Coastal storms in NSW in August and November 1986 and their effect on the coast

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THE UNIVERSITY OF NEW SOUTH WALES
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COASTAL STORMS IN N.S.W. IN AUGUST AND NOVEMBER 1986

by

K.B. Higgs and R. Nittim

Technical Report No. 88/06
June 1988

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And their effect on the coast

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K.B. Higgs

and

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REPORT PREPARED FOR

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NSW AUSTRALIA

By

University of NSW Water Research Laboratory

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PREFACE

The work was undertaken and the report prepared under the direction of the Director of the Water Research Laboratory, acting on behalf of the client, Public Works Department, New South Wales.

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C.R. DUDGEON
Director

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Title

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And their effect on the coast

Author (s)

K.B. HIGGS and R. NITTIM

Sponsoring Organisation

Public Works Department, New South Wales

Supplementary Notes

The work was undertaken and the report prepared under the direction of the Director of the Water Research Laboratory acting on behalf of the client, Public Works Department, New South Wales.

Abstract

Two severe storms occurred in the second half of 1986, the first in August and the second in November. This report brings together the data that describe the weather and the sea during the storms and then documents the investigations carried out to determine the effect of the storms on the beaches in the Gosford, Sydney and Batemans Bay areas.

Distribution Statement

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1. INTRODUCTION

During the storms of August and November 1986, significant beach erosion and storm wave run-up occurred along the coast of New South Wales. Various data on these aspects were obtained by the Public Works Department of NSW (PWD) either during or immediately after the storms and are presented in this report together with relevant information collected before the storms.

Wave and tide data were recorded by the Department's Manly Hydraulics Laboratory and by the Maritime Services Board (MSB), at various locations along the NSW coast. The wind, atmospheric pressure and rainfall data were monitored by the Bureau of Meteorology. This storm data has been collated in this report. Run-up levels at selected locations on some Sydney and Batemans Bay beaches were measured by the Department and the Eurobodalla Shire Council. Measured run-ups for the Sydney Beaches are compared with those predicted with simple theory and the differences are discussed. The prediction of storm wave run-up levels for Batemans Bay is the subject of a separate study.

In addition, land surveys, aerial photography, offshore profiling, sand sampling data and video records of storm erosion damage are available for some areas. Where this type of data was available both before and after the storms, an assessment was made of the beach erosion or accretion and offshore profile change.

The Department has arranged that this information be collated into a readily accessible form and limited analysis carried out, so that it can be used to provide reliable and substantiated advice on coastal hazards in the future. The Water Research Laboratory (acting through Unisearch Ltd) was commissioned to carry out this work. The data collected and the analysis and interpretation of it, are detailed in the following sections.

2. SUMMARY

Two severe storms occurred in the second half of 1986, the first in August and the second in November. This report brings together the data that describe the weather and the sea during the storms and then documents the investigations carried out to determine the effect of the storms on the beaches in the Gosford, Sydney and Batemans Bay areas.

THE AUGUST STORM – 4TH TO 9TH AUGUST 1986

A low pressure system moving across NSW deepened into an intense coastal low off Coffs Harbour and brought gale force winds and heavy rainfalls to the NSW Central Coast between 4th and 9th August.

Atmospheric pressure fell to 1002 mb, 16 mb below normal August pressure for Sydney; winds gusted to 54 knots and heavy rain fell on the Georges River catchment causing severe flooding in the Liverpool area.

The maximum wave height of 13.2 m was recorded off Botany Bay on the 5th with a second maximum of 12.6 m on the 8th. Maximum significant wave height of 7.5 m was recorded on the 6th and again on the 8th and the significant wave height exceeded 4.0 m for four days. A maximum wave period of 15.1 seconds was recorded on the 8th and wave periods stayed in the range of 11 to 13.5 seconds from the 6th to the 15th August.

The storm coincided with spring tides, a gauge height of 1.77 m being predicted at Fort Denison on the 6th and 7th. The measured tide was 1.99 m, 0.22 m higher than predicted and it stayed 0.1 m or more above predicted for four days.

THE NOVEMBER STORM – 17TH TO 23RD NOVEMBER 1986

An intense low developed over southern NSW bringing gale force winds to the Central and Southern NSW coast.

Atmospheric pressure fell to 993 mb, 21 mb below the normal November pressure for Sydney; winds gusted to 48 knots. Heavy rainfall was recorded in the Batemans Bay region and light rainfall in the Gosford and Sydney regions.

Maximum wave height of 12.2 m was recorded off Botany Bay on the 20th. Maximum significant wave height of 6.9 m was recorded on the same day and the significant wave height exceeded 4.0 m for two days. Maximum wave period of 13.5 seconds was recorded several times between 19th and 22nd and the wave period stayed above 10 seconds between 18th and 23rd.

The storm coincided with spring tides, gauge heights between 1.71 and 1.67 m being predicted at Fort Denison between 18th and 20th. The measured maximum tide was 1.95 m on the 20th, 0.28 m above the predicted and it stayed 0.1 m or more above the predicted for two days.

RECURRENCE INTERVALS OF THE AUGUST AND NOVEMBER STORMS

Following the classification of storm severity adopted in the PWD Elevated Ocean Levels reports (PWD 1985b and 1986a) both the August and November storms fall into the extreme category (category "X"), that is, storms where the significant wave height exceeds 6.0 m. These storms occur, on the average, every 3.5 years. More precise recurrence intervals can be calculated on the basis of published wave height exceedance statistics as discussed in Section 3.3.4, but the published data give widely differing results and at present only ranges of recurrence interval can be stated. Thus the August storm had a recurrence interval between 6.5 and 3.0 years and the November storm between 3.5 and 1.5 years.

ELEVATED OCEAN LEVELS

Ocean level rises along a coastline during a storm due to the coincidence of high tide, storm surge, wave set-up and wave run-up. Tide gauges record the tide plus the storm surge, including the atmospheric set-up and wind set-up. Wave set-up in the surf zone is not at present being monitored except on an experimental research basis but the final wave run-up levels, which include all the set-up components, can be measured during the storm or immediately after the storm from debris lines.

Run-up levels can also be estimated from theory knowing the predicted tides and the wind field and wave statistics of the storm.

Measurements of wave run-up taken in August and November are compared with the theoretical estimates and reasonable agreement is found on exposed beaches where wave refraction effects are minimal. In the August storm measured run-up levels of 4 to 6 m AHD on Narrabeen/Collaroy Beach compare well with the theoretical estimate of 6.1 m AHD. In the Batemans Bay area, on the exposed beach of Malua Bay, the measured run-up level of 5.5 m AHD compares well with the theoretical estimate of 5.2 m AHD.

In the November storm run-up levels were measured only in the Batemans Bay area and the observed run-up level of 5.5 m AHD at Malua Bay compares reasonably well with the theoretical estimate of 4.9 m AHD.

COASTAL EROSION

Beach erosion occurs during storms where high energy waves cut the beach berm, moving the sand into an off-shore storm bar. Build-up of the bar causes the storm waves to break further off-shore thus reducing the wave energy reaching the beach until an equilibrium storm beach profile, comprising an erosion scarp and an off-shore storm bar, develops. Low energy wave climate slowly moves the sand stored in the off-shore bar back into the beach berm.

Beach erosion in the Gosford area was monitored by photogrammetric means for the August storm and by beach surveys carried out by the Soil Conservation Service for both August and

November storms.

Maximum beach berm erosion of 200 m^3/m of beach length was recorded on Forresters Beach. On the other beaches the berm erosion maxima reached to between 100 and 150 m^3/m. In a previous study (PWD 1985a) the PWD had determined design storm erosion volumes for Wamberal, Terrigal and Avoca beaches varying between 50 and 250 m^3/m. The berm erosion in the August 1986 storm on these beaches was significantly smaller.

The beach surveys carried out by the Soil Conservation Service indicated similar berm erosion volumes but also showed that while severe erosion took place in the August storm, the less intense and shorter November storm seems to have caused no further erosion, but possibly slowed down the beach recovery.

The state of some of the Gosford and Sydney area beaches following the August 1986 storm was recorded on video cassette by the Public Works Department of NSW, Coastal Branch. Details of these are given in Appendix A.

Offshore surveys carried out in the Gosford area in 1983/84 were compared with surveys done after 1986 storms. Only four survey lines were available for comparison and these showed that between 100 and 300 m^3/m of sand had been stored in the offshore storm bar. No changes in the offshore profile could be reliably detected below RL –16 m AHD.

In Warringah, beach erosion from the August storm was monitored by photogrammetric means. Maximum beach berm erosion of 180 m^3/m was recorded on South Narrabeen Beach. Narrabeen Beach showed less than 100 m^3/m erosion on average and on Collaroy Beach the erosion varied between 100 and 150 m^3/m. In general the erosion observed during the August 1986 storm was significantly less than the erosion that occurred in the 1974 storms.

Offshore surveys were carried out on Collaroy and Narrabeen Beaches in 1979 and 1983 and after the 1986 storms. The location and profile data of the survey lines is assembled in this report but detailed analysis of the survey records is required before any pre and post storm comparisons can be carried out.

3. ENVIRONMENTAL CONDITIONS

3.1 METEOROLOGICAL DATA

The following information is compiled primarily from the Bureau of Meteorology Monthly Summaries for August and November 1986 (Bureau of Meteorology, 1986a and 1986b). It has been supplemented with data from their hourly data sheets, 9 am and 3 pm weather bulletins, and chart records from various instruments. The location of the weather stations is given in Figure 1. The one hour mean wind speed used here is the average wind speed over an hour, and has been estimated from the chart records. The 10 minute mean wind speed obtained from the Bureau of Meteorology is the average wind speed over a 10 minute period. The one hour figures have been used where possible because they are more relevant to wave generation and wind set-up.

3.1.1 August 1986 Storm Description

On the 4th of August a low near Adelaide moved to the NSW coastal area and over the next few days deepened into an intense coastal low near Coffs Harbour. Upper air influences deepened the low to below 990mb, and for the period from the 4th to the 8th the NSW Central Coast was buffeted by strong to gale force winds and intense rainfall. Strong winds were reported in coastal waters throughout NSW from the 4th to the 9th and coastal gales from the 5th to the 8th. Oceanic gales were reported from the 5th to the 12th.

At Sydney Airport (Mascot) wind gusts reached a maximum of 54 knots (28 m/s) early on the 6th August and one hour mean wind speeds were up to 28 knots (14 m/s) on that day (Table 1 and Figure 2). Wind direction was generally from the ESE and SE (Figure 2). At Moruya Heads (approx 22 km south of Batemans Bay) 10 minute mean wind speed is recorded twice daily and reached a maximum of 24 knots (12 m/s) on the 6th. (Table 1 and Figure 3). Wind directions were generally from the south and SSE but turned to the SSW on the afternoon of the 6th (Figure 3).

TABLE 1. Maximum Wind Speeds For August and November 1986 Storms

Location	August		November	
	Mean	Gust	Mean	Gust
Sydney Airport	14	28	14	25
Moruya Heads	12		26	

Wind Speeds in metres/sec.

These strong winds generated very rough seas and heavy swell which created serious problems for shipping off the Illawarra Coast. In the Metropolitan area, the gales downed high tension wires in a south-western suburb, causing the death of two people. Much minor damage to property and trees was also sustained.

Record rainfall for August was received in the Metropolitan and adjacent Tableland regions during the August 1986 storm. Daily rainfall at Sydney Airport was 111 mm in the 24 hours to 9 am on the 5th, and 207 mm in the following 24 hours (Figure 2). This was the highest daily rainfall for several years. As a consequence major flooding occurred on the 5th to 8th in the Georges River and Nepean-Hawkesbury Rivers and minor flooding on the Shoalhaven River on the 6th. Widespread and severe local flooding also occurred on the 5th and 6th, mainly in the metropolitan district. The flooding was responsible for the loss of several lives and the damage bill to homes, properties, and vehicles by water was estimated at hundreds of millions of dollars. Rainfall at Moruya Heads was much less severe, with 35 mm recorded in the 24 hours to 9 am on the 3rd and 4th August (Figure 3).

Daily synoptic charts for the 3rd to the 9th August are shown in Figure 4. Atmospheric pressure at Sydney airport is plotted as a time series in Figure 2 and indicates that a low of 1002 mb occurred at about midnight on the 5th August. Normal August atmospheric pressure for Sydney is 1018 mb (Bureau of Meteorology, 1986a). Atmospheric pressure at Moruya Heads, recorded seven times each day by the Bureau of Meteorology, is plotted as a time series in Figure 3 and indicates that a low of 1010 mb occurred at about 5:00 pm on the 5th August. Normal August atmospheric pressure for Moruya Heads is 1017 mb (average of the 9:00 am and 3:00 pm values obtained from the Bureau of Meteorology, Melbourne).

The one hour mean wind speed and direction for Sydney Airport, at hourly intervals has been extracted from Bureau of Meteorology charts and time series plots are given in Figure 2. Daily rainfall data is also shown. The 10 minute mean wind speed and direction at Moruya Heads are measured twice daily by the Bureau. This data was obtained from the Bureau and is plotted in Figure 3 together with the daily rainfall.

The storm coincided with predicted spring tides.

3.1.2 November 1986 Storm Description

Strong winds were reported in coastal waters from the 17th to 23rd November and strong to gale force wind over much of the state on the 18th and in the eastern half on the 19th. These were in association with an intense low which developed over the southern NSW coast on the 18th November. Gale force winds were reported in ocean waters on the 18th and 19th, in coastal waters over southeastern parts of the state on the 20th and near the NSW/Victorian border on the 21st.

Winds gusts at Sydney Airport reached 48 knots (25 m/s) at about midday on the 20th, and one hour mean wind speeds were generally 20 to 27 knots (10 to 14 m/s) for most of the afternoon. Wind direction was from the west to south west on the 19th and south west to south on the 20th and 21st (Figure 2). At Moruya Heads the 10 minute mean wind reached 26 knots (13 m/s) from the SSW on the afternoon of the 19th. No damage was reported, but heavy swell arising from gale force winds at sea caused some difficulties.

Rainfall for the month was generally average to above average, with very much above average falls noted in some coastal areas and adjacent highlands, particularly Illawarra, and in parts of the Riverina and SW slopes. The highest daily rainfall at Sydney Airport was 47 mm in the 24 hours to 9:00 am on the 14th, about 4 days before the storm occurred. During the storm period, the rainfall in Sydney was generally low with a maximum of 25 mm in the 24 hours before 9:00 am on the 19th (Figure 2). No major flooding was reported. At Moruya Heads the rainfall was more severe with 115 mm recorded in the 24 hours to 9 am on the 19th November (Figure 3).

Daily synoptic charts for the 16th to the 23rd November are shown in Figure 4. Atmospheric pressure at Sydney airport is plotted as a time series in Figure 2 and indicates that a low of 993 mb occurred at about 5:00 pm on the 18th. Normal November atmospheric pressure for Sydney is 1014 mb (Bureau of Meteorology, 1986b). Atmospheric pressure at Moruya Heads is plotted as a time series in Figure 3 and indicates that a low of 992 mb occurred at about 2:00 am on the 19th. Normal November atmospheric pressure for Moruya Heads is 1014 mb (average of the 9:00 am and 3:00 pm values obtained from the Bureau of Meteorology, Melbourne).

One hour mean wind speed and direction for Sydney Airport, at hourly intervals has been extracted from Bureau of Meteorology charts and time series plots are given in Figure 2. Daily rainfall data is also shown. The 10 minute mean wind speed and direction for Moruya Heads are measured twice daily by the Bureau. This data was obtained from the Bureau and is plotted in Figure 3 together with the daily rainfall.

The storm coincided with predicted spring tides.

3.2 TIDE LEVELS

3.2.1 Fort Denison

Tide levels are recorded by the MSB at Fort Denison in Sydney Harbour. The location is well inside the harbour and is very protected from ocean waves. Water levels recorded would include barometric and wind set-up as well as astronomical tides, but would not include wave set-up since it is in a very sheltered location and is not within the breaker zone. The gauge uses a Harrison recorder that was installed in 1908.

The present gauge datum is 0.925 m below AHD and is referred to as "the zero of the Fort Denison Tide Gauge". It has been used for all tide levels in this report, unless otherwise specified. This datum is approximately ISLW (Indian Spring Low Water) and is often referred to by that name. This has been done in this report. However, ISLW is now treated as a variable not a datum. Eastern Standard Time is used throughout the year and has been used in this report.

The tides recorded during both the August and November 1986 storms have been replotted from high and low times and heights obtained from the MSB, and are reproduced in Figures 6 and 7. These plots also show the predicted tides at Fort Denison and the residuals between measured and predicted tides.

It should be noted that the predicted tides are calculated using harmonic constituents and mean sea level derived in an earlier year, and that these can change from year to year. It is common for measured and predicted tides to differ even in the absence of storms. Variations of up to ±0.2 m have been observed and variations of ±0.1 m are typical. Care should therefore be taken in interpreting tidal residuals, since they are only partly due to the storms.

The maximum level recorded during the August storm was 1.99 m above tide gauge zero (1.06 m above AHD), and occurred at approximately 9:05 pm on the 6th. The level was 0.22 m above the predicted height of 1.77 m (0.85 m AHD) for that time. The tidal residual exceeded 0.2 m for about 1.5 days and exceeded 0.1 m for almost 4 days (Figure 6). Tide predictions for Fort Denison are supplied to the MSB by the Tidal Laboratory, Flinders Institute for Atmospheric and Marine Sciences, Flinders University of South Australia. About 8% of predicted high tides exceed 1.77 m (Easton, 1970). An analysis of recorded extreme water levels at Fort Denison for the period 1883 to 1975 (LePlastrier, et al. 1976) indicates that a level of 1.99 m is likely to occur on average once or twice per year (Figure 8).

The maximum level recorded during the November storm was 1.95 m above tide gauge zero (1.02 m above AHD), and occurred at approximately 10:00 am on the 20th. This was 0.28 m above the predicted height of 1.67 m (0.75 m AHD) for that time. The tidal residual exceeded 0.2 m for one high and two low tides and exceeded 0.1 m for 2 days. About 16% of predicted high tides exceed 1.67 m (Easton, 1970). Recorded water levels at Fort Denison indicate that a level of 1.95 m is likely to occur on average two or three times per year.

The tide predictions indicate spring tides of height 1.77 m above Fort Denison Zero on the 6th and 7th August and 1.71 m on the 18th November.

The predicted and measured maximum tide levels for the two storms are summarised in Table 2. The maximum recorded tide levels for the two storms only differ by 0.04 m and are not abnormally high. The highest recorded tide level at Fort Denison is 2.37 m (1.45 m AHD), and occurred during storms in May 1974 (PWD, 1985b).

TABLE 2. Maximum Tide Levels For August and November 1986 Storms

Tide	August	November
Predicted Fort Denison	0.85	0.75
Recorded Fort Denison	1.06	1.02
Recorded Batemans Bay Zwarts	0.86	1.00
Recorded Batemans Bay Floatwell	NA	1.02

Heights in metres above AHD.

An assessment of the possible components of the tidal residuals is given in Section 4.3.

3.2.2 Batemans Bay

Tide levels are recorded by the PWD at two locations in Batemans Bay. A Zwarts gauge consisting of a Zwarts pole acoustic water level recorder with a Datataker logging system is located approximately 250 m north of Snapper Island (AMG Coordinates 247 791.5 E, 6 043 097.3 N). The location is shown in Figure 14a. The location has a mean water depth of about 6 m and is exposed to wave action. The gauge was operating during both the August 1986 and November 1986 storms. It records water levels at one second intervals and the data is analysed to give wave data as well as tidal data. The water levels are based on Batemans Bay Hydro Datum (BBHD) which is 0.889 m below AHD.

