



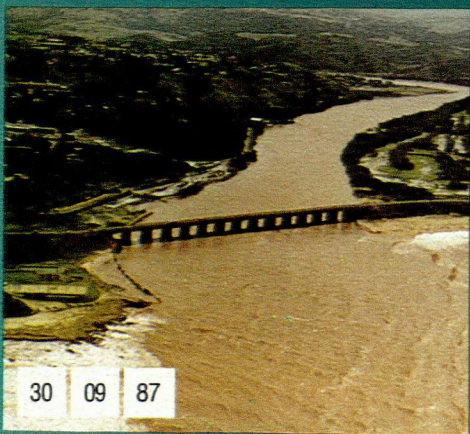
SURVEY OF SEPTEMBER 1987 NATAL FLOODS

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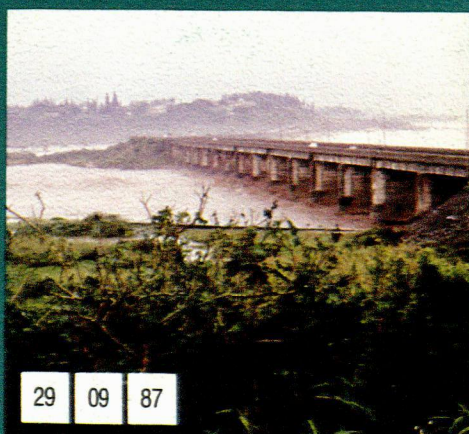
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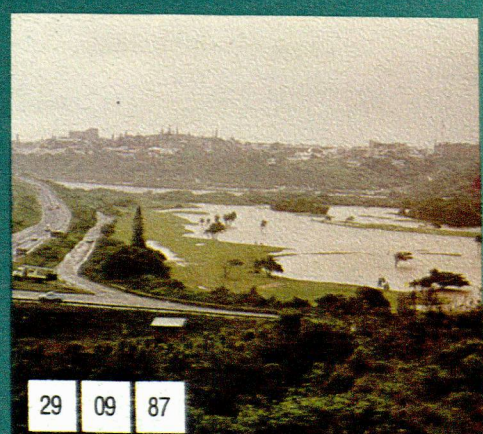
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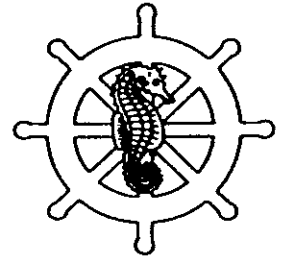
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SURVEY OF SEPTEMBER 1987 NATAL FLOODS

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COVER: The top photograph is an aerial view of the Mzimkulu River: 'A' indicates a low-level bridge that has been washed away, and 'B' the massive silt plume. The photographs below indicate the road and rail bridge at the mouth of the river as well as the inundated golf course near the mouth. The photographs are taken from a colour brochure published by the Division for Earth, Marine and Atmospheric Science and Technology of the CSIR in Stellenbosch.

ABSTRACT

During the September 1987 floods in Natal various organisations collaborated by observing the effects of the floods. The efforts of the CSIR in Stellenbosch and Durban, and the Geology Departments of the Universities of Natal and Port Elizabeth were coordinated to prevent overlap. SANCOR undertook to partly fund these observations, and the results of the work done to date in report or publication form are combined in this report to give a comprehensive overview.

A report in photo brochure form has also been compiled, but due to its format it is not included in this report. (Compiled by J E Perry, CPMA, Stellenbosch.)

The financial contribution of SANCOR to the observations and the publication of this report is acknowledged by all authors and people that took part in the surveys.

OPSOMMING

Tydens die vloede in Natal gedurende September 1987 het verskeie instansies saamgewerk aan die waarneming van die uitwerking van die vloede. Die pogings van die WNNR in Stellenbosch en Durban, asook die Geologiese departemente van die Universiteite van Natal en Port Elizabeth is gekoördineer om oorvleueling te voorkom. SANKON het onderneem om die waarnemings gedeeltelik te finansier. Die resultate van die werk tot op datum in verslag- of publikasievorm, is in hierdie verslag saamgevat ten einde 'n omvattende oorsig te gee.

Die verslag is ook in die vorm van 'n fotobrosjyre saamgestel, maar kon egter as gevolg van die formaat nie in hierdie verslag ingesluit word nie. (Saamgestel deur J E Perry, KBA, Stellenbosch.)

SANKON se finansiële bydrae tot die waarnemings en die publikasie van dié verslag word deur al die outeurs en persone wat aan die opmetings deelgeneem het erken.

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SECTION I

1. MAIN REPORT

1.1 Abstract

During the September 1987 floods in Natal various organisations collaborated by observing the effects of the floods. The efforts of the CSIR in Stellenbosch and Durban, and the Geology Departments of the Universities of Natal and Port Elizabeth were coordinated to prevent overlap. SANCOR undertook to partly fund these observations, and the results of the work done to date in report or publication form are combined in this report to give a comprehensive overview.

A report in photo brochure form has also been compiled, but due to its format it is not included in this report. (Compiled by J E Perry, CPMA, Stellenbosch.)

The financial contribution of SANCOR to the observations and the publication of this report is acknowledged by all authors and people that took part in the surveys.

1.2 Background

During the floods in Natal at the end of September 1987 various organisations decided to carry out surveys and observe the effect of the floods on sedimentation, flood duration, flood levels and damage. To prevent duplication it was decided that the Geology Department of the University of Natal jointly with the then NIWR, CSIR would investigate the Mgeni and Mdloti Rivers as these were current study areas. The rest of the coast was covered by two teams from the then Sediment Dynamics Division (SDD) of NRIO, CSIR.

SANCOR recognized that these studies were very important and undertook to partly finance them. As a result of the work two publications have been produced by University of Natal/NIWR, CSIR and two reports by the Sediment Dynamics Division, NRIO, CSIR.

This report now combines the efforts of the two groups in one volume. The one report by the old SDD of NRIO, now part of the Coastal Processes and Management Advice Programme of EMA, CSIR is a photo album and will not be found in this report.

1.3 Composition

This report consists of two main sections. Section 1 combines the available report/publications and in Section 2 the full text with figures of each report/publication is given.

1.4 Main Conclusions

For detailed conclusions the relevant section of each report/publication must be read. However, the overall conclusions are summarised below.

- 1) The floodplains of most of the rivers are still active sites of erosion and sedimentation and any present or future development must recognise this fact.
- 2) The bigger rivers (Mgeni, Mvoti) had flood duration periods of up to twenty four hours and this caused dramatic erosion.
- 3) The floods did not cause a general lowering of river bed levels as expected but in some cases cause a raising of bed levels. In many cases dramatic horizontal erosion took place.
- 4) The most dramatic erosion was in the Mgeni and Mvoti Rivers. In the Mgeni the island near the mouth was totally removed and scour of generally about 2 m took place. In the Mvoti the river channel, normally 35 m, widened to about 900 m and deposited large quantities of sediment over this flood plain. In the Mgeni, lateral constraints forced the river to erode downwards into its bed: the Mvoti had no such lateral constraints and the river flowed over a broad flood

plain, and deposited large volumes of sand there. The suspended sediment in the Mgeni system probably bypassed the estuary and was deposited in the ocean.

- 5) Many bridges were washed away but the destruction of the Mdloti and Tugela River bridges caused the greatest disruption.
- 6) In most cases the surveys established the flood levels and this will be invaluable data for the future.
- 7) The surveys and observations showed that it is possible (however difficult) to get cross-sections and other data shortly after major floods. There is however no good data on flood hydrographs, flood velocities and scour taken during the floods. Although a difficult task this is possible as was shown during the observations by the CPMA Programme on the floods at the Orange River mouth in March 1988.

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PART 1

REPORT PUBLICATIONS

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- 2: Cross-section and volume data for 1984 and 1987.
- 3: Cross-sectional data indicating the increase in volume of the estuary between various surveyed sections as a result of the flood.

LIST OF FIGURES

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- 2 Catchment area of the Mgeni River showing the major dams in the system and calculated sediment yield potential in various areas (after Rooseboom, 1975).
- 3 Cross-section of sub-surface estuarine sediments at Athlone Bridge (modified after Orme, 1974). (for location see Figure 4). Note the change in bedrock slope at approximately 15 m below MSL.
- 4 Pre-flood morphology of the Mgeni Estuary showing the main sediment types in the channel areas.
- 5 Rainfall isohyets for the period September 25th - September 30th 1987 (after Kovacs, 1988).
- 6 Standing waves up to 4 m amplitude developed in the channel of the estuary during the flood.

- 7 Pre- and post-flood channel cross-sections. The area a&b of sediment eroded is shaded. Positions of channel cross-sections are shown in the top left-hand corner.

- 8 Aerial photographs of the Mgeni Estuary before and after the flood event. Note the extent of bank erosion in the upper estuary and the loss of the central island and sandspit. The post-flood photograph shows a wide channel with the overbank deposits clearly visible.

1. REPORT/PUBLICATIONS

1.1 Geomorphological Effects of the September 1987 flood on the Mgeni Estuary.

A more up-to-date version of this paper by J A G Cooper¹, T R Mason² J S V Reddering³ and W K Illenberger³ has been accepted for publication in Earth Surface Processes and Landforms.

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1.2 Abstract

The Mgeni Estuary is situated on the east coast of South Africa. Tidal salinity changes commonly extend 2.5 km upstream from the mouth. The subtropical climatic regime causes seasonal flooding, the geomorphological effects of which are increased by a steep river gradient. This paper describes the effects of catastrophic flooding during September 1987. A 120-150 year flood event with an estimated discharge of 10800 cumecs, resulted in the erosion

of $1.86 \times 10^6 \text{m}^3$ of sediment from the estuary. This increased the total volume of water below the mean high water level from $0.35 \times 10^6 \text{m}^3$ before the flood to $1.85 \times 10^6 \text{m}^3$ when the flood had waned. The post-flood intertidal volume (tidal prism) of the estuary was $0.43 \times 10^6 \text{m}^3$ compared to $0.19 \times 10^6 \text{m}^3$ before the event.

The nature and extent of erosion in the estuary was controlled by the composition of the estuary banks and bed material. Gravel and sand substrates were preferentially eroded from the estuary bed before the cohesive bank materials were undercut in sections of the estuary. Mud and fine sand were deposited on overbank areas when the flood waned and a lag of coarse sand and gravel was produced on the estuary bed. Calculations show that approximately 46% of the bedload sediment supplied to the estuary since 1917 was retained in the estuary until the 1987 flood. The remainder was transported through the system and into the Indian Ocean. The results of the study show that catastrophic floods play an important role in sedimentation in small estuaries.

1.3 Introduction

The impact of catastrophic events on the environment has received considerable attention over the past few years and this has led to increased recognition of their importance in geomorphology and sedimentology. Catastrophic sedimentation events are low frequency and high intensity events which may be considered instantaneous in a geological sense. The energy levels of the sediment-transporting mechanisms are usually several orders higher than under normal sedimentary conditions. In some cases these may be more important in sedimentological terms than day-to-day processes, and may therefore have a higher preservation potential in the geological record.

Estuaries are important environments to man and an understanding of their functioning is vital as increased human pressure is placed upon them. The effects of catastrophic events in estuaries may be particularly devastating due to surrounding

infrastructures. Because much published work on estuaries originates in the eastern United States the most thoroughly studied catastrophic events so far as estuaries are concerned are hurricanes and tropical cyclones (Ball *et al.*, 1967; Andrews, 1970; Hayes, 1978). The effects of fluvial flooding on estuarine environments are poorly documented and few studies have been undertaken, particularly from a geomorphological viewpoint. Notable exceptions include the work of Nicholls (1967), Zabawa & Schubel (1974) and Schubel & Zabawa (1977) which dealt with much larger estuaries, and Reddering & Esterhuysen (1987) who considered estuaries of equivalent size but floods of much less severity than those considered in this paper.

In alluvial systems a rising flood stage produces a series of equilibrium or regime adjustments involving sediment capacity, water discharge and various morphological variables. If a river has an excess sediment transporting capacity, adjustment occurs by erosion of the bed and/or banks. If the sediment concentration becomes too great for a particular flood stage this is deposited in overbank areas. Each of these mechanisms is a response to the flood discharge which enables a river to maintain equilibrium (Maddock, 1976).

The relative importance of floods in modifying river channels is a matter of debate with some authors placing more importance on catastrophic floods than others. Leopold *et al.*, (1964) considered that the major work of rivers was accomplished during high frequency and low intensity floods rather than during the lower frequency catastrophic floods. Other workers, however, argue that catastrophic floods have a much greater geomorphological impact (see for example Gifford, 1953; Williams & Guy, 1973).

Nichols & Biggs (1985) considered that flood-induced morphological changes within an estuary are relatively small except when the flood extends to the estuary mouth. This conclusion was based, however, on work in large estuaries.

Maximum erosion of sediment from the mouth area of estuaries was noted by Reddering & Esterhuysen (1987) who attributed this to the uncohesive nature of the sediment in that area.

Because of climatic and geomorphological conditions floods are a seasonal phenomenon in Natal Province, South Africa. Particularly severe floods occur several times per century and their effects are devastating, not least in the estuarine environment.

Catastrophic floods in Natal at the end of September 1987 had such devastating consequences that the province was declared a National Disaster Area. Roads and bridges were washed away and hundreds of lives were lost. The floods caused appreciable geomorphological changes throughout local River systems including the estuaries but the extent of changes varied between different systems (Cooper, 1988; Grobblers *et al.*, 1988; Mason & Cooper, 1988), the main controlling factors being catchment size and estuary morphology. This paper focuses on the Mgeni Estuary (29|48'S; 31|02'E) which is situated just north of the city of Durban on the east coast of South Africa. The paper aims to document and interpret changes which took place in channel morphology and bottom sediment distribution as a result of the flood.

1.4 Regional Setting

The province of Natal is situated on the eastern side of South Africa (Figure 1). It has a rugged topography which rises steeply from the Indian Ocean to the Drakensberg escarpment (maximum elevation 3500 m) over a distance of some 300 km (King, 1953). The steep, deeply dissected hinterland is drained by an abundance of small rivers, each of which flows into the Indian Ocean via an estuary or lagoon. Seventy-four estuaries occur on the 583 km coastline (Begg, 1978). The climate of the area is essentially subtropical with a warm, wet summer and cool, dry winter. Marked seasonality in rainfall leads to regular flooding

in the summer months (September to February) and because of the steep hinterland, flow velocities during floods are particularly high. Severe flooding is commonly associated with abnormal weather conditions (Tyson, 1986). Floods in September 1987 resulted in extensive damage to property and the communications infrastructure in Natal. One of the most severely affected estuaries was that of the Mgeni River. Other significant floods were recorded in the Mgeni Estuary in 1856, 1869, 1878, 1905, 1917, 1935, 1943, 1947, 1953, 1959, 1976 and 1984. Of these the highest recorded discharge ($5700 \text{ m}^3\text{s}^{-1}$ in the estuary) was in 1917.

1.5 The Study Area

The Mgeni River is the fourth largest in Natal and drains an area of 4432 km^2 (Figure 2). It is 232 km in length (Begg, 1978) and has a gradient of approximately 1:120. Mean annual runoff is $323 \times 10^6 \text{ m}^3$ (NRIO, 1986). Mean discharge varies from $18.4 \text{ m}^3\text{s}^{-1}$ in summer to $6.5 \text{ m}^3\text{s}^{-1}$ in winter (Orme, 1974). The maximum annual sediment yield was estimated at 1.6×10^6 tonnes (NRIO, 1986) using a sediment yield map compiled by Rooseboom (1975). However, the presence of four dams in the catchment (Table 1) effectively reduces the amount of bedload sediment reaching the coast. Another dam is under construction at Inanda, some 30 km upstream from the estuary (Figure 2). The catchment area below the four active dams is approximately 1700 km^2 and the sediment yield from this area was calculated at 0.5×10^6 tonnes a^{-1} . The volume of bedload sediment may be calculated from this figure if the following assumptions are made.

- 1) bedload is approximately 12% of the total sediment load. This figure is based on Swart (1987) and is similar to the bedload/suspended load ratio of the Tugela River which occupies a similar setting to the Mgeni, some 100 km to the north (Rooseboom, 1982);

- 2) bedload sediment has a density of 2600 Kg/m^3 . This is based on the densities of quartz and K-feldspar (CERC, 1973) which are the major components of sediment in the Mgeni River (Cooper, 1986). This yields a volume of $60 \times 10^3 / 2,6 = 23077 \text{m}^3$.
- 3) the porosity of the bedload sediment is 40% (Blatt et al. 1980). Therefore the total volume of bedload material is $23077 \times 10/6 = 38,4 \times 10^3 \text{m}^3$.

Using the formula of Flemming & Hay (1984) for bulk density of South African marine sands a value of $40.0 \times 10^3 \text{m}^3 \text{a}^{-1}$ was obtained. This figure is slightly higher than the $38,4 \times 10^3 \text{m}^3 \text{a}^{-1}$ as Flemming & Hay considered beach sands which have a high proportion of skeletal carbonate material, however, the close agreement of these figures gives confidence in the calculation.

1.6 Methods

The geomorphology and sedimentology of the Mgeni Estuary were studied intensively prior to the 1987 flood (Cooper, 1986, 88; Cooper & Mason, 1987; Cooper & McMillan, 1987). In the course of these studies sediment samples were collected on a predetermined grid pattern and the estuarine sedimentary facies were mapped. Regular surveys of the estuarine channels were carried out by the Durban City Engineers Department. Following the flood, sediment samples were collected from the same sites and the estuary was resurveyed with respect to MSL using a theodolite and an 8 m stadia rod. This was carried across the estuarine channel by a swimmer and readings taken at points of inflection on the channel bed. Sediment samples were analysed for grain size using a computer-linked settling tube after removal of the mud ($<0.063 \text{ mm}$) and gravel ($>2 \text{ mm}$) fractions by wet sieving. Carbonate content was determined gasometrically (Schink et al., 1979) and organic content by loss on ignition (Dean, 1974).

1.7 Pre-flood Geomorphology and Sediment Dispersal Patterns

The estuary is situated on unconsolidated sediments which accumulated during and since the Flandrian Transgression. Bedrock outcrops at the surface along the north bank of the estuary and borehole data (King & Maud, 1964; Orme, 1974) define a buried bedrock channel which in cross-section slopes gently from the north to a depth of -15 m MSL before falling steeply to a maximum of -52 m in the south (Figure 3).

The pre-flood geomorphology of the Mgeni estuary was studied by Cooper (1986, 1988) and Cooper & Mason (1987). The estuary consisted of a single channel (average width 60 m) which bifurcated and rejoined around an elongate central island with a mean elevation of 2 m MSL. (Figure 4). The island formed during the past 70 years by the coalescence and subsequent emergence of braid bars and has undergone intermittent accretion and erosion (Cooper, 1986). It was fringed in part by stands of the mangrove *Avicennia marina* while terrestrial vegetation grew on the more elevated portions. The course of the estuary was diverted at the coast by a south-extending sandspit built up by littoral drift and wave action and a constricted mouth was formed against an artificial rocky groyne. Rock outcrops on the north bank of the estuary form a steep, high bank while the south bank comprises a low-lying alluvial plain. A mangrove swamp north of the estuary was drained by a tidal channel (Beachwood Creek) which entered the estuary near the inlet. The cohesive steep estuary banks meant that intertidally exposed areas were restricted to the flood-tidal delta near the mouth and side-attached braid bars in the upper estuary.

Mean spring tidal range at the coast is approximately 2 m which, through the damping effect of the inlet, produces a mean tidal range of 1.4 m in the estuary making it microtidal. Tidal salinity changes extended 2.5 km upstream from the mouth and a salt wedge developed in the channel at high tide. Upward mixing of the salinity intrusion by wave action was limited as the moon

axis of the estuary is orientated perpendicular to the predominant wind direction and ocean waves were prevented from entering the estuary by the sandspit at the mouth.

Sediments in the estuary consisted mainly of fluvially-derived gravel and mud with marine sand deposited in the lower 200 m of the estuary by flood-tidal transport through the inlet and overwash across the sandspit. An extensive flood-tidal delta was present in the lower estuary and a dynamic equilibrium appears to have existed between sediment accumulation during low flow periods and erosion during seasonal floods.

The mud content of the estuarine sediments was generally less than 10% and showed a gradual upstream increase. Maximum concentrations of over 50% occurred on small sections of the channel margins where flow velocities were at a minimum. In some areas mud deposition was aided by the trapping ability of mangrove pneumatophores (Bird, 1986). Even a low mud content imparts cohesiveness to estuarine sediments making them more resistant to erosion under normal flow conditions (Terwindt *et al.*, 1968). Thus much of the bed could be considered moderately erosion-resistant. Mud deposited on the bed of the estuary was mixed with other grainsizes largely by the burrowing activity of the estuarine infauna (Cooper, 1986).

Gravel (>2 mm) comprised over 30% of the bottom sediment through most of the estuary (Figure 4). The near-constant amount of gravel with depth in the estuarine sediment indicates that it cannot be considered as diagnostic of the erosion base as is in the case in many other South African estuaries (Reddering & Esterhuysen, 1987). The abundance of gravel in the Mgeni Estuary may be attributed to a deeply weathered megacrystic granite gneiss some 35 km upstream which supplies much of the bedload sediment. The high gravel content precluded the formation of a small-scale bedforms but side-attached braid bars were developed, particularly in the north channel of the estuary.

High concentrations (>80% of sand-sized sediment occurred mainly in the lower 200 m of the estuary reflecting its derivation from a marine source via flood-tidal transport through the tidal inlet and washover across the sandspit. Such an origin was corroborated by grain surface textures, carbonate content and foraminiferal assemblages (Cooper, 1986, Cooper & McMillan, 1987). The absence of mud in this sediment meant that it was poorly cohesive and mobile, forming both large and small-scale bedforms in the lower estuary. Variations in the volume of the flood-tidal delta revealed by aerial photography indicate that this sediment is more susceptible to erosion by frequent, low-discharge floods than the cohesive sediments upstream.

1.8 Flood Conditions

Weather conditions September 1987

The province of Natal experiences over 1000 mm of rainfall annually (Tyson, 1986), however extremely high rainfall over a few days may occur, leading to widespread flooding. Such was the case in September 1987. On 25th September a strong Atlantic high pressure system began to advect cold, moist air over the southern part of South Africa. Over the interior of the country moist, warm air flowed in from the north along the eastern side of a surface low pressure system combined with an upper air cut-off low (Kovacs 1988). The following day (26th September) heavy rain began to fall, centred over the province of Natal. This persisted for 5 days during which up to 800 mm of rain fell (Figure 4). Cut-off lows are unstable baroclinic systems which slope to the west with increasing height (Stranz & Taljaard, 1965). They are associated with strong convergence and are responsible for many of the flood-producing rains over South Africa (Taljaard, 1982).

During the 1987 floods the water level in the lower Mgeni River rose to 5 m above normal high tide level, inundating the surrounding low-lying land to the south and the mangrove swamp to

the north. Salinity dropped to zero in the entire estuary and a plume of turbid fresh water extended over 2 km into the Indian Ocean. Suspended sediment concentrations in the river waters reached 5698 mg l^{-1} (Simpson, pers. comm). This compares with a mean concentration of 165 mg l^{-1} (Brand *et al.*, 1967) under normal flow conditions. The adjacent shoreline became littered with hundreds of tonnes of vegetal debris including large trees as these were thrown onto the beaches by large waves.

The steep river gradients meant that the surface runoff was transported rapidly to the sea, flood peaks occurring at about midnight on the 28th of September. Surface current velocities of $6-7 \text{ ms}^{-1}$ were recorded in the estuary by timing floating objects over a fixed distance. The accurate recording of the flood peak was not achieved as all gauging stations were washed away. Kovacs (1988) recorded peak discharges at three points upstream (Table 1) but not in the estuary itself. Ouryvaev & Lukashenko (1976) have demonstrated that an estimate of flood discharge may be made using the cross-sectional area and the estimated surface flow velocity. Application of this method using an estimated velocity of 6.5 ms^{-1} and the cross-sectional area at Section 2 (Figure 7) given a water level of +5 m MSL (2642 m^3) yielded an estimated peak discharge of $17173 \text{ m}^3\text{s}^{-1}$. Considering the flow velocity profile in river channels during floods Ouryvaev & Lukashenko (1976) indicated that the mean velocity could be calculated by multiplying the surface velocity by a constant between 0.6 and 1.0. In the case of the Mgeni where the width was relatively great in relation to the flow depth, bed friction is likely to be high and thus the calculated discharge was reduced by a factor of 0.6. This figure has been widely used in South African rivers in engineering design projects (Huizinga, pers comm.). This yields a corrected figure of $10303 \text{ m}^3\text{s}^{-1}$ for the peak flood discharge. The potential error due to bed friction is in the range 10-15% (Ouryvaev & Lukashenko, 1976). The figure is considerably larger than the $5000 \text{ m}^3\text{s}^{-1}$ discharge calculated for Inanda, 25 km upstream, but this may be attributed to high rainfall in the area between Inanda and the estuary and

the presence of a large number of tributaries in the lower reaches of the Mgeni River.

Even considering all the potential sources of error in the calculation together with the possibility of non-coincidence of the flood peak with maximum bed erosion, the impression gained is that the September 1987 flood of the Mgeni Estuary was the largest yet recorded.

Trains of standing and upstream-breaking waves of 4 m wavelength formed in the estuarine channel (Figure 6). Under these conditions the normally constricted estuary mouth cross-section was enlarged by complete erosion of the mobile sandspit. Sediment was scoured from the estuarine channel and the vegetated island in midstream was completely eroded, together with sections of the estuary bank, particularly on the south side. The variation in nature and extent of sediment erosion and deposition through the estuary is discussed below.

1.9 Post-flood Morphology

Following the flood peak it was possible to assess the full geomorphological impact of the flood on the estuary. While large amounts of sediment had been eroded from the channel the falling flood stage deposited fine sand in overbank areas and large volumes of mud accumulated on the intertidal and supratidal sections of the mangrove swamp. Underwater observations using SCUBA were unsuccessful due to the turbidity of the water.

Sediment samples collected from the channel immediately after the flood (2nd October 1987) consisted predominantly of coarse sand and gravel. All mud had been eroded from the estuary and the carbonate and organic content of the sediment was reduced to zero indicating the removal of accumulated marine sand, fine sediment and organic detritus.

The overbank deposits consisted of well sorted fine sand on the south bank while up to 1 m of mud was deposited supratidally in the mangrove swamp to the north. Overbank deposits consisting of fine, angular, well-sorted sand (mean grainsize 0.12 mm) were deposited on the south bank, often forming small antidunes (50 cm wavelength). Local flow reversal produced by eddy currents on the overbank areas resulted in upstream-dipping planar cross-bedded units up to 2 m thick in the overbank sands. Similar features were noted by Hiller & Stavrakis (1982) and Reddering & Esterhuysen (1987) in overbank deposits. A layer of mud up to 1m thick was deposited in the mangrove swamp as a result of ponding in that area which enabled suspension settling of fine suspended sediment.

1.10 Channel Cross-sections

A survey of the channel cross-sections was carried out 20 days after the flood peak. Although some mud had been deposited from suspension in the upper estuary, coring revealed that its thickness did not exceed 4-5 centimetres. Thus the surveyed sections may be considered representative of the post-flood erosion base of the estuary. Comparison of the surveyed sections with channel cross-sections surveyed in 1984 allowed the volume of sediment eroded by the flood from various parts of the estuary to be calculated. Until September 1987 the morphology of the estuary changes little since the 1984 sections were surveyed and they accurately depict the pre-flood morphology of the estuary. The data were processed by computer and the channel cross-sectional area, hydraulic radius and effective width, calculated for mean high tide level (HTL) and mean low tide level (LTL), were deduced from water level records. The volume of sediment eroded from below HTL could therefore be calculated. The amount of supratidal sediment eroded was calculated by multiplying the difference in surface water area before and after the flood by the mean height between HTL and ground surface.

The post-flood channel cross-sections are shown superimposed on the pre-flood sections in Figure 7. The channel characteristics calculated from these cross-sections are shown quantitatively in Table 2 while the calculated changes in volume are contained Table 3.

During the flood a classical funnel-shaped estuary was produced (Figure 8). The survey showed a near constant downstream increase in cross-sectional area. This was accomplished by both widening and deepening of the channel. Erosion of the estuarine bed throughout the estuary led to an increase in mean depth at high tide from 1.18 m before to 2.95 m after the flood. An increase in width was accomplished by erosion of the south bank in the upper estuary, the island in the middle estuary and the north bank and sandbar in the lower estuary. Maximum depth increase, concomitant with minimum increase in width, occurred just upstream of the former position of the island.

The flood channel became wider and shallower towards the mouth of the estuary due to the erosion of the central island which effectively spread the erosive power of the flood over a wider area thus increasing bed shear stress. The deepest part of the flood channel was adjacent to the north bank in the upper estuary where scouring was enhanced by the presence of rock outcrops. In this maximum depths of 6.5 m below MSL were recorded. Downstream the thalweg split, forming two less prominent channels. The estuary mouth was insufficient to cope with the flood discharge and consequently the sandbar to the north of the mouth was eroded as was part of the mangrove swamp.

A total volume of $1.8 \times 10^6 \text{m}^3$ of sediment was eroded from the estuarine area (Table 3). Of this $309 \times 10^3 \text{m}^3$ or 17% was from areas above HTL (supratidal). The remaining $1.5 \times 10^6 \text{m}^3$ represents the increase in volume of the estuary due to the erosion of sediment from below HTL. The greatest increase in volume was below LTL ($1.28 \times 10^6 \text{m}^3$). An increase of

approximately $271.7 \times 10^3 \text{m}^3$ (15% of the total volume increase) occurred in intertidal volume (tidal prism) establishing a post-flood tidal prism $425 \times 10^3 \text{m}^3$.

1.11 Discussion

The pattern of sediment erosion in the estuary appears to have been controlled by the geomorphology of the system. Rock outcrops prevented erosion of the northern bank and enhanced downward scouring of the bed at cross-sections 9-12. The gently dipping bedrock surface was encountered at shallow depths in this (see Figure 3) and therefore the semi-consolidated muddy south bank was also eroded to cope with the increasing discharge. Downstream of this at sections 7 and 8 bedrock outcrops at greater depth and maximum downcutting occurred. Consequently the banks were little eroded in that area. This is also attributed to the presence in that area of high concentrations of gravel (Cooper & Mason, 1987) which had accumulated from bedload as a consequence of flow separation around the central island. This was the mechanism by which the island accreted upstream (Cooper, 1986) and the selective deposition of gravel in that area had led to a marked local decrease in channel depth before the flood. Thus maximum depth increase in this area during flooding was due partly to the erosion of a topographic high in the channel bed. The high porosity of the gravel probably enhanced its erosion potential.

While less severe floods have periodically eroded accumulated marine sand from the lower estuary during the last century little erosion of the channel banks appears to have occurred since the last major flood in 1917. Evidence for this is provided by two old railway trucks which were swept off the railway bridge during the 1917 flood. These trucks were uncovered, having been buried for 70 years under the golf course. The channel banks and central island have undergone intermittent accretion since that time. It is therefore possible to make a crude estimate of the net sediment accumulation rate in the estuary and, knowing the

sediment yield from the catchment, to calculate the net proportion of sediment retained in the estuary annually. The amount of marine-derived sand must be excluded from the calculation as this undergoes higher frequency erosion and accumulation cycles.

The total amount of sediment eroded from areas upstream of section 2, upstream of the flood-tidal delta, was approximately $1.5 \times 10^6 \text{ m}^3$ (Table 3) which could be considered equal to the net amount of sediment accumulated since 1917. This yields a mean sediment accumulation rate of $21.4 \times 10^3 \text{ m}^3$ per year since 1917. If one considers only the supratidal sediment upstream of section 2 the accumulation rate is $3.4 \times 10^3 \text{ m}^3$ per year which may be considered equivalent to the suspended sediment accumulation as this is restricted largely to overbank deposition. The volume of bedload sediment deposited since 1917 is therefore $1.24 \times 10^6 \text{ m}^3$ or $17.8 \times 10^3 \text{ m}^3$ per year. This is approximately 46% of the annual bedload sediment yield. Using an estimated surface area of the estuary of $1 \times 10^6 \text{ m}^2$ one may calculate a mean bedlevel increase of 170 mm per year. This compares with a mean accumulation rate of 4.25 mm per year over the past 8000 years based on a radiocarbon date quoted by King & Maud (1964). The modern rate appears to be anomalous but no account has been taken of stillstands or minor regressive phases during the course of the Flandrian transgression in calculating the mean accumulation rate. Martin (1987) noted a recent increase in sedimentation rates in the Natal valley in the south-west Indian Ocean which he attributed to increased sediment yield from east coast rivers in southern Africa due largely to human influence. This suggests that sedimentation rates in estuaries should be relatively low at present as most river-derived sediment is passed into the Ocean. It is apparent from this study that sediment accumulation and erosion in the Mgeni Estuary is strongly episodic and thus consideration of mean sedimentation rates may be misleading. The erosion of $1.8 \times 10^6 \text{ m}^3$ of sediment from the estuary alone in a few days and its almost instantaneous deposition in the Indian Ocean clearly illustrates the importance of catastrophic floods

not only in the estuarine environment but also on the adjacent shelf and nearshore zone where large influxes of sediment have a dramatic impact on beach accretion and shelf sedimentation patterns. Connell (pers comm.) reported that much of the shallow marine environment off the Natal coast was covered with a layer of organic-rich mud for several months following the floods. Durban's beaches underwent substantial increases in both width and height as a result of increased sediment availability.

The results of this survey clearly show the importance of catastrophic flooding on small estuaries. In the case of the Mgeni Estuary erosion during a single flood effectively restored the estuary to its 1917 situation, removing sediment which had been resident in the estuary since that time. This is in contrast to larger estuarine systems where, for example in Chesapeake Bay, Schubel & Zabawa recorded the deposition of a layer of sediment equivalent to 30 years of "fair-weather" deposition as a result of 10 days of flood action. In the case of smaller estuaries such as the Mgeni Sediment is eroded from the system and deposited on the adjacent continental shelf.

Erosion of the muddy estuary banks only occurs at high discharges associated with catastrophic floods while sand in the flood-tidal delta and sandspit is eroded and deposited annually by seasonal floods in the shorter term. Under such conditions the estuary attains a long-term equilibrium between sediment deposition and erosion which will be maintained unless there is a change in the relative level of land and sea.

1.12 Post-flood Recovery

At the time of writing it is 8 months since the flood took place. Since then the estuary bed has undergone rapid accretion due to the deposition of fine-grained fluvial sand. Because recreational assets such as a golf course were damaged by the flood the estuary banks have been partly reclaimed and armoured. Coarse sediment deposited offshore as a subaqueous delta was

rapidly reworked by wave action and transported landward to reconstruct the sandspit. The mechanism of delta modification was described by Cooper (1988). Studies of the post-flood recovery of the estuary are being undertaken. The suspended sediment transported into the sea discoloured the coastal waters for 6 months after the floods before eventually being reworked from the coastal zone. Debris was artificially removed from recreational beaches while in other areas it was covered by newly deposited sand.

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TABLE 1

Details of dams in the Mgeni River Catchment showing peak flood discharge records for the September 1987 flood.

DAM	CATCHMENT AREA (km ²)	VOLUME m ³ x10 ⁶	YEAR CONSTRUCTED	1987 PEAK FLOOD DISCHARGE (m ³ s ⁻¹)
Henley	?	?	1942	
Nagle	3315	20.8	1950	
Midmar	928	172.0	1963	1500
Albert Falls	1644	261.0	1975	2200
Inanda	4620	under construction		5000

TABLE 2

Cross-section and volume data for 1984 and 1987. X-area is the cross-sectional area at high and low tide levels (HTL and LTL respectively). The volume of the estuary contained between successive sections are given for high and low tide levels and the intertidal volume in each section is calculated.

Section Number	X-AREA HTL m ²	X-AREA LTL m ²	VOLUME HTL x10 ³ m ³	VOLUME LTL x10 ³ m ³	VOLUME Intertidal x10 ³ m ³
1984					
1	18.1	13.2			
2	310.8	160.5	32.3	17.6	14.7
4	243.0	105.1	88.4	42.2	46.2
4A	162.2	79.9	38.6	17.7	20.9
5	165.0	70.4	32.7	15.0	17.7
6	145.4	56.3	34.1	13.9	20.2
7	120.3	48.2	18.9	7.3	11.6
8	123.2	38.2	17.4	6.0	11.4
9	100.8	53.1	27.7	11.3	16.4
10	81.2	46.9	20.3	11.2	9.1
12	86.5	51.4	35.2	20.6	15.4
Total			345.6	162.8	182.8
1987					
1	1204.8	909.0			
2	1085.5	818.4	274.6	207.2	67.4
4	969.3	714.8	328.5	245.1	83.4
4A	1029.6	791.3	191.9	144.5	47.4
5	908.5	713.0	193.7	150.4	43.3
6	726.4	558.5	179.5	139.5	40.0
7	658.8	540.1	96.9	76.9	20.0
8	541.6	429.0	83.9	67.7	16.2
9	596.3	462.7	141.0	110.5	30.5
10	600.0	458.5	133.9	103.2	30.7
12	460.0	363.7	221.9	172.3	49.6
Total 1987			1845.8	1417.3	428.5
less 1984 volume			345.6	162.8	182.8
Volume increase			1500.2	1254.5	245.7

TABLE 3

Cross-sectional data indicating the increase in volume of the estuary between various surveyed sections as a result of the flood.

Volume increase (m³).

