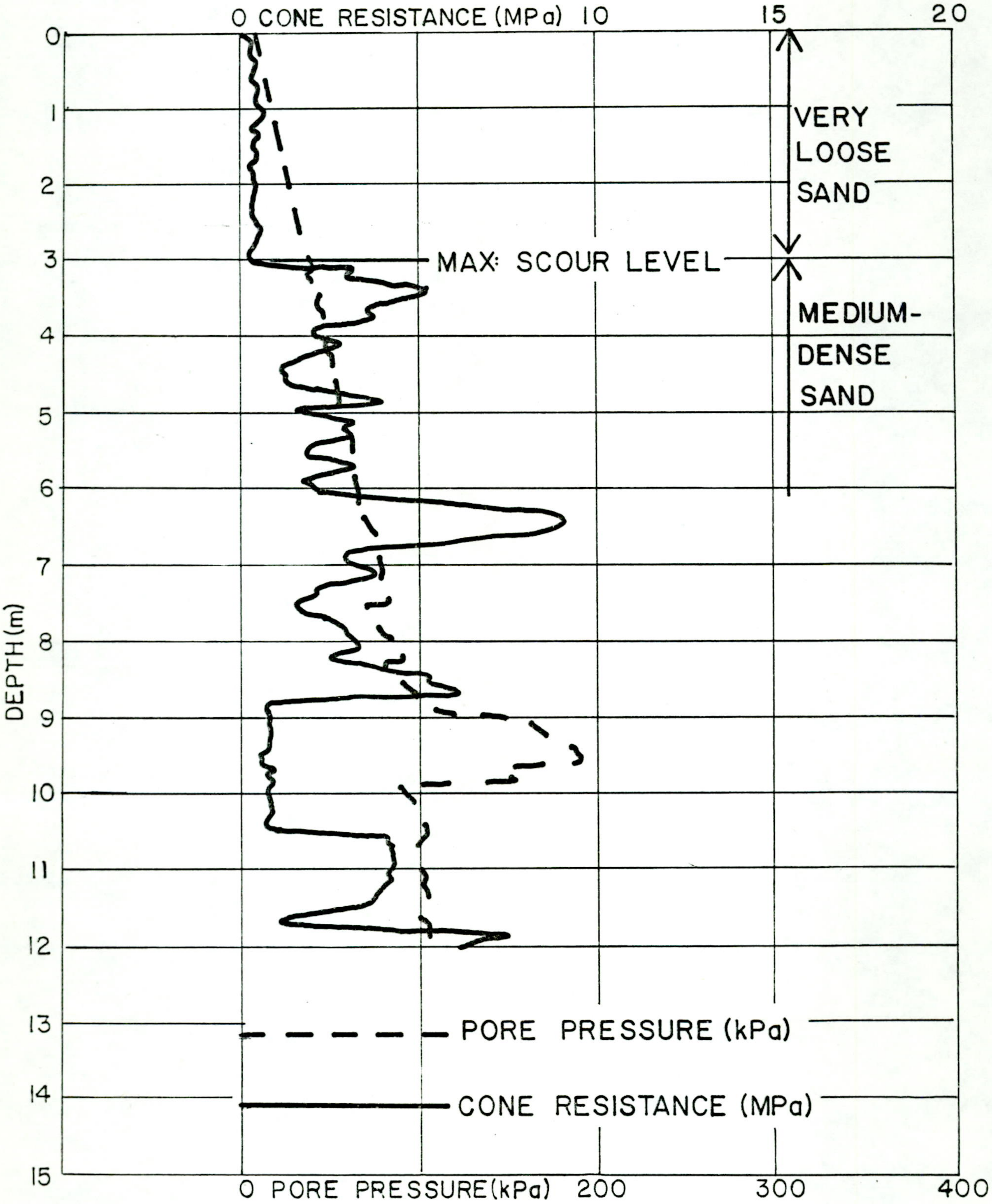


FIGURE 3 EXAMPLE OF PIEZO PROBE PENETRATION TEST

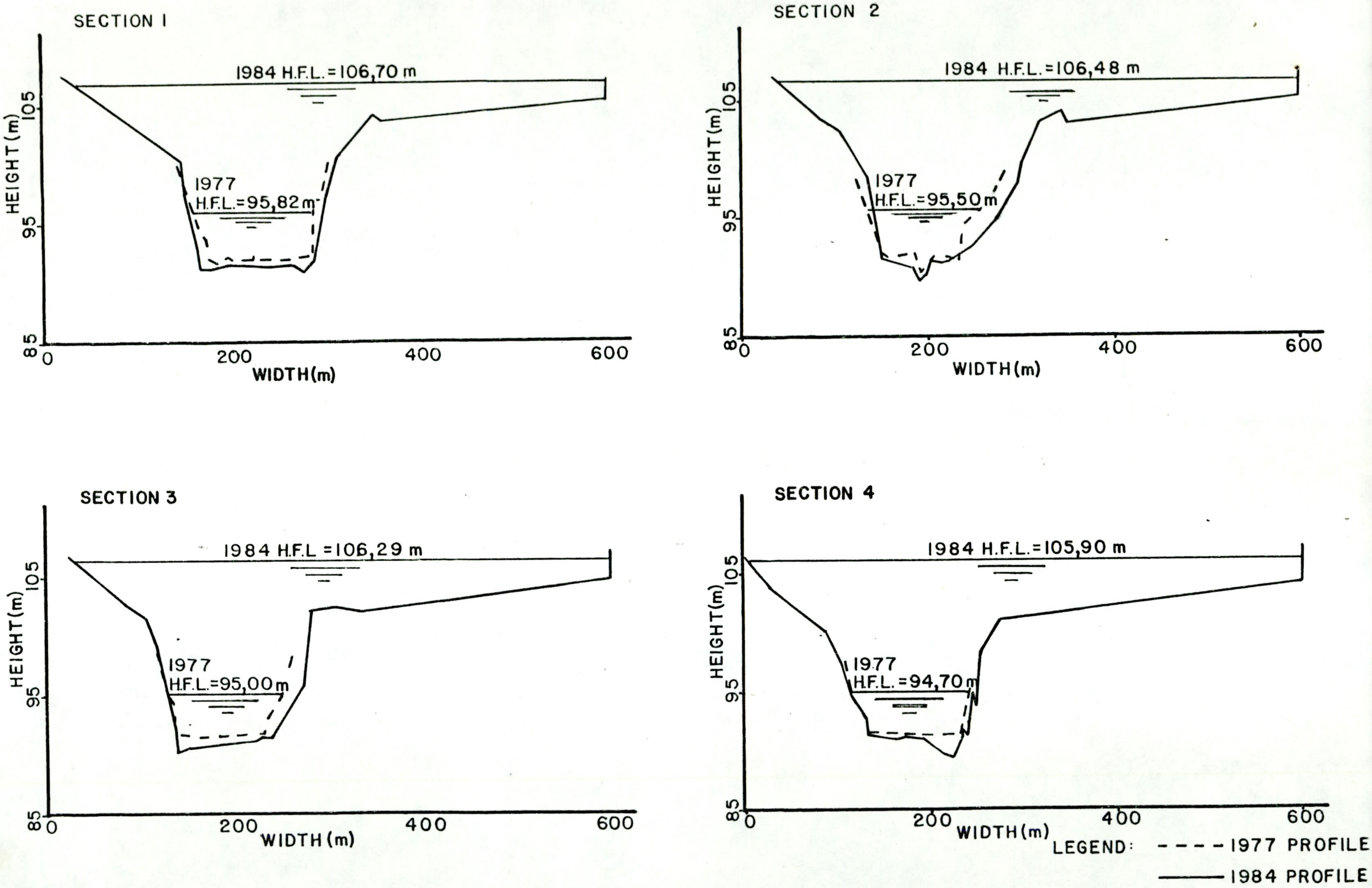


FIGURE 4 COMPARISON OF CROSS SECTION CHANGES AT SITE I : BLACK MFOLOZI RIVER

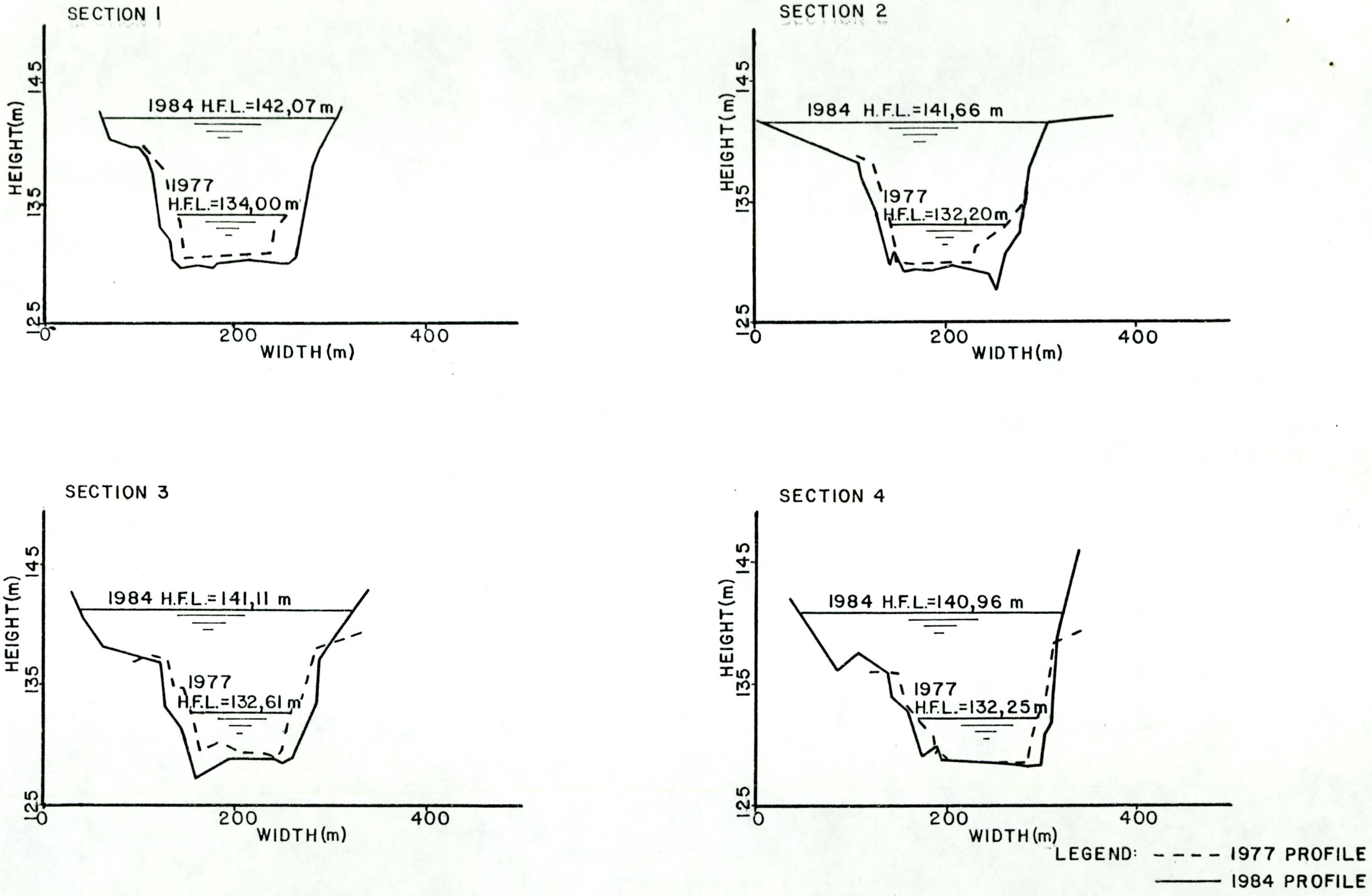


FIGURE 5 COMPARISON OF CROSS SECTION CHANGES AT SITE 2 : WHITE MFOLOZI RIVER

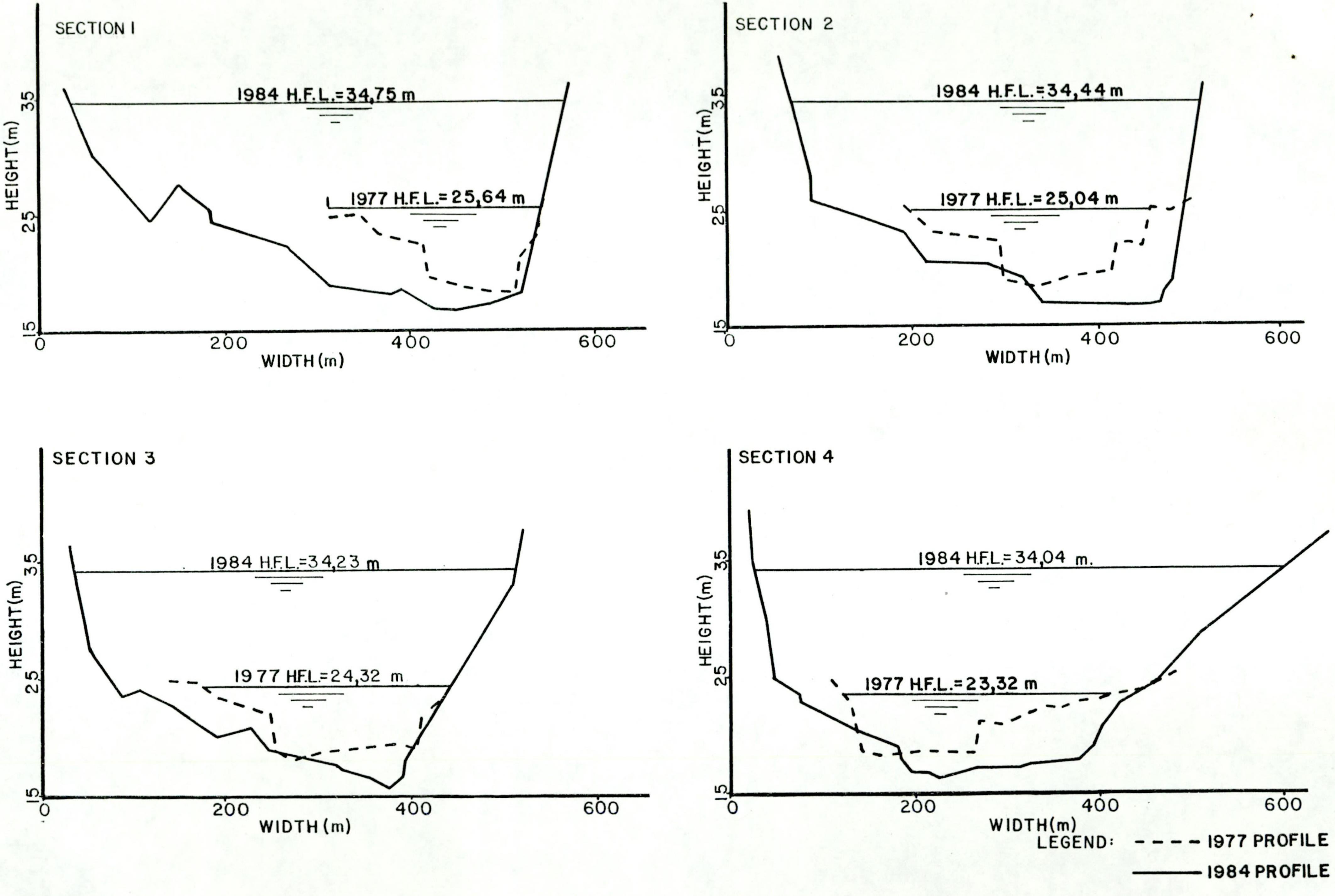
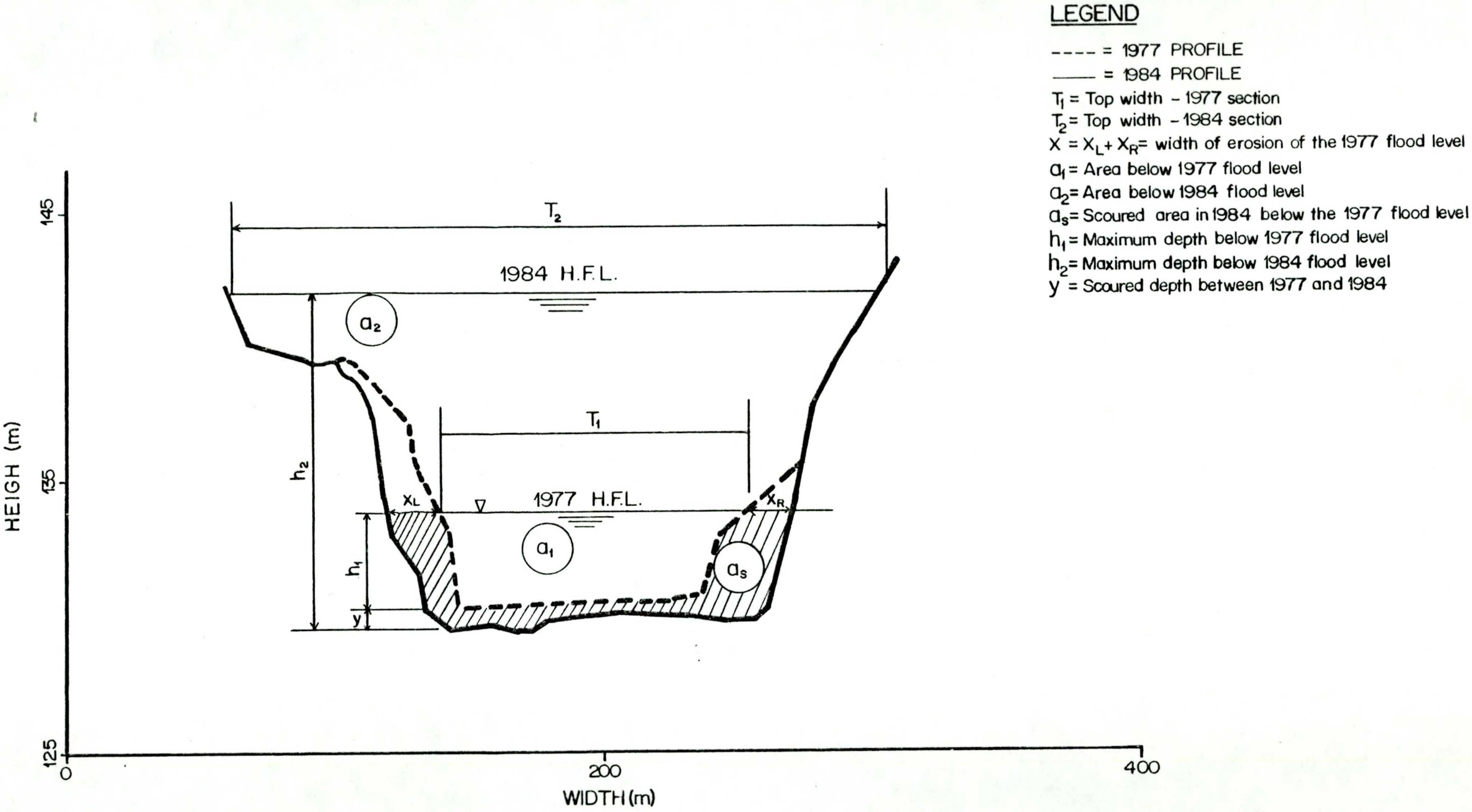


FIGURE 6 COMPARISON OF CROSS SECTION CHANGES AT SITE 3 'MFOLOZI RIVER



LEGEND

---- = 1977 PROFILE
―― = 1984 PROFILE
T_1 = Top width - 1977 section
T_2 = Top width - 1984 section
$X = X_L + X_R$ = width of erosion of the 1977 flood level
a_1 = Area below 1977 flood level
a_2 = Area below 1984 flood level
a_s = Scoured area in 1984 below the 1977 flood level
h_1 = Maximum depth below 1977 flood level
h_2 = Maximum depth below 1984 flood level
y = Scoured depth between 1977 and 1984

FIGURE 7. PARAMETERS USED TO MEASURE CHANGES IN CHANNEL GEOMETRY.