A Floatwell recorder consisting of a float gauge with an optically read pulley wheel and a solid state recorder, is located at the Clyde Princess Jetty near the entrance to the Clyde River, adjacent to the Batemans Bay town centre (AMG Coordinates 244 570 E, 6 044 985 N). The location is shown in Figure 14a. This part of the bay is protected from most wave action. The gauge was operating during the November but not the August storm. It records water levels at one minute intervals. The water levels are based on AHD.

Eastern Standard Time is used throughout the year and has been used in this report.

The data from both recorders is numerically filtered and water levels at 15 minute intervals are stored in the PWD database at Manly Vale. This data was used to reproduce the tide records in Figures 9, 10 and 11. These plots also show the predicted tides at Fort Denison. A value of 0.036 m has been subtracted from the predicted heights to convert from Fort Denison Datum to BBHD.

Tide levels recorded at the Zwarts gauge during the August and November storms are plotted in Figures 9 and 10 together with the predicted highs and lows for Fort Denison. The maximum level recorded at the Zwarts gauge during the August storm was 1.75 m BBHD (0.86 m AHD), and occurred at approximately 9:15 pm on the 6th August. The level was approximately equal to the predicted height of 1.77 m (0.85 m AHD) at Fort Denison for that time. The maximum level recorded during the November storm was 1.89 m BBHD (1.00 m AHD), and occurred at approximately 9:15 am on the 19th November. The level was 0.25 m above the predicted height of 1.67 m (0.75 m AHD) at Fort Denison for that time. The gauge failed for about 3 days between 15th and 18th, just before the November storm.

Comparisons of predicted high and low tides at Fort Denison with measured tides at the Batemans Bay Zwarts gauge are given in Figures 9 (August) and 10 (November). The low tide residuals are generally larger than the high tide residuals.

The Floatwell gauge was not operating during the August storm. Tide levels recorded at the Floatwell gauge during the November storm are plotted in Figure 11 together with the envelope of tide levels from the Zwarts gauge. The maximum level recorded during the November storm was 1.91 m BBHD (1.02 m AHD), and occurred at approximately 9:30 am on the 19th. The level was 0.19 m above the predicted height of 1.76 m (0.83 m AHD) at Fort Denison for that time. The predicted and measured maximum tide levels for the two storms are summarised in Table 2. Comparison of measured tides at the Zwarts gauge with those at the Floatwell gauge is also given in Figure 11. The differences are generally less than 0.1 m, but exceed 0.2 m on a number of occasions.

Batemans Bay is about 230 km south of Sydney but the tides are generally fairly similar in both time and height. There are no tidal predictions for Batemans Bay, but an analysis of the tidal constituents at the Zwarts gauge (PWD, 1987) indicated the same mean sea level as Fort Denison. Tide level statistics are not available but are likely to be similar to those for Fort Denison (see Section 3.2.1).

An assessment of the possible components of the tidal residuals is given in Section 4.3.

3.2.3 Other Tidal Data

Tidal data is available from the PWD for a number of other locations on the coast but these have not been considered here. These include, North Coast, Ettalong, Camp Cove, Balgowlah, Botany Bay, Port Kembla and Eden.

3.3 WAVE HEIGHTS AND PERIODS

3.3.1 Offshore Botany Bay

Wave height and period data for both the August 1986 and November 1986 storms, were recorded offshore of Botany Bay. The instrument is a Datawell Waverider buoy operated by the MSB and is located in approximately 75 m of water about 3 km east of Cape Solander, (Latitude 34° 02′ 34″ S, Longitude 151° 15′ 08″ E). The location is shown in Figure 1. Wave data from this location has been collected almost continuously since April 1971 and long term wave statistics are available. The instrument measures water surface elevation as a time series and cannot measure wave direction. The data is transmitted to shore and is recorded and analysed by the MSB. Recently the PWD Manly Hydraulics Laboratory has arranged to access this data. Data used for this report was obtained from the PWD.

The water level is recorded every half second for 34 minutes in each hour and both time series and spectral analysis are carried out. Details of the analysis are given in Reference PWD, 1986b. The commonly used parameters are the significant and maximum wave heights, which are determined with the time series analysis, and the spectral peak period, which is determined from the spectral analysis. The significant wave height is the average height of the one-third highest waves in the wave group. The maximum wave height is the highest wave for the same group. The spectral peak period is the wave period corresponding to the maximum of the energy spectrum. Eastern Standard Time is used throughout the year and has been used in this report.

The wave heights measured at the offshore Botany Bay Waverider buoy are generally considered to be deep-water values. However, since the instrument is in approximately 75 m of water the longer period waves have already been affected by shoaling and refraction. Small amplitude wave theory predicts that a 10 second wave travelling from deep water to a depth of 75 m will have its wave height reduced by about 1% by shoaling. A 12 second wave will have been reduced by about 4% and a 14 second wave by about 7%. Small amplitude wave theory also predicts that wave refraction offshore from the waverider buoy would be small for 10 second and shorter wave periods, but could be significant for the longer period waves, particularly those with wavefronts at large angles to the contours.

In the August 1986 storm the wave heights reached a maximum during the night of the 5th, dropped during the 6th and 7th, then reached a second maximum on the morning of the 8th (Figure 12a). The maximum wave height recorded was 13.2 m at 7:00 pm on the 5th and the maximum significant wave height was 7.5 m at 2:00 am on the 6th and 9:00 am on the 8th. In the November 1986 storm the maximum and significant wave heights were 12.2 m and 6.9 m respectively, both at 7:00 am on the 20th (Figure 12b). The significant wave height exceeded 4 m for approximately 4 days during the August storm but for only approximately 2 days during the November storm. These times have been used to indicate the storm durations. The maximum and maximum significant wave heights recorded for the two storms are summarised in Table 3.

TABLE 3. Maximum Wave Heights For August and November 1986 Storms

Location	August		November	
	Hs	Hmax	Hs	Hmax
Offshore Botany Bay	7.5	13.2	6.9	12.2
Offshore Batemans Bay	5.6	11.2	6.0	10.3

Significant Wave Height (Hs) and Maximum Wave Height (Hmax) in metres.

Immediately prior to the two storms the spectral peak wave period dropped to a low of about 6 seconds. It then increased and was generally between 9 and 13 seconds during the August storm and between 11 and 13.5 seconds during the November storm (Figures 12 a and 12 b). The maximum periods recorded were 15.1 seconds at 9:00 am on the 8th August and 13.5 seconds at numerous times between the 19th and 21st of November. These figures indicate that in the offshore Botany Bay region the August storm had slightly larger wave heights, slightly shorter wave periods and was of a significantly longer duration than the November storm.

Plots of significant wave height, maximum wave height and spectral peak period versus time for the 1st to 14th August and the 15th to 28th November are shown in Figures 12 a and 12 b.

3.3.2 Offshore Batemans Bay

Wave data for both the August and November 1986 storms, were recorded offshore from Batemans Bay. The instrument is a Datawell Waverider buoy operated by the PWD and is located in approximately 75 m of water approximately 7 km offshore, Latitude 35° 42′ 30″ S, Longitude 150° 21′ 24″ E (AMG Coordinates 6 045 000 N, 260 640 E). The location is shown in

Figure 1.

Wave data from this location has been collected almost continuously since 27th May 1986. The data is transmitted to shore and is recorded and analysed by the PWD Manly Hydraulics Laboratory. Eastern Standard Time is used throughout the year and has been used in this report. Analysis is identical to that for Botany Bay. The buoy is in a similar depth of water to the Botany Bay Waverider buoy, so wave shoaling and refraction offshore from the buoy would be similar.

In the August storm the maximum wave height recorded was 11.2 m at 8:00 am on the 6th and the maximum significant wave height was 5.6 m at 7:00 am and 9:00 am on the 6th (Figure 12 c). In the November storm the maximum wave height was 10.3 m at 3:00 am on the 19th and the maximum significant wave height was 6.0 m at 10:00 am and 2:00 pm on the 20th (Figure 12 d). The significant wave height exceeded 4 m for approximately 3 days during both the August storm and the November storm. The maximum wave heights are summarised in Table 3.

Immediately prior to the two storms the spectral peak wave period dropped to a low of about 6 seconds. It then increased and was generally between 10 and 13 seconds during both storms. The maximum wave period recorded was 13.5 seconds in both storms (Figures 12 c and 12 d). In the Batemans Bay region, the August and November storms had similar wave heights, wave periods and durations. The wave heights were lower than those recorded at offshore Botany Bay.

3.3.3 Other Wave Data

Offshore wave data for Byron Bay, Coffs Harbour, Crowdy Head, Port Kembla and Eden is available from PWD, Manly Hydraulics Laboratory, and data from Newcastle is available from the MSB, but these have not been included here. Inshore wave data from Coffs Harbour is also available from PWD.

3.3.4 Recurrence Intervals

Following the terminology adopted in the Elevated Ocean Levels Reports (PWD 1985b and 1985a) where storms with significant wave height greater than 6 m are classified as extreme (X), the August and November 1986 storms belong to the "X" category.

A rough estimate of recurrence interval can be based on the occurrence of "X" storms. In the 30 years 1956 to 1985, 14 "X" storms occurred, however, on several occasions two "X" storms were recorded in the same year and on an annual basis "X" storms occurred only in 9 years. This gives an approximate recurrence interval of 3.5 years for "X" category storms over this period.

More detailed analyses were carried out by McMonagle & Fidge (1981) and Youll (1981) who calculated recurrence intervals for wave height data from the offshore Botany Bay waverider. Both authors analysed approximately 9 years of data from the period May 1971 to April 1981. McMonagle & Fidge presented their results as a recurrence interval versus significant wave height (Hs) and Youll plotted Hs against the number of storms per year during which that wave height was recorded. Recurrence intervals for the August and November storms based on these two approaches are given in Table 4.

TABLE 4. Recurrence Interval of Offshore Botany Bay Wave Heights for August and November Storms

Storm Date	Hs (m)	Recurrence Interval (years)	
		McMonagle Fidge	Youll
August 1986	7.5	6.5	3.0
November 1986	6.9	3.5	1.5

Different methodology was used in the two papers to calculate the significant wave height versus recurrence interval relationship. The above recurrence intervals are given as a guide only and it is outside the scope of this report to determine which method is more appropriate for quantifying the severity of coastal storms.

3.4 STORM HISTORY - AUGUST 1985 TO AUGUST 1986

Wave data from the offshore Botany Bay and Port Kembla waverider buoys has been used to assess the storm history for the year prior to the August and November 1986 storms. All storms with a significant wave height above 2.5 m are summarised in Table 5. This data can be used to gauge the erosion or accretion state of the beaches at the time of the various surveys.

The offshore Botany Bay records show that the previous severe storm was nearly ten months before the August 1986 storm. The offshore Port Kembla records are similar but indicate that a storm in April 1986 was more intense in that area than in the offshore Botany Bay area.

TABLE 5. Recorded Storm Events, August 1985 to August 1986

Botany Bay			Port Kembla		
Storm Date	Category	Description	Storm Date	Category	Description
26 Oct 85	X	Severe			
19-23 Nov 85	B	Moderate	19 Nov 85	B	Moderate
1 Dec 85	C	Low	26-30 Nov 85	C	Low
3 Jan 85	C	Low			
18-24 Jan 86	B	Moderate	18-24 Jan 86	B	Moderate
23 Feb 86	C	Low	3-10 Feb 86	C	Low
8-14 Mar 86	B	Moderate	8-13 Mar 86	C	Low
6 Apr 86	B	Moderate	7 Apr 86	A	High
17 Apr 86	C	Low	17 Apr 86	C	Low
30 Apr 86	C	Low	30 Apr 86	C	Low
21 May 86	B	Moderate	21 May 86	B	Moderate
31 May 86	C	Low	1 Jun 86	C	Low
11-17 Jun 86	C	Low	18 Jun 86	C	Low
29 Jun 86	C	Low	30 Jun 86	C	Low
			26 Jul 86	B	Moderate
5-6 Aug 86	X	Severe	5-6 Aug 86	X	Severe

Note:

Description	Category	Significant Wave Height
Severe	X	> 6.0 m
High	A	5.0-6.0 m
Moderate	B	3.5-5.0 m
Low	C	2.5-3.5 m

4. WAVE RUN-UP

4.1 MANLY WARRINGAH BEACHES

Maximum wave run up levels occurring along the Manly Warringah coast during the August 1986 storm, have been estimated by PWD, Coastal Branch (PWD, 1987). The positions of maximum run-up, as indicated by the storm debris line, were observed at 38 locations during the peak of the storm and on 11th and 12th August 1986. For each of these locations, the beach profile down to about the water's edge was determined photogrammetrically, from aerial photography taken on 18th August (See section 5.2.1) and the elevation of maximum run-up determined. The run-up and profile data is held by PWD (Reference 17).

The locations and run-up levels are shown in Figures 13 a-d. Wave run-up levels recorded in August varied from 3.0 m AHD on Long Reef Beach to 7.2 m AHD on Narrabeen Beach. These were between 2.1 m and 6.3 m above the predicted maximum tide level of 0.9 m AHD at Fort Denison. Typical values were 5 m to 7 m at exposed locations, and less in the more sheltered areas. Values above 6 m AHD were observed at near vertical erosion scarps or at rock walls (PWD 1987).

An assessment of these run-up levels is given in Section 4.3.

Run-up was not recorded after the November storm.

4.2 BATEMANS BAY BEACHES

Maximum run-up levels were recorded at six locations in the Batemans Bay region soon after the August 1986 storms. On each occasion the location and elevation of the maximum run-up were determined or pegged for later measurement. This was repeated but with 24 locations soon after the November 1986 storm. The locations were revisited and the beach profiles surveyed in December 1986. The profile data is held by PWD (Reference 18).

The locations and run-up levels for both storms are given in Figures 14 a-c. Run-up levels shown in parenthesis on these drawings correspond to the November storm.

In the Batemans Bay area the August levels varied from 1.9 m AHD in Chain Bay to 5.5 m AHD in Malua Bay. These are between 1.0 m and 4.6 m above the predicted maximum tide level of 0.9 m AHD at Fort Denison. In November they varied from 1.4 m AHD at Surfside Beach to 3.7 m AHD in Chain Bay. These are between 0.4 m and 2.7 m above the predicted maximum tide level of 1.0 m AHD at Fort Denison. However, since only a limited number of measurements were taken, the actual range of run-up levels that occurred is likely to be greater. The significantly different values for Chain Bay for the two storms are probably partly due to different offshore wave directions.

An assessment of these run-up levels is given in Section 4.3.

4.3 THEORETICAL ASSESSMENT

Wave run-up is the result of wave momentum being dissipated on the beach or other shoreline. The level reached depends on the water level near the shore, the wave characteristics and the beach characteristics. These are all very site specific and time dependent, so variations in run-up levels can be large. For predictions of wave run-up, the water level used must include tide, wave set-up, wind set-up and barometric set-up. These are all additive, and it is usually sufficient to consider only the maximum water level for the storm. However, the maxima of the various components do not always coincide.

The run-up process is a very complex phenomenon governed by the morphodynamic interaction of the beach with the wave climate. Both the wave set-up and wave run-up are driven by surfbeat and sub-harmonic oscillations in the surf zone (Short & Wright, 1984). Theoretical descriptions, however, are based on the simpler approach of radiation stress for wave set-up, and wave run-up predictions are based on empirical observations.

Theoretical prediction of wave run-up for a particular location requires the calculation of the local breaking wave height. This presumes that bathymetric surveys are available to calculate wave refraction. These calculations must then be carried out for each locality of interest.

In this study only generalised run-up predictions are made, assuming no wave refraction and a few typical beach slopes.

An estimate of the separate components of total run-up is made in the following sections.

4.3.1 Tide Prediction

Tides on the east coast of Australia generally have a range of between 1 m and 2 m, and are the largest cause of water level variation. Tidal predictions are based on the analysis of tides in earlier years and there are a number of limitations involved.

First, the tide recorders record changes in water level from whatever cause. This will generally include barometric set-up and wind set-up. These are often grouped together and called storm surge or meteorological tides. The gauges are normally located in an area which is not subject to breaking waves, so wave set-up is not included. If the gauge is located in an estuary, the water level can also be influenced by freshwater flows.

The recorded tide is digitised, normally at one hour intervals, and about one year's data (usually 369 days) is analysed to determine harmonic constituents and the mean tide level. The period of the constituents obtained generally varies from 1 year to about 3 hours (2 hours if shallow water constituents are included). Some non-tidal effects may be included in the constituents if they have a harmonic form. For instance seasonal effects can be included in the 1 year (SA) component. However, it is normally assumed that non-tidal effects such as wind and barometric set-up are not included and that the analysis represents normal or average conditions.

If one year tidal analyses are carried out for a given location for a number of consecutive years, there will be some variation of the constituents. There are a number of reasons for this, including annual variations in climate, mean sea level, etc and astronomical causes having periods greater than a year.

Tidal predictions based on these one year analyses cannot include the effects of longer term variations, and are rarely assumed to be accurate to better than 0.1 m. Care must therefore be taken in interpreting differences between measured tides and predictions based on analysis of a different year's tides.

4.3.2 Wave Set-up

When waves break on the shore, there is a decrease in mean water level or set-down relative to that just prior to breaking, with the maximum set-down close to the breaking point. From the breaking point the mean water surface slopes upward to the point of intersection with the shore. Wave set-up is defined as the super-elevation of the mean water level caused by wave action alone, and is related to the conversion of the kinetic energy of the wave motion to potential energy. It depends on a train of waves arriving at the shore over a sufficient period of time to establish an equilibrium water level. A duration of an hour is considered a minimum for the full set-up to be established. The larger waves in the spectrum are generally too infrequent to contribute to the wave set-up and the significant wave height is normally used. The wave set-up can be calculated from the breaking wave height which in turn is calculated from the offshore wave height, wave period, and the beach slope. Normally the equivalent un-refracted offshore wave height and the spectral peak period are used. Wave refraction can have a significant influence on breaking wave height, and therefore wave set-up, but it is site specific and has not been fully considered here.

Various methods are available for estimating the breaker height, one being the empirically derived curves of Goda (CERC, 1984, p2-131). These give a breaker height index (breaking wave height over equivalent unrefracted offshore wave height) in terms of offshore wave steepness (wave height over wave length) and beach slope. Empirical relationships derived by Weggel (CERC, 1984, p2-130) can be used to derive the depth of breaking from the breaking wave height, period and beach slope.

The net wave set-up relative to the normal still water level outside the breaker zone, can be estimated by calculating the set-down at the breaking zone and the wave set-up between the breaker zone and the shore, using the theory of Longuet-Higgins and Stewart, (CERC, 1984, p3-101).

In a real situation the incident wave height will be non-uniform and there will be gaps in the breaker line due to uneven topography and rip channels. These will reduce the wave set-up in some areas, so the calculated values would be the maximum. In some areas, however, wave refraction will increase local wave heights and cause the wave to break in deeper water with a larger breaking wave height. This would result in higher wave set-ups than the unrefracted estimates given here. In other areas the opposite will occur and wave set-ups will be less than the estimates given here.

Calculations of maximum unrefracted wave set-up for the Batemans Bay and Sydney regions during the August and November storms (ignoring refraction, etc) have been carried out using the methods outlined above. Beaches in the Sydney area are generally on the open coast and this approach should give a useful prediction of run-up levels. Batemans Bay beaches are generally within the relatively shallow bay, and wave refraction would be significant. The unrefracted estimates will not be applicable to these beaches, but may be appropriate for Malua Bay.