Section no.	Intertidal	Subtidal	Supratidal	Total
1				
2	52 629	189 615	61 095	303 339
3	37 138	202 941	44 365	284 444
4	52 629	100 597	32 110	185 336
5	25 622	135 342	31 306	192 270
6	19 733	125 612	23 331	168 676
7	3 649	74 316	9 332	87 297
8	4 817	61 654	5 216	71 687
9	14 042	127 003	17 884	131 199
10	21 672	91 981	27 424	141 077
11	35 117	151 642	43 324	230 083
	<hr/>	<hr/>	<hr/>	<hr/>
TOTAL	271 128	1 281 523	309 306	1861 957

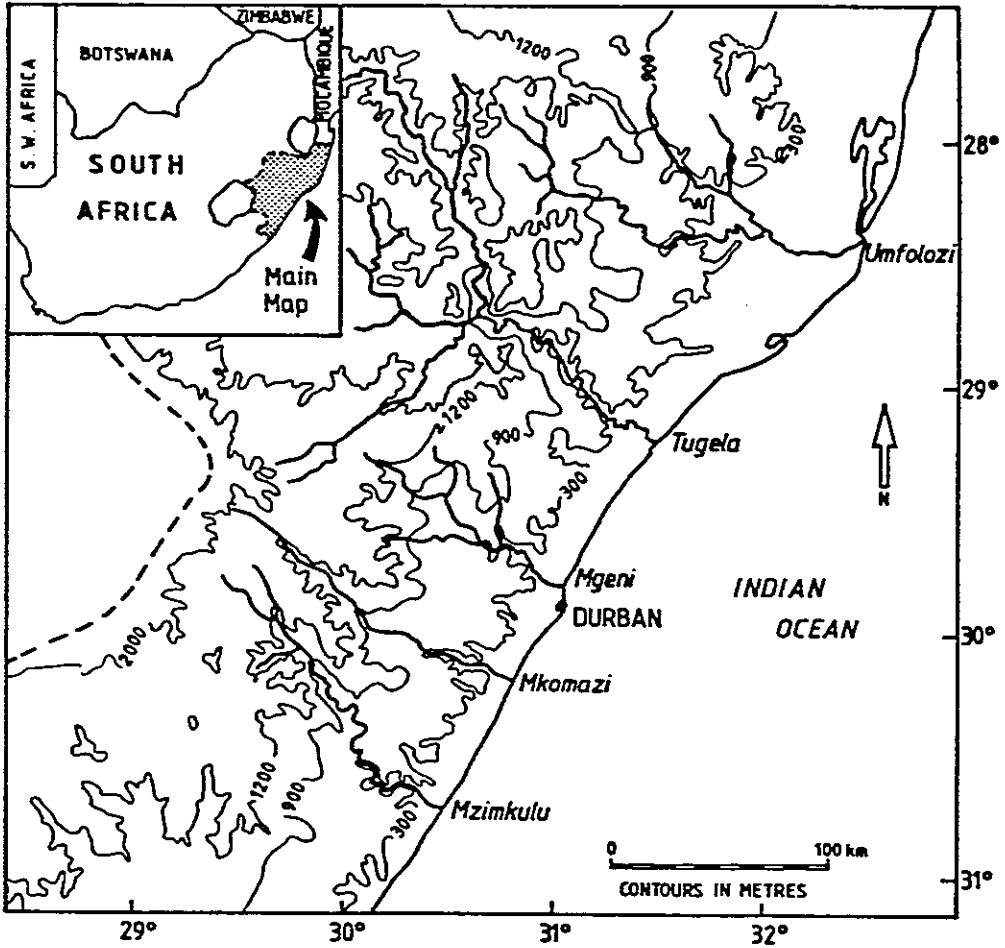


FIGURE 1

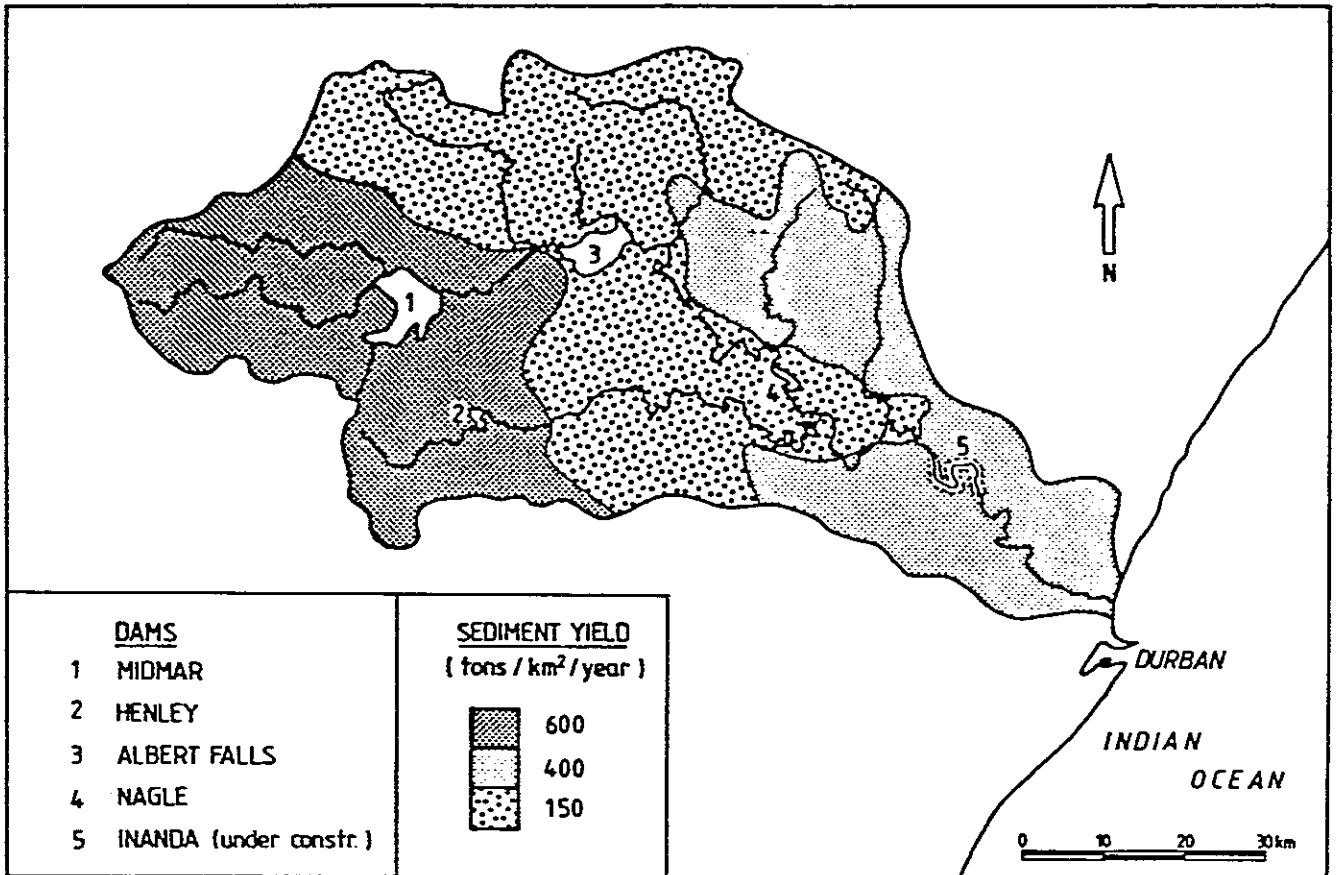


FIGURE 2

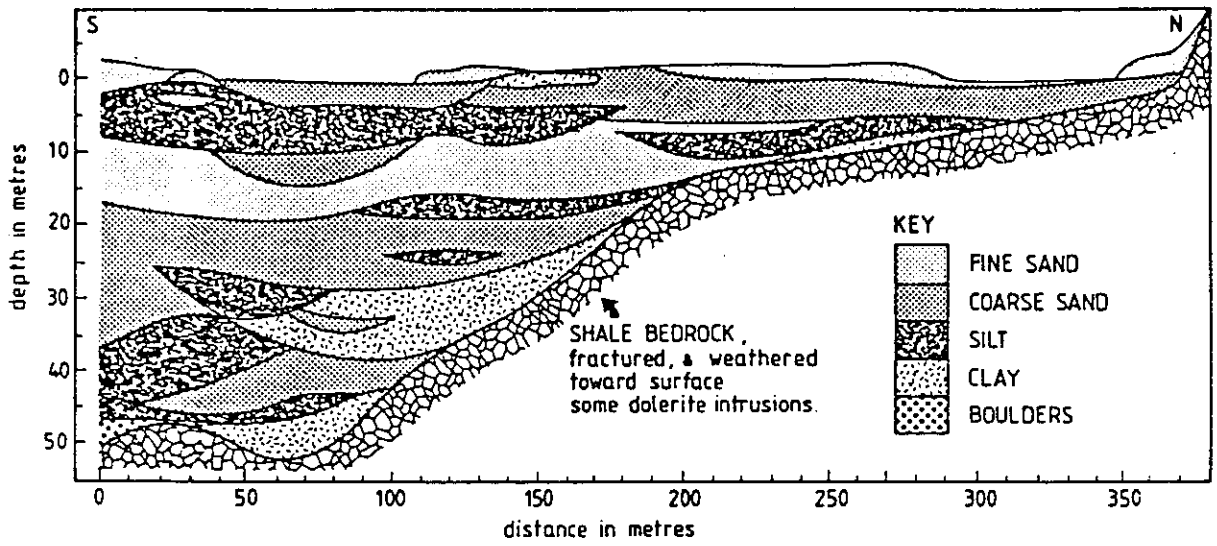


FIGURE 3

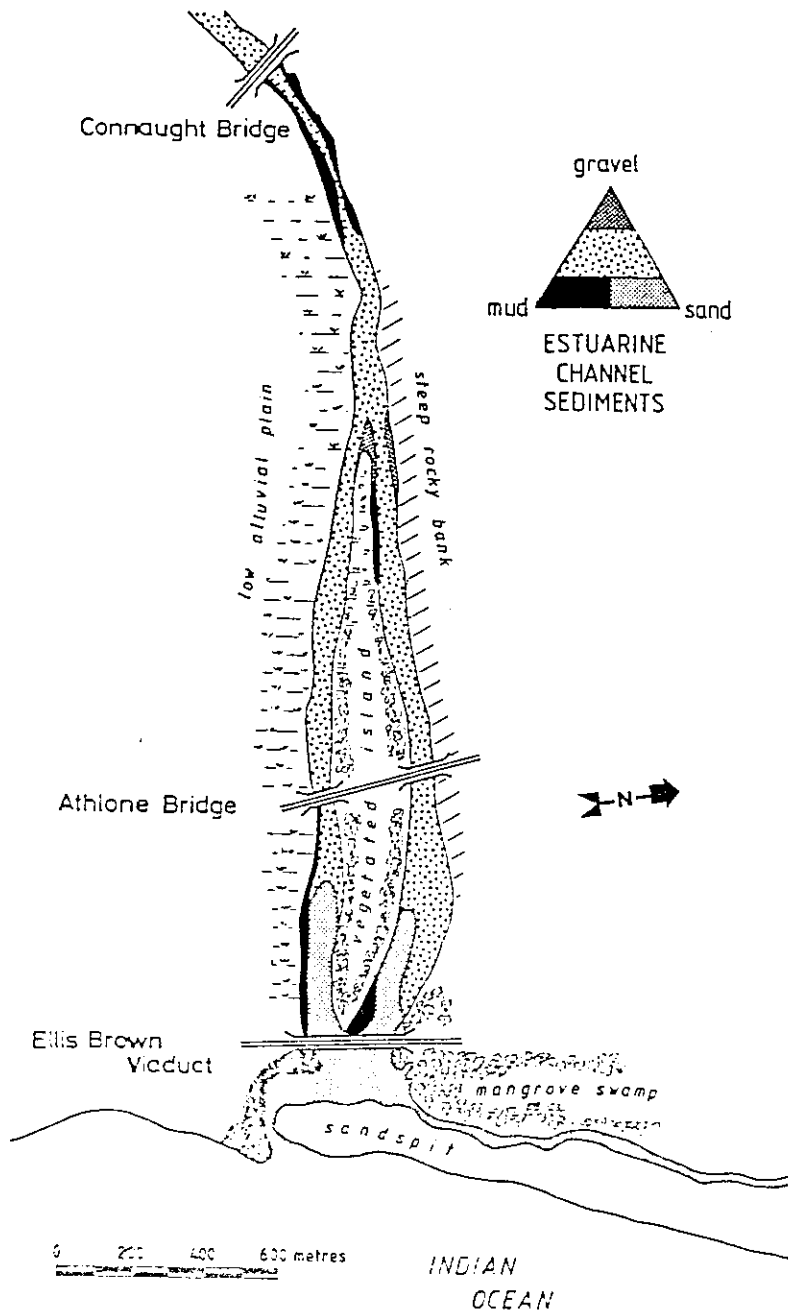


FIGURE 4

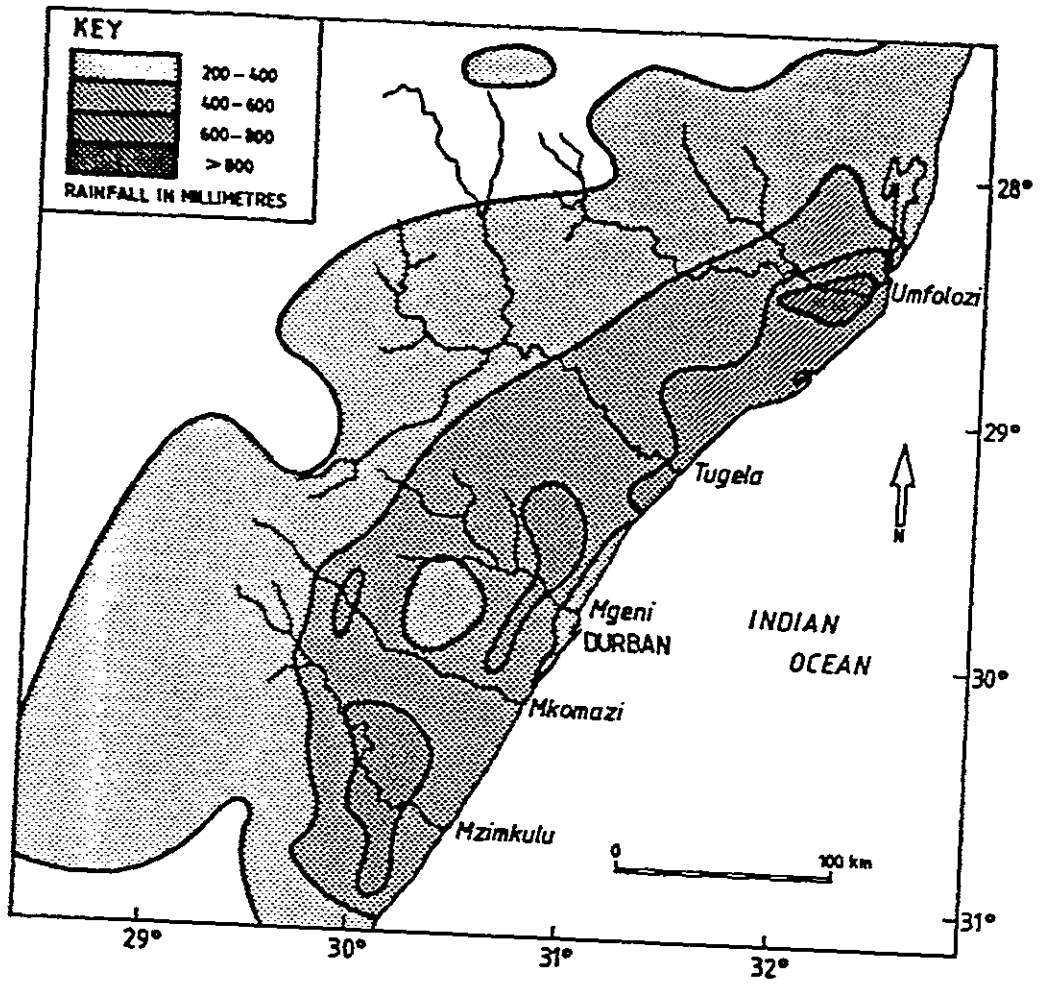


FIGURE 5

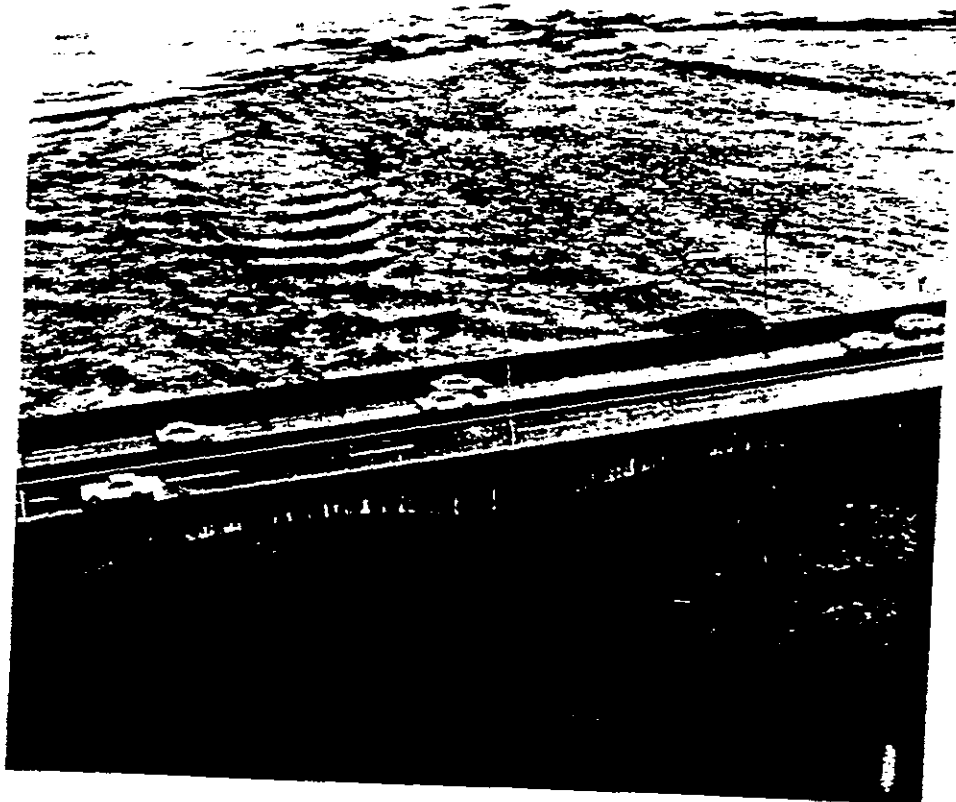


FIGURE 6

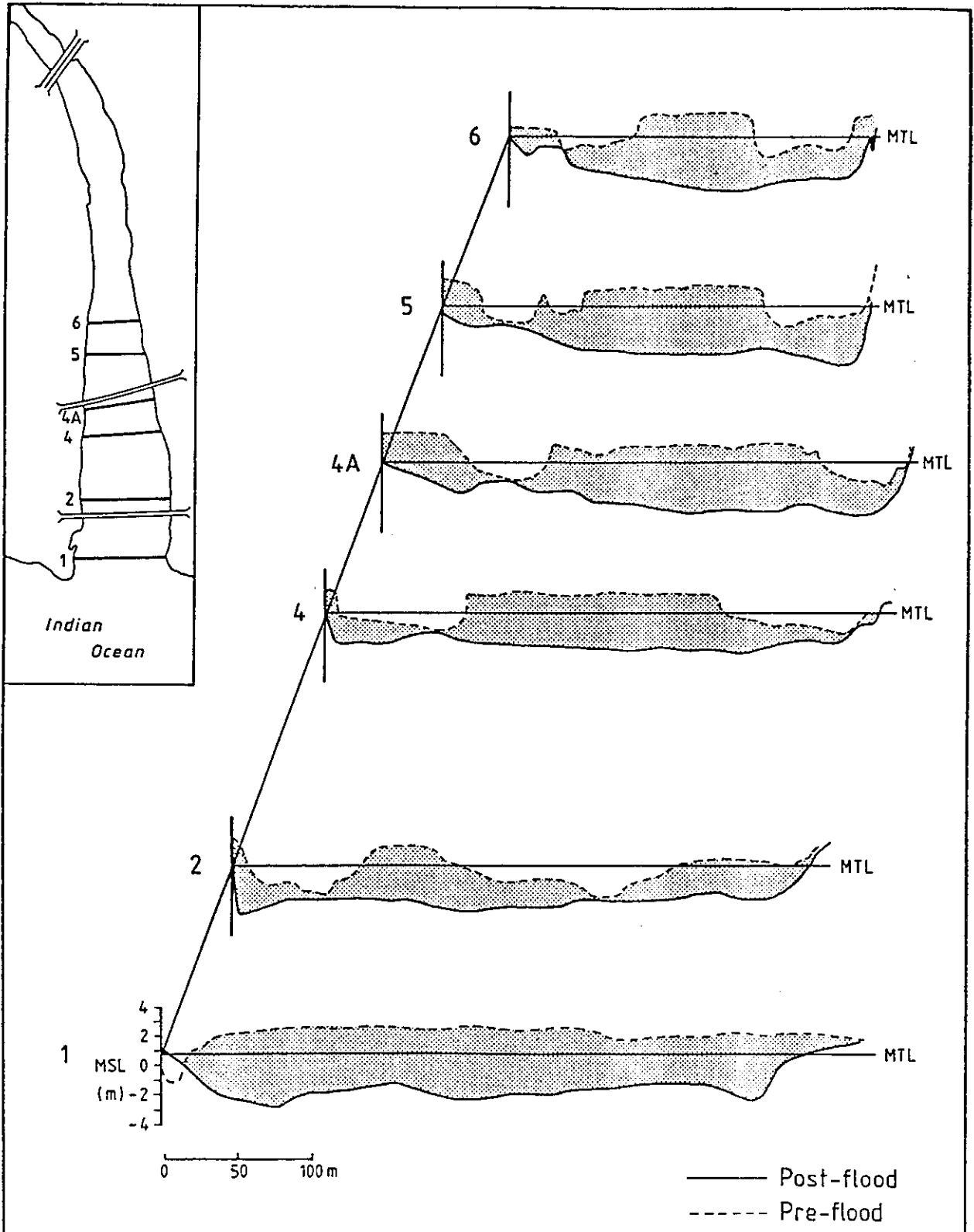


FIGURE 7a

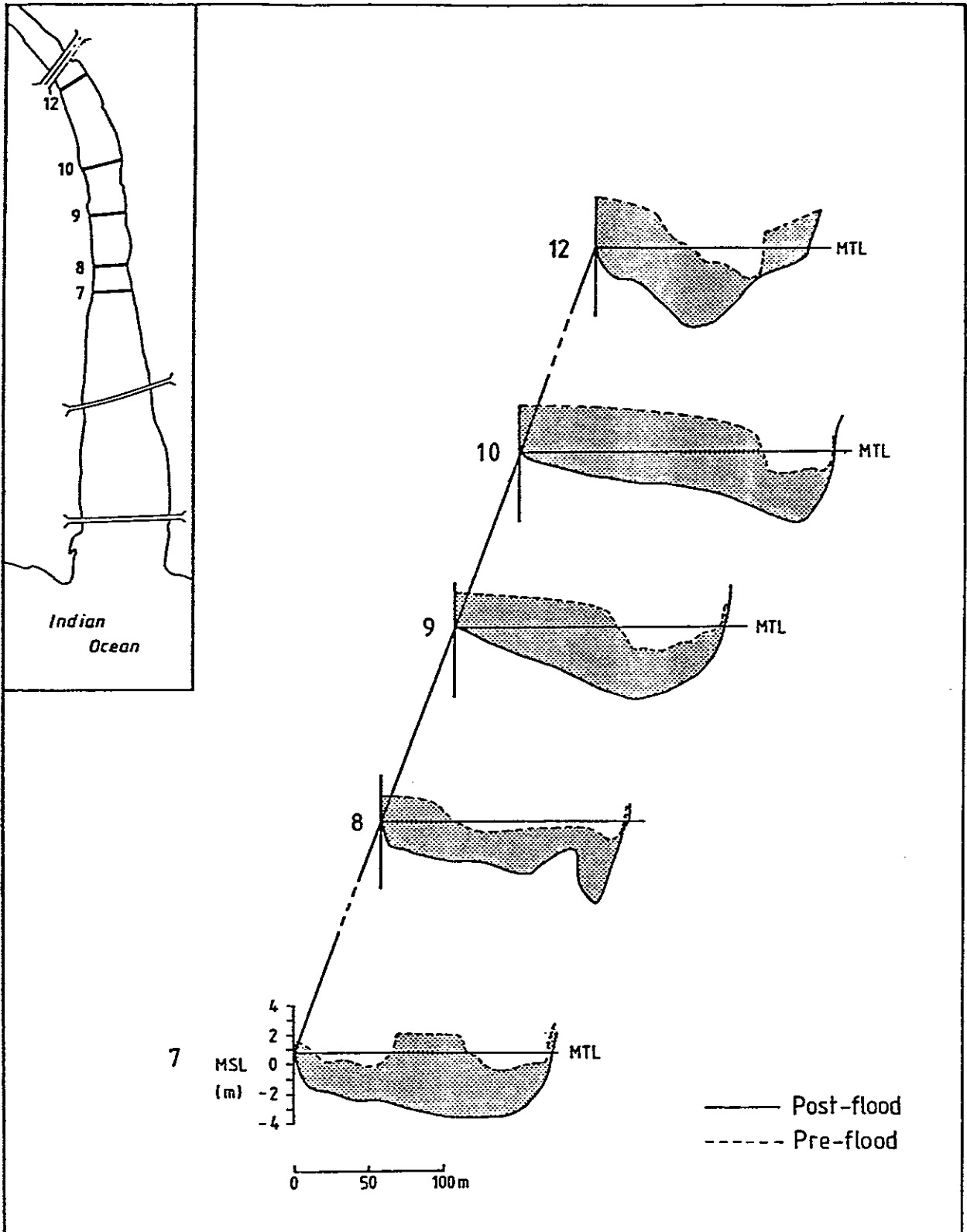


FIGURE 7b

The Umgeni River.



30th June 1985



10th October 1987

FIGURE 8

PART 2

MDLOTI LAGOON: EFFECTS OF SEPTEMBER 1987 FLOOD

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2. MDLOTI LAGOON: EFFECTS OF SEPTEMBER 1987 FLOOD

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2.1 Abstract

The September 1987 Natal flood demonstrated how geomorphology controls the damage caused by a catastrophic event in a small, sensitive coastal environment. The flood impact on estuaries and lagoons is limited by factors such as; the catchment size, the presence of man-made structures in and around the lagoon and the presence of rock outcrop (serving as a base level) at the lagoon mouth. Sediment in Mdloti Lagoon is dominated by fluvial sand and gravel derived from varied lithologies in the catchment area. Marine sand enters the lagoon by barrier overwash. Fine muds (silts and clays) are dominant in tranquil areas of the lagoon away from the channels. Mdloti Lagoon underwent major

sedimentological and morphological changes during the flood. Sediment distribution within the lagoon is governed largely by the position and size of the lagoon mouth and hence the degree to which the sea may enter the system and redistribute the sediments. The effects of floods and their significance as regulating factors of sedimentation processes between estuaries and the sea is poorly known: the effects of large catastrophic floods are almost totally unknown. The return time of these major floods was previously estimated as being hundreds of years. For the Natal coast a return time of 30 years appears to be a better estimate.

2.2 Introduction

Previous work

An earlier SEAL report (Grobber *et al.*, 1987) documented the sediment distribution patterns in Mdloti Lagoon before the September 1987 and February 1988 events.

Locality

Mdloti Lagoon is situated on the Natal north coast approximately 20 km from Durban. This study forms part of a SANCOR-funded programme in which the physical characteristics of estuaries are studied. A major flood in September 1987 provided a rare opportunity to resurvey and examine the sediment distribution in estuaries which we had recently studied. Figure 1 shows the sediment facies distribution before the flood, and Figure 2 the estimate of grain size distributions based on a walking traverse through the area immediately after the flood.

This work documents the follow-up study which took place in Mdloti Lagoon which recorded changes resulting from the flood. Knowledge of modern coastal sediments and their modification during catastrophic events such as the 1987 flood needs to be applied to practical engineering problems like bridge design and construction (Pegram & Adamson 1988), and may also prove useful when formulating palaeoenvironmental models for ancient sedimentary deposits.

Lagoon morphology

The Mdloti River floodplain is 600 m wide and its catchment area is approximately 500 km². Before the flood the deepest point in the lagoon was 2.3 m: after the event scours near the N2 road bridge were over 3.5 m deep. The lagoon (13.6 ha) originally had two main channels but construction of the N2 road bridge in 1960 confined the flow to a southern channel and blocked the northern channel with the road bridge approach embankment. The floodwater chose to follow both channels and in so doing destroyed about 100 m of road and part of the bridge. The sandy island (braid bar) separating the two channels was eroded. The post-flood recovery phase has left the Mdloti River as one large channel which is being modified by newly emergent sand bars. Just as the recovery of the channel was proceeding and the new road bridge finished, a smaller flood came through the system in February, and further modified the channel geometry.

For thirty percent of the year (Begg, 1978) Mdloti Lagoon usually has a small mouth (20-30 m wide), situated in a central or southern position on the large beach-barrier sandbar separating the lagoon from the ocean. During the September flood almost the entire length of the sandbar was eroded and the lagoon mouth was about 400 m wide. Within 5 weeks the sand bar had been re-established in its pre-flood position. The February flood opened a narrower mouth and the sea flooded the lagoon with each high tide, while marine waves eroded the river banks on the seaward side of the bridge.

Regional setting

The Mdloti River derives its sediment load from various lithologies ranging from gneisses and granites of the Natal-Namaqua Basement Complex, Dwyka Tillite, Natal Group Sandstone, shale and sandstone of the Pietermaritzburg and Vryheid Formations and Berea-Type red sands. The geology in the vicinity of the lagoon contains subtle hints of a complex history of glacio-eustatic sea level changes which have modified the coastal landscape.

The floodplain consists of fluvial and estuarine sediments which have accumulated since the beginning of the Flandrian Transgression 10 000 years ago (SACS, 1980). Borehole log data (Orme, 1974) show bedrock 31 m beneath the "typically estuarine sediments" to be Vryheid Formation sandstone. Many Natal rivers have incised their floodplains to a level of 1.5 - 2.0 m below the present floodplain level.

Most sediment entering the lagoon is terrestrial mud, silt and sand brought down by the Mdloti River. Minor amounts of sediment are blown off the beach or washed over the sandbar during storms. We consider this sediment to be marine-derived. The annual sediment yield of the Mdloti catchment system is estimated at 210800 tons (Orme, 1974; Rooseboom, 1975).

Fauna and Flora

The lagoon is normally brackish (hyposaline) and the lagoonal vegetation and mud provide a variety of microhabitats for highly specialized animals. Most species are sessile infaunal burrowers rather than epifaunal and remain down multifunction (protective and dwelling) holes in the muddy substrate for long periods of time. Most of the benthic fauna were swept from the lagoon by the flood. The pre-flood faunal and floral varieties are discussed in SEAL report No 3 (Grobber, Mason & Cooper, 1987).

Three months after the floods few benthic organisms had recolonized the lagoon. We consider estuarine benthic organisms to be sensitive indicators of water quality, flow regime and sediment characteristics: their burrows and trails (trace fossils; ichnofossils) are useful for palaeoenvironmental interpretation.

Since the flood the first flora to recolonize the lagoon banks and emergent sand bars are **Phragmites** reeds and various grasses. Juvenile **Barringtonia racemosa** trees fringing the water's edge were removed by the floodwater. Older established "mangrove" stands which grew in the central portion of the floodplain were also eroded by the flood.

2.3 Sediments: Texture

Fine sediments

Before the flood fine sediment (silt and clay) predominated on the marshland and *Barringtonia*-lined lagoon margins. Muddy sediment probably constitutes about 60% of the present surface sediment, only being absent in the channel areas. During the flood the entire lagoon floor consisted predominantly of sand and gravel (map X) with the only mud being found in the protected "mangrove" stands and in the small northern portion of the lagoon which remained unaffected by the flood.

Once the sandbar re-formed and isolated the tranquil lagoon environment from the high energy ocean environment, rapid suspension settling followed, depositing a 0.5-1.0 m thick mud slurry on top of the fluvial sands and gravels. This resulted in about 80% of the lagoon surface area being covered by a muddy surface sediment layer. This is noted on the two mud percentage distribution maps (Figs 7 & 8) where the map plotted for surface samples indicates a much higher mud content and distribution than for the samples collected 0.5 m below the sediment surface.

The post-flood surface mud distribution map clearly demarcates the flood channel which switched from its southern (pre-flood) position to the northern bank of the lagoon. Mud percentage values within and immediately adjacent to the channel are low with sand- and gravel-sized sediment being dominant.

Sand and gravel

Sandy sediment was the predominant sediment type before and during the flood period but as the energy levels dropped the mud settled and the remaining fluvial sands and gravels serve to demarcate the channel positions. Further upstream, emergent sand bars draped with thin but extensive mud layers flank the active channel.

The two distribution maps (Figs 3 & 4) of gravel percentages representing samples collected at the sediment surface and at - 0.5 m below this appear to be totally unrelated. This is attributed to the different energy conditions that prevailed during the deposition of these two horizons. During, and for a while after, the flood the lagoon had a very wide mouth and was thus exposed too the high energy marine regime. Sediment within the lagoon was redistributed and a marine component was added during this time by wave, tidal and current action. This formed a flood-tidal delta of coarser sediment which exists at - 0.5 m depth lagoon ward of the sandbar extending up the southern half of the lagoon, counterbalancing the fluvial component of the northern half of the lagoon.

The introduction of marine sediment into the lagoon while the mouth was open is shown by the higher carbonate values in this region (Figs 11, 12, 13 7 14). The surface sediment (gravel) distribution (Figure 3) represents deposition in a much changed environment when the mouth of the lagoon was very restricted or even closed as a result of the sand bar having built back up again. Hence the distribution pattern indicates the dominance of fluvial processes with very little marine interference.

The body of coarse sediment extending from the northern bank of the lagoon to the southern end of the sandbar marks the channel course just prior to the closing of the mouth and corresponds with the position of the lagoon mouth at that time. Low gravel percentages recorded in the surface sediment are a consequence of the high mud content of the surface sediment.

2.4 Sediments: Composition

Calcium carbonate

The lagoonal sediment is almost carbonate free and the only significant gasometric carbonate readings were obtained from samples collected adjacent to the beach barrier and in the mouth region. This carbonate was probably derived from marine sediment

rich in shelly material which entered the lagoon by marine processes whilst the lagoon mouth was open. Marine sediment is also introduced by aeolian and barrier overwash processes.

Few benthic foraminifera or micromolluscs were found in the lagoon sediment. Most of the detectable carbonate resulted from the presence of broken shells of marine genera. Occasional high carbonate percentages recorded in the typically fluvial sediment may be caused by the local presence of shell fragments probably of a mud-boring estuarine molluscan fauna.

Organic carbon

The organic carbon content of the sediment is relatively high in surface sediment samples and much lower for samples collected at depth. As expected the organic carbon and percentage mud distributions are similar as virtually identical conditions are required for their deposition. A linear relationship between organic carbon and percentage mud values, as exists in Mdloti Lagoon, has also been noted in other areas (Flemming, 1977; Cooper & Mason, 1987).

Organic detritus is produced from decaying plant fragments, faecal discharge from fish, birds and small crustaceans and the erosion of older floodplain deposits.

2.5 Discussion

The September 1987 Natal floods affected different estuarine systems in different ways. We believe that the severity of flood damage is controlled largely by: the size of the catchment area; the presence of man-made structures in and around the estuary; the presence of dams on the rivers to attenuate the water volume; and the presence of rock outcrop (i.e. acting as a base level) at the estuary mouth.

In Mdloti Lagoon the sediment texture, composition and distribution within the lagoon were altered by the flood. The flood formed a new erosional base level, and on top of this an "ideal" upwardfining sequence of lagoonal sediments was deposited.

During the flood the main channel moved from a southern position on the floodplain to a more central location with disastrous effects on the road and bridge crossing the floodplain. This simply emphasises the vulnerability of man-made structures to destruction by flooding rivers when built on floodplains. This need not be so if we are prepared to engineer the structures to new standards. It is easy to locate old fluvial channels on aerial photographs or by using sediment distribution mapping. Road construction ought to take note of these relic features as they are likely to be reactivated during major floods.

The geomorphology of Mdloti River mouth makes it impossible for the river to flow anywhere else during a major flood. The shorter southern route to the sea is blocked by a solid rock outcrop which diverts the flow northward into the older abandoned northern channel. In an earlier report (Grobber *et al.*, 1987) we pointed out on a map and photograph where earlier floods had undermined the toe of the northern embankment slope. This was the area eroded by the 1987 flood and after the initial undermining was completed, the embankment was totally destroyed.

It now appears that floods of the 1987 magnitude are not such rare events. Intuitively, it is reasonable to assume that with three recorded on the Mgeni River catchment in the past 131 years (1856, 1917 and 1987) they must be considered to have a return time of 50 years. Pegram and Adamson (1987) provide a more rigorous mathematical treatment of rainfall data and conclude that the risk analysis for major storms in the Natal-Kwazulu region has underestimated the return time of these events. They base their work upon the recognised fact that there are two major

storm-producing mechanisms, one is the "normal" local scale of weather pattern and the second is the larger scale synoptic event (cut-off low; Kovacs 1988) which has a regional significance.

Interpretation of the rainfall data is likely to be contentious as many difficult-to-define factors must be considered in such analyses. These include: statistically lower rainfall figures during the database measurement period; and many new dams on the catchments have reduced the flood peak discharge. In addition, the effects of short (Tyson cycles) and long term (Milankovitch cycles) variation upon weather patterns must be taken into account, but these data are notoriously "noisy", and even short period Tyson cycles represent a weak oscillation between above- and below-average rainfall (Preston-Whyte & Tyson, 1988).

Further intuitive thinking suggests to us that if a statistical calculation shows the flood frequency prediction to be too low for the Mgeni catchment on the basis of three major floods since 1856, then the return frequency for the **whole Natal coast** must be even shorter than 50 years if we include the tropical cyclones Demoina and Imboa which hardly affected the Mgeni catchment though it caused major damage further north.

Kovacs (1988) showed that catchment size had a direct influence on the flood volume. In uMgababa Lagoon the small catchment size resulted in a small flood volume and Umnini Dam situated 4 km upstream of the estuary controlled the smaller flood volume and attenuated the flood peak. Conversely, damage caused to the Mdloti system, with a catchment area 12 times greater than the uMgababa system, might have been reduced if more attention had been given to the flood plain geomorphology.

It must be emphasized that without longer term follow-up studies we cannot be sure if sediment distribution patterns are stable in the regime of normal seasonal floods which flush the estuaries. In this study follow-up data were collected sooner than anticipated because of the magnitude of the flood event.

Assuming most floods are less severe than the September 1987 event, the fact that pre- and post-flood sediment distribution patterns are different simply emphasises the inherent dynamism of fluvial processes and may also indicate the system is metastable.

The Mdloti, Mgeni and Mvoti estuaries lack prominent rock outcrop at the seaward end of the estuary and this dramatically affected their behaviour during the flood and influences the stability and form of the estuary mouth. Catchment size and the presence of dams in close proximity to the estuary have a marked effect on the flood volume passing through the estuary thus minimizing the flood impact and resulting in less destruction.

It is well known that many organisms, originally considered to be exclusively estuarine, have a marine phase in their life cycle. If the estuary mouth is restricted or totally closed as a result of accumulated sediment (70% of the year in the case of Mdloti Lagoon) it can adversely affect recruitment back into estuarine populations. Floods do then have at least one advantageous effect on closed estuaries by flushing them from time to time and permitting migration of animals from one environment to another.

2.6 Conclusions

The post-flood gravel and mud distributions define the flood channel which incorporates portions of both pre-flood channels. Post-flood samples collected 0.5 m below the sediment/water interface indicate a predominance of coarser sediment (smaller phi values). It is unlikely that this is solely due to downstream movement of gravel but may be caused by selective winnowing of the fines by flood scour and the subsequent exposure of underlying gravels and sands.

The fluvially-derived lagoonal sands are mostly quartz with subordinate amounts of feldspar, amphibole and heavy minerals. Settling tube data reveal that the sand is medium to coarse-grained and generally poorly to moderately sorted. Near

symmetrical distributions (leptokurtic) with calculated skewness values of about zero were obtained.

It appears that a combination of catchment size and the sediment trapping ability of dams control the impact of floods. Areas which were most badly damaged were areas of maximum impact by man. Other areas which remained unscathed, due to the attenuation of the floodwater peak, were relatively pristine and small.

Comparing the damage caused by the flooding Mdloti to other fluvial systems along the Natal coast it is evident that the following factors contribute to the susceptibility of the estuary to damage: 1) encroachment by buildings and agriculture onto the floodplains; 2) building of roads directly adjacent to the rivers; 3) misalignment of bridges; 4) and the blocking of flood channels with embankments and bridge approach roads. Planners and engineers need access to good basic data on the coastal zone before decisions are made about the siting of man-made structures in this environment.

Domestic, agricultural and industrial freshwater requirements are increasing with a subsequent increase in the number of dams being built on fluvial systems. Consequently, the estuaries suffer a reduced fluvial input with a corresponding reduction in seasonal changes, intensity, frequency and duration of fluvial flooding. If our estuarine environments are to be managed effectively, a knowledge of the effect of flooding and its significance as a regulating factor of interactions and processes within and between estuaries and the sea is essential.

24th August 1988

2.7 Diagrams

The text figures represent data collected before and after the flood. Diagrams are presented on facing pages for ease of comparison.

2.8 Cross-sections

The cross sections were surveyed immediately after the flood. Since then the pegs near the mouth have been buried by sediment and some of the rocky outcrops used have also disappeared under the sand. No resurvey has been carried out to tie these cross-sections to a new datum horizon. They are given with reference to mean sea level. The section lines are marked on Fig 26.