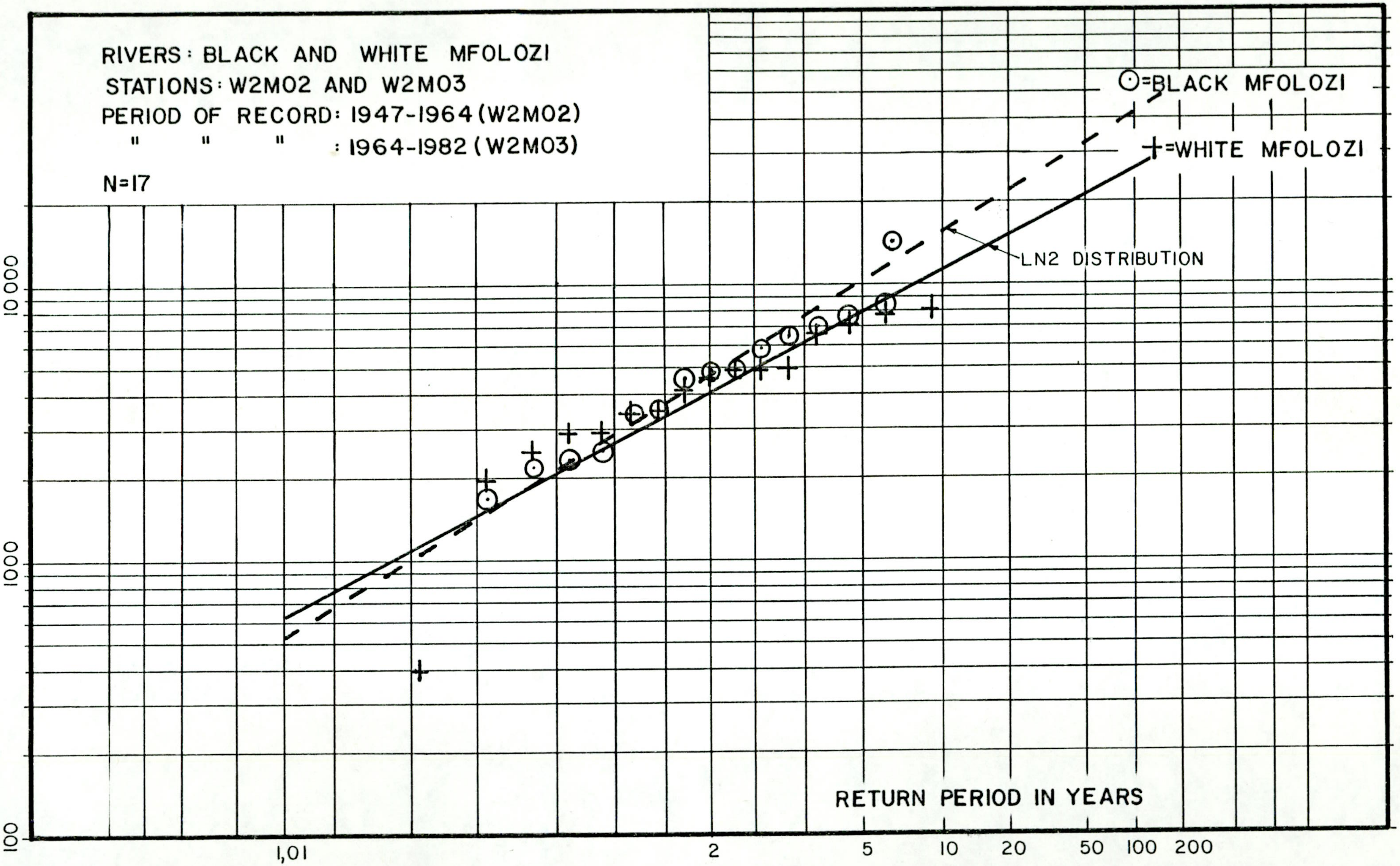


FIGURE 8 FLOOD PEAK DISTRIBUTION OF THE BLACK AND WHITE MFOLOZI

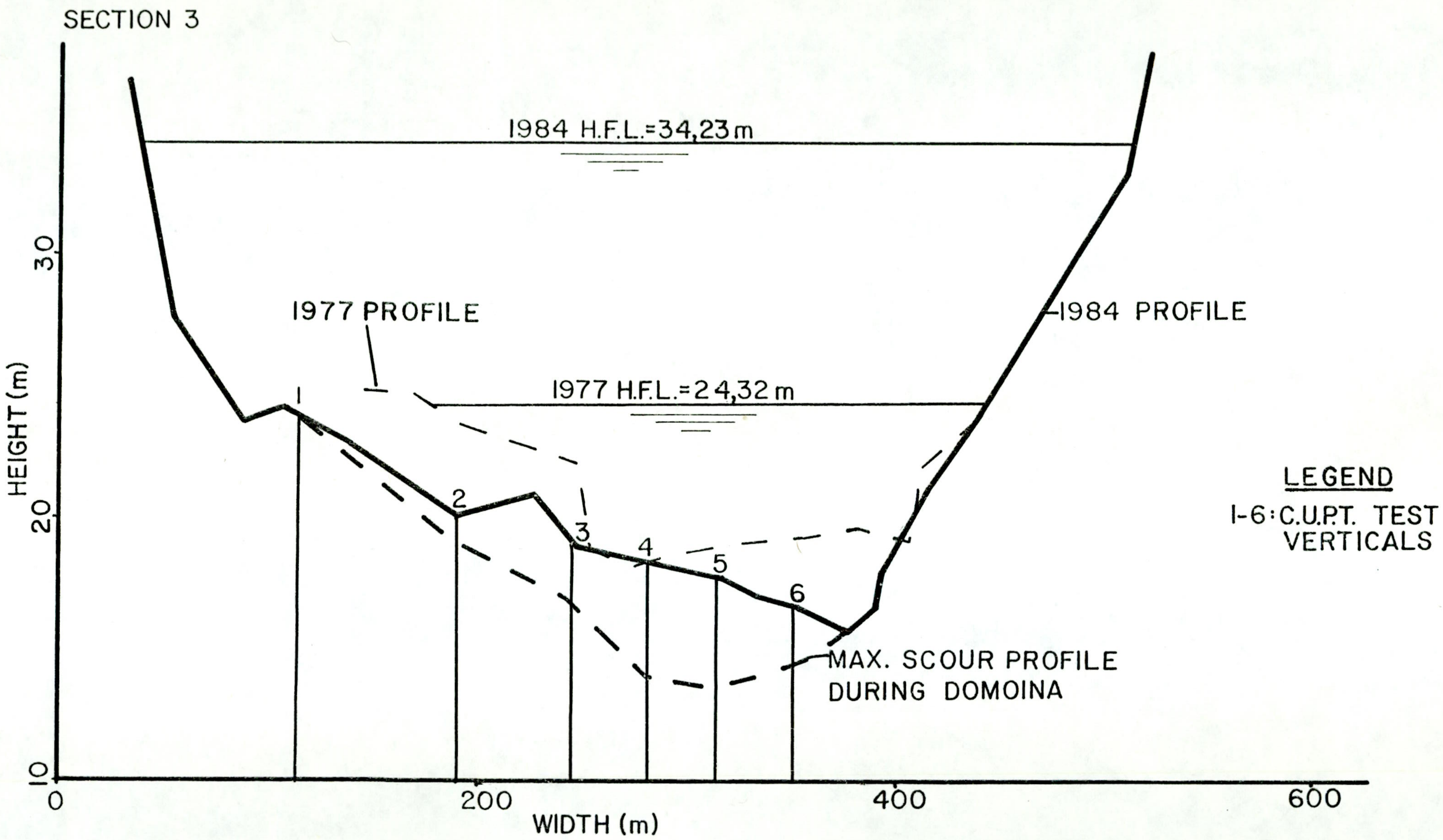


FIGURE 9 MAXIMIUM SCOUR PROFILE DURING DOMOINA AT SITE 3: MFOLOZI RIVER

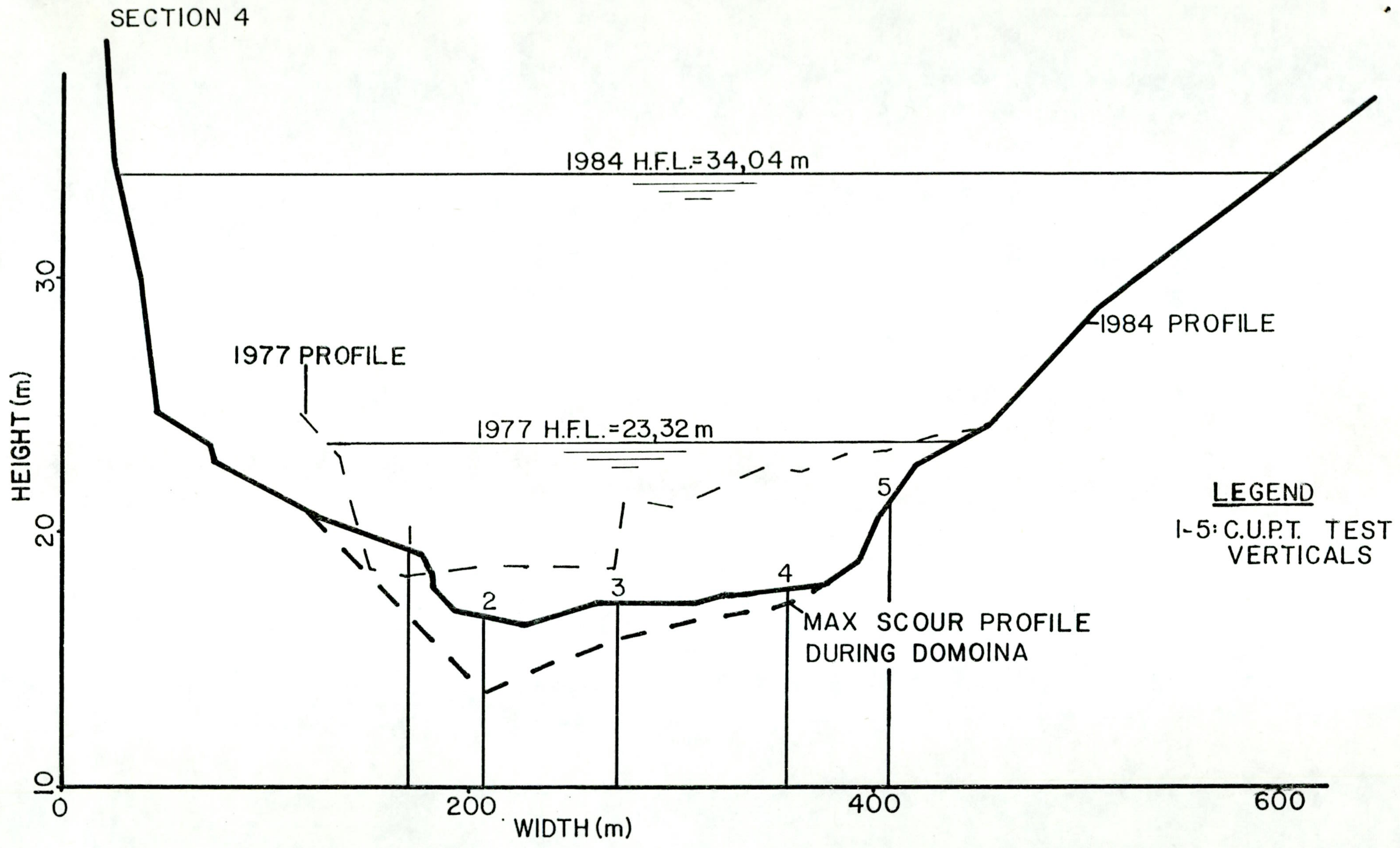