The offshore significant wave height has been used in place of the equivalent unrefracted offshore wave height to estimate the breaking conditions. For the August storm the maximum significant wave height was 7.5 m offshore from Botany Bay, and 5.6 m offshore from Batemans Bay. For the November storm the maximum significant wave height was 6.9 m offshore from Botany Bay, and 6.0 m offshore from Batemans Bay. Offshore bed slopes in the region of the wave break are variable but are generally in the range 0.02 to 0.05.

Calculated breaking wave heights, water depths at breaking point and wave set-up for these two beach slopes and various wave heights and periods, are given in Table 6. The figures indicate that for conditions occurring during the two storms, the wave set-up is strongly dependent on wave height, and much less dependent on wave period and bed slope. The small differences in wave period between the two storms would have a negligible effect on wave set-up.

TABLE 6. Estimated Wave Set-up for Various Wave Conditions

Wave Period (s)	Wave Height (m)	Bed Slope=0.02			Bed Slope=0.05		
		Hb (m)	db (m)	Set-up (m)	Hb (m)	db (m)	Set-up (m)
10	4	4.5	5.2	0.57	5.1	5.2	0.56
10	5	5.4	6.3	0.69	6.1	6.3	0.70
10	6	6.3	7.5	0.85	7.0	7.5	0.84
10	7	7.1	8.6	0.99	7.9	8.6	0.99
10	8	8.0	9.8	1.14	8.8	9.9	1.16
12	4	4.9	5.6	0.61	5.6	5.5	0.58
12	5	5.9	6.7	0.74	6.6	6.6	0.72
12	6	6.7	7.8	0.86	7.6	7.7	0.84
12	7	7.6	8.9	0.99	8.5	8.8	0.97
12	8	8.5	10.0	1.12	9.5	10.0	1.12
14	4	5.3	5.9	0.65	6.1	5.8	0.62
14	5	6.3	7.1	0.78	7.2	6.9	0.74
14	6	7.3	8.3	0.91	8.2	8.1	0.87
14	7	8.2	9.4	1.04	9.2	9.2	1.00
14	8	9.0	10.5	1.15	10.2	10.3	1.12

Notes:

1. Hb = Breaking Wave Height, from Goda, CERC, 1984, p2-131, Figure 2.72
2. db = Depth of Breaking, from Weggel, CERC, 1984, p2-130, Equation 2.92
3. Set-up = net wave set-up, from Longuet-Higgins & Stewart, CERC, 1984, pp3-101,102, Equation 3-77

Using the Botany Bay wave data, the maximum wave set-up in the absence of refraction, assuming beach slopes are typical, is estimated at 1.1 m in August and 1.0 m in November. These figures should be applicable to beaches in the Manly Warringah and Gosford area. Using the Batemans Bay wave data, the figures are estimated at 0.8 m in August and 0.85 m in November. These figures should be applicable to Malua Beach. These values are summarised in Table 7.

Most tide recorders are located outside of the breaker zone, so wave set-up does not normally contribute to the difference between predicted and measured tides. Batemans Bay Zwarts gauge is in an area which could be within a breaker zone, in some severe storms where waves break across most of the inner Bay area. However, this does not appear to have been the case during the August and November storms.

4.3.3 Wind Set-up

Wind set-up is the raising of the mean water level near the shore resulting from wind stress acting on the water surface. It is one of the reasons why predicted and measured tides differ. The set-up varies with the wind velocity and the fetch available. In the ocean situation it is the comparatively shallow areas of the continental shelf that are affected. It can be estimated using the theory given by Silvester (1974, p184). This gives the set-up as a function of the fetch length and depth as well as the wind speed.

In this situation the fetch is that part of the wind field that is acting on continental shelf waters. If the wind field is large in comparison to the width of the shelf, and the winds are directly onshore, the fetch length is generally taken to be equal to the width of the shelf (Silvester, 1974). This is approximately 40 km at Gosford and the northern Sydney beaches, and 30 km at Batemans Bay. If the winds are at an angle to the coast, the fetch is increased, but this is limited by the size of the wind field. The depth at the edge of the shelf is taken as 200 m. The depth at the shoreward limit of the fetch, has been taken as 1 m.

During the August 1986 storm the maximum one hour mean wind speed at Sydney Airport was about 28 knots (14 m/s) from the SE direction. These winds were not directly onshore but it is assumed that they would produce a similar set-up to the same wind directly onshore since the fetch length is increased and the onshore component of the wind decreased. It is assumed that winds in the Manly Warringah and Gosford area would be similar to those at Sydney Airport. Wind speeds at Moruya Heads were only slightly lower but were from the SSW to SSE, so the wind set-up is unknown.

During the November 1986 storm the maximum one hour mean wind at Sydney Airport was 27 knots (14 m/s) from the west to south direction. Wind speeds at Moruya Heads were similar but were from the SSW direction. It is not known whether the southerly winds would produce set-up or not, but the offshore winds could produce some set-down. A figure of 14 m/s has been adopted here to estimate the maximum wind set-up in the Sydney region during the August 1986 storms. Wind directions in the Sydney region during November, and in the Batemans Bay area during both August and November, were along-shore, or off-shore. The contribution of these winds to the set-up is not known but is not thought to be large.

The values given above indicate a maximum wind set-up of 0.06 m at the Gosford and northern Sydney beaches, during the August storm. Given the uncertainty in the calculations, it is estimated that the wind set-up in the Sydney and Gosford regions is unlikely to have exceeded 0.1 m. For the November storm in the Sydney region, and both storms in the Batemans Bay region, the wind set-up is likely to have been less and can probably be ignored.

4.3.4 Barometric Set-up

Barometric set-up is the raising of mean water level caused by a drop in atmospheric pressure. It is one of the reasons why predicted and measured tides differ. An estimate of barometric set-up can be made using simple hydrostatic theory which predicts a set-up of 10 mm per millibar (mb) pressure drop. The average barometric pressure varies from place to place and from month to month. For Sydney it is 1018 mb for August and 1014 mb for November. For Moruya Heads near Batemans Bay it is 1017 mb for August and 1014 mb for November (see Section 3.1).

In the August storm the pressure dropped to below 990 mb at the centre of the depression, but the centre was located some distance offshore. The lowest pressure at Sydney Airport was approximately 1002 mb and at Moruya Heads was 1010 mb. Hence, the Sydney records indicate a maximum pressure drop of 16 mb and the Moruya Heads records indicate a maximum pressure drop of 7 mb. These correspond to barometric set-ups of 0.16 m and 0.07 mb respectively. The variation in atmospheric pressure along the NSW coast from the Gosford area to Batemans Bay at the time is not known, but it is unlikely that the barometric set-up in August would have exceeded 0.2 m.

In the November storm the Sydney Airport records indicate that the lowest pressure was approximately 993 mb. At Moruya Heads the lowest pressure recorded during the storm was 992 mb. This indicates maximum pressure drops of 21 mb and 22 mb respectively and corresponds to barometric set-ups of 0.21 m and 0.22 m. The variation in atmospheric pressure along the NSW coast from Gosford area to Batemans Bay at the time is not known, but it is unlikely that the barometric set-up in November would have exceeded 0.25 m.

4.3.5 Storm Sea Level

The sea level outside the breaker zone during a storm is normally estimated by summing the tide height and the wind and barometric set-ups. Inside the breaker zone, the wave set-up must also be included. In predicting the storm sea level at the peak of a storm, the worst case is normally considered and it is assumed that the maximum predicted tide, and the maxima of each component of set-up occur simultaneously. This approach has been adopted for his report and Table 7 gives the recorded wave heights, estimated components of run-up and the storm sea level and run-up levels at the peak of both storms for the Sydney area and Batemans Bay.

The August storm occurred during spring tides and was of sufficient duration to ensure that low atmospheric pressure, strong winds and large wave heights occurred at the maximum high tide. The last high tide on the 5th corresponded closely to the first peak in the wave height. The barometric pressure reached a minimum and the wind speed reached a maximum close to this time. It is therefore valid for the maximum storm sea level for this storm to be estimated by adding the maximum predicted tide to the estimated wave, wind and barometric set-ups.

In the Sydney region in August the maximum storm sea level outside of the breaker zone is estimated to have been 0.85+0.06+0.16 = 1.07 m AHD. This agrees closely with the maximum recorded tide level of 1.06 m AHD at Fort Denison. The storm sea level within the breaker zone is estimated to have been the level outside the breaker zone plus 1.1 m wave set-up, ie 2.17 m AHD.

In the Batemans Bay region in August the maximum storm sea level outside of the breaker zone is estimated to have been 0.85+0.00+0.07 = 0.92 m AHD. This is 0.06 m higher than the maximum tide level of 0.86 m recorded at Batemans Bay Zwarts gauge. The storm sea level level within the breaker zone is estimated to have been the level outside the breaker zone plus 0.8 m wave set-up, ie 1.72 m AHD.

The November storm was of shorter duration and the maximum wave heights occurred after the largest tides. The barometric pressure reached a minimum before both the maximum tide and the maximum wave height. The maximum storm sea level should therefore be less that obtained by adding the individual maxima.

In the Sydney region for November, the maximum storm sea level outside of the breaker zone, estimated by summing the tide, wind set-up and barometric set-up, is 0.75+0.00+0.21 = 0.96 m AHD. This is 0.06 m lower than the maximum recorded tide level of 1.02 m AHD at Fort Denison. The storm sea level within the breaker zone is estimated to be this plus 1.0 m wave set-up, ie 1.96 m AHD.

In the Batemans Bay region for November, the maximum storm sea level outside the breaker zone is estimated to have been 0.75+0.00+0.22 = 0.97 m AHD This is slightly lower than the maximum tide level recorded at Batemans Bay Zwarts (1.00 m AHD) and Floatwell (1.02 m AHD) gauges. The maximum storm sea level within the breaker zone is estimated to be 0.97 m AHD plus 0.85 m wave set-up, ie 1.82 m AHD. For the November storm these levels are likely to be over estimates of set-up since the peaks of each component did not coincide. The estimated water level components are summarised in Table 7.

4.3.6 Wave Run-up

The elevation of the final run-up of the waves on a beach, is used to assess the possible extent of coastal inundation. This water level is that produced by adding the predicted wave, wind and barometric set-ups and the wave run-up to the predicted tide level.

In the Manly Warringah area many of the beaches are exposed to ocean storms and simple estimates of wave breaking and run-up may be useful. In Batemans Bay, however, many of the beaches are partly sheltered from ocean storms and the shallowness of the bay makes wave refraction more significant. Simple estimates of wave breaking parameters and run-up are therefore probably only applicable in the Malua Bay area.

The Gosford and Sydney beaches considered here generally show a bar formation during a storm. The slope on the outer face of the bar is typically 0.02 to 0.05 and the top of the bar is 4 to 6 m below AHD (5 to 7 m below high tide level). These parameters would vary with location and with the extent and duration of the storm. Inshore of the bar the depth is usually slightly greater than at the bar. The slope of a beach in the run-up region varies with location, elevation and time, and is dependent on factors such as the wave exposure and sand grain size. Typical values are 0.05 to 0.10. At the very back of a beach the slopes are often much steeper and in some cases man made structures occur.

The data used in this report to estimate wave run-up was derived by Saville, (1958) and is from small scale laboratory tests of monochromatic waves on smooth impermeable slopes (CERC, 1984, p7-16).

In the August storm the maximum wave height recorded was 13.2 m at offshore Botany Bay and 11.2 m at offshore Batemans Bay. In the November storm the maximum wave height recorded was 12.2 m at Botany Bay and 10.3 m at Batemans Bay. The wave periods were typically 10 to 13 seconds.

The height of the run-up above still water level, is dependent on the wave steepness which increases with wave height, but decreases with wave period. The maximum run-up therefore does not necessarily correspond to the maximum wave height. The wave steepness has been calculated for each set of wave data and the maxima have been determined. At Botany Bay the maximum deep water wave steepness was 0.013 in both storms, and at Batemans Bay it was 0.016 in both storms (calculated from the hourly maximum wave heights and peak periods). Saville's data (CERC, 1984, pp 7-19]) gives wave run-up for these wave steepnesses on a slope of 0.1 as being about 0.3 times the offshore wave height. The figures for the two locations and two storms are given in Table 7.

TABLE 7. Estimated Components of Run-up for August and November 1986 Storms

	Sydney		Batemans Bay	
	August	November	August	November
Significant Wave Height (Hs)	7.5	6.9	5.6	6.0
Maximum Wave Height (Hmax)	13.2	12.2	11.2	10.3
Maximum Wave Steepness	0.013	0.013	0.016	0.016
Predicted High Tide Level	0.85	0.75	0.85	0.75
Estimated Barometric Set-up	0.16	0.21	0.07	0.22
Estimated Wind Set-up	0.06	0.00	0.00	0.00
Estimated Wave Set-up	1.10	1.00	0.80	0.85
Estimated Storm Sea Level	2.17	1.96	1.72	1.82
Estimated Run-up (0.3×Hmax)	3.96	3.66	3.36	3.06
Estimated Run-up Level	6.1	5.6	5.1	4.9

Heights in metres, Levels in metres above AHD

4.4 COMPARISON OF MEASURED AND THEORETICAL RUN-UP LEVELS

Wave run-up levels recorded in Manly Warringah in August varied from 3.0 m AHD on Long Reef Beach to 7.3 m AHD at the south end of Narrabeen Beach (Figures 13 a-d). Typical run-up levels were 4 to 6 m AHD with levels above 6 m AHD being recorded on steep erosion scarps and rock walls. These compare favourably with the estimated value of 6.1 m AHD (Table 7). For more detailed analysis, see PWD (1987).

The Long Reef Beach site is partially protected by reef and the measured wave run-up in that area is less than the maximum estimated. Narrabeen and Collaroy Beaches is very exposed and could be subject to the maximum wave set-up. The measured run-up levels are higher than the simple estimates made here. It must be remembered that the run-up was measured at a limited number of locations, and the maximum and minimum values may have exceeded those measured. In addition, the estimated wave set-up is for unrefracted waves, and the actual set-up could be higher or lower.

In the Batemans Bay area the August run-up level of 5.5 m AHD at Malua Bay (Figure 14 c) compares favourably with the estimated value of 5.1 m AHD (Table 7). In November no run-up measurements were taken at Malua Bay.

5. BEACH SURVEYS

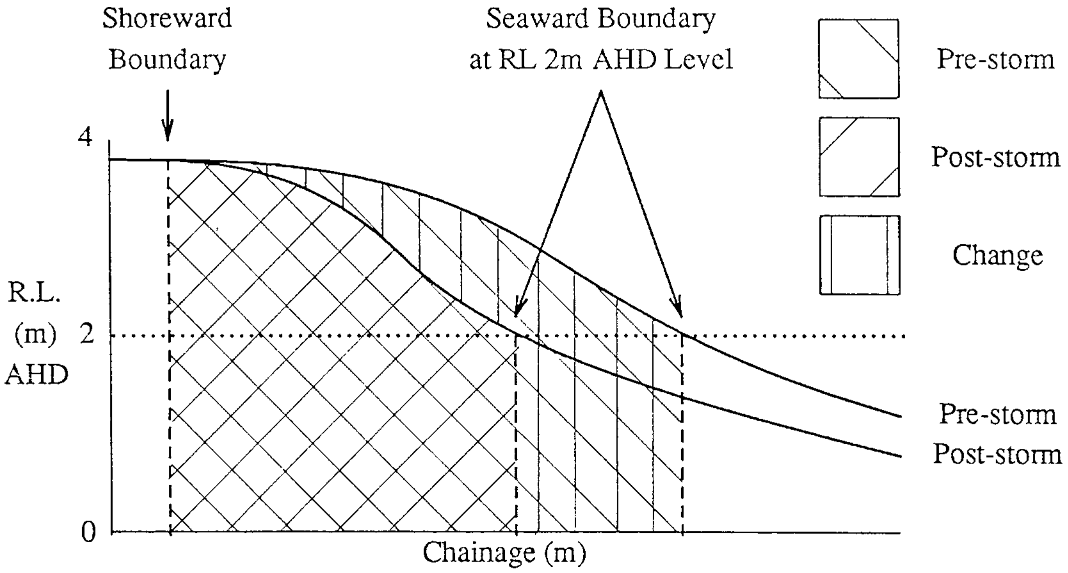
5.1 GOSFORD BEACHES

5.1.1 Photogrammetric Data

Aerial photographs of the Gosford area beaches were taken by Central Mapping Authority (CMA) at an approximate scale of 1:8 000 on the 23rd August 1984 and on the 18th August 1986. In the period prior to the 1984 photography, no severe storms (category "X") had occurred since 1978, and the beaches were in an accreted state. There were two severe storms between the two dates of photography, one in October 1985 and the other in August 1986 (Table 5). The August 1986 storm occurred shortly before the 1986 photography, and the beaches were generally in an eroded state.

Photogrammetric analysis was carried out by PWD Coastal Branch, using a WILD AC1 stereo-restitution instrument to produce cross-section data at 10 m intervals along the main beaches from Forresters Beach to MacMasters Beach. The PWD used this data to calculate beach volumes per metre of beach length, at each section for both dates. The volumes were those measured per metre of beach length, above 0 m AHD, between a starting chainage at the top or bottom of the back beach escarpment and the 2 m beach berm contour line for each date. The starting chainages selected from aerial photographs taken in August 1978 were used throughout. This ensured that beach volumes were calculated in a consistent way and allowed comparisons to be made with previous work.

The differences between the 1984 and 1986 volumes have been determined to assess changes to the beaches during the two year period. It should be noted that these differences do not represent the true erosion or accretion volumes, since they include material below the new profile and between the new and old 2 m contour lines (see figure below). However, they are still a useful indication of the beach erosion or accretion. Although two severe storms occurred between the dates of photography, the August 1986 storm appears to be responsible for much of the change.



Schematic diagram showing areas used to calculate beach volumes.

Plots of change in beach volume versus distance along the beach, (section number), have been prepared for Forresters Beach, Wamberal and Terrigal Beaches, Avoca Beach and Copacabana and MacMasters Beaches (see Figures 15 to 18). Each plan shows changes in beach volume per metre of beach length, between August 1984 and August 1986.

At Forresters Beach the volumes generally indicate slight to severe erosion up to about 200 m^3/m, in the two year period. There is accretion of up to about 70 m^3/m towards the southern end. Wamberal and Terrigal Beaches also show slight to severe erosion up to about 150 m^3/m, except at the southern end, which does not appears to have been significantly affected by the storm. Avoca Beach shows erosion to over 100 m^3/m, but shows little change at the ends of the beach. Copacabana and MacMasters Beaches generally show erosion up to about 70 m^3/m, but some places show accretion up to about 20 m^3/m.

In 1985 the PWD Coastal Branch carried out a similar photogrammetric analysis on Wamberal, Terrigal and Avoca beaches, using aerial photography dated 1965, 1969, 1973, 1974, 1977 and 1978 (PWD 1985a). For Wamberal, Terrigal and Avoca beaches the design storm erosion demands taken from that report have been included in Figures 16 and 17 for comparison purposes. In all locations the 1984 to 1986 changes are less than the design storm erosion demand.

Aerial photographs of the coast from Narrabeen to Budgewoi were also taken by PWD from an altitude of 762 m on 11th August 1986. Details of these are given in Appendix A.