2.9 References

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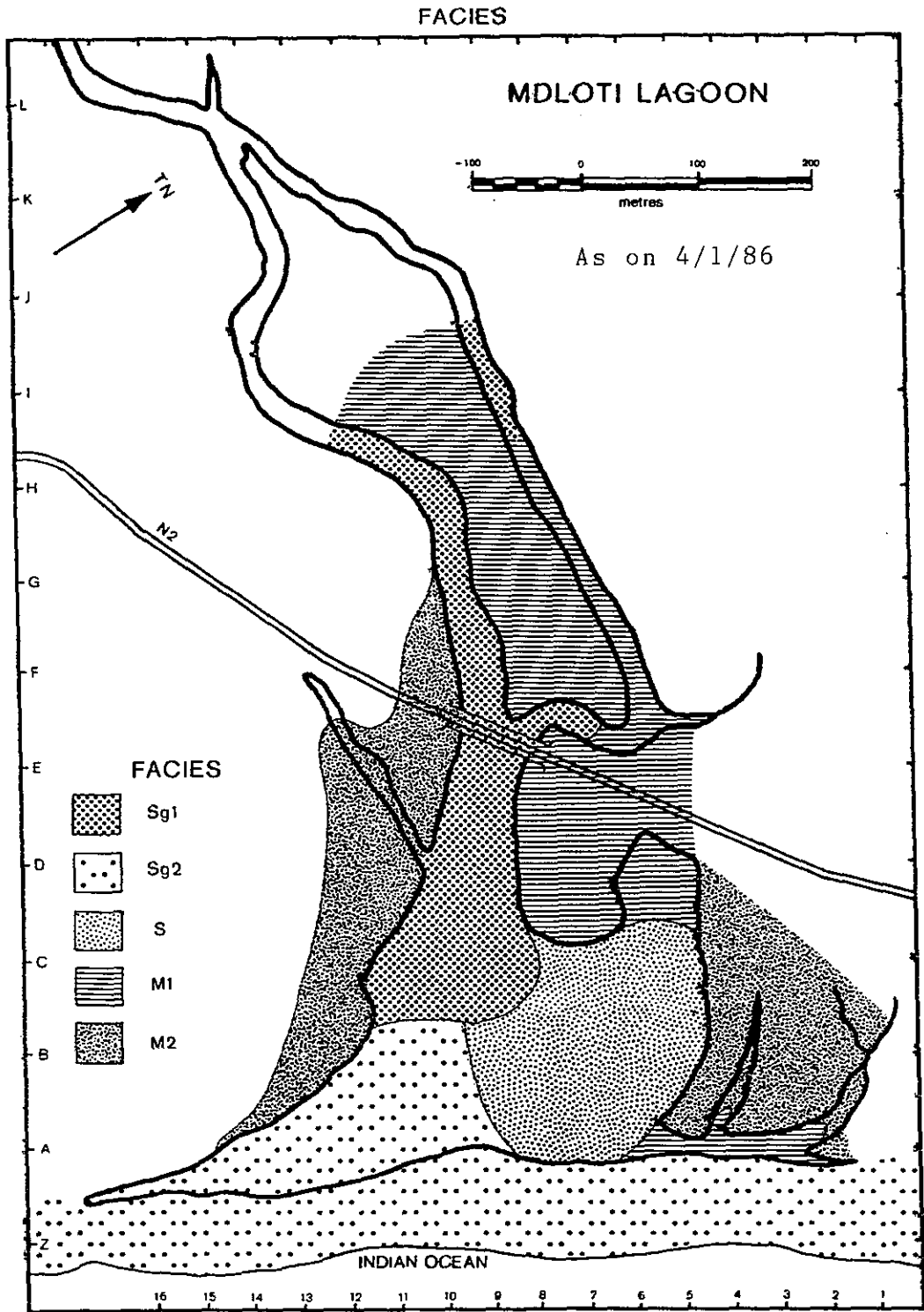
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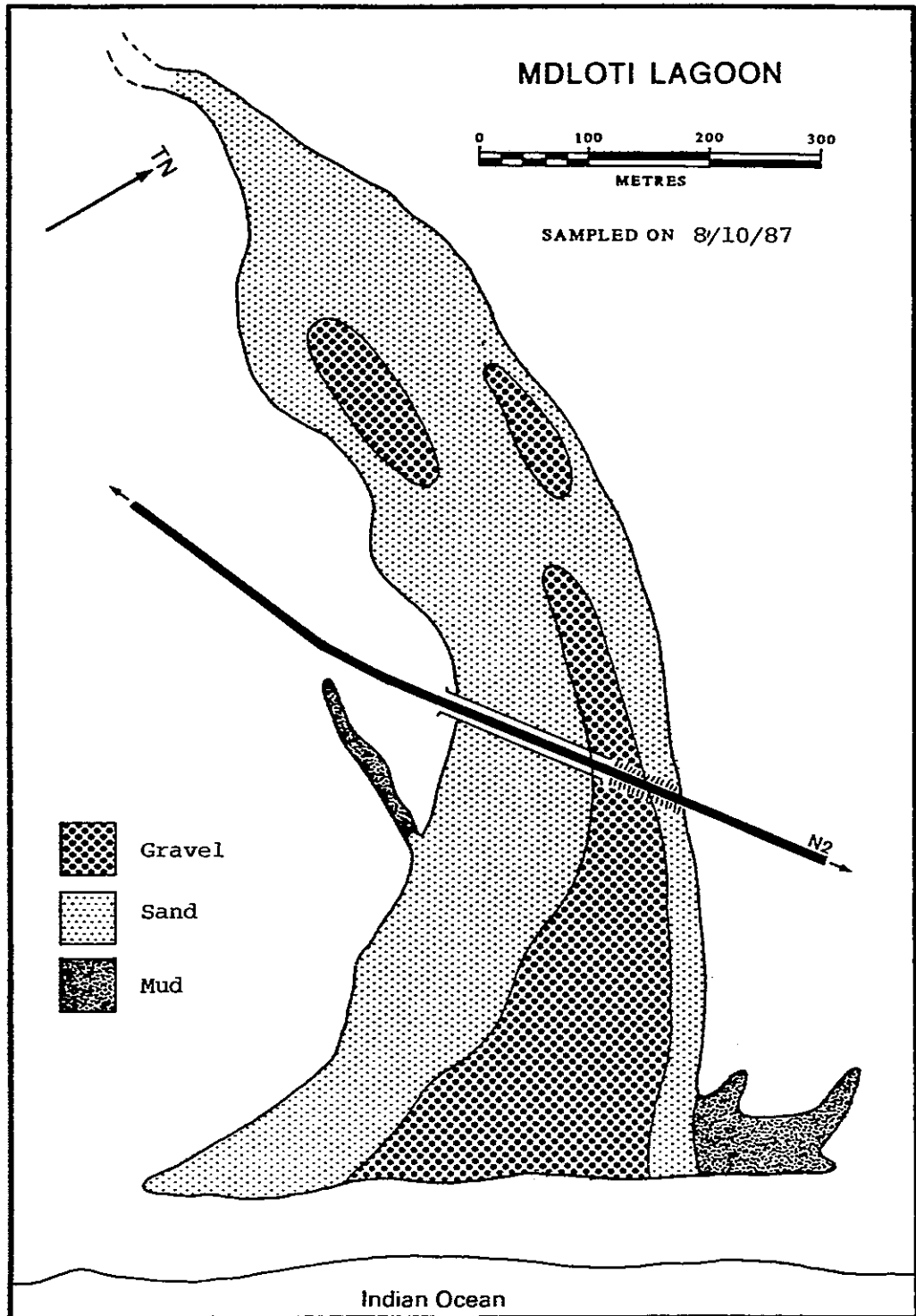
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Facies distribution for pre-flood conditions.

FIGURE 1

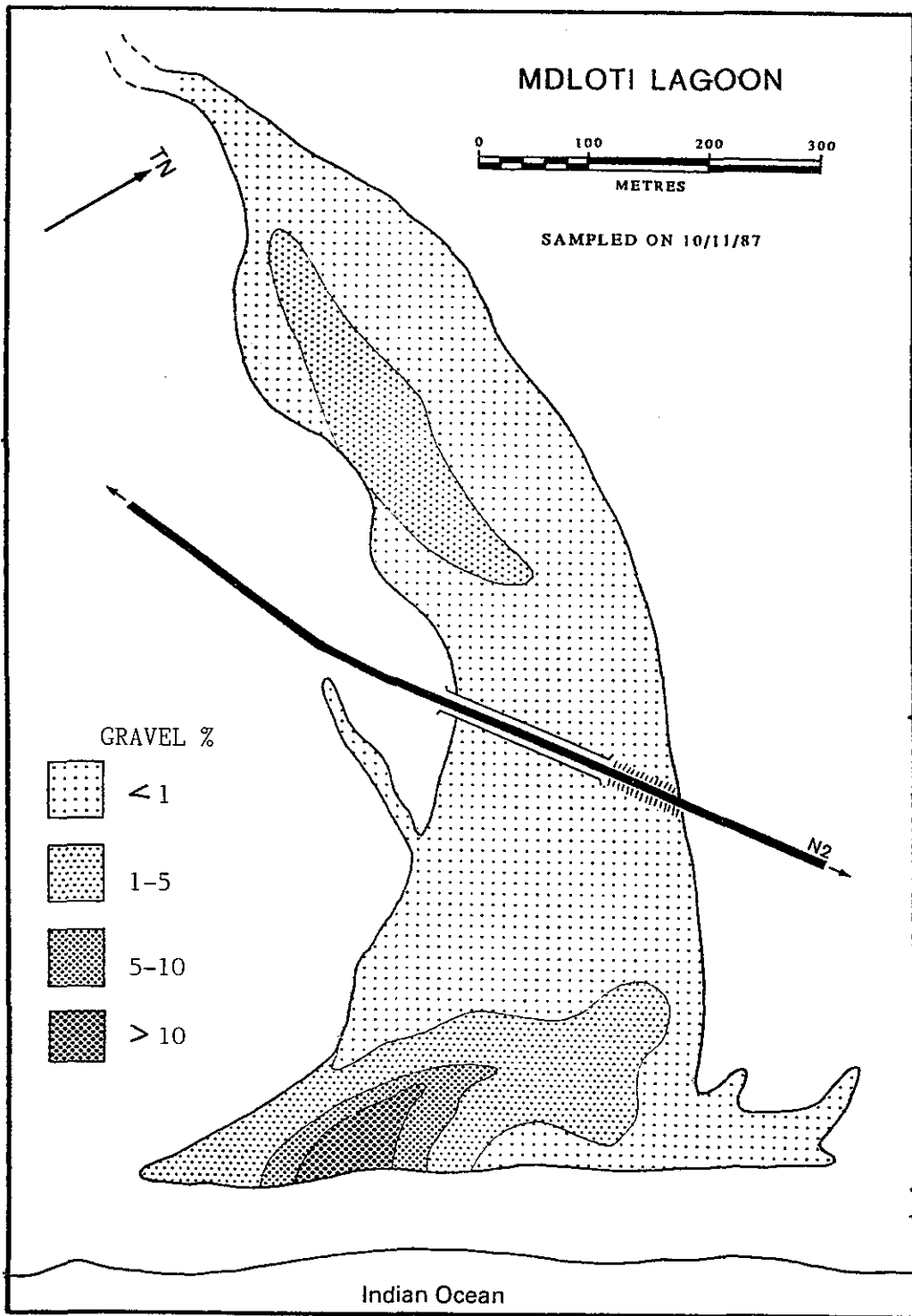
GRAIN SIZE



Grain size distribution based only on field observations immediately after the flood. A month later (sampling date 10/11/87) the lagoonal surface sediment distribution had changed significantly from being gravel/sand dominant to mud dominant.

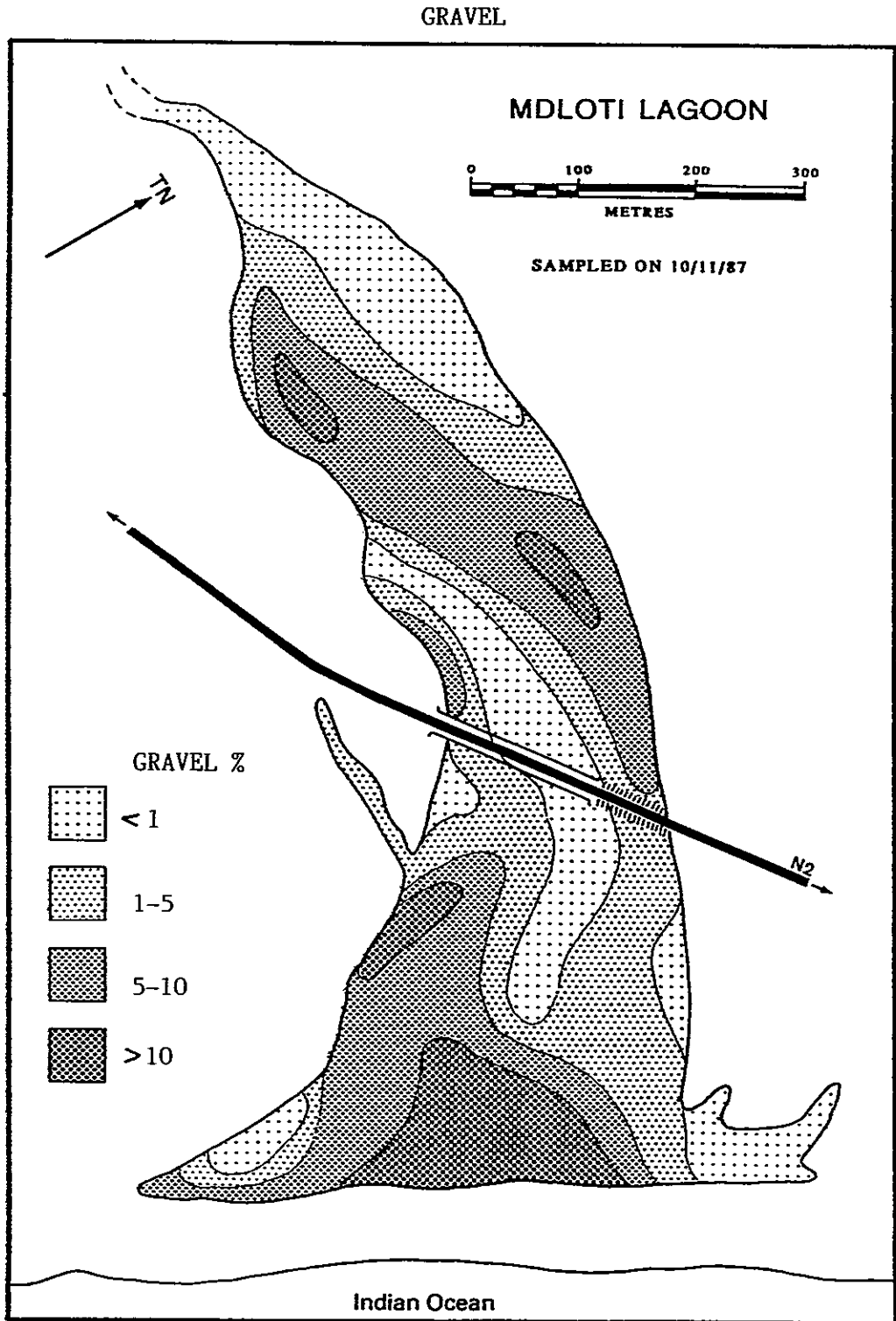
FIGURE 2

GRAVEL



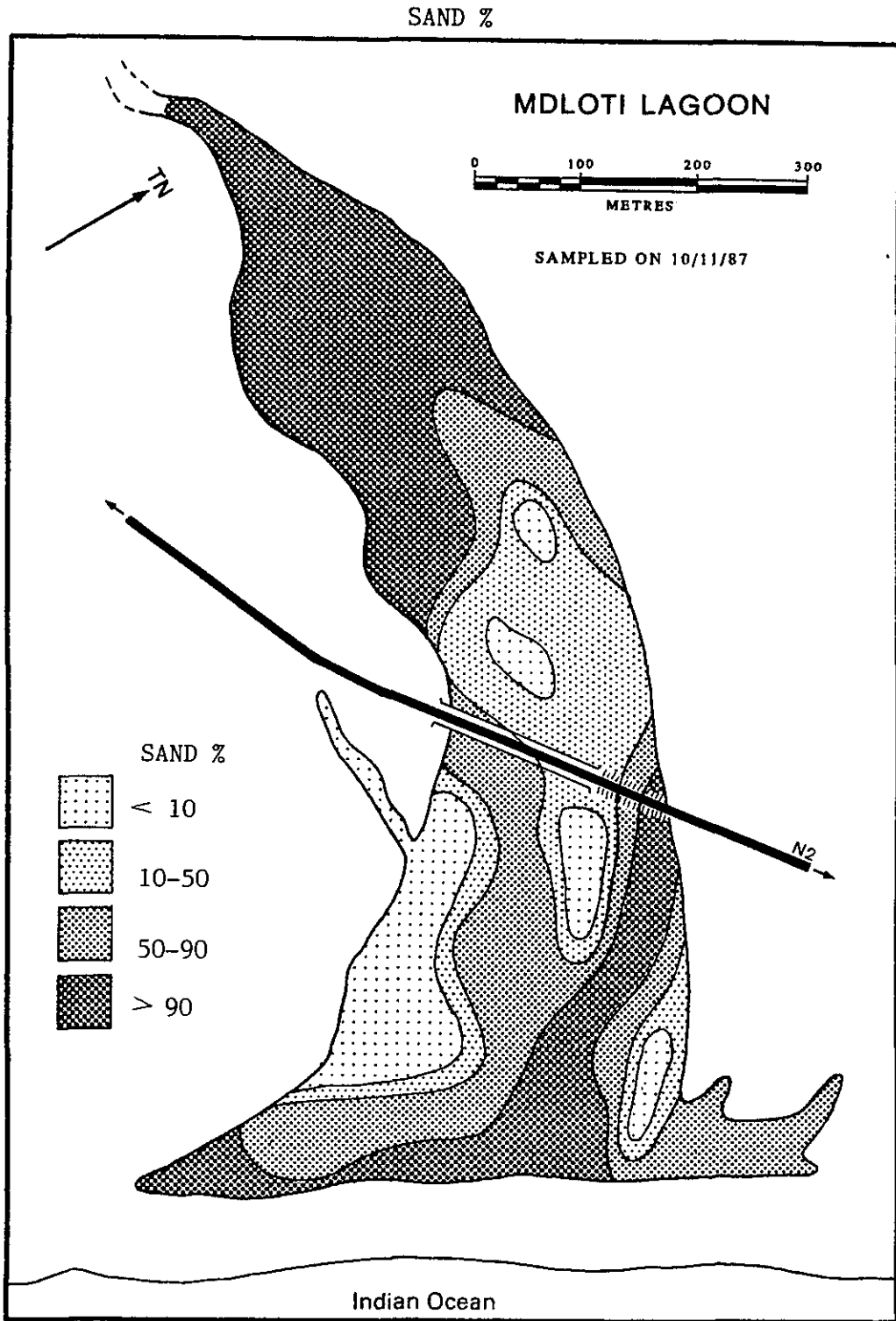
Gravel distribution for samples collected at the sediment surface - Post-flood.

FIGURE 3



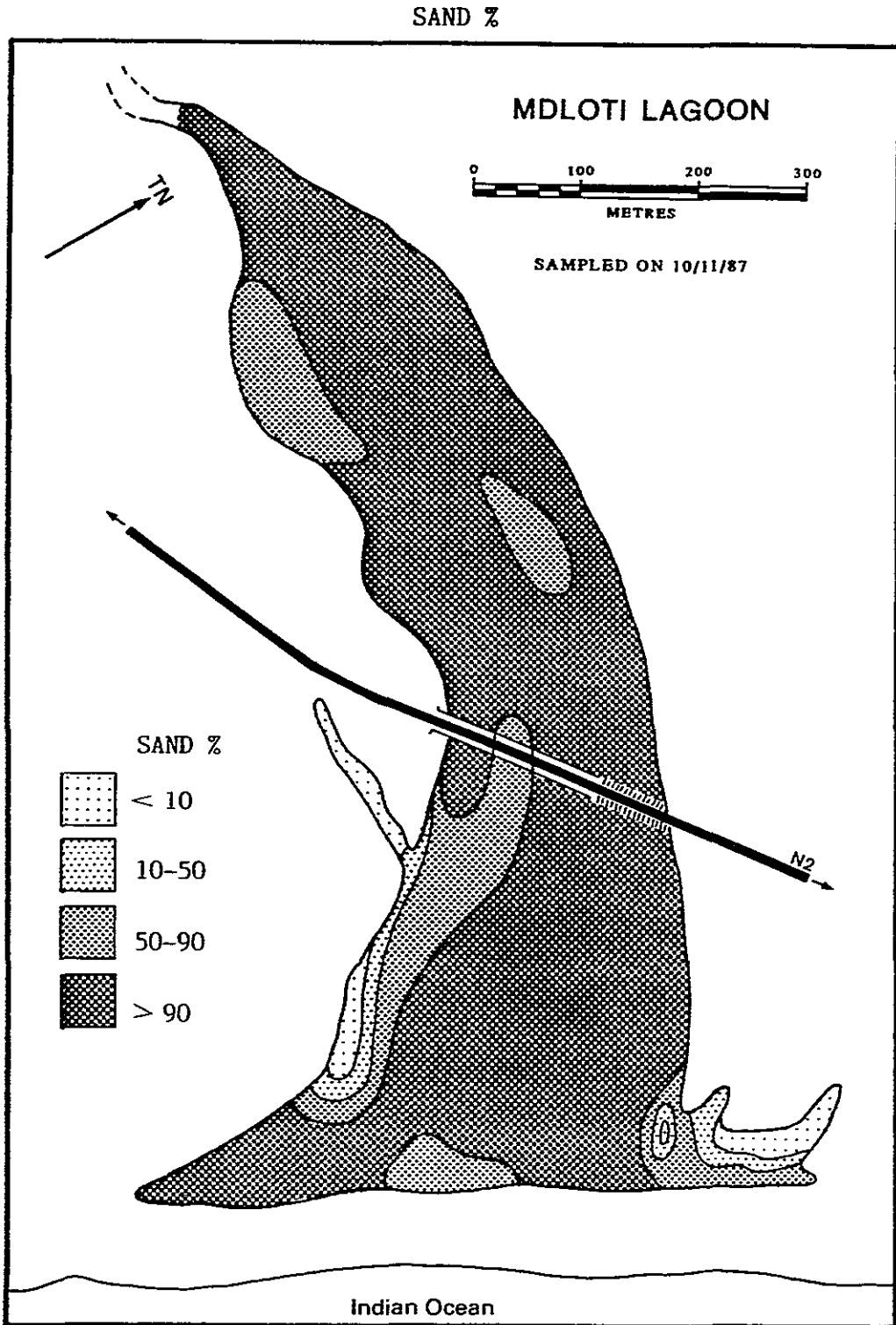
Gravel distribution for samples collected 0.5m below the sediment surface; Post-flood.

FIGURE 4



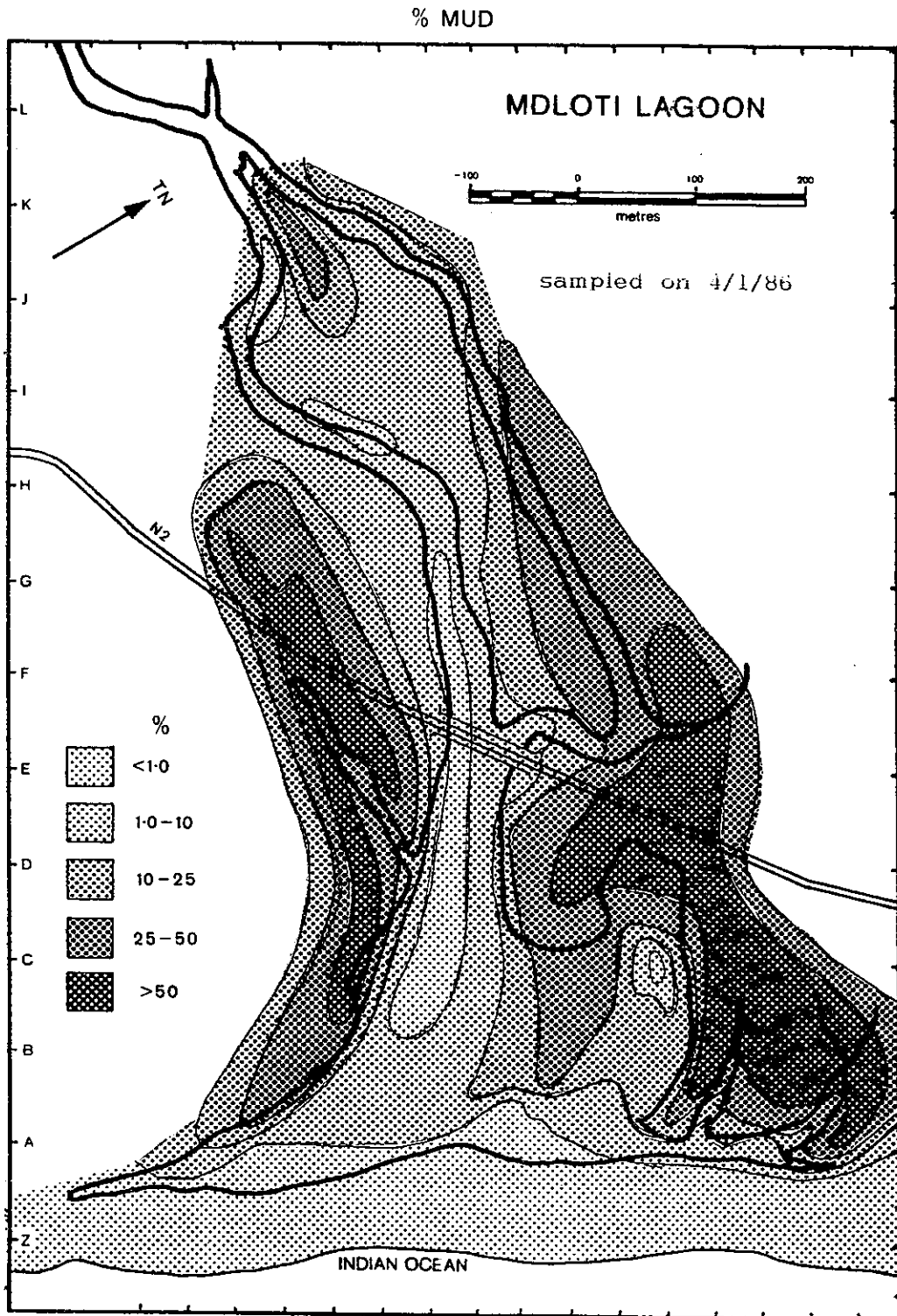
Sand distribution for samples collected at the sediment surface; Post-flood.

FIGURE 5



Sand distribution for samples collected 0.5m below the sediment surface; Post-flood.

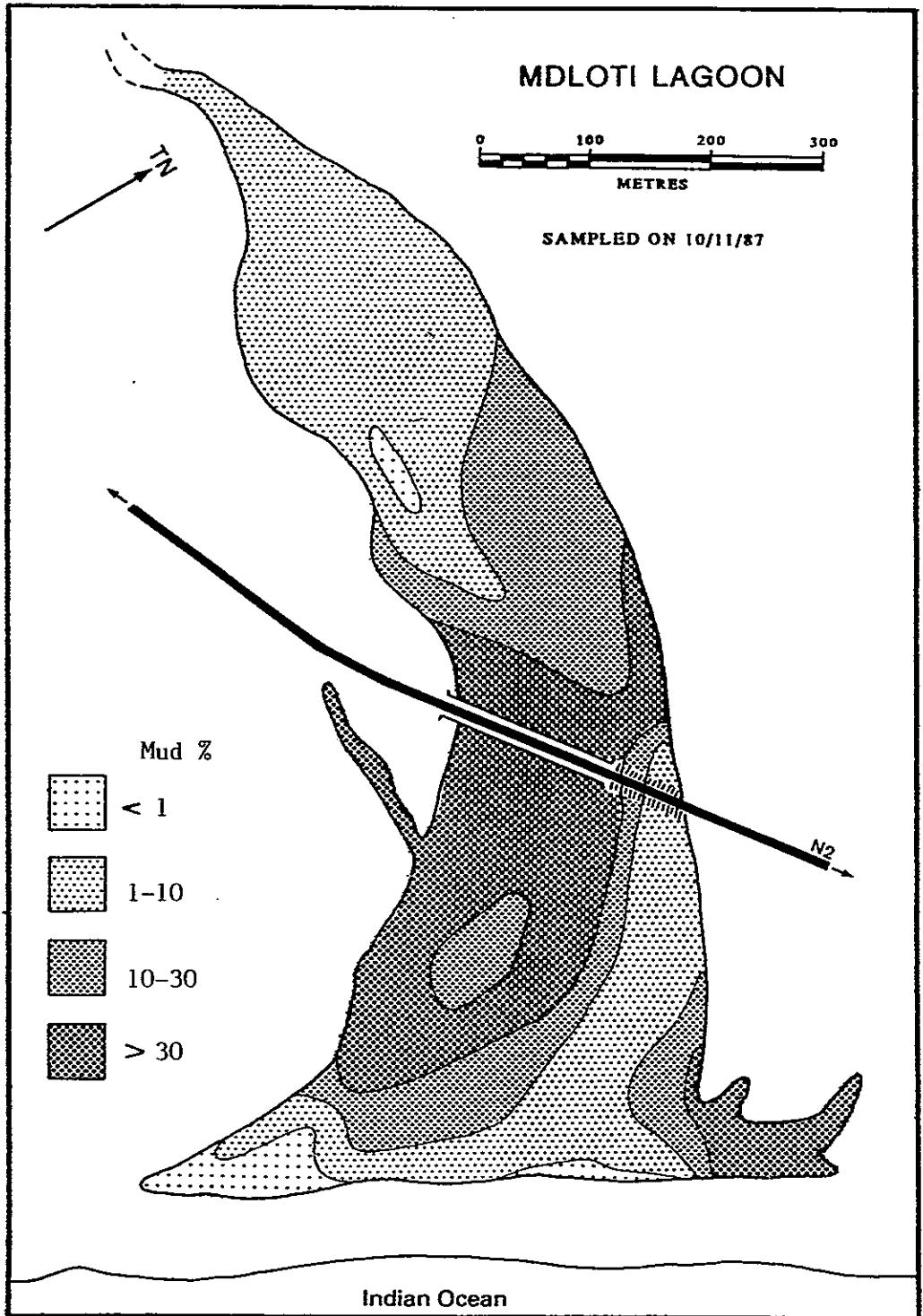
FIGURE 6



Mud distribution for samples collected at the sediment surface; Pre-flood.

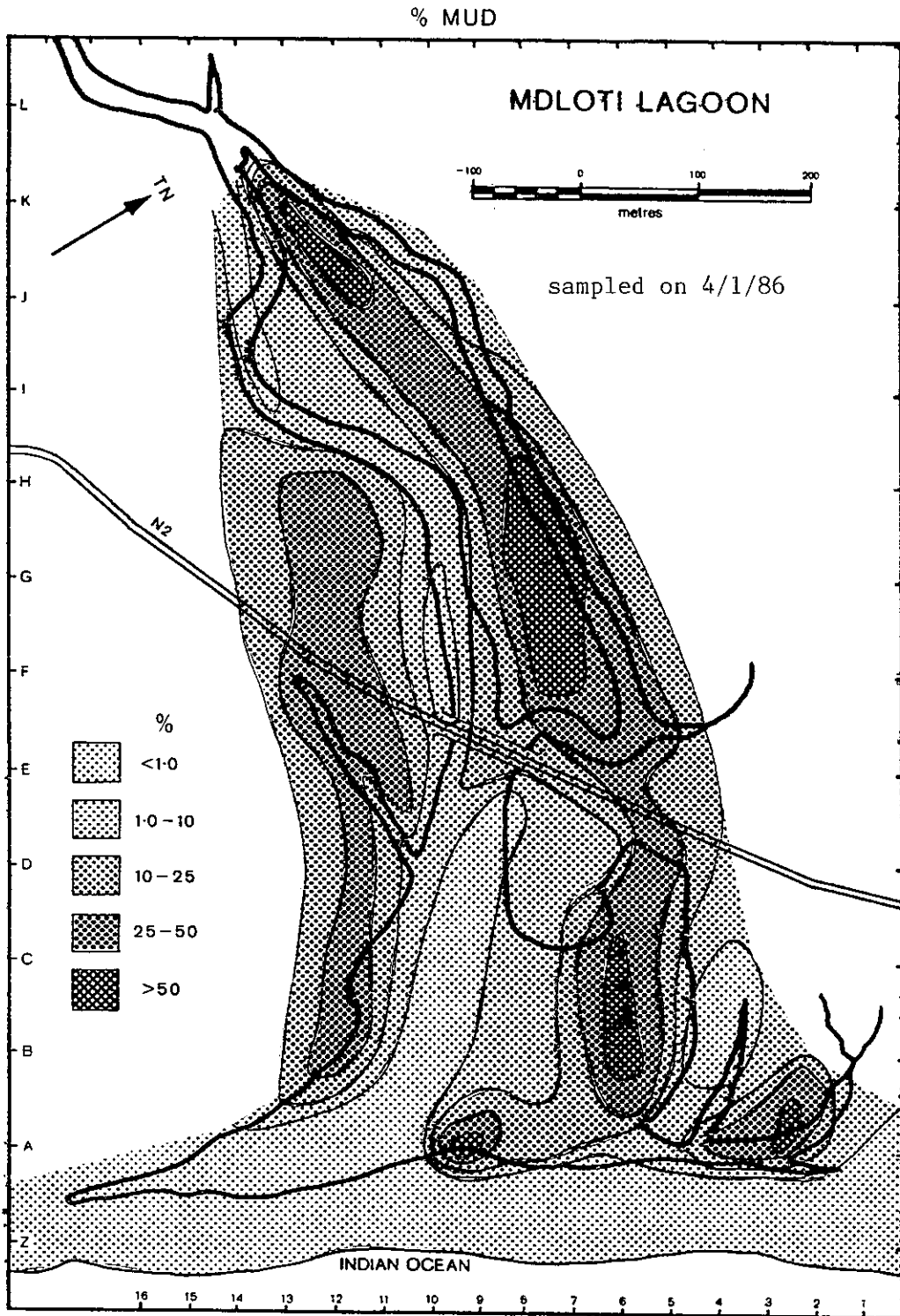
FIGURE 7

MUD



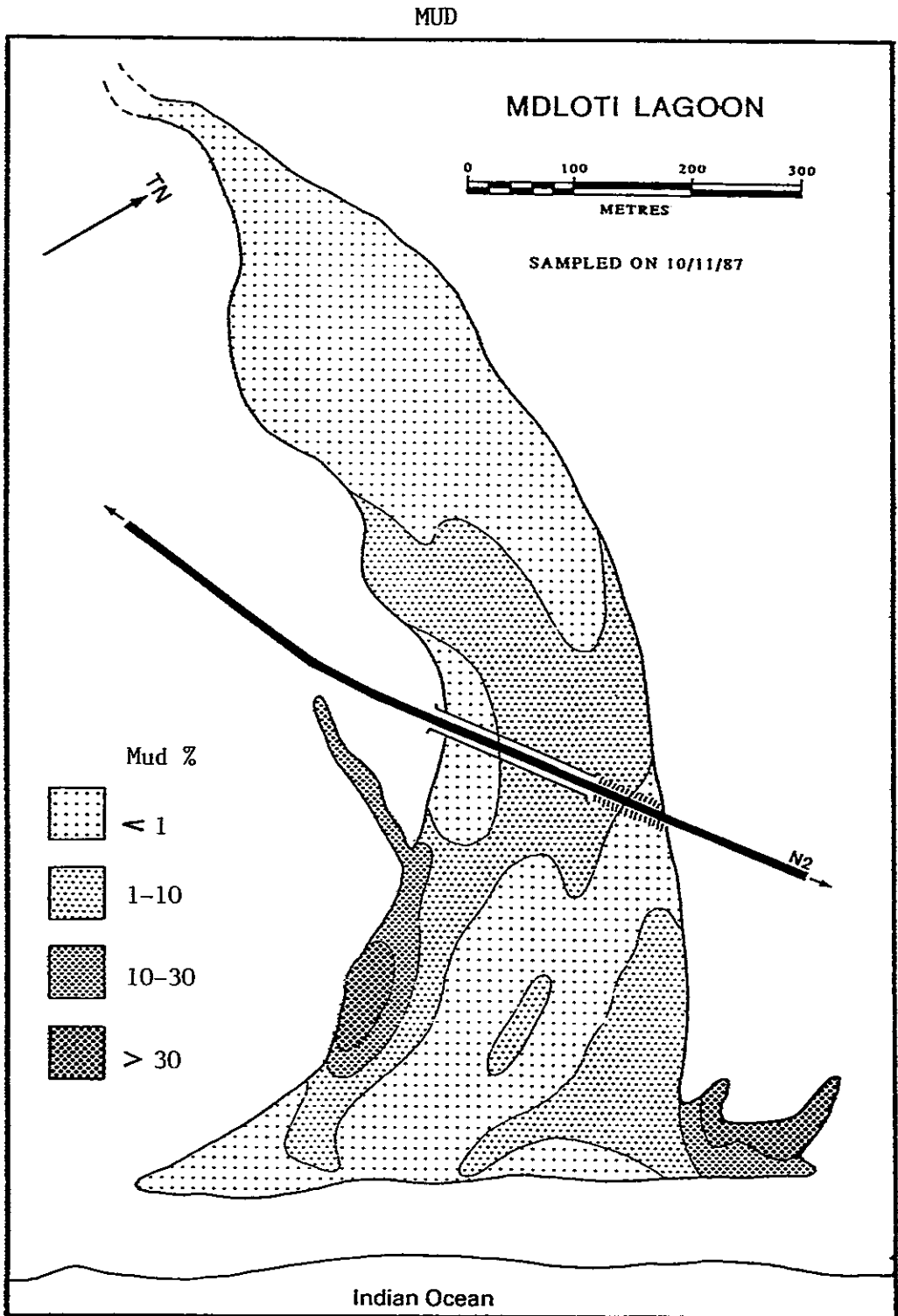
Mud distribution for samples collected at the sediment surface; Post-flood.

FIGURE 8



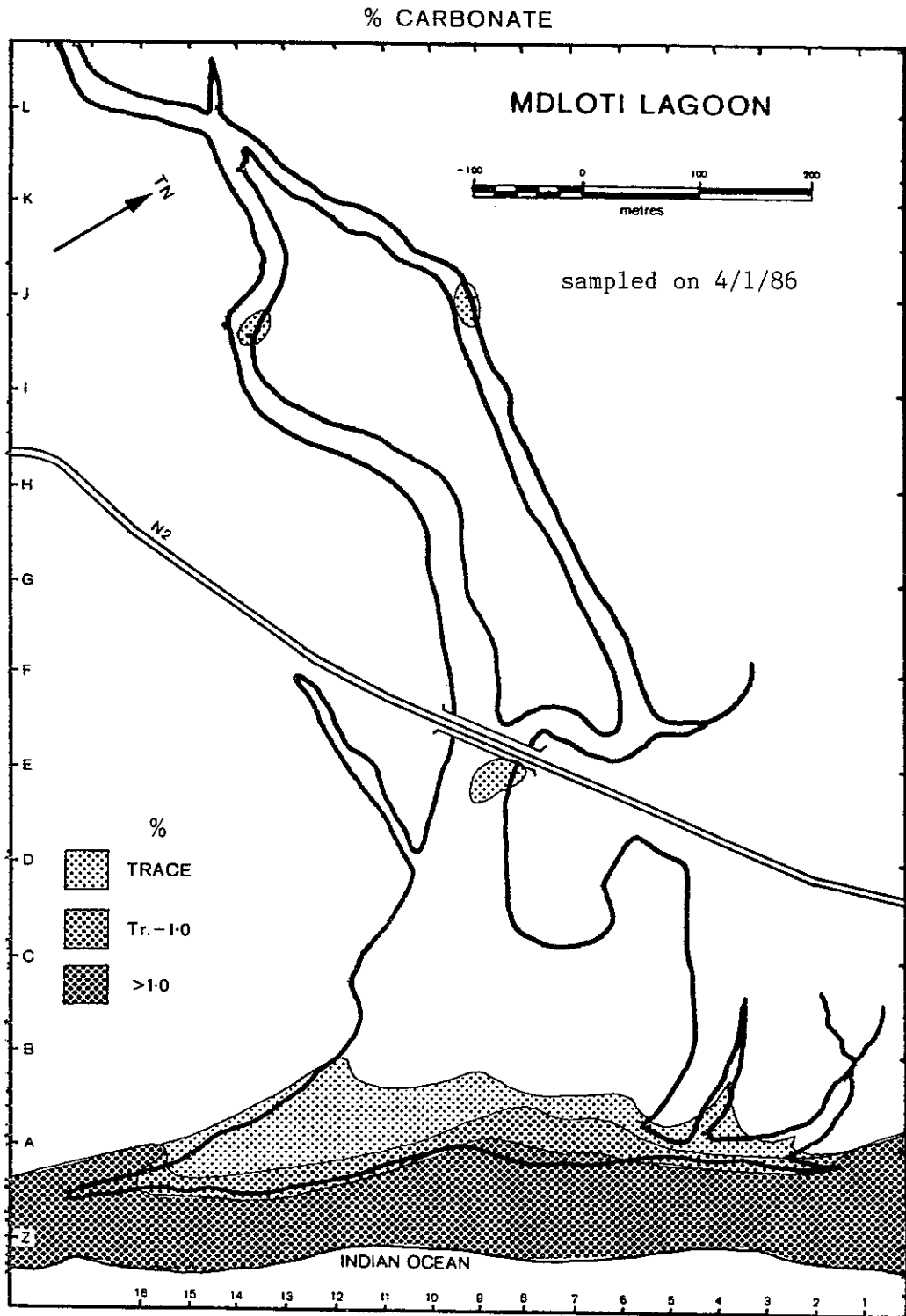
Mud distribution for samples collected 0.5m below the sediment surface; Pre-flood.

FIGURE 9



Mud distribution for samples collected 0.5m below the sediment surface; Post-flood.