FIGURE 10 MAXIMIUM SCOUR PROFILE DURING DOMOINA AT SITE 3: MFOLOZI RIVER

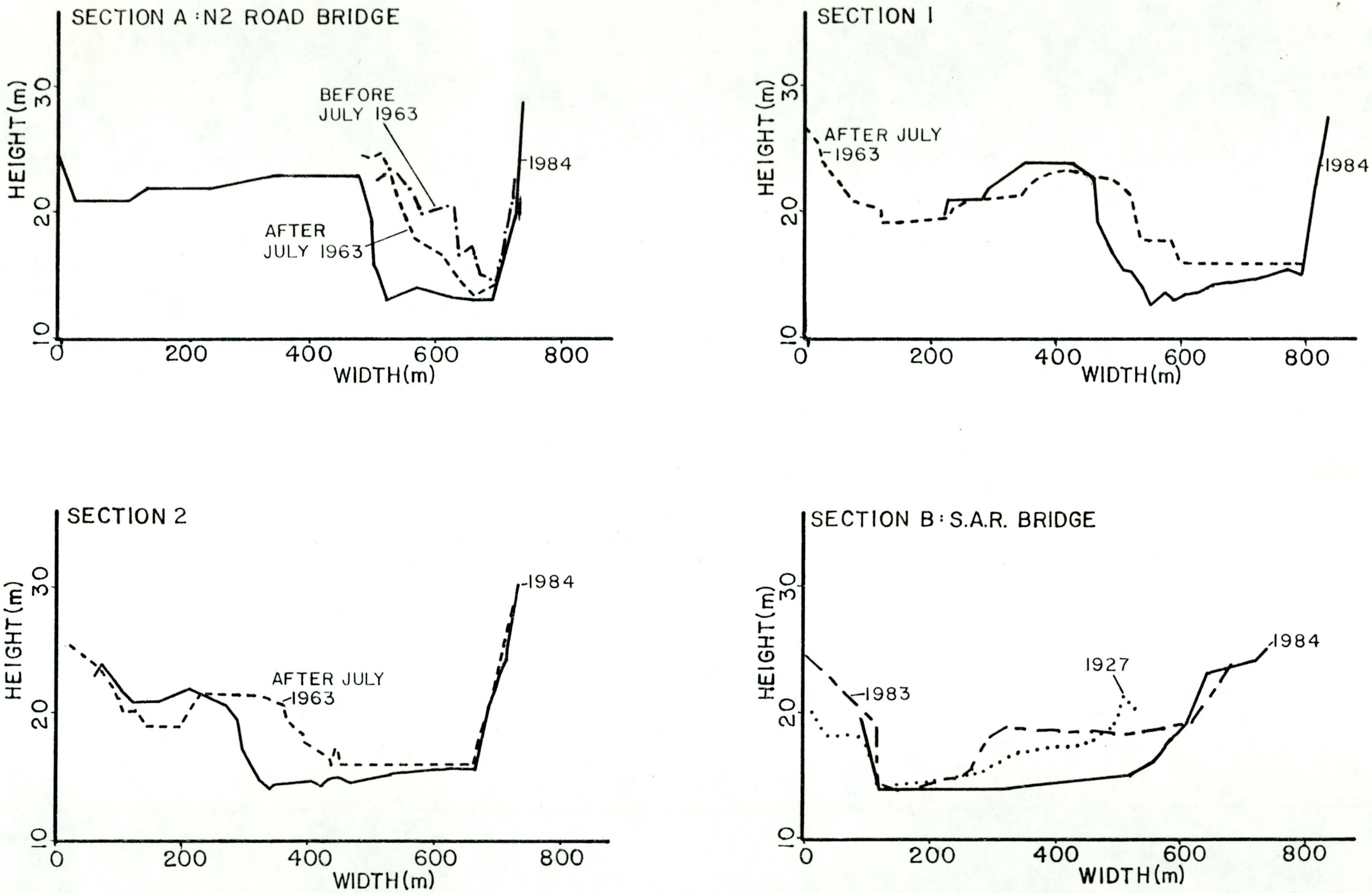


FIGURE II COMPARISON OF CROSS SECTION CHANGES AT SITE 4 : MFOLOZI RIVER

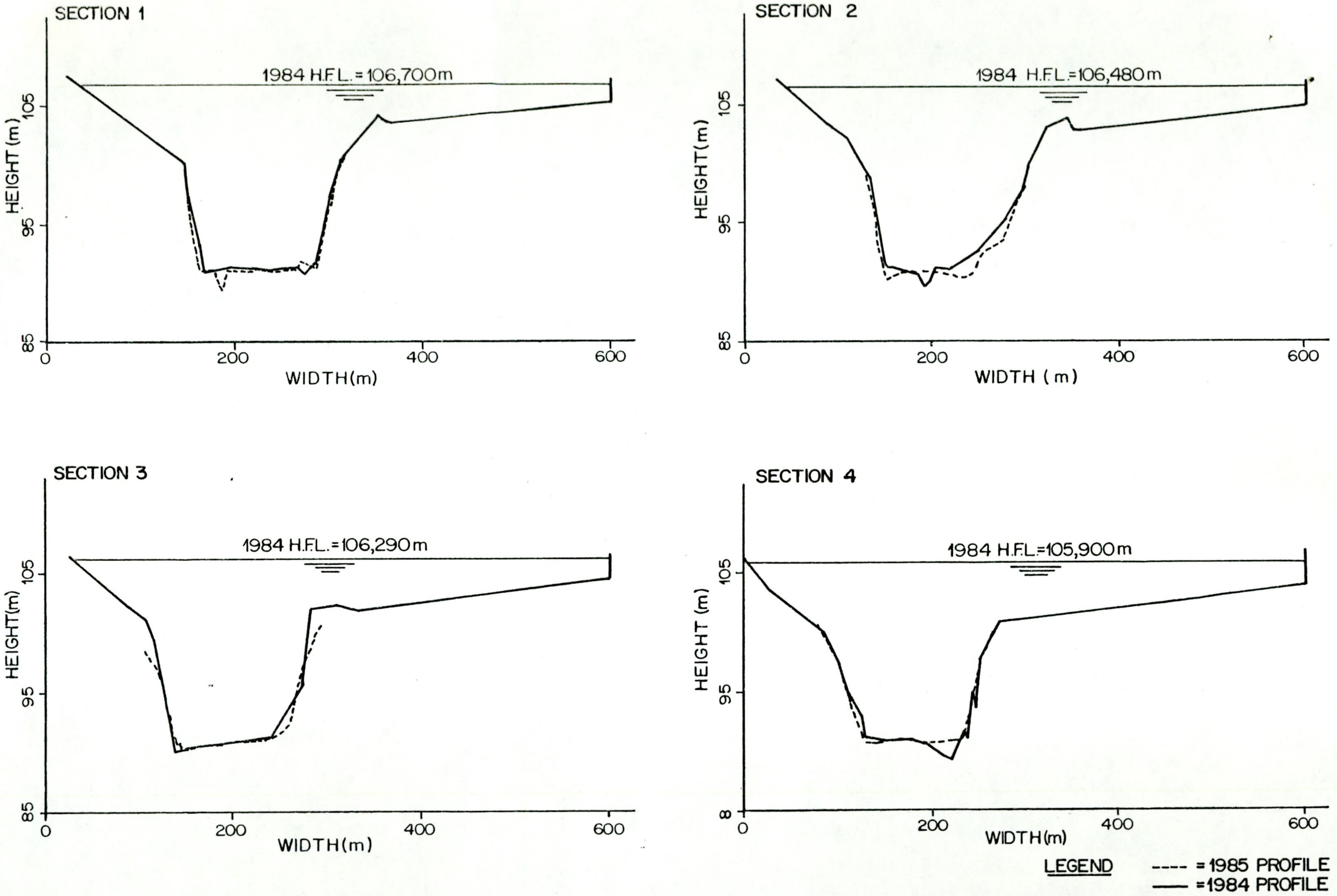


FIGURE 12 COMPARISON OF CROSS SECTION CHANGES AT SITE 1, BETWEEN 1984 AND 1985