5.1.2 Ground Survey Data

Wamberal and Terrigal Beaches have been surveyed along five profile lines by the Soil Conservation Service (SCS). The profile lines extended from the back beach area to approximately RL 2.0 m AHD and were surveyed on 7 occasions between 27th June 1986 and 17th December 1986. Profile plots are presented in Figures 19 a-e. An assessment of storm erosion volumes has been carried out from these surveys. Beach volumes, defined in a similar way to the photogrammetric analysis, were calculated for all survey dates. Plots of change in beach volume versus time for all sections are given in Figures 20 a-e.

These plots indicate that the August 1986 storm caused significant erosion. The pre and post August storm volumes generally differ by 100 to 120 m^3/m on Wamberal Beach and about 70 m^3/m on Terrigal Beach. The changes are summarised in Table 8. Between the August and October surveys there was slow but steady recovery at some sections and little change at others. The October and December surveys indicate that the November 1986 storm may have caused a slowing down of the recovery.

TABLE 8. Change in Beach Volume (m^3/m), Wamberal and Terrigal Beaches
August 1986 Storm

Location	Ground Survey Data June 86 - August 86	Photogrammetric Data August 84 - August 86
Wamberal Line 4	114	125
Wamberal Line 3	105	77
Wamberal Line 2	99	40
Wamberal Line 1	104	92
Terrigal Line 1	71	13

Direct comparison of the ground survey beach volumes with photogrammetric results cannot be made, since the starting chainages for the volume calculations are different. However, the starting chainages were in a similar part of the beach, and in an area which was not significantly altered by the storms, so the differences in volumes are comparable (Table 8). For the August storm, the pre and post storm survey dates from the photogrammetry are 23rd August 1984 and 18th August 1986, while those for the ground survey data are 27th June 1986 and 13th August 1986. The June to August 1986 ground survey erosion volumes have been plotted on the photogrammetric plans to allow comparison (Figure 16).

In addition, video records were made by the Public Works Department of NSW, Coastal Branch to document the state of the beaches immediately after the August 1986 storm. Details of these are given in Appendix A.

5.2 MANLY WARRINGAH BEACHES

5.2.1 Photogrammetric Data

As part of the Collaroy/Narrabeen Beaches, Hazard Definition Study (PWD, 1987) an assessment of the August 1986 storm erosion on Collaroy and Narrabeen Beaches has been made. A summary of this information is included in this report so that a complete data set of storm information is available within the one document.

Aerial photographs of Collaroy and Narrabeen beaches were taken by CMA at an approximate scale of 1:10 000 on the 18th August 1986, just after the August 1986 storm. Aerial photographs, taken by CMA between the 7th and 19th April 1985 were also available. As mentioned in Section 5.1.1, there was an earlier severe storm in October 1985 which is also between the dates of photography. Photogrammetric analysis of the two sets of photographs was carried out by PWD, Coastal Branch as detailed in Section 5.1.1. The differences between the 1985 and 1986 beach volumes have been determined to assess the extent of erosion caused by the August 1986 storm. Plots of volume change per metre length of beach are reproduced in Figures 21 and 22.

The Collaroy Beach volume changes generally indicate erosion of between about 50 and 175 m^3/m length of beach. The Narrabeen Beach volume changes vary from accretion of about 50 m^3/m to erosion of about 100 m^3/m length of beach.

As part of the above mentioned study, an assessment was made of beach changes related to the May/June 1974 storms. Beach volumes were determined from 1972 and 1974 aerial photographs. The changes are shown in Figures 21 and 22 for comparison purposes. The Figures indicate that these two severe storms have affected these beaches to varying degrees along their length and the estimated 1974 erosion does not represent the maximum recorded erosion at all points on the beach.

Aerial photographs of the coast from Narrabeen to Budgewoi were also taken by PWD from an altitude of 762 m on 11th August 1986. Details of these are given in Appendix A.

5.2.2 Ground Survey Data

The Manly Warringah beaches were surveyed on the 11th, 12th and 14th August 1986 at a number of locations corresponding to wave run-up measurements. The locations are shown in Figures 13 a-d. The surveys generally extended from the back beach area to the water line and were perpendicular to the beach alignment.

In addition, video records were made by the Public Works Department of NSW, Coastal Branch to document the state of the beaches immediately after the August 1986 storm. Details of these are given in Appendix A.

5.3 BATEMANS BAY BEACHES

5.3.1 Ground Survey Data

The beaches were surveyed in December 1986 at a number of locations corresponding to wave run-up measurements. The locations are shown in Figures 14 a-c. The surveys generally extended to the water line and were perpendicular to the beach alignment.

6. OFFSHORE SURVEYS

6.1 SURVEY METHODS

PWD Coastal Branch has surveyed the ocean bed in a number of locations, including the Gosford and Manly Warringah areas. The surveys are generally carried out from the Department's 5.5 m "Sea Master" Shark Cat. They involve echo sounding along fixed profile lines with a "Raytheon" echo sounder and position fixing at regular intervals with a Motorola Mini-ranger System. Some lines extend to about 7 km offshore but others are much shorter. They generally extend shoreward to about the wave breaker line.

Before and after the survey the echo sounder is calibrated with a bar check. This consists of lowering a reflective bar to various fixed depths below the boat and adjusting the recorder to give the correct depths.

The boat generally aims to travel along a straight path directly towards one of several Mini-Ranger shore stations. Depth is recorded continuously on the echo sounder chart and the position is fixed at intervals of 50 m to 200 m by recording the distance from two shore stations. The location of the shore stations is known, so each fix is later converted to Australian Mapping Grid (AMG) coordinates. The depth at each fix, and its coordinates are tabulated for plotting purposes. The recorded tide height from an appropriate gauge is used to correct the depths to a fixed datum. If required the echo sounder data is digitised or a limited number of data points are selected to define changes in bed slope. These are used to supplement the data obtained at the fixes. If this is done it is assumed that the boat travelled at constant speed and in a straight line between fixes.

6.2 GOSFORD BEACHES

PWD Coastal Branch surveyed the ocean bed offshore of the Gosford area between Wamberal Beach and MacMasters Beach, in 1983/84 and again in 1986. Between October 1983 and January 1984, 21 lines were surveyed all to approximately 7 km offshore. Fourteen lines were surveyed in late August 1986, about three weeks after the storm, and four of these (Lines 5, 9, 12 and 13) corresponded with lines surveyed in 1983/84. These four lines have been used to assess changes between 1983/84 and 1986. The locations of the four profile lines is shown in Figure 23.

The purpose of the 1986 surveys was to monitor changes in the nearshore sea bed profiles as a result of the August storm and most were not surveyed as far seaward as they were in 1983/84. Three of the lines used for comparison extended to 3 or 4 km offshore and one to 7 km offshore, during the 1986 survey. The plan position of the 1986 survey lines generally corresponded to the earlier surveys, except for Line 12, for which there was a maximum deviation of about 75 m. Comparison of 1983/84 and 1986 profiles should therefore be done with caution since differences can be caused by positioning errors as well as by profile changes.

In Figures 24 a to 27 a, the profiles are plotted in section to allow comparison of the 1983/84 and 1986 data. The shoreward part of these profiles have been replotted at a larger scale in Figures 24 b to 27 b to show more detail of the nearshore area. These figures, and the description which follows, give depths and levels relative to ISLW.

The offshore area beyond RL -15 m generally shows small differences of up to 0.5 m between 1983/84 and 1986 and this could be due to inaccuracy in the echo sounding and survey location. Line 12 shows differences of up to 2 m where it crosses a reef area, but this is thought to be due to the irregular nature of the seabed in that area and the poor alignment of the profiles. The nearshore profile shallower than RL -15 m generally shows the formation of a bar as a result of the storm. The top of the bar is generally 3 to 5 m below ISLW and the height of the bar is up to 2 m above the 1983/84 level.

The 1983/84 surveys cannot be classified as representing pre-storm conditions, although there was little evidence of any significant bar formation. However, if it is assumed that the 1983/84 data represents the pre-storm profile, and that the 1986 data represents the post-storm profile, then the differences between the two can be used to estimate the offshore fill due to the storm. Calculation of volumes of sediment moved between these dates is extremely approximate since only a few data points are available and these figures are only given as an indication of the likely storm effects on the offshore profile. However, the data indicates that the volume of sediment moved into the offshore bar is between 100 and 300 m^3/m of beach length. The values are shown in Figures 24 b to 27 b.

The seaward extent of sediment movement during the August storm has been assessed from this data together with offshore sediment descriptions and is discussed in Section 7.4.

6.3 WARRINGAH BEACHES

The area offshore of Collaroy and Narrabeen Beaches was surveyed in 1979/83 and again in August 1986 by PWD, Coastal Branch. Eight profile lines were surveyed in 1979/83 and nine in 1986. They extended to between 0.7 and 2.0 km offshore. The location of the lines is shown in Figure 28. The plan position of the 1986 survey lines corresponded approximately to the earlier surveys, but some lines were not very straight and the two surveys were as much as 75 m apart (see Figure 28).

The profiles of the 17 offshore lines have been plotted in Figures 29 to 45). These figures show the cross-sections plotted with straight lines joining the arbitrary fix points. Intermediate points between fixes do not necessarily lie on these straight lines. However, echo sounder charts are available if more detailed data is required (See Appendix A).

The profile data as assembled at present does not allow pre and post storm comparisons to be made as the lines have been plotted from arbitrary origins. The full survey data is, however, available for analysis as indicated in Appendix A.

6.4 ASSESSMENT OF ACCURACY OF OFFSHORE SURVEYS

The Gosford offshore data has been examined in order to estimate the errors in depth sounding, and position fixing, and to assess their impact on results. They can be divided into measurement errors related to the limitations of the equipment and operating technique, and positioning errors related to the difficulty of positioning or re-positioning the boat at the intended locations.

The accuracy of echo soundings is normally assumed to be ±0.25 to ±0.5 m (PWD estimate) but this depends on the calibration of the instrument and on the method of use. The instrument measures the distance from the transponder to the seabed, by timing the interval between the transmission of sound waves and the reception of the reflected signal from the seabed. The sources of inaccuracies include the following. The speed of sound in water varies with temperature and salinity and calibration of the instrument involves a correction for these parameters. This is normally included as part of the bar check (see Section 6.1). It is generally assumed that the instrument is mounted so that the distance measured is the true vertical distance to the bed, but this cannot always be the case since the boat is tilting with the waves. This is not normally a significant problem with a boat like a "Sea Master" Shark Cat. The depth of the transponder below the sea surface is corrected for in the bar check, but is not always constant, particularly if there are significant changes to the weight distributions on the boat or the boat travels at high speed. Again this is not normally a significant problem with a boat like a "Sea Master" Shark Cat. Depths below sea level are converted to depths below some datum using tide records from a nearby location. This assumes that the tide level offshore is the same as that onshore. This is valid in the locations considered here, but may not be in locations on the outer part of broad continental shelves.

The Motorola Mini-Ranger System used to measure distances to the shore stations, uses a pulse radar, transmitter-receiver system. The manufacturers quote a "probable range error" of ±3 m (Motorola, 1972). If the angle between the measured distances is 90 degrees, the maximum error in positioning a fix can be estimated as 1.4 (the square root of two) times the range error. This assumes that the ranges are large compared to the range error. If the angle is 60 or 120 degrees, the maximum error is twice the range error, and if it is 30 or 150 degrees it is 4 times. It can be significantly more if the angle between the two distance measurements is smaller than 30 or larger than 150 degrees.

When used in conjunction with an echo sounder, an additional error is introduced if the recording of the position fix is not done at precisely the same time as the recording of the depth. To these possible errors can be added any horizontal distance between the instrument and the echo sounder. If the shore station is in a very elevated location, a correction may be required to convert the measured range to its horizontal equivalent. This correction has been included in the surveys described here. The error in positioning or repositioning the shore stations is not known, but is unlikely to exceed 2 m.

The offshore Gosford surveys had the primary shore station at the origin of the line and a secondary station between 0.8 and 10.0 km along the coast. On the longer lines, a different secondary station was used on the offshore portions. During the 1983/84 and 1986 surveys, the smallest angle between ranges was about 30 degrees. The maximum error in positioning the mini-ranger relative to the shore stations would be about 12 m. Since both stations are on the shore, this error is likely to be greatest in the longshore direction. The overall positioning error is unlikely to exceed 20 m.

When offshore profiles are surveyed the boat attempts to travel at constant speed and in a straight line from a known location towards a shore station. This cannot always be achieved, and it is common for the boat to stray off course. Examination of the profile lines from the offshore Collaroy and Narrabeen surveys (Figure 28) indicates that the boat tracks are far from straight, with misalignment often greater than 50 m. When re-surveying an offshore profile line it is important to relocate and duplicate the boat track as accurately as possible. If this is not achieved satisfactorily then the profile comparison may not be valid. Comparison of the boat tracks from the 1979/83 and 1986 offshore Collaroy and Narrabeen surveys (Figure 23) indicates that the two surveys were sometimes as much as 75 m apart. Comparison of the boat tracks from the 1983/84 and 1986 offshore Gosford surveys (Figure 28) indicates that boat positioning was generally good (10 to 20 m) but that occasionally the two surveys were as much as 75 m apart. Profiles are normally plotted as a depth versus distance from the shore station, so positioning errors will result in depth errors due to the variations in depth perpendicular to the track line. These errors may be large where the seabed is steep, rough or irregular or where there are reefs and channels.

Bed slopes 7 km offshore are typically 0.001 to 0.003, so an onshore offshore positioning error of 10 m would produce a maximum error of about 0.03 m. Longshore positioning errors should be much less important since the lines are approximately perpendicular to the contours. These can therefore be ignored except where the bed is rough. Bed slopes 1 to 2 km offshore are typically 0.01 to 0.02 so onshore-offshore positioning errors are much more significant. An onshore-offshore positioning error of 10 m would result in a maximum error in depth of 0.2 m. Closer inshore the slopes are steeper still and can exceed 0.04. An onshore-offshore positioning error of 10 m in this region would result in an error in depth in excess of 0.4 m.

7. OFFSHORE SEDIMENT SAMPLES - GOSFORD BEACHES

7.1 SAMPLE COLLECTION

Bed sediments were collected during the offshore surveying work in 1983/84 and again in late August 1986. The samples were dredged from the bed using a simple 100 mm diameter cylinder. The locations were on or close to the four main offshore profile lines numbered 5, 9, 12 and 13 described in Section 6.2 and to four subsidiary lines numbered 71, 72, 74 and 76 (see Figure 23). Samples on the four main lines are also shown on the profile plots in Figures 24 to 27. The depths and locations were fixed by the same equipment as was used for the offshore profiling (see Section 6.1).

7.2 SAMPLE CLASSIFICATION

An offshore sand classification system postulated by Roy (1978) describes the original source of the sediment and various zones of sediment activity. Essentially there are two groups of sand, classified as nearshore and inner-shelf sands. The nearshore sands form the active wedge of the beach profile and consist of inner and outer nearshore sands. The inner nearshore sands are "beach" sands which are readily eroded in storms and deposited on the nearshore slope over the outer nearshore sands. The inner nearshore sands (INS) are usually coarser than the outer near shore sands (ONS). This is a fairly reliable trait to enable differentiation of the two groups. Other characteristics such as colour and grain size sorting tend to be less reliable. The inner shelf sands are less active and are usually only disturbed in severe wave conditions. These sands are generally coarser, more poorly sorted and contain more iron-staining which gives a red-brown colour, than the ONS sands. Often some mud is evident in this region.

The extent of offshore transport can be estimated by combining results from the profile comparisons and sediment type changes. Areas in which the sand type changes from ONS to INS or the sand is much coarser, and which are associated with deposition on the profile, have been assumed to indicate the extent of offshore transport for that storm. The changes observed cannot be directly related to the August storm because the 1983/84 surveys were a considerable time before and do not represent pre-storm conditions. However, the analysis gives an indication of the likely effects of storms on the offshore profile.

7.3 SAMPLE DESCRIPTIONS

Details of approximate distances from the shore station, depths and sediment classifications of the samples from offshore Terrigal, Wamberal, Avoca, MacMasters and Copacabana are given in Table 8.

TABLE 9. Details of Offshore Samples, Gosford Area. 1983/84 and 1986 Surveys

Location	Line No.	Sample No.		Approx Distance Offshore(m)		Depth ISLW(m)		Sediment Description	
		83/84	Post Storm	83/84	Post Storm	83/84	Post Storm	83/84	Post Storm
Wamberal	13	89		600		12.0		INS/ONS	
			174		600		12.2		INS/ONS
		88		1400		25.5		INS/ONS	
			175		1400		25.3		INS/ONS
		87		1850		30.5		River Cobbles	
			176		1850		30.3		River Gravel
Terrigal	12		164		200		1.2		INS
		113		400		8.3		ONS	
			165		450		9.9		INS/ONS
			166		1000		18.4		ONS on Reef
		112		1050		18.6		ONS on Reef	
		111		1500		24.0		Reef	
			167		1600		24.1		Reef
Avoca	9		168		275		2.7		INS
		56		300		4.4		INS	
			169		320		4.8		INS
			173		600		11.7		INS
		57		1000		18.9		ONS	
		63		1600		27.5		ONS	
			170		1700		28.0		ONS
		58		2200		34.3		ONS	
			171		2500		37.0		ONS
		62		2700		38.4		ONS	
Avoca	74		184		250		6.0		INS
			187		340		8.6		INS
			186		380		9.9		INS
			173		440		11.7		INS
			185		550		12.9		INS
			183		740		18.0		INS/ONS
			182		1200		23.3		ONS
Avoca	76		190		300		6.8		INS
			189		340		8.3		INS
			188		690		14.3		INS/ONS
			182		1250		23.3		ONS
MacMasters	5	33		350		9.1		ONS	
		34		850		18.9		ONS	
			192		1050		23.4		ONS
		35		1400		31.3		ONS	
Copacabana	71		196		150		4.4		INS
			197		175		4.5		INS
			195		300		6.9		INS
			198		300		6.4		INS
			194		480		12.0		ONS
			193		700		17.0		ONS
			192		1000		23.4		ONS
			191		1300		29.5		ONS

7.4 COMPARISON OF 1983/84 AND POST STORM OFFSHORE DATA

7.4.1 Wamberal/Terrigal Beaches

The 1983/84 Line 12 samples indicate that the INS/ONS boundary was located in water depths less than 8 m (below ISLW). The post-storm samples indicate a mixed INS/ONS sample at about 10 m water depth. However, there are no other samples in water depths between 1 m and 18 m to better define the possible deposition of beach sand (INS) in the offshore area. The extent of accumulation evident from the profile plots is relatively small compared to that on other profiles. It would seem that the cut and fill process at this point was not as significant as at other locations and hence it is more difficult to obtain INS sand which has not been mixed with ONS sand. The profile plots indicate that it is likely that beach sand has been deposited out to a water depth of about 9 m. The volume of sand moved into the bar between 1983/84 and 1986 is estimated at 100 m^3/m (Figure 26b).

The possible accumulation of beach sand in the offshore area is more evident on Line 13, where the volume of sand moved into the bar is estimated at 260 m^3/m (Figure 27b). However, samples were not taken in water depths less than 12 m in either the 1983/84 or post storm conditions. It is likely that deposition of beach sand on this profile was limited to water depths less than 12 m.

7.4.2 Avoca Beach

The 1983/84 Line 9 samples indicate that the INS/ONS boundary was in depths between 4 m and 19 m. The post-storm samples indicate the boundary is in depths between 12 and 28 m. The large depth range between samples spanning the inferred boundary for both the 1983/84 and post storm conditions makes it difficult to estimate if any INS sand has been transported offshore. However, the profile plots indicate that significant quantities of sand accumulated in water depths between 4 and 12 m. The volume of sand moved into the bar between 1983/84 and 1986 is estimated at 320 m^3/m (Figure 25b). This sand is assumed to be INS sand cut from the profile further inshore by wave action and deposited by currents out into these depths of water.