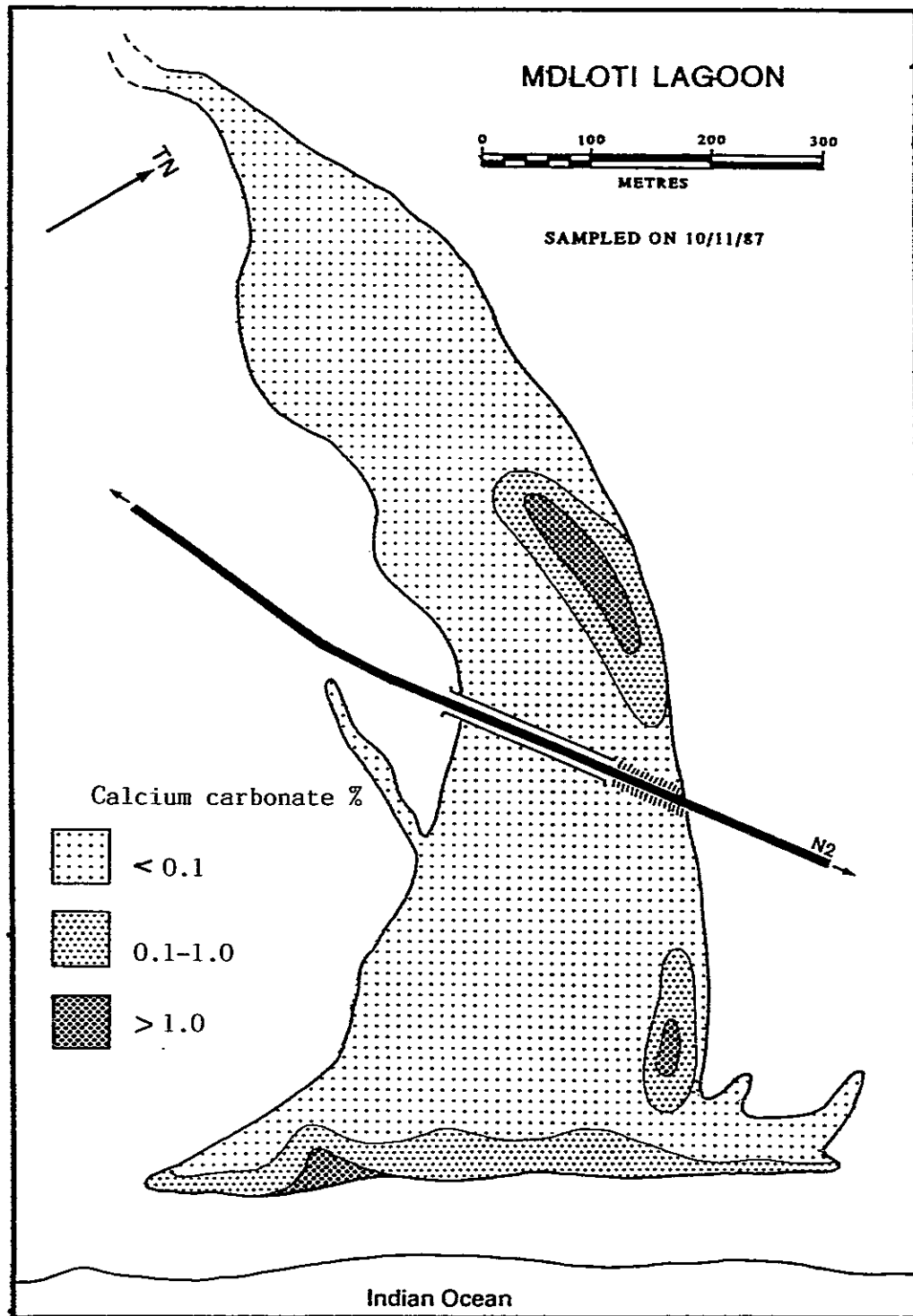
FIGURE 10



Calcium carbonate distribution for samples collected at the sediment surface; Pre-flood.

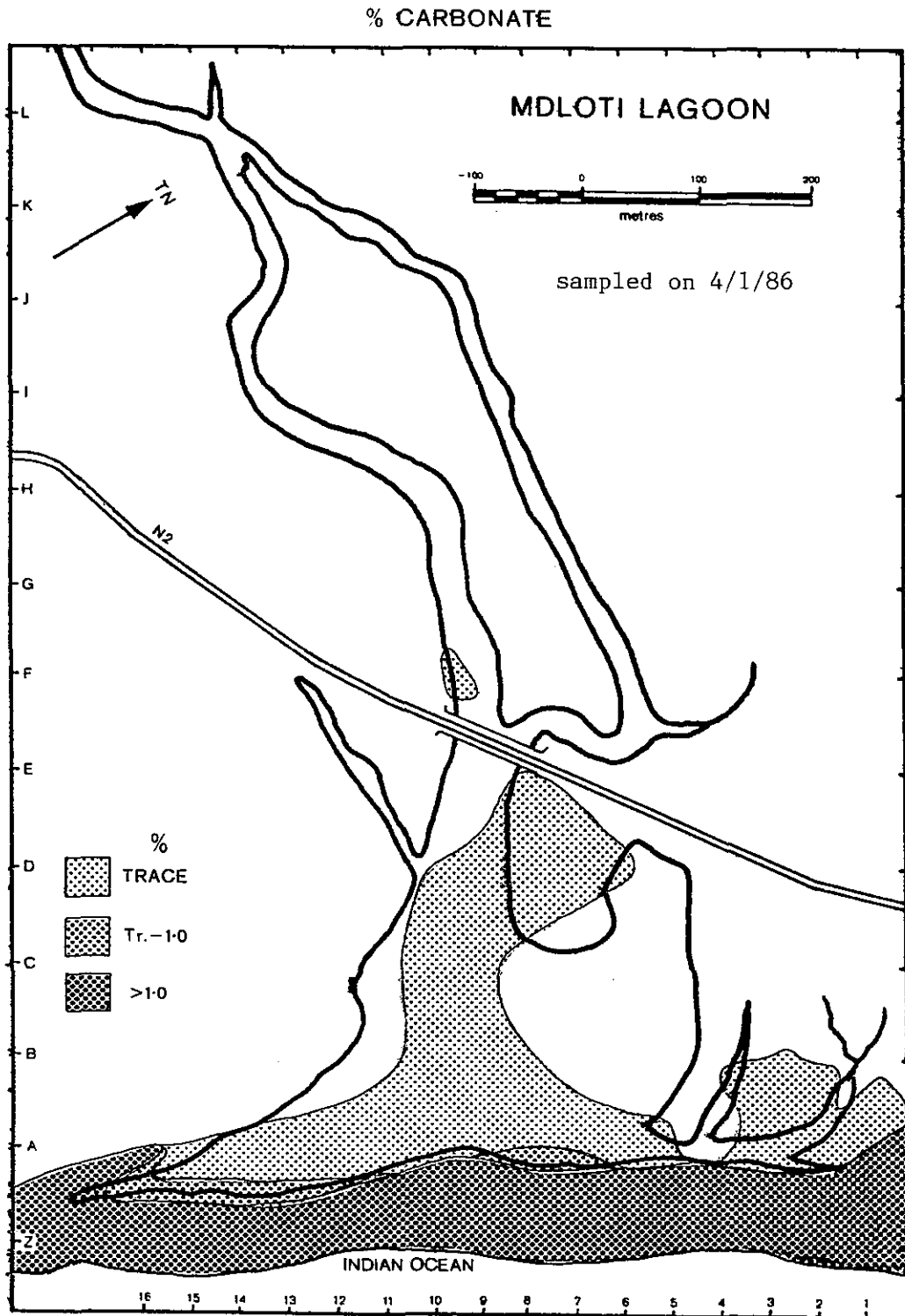
FIGURE 11

CALCIUM CARBONATE



Calcium carbonate samples collected at the sediment surface;
Post-flood.

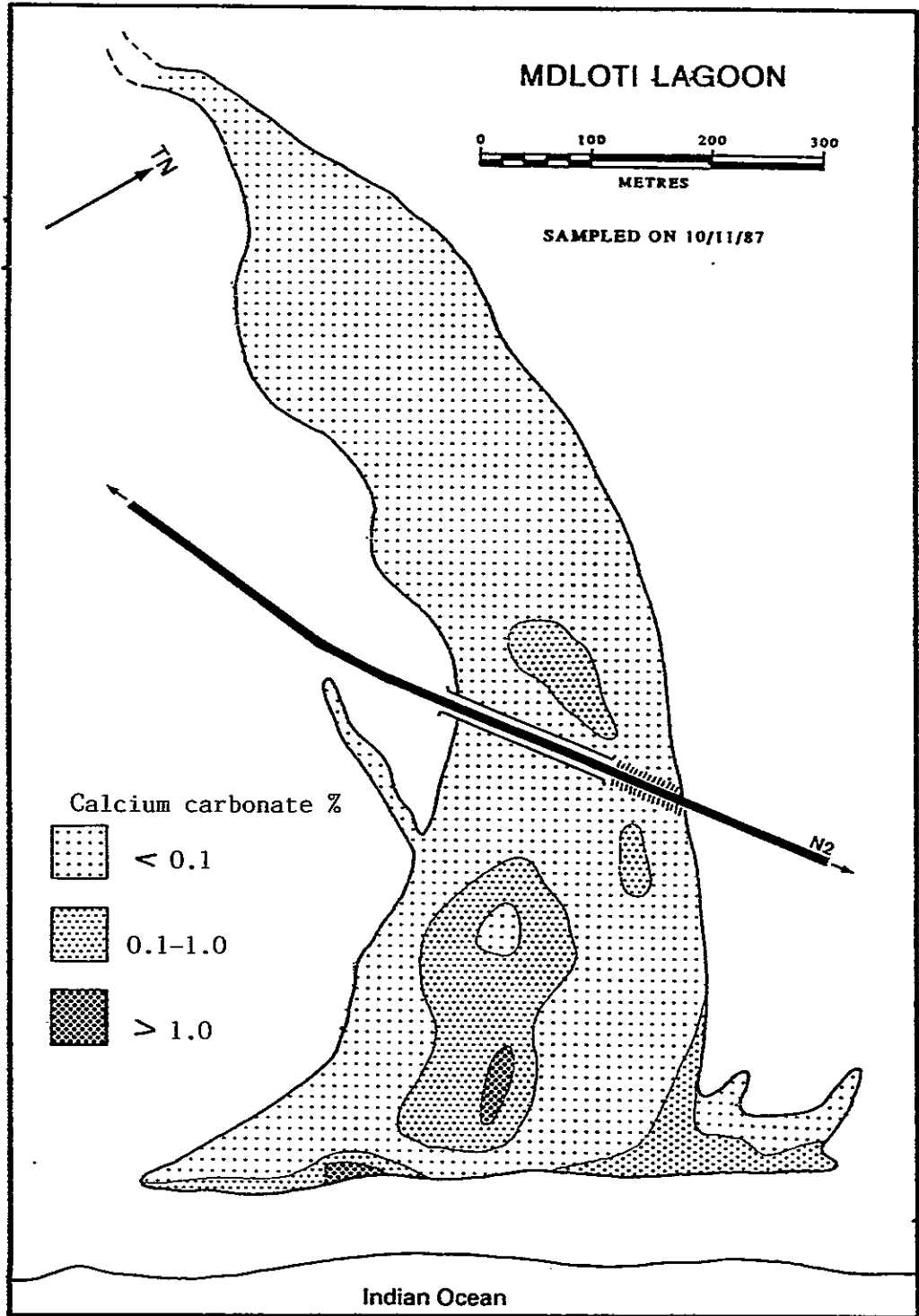
FIGURE 12



Calcium carbonate distribution for samples collected 0.5m below the sediment surface; Pre-flood.

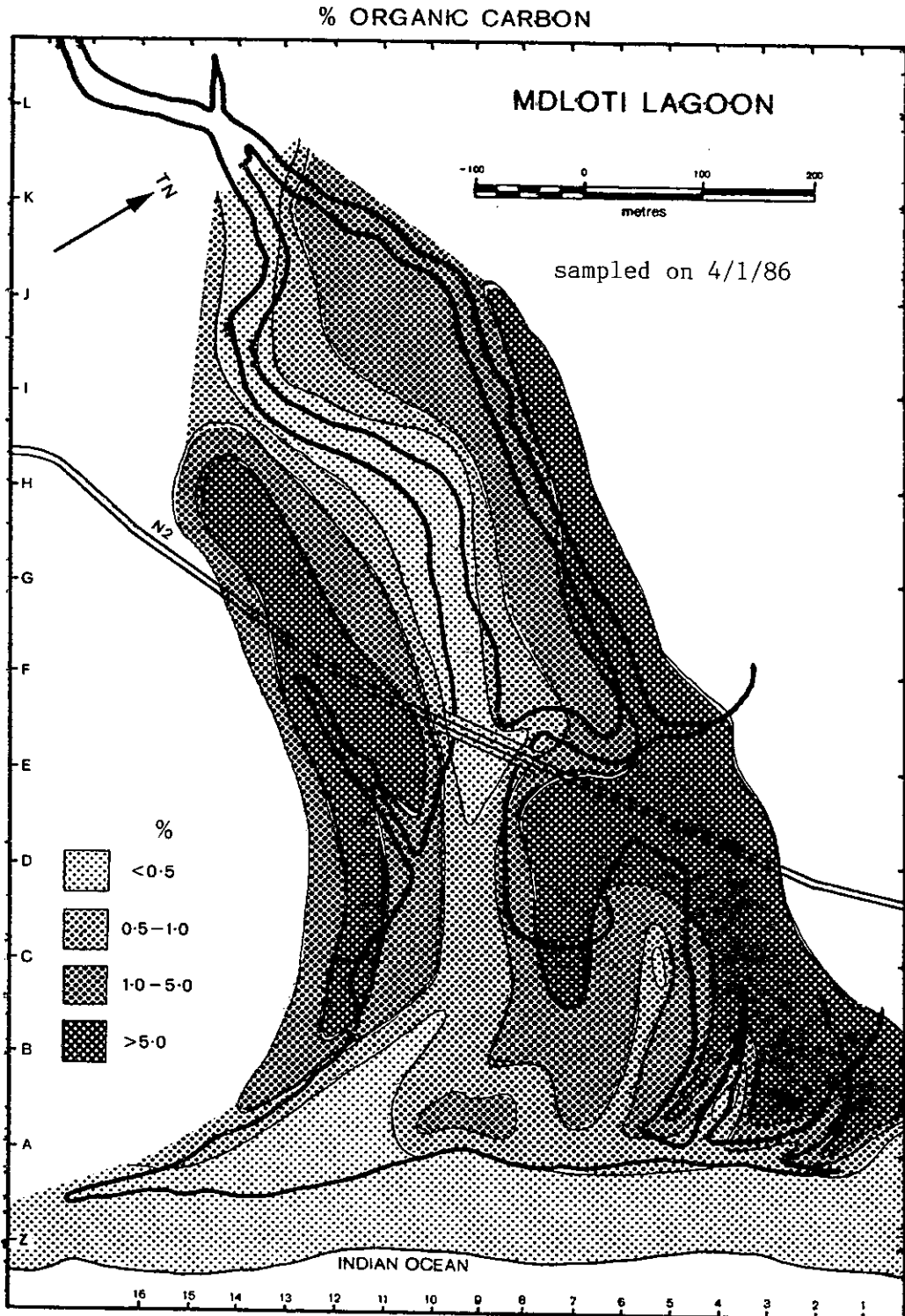
FIGURE 13

CALCIUM CARBONATE



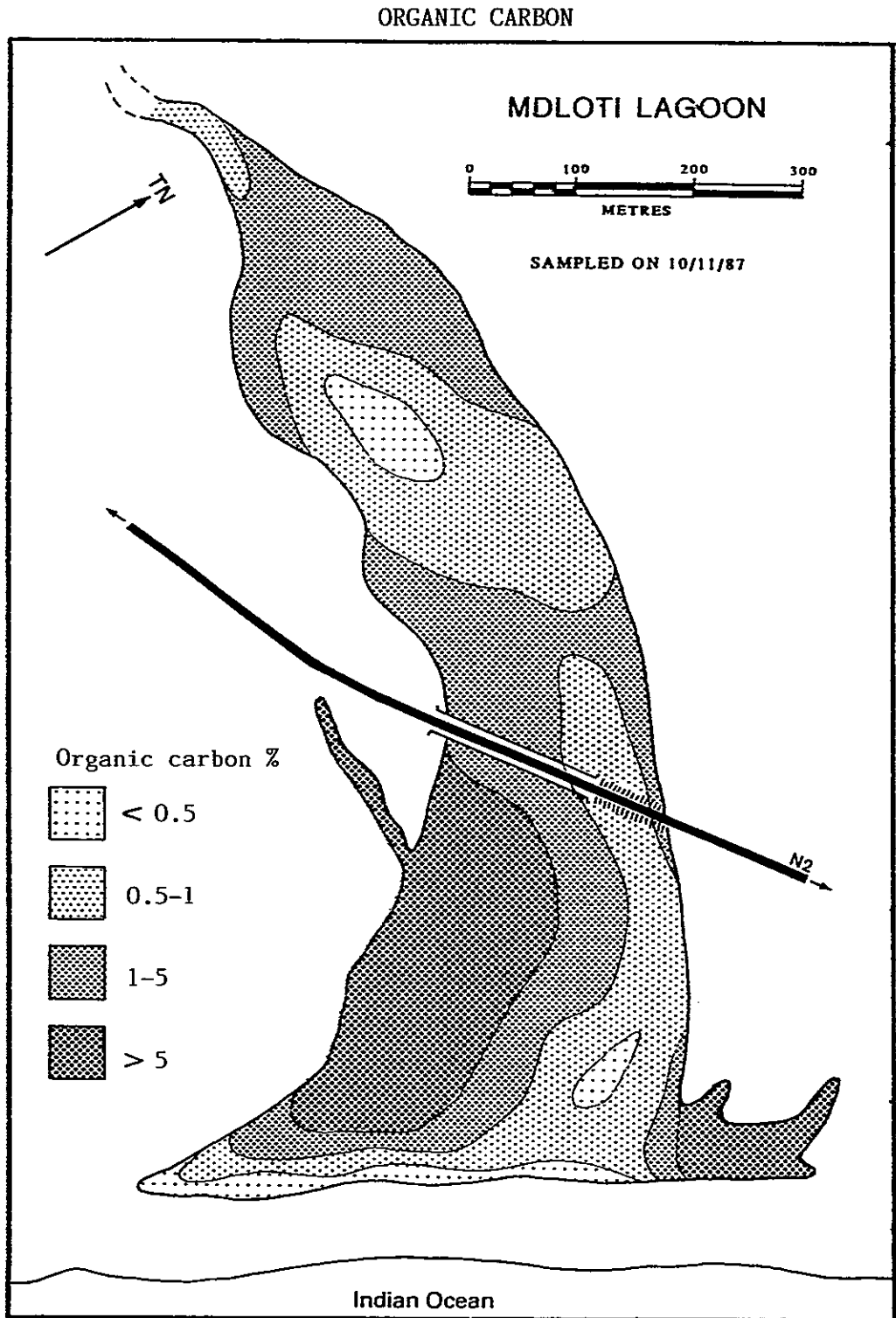
Calcium carbonate distribution for samples collected 0.5m below the sediment surface; Post-flood.

FIGURE 14



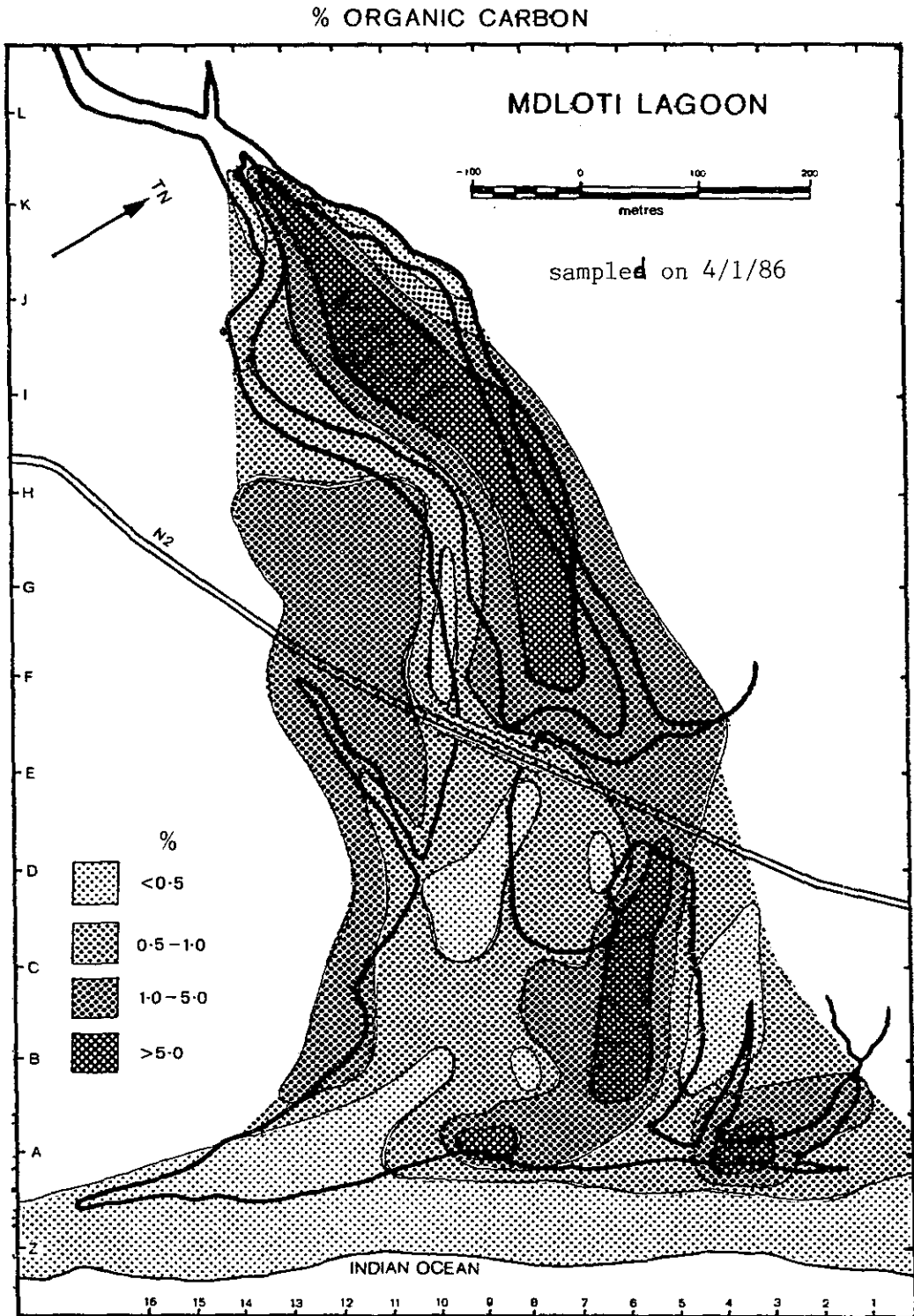
Organic carbon distribution for samples collected at the sediment/water interface; Pre-flood.

FIGURE 15



Organic carbon distribution for samples collected at the sediment surface; Post-flood

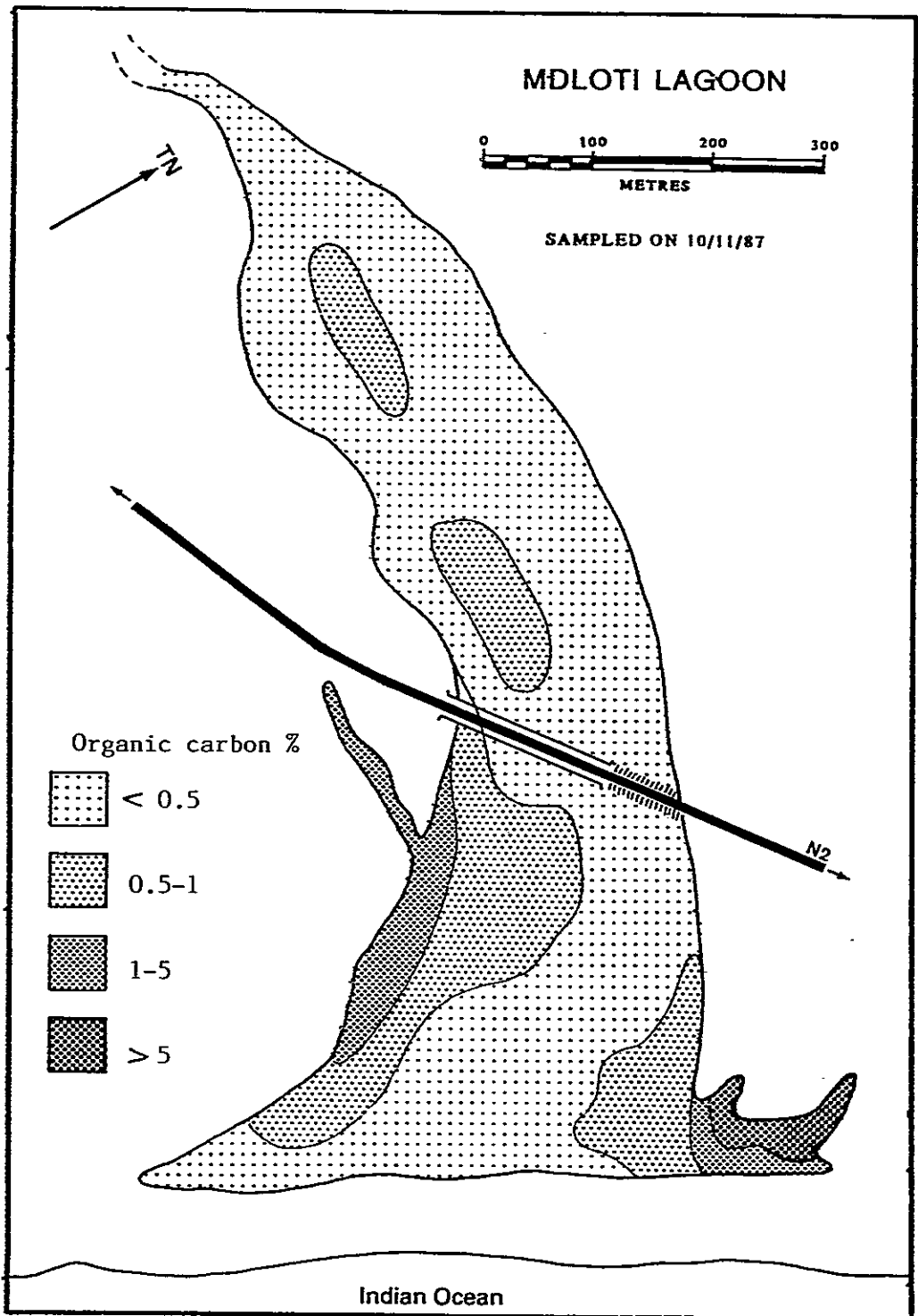
FIGURE 16



Organic carbon distribution for samples collected 0.5m below the sediment surface; Pre-flood.

FIGURE 17

ORGANIC CARBON



Organic carbon distribution for samples collected 0.5m below the sediment surface; Post-flood.