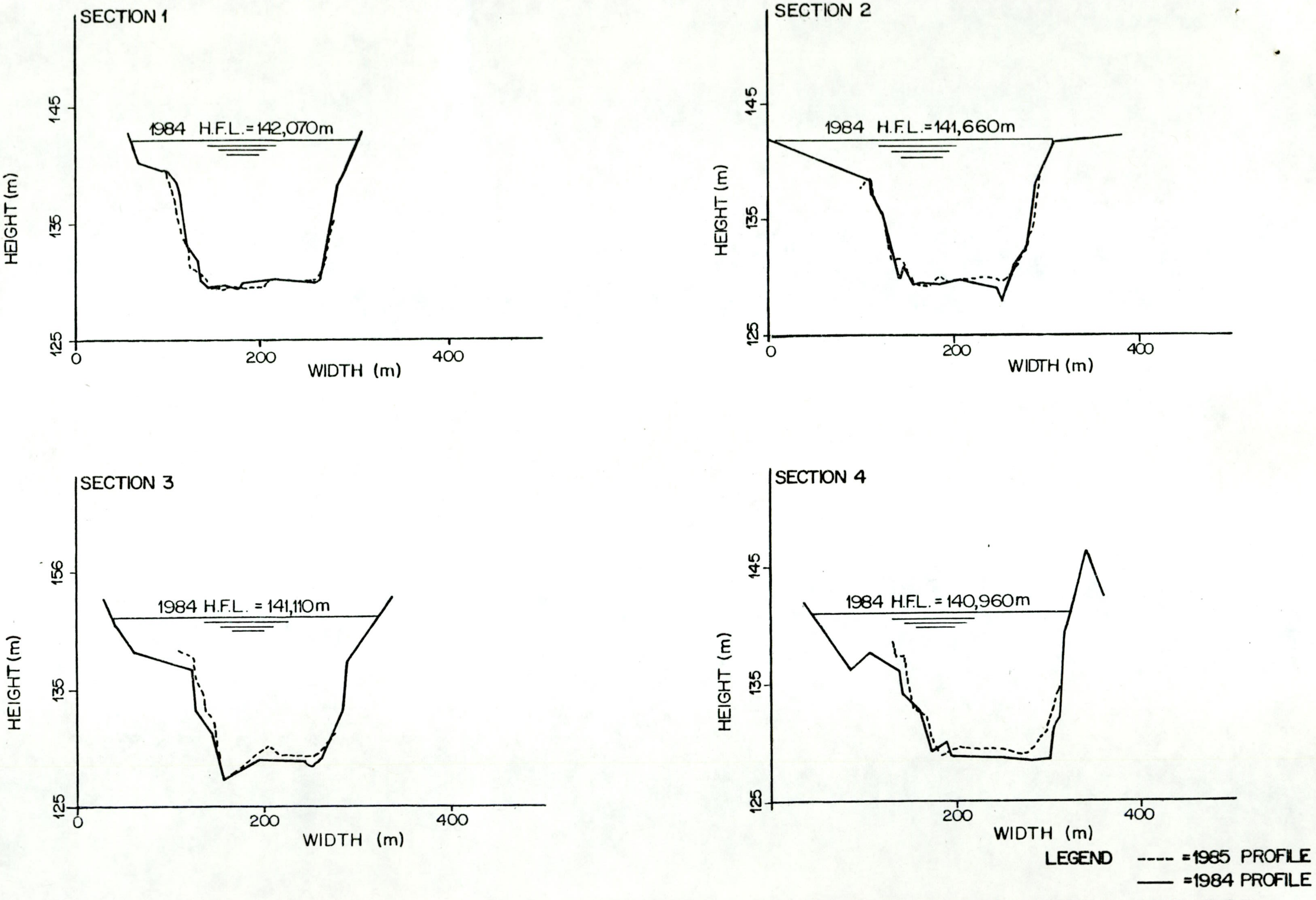


FIGURE 13 COMPARISON OF CROSS SECTION CHANGES AT SITE 2, BETWEEN 1984 AND 1985

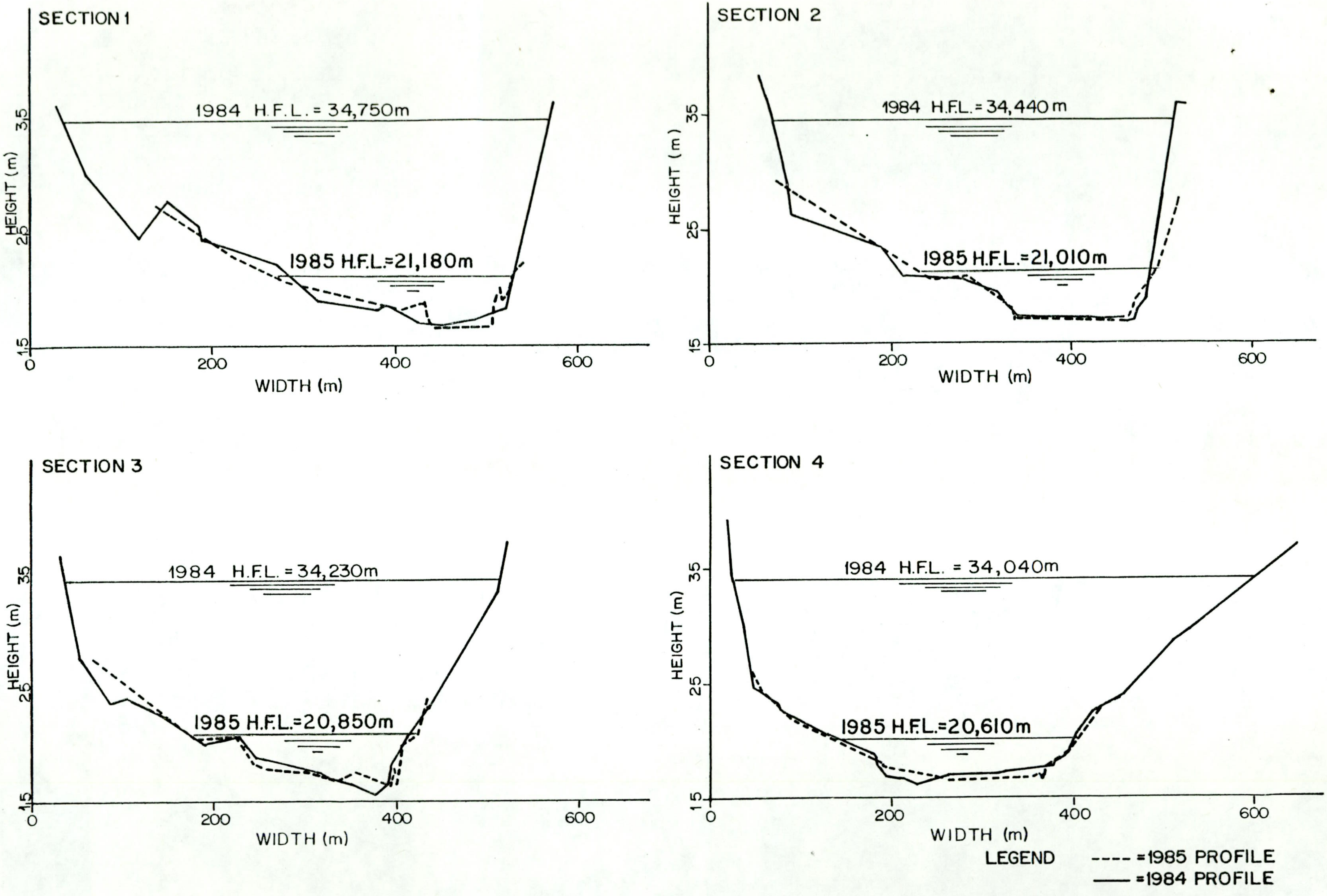
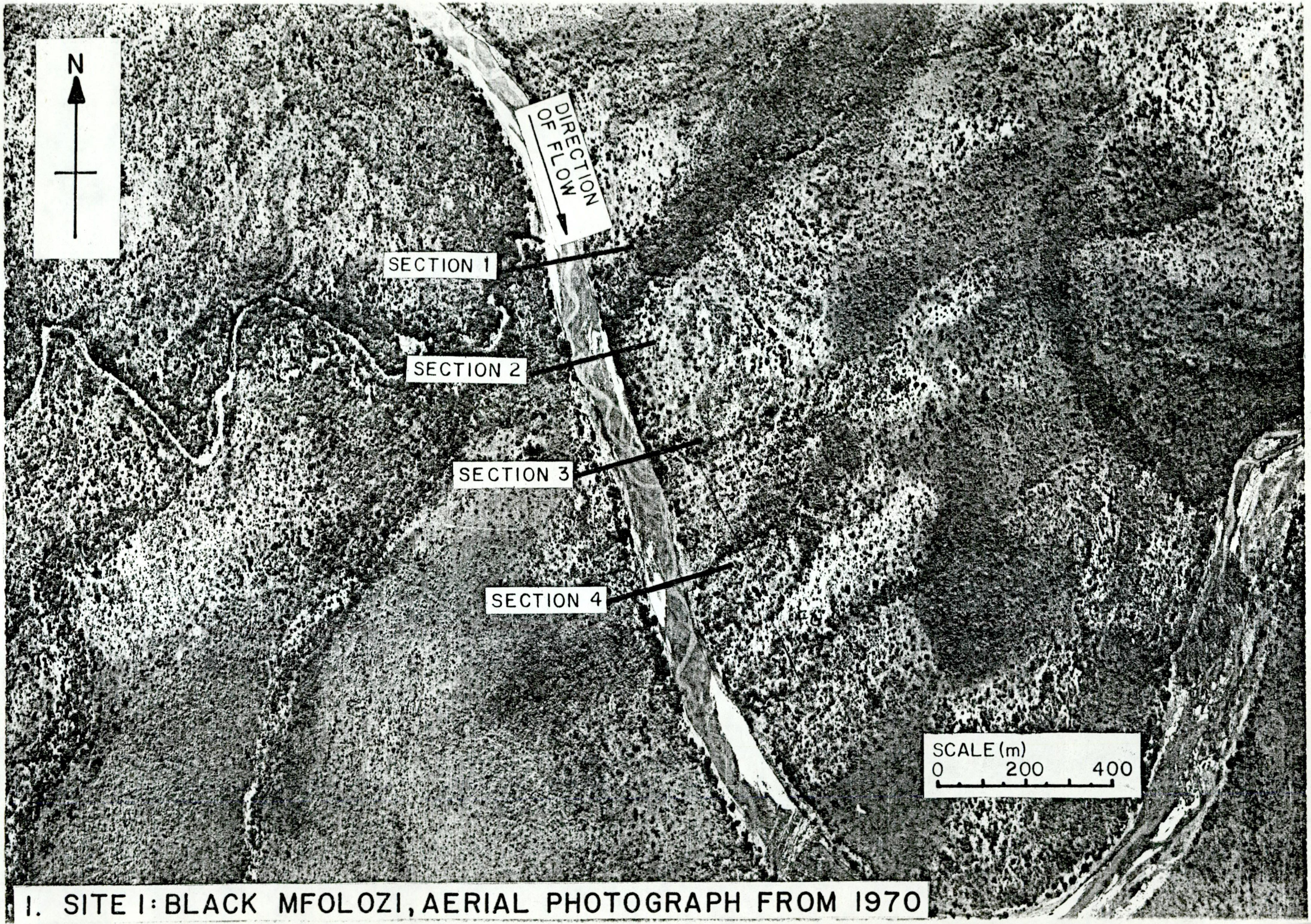
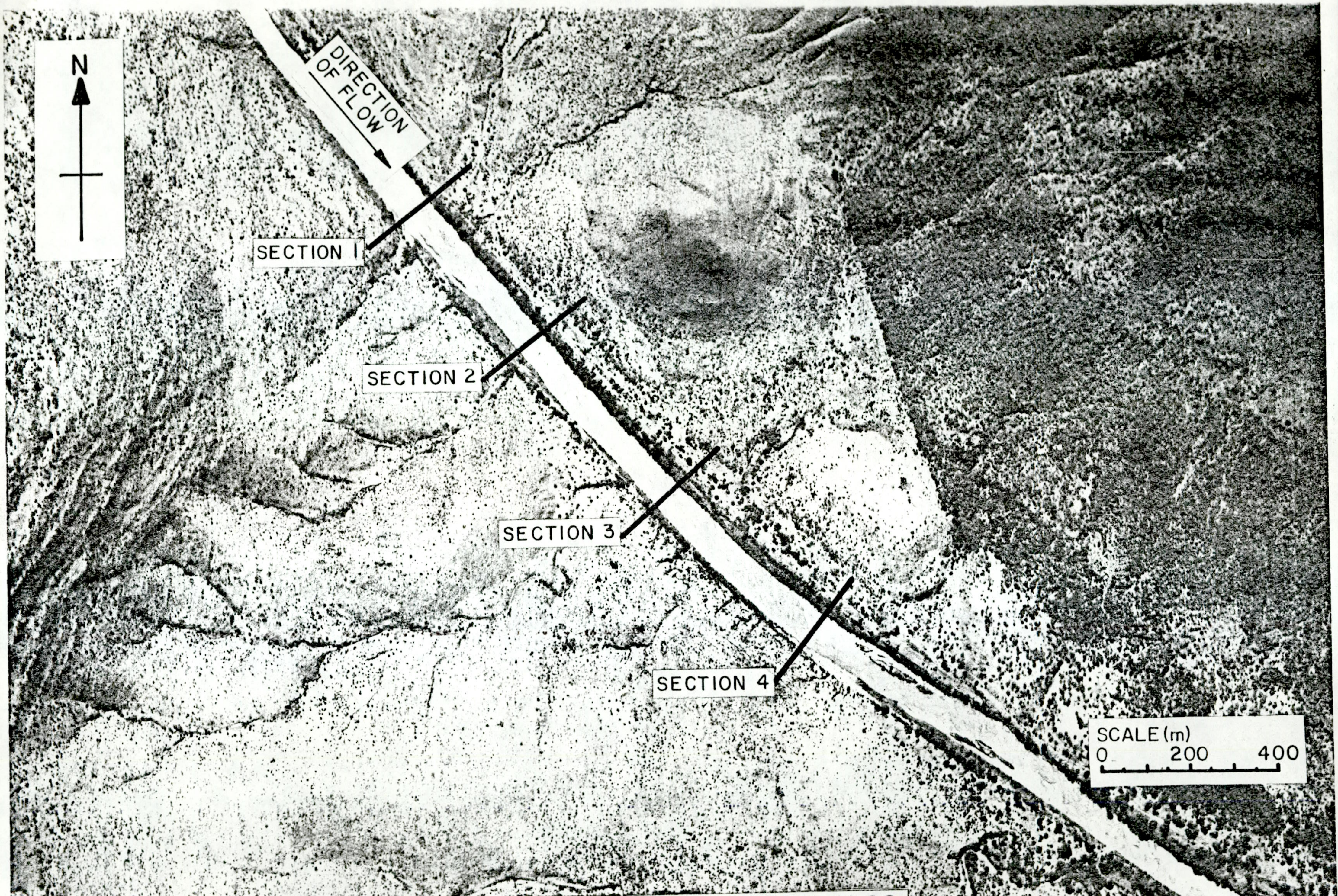