Samples from Lines 76 and 74 indicate that the INS/ONS boundary is located in water depths of about 14 and 18 m respectively. This supports the view that on Line 9 beach sands have been moved into water depths up to about 12 m.

7.4.3 MacMasters/Copacabana Beaches

For both 1983/84 and post-storm conditions, the Line 5 samples are all ONS sand. However, there were no post storm samples taken from water depths less than 23 m. The post storm profiles show an accumulation of sand in water depths from about 3 to 10 m. The volume of sand moved into the bar between 1983/84 and 1986 is estimated at 170 m^3/m (Figure 24b). This is assumed to be beach sand (INS) cut from the profile further inshore.

The post-storm samples from Line 71 indicate that the INS/ONS boundary was probably in depths of water of about 9 m. This supports the assumption that beach sands at the Line 5 profile, were moved out to about 10 m water depth between the two surveys.

8. REFERENCES

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[18] Public Works Department of NSW, Coastal Branch, file No. R1001/61.

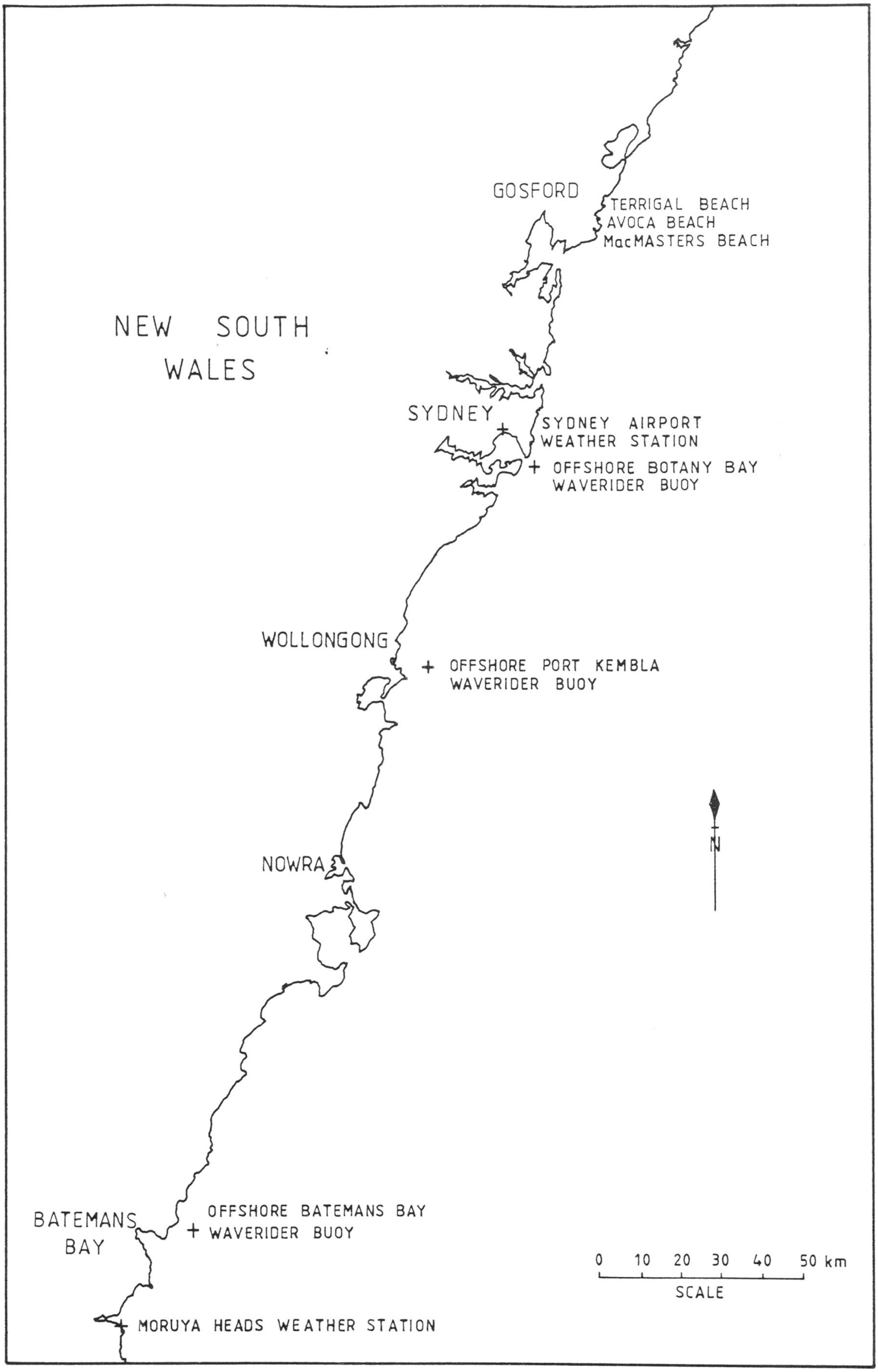
APPENDIX A. List of Storm Data

The Public Works Department of NSW, Coastal Branch holds records of the data used to prepare this report. This data includes the following:-

1. Collaroy and Narrabeen Beaches, Photogrammetric plots and profile comparisons. Drawing No. 86116.
2. Collaroy and Narrabeen Beaches, Offshore survey data.
   20th to 21st August 1986, Collaroy/Narrabeen book No. 87066.
   26th July 1979 to 12th May 1983, Collaroy/Narrabeen book No. 82310.
   Echo sounding charts contain detailed information on sediment/reef boundaries and seabed morphology between fix points.
3. Gosford Beaches, Photogrammetric plots and profile comparisons. Drawing No. 83042.
4. Gosford Beaches, Offshore survey data. Survey date, 25th to 29th August 1986.
5. Warringah Beaches, Wave run-up measurements. Survey date, 12th to 14th August 1986.
6. Batemans Bay Beaches, Wave run-up measurements. Survey dates, 6th August and 19-20th November 1986.
7. Central Mapping Authority Aerial Photography,
   Bondi Beach to Wybung Head. Photography date, 18th and 19th August 1986.
8. Public Works Department of NSW Aerial Photography,
   Narrabeen to MacMasters Beach, Film No. 70.86.52, Print Nos. 1 to 66
   MacMasters Beach to Budgewoi, Film No. 70.86.53, Print Nos. 1 to 77.

The Public Works Department of NSW, Coastal Branch, also has a video cassette library containing a number of V.H.S. video tapes which record the state of the beaches and erosion damage following the August 1986 storms. The tapes have no sound recorded. Details are as follows:-

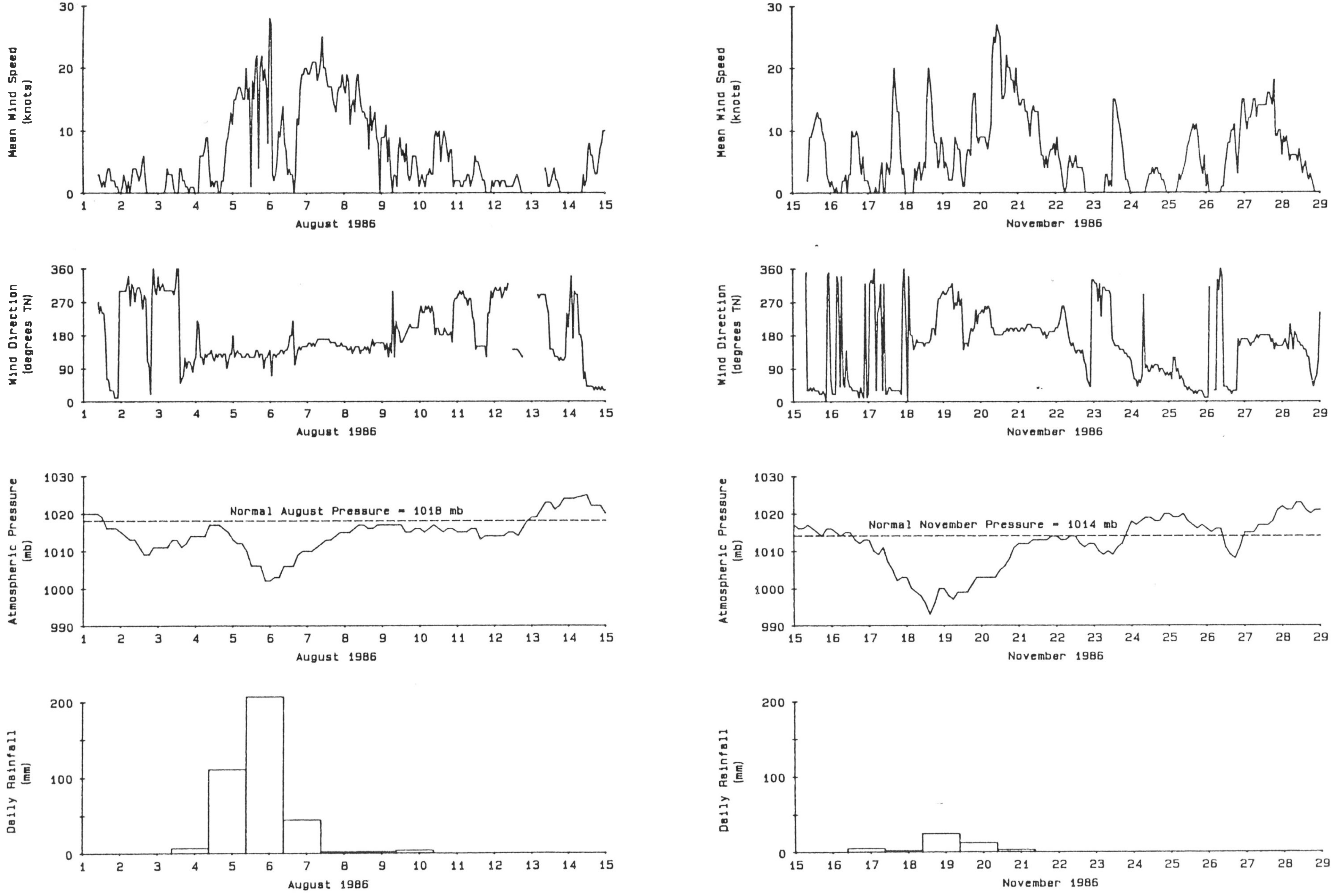
Cassette No.	Subject	Picture Quality
22	Narrabeen Beach, 9/9/86	Variable
24	Narrabeen to Lady Robinsons Beach, 8/8/86	Good
25	Patonga to Lady Robinsons Beach, 9/8/86	Good
26	Gosford Beaches, 9/8/86 and 14/8/86	Good
28	Long Reef to Cronulla, 18/8/86	Good



LOCALITY MAP

FIGURE 1

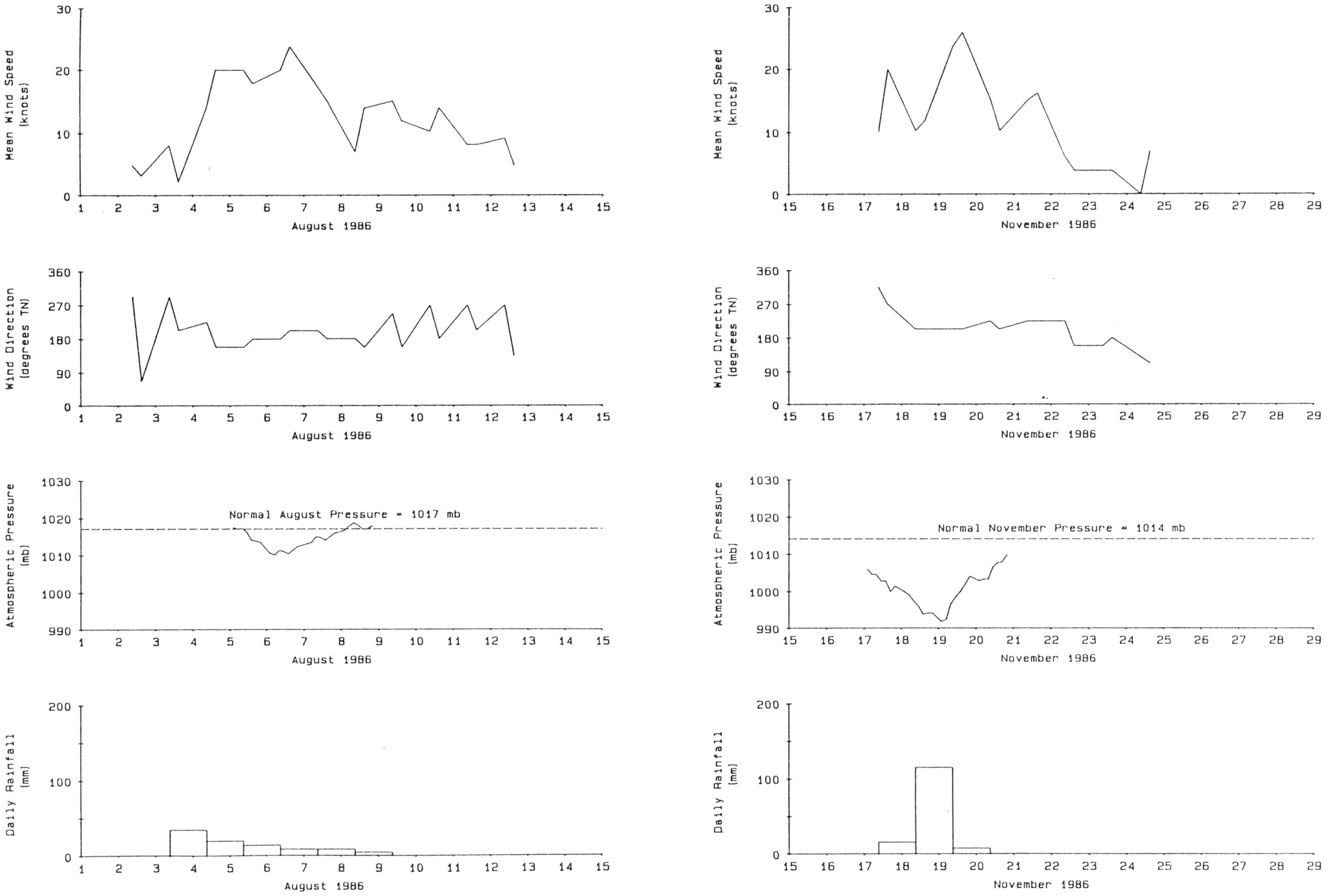
FIGURE 2.



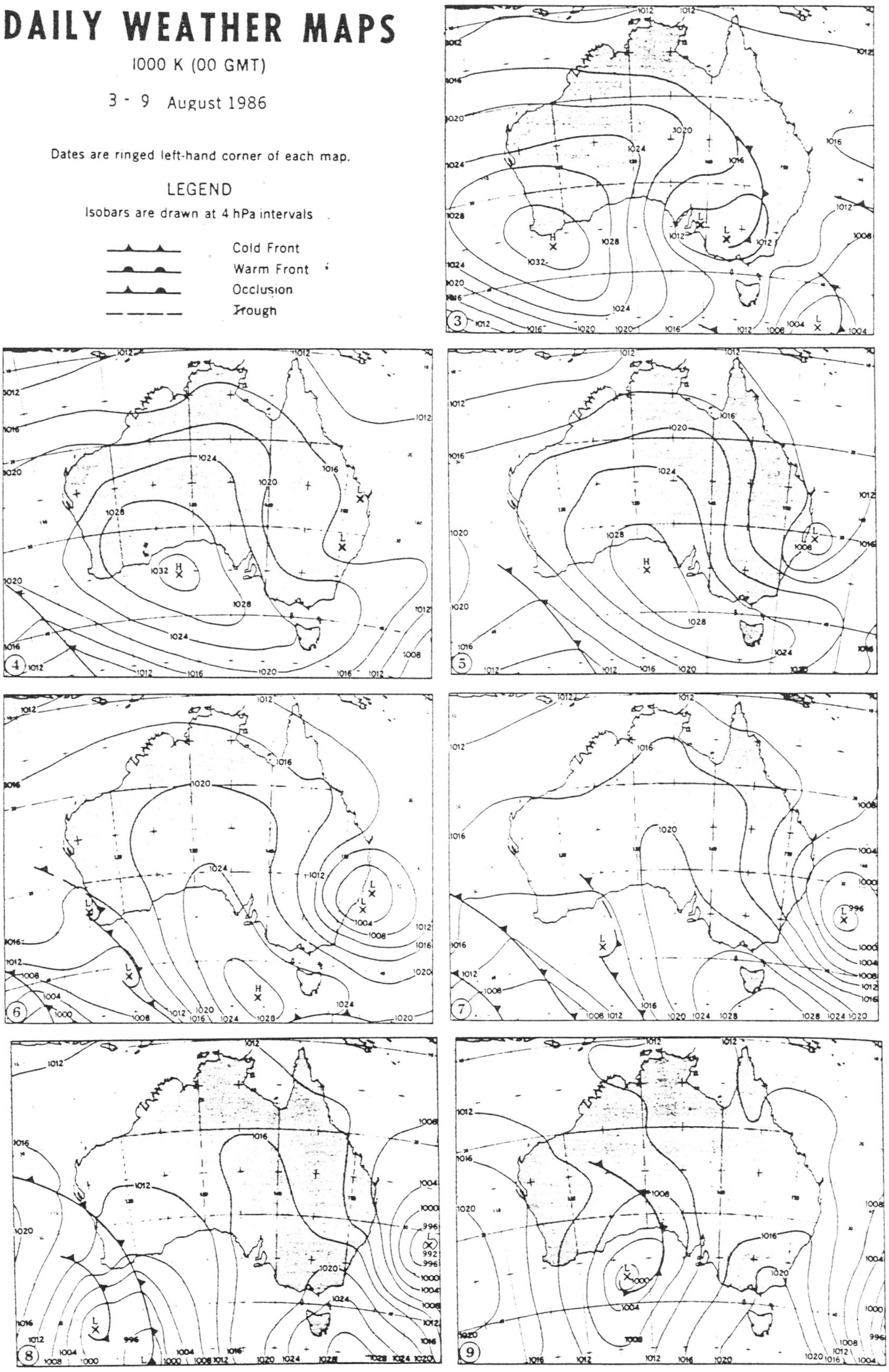
Meteorological Conditions, Sydney Airport, August and November 1986

Source of Data: Bureau of Meteorology

FIGURE 3.



Meteorological Conditions, Moruya Heads, August and November 1986
Source of Data: Bureau of Meteorology



DAILY WEATHER MAPS

1000 K (00 GMT)

3 - 9 August 1986

Dates are ringed left-hand corner of each map.