FIGURE 18

Line 1

Midloti estuary, looking upstream

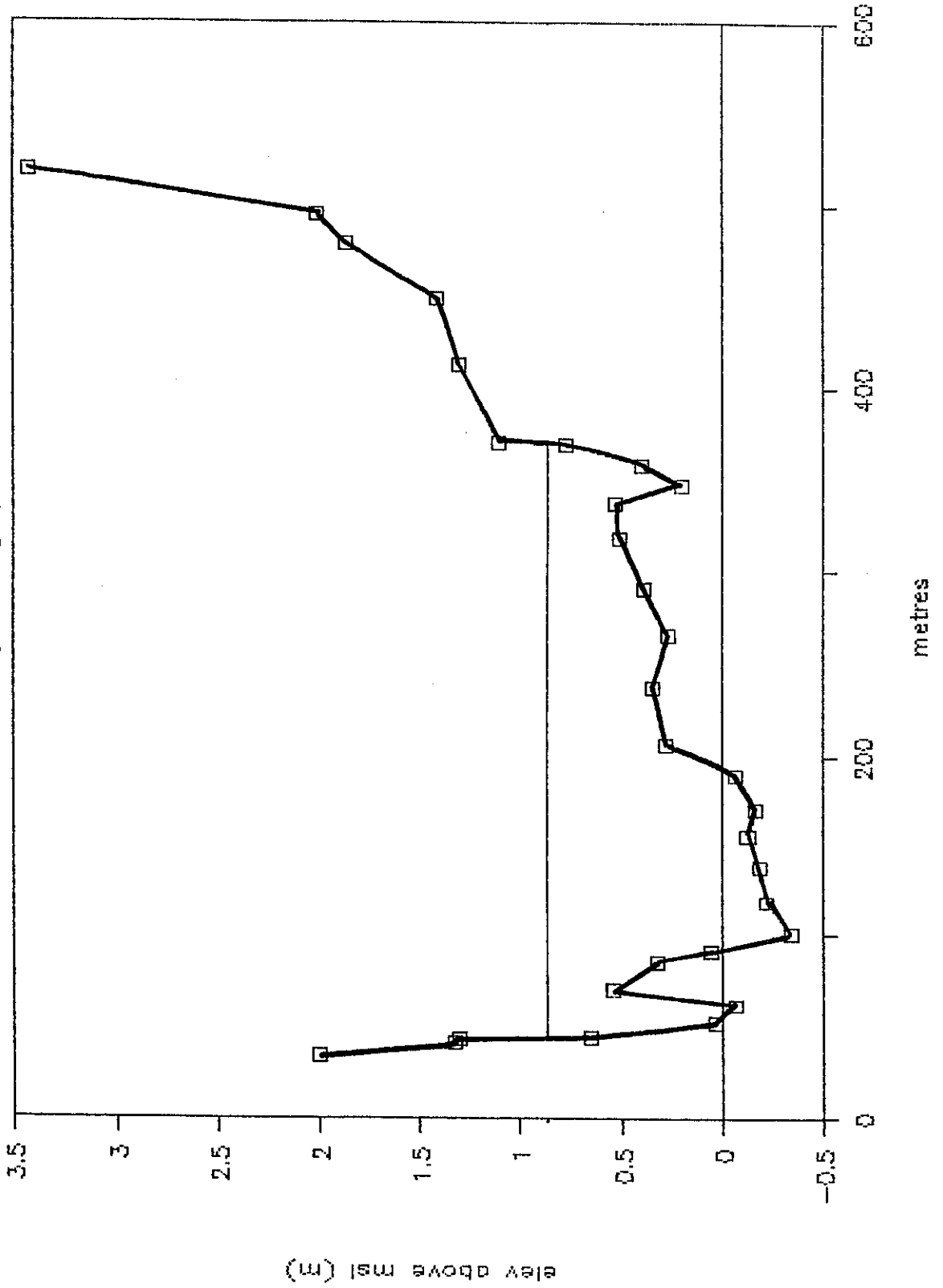


FIGURE 19

Line 2

Mdlobi estuary, looking upstream

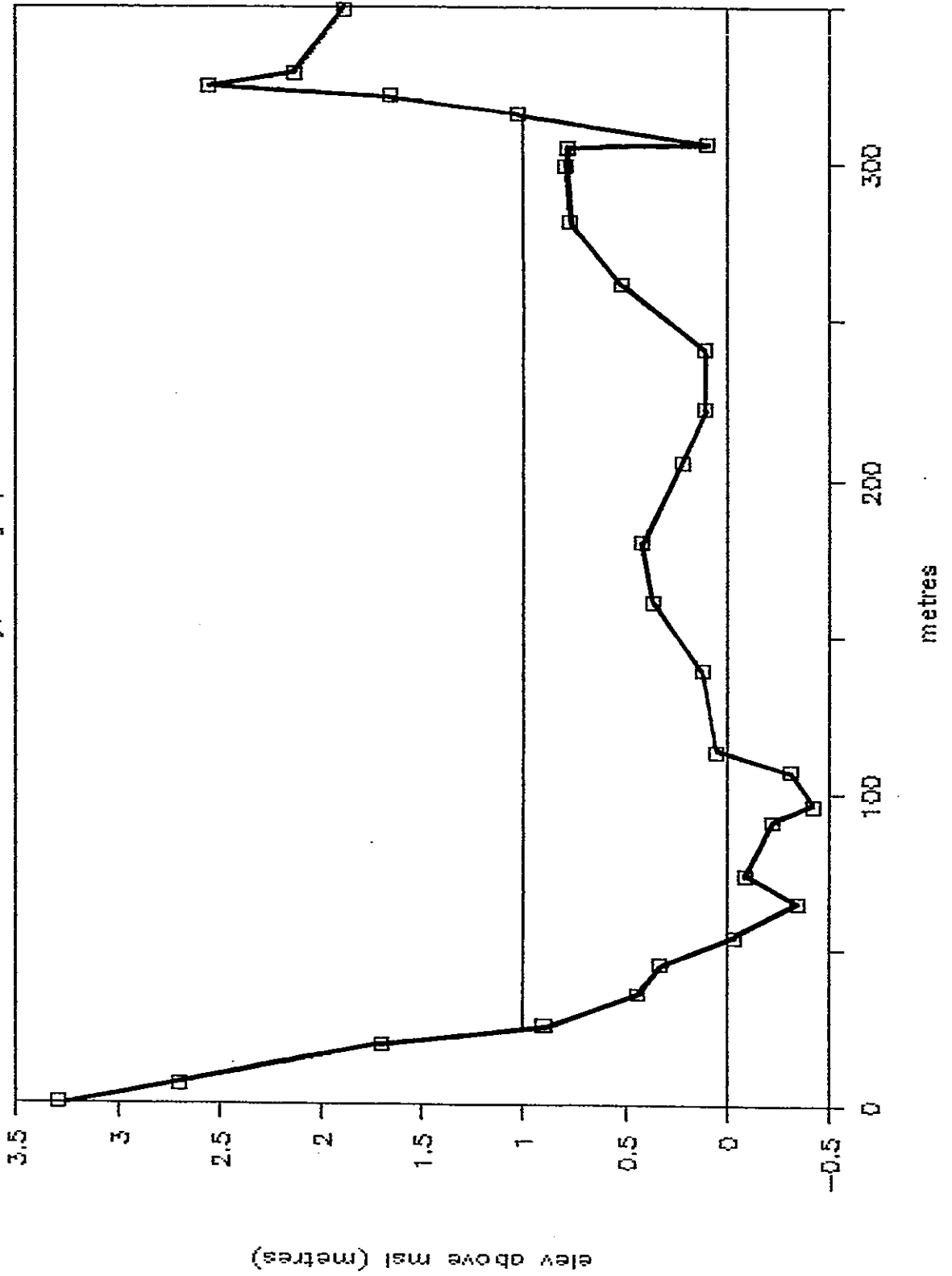


FIGURE 20

Line 3

Mdloti estuary, looking upstream

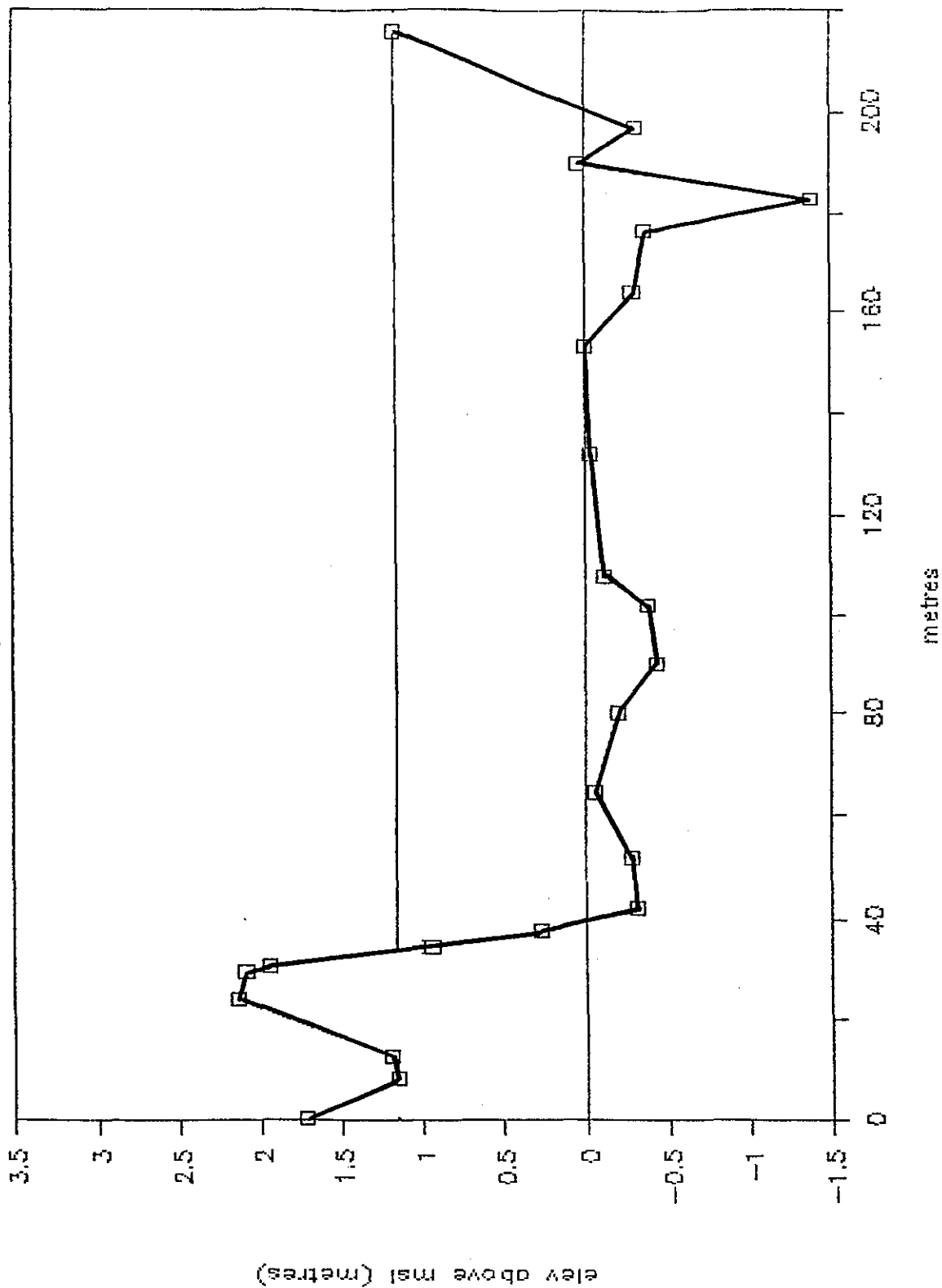


FIGURE 21

Line 4

Mdloti estuary, looking upstream

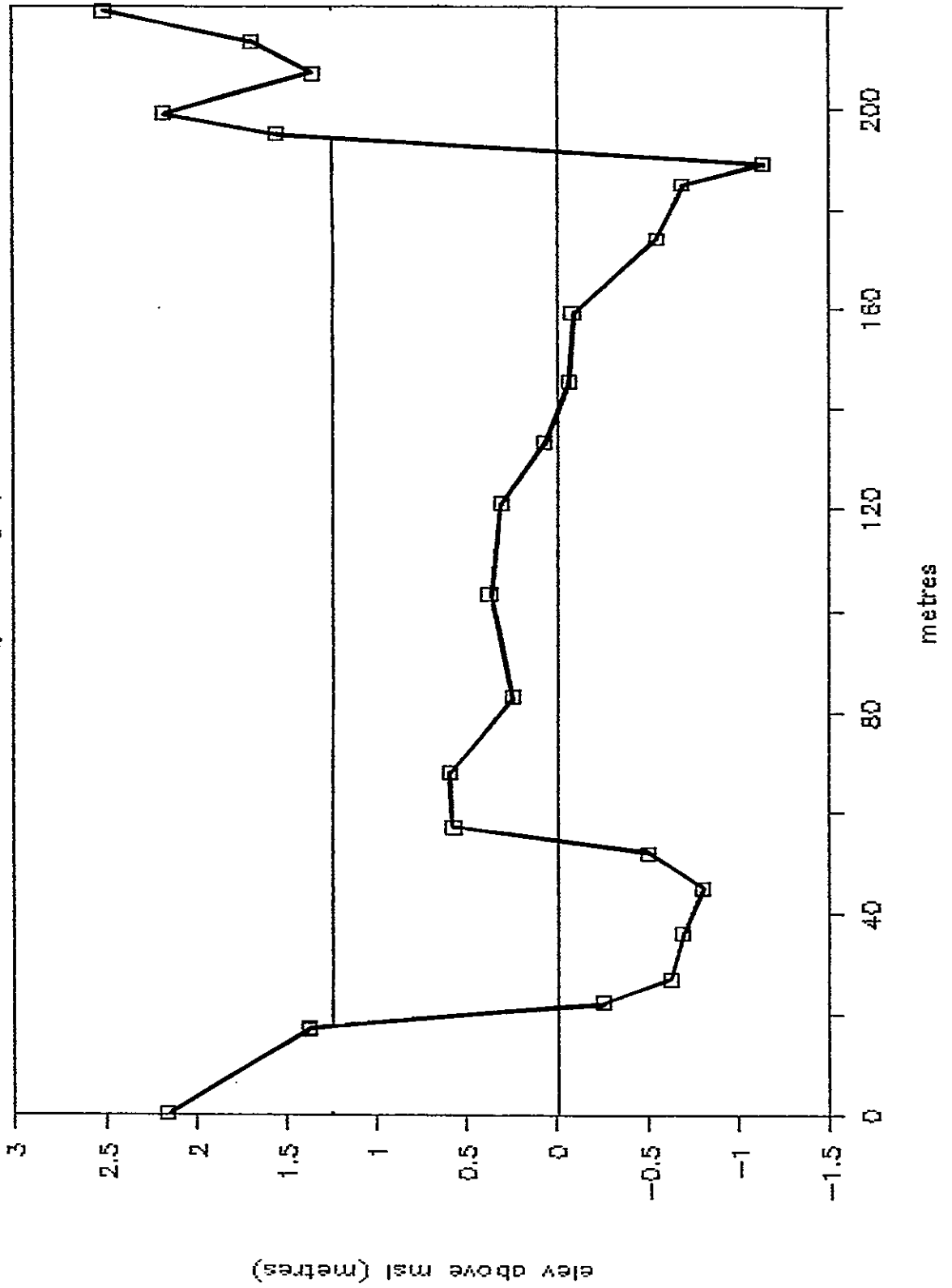


FIGURE 22

Line 5

Mdlobi estuary, looking upstream

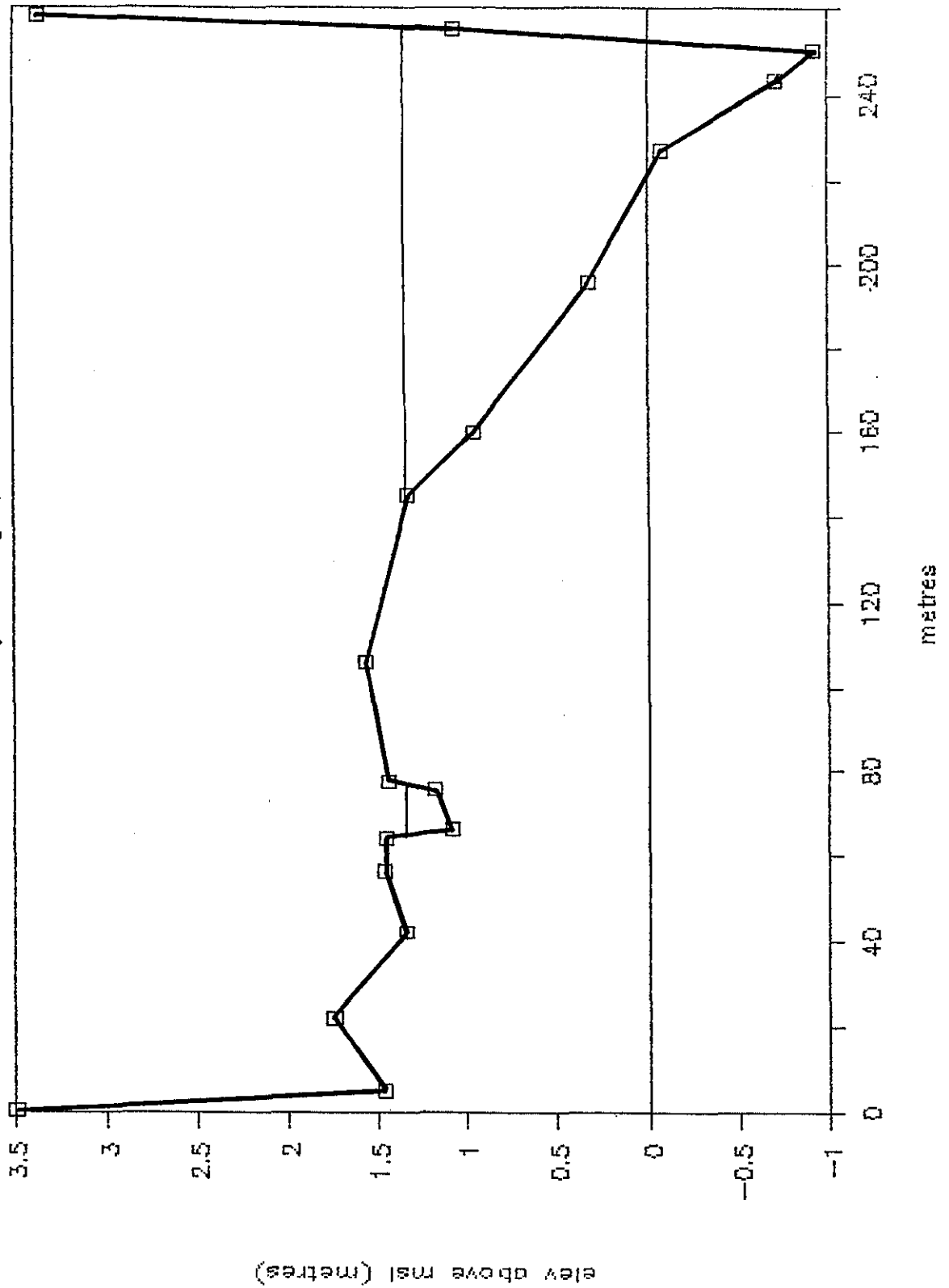


FIGURE 23

Line 6

Mdloti estuary, looking upstream

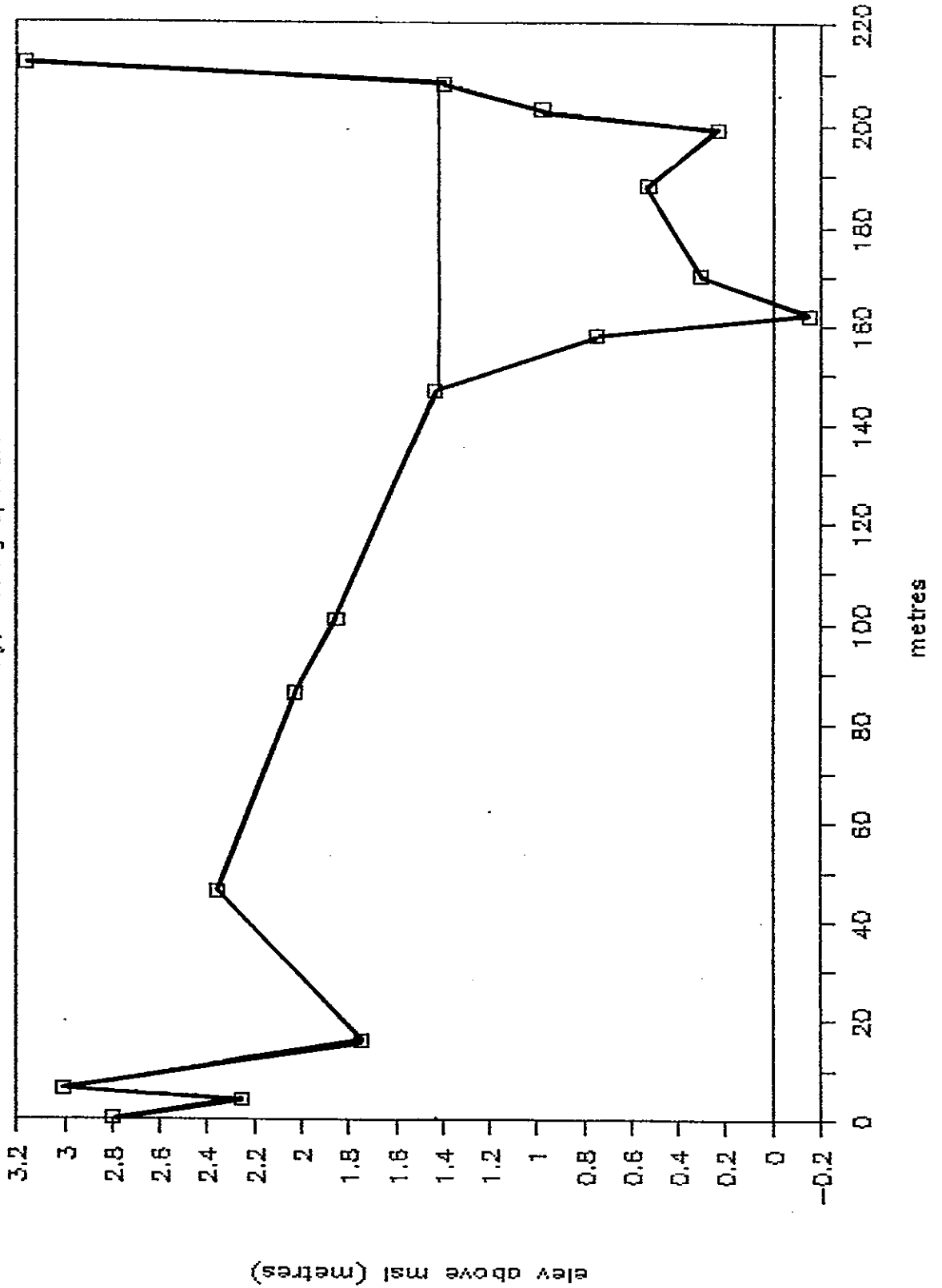


FIGURE 24

Line 7

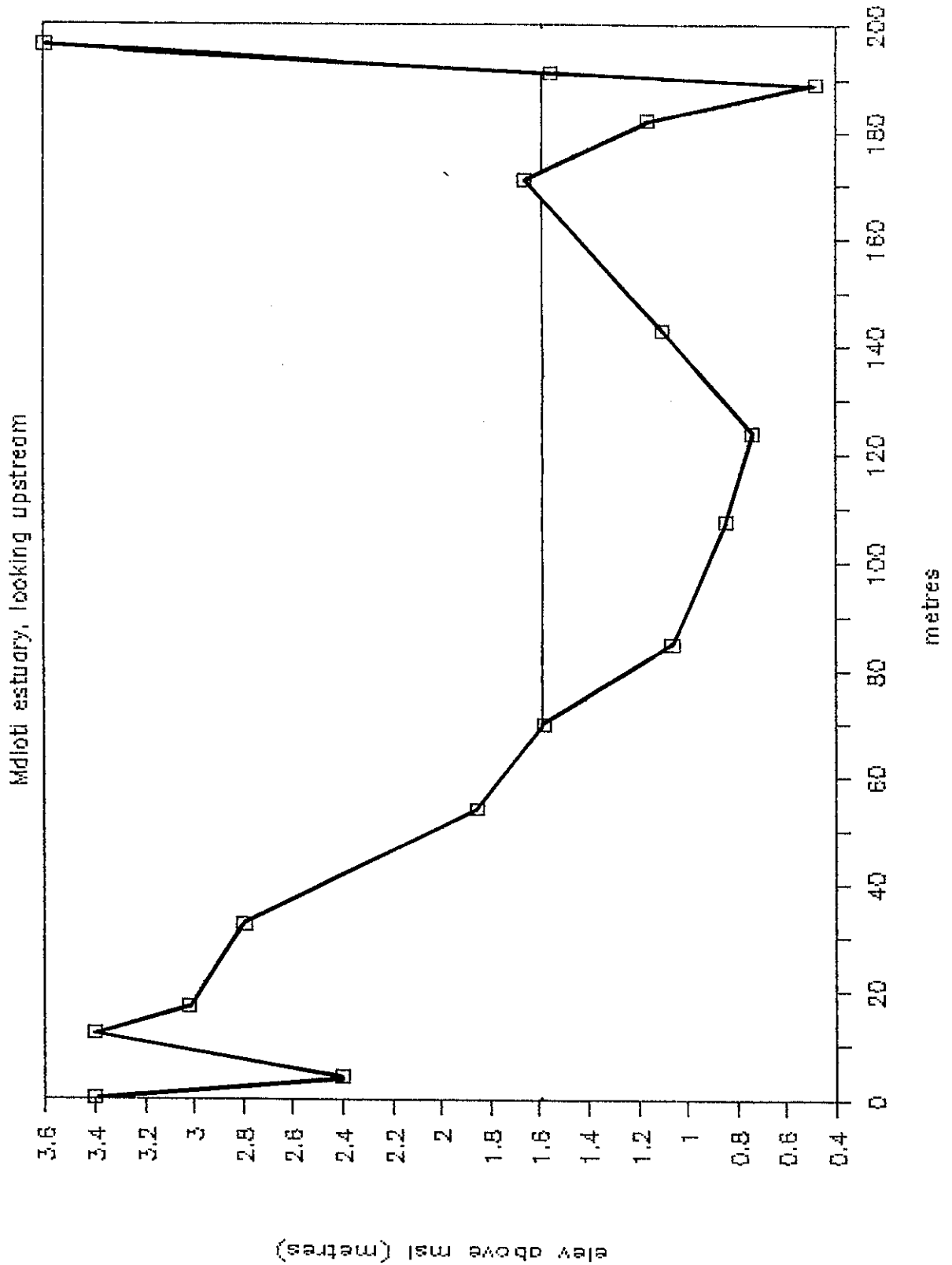
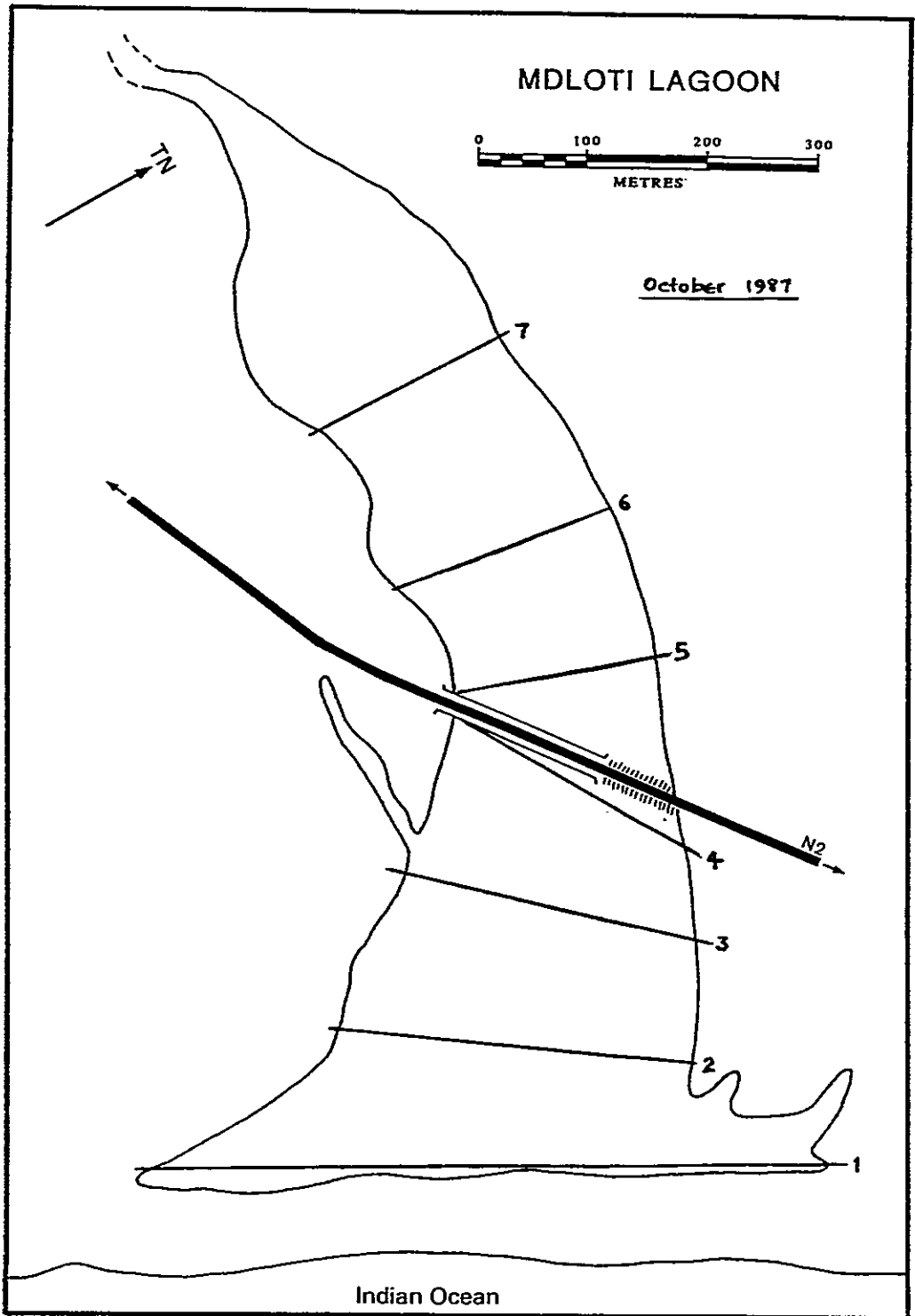


FIGURE 25



CROSS-SECTIONS : POSITION OF SECTION LINE

FIGURE 26

PART 3

SURVEY OF ESTUARIES AFTER NATAL FLOODS OF 28/29 SEPTEMBER 1987.
(MLALAZI, ZINKWASI, MVOTI, MZUMBE, MBIZANA AND MPENJATI)

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3 SURVEY OF ESTUARIES AFTER NATAL FLOODS OF 28/29 SEPTEMBER 1987. (MLALAZI ZINKWASI, MVOTI, MZUMBE, MBIZANA AND MPENJATI).

This report was compiled by L van der Merwe¹

1. Coastal Processes Management Advice Programme
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3.1 Scope

Selected rivers along the Natal coastline were surveyed after the devastating floods of 28 to 29 September 1987. Profiles were taken on predetermined positions and were compared with available data collated in the CSIR Baseline Data Bank in Stellenbosch.

This report contains the results of the surveys done on the Mlalazi, Zinkwasi, Mvoti, Mzumbe, Mbizana and the Mpenjati Rivers after the September floods. According to the surveys the Mlalazi and the Mvoti were the worst hit by the floods.

The survey of estuaries north of Durban was carried out from 4 to 15 October 1987 by four members of the Coastal Processes and Management Advice Programme (formerly Sediment Dynamics Division of the NRIO) including Leon van der Merwe, who compiled this report. During that period beach sections north and south of Durban were also surveyed but those are not dealt with in this report. The estuaries south of Durban were visited by other

members of the same Programme team. The results of the surveys of these rivers (Mzumbe, Mbizana and Mpenjati) are included in this report. Photographs of and observations made on selected estuaries north and south of Durban are being compiled in an album by Mrs. J E Perry of the same Programme.

D H SWART
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COASTAL PROCESSES AND MANAGMENT
ADVICE PROGRAMME

Stellenbosch, South Africa
April 1988

3.2 Inferences from the Synoptic Weather Map Supplied by the Weather Bureau During the Flood

26-09-87

The intense high south-east of the country was advecting very cold, moist air into the deep low over the interior, which was associated with an upper-air cut-off low. General rain was predicted over the eastern half of the country with heavy rains over Transvaal, Free State and Natal. (Figure 1)

27-09-87

The intense high was moving slowly eastward and the strong flow of cold, moist air continued into the deep interior low. Coupled with an upper-air cut-off low, general rain persisted over the eastern interior and over the south-eastern and eastern regions. Heavy falls occurred and snow fell on the Drakensberg. Cape St Lucia recorded 164 mm and Richards Bay 106 mm of rain on the 27th September 1987. (Figure 1)

28-09-87

The interior low and Indian Ocean high were both moving slowly eastward and extensive rain continued over the eastern half of the country with heavy rain in Natal and snow on the Drakensberg.

Places like Babanango, Cedara, Louis Botha, Gluckstad, Hluhluwe, Richards Bay and Underberg recorded rainfall figures of more than 100 mm for the previous 24 hours. (Figure 2)

29-09-87

The surface low and the upper-air cut-off low were moving eastward and further heavy falls were recorded over Natal and the Eastern Cape.

Rainfall figures for the previous 24 hours supplied by the weather bureau on 29-09-87 were: Babanango 144 mm, Cape St Lucia 128 mm, Darville near Pietermaritzburg 225 mm, Louis Botha Airport 132 mm, Empangeni 401 mm, Estcourt 82 mm, Matatiele 60 mm and Melmoth 210 mm. (Figure 2)

On 30-09-87 the rainfall subsided and Natal could begin to assess the devastation of the flooding during which a number of people were drowned, many people rendered homeless and widespread damage done to the infrastructure (bridges wholly or partially washed away, roads flooded and valuable farmlands eroded).

3.3 The Mlalazi River (NN15)

Survey and Observations after the September 1987 Floods

At the N2 road bridge (Figure 3 Profile 1) the approach of the new bridge was damaged on the Empangeni side. The approach of the disused old single-lane concrete bridge was totally washed away.

In Figure 4 (see Figure 3 for position of profiles) it can be seen that the highest flood level during the September 1987 flood event was 8,72 m above mean sea level (MSL) (all levels referred to in this report are relative to MSL) at the N2 bridge and that the bridge deck was partially under water during the peak of the flood. There was scour of about 4 m for approximately 20 m of channel width near the left bank after the February 1987 survey. In general, since the first survey in 1975, there has only been a reworking of sediments at this site.

The survey stations at Profile 2 and 3 were destroyed by the flood. The caravan/mobile-home park with its ablution blocks on the north bank, between profiles 2 and 3, were totally destroyed (see Figure 3).

At Profile 4 (Figure 5) the highest water level in September 1987 was 6,1m. There has been degradation of about 1 m since the previous survey of 24 March 1987. Near this position a dredger that was taking sediment from the river to be used for the new N2 freeway had capsized during the flood and traces of oil from its bunker tank were observed.

Profile 5 (Figure 6) shows that the September 1987 flood was 2,3 m higher than the flood event of 1969. The highest water level in September 1987 was 5,9 m at this position according to the debris line on the railway bridge. Only slight scouring occurred at the piers of the railway bridge. A few of the wrecked mobile-homes from the caravan park near Profile 3 were scattered in the area near the bridge.

At Profile 6 (Figure 7) the debris line measured 6,1 m in the trees. Because of the wide flow and damming effect as the river nears the ocean, the flow velocity would have been slower here and the resultant slight aggradation is seen in Figure 7 between the surveys of 24 February 1987 and 11 October 1987.

Relatively small changes in the depth of the river bed occurred at the last profile, Profile 7 (Figure 8). Except for the thatched sunshades along the picnic/area that were swept away there was no visible damage to the ablution block on the right bank near Profile 7. The debris line in the trees on the left bank was 4,9 m for the September 1987 flood.

The pre- and post-flood surveys clearly show that some erosion had taken place in the upper reaches of the estuary with limited deposition of sediment in the lower reaches. However, net aggradation/degradation at all the cross sections is of small

magnitude and may even prove to be negligible after the end of the dry season surveys. The scour and fill process would therefore indicate that this estuary is in dynamic equilibrium under present conditions of silt supply, river flow and sea level. The Mlalazi is one of the few estuaries, sensu stricto, along the Natal and Kwazulu coast with regard to tidal exchange.

3.4 The Zinkwasi River(NN10)

Survey and Observations after the September 1987 Floods

The positions of the profiles taken in the Zinkwasi River are shown in Figure 9. Profile 1 at the Zinkwasi N2 bridge lies upstream of any estuarine influence. This profile (Figure 10) shows degradation of about 1,5 m under the bridge.

Profile 2 (Figure 11) at the head of the "estuary" shows a peak flood level of 6,8 m. There was no change in bed level between the pre- and post-flood surveys, as the low-level causeway in this position inhibits scour.

Profile 4 (Figure 12) shows degradation of about 30 cm after the flood. Debris on the bridge indicated that the flood level was at least 5 m MSL.

Profile 6 (Figure 13) shows no real change after the flood which had a peak level of 2,1m. This profile indicates that the lowest reaches are in dynamic equilibrium.

The mouth of the river was scoured wide open and the adjacent banks were strewn with debris.

3.5 The Mvoti River(NN7)

Survey and Observations after the Floods of September 1987

The positions of the profiles taken in the Mvoti River can be

seen in Figure 14. From Profile AA (Figure 15), comparing the pre- and post-flood surveys, it is clear that this river had experienced a devastating flood. The concrete pump house of the SAPPI Paper Mill on the left bank (as it was during the pre-flood survey on Profile AA) disappeared during the flood event and no trace of it could be found afterwards. The level of the roof of this structure was 15,58 m. The debris line indicated a flood level of more than 12 m and Figure 15 gives an indication of the massive erosion that occurred. The bed level shows aggradation of 1 m but the channel width has increased from 30 m to 235 m.

A low-water bridge at Profile BB, which belonged to the Gledhow Sugar Estate and is shown on Figure 14 was washed away. No profile could be taken at this position because of the high flow velocity of the river on the day of the visit.

Figure 16 shows Profile CC measured at the downstream side of the N2 road bridge. A section of the road embankment (83 m long) had been washed away but the bridge was intact. The flood level was just above 12 m, about 2 m under the bridge deck level. The October 1987 profile shows some degradation and once again a marked increase (170 m) in channel width.

Figure 17 gives an idea of the enormity of the flood and scour at Profile DD, with vast areas of sugar cane washed out to sea. The debris line shows a flood level of more than 9 m and the river was more than 690 m wide at this position. The exact width could not be measured because of the sugar cane plantation on the left bank. The profile shows degradation and the new "normal" flow channel would appear to have a bankfull width of 245 m (c.f. 55 m previously).

Profile EE (Figure 18) tells the same story as Profile DD and the flood level was about 4,7 m. During the survey on the 6 October 1987 great difficulty was experienced in measuring the profile because of the high flow rate of the river. There was degradation of about 1 m and the "normal" flow channel width increased from 40 to 470 m.

Profile FF (Figure 19), not previously surveyed, was surveyed 400 m downstream of Profile EE (Figure 18) to get a profile as near to the mouth as possible.

All the profiles show that whereas the river was about 30 m wide before the flood the intensity of the flood widened the river to between 400 and 900 m, removing vast areas of sugar cane on the flood plain. It is also interesting to note that the previous river bed level at Profile AA (Figure 15) was raised by about 1 m. This is a "fluvial delta" effect at a position where river flow velocity was checked.

It will be very interesting to monitor probable further aggradation across the profiles further downstream as the southerly-extending spit becomes firmly established at the mouth.

3.6 The Mzumbe River(NS26)

Profiles taken after the September 1987 Flood

Figure 20 shows the positions of the profiles taken in the Mzumbe River.

When compared with previous cross-sections for Profiles AA (Figure 21), BB (Figure 22), CC (Figure 23), DD (Figure 24) and EE (Figure 25) ,all the surveys show very little change with only a little degradation at all profiles.

3.7 The Mbizana River(NS10)

Profiles taken after the September 1987 Flood

Figure 26 shows the positions of the profiles taken in the Mbizana River. Profile 3 (Figure 27) at the new Mbizana Road Bridge between Port Edward and Margate indicates degradation of less than 1 m under the bridge. Profile 3A (Figure 28) was also taken on 6 October 1987 for future reference.

At Profile 4 (Figures 29) aggradation of about 0,5 m has taken place since the pre-flood survey. Sandmining is taking place in this area and some of this accretion will be removed. The other profiles in Figure 26 could unfortunately not be surveyed because of the existing conditions and time constraints.

3.8 The Mpenjati River(NS7)

Profiles taken after the September 1987 Flood

Two profiles (Profiles 2 and 3) were surveyed on 6 October 1987 at the old and new Mpenjati bridges on the R61 road between Margate and Port Edward (Figure 30).

Profile 2 (Figure 31) shows the old R61 road bridge profile. Aggradation of about 0,5 m occurred between the surveys of 18 February 1987 and 6 October 1987 . At the new bridge Profile 3 (Figure 32), there was some deposition near the left bank while scouring of more than a metre occurred near the right bank.

3.9 Conclusions

A. Flood Severity and Flood Damage

Of the six rivers surveyed after the September 1987 floods (Mlalazi, Zinkwasi, Mvoti, Mzumbe, and Mpenjati), the Mvoti and Mlalazi were the worst hit, as far as visual damage in the lower reaches of the rivers was concerned. The long period of sustained heavy rainfall resulted in peak flow durations of up to 24 hours in the larger catchments of Natal and considering the six rivers in order of catchment size, we found the following:

- (i) The Mvoti is by far the largest of the rivers surveyed, with a catchment area of 2829 km², a length of 197 km and an overall gradient of 1:133 (Table I). This river is subject to fairly frequent severe flooding and the September 1987 flood level was the

highest on record. Vast areas of cane fields on the flood plain of the lowest reaches of the Mvoti were totally or partially destroyed as the whole valley was inundated and the river took its flood course straight out to sea, breaching the normal long southerly-extending spit at the mouth.

- (ii) The Mlalazi and the Mzumbe (catchment areas approximately one -fifth of the Mvoti - see Table I) experienced widespread inundation of their flood plains, but the resultant damage was different in each case. The artificially stabilized spit at the mouth of the Mzumbe was not breached during the September 1987 flood as it was in the major flood of May 1959 and there was no damage to the bridge structures at the mouth. The Mlalazi flood plain has more settlement than that of the Mzumbe and the effects of the major flood were therefore felt more acutely in terms of property and structural damage.
- (iii) The remaining three smaller rivers, the Mbizana, Mpenjati and Zinkwasi, experienced lesser floods. The severity being proportional to their catchment areas, the Mbizana was the worst hit of the three. Both the Mbizana and the Mpenjati are subject to fairly frequent severe floods.

B. Characteristics and Normal Functioning of the "Estuaries"

The six sets of surveys provide data which are invaluable with regard to flood levels and therefore indirectly to areas subject to inundation. These data prove that the flood plains in the lowest reaches of all six rivers are still "active" and that the whole of each valley area is subject to inundation.

These data also quantify the character of the "estuary" - especially with regard to salinity in that if the bed level is

higher than +1 m to MSL there is little chance of any tidal penetration. Thus the following comments may be made for the six rivers:

- (i) All five sets of profiles of the Mlalazi reveal bed levels lower than MSL. This, combined with the fact that the mouth stays open throughout the year, ensures an estuarine length of at least 10 km. The Mlalazi is one of the very few estuaries, sensu stricto, in Natal and Kwazulu.
- (ii) The Zinkwasi does have bed levels low enough for possible tidal influence but, owing to its smaller catchment area and lower run-off generally, the mouth is closed for about 84 per cent of the year. Therefore, although there is salinity, tidal influence is very restricted.
- (iii) Regarding the Mvoti, these survey data are of particular interest. The Mvoti is on the verge of becoming a "River Mouth" with bed levels of +1 m to MSL close to the mouth itself. The 1987 major flood with its resultant degradation in the lowest reaches of the river will permit a longer estuarine length for a while. The mouth of the Mvoti is open for most of the year but how long the estuarine characteristics will prevail once the long southerly-extending spit is re-established, is not known. Subsequent surveys will provide the answer.
- (iv) The Mzumbe, with bed levels of +1 m or higher to MSL maintained after major flood scour and fill, is open to the sea for 90 per cent of the year. With these bed levels now quantified, the Mzumbe may be regarded as a fluvio-dominated "River Mouth".
- (v) The Mpenjati and Mbizana are closed at the mouth for two thirds of the year and are regarded as Lagoon/Estuaries. The invaluable data on bed levels from the cross-sections surveyed indicate a very delicate balance with regard to any

possible tidal influence in these rivers. They may be trending towards fresh-water "Lagoons". Subsequent surveys will determine the trends.

3.10 Recommendations

1. As these survey data provide a valuable insight into the hydro-functioning of the lowest reaches of Natal rivers, the monitoring should be continued. Ideally, this should be done at the end of each wet and dry season (about the end of April and end of September) as well as after any major floods.
2. These data quantify several very meaningful hydro factors for planners, namely;
 - (a) levels (and therefore indirectly areas) of inundation during floods;
 - (b) whether one has a fresh water, saline and/or tidal "estuary" to conserve or develop;
 - (c) whether the characteristics of "b" are relatively stable or are showing trends in one or other direction;
 - (d) whether the river bed is aggrading, degrading or in apparent dynamic equilibrium;
 - (e) channel widths and lateral stability (items "a" and "e" being important for planning of structures such as bridges etc).

It is therefore strongly recommended that these surveys be extended to cover more rivers. Such surveys of the lowest reaches of the rivers under their jurisdiction could be carried out by local authorities.

3. As the shape of the hydrograph provides such a great deal of information concerning the nature of any flood and can be used to improve the quantitative assessments of discharges and run-off it is strongly recommended that water levels be recorded at hourly intervals during both the rising and falling stages of a major flood wherever practicable (e.g. at bridge sites).
4. It would definitely be an added advantage if surface flow velocities could be monitored during floods although one appreciates the difficulties and hazards encountered at such times.

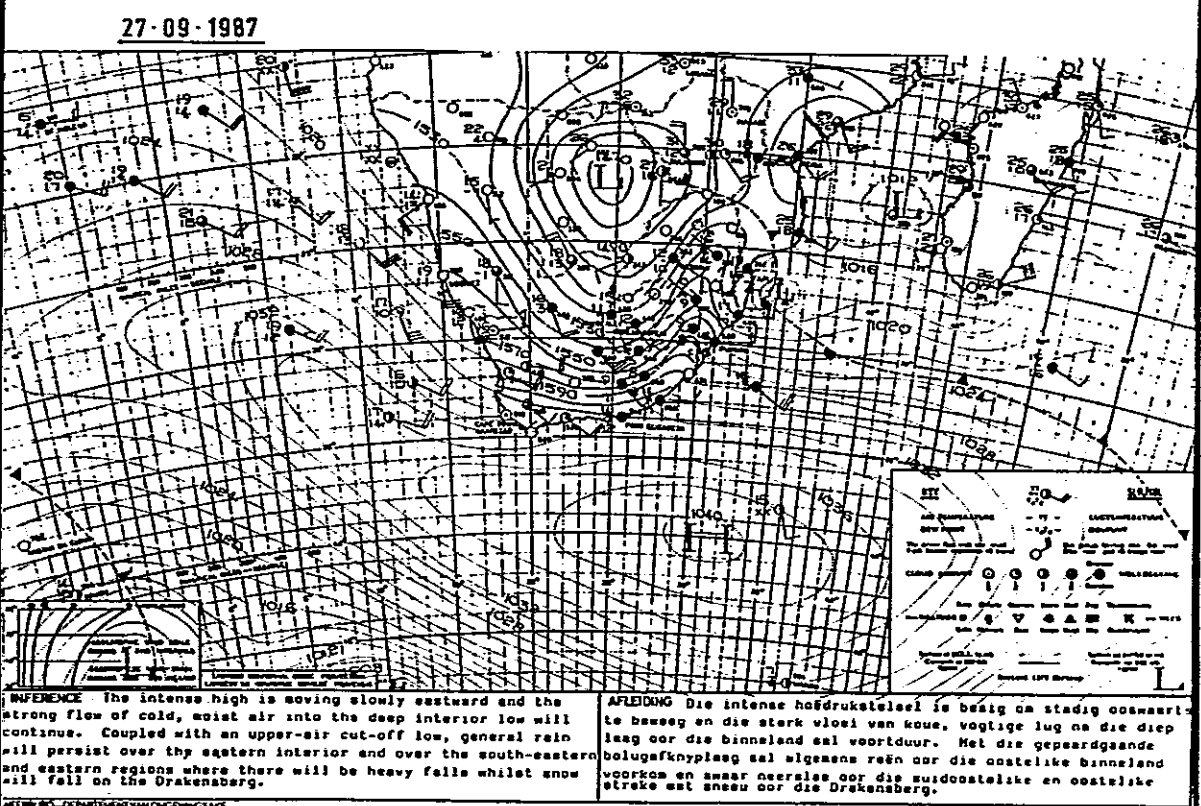
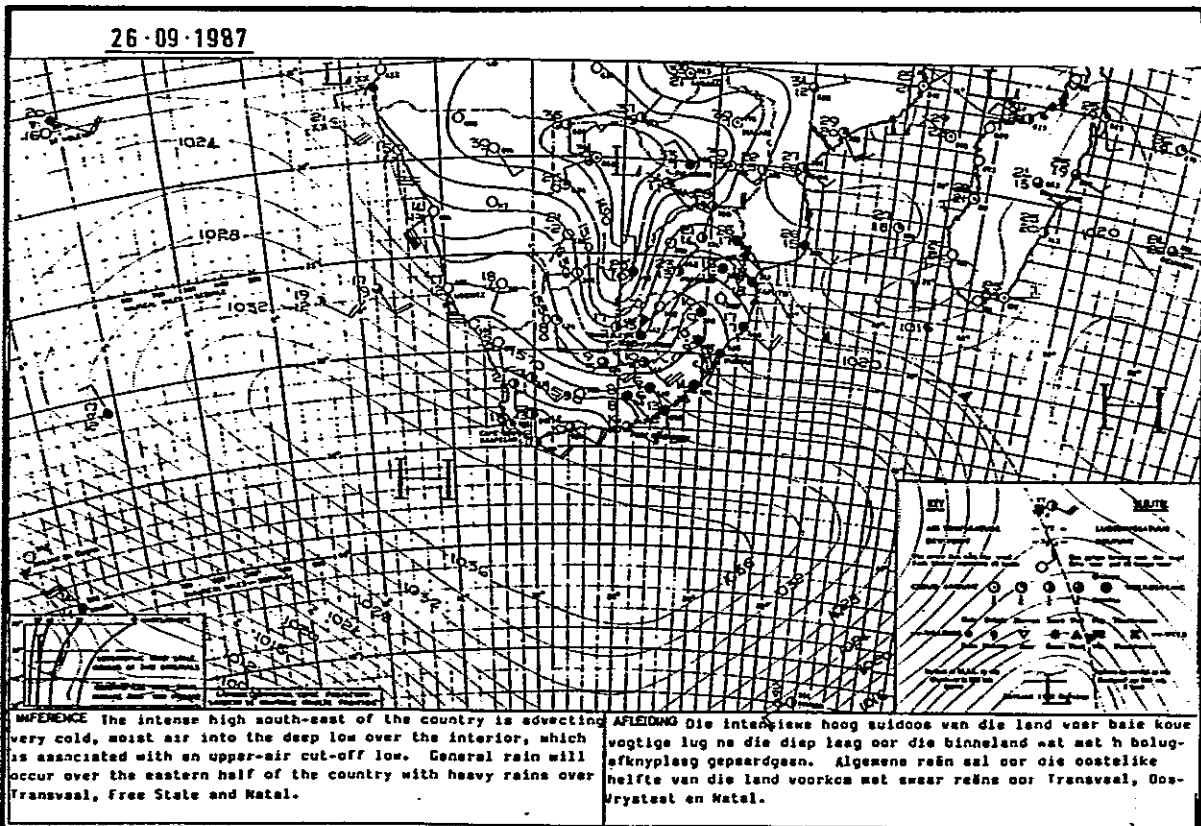
3.11 References

1. WEATHER BUREAU, Daily weather bulletin September 1987, Department of Environmental Affairs.
2. VAN NIEKERK, S.J. Post flood Surveys on the Mzumbe River done by Strydom, Newmark and Anthony. Umtentweni.
3. PERRY, J.E. Basic Physical Geography/Hydro Data for Natal "Estuaries", NRIO DATA REPORT D8607.