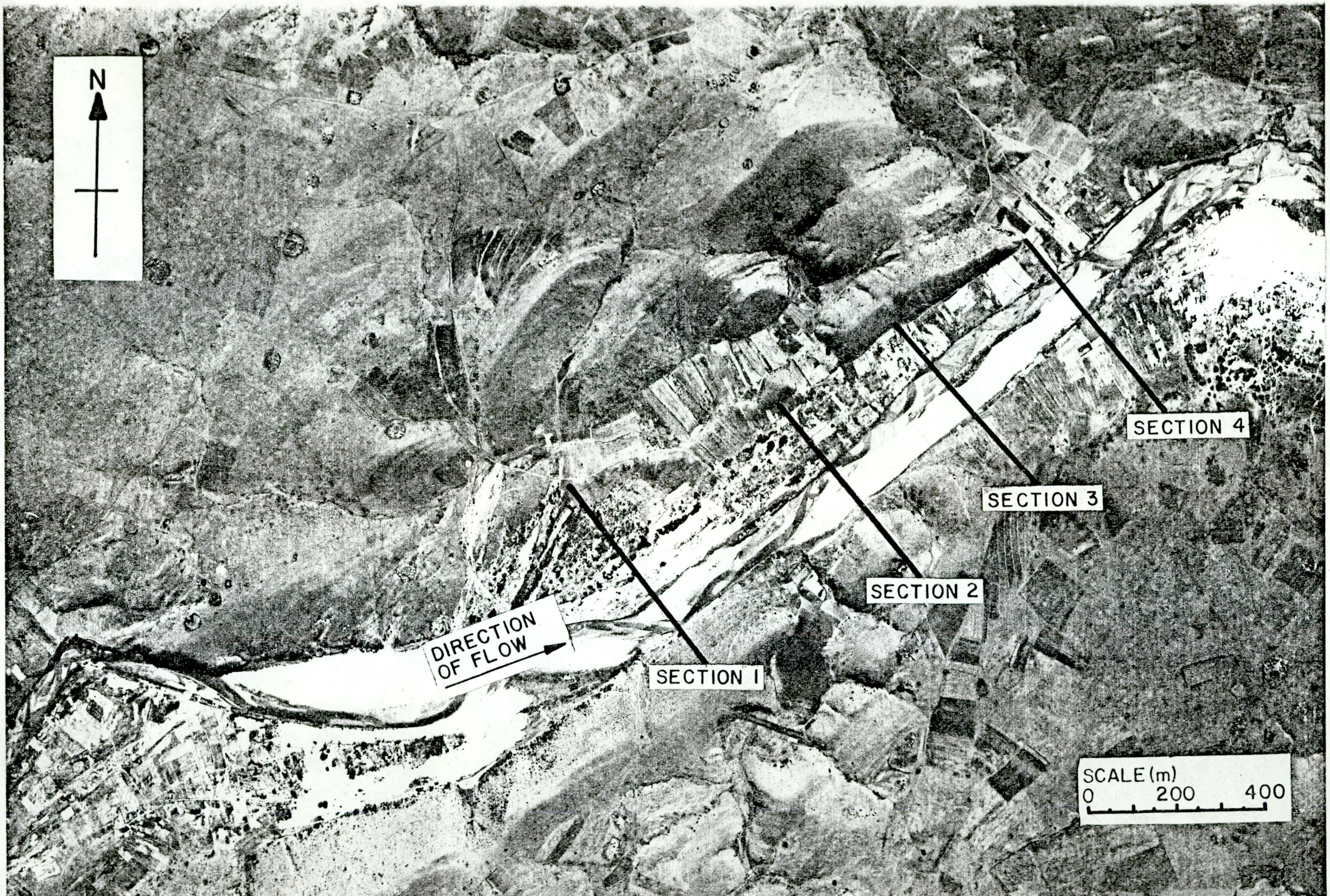
FIGURE 14 COMPARISON OF CROSS SECTION CHANGES AT SITE 3, BETWEEN 1984 AND 1985



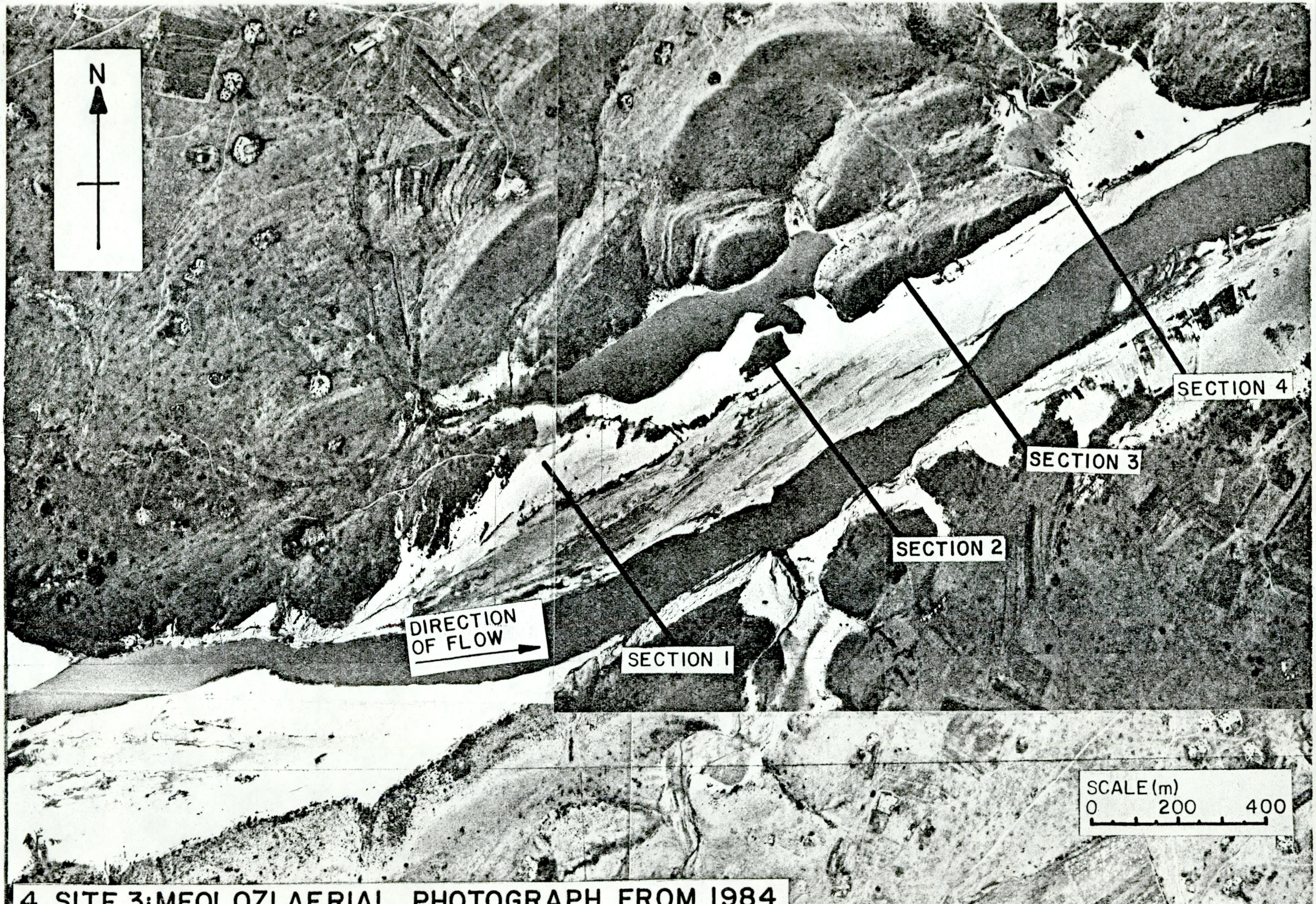
1. SITE 1: BLACK MFOLOZI, AERIAL PHOTOGRAPH FROM 1970



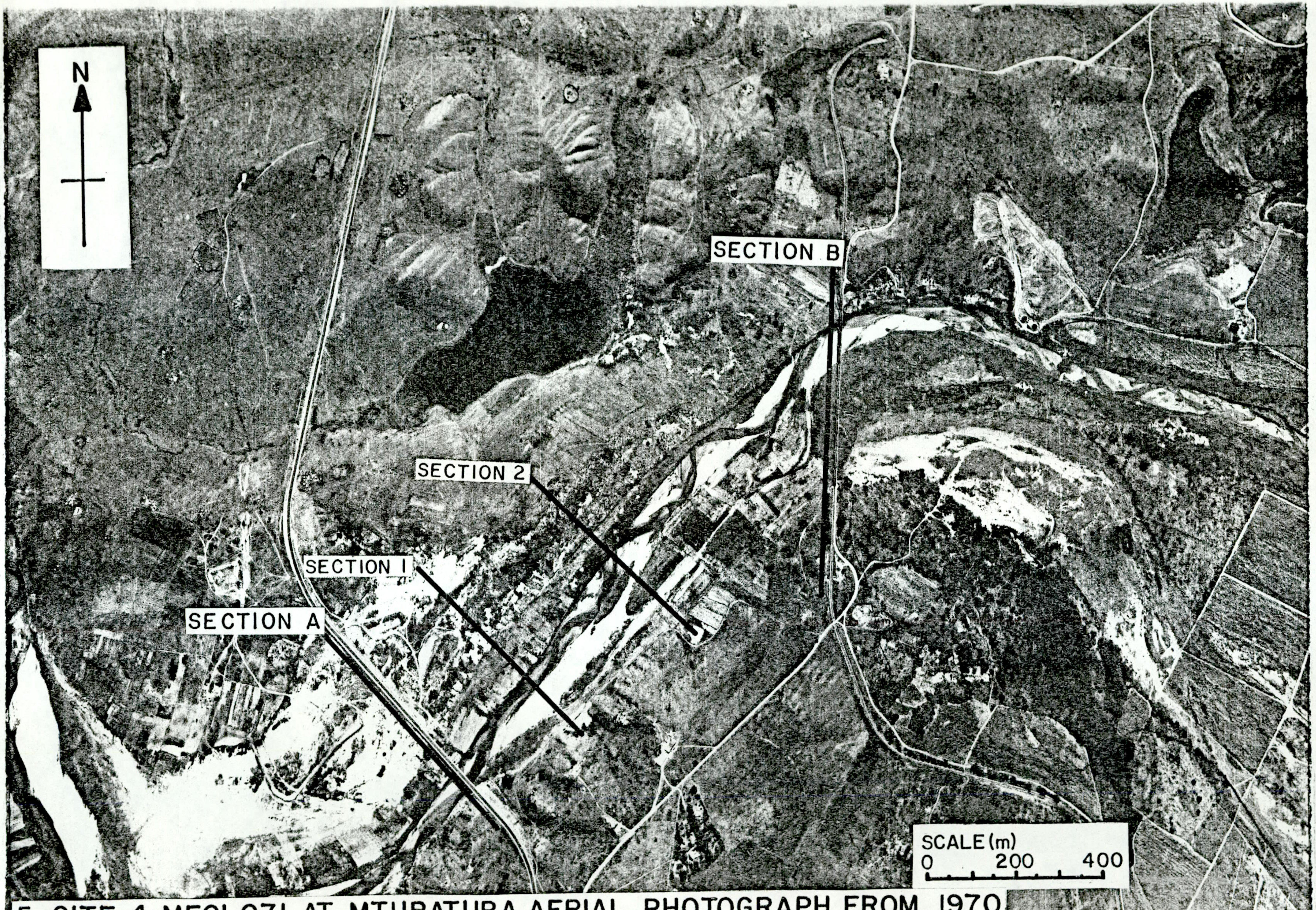
2. SITE 2: WHITE MFOLOZI, AERIAL PHOTOGRAPH FROM 1969



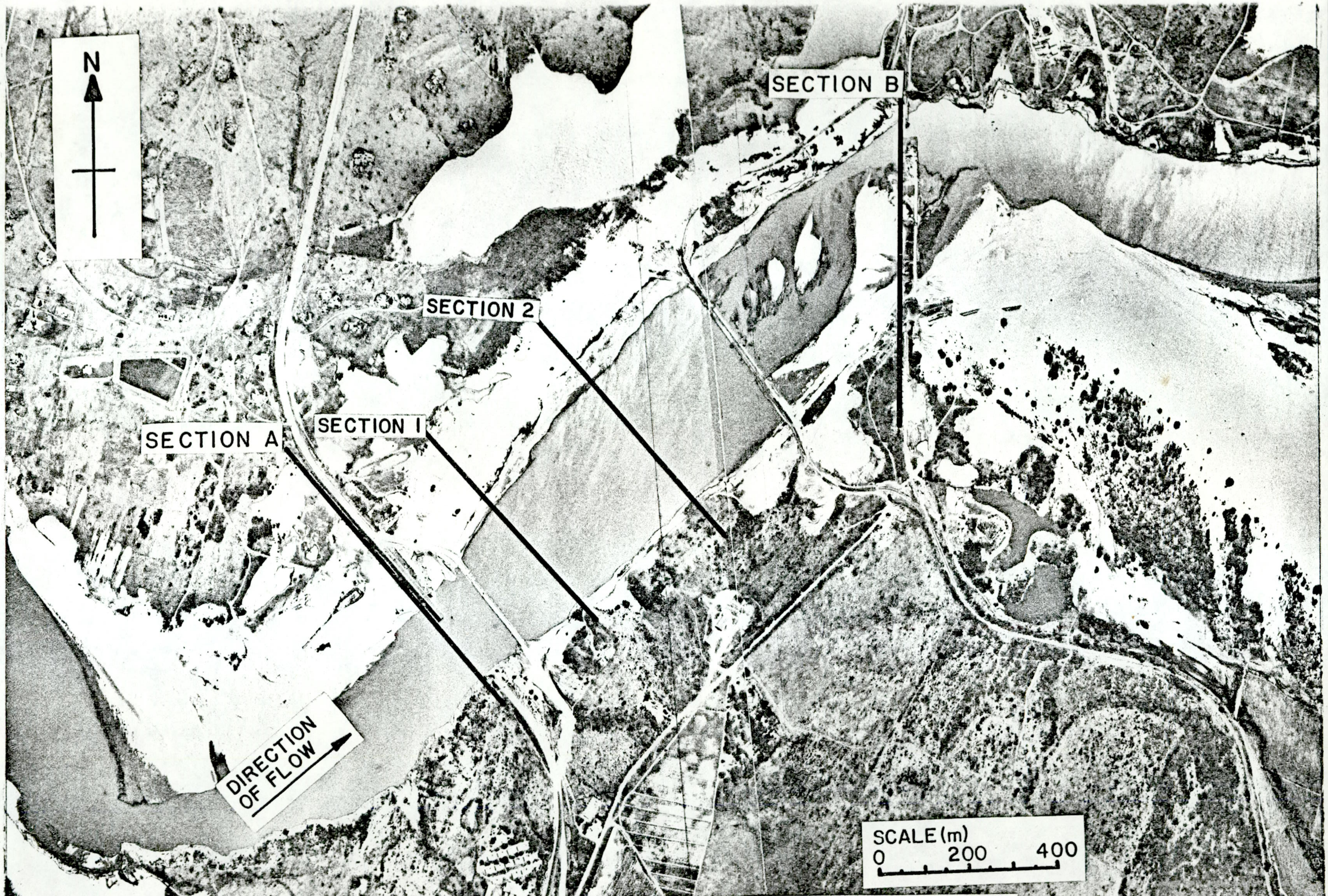
3. SITE 3: MFOLOZI, AERIAL PHOTOGRAPH FROM 1969



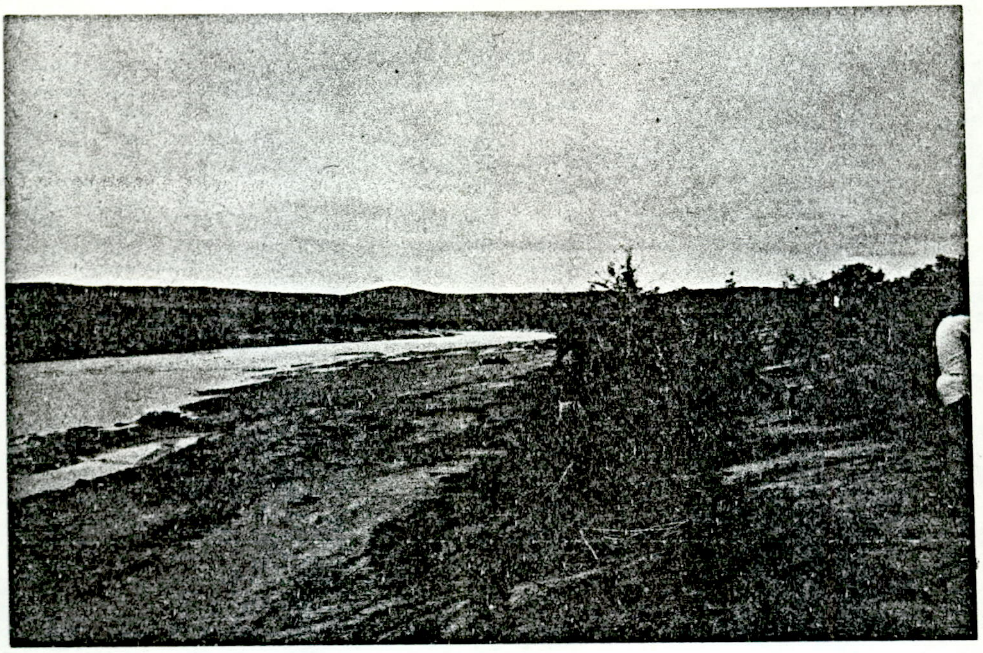
4. SITE 3: MFOLOZI, AERIAL PHOTOGRAPH FROM 1984