LEGEND

Isobars are drawn at 4 hPa intervals

Cold Front

Warm Front

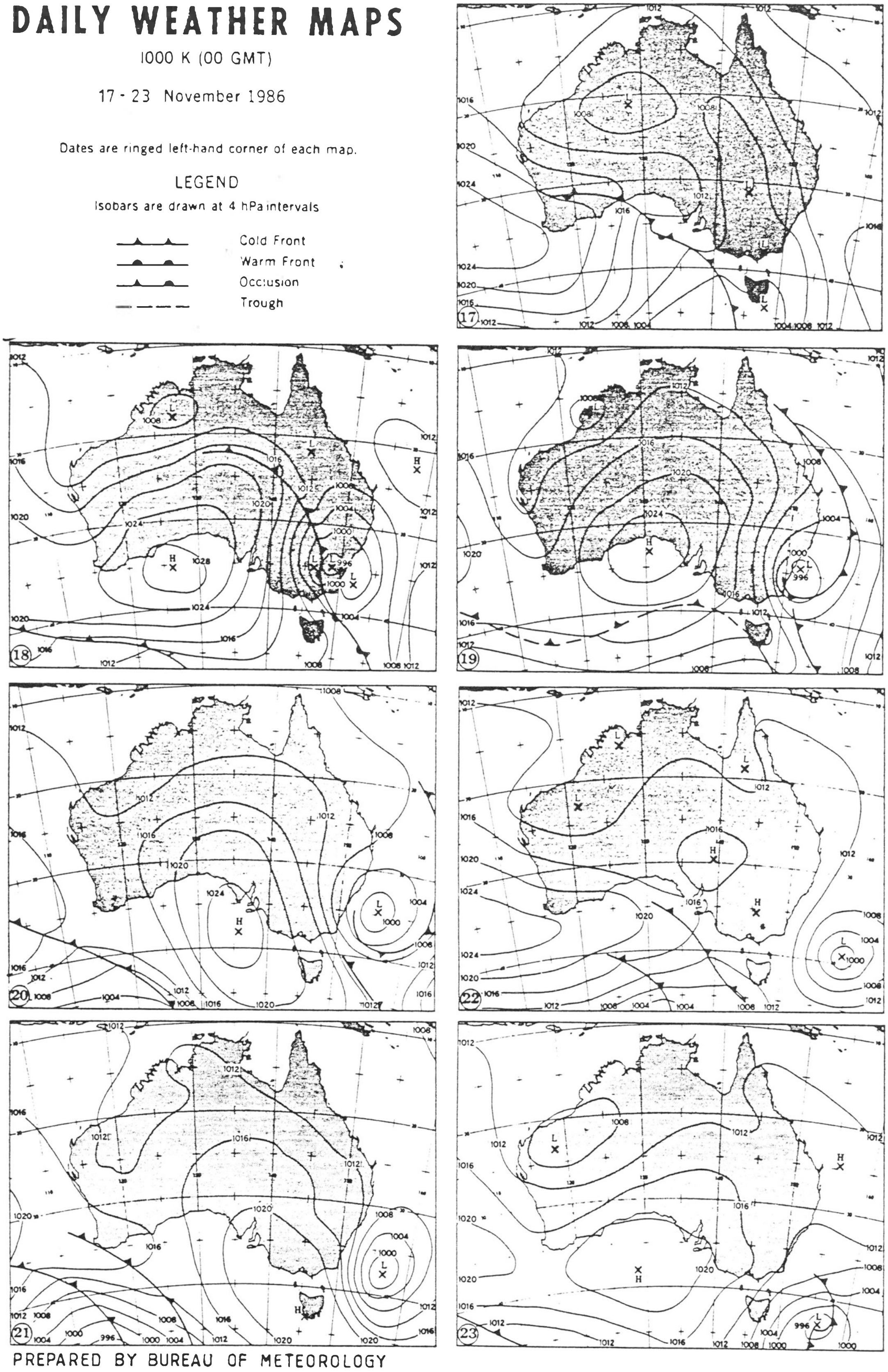
Occlusion

Trough

PREPARED BY BUREAU OF METEOROLOGY

SYNOPTIC CHARTS
3rd to 9th AUGUST 1986

FIGURE 4



DAILY WEATHER MAPS

1000 K (00 GMT)

17 - 23 November 1986

Dates are ringed left-hand corner of each map.