TABLE 1

REF	RIVER	Locality		Catchment Area (km ²)	River Length (km)	Elevation of source (m above MSL)	River Gradient (1:)	(Simulated Annual Run-off Median Annual Run-off (m ³ x 10 ⁶))	Average Catchment Sediment Yield (Tons/Year)
		Latitude	Longitude						
NN15	MLALAZI	28°55'45"	31°48'40"	492	54	549	98	85,37	49 200
NN10	ZINKWASI	29°16'59"	31°26'40"	73	22	229	96	11,09	29 200
NN7	MVOTI	29°23'30"	31°20'10"	2829	197	1479	133	335,90	813 850
NN26	MZUMBE	20°36'45"	30°32'55"	536	84	933	90	56,60	214 400
NS10	MBIZANA	30°54'40"	30°20'00"	145	26	480	54	26,08	72 500
NS7	MPENJATI	30°58'30"	30°16'55"	100	18	480	38	22,51	60 000

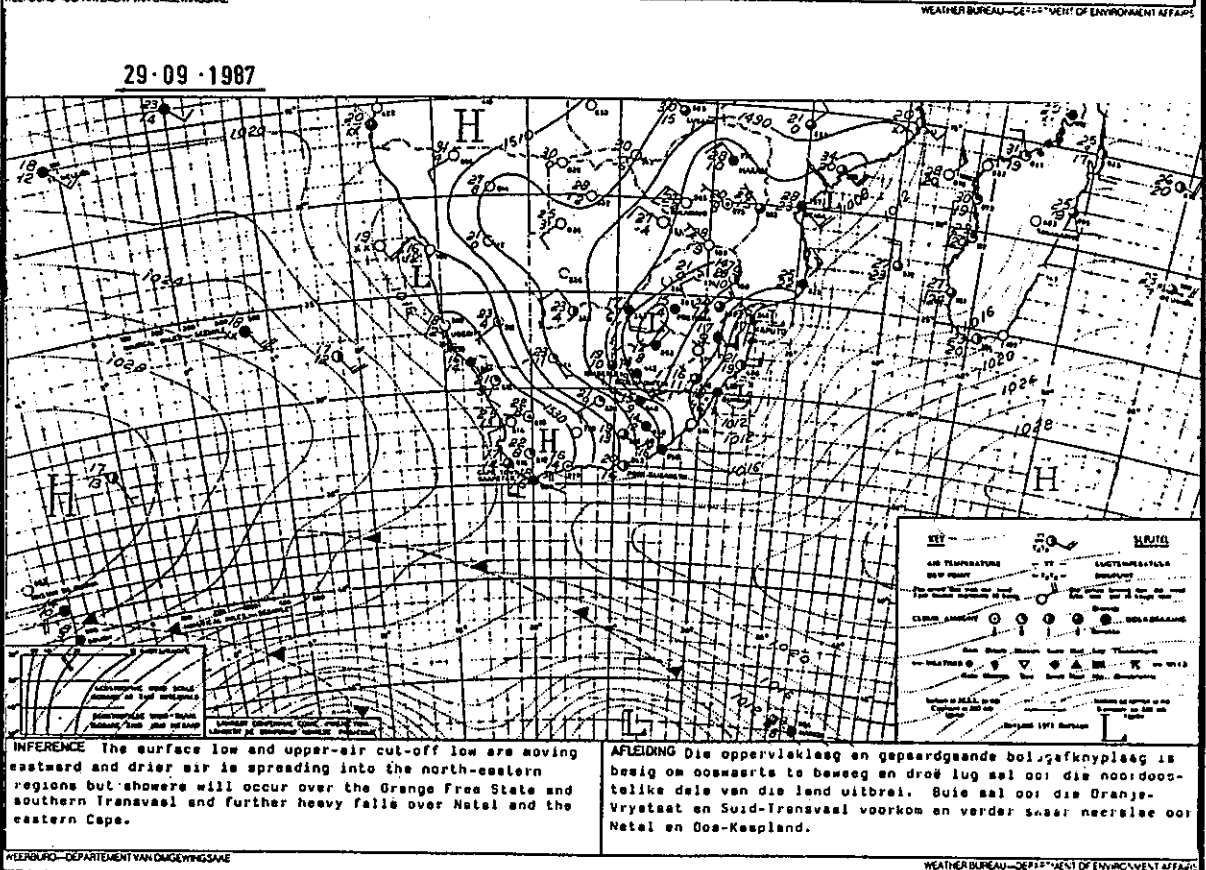
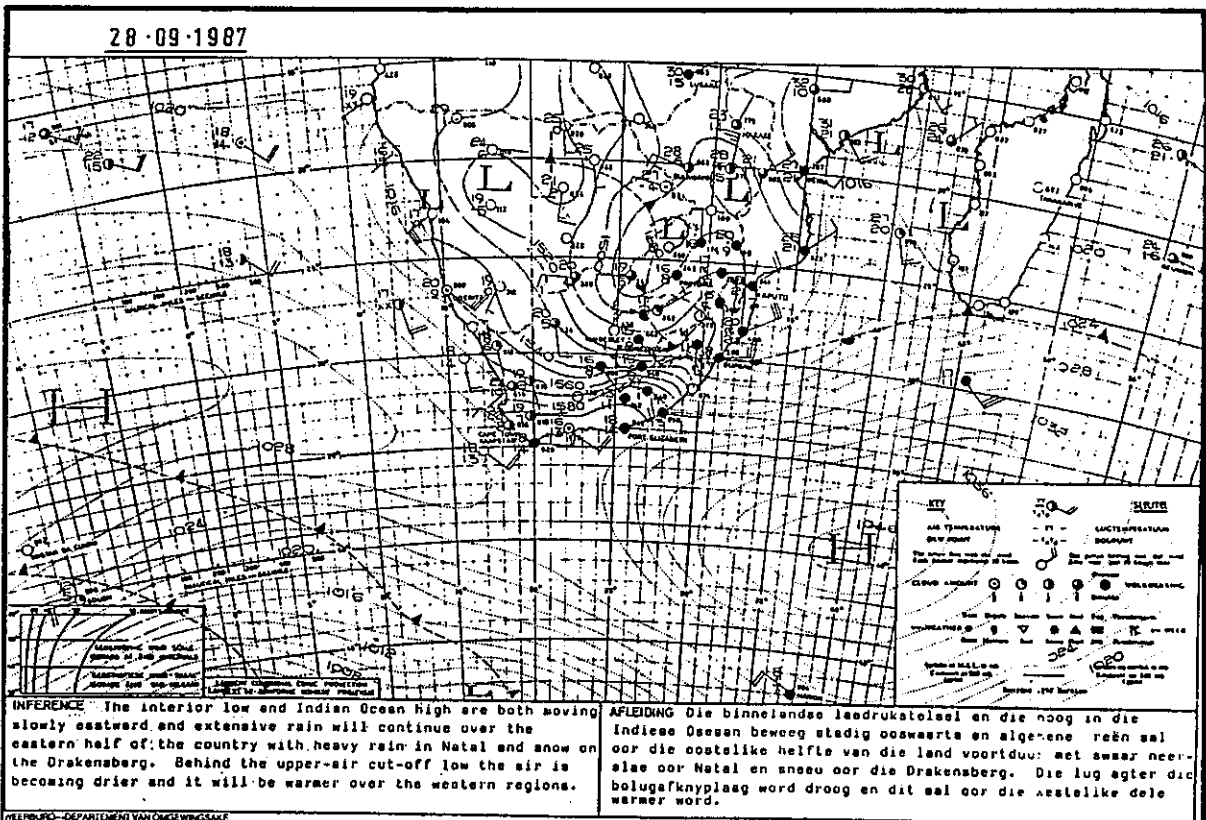
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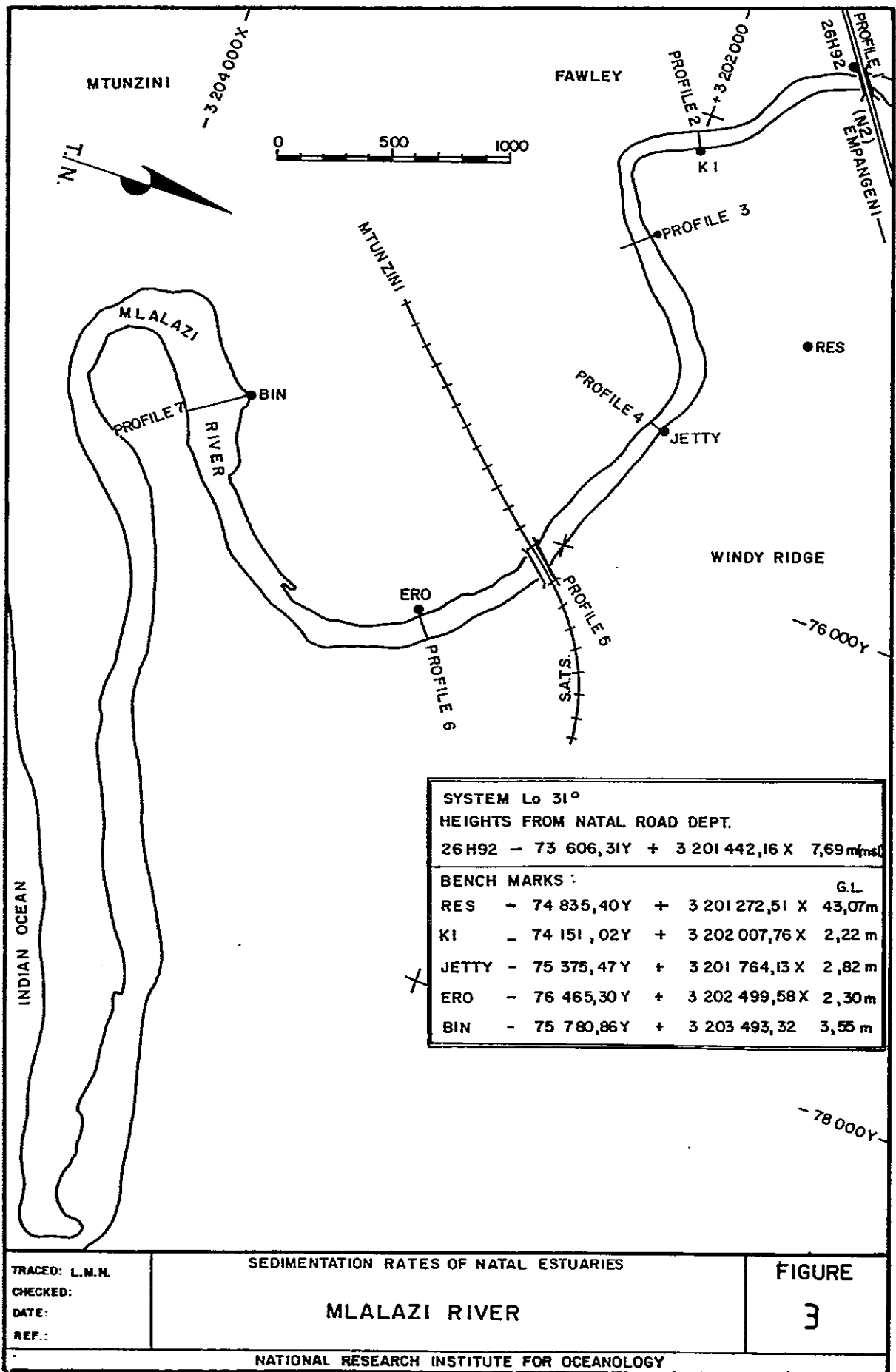
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SYNOPTIC WEATHER MAPS FOR 26 AND 27 SEPT. 87

FIGURE
 1



<p>TRACED: CHECKED: DATE: REF.:</p>	<p>SYNOPTIC WEATHER MAPS FOR 28 AND 29 SEPT. 87</p>	<p>FIGURE 2</p>
<p>NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY</p>		



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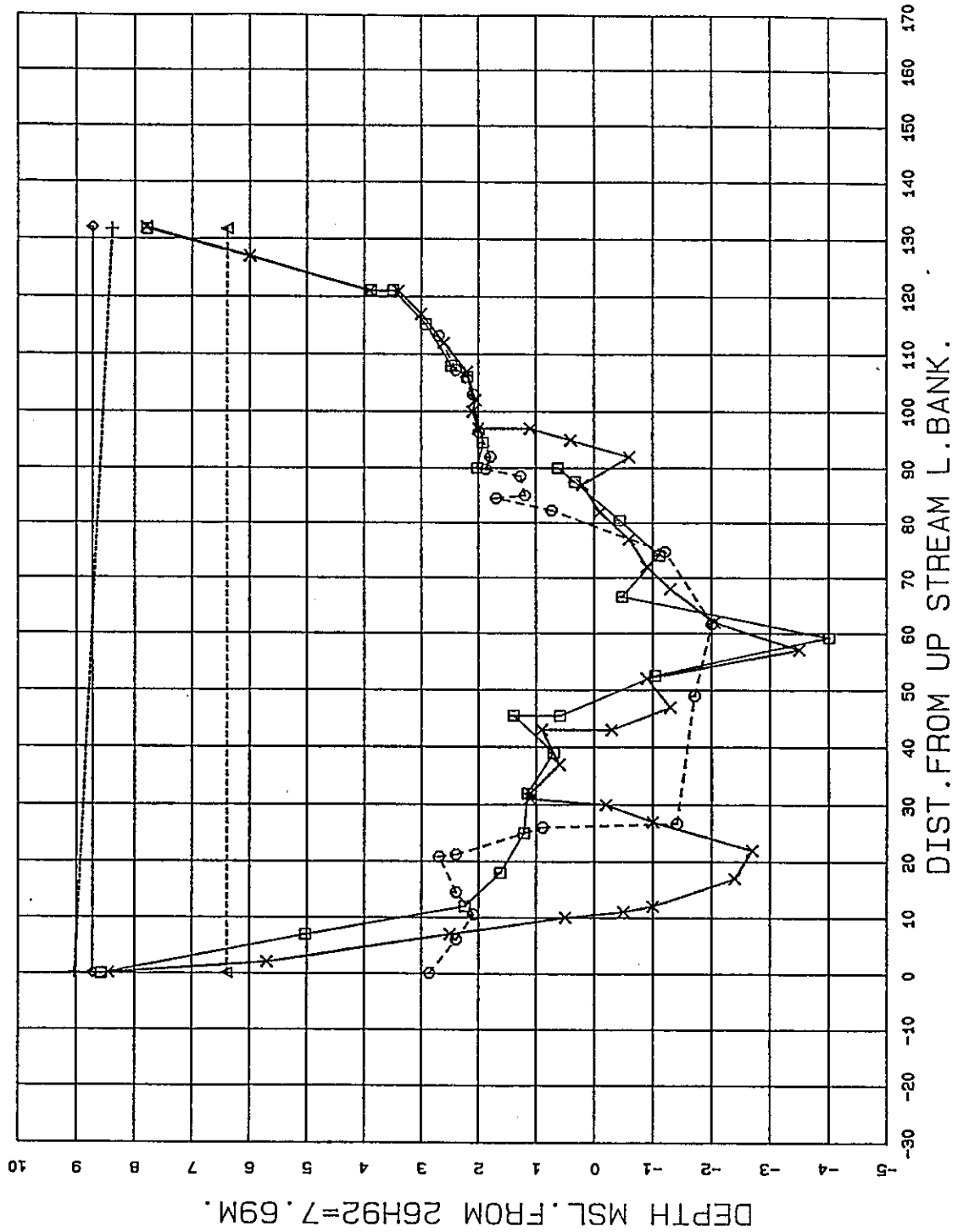
SEDIMENTATION RATES OF NATAL ESTUARIES

MLALAZI RIVER

FIGURE

3

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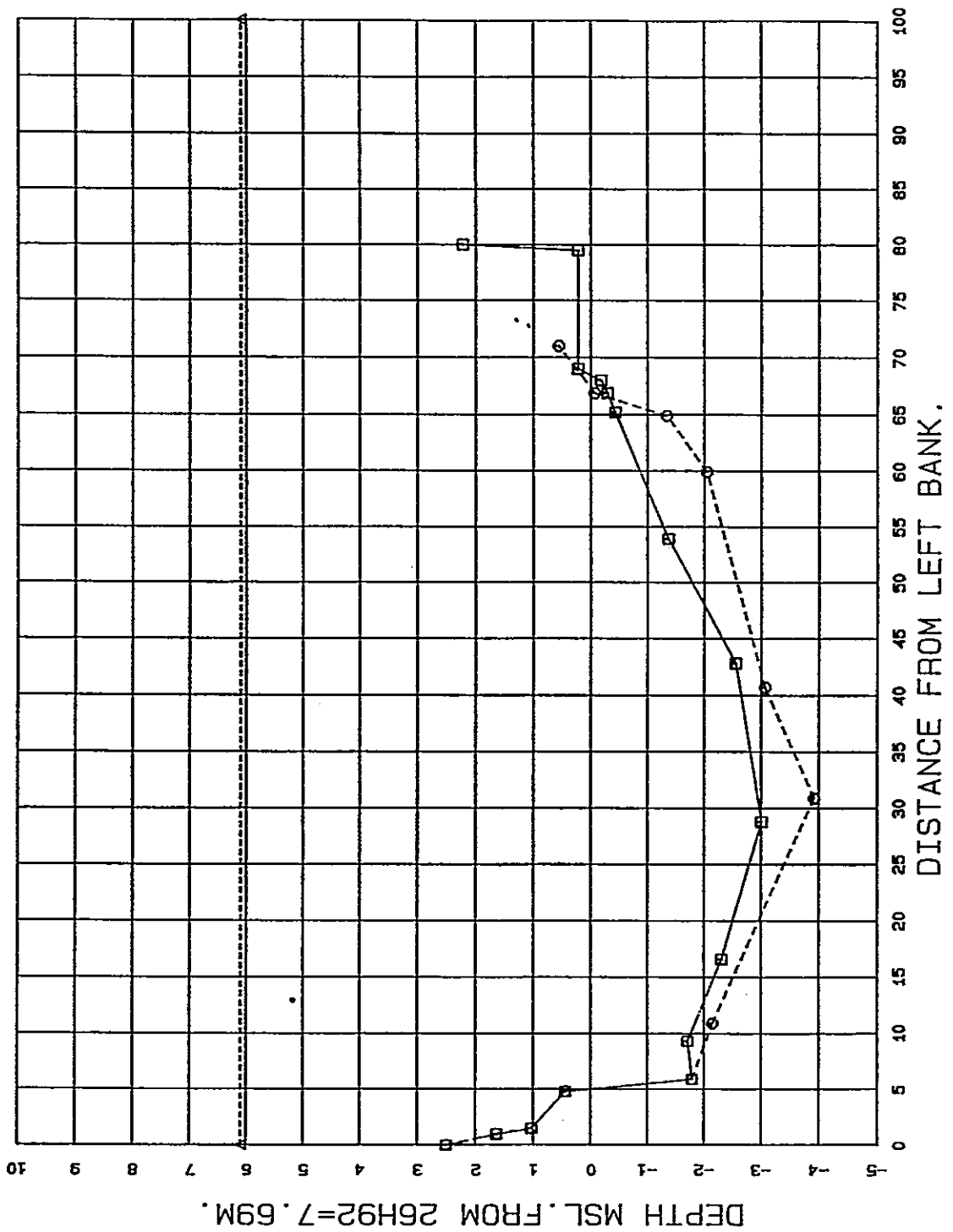
LEGEND : □ — 24-02-87 ◆ — FLOOD 9-87
 ○ — NOV. 1975
 △ — FLOOD 1969
 + — KERB LEVEL
 × — 11-10-87

PROFILE 1

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MLALAZI (N2) BRIDGE.

FIGURE
 4



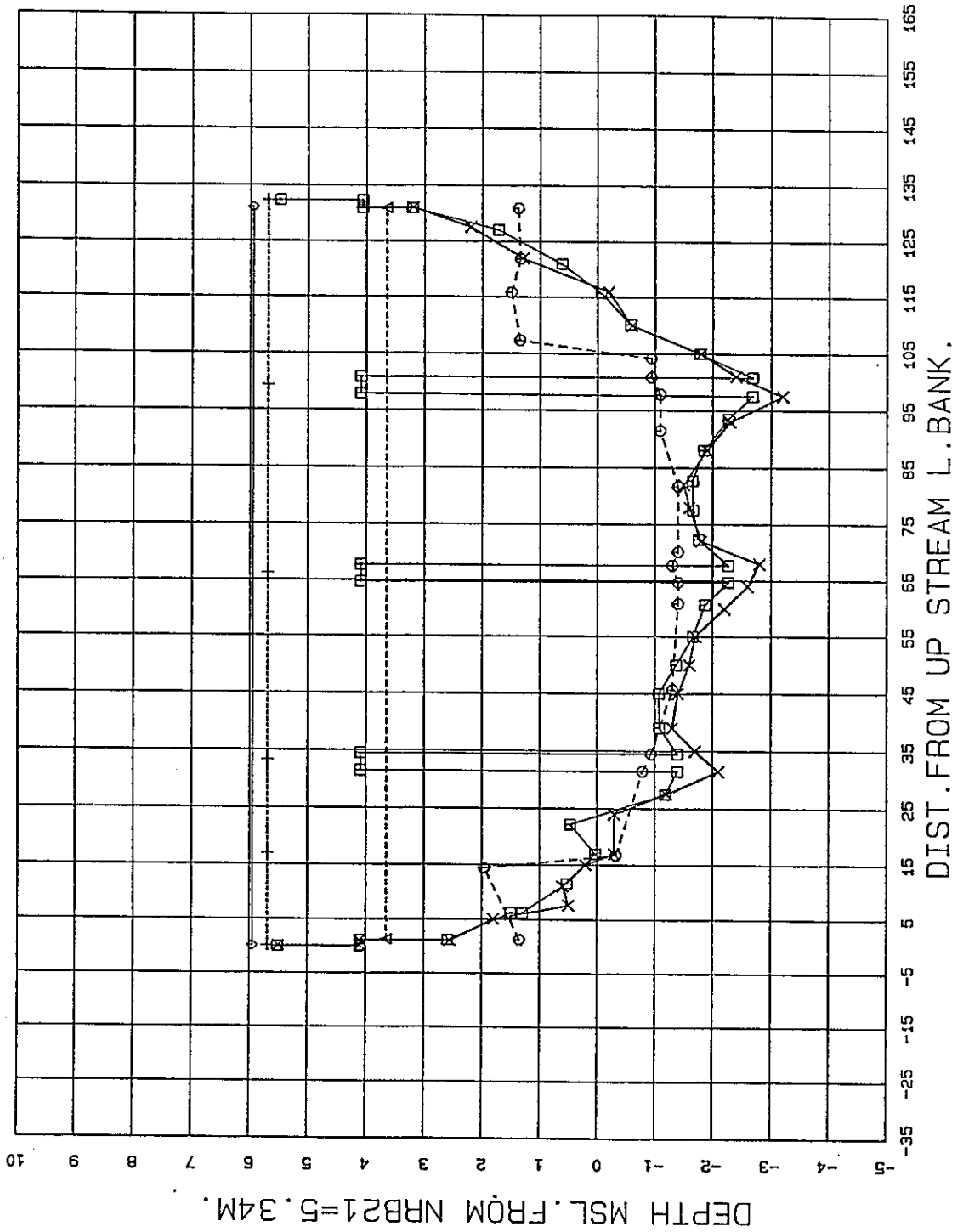
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 △-----△ FLOOD 9-87

PROFILE 4

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MLALAZI RIVER BED.

FIGURE
 5



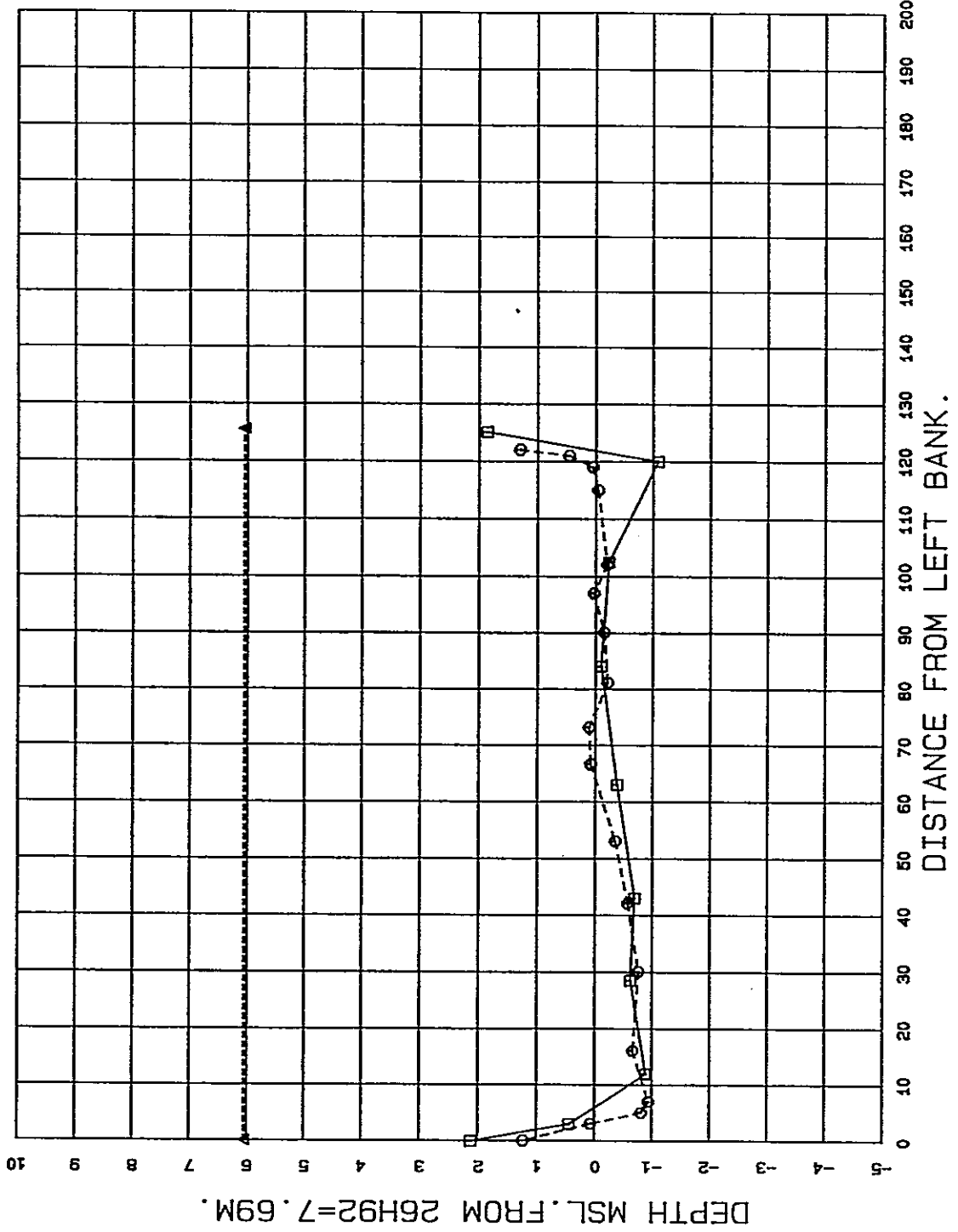
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 ○ — 1932
 △ — FLOOD 1969
 + — CAT-WALK
 × — 11-10-87

PROFILE 5

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MLALAZI RAIL BRIDGE

FIGURE
 6



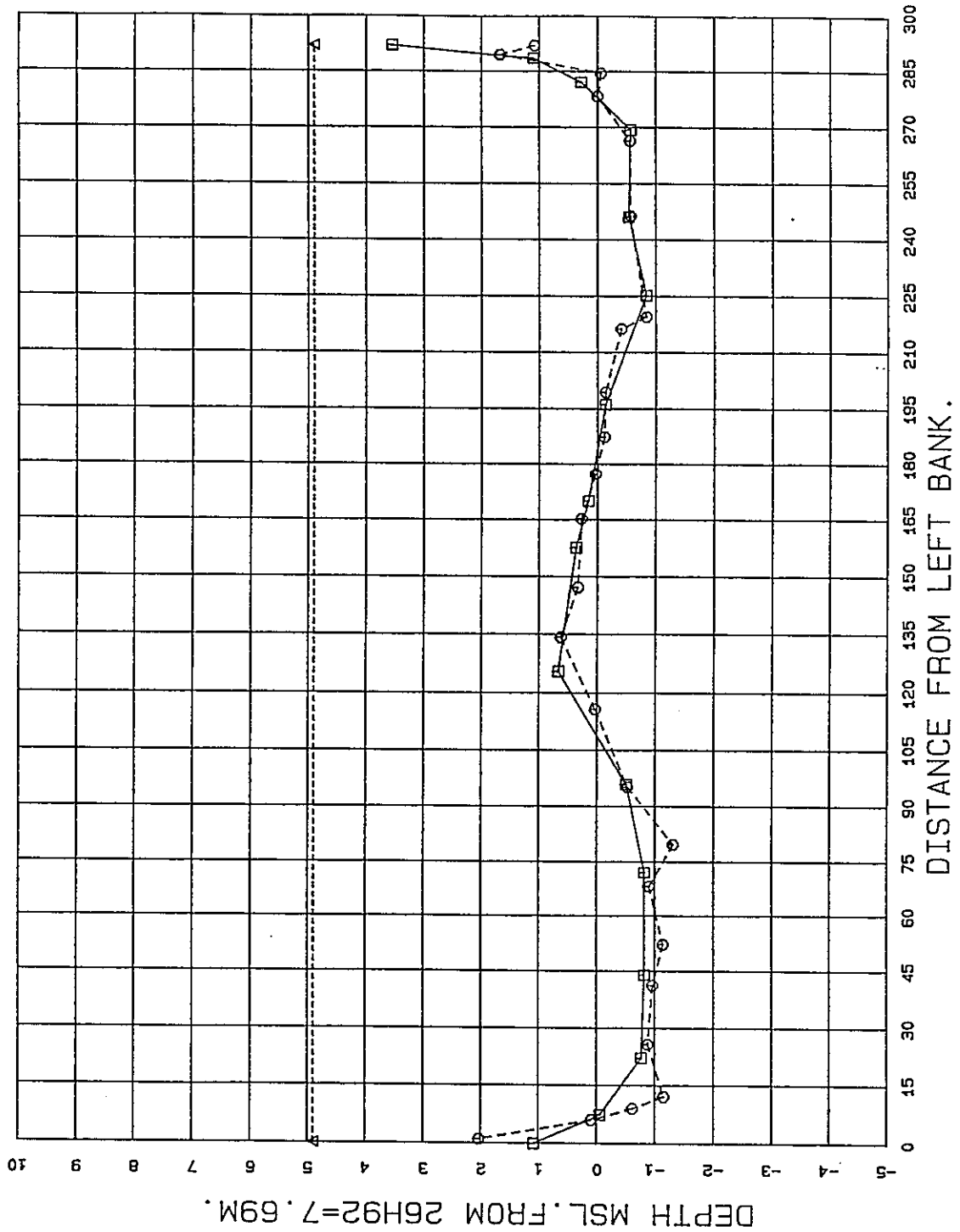
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 ○ - - - 11-10-87
 △ ····· FLOOD 9-87

PROFILE 6

SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MLALAZI RIVER BED.

FIGURE
 7

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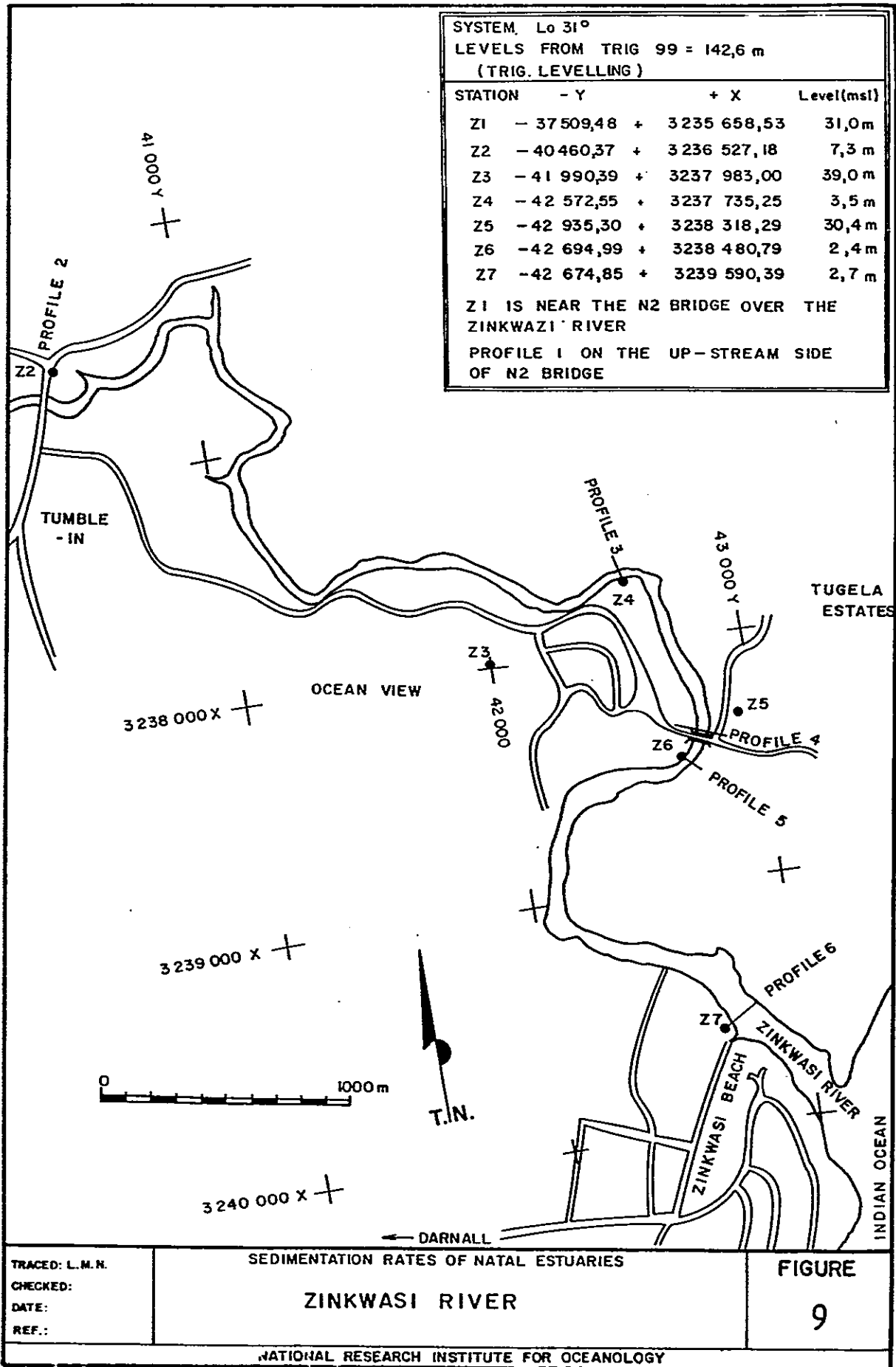
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 ○ --- 11-10-87
 △ ----- FLOOD 9-87

PROFILE 7

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MLALAZI RIVER BED.

FIGURE
 8



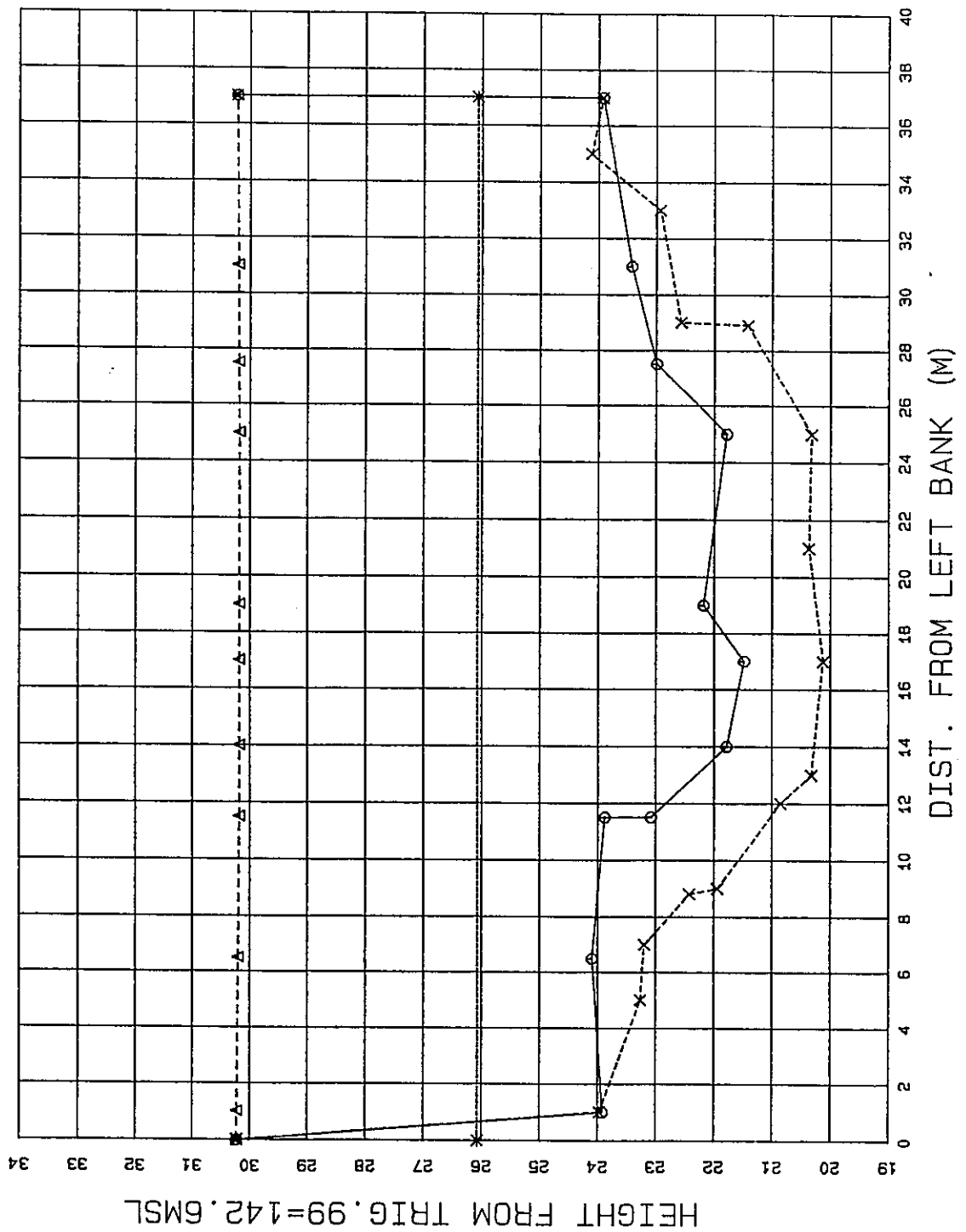
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SEDIMENTATION RATES OF NATAL ESTUARIES

ZINKWASI RIVER

FIGURE

9



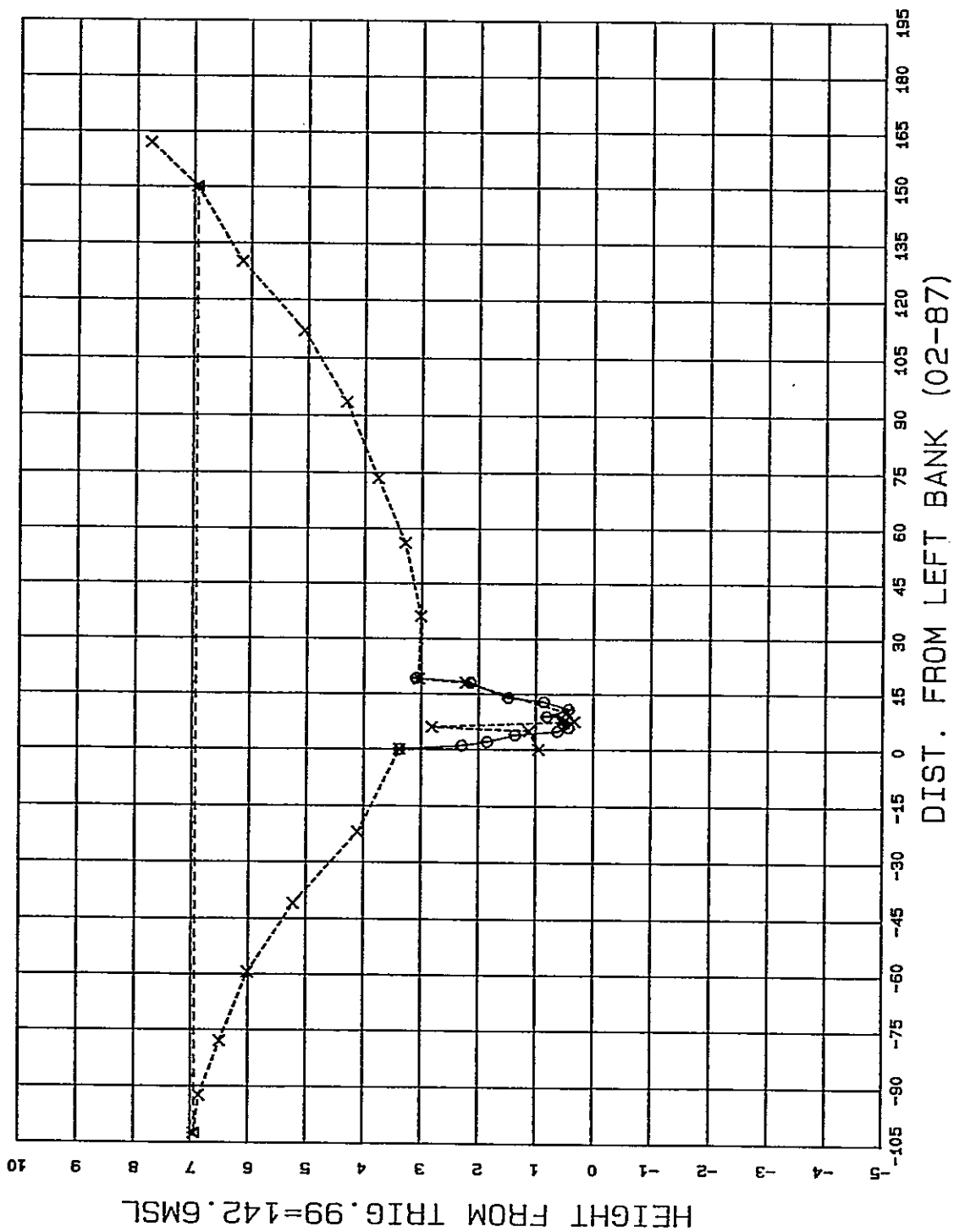
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 ▲---▲ KERB-LEVEL
 X---X 87-10-10
 --- FLOOD 9-87

PROFILE 1

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF ZINKWAZI N2 BRIDGE.