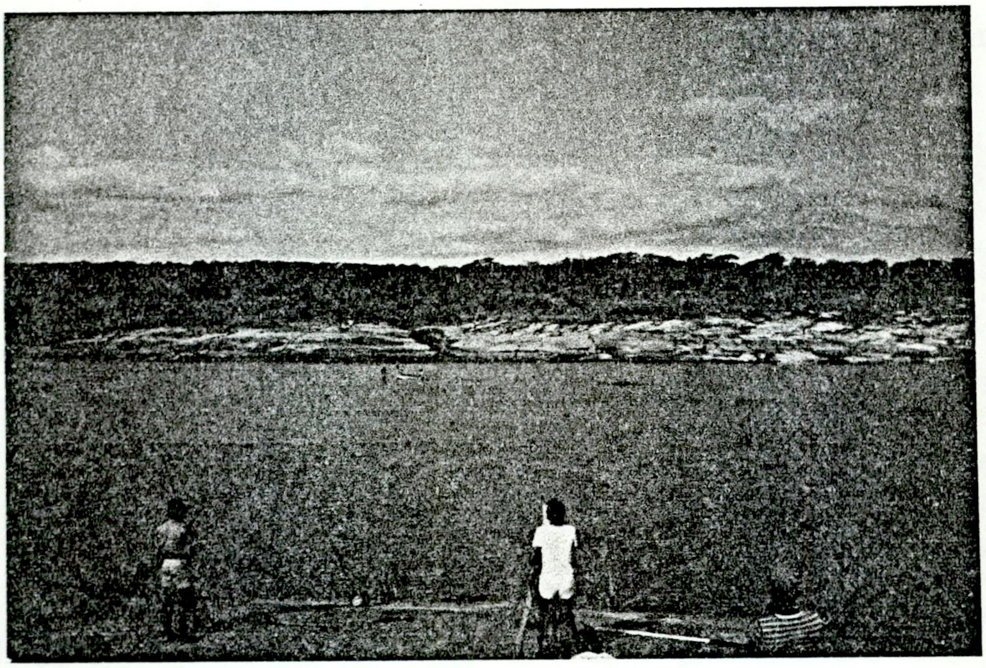
5. SITE 4: MFOLOZI AT MTUBATUBA, AERIAL PHOTOGRAPH FROM 1970



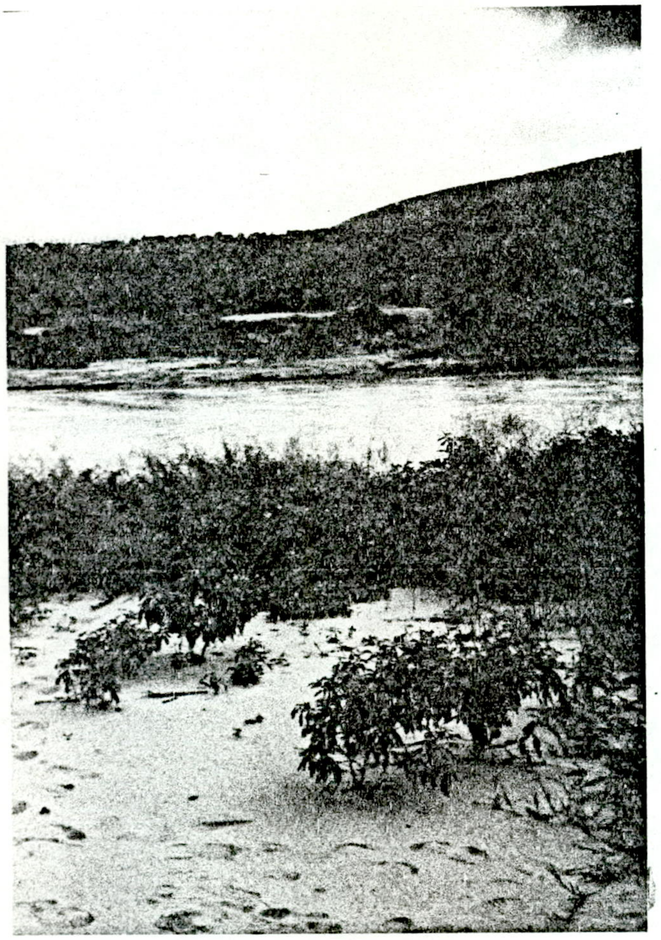
6. SITE 4: MFOLOZI AT MTUBATUBA, AERIAL PHOTOGRAPH FROM 1984



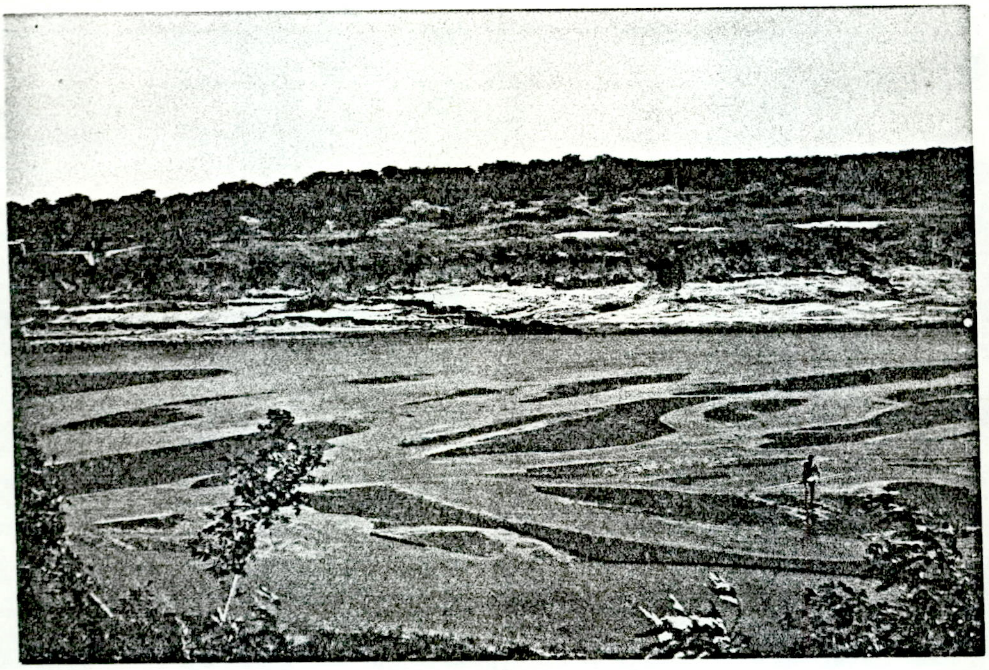
7. BLACK MFOLOZI: GENERAL DOWNSTREAM VIEW



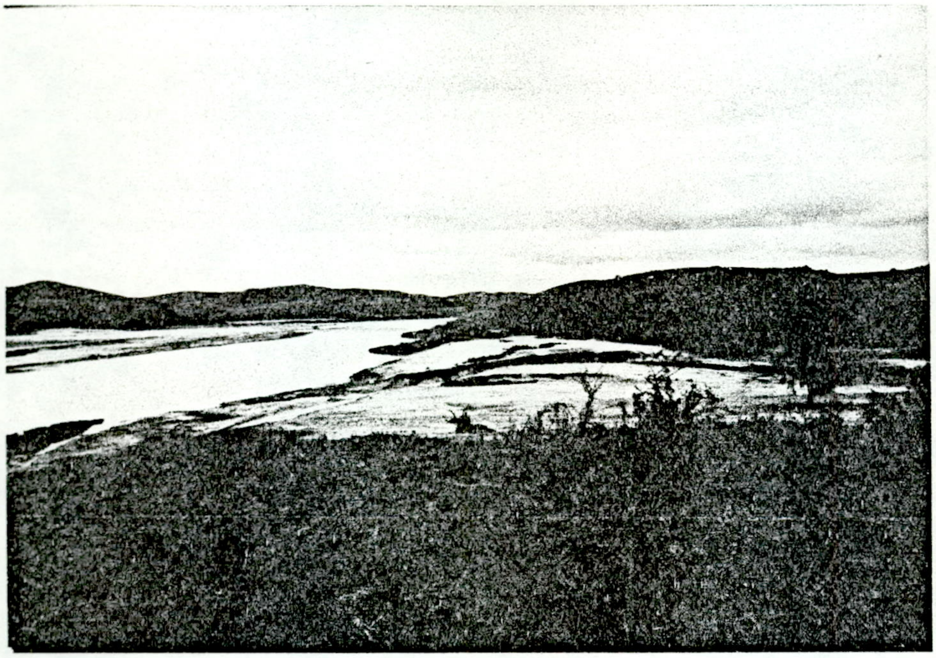
8. BLACK MFOLOZI: ROCK OUTCROP



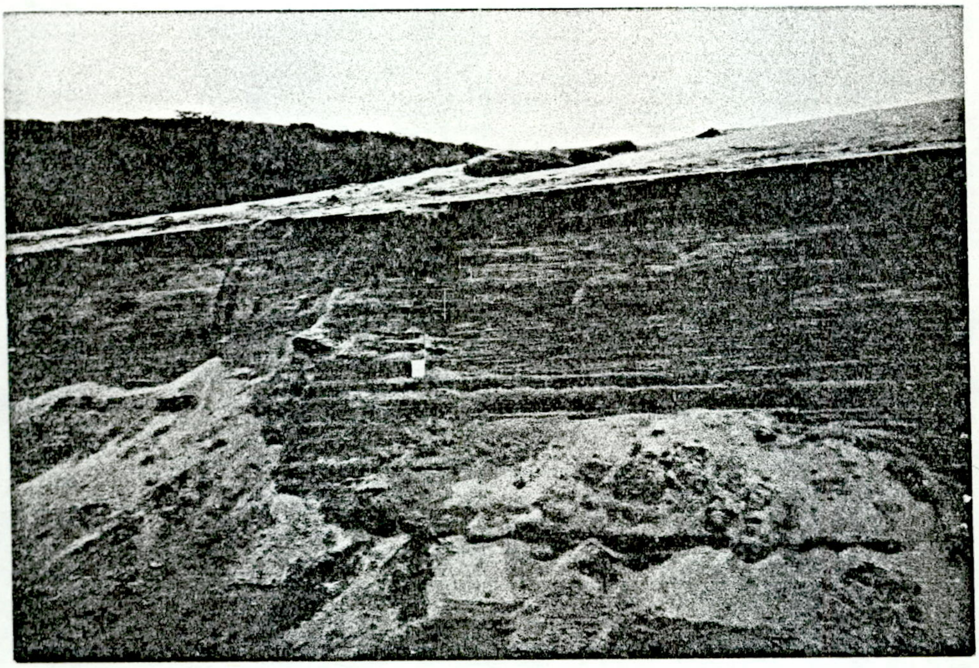
9. WHITE MFOLOZI: GENERAL VIEW FROM LEFT BANK TO RIGHT BANK



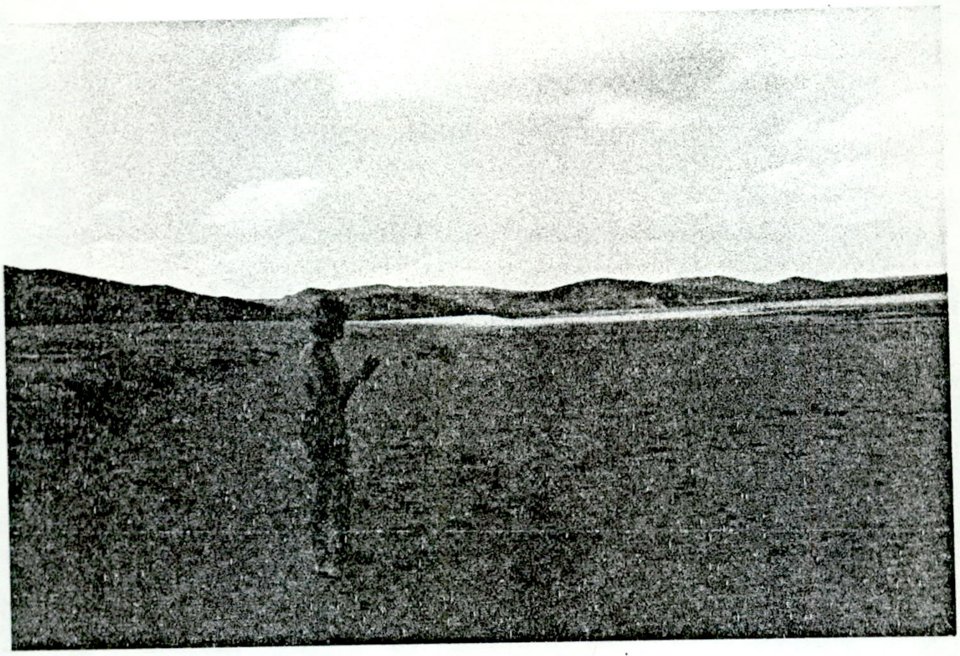
10. WHITE MFOLOZI: BANK EROSION, CHANNEL AND FLOOD PLAIN SEDIMENT DEPOSITS



11. MFOLOZI: GENERAL VIEW

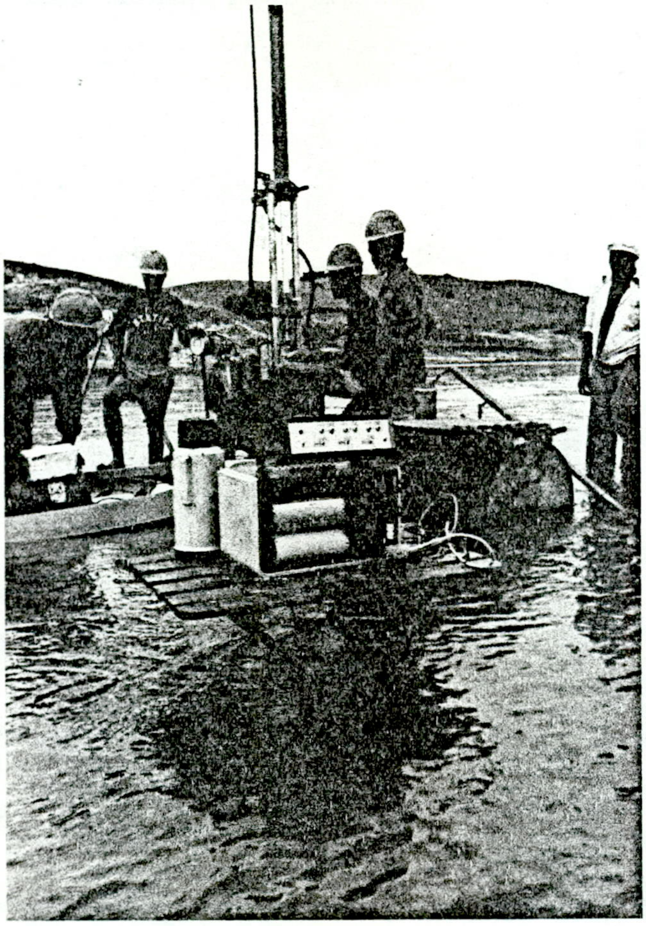