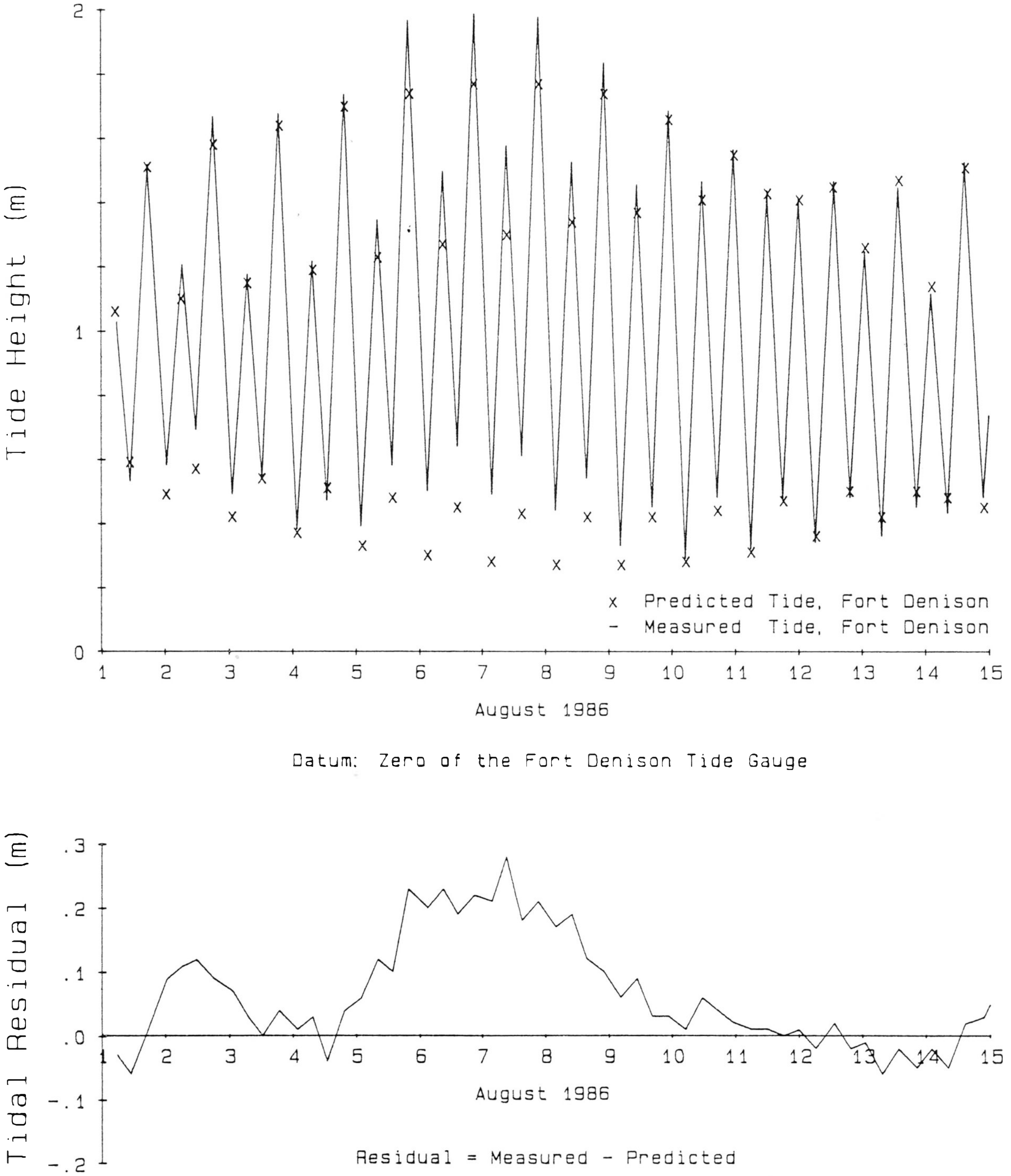
LEGEND

Isobars are drawn at 4 hPa intervals

PREPARED BY BUREAU OF METEOROLOGY

SYNOPTIC CHARTS
17th to 23rd NOVEMBER 1986

FIGURE 5

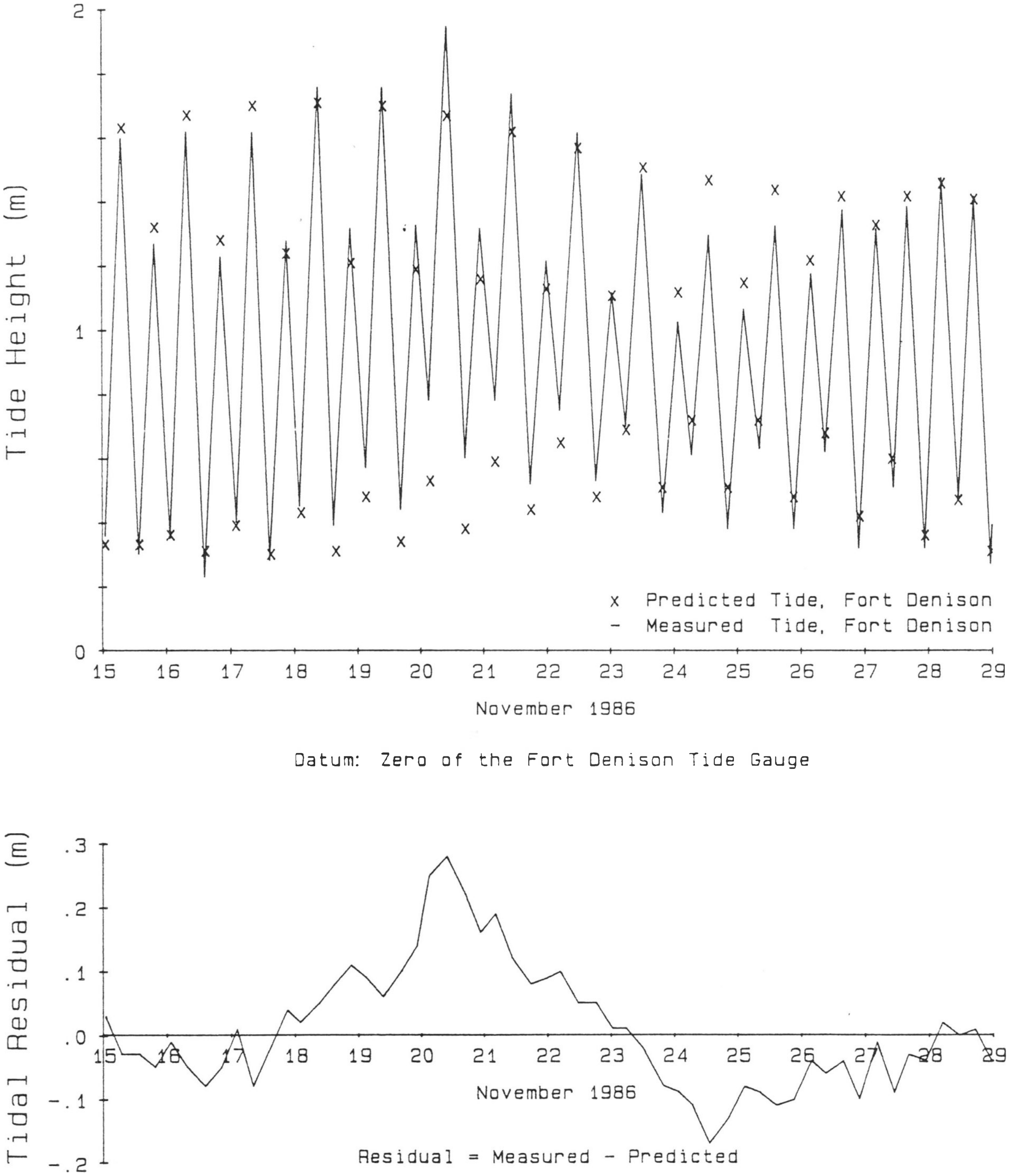


Datum: Zero of the Fort Denison Tide Gauge

Tide Height, Fort Denison, Sydney
August 1986

Source of Data: MSB

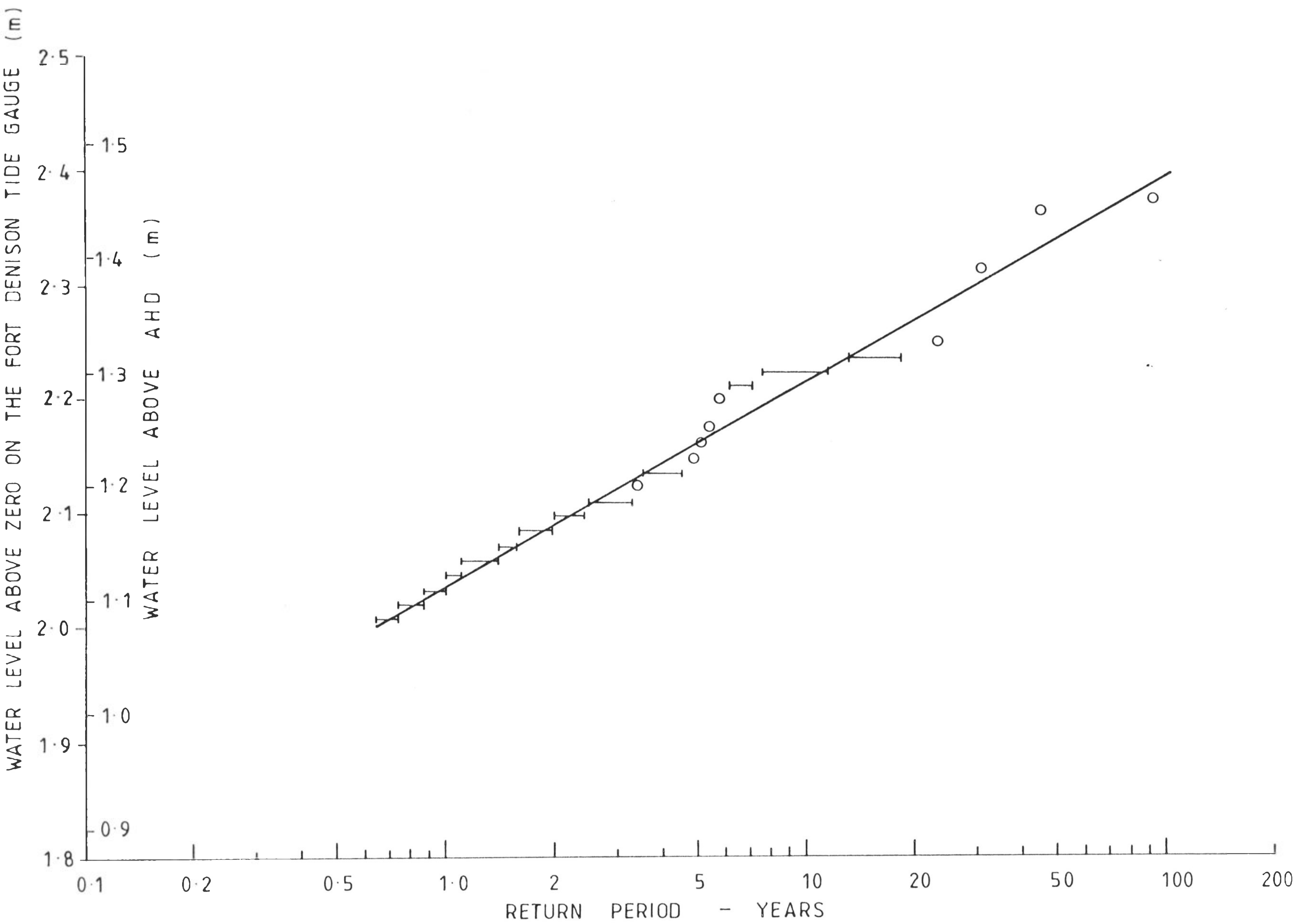
FIGURE 6



Tide Height, Fort Denison, Sydney
November 1986

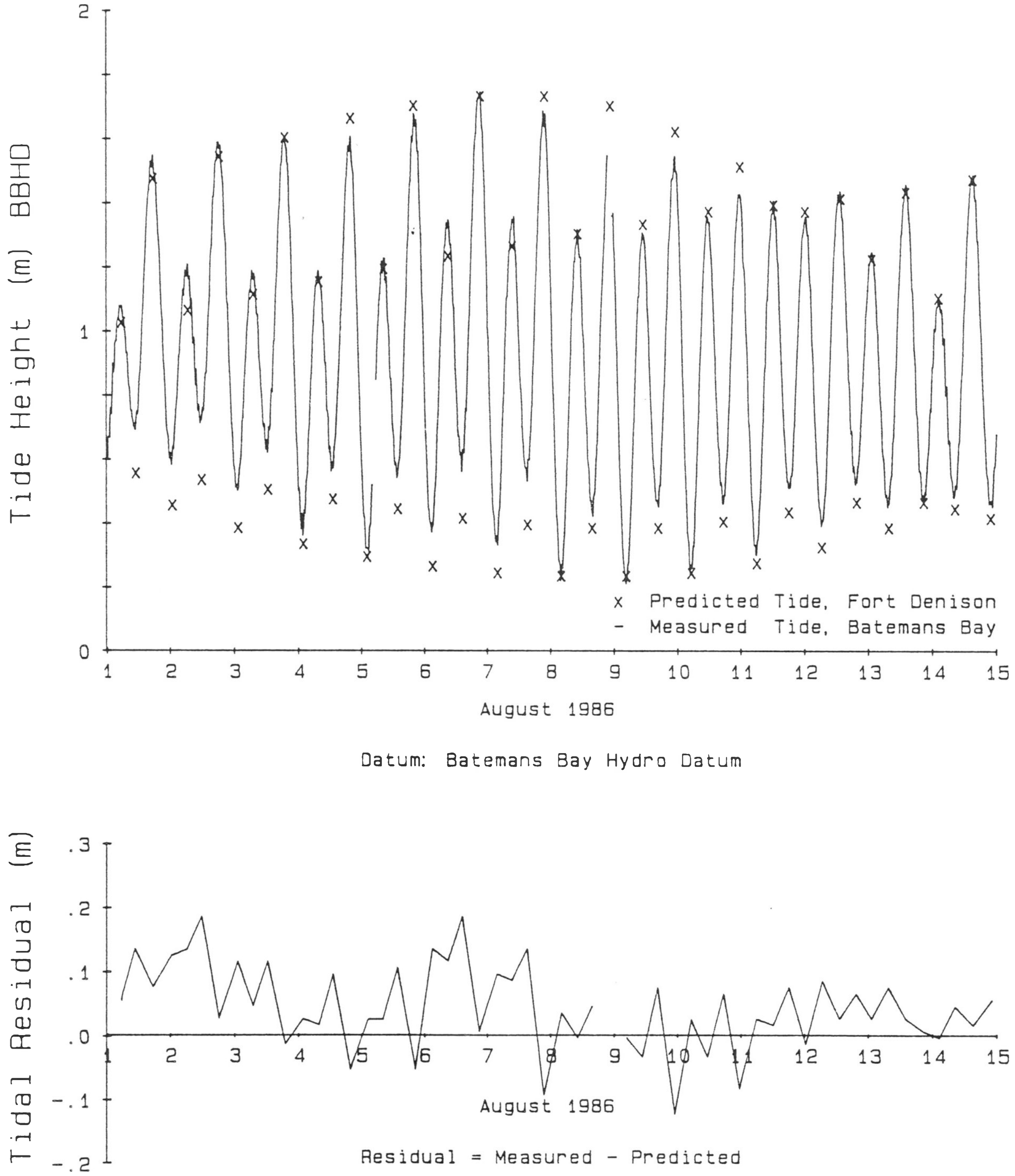
Source of Data: MSB

FIGURE 7



RETURN PERIOD OF RECORDED WATER LEVELS AT FORT DENISON FOR PERIOD 1883 TO 1975

FIGURE 8



Datum: Batemans Bay Hydro Datum

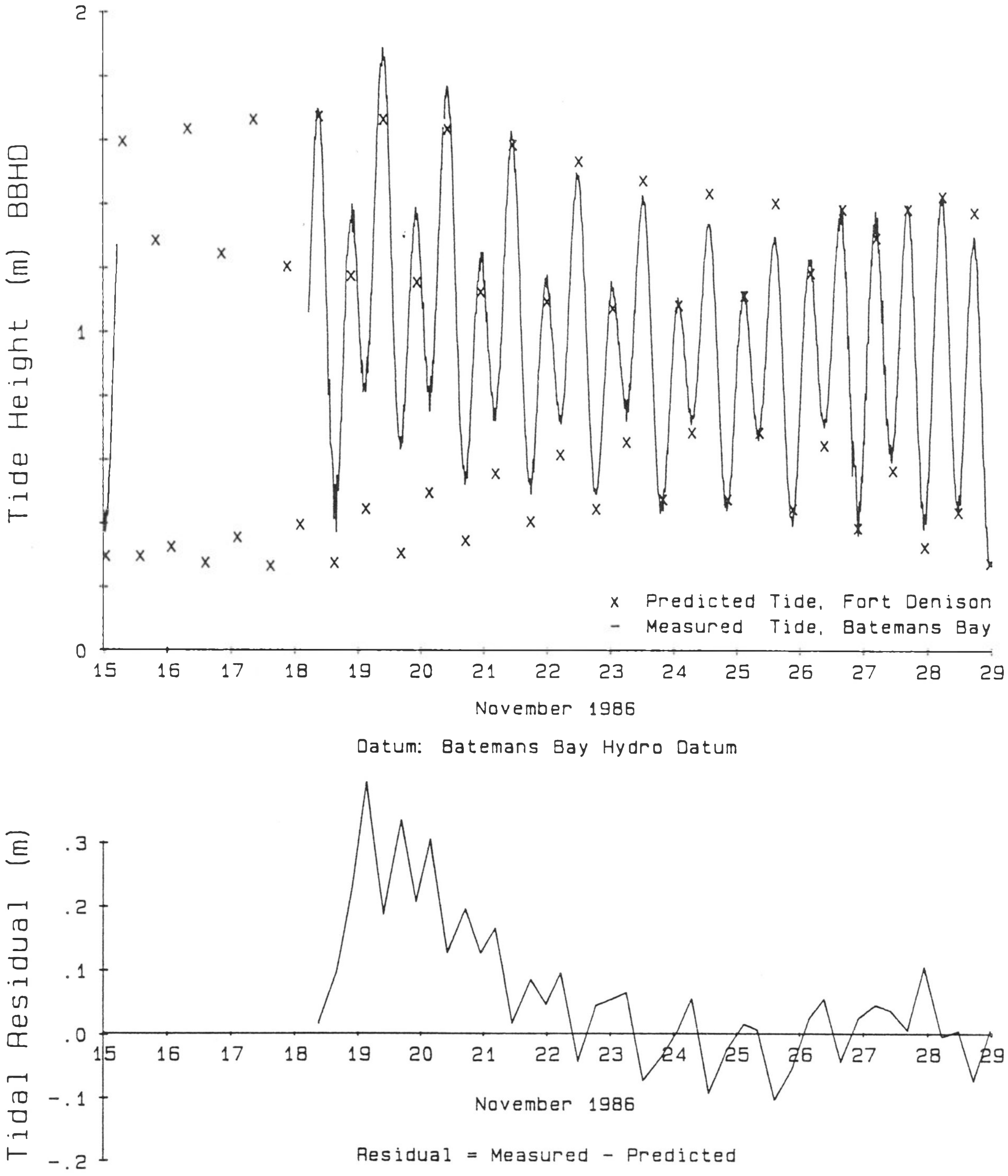
Residual = Measured - Predicted

Tide Height, Batemans Bay Zwarts Gauge

August 1986

Source of Data: PWD/MSB

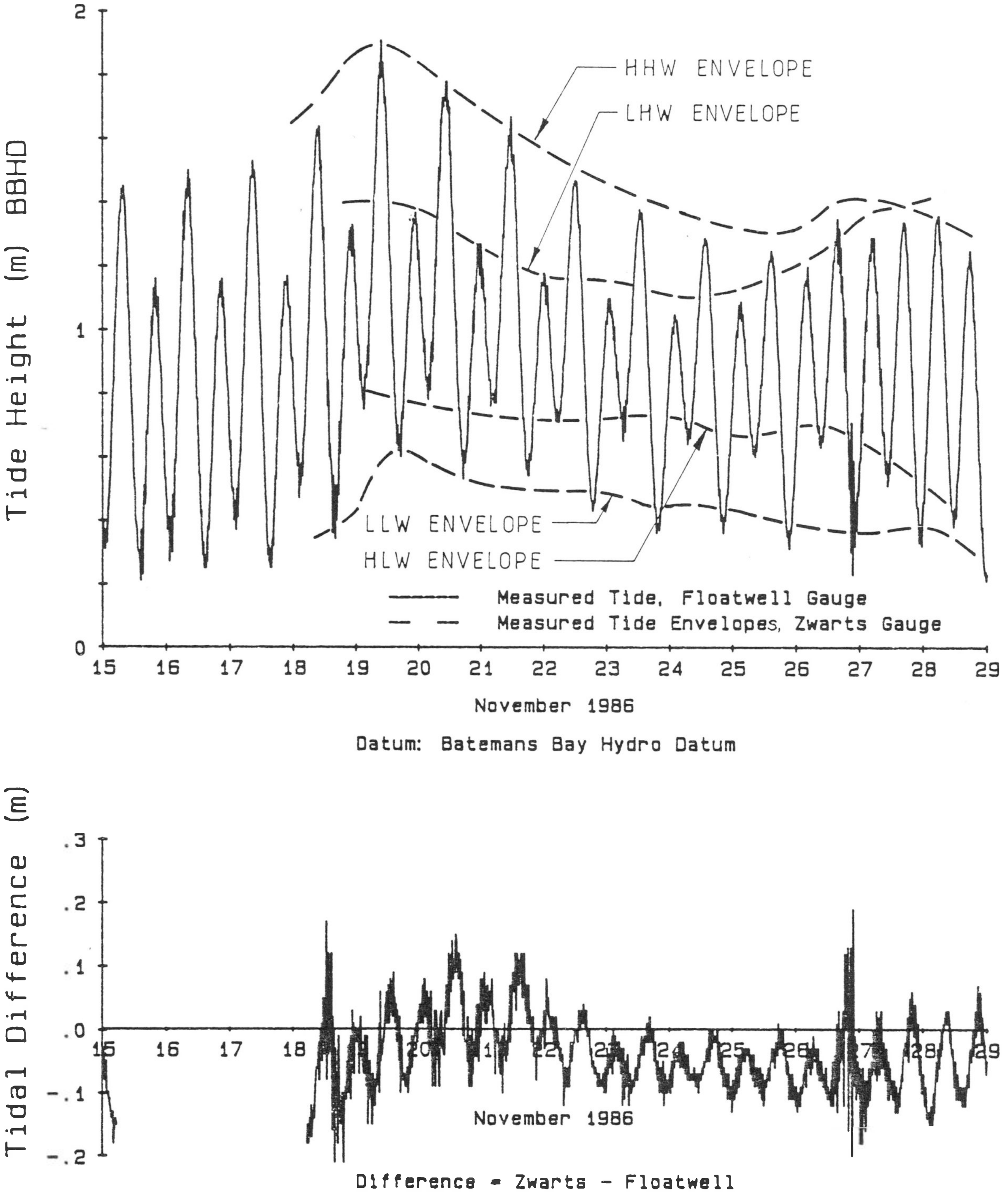
FIGURE 9



Tide Height, Batemans Bay Zwarts Gauge
November 1986

Source of Data: PWD/MSB

FIGURE 10



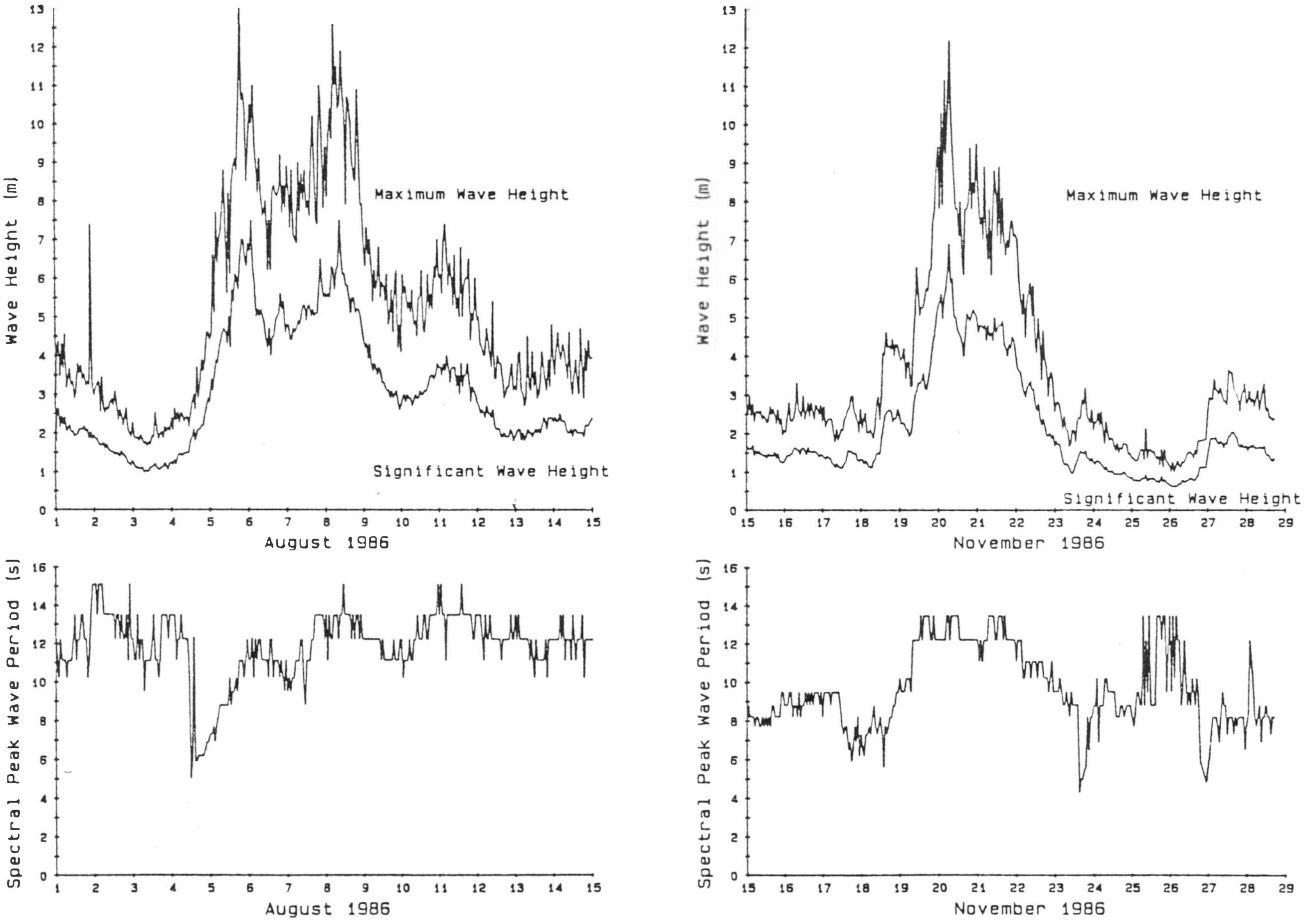