FIGURE
 10



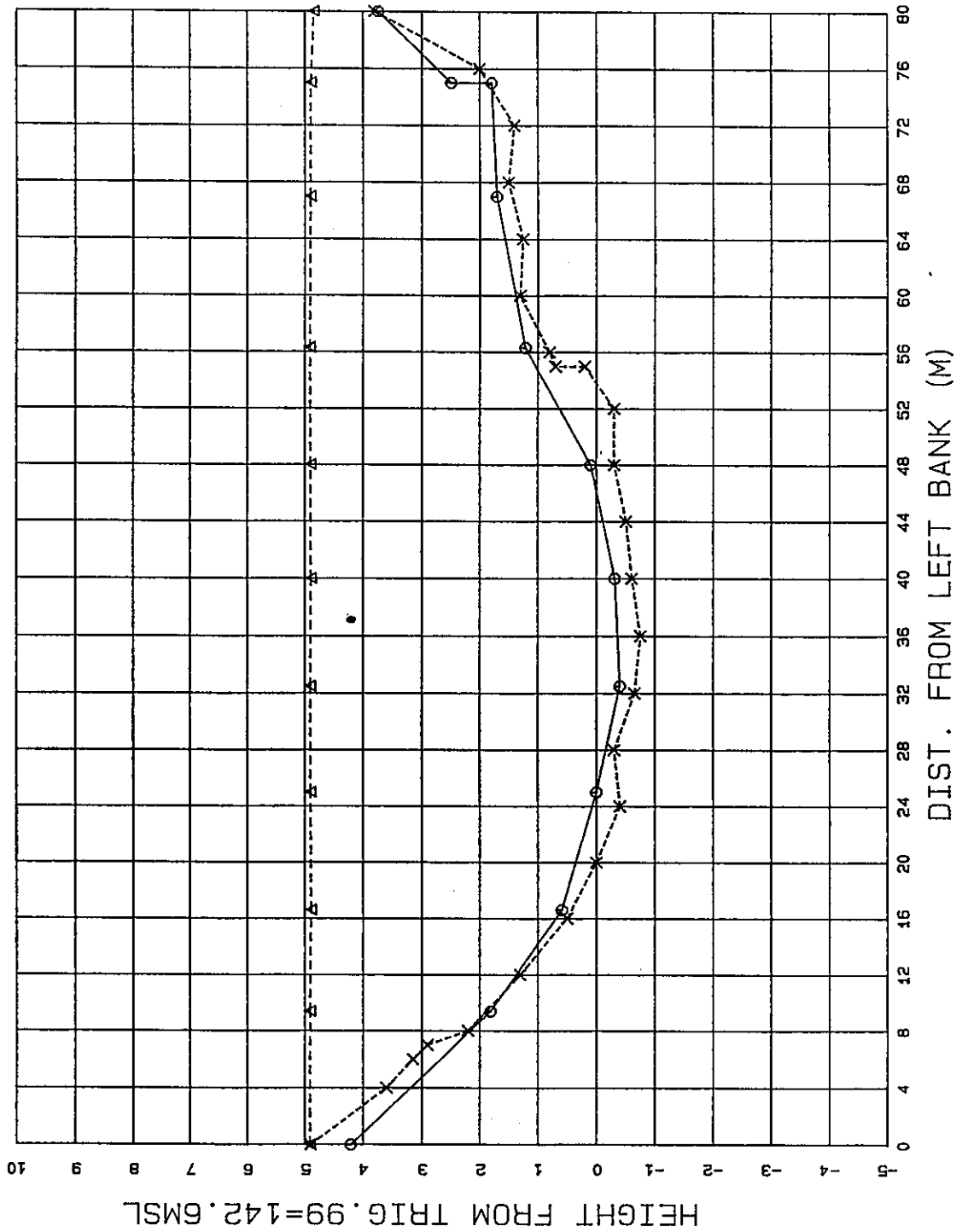
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 △----△ FLOOD 9-87
 X-----X 87-10-10

PROFILE 2

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF ZINKWAZI RIVER BED.

FIGURE
 11



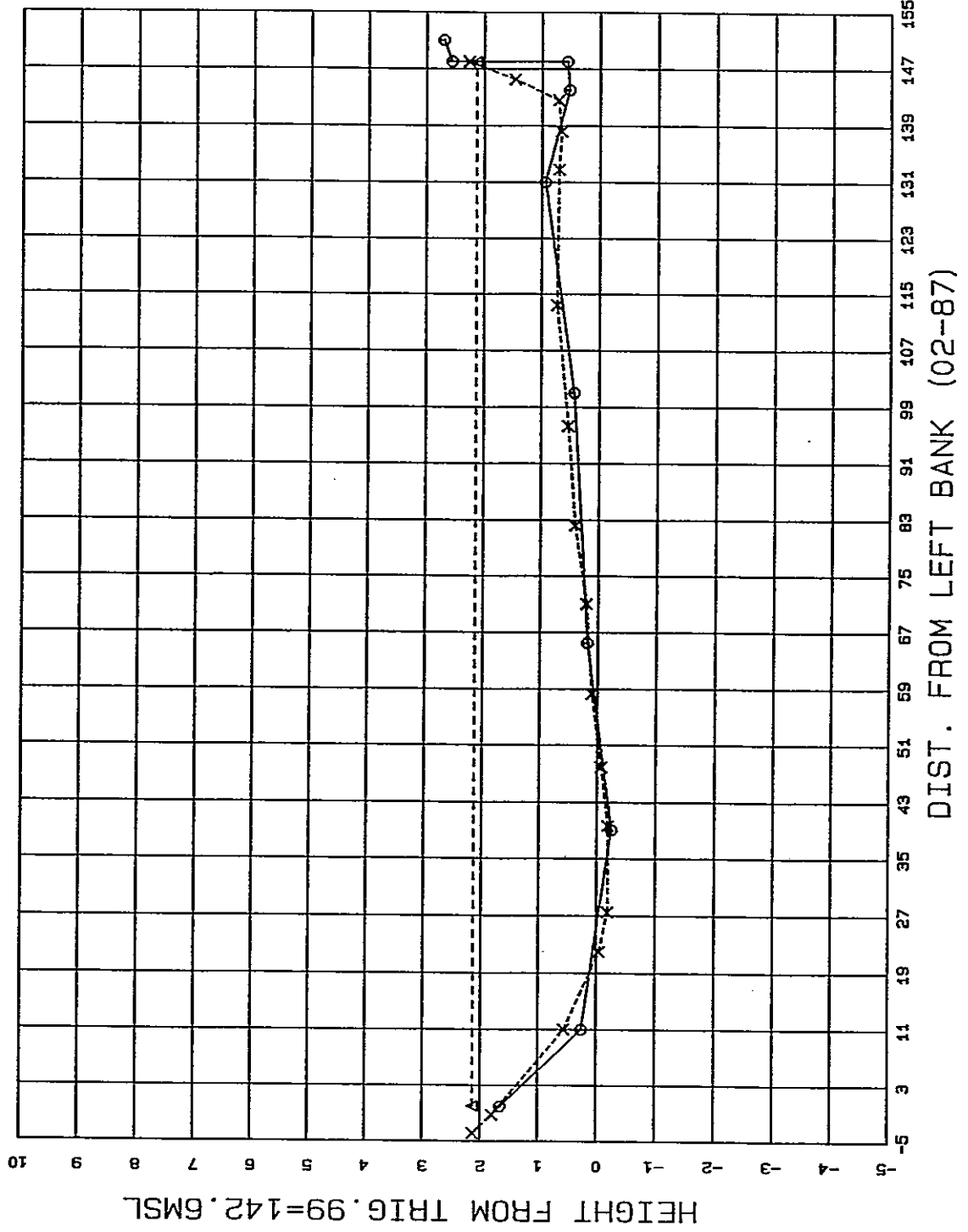
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 ▲-----▲ KARB-L-LEVEL
 X-----X 87-10-10

PROFILE 4

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF TUGELA ESTATE BRIDGE.

FIGURE
 12



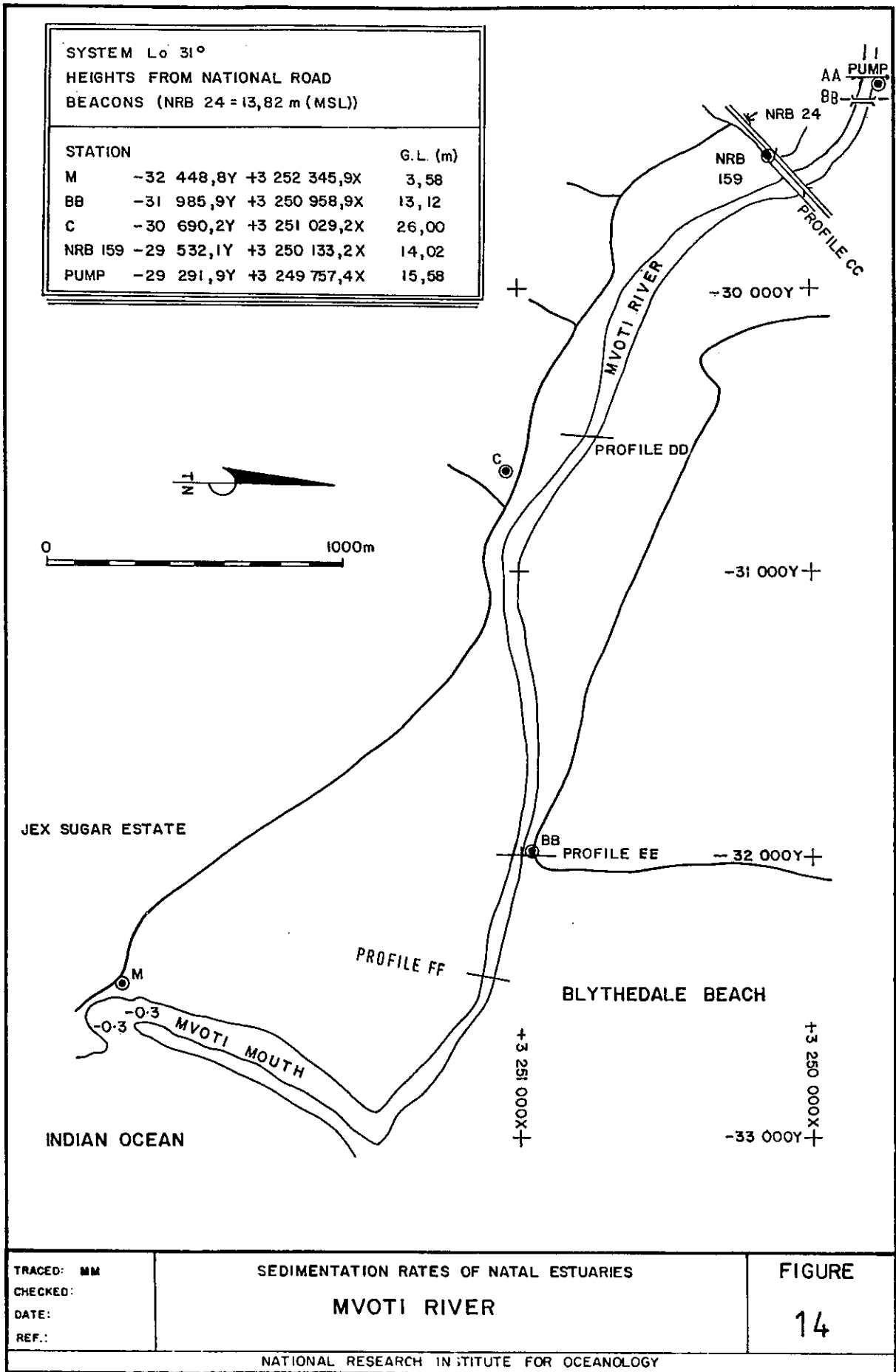
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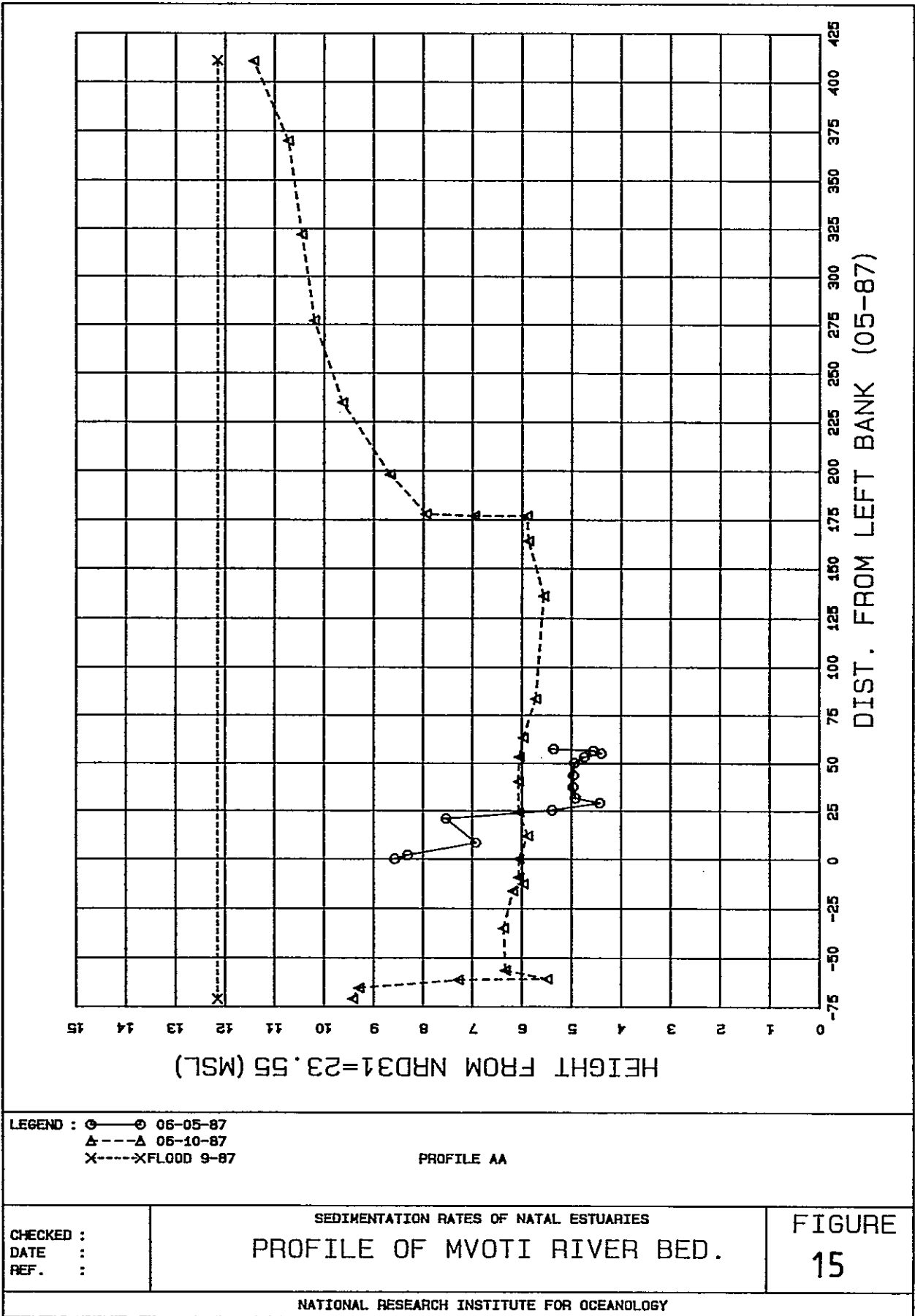
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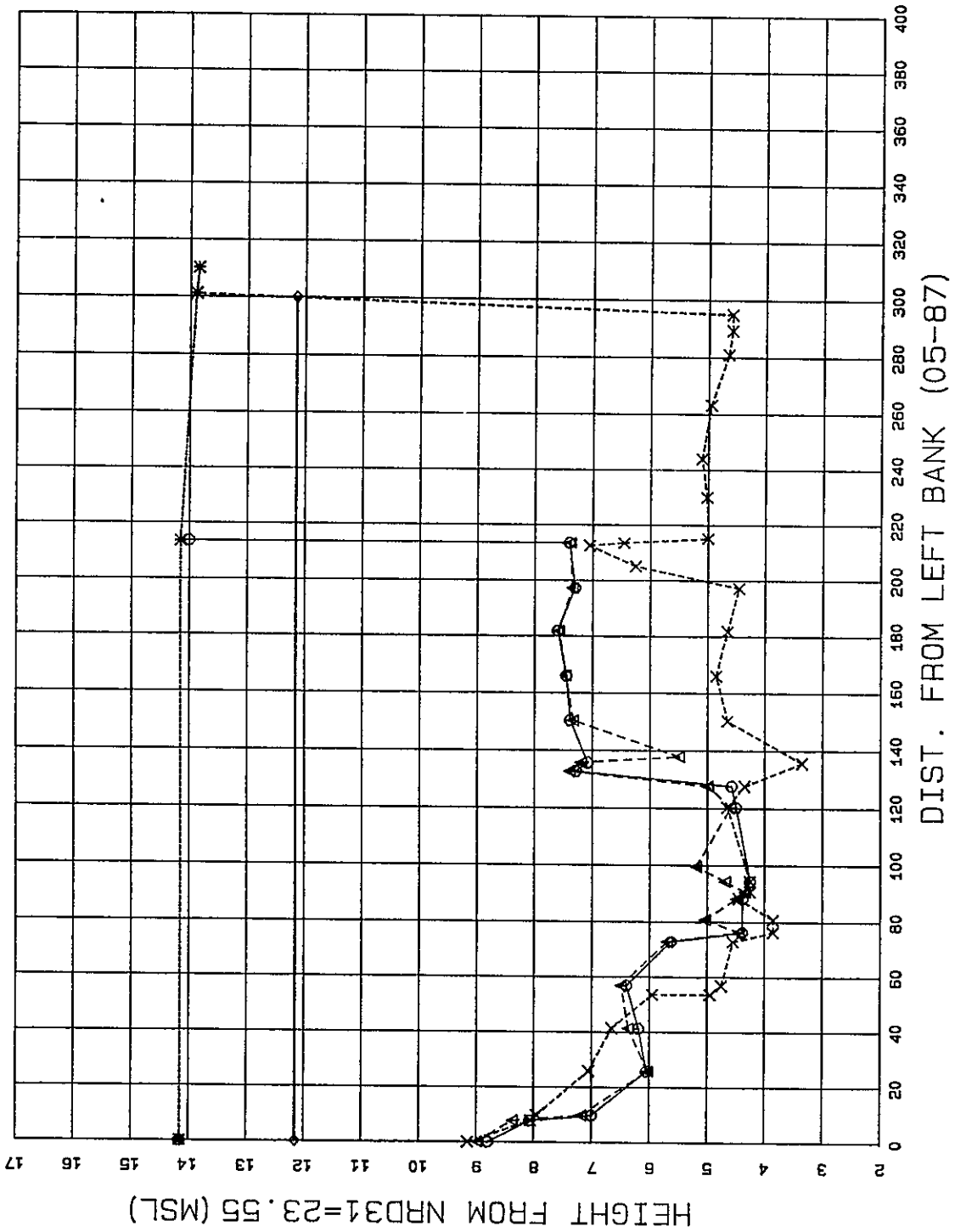
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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF ZINKWAZI RIVER BED.

FIGURE
 13







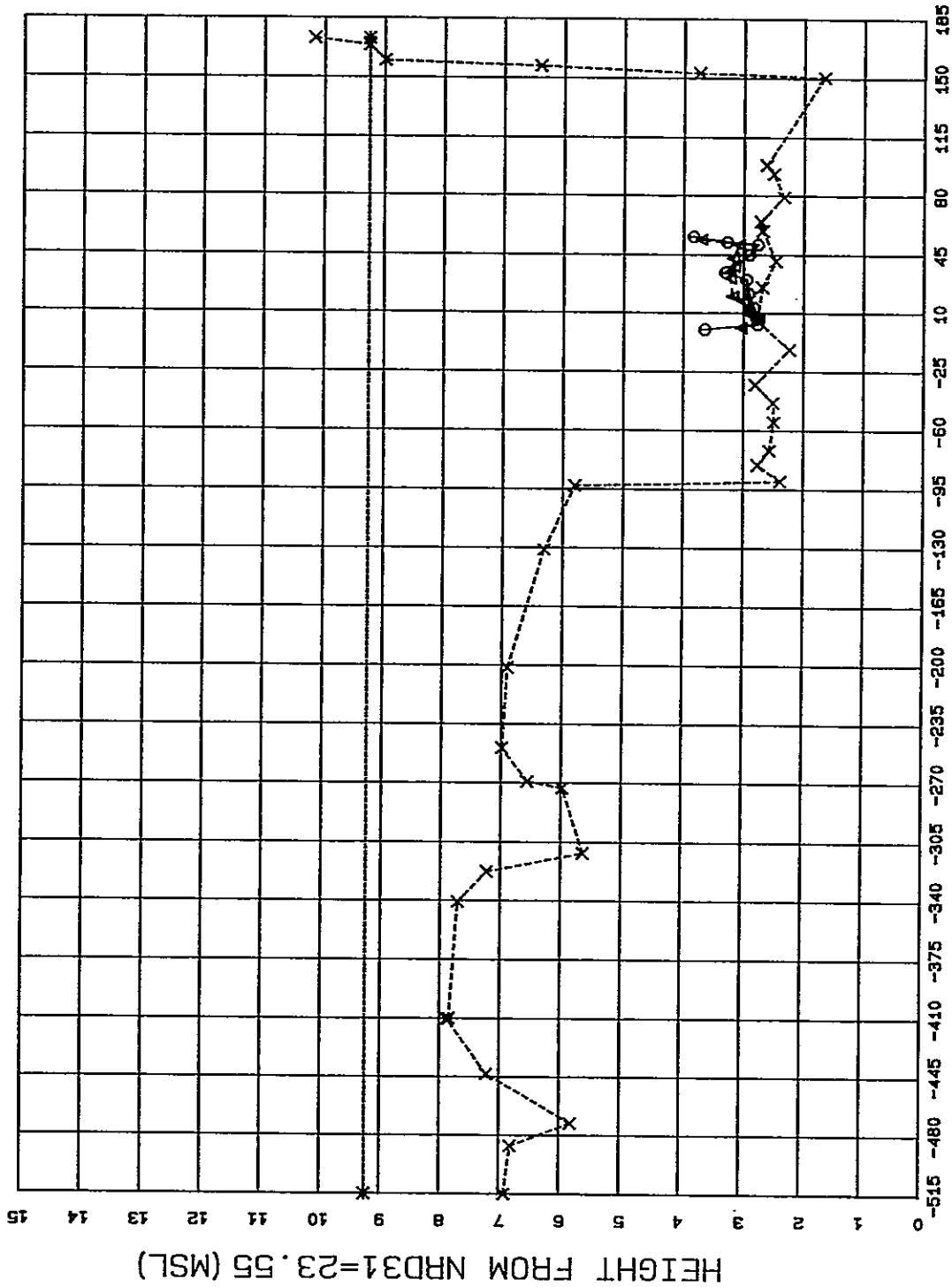
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 △---△ 06-05-87
 X---X 08-10-87
 --- DECK-LEVEL
 ◆——◆ FLOOD 9-87

PROFILE CC

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MVOTI (N2) BRIDGE.

FIGURE
 16



DIST. FROM LEFT BANK (05-87)

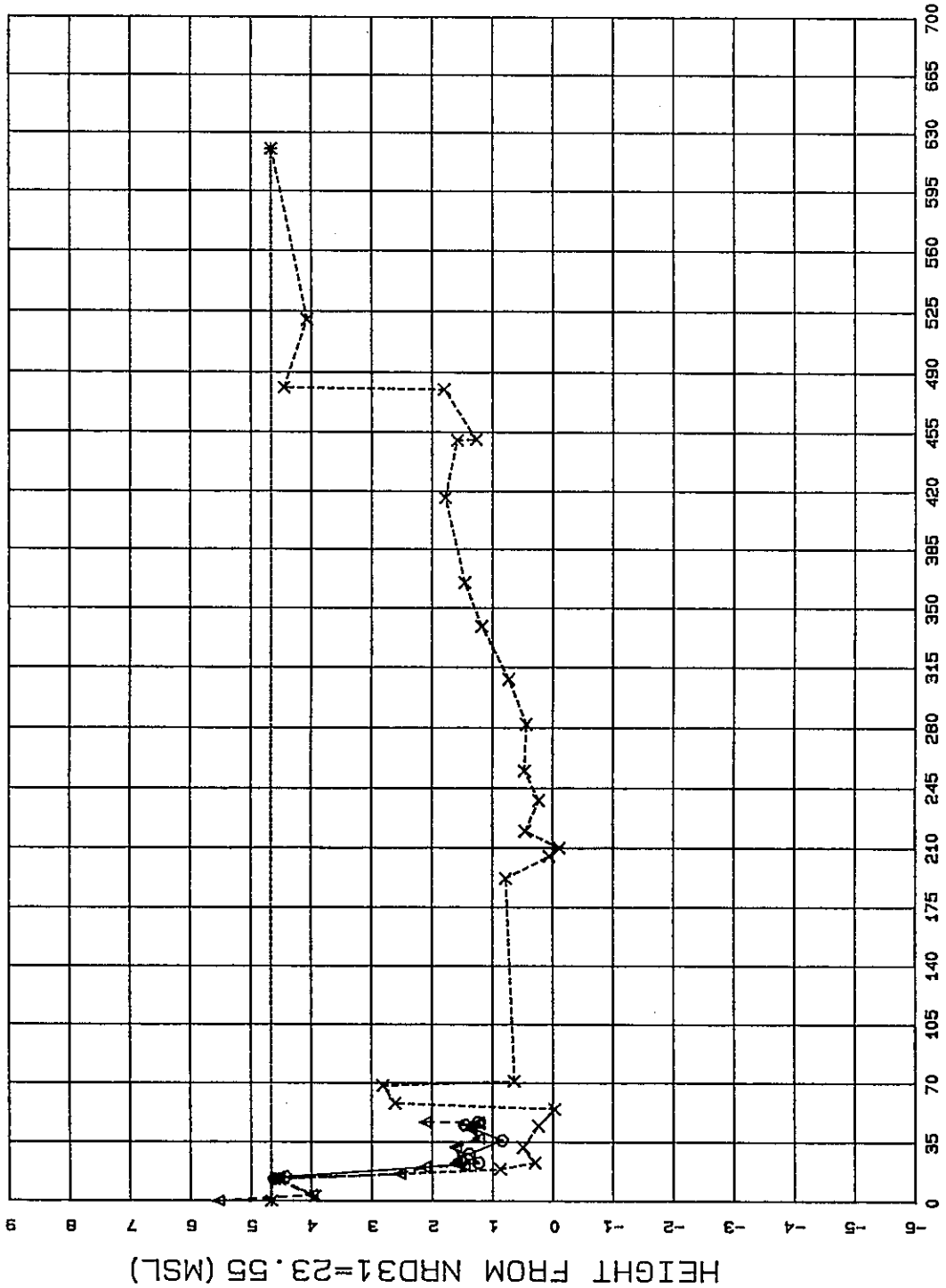
LEGEND : \odot — \odot 25-11-86
 \triangle --- \triangle 06-05-87
 \times --- \times 06-10-87
 $*$ --- $*$ FLOOD 9-87

PROFILE DD

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 DATE :
 REF. :

SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MVOTI RIVER BED.

FIGURE
 17



DIST. FROM LEFT BANK (05--87)

HEIGHT FROM NRD31=23.55 (MSL)

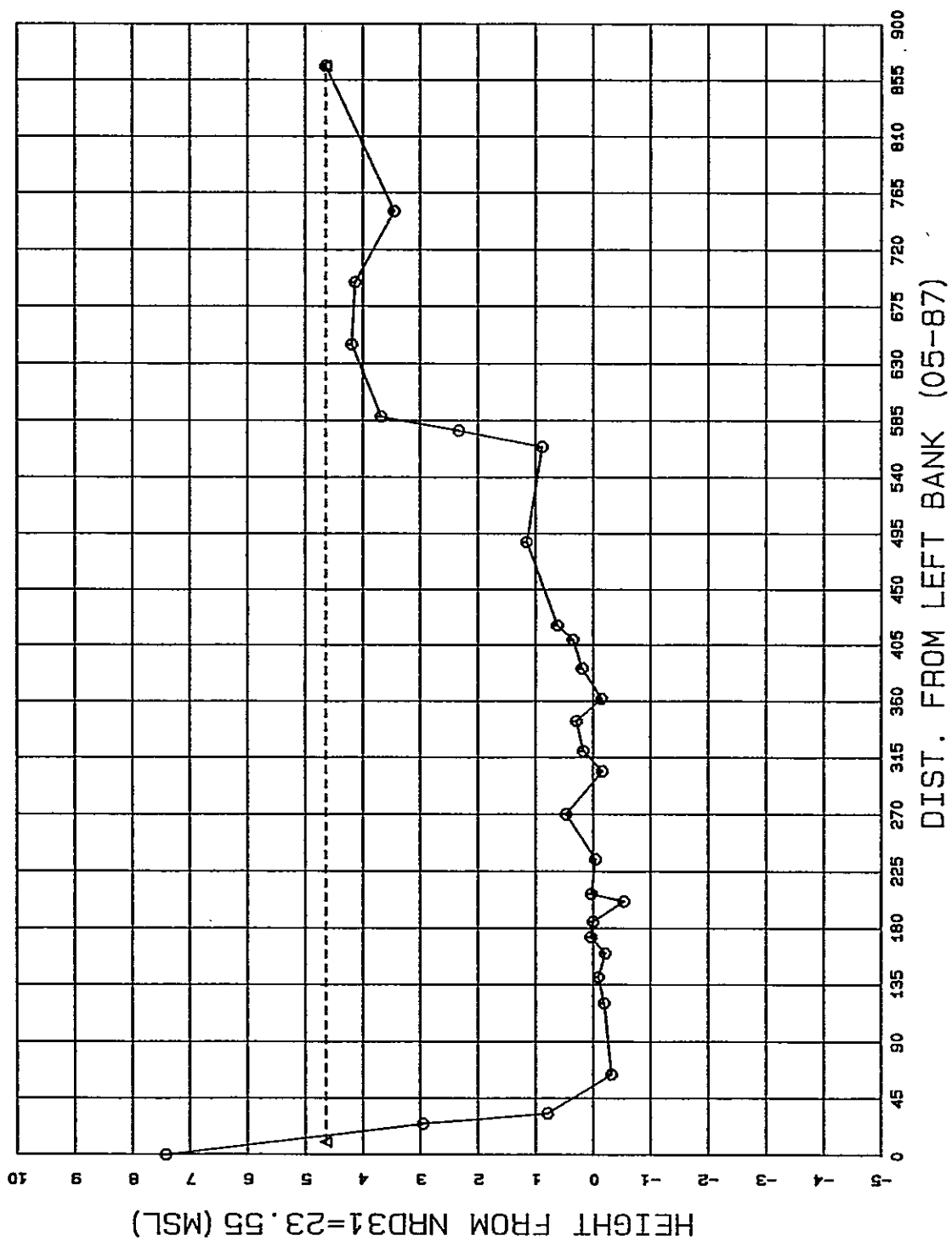
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 X---X 06-10-87
 --- FLOOD 9-87

PROFILE EE

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 DATE :
 REF. :

SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MVOTI RIVER BED.

FIGURE
 18



LEGEND : ○—○ 06-10-87
 ▲----▲ FLOOD 9-87

PROFILE FF

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF MVOTI RIVER BED.

FIGURE
 19

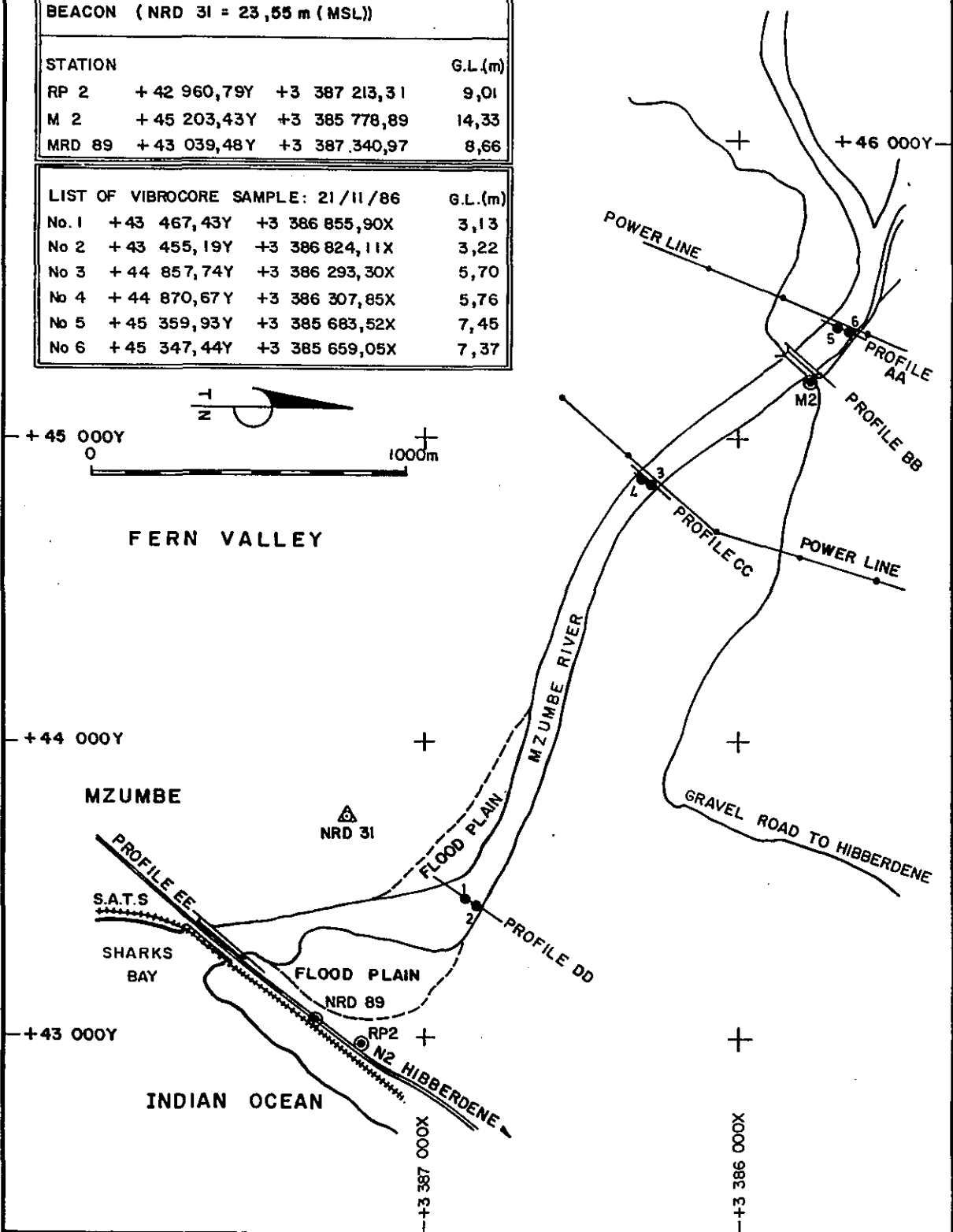
SYSTEM L₀ 31°
 HEIGHTS FROM NATAL ROAD DEPT.
 BEACON (NRD 31 = 23,55 m (MSL))

STATION		G.L.(m)
RP 2	+ 42 960,79Y +3 387 213,31	9,01
M 2	+ 45 203,43Y +3 385 778,89	14,33
MRD 89	+ 43 039,48Y +3 387 340,97	8,66

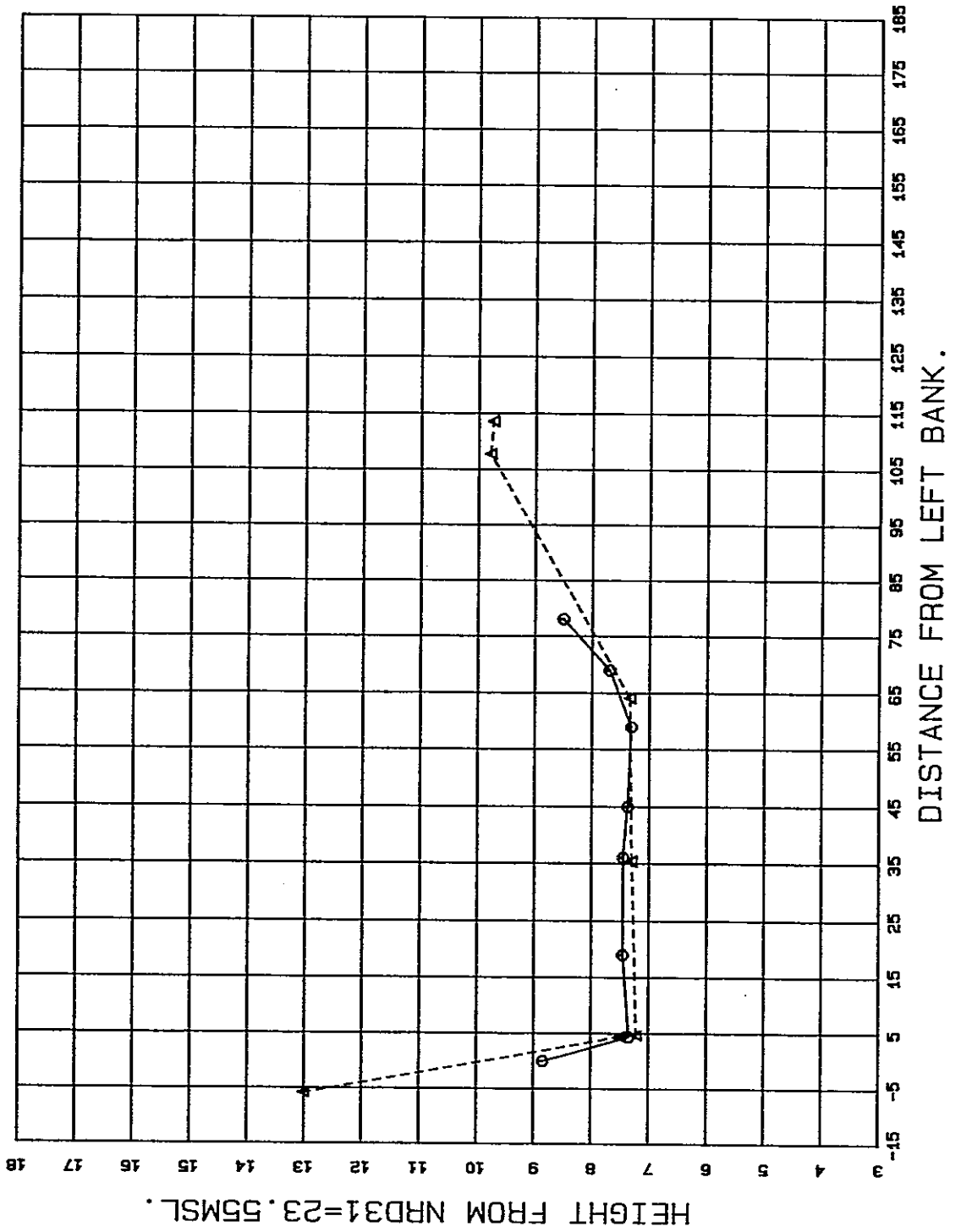
LIST OF VIBROCORE SAMPLE: 21/11/86		G.L.(m)
No. 1	+ 43 467,43Y +3 386 855,90X	3,13
No 2	+ 43 455,19Y +3 386 824,11X	3,22
No 3	+ 44 857,74Y +3 386 293,30X	5,70
No 4	+ 44 870,67Y +3 386 307,85X	5,76
No 5	+ 45 359,93Y +3 385 683,52X	7,45
No 6	+ 45 347,44Y +3 385 659,05X	7,37



FERN VALLEY



TRACED MM CHECKED DATE: REF:	SEDIMENTATION RATES OF NATAL ESTUARIES MZUMBE RIVER	FIGURE 20
NATIONAL RESEARCH INSTITUTE FOR OCEANOLOGY		



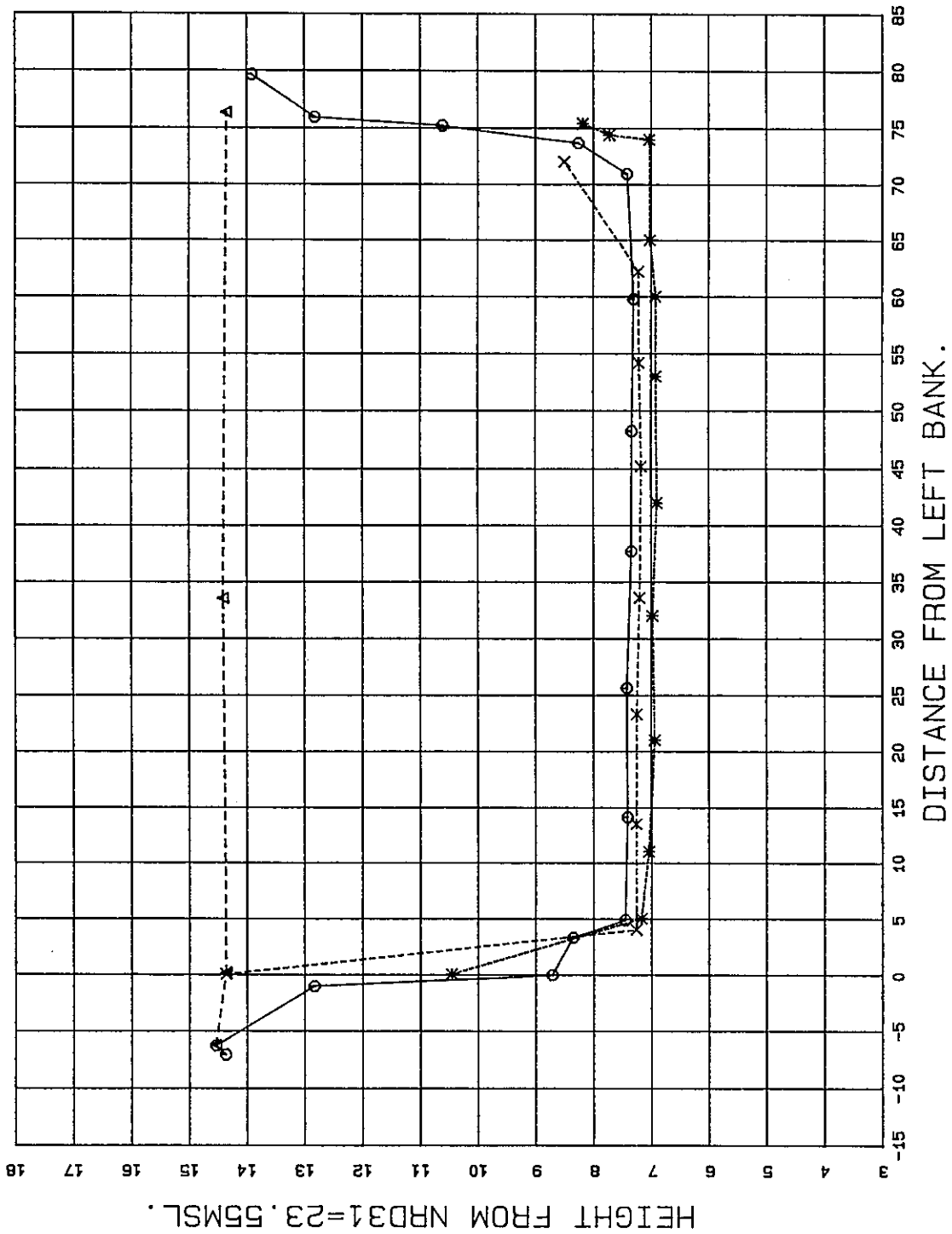
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PROFILE AA

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SEDIMENTATION RATES OF NATAL ESTUARIES
 MZUMBE RIVER PROFILE.