12. MFOLOZI: ERODED SAND BANK

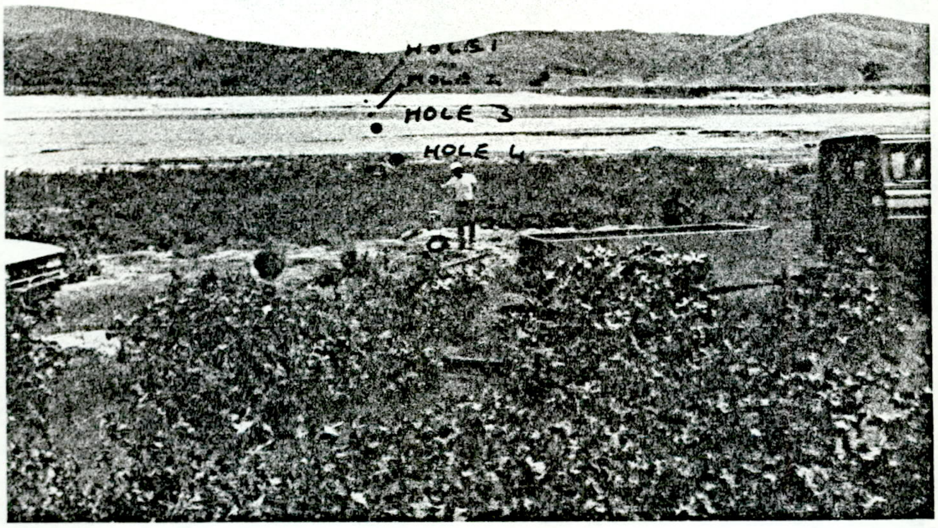


13. MFOLOZI: SEDIMENT DEPOSITS, LEFT BANK, LOOKING DOWNSTREAM

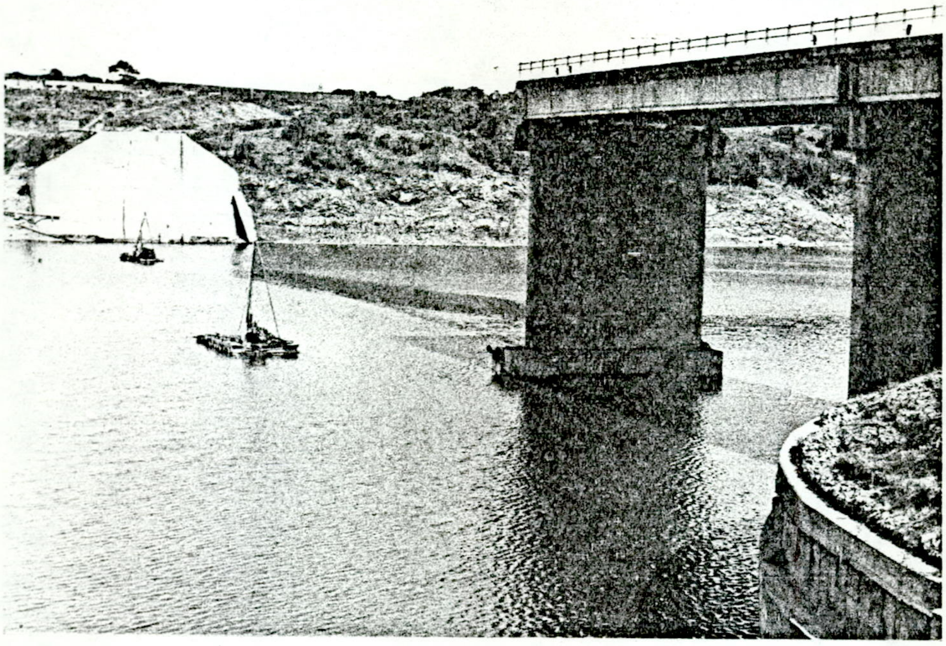
14. CUPT PROBE



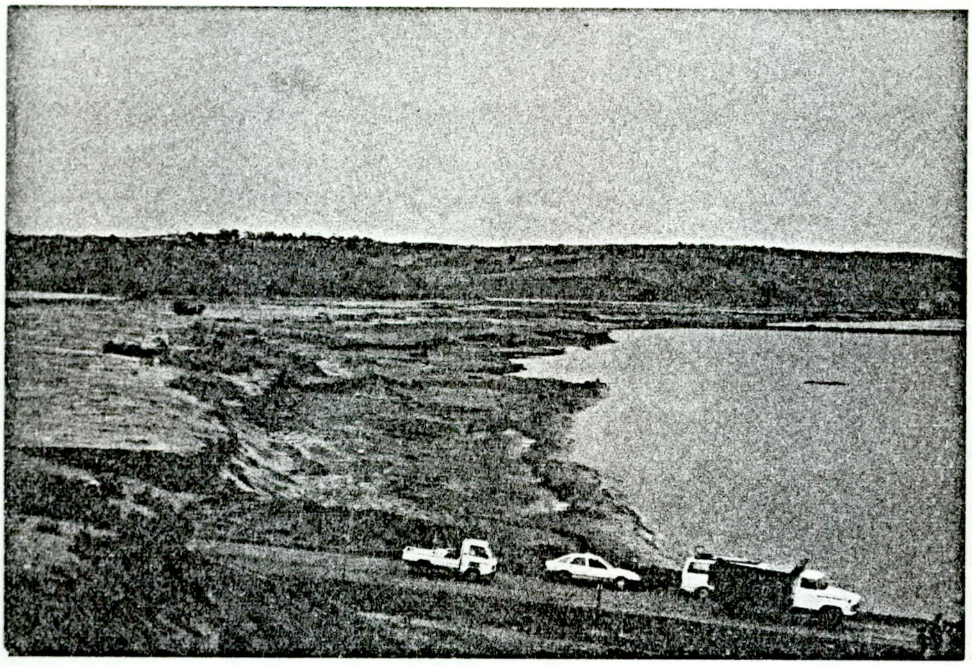
15. CUPT PROBE: VIEW OF RECORDING EQUIPMENT



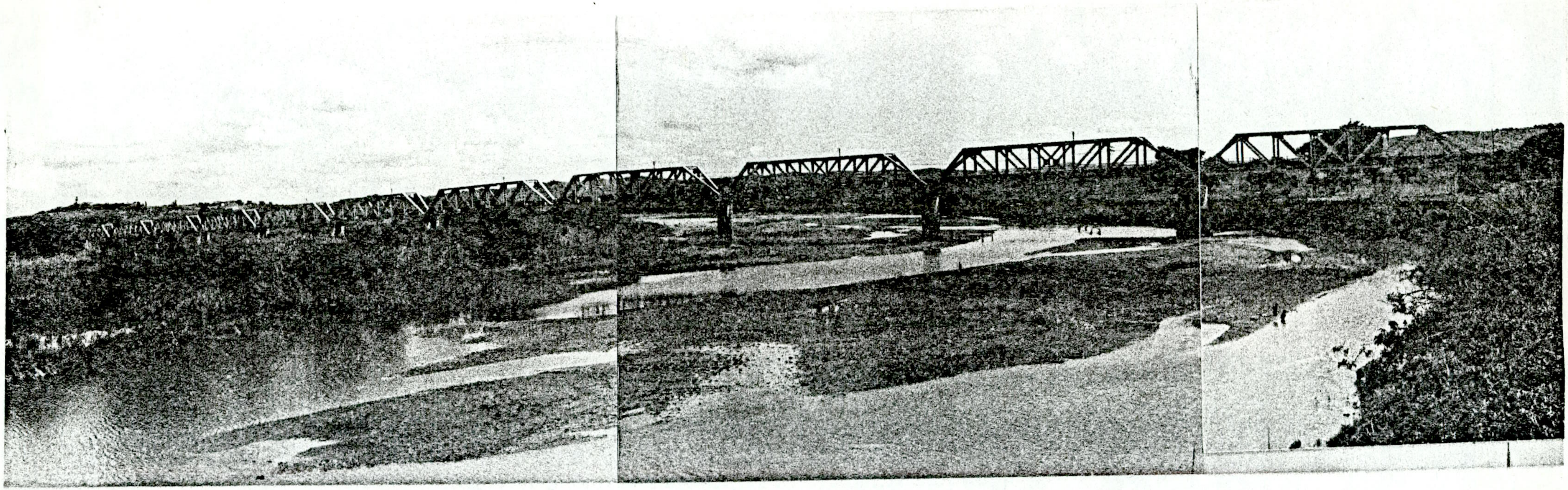
16. CUPT TESTS: LOCATION OF HOLES AT SECTION 4, SITE 3



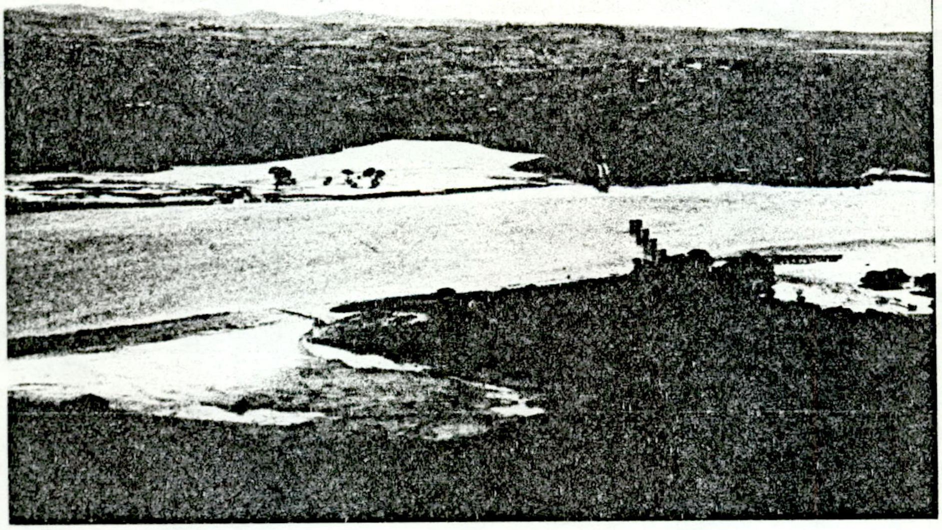
17. MFOLOZI: DESTROYED N2 BRIDGE AT MTUBATUBA



18. MFOLOZI: GENERAL VIEW DOWNSTREAM OF THE N2 BRIDGE



19. S.A.R. BRIDGE AT MTUBATUBA. DOWNSTREAM SIDE OF BRIDGE, BEFORE DOMOINA



20. S.A.R. BRIDGE AT MTUBATUBA, AFTER DOMOINA