Comparison of Tides, Batemans Bay

Zwarts and Floatwell Gauges

November 1986

Source of Data: PWD

FIGURE 11

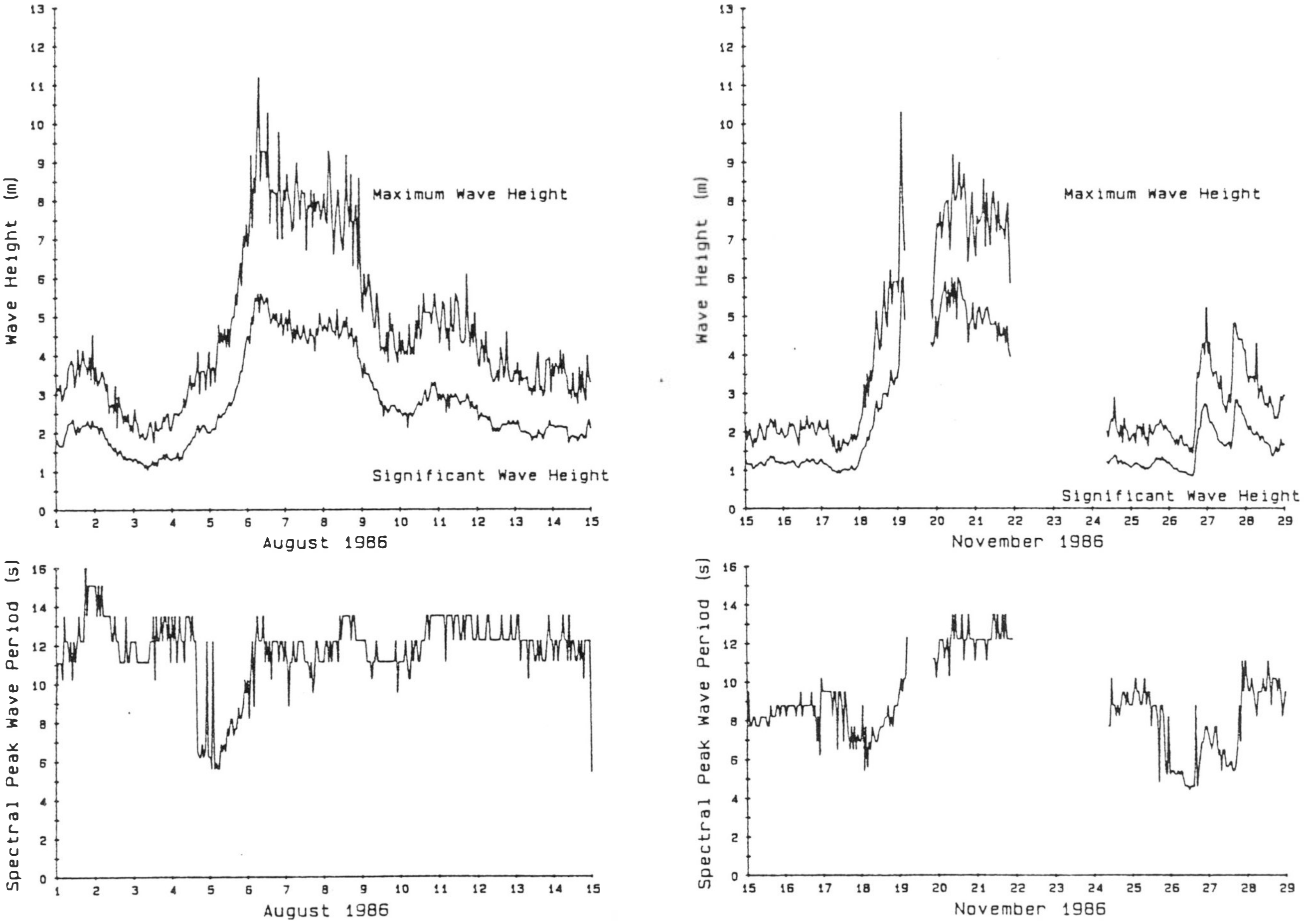


A. Offshore Botany Bay, August 1986

Source of Data: MSB/PWD

B. Offshore Botany Bay, November 1986

Source of Data: MSB/PWD



C. Offshore Batemans Bay, August 1986

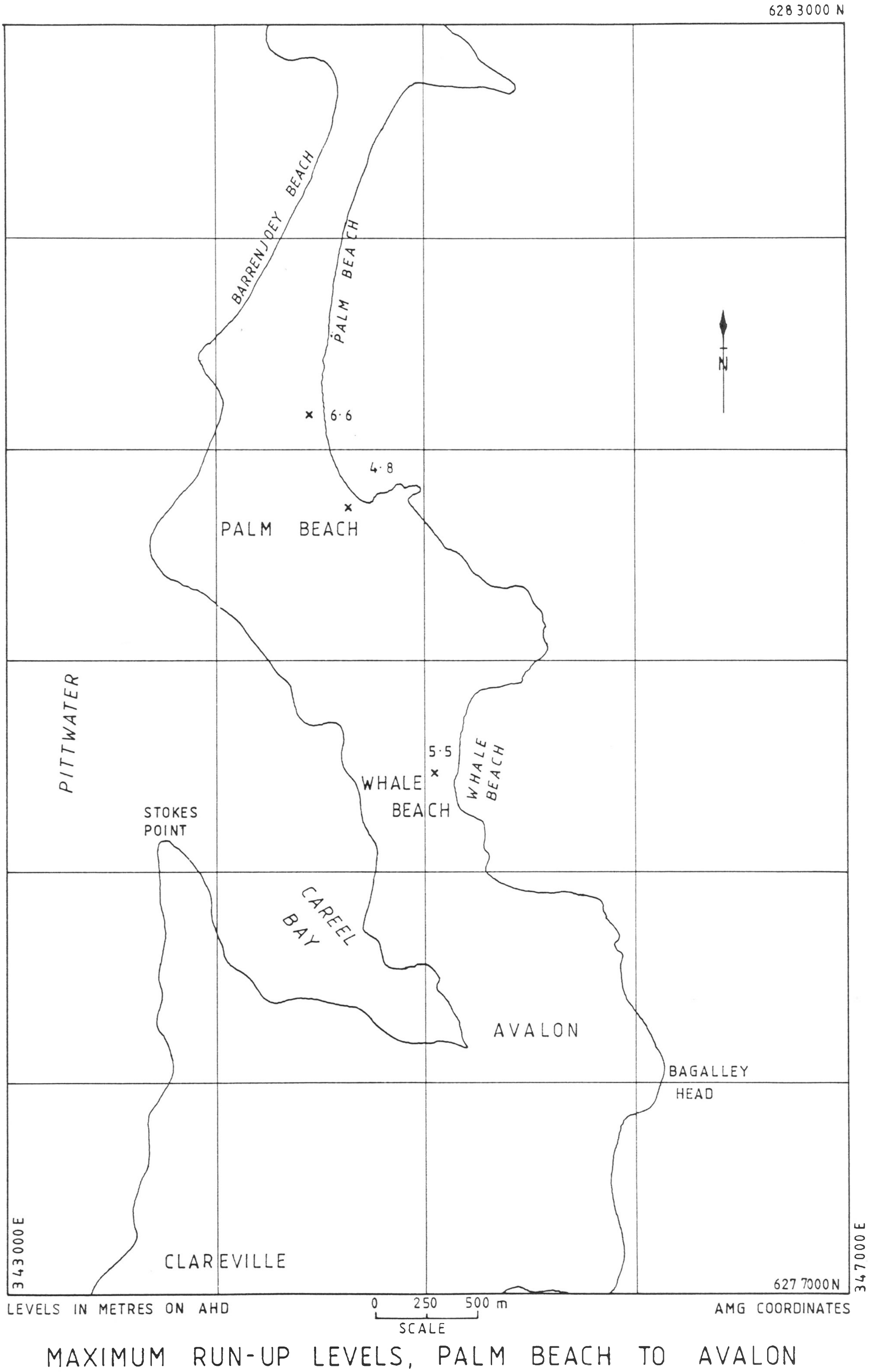
Source of Data: PWD

D. Offshore Batemans Bay, November 1986

Source of Data: PWD

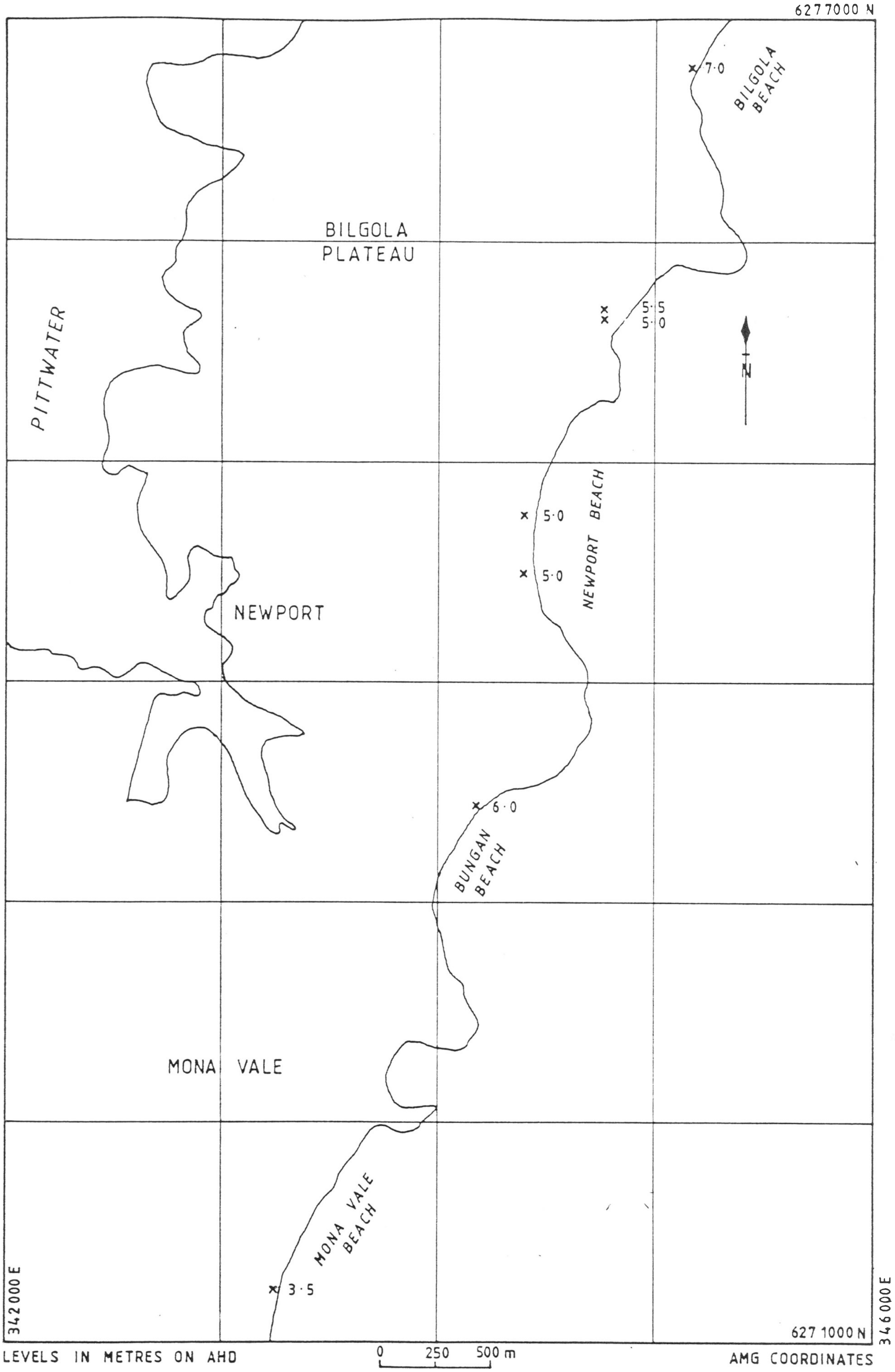
Wave Height and Period, Botany Bay and Batemans Bay

FIGURE 12



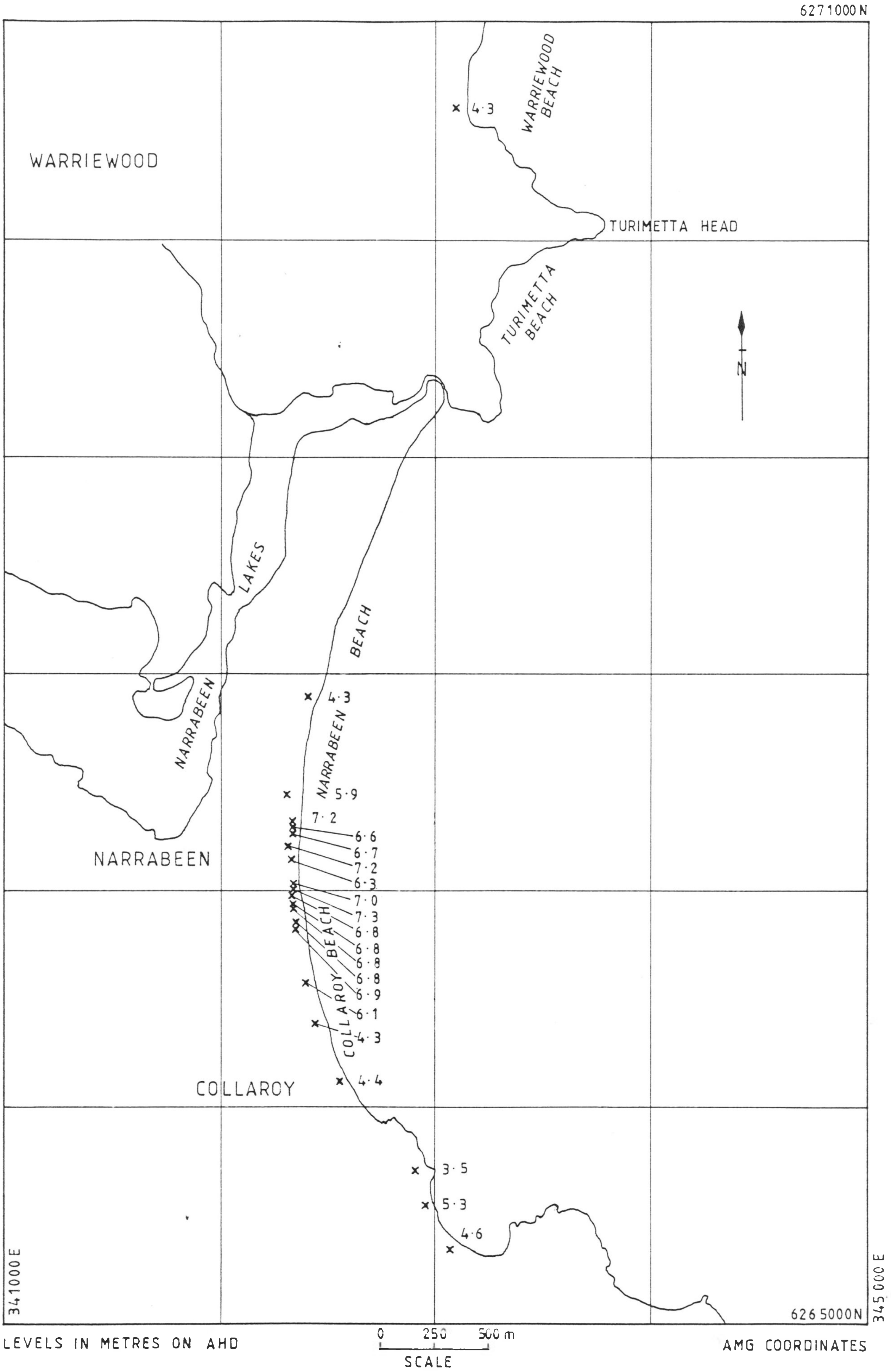
MAXIMUM RUN-UP LEVELS, PALM BEACH TO AVALON
AUGUST 1986

FIGURE 13 a



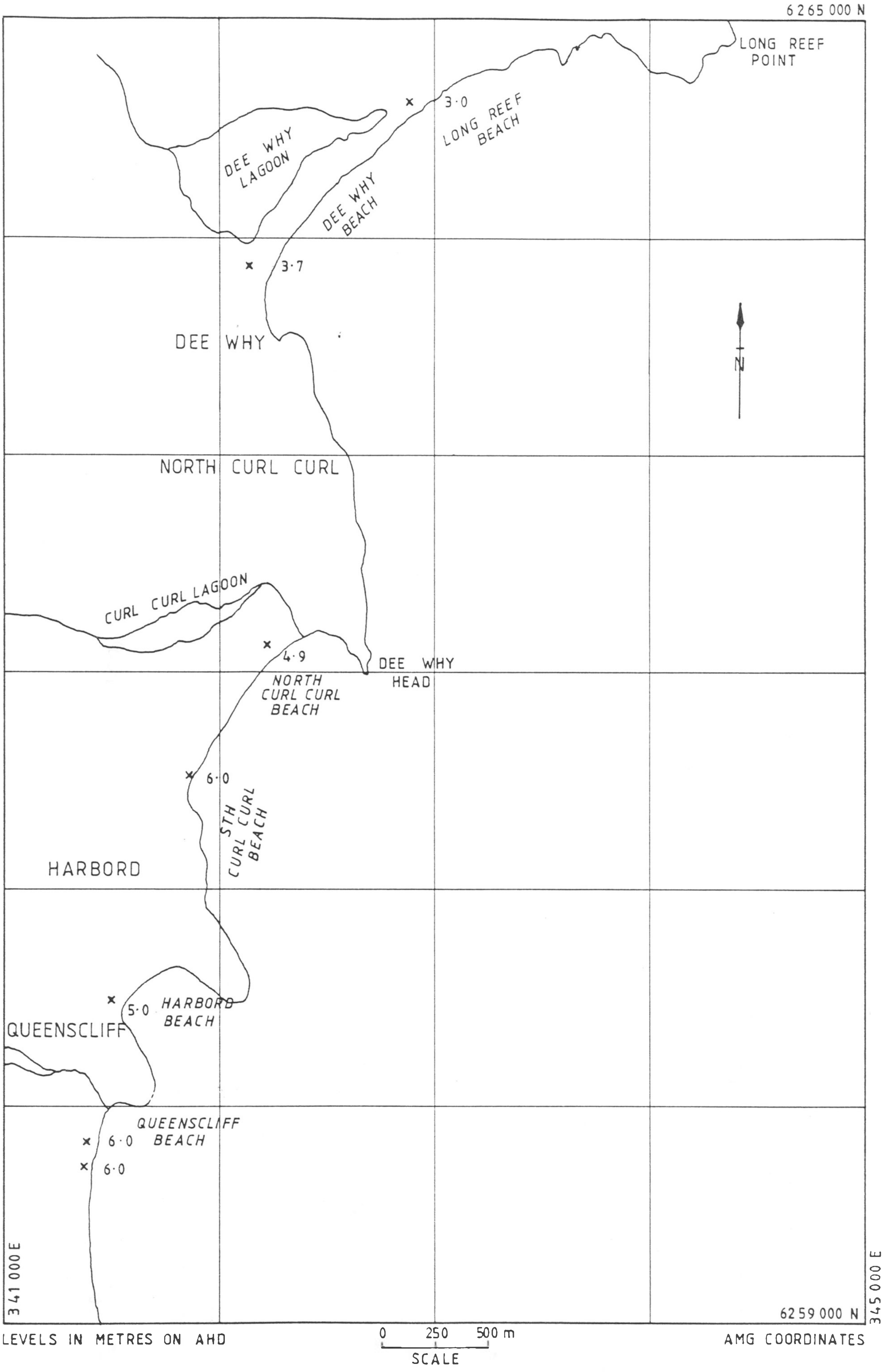
MAXIMUM RUN-UP LEVELS, AVALON TO MONA VALE
AUGUST 1986

FIGURE 13 b



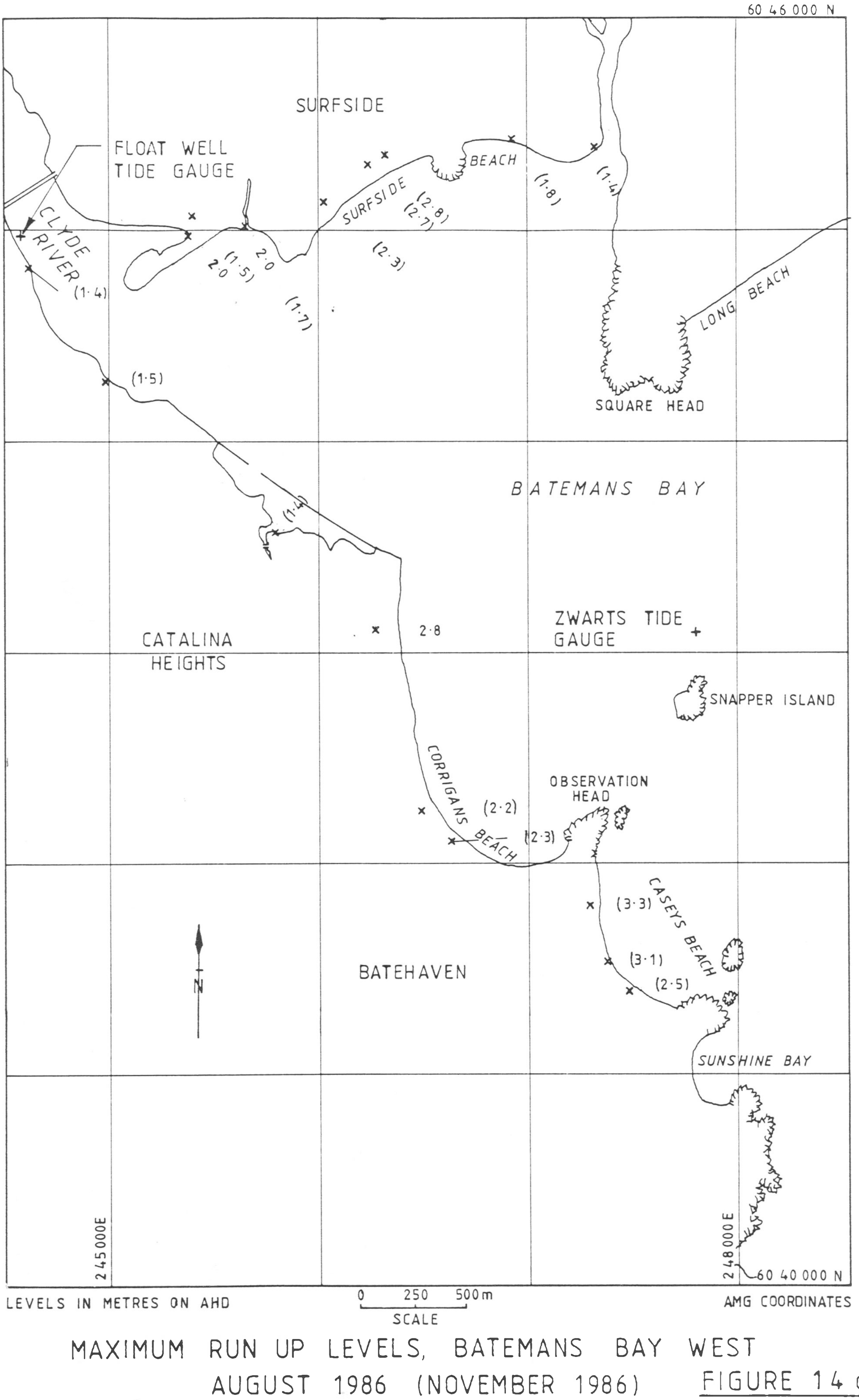
MAXIMUM RUN-UP LEVELS, NARRABEEN TO COLLAROY
AUGUST 1986

FIGURE 13c

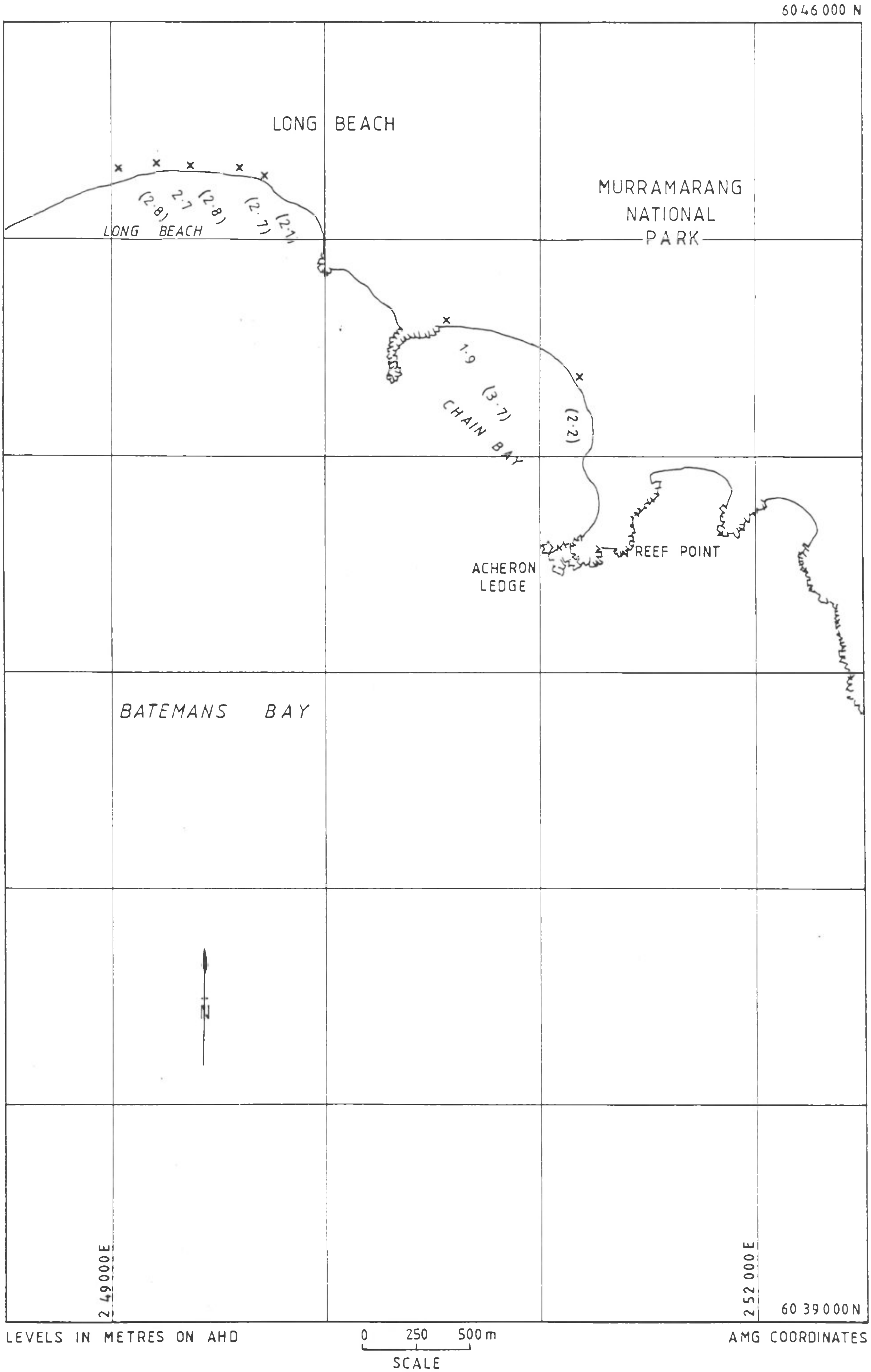


MAXIMUM RUN-UP LEVELS, LONG REEF TO QUEENSCLIFF
AUGUST 1986

FIGURE 