FIGURE
 21



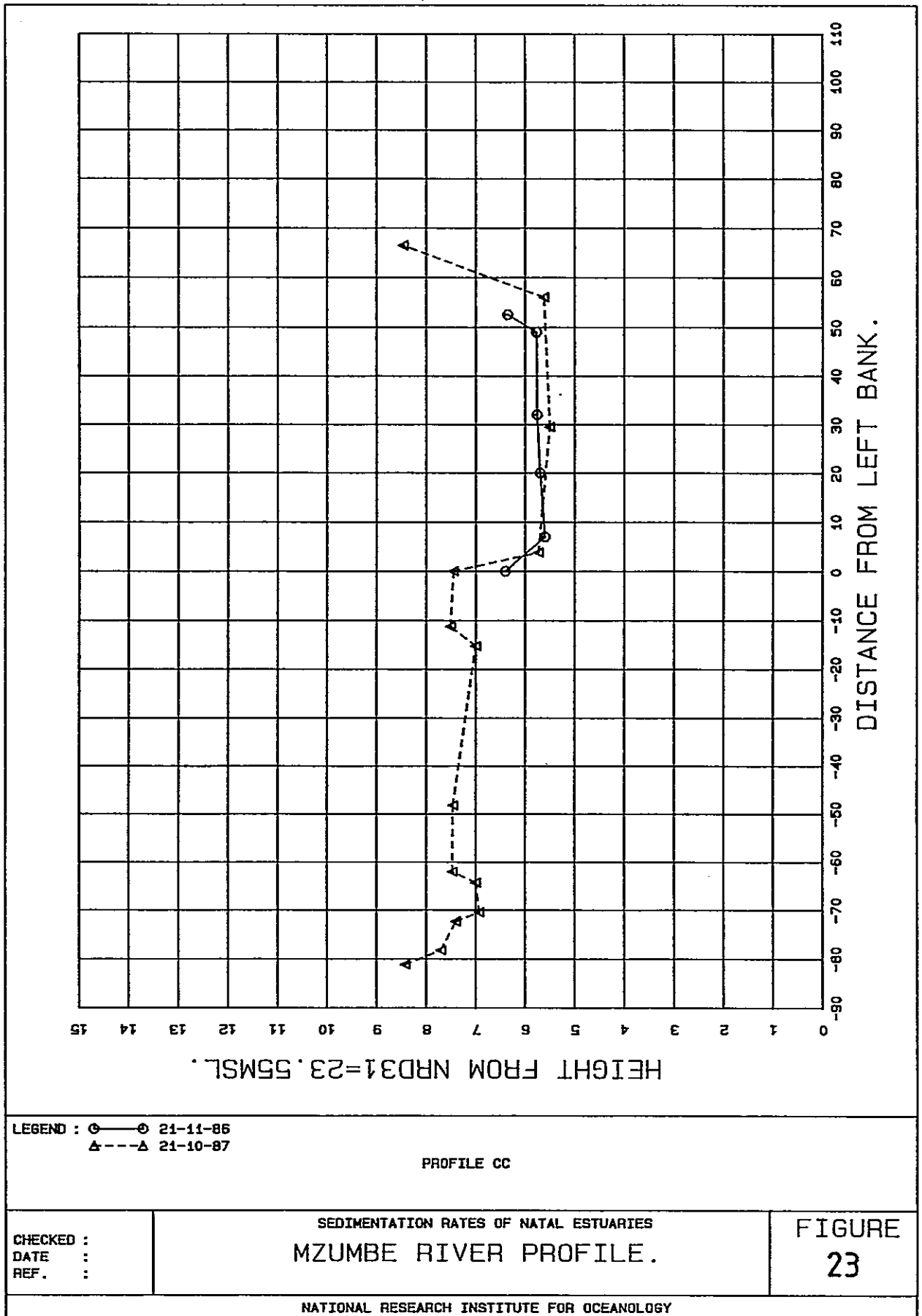
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 X 21-11-85
 * 21-10-87

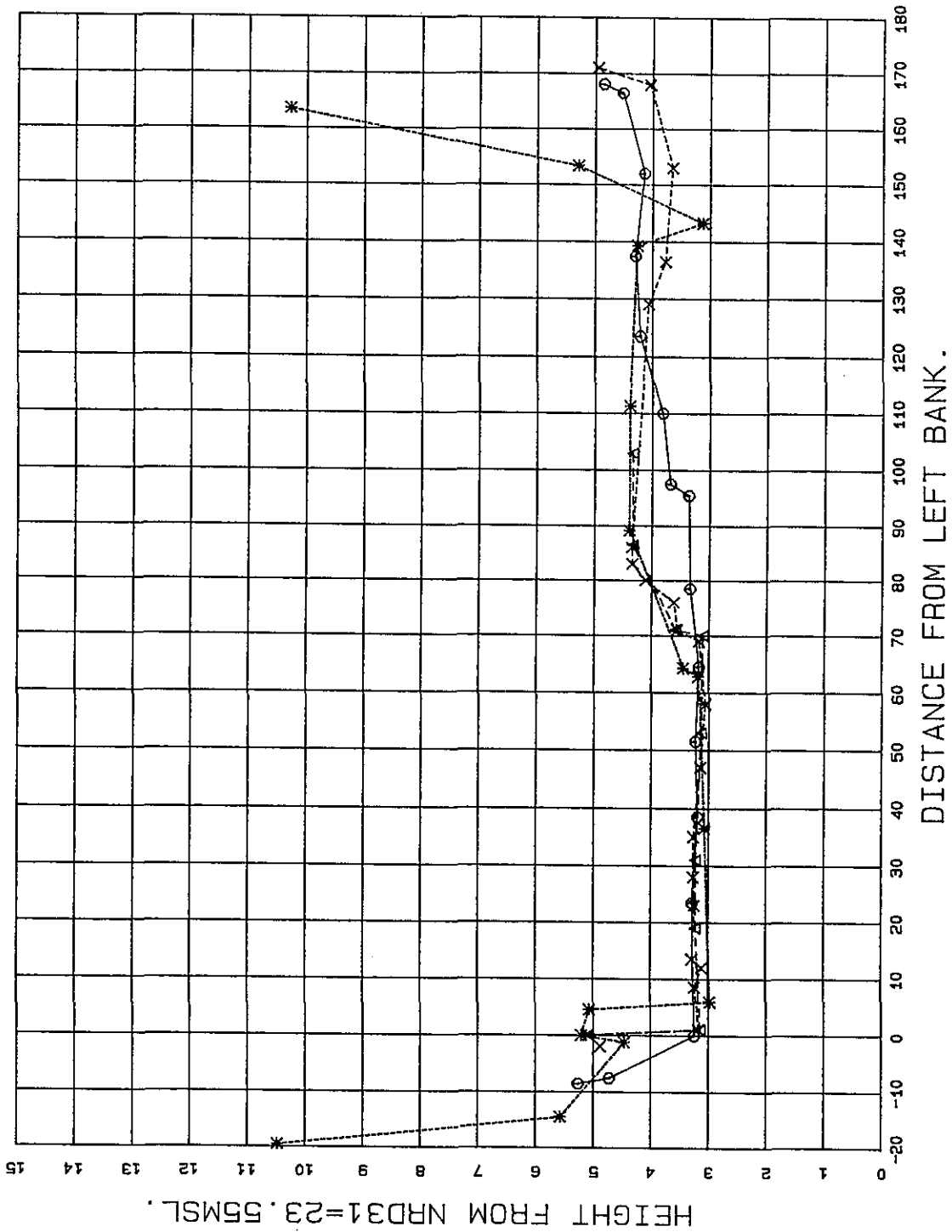
PROFILE BB

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 DATE :
 REF. :

SEDIMENTATION RATES OF NATAL ESTUARIES
 OLD MZUMBE STEEL BRIDGE.

FIGURE
 22





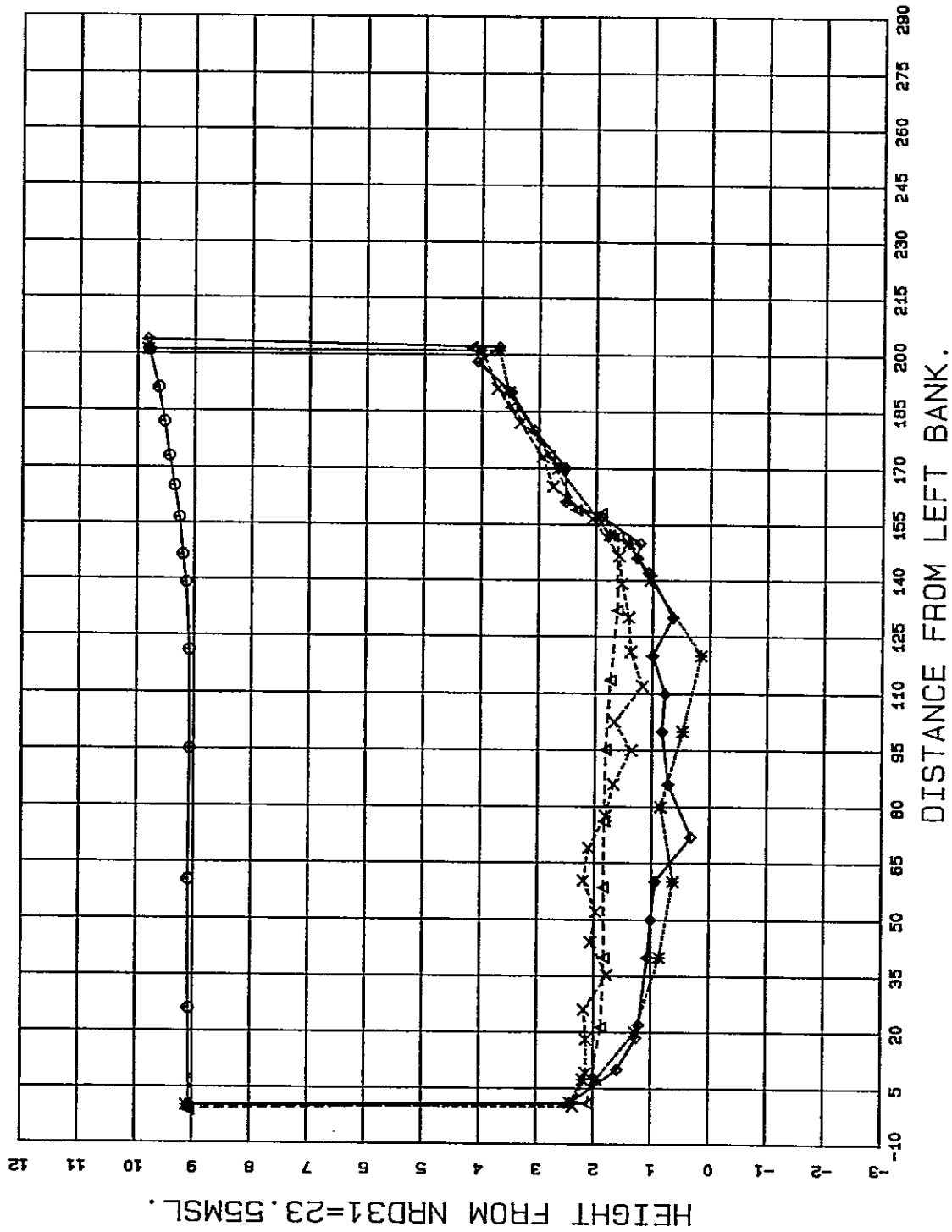
LEGEND : ○——○ 20-06-79
 △---△ 21-11-86
 ×-----× 21-02-87
 ----- 21-10-87

PROFILE DD

CHECKED :
 DATE :
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SEDIMENTATION RATES OF NATAL ESTUARIES
 MZUMBE RIVER PROFILE.

FIGURE
 24



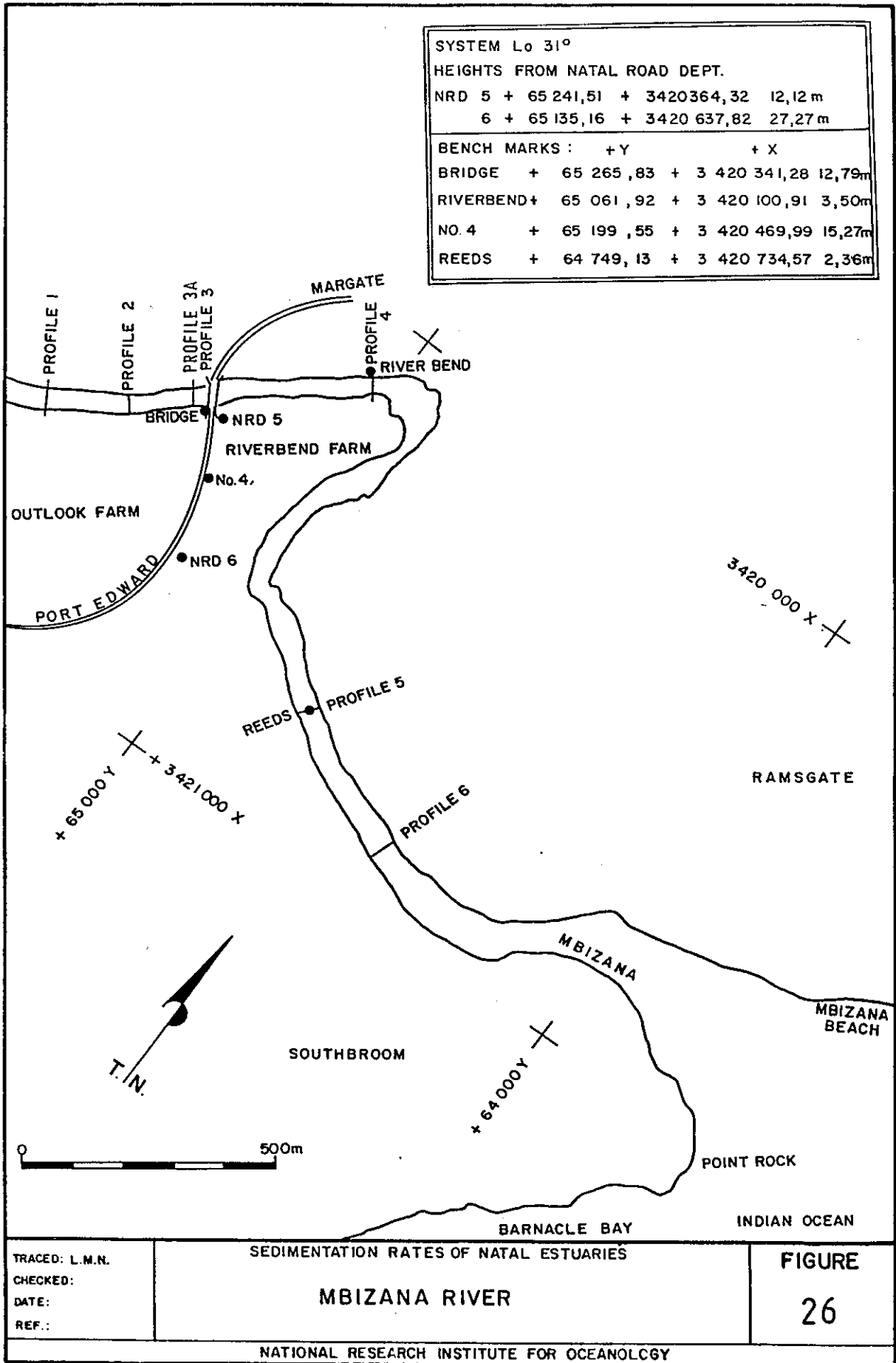
LEGEND : ○—○ KERB-LEVEL
 ▲---▲ 20-06-79
 ×---× 21-11-86
 --- 05-10-87
 ◆---◆ 21-10-87

PROFILE EE

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SEDIMENTATION RATES OF NATAL ESTUARIES
 EXISTING MZUMBE N2 BRIDGE PROFILE

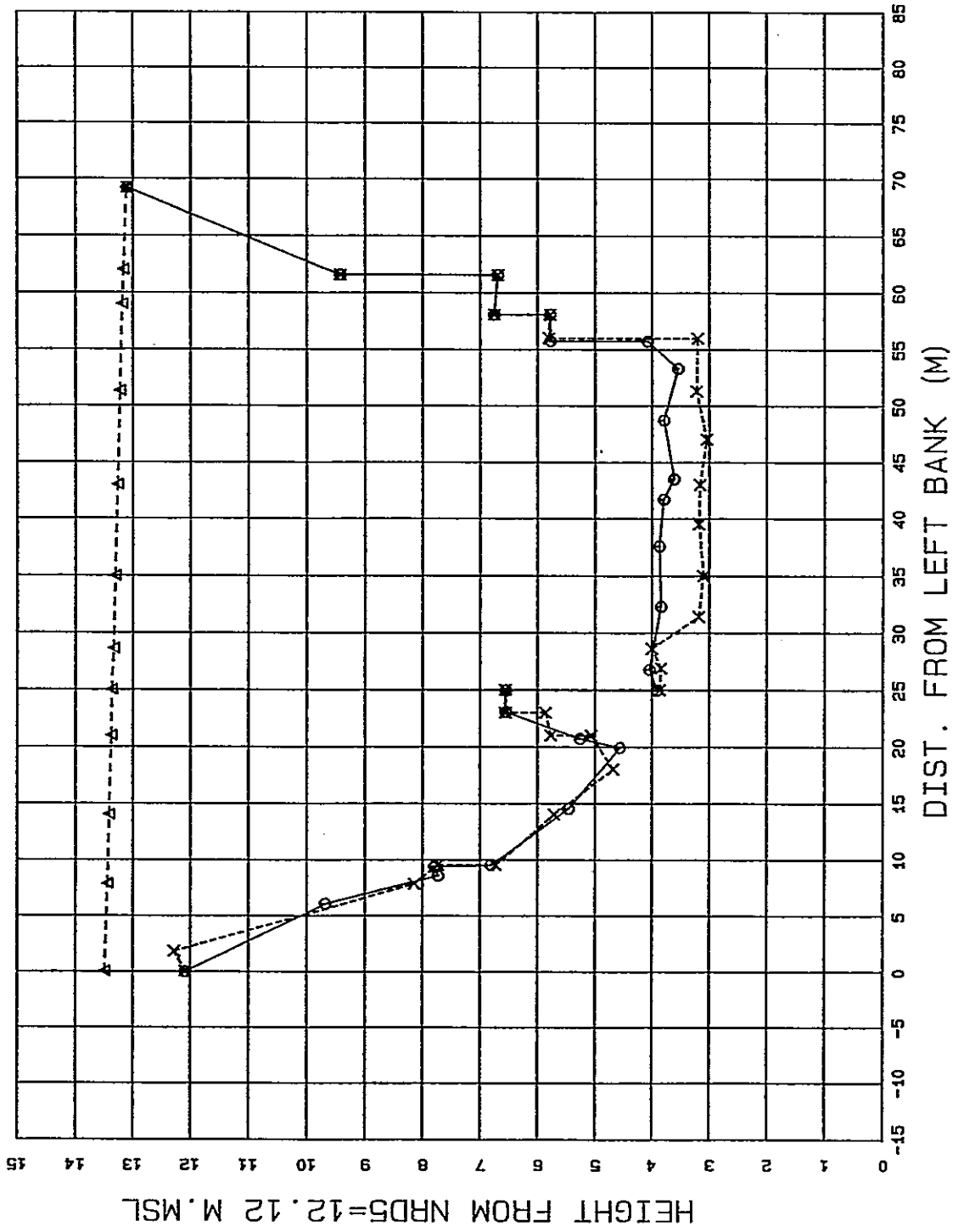
FIGURE
 25



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SEDIMENTATION RATES OF NATAL ESTUARIES
MBIZANA RIVER

FIGURE
 26



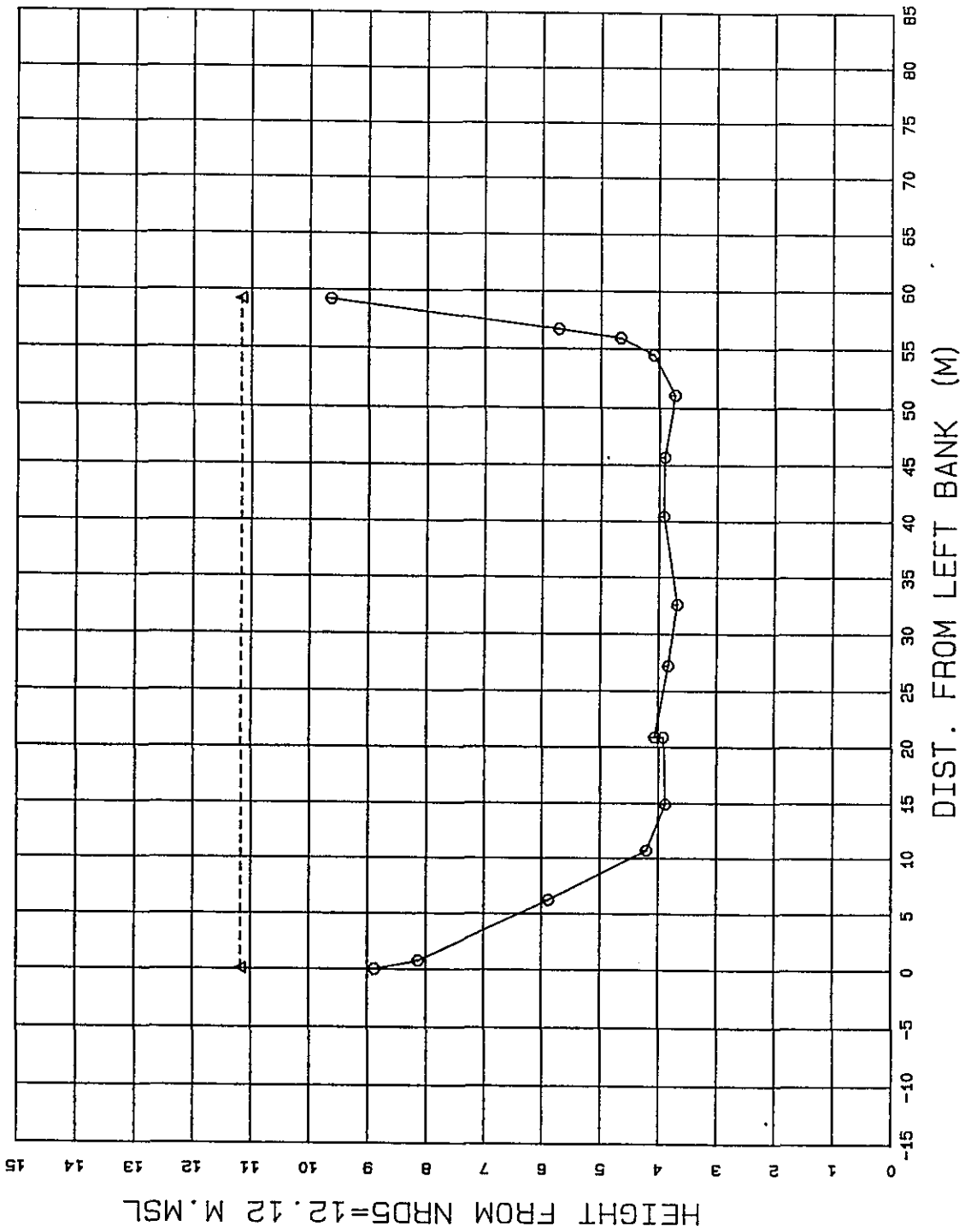
LEGEND : ○—○ 05-10-87
 ▲---▲ KERB-LEVEL
 X---X 20-02-87

PROFILE 3

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF NEW MBIZANA BRIDGE.

FIGURE
 27



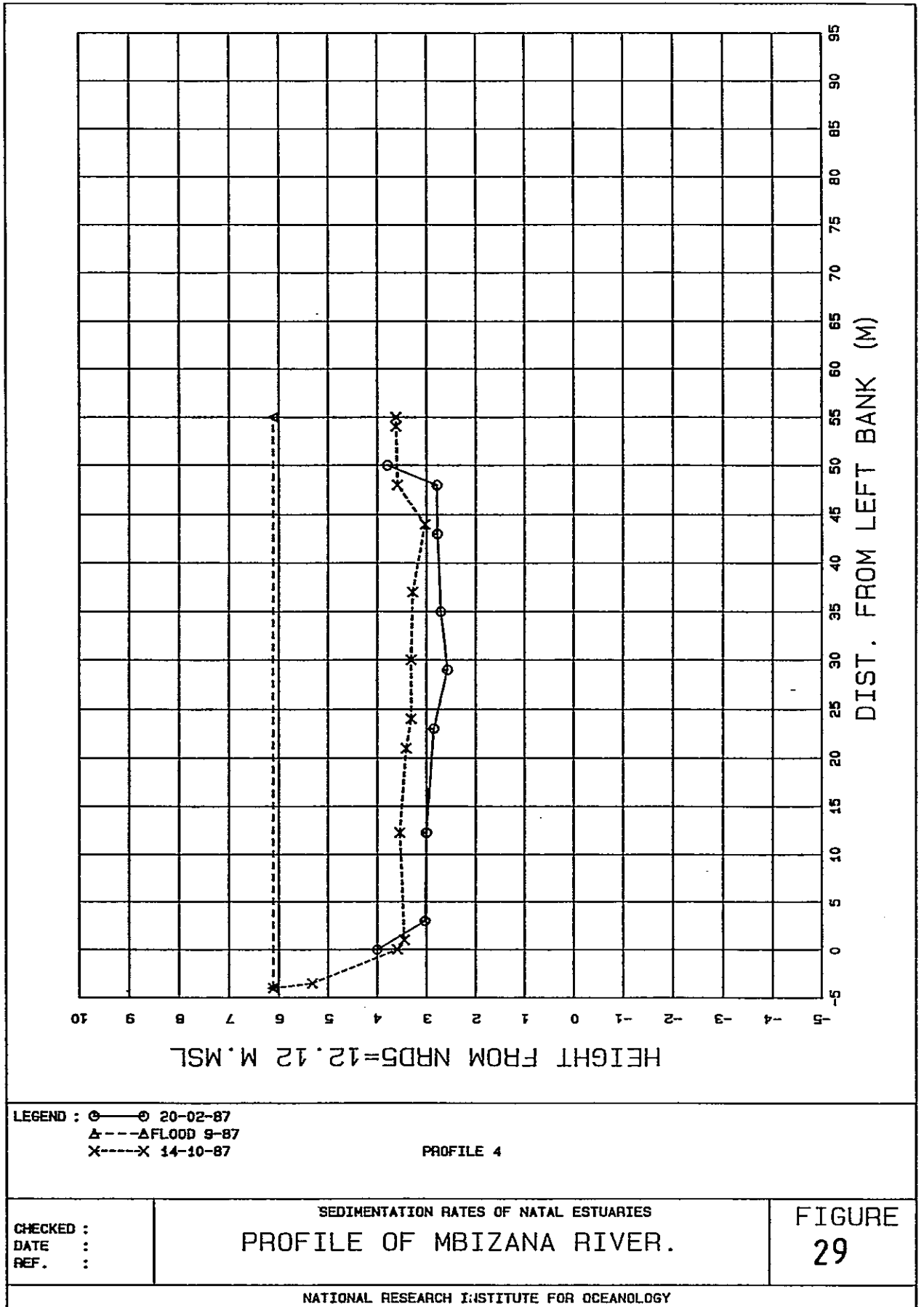
LEGEND : ○—○ 06-10-87
 ▲---▲ KERB-LEVEL

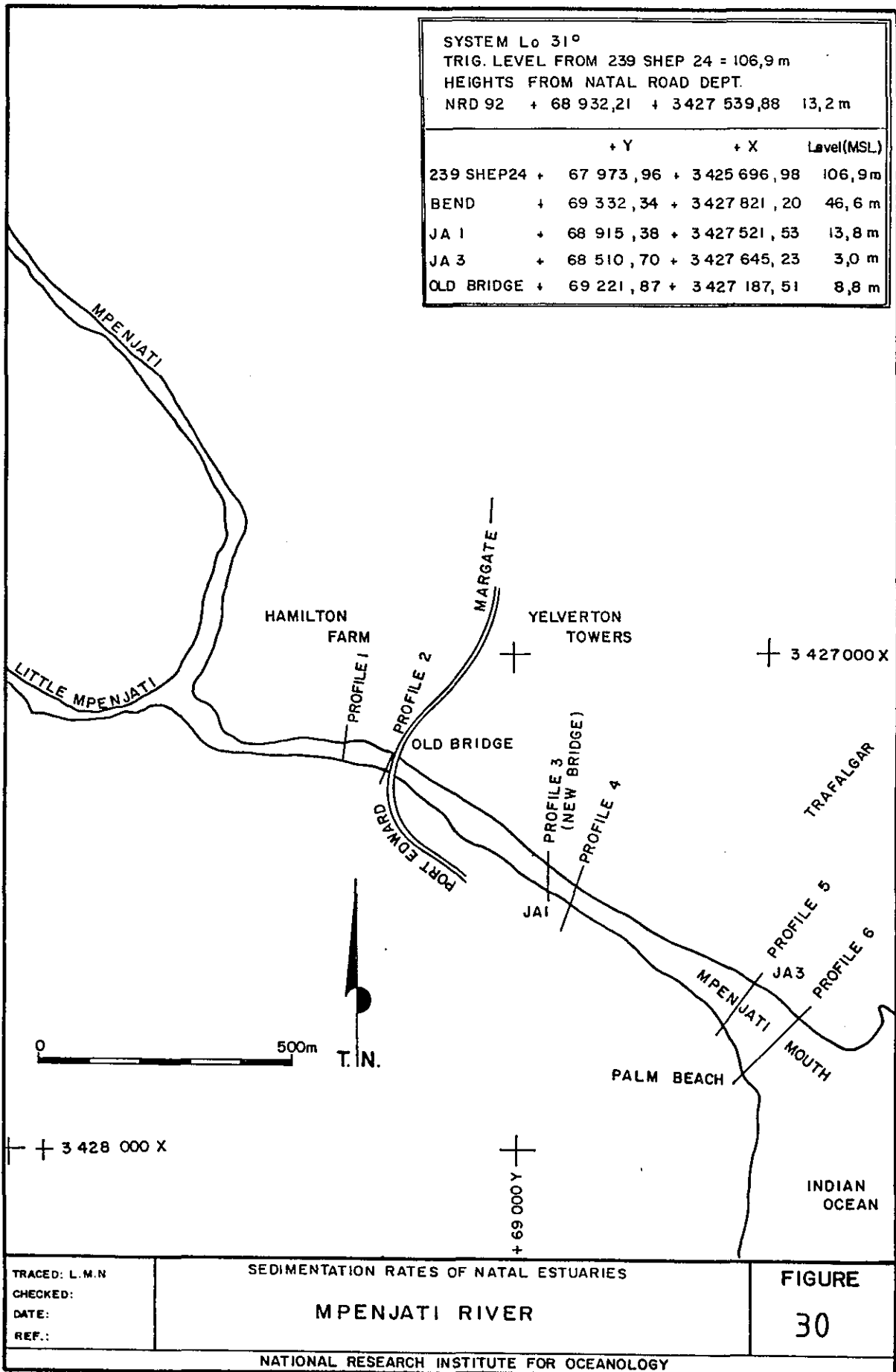
PROFILE 3A

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF OLD MBIZANA BRIDGE.

FIGURE
 28

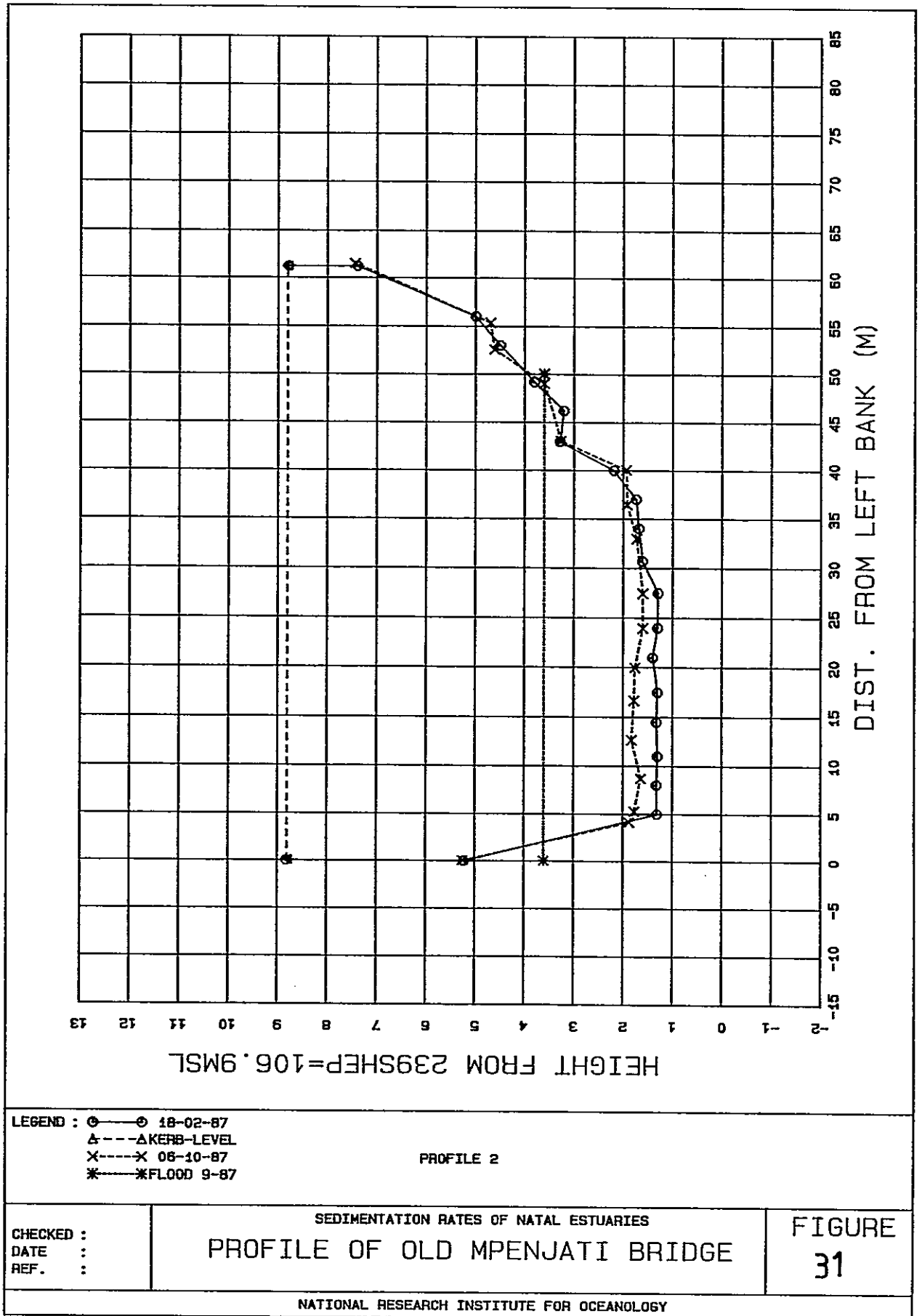


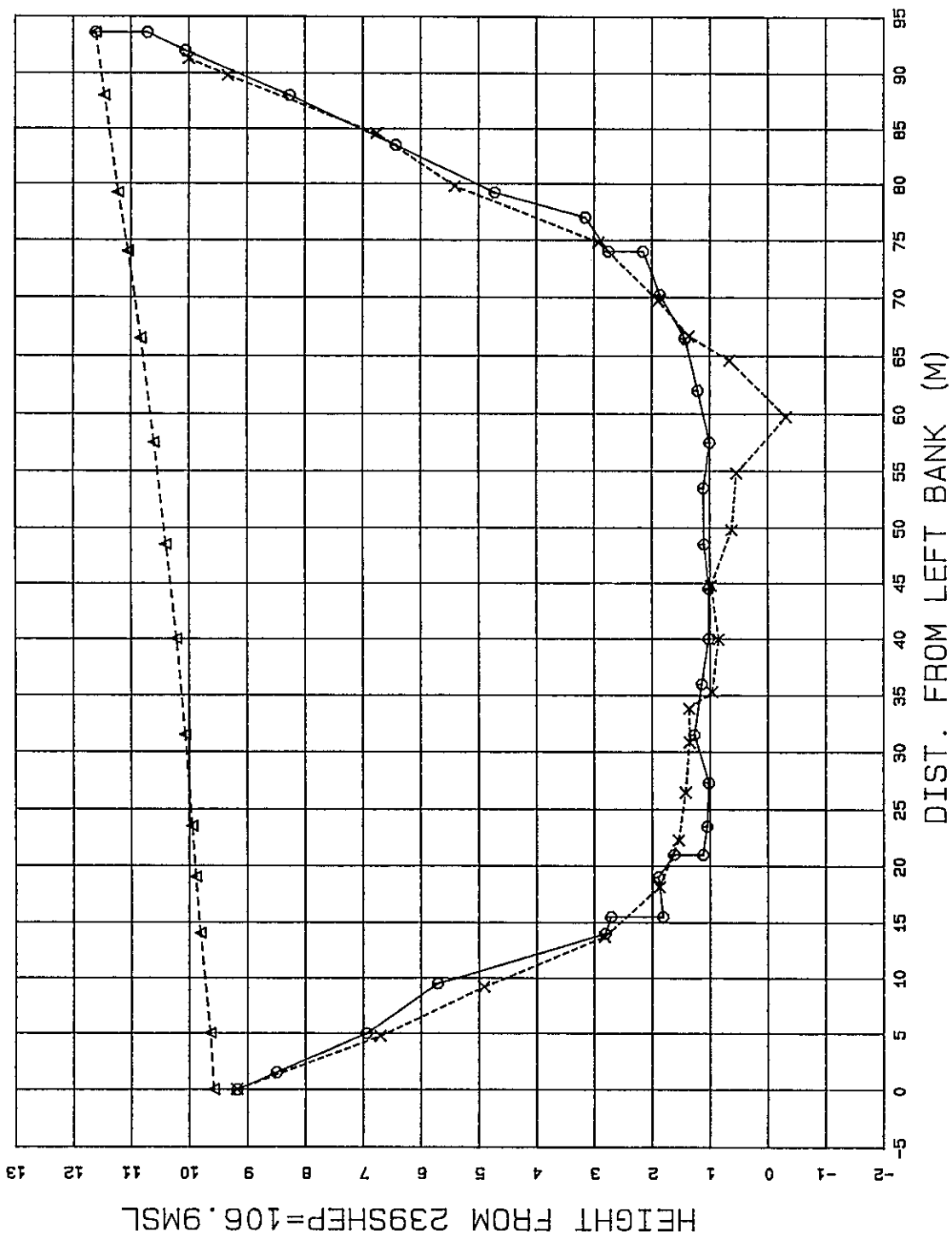


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SEDIMENTATION RATES OF NATAL ESTUARIES
MPENJATI RIVER

FIGURE
30





LEGEND : ○—○ 18-02-87
 ▲---▲ KERB-LEVEL
 ×---× 06-10-87

PROFILE 3

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SEDIMENTATION RATES OF NATAL ESTUARIES
 PROFILE OF NEW MPENJATI BRIDGE

FIGURE
 32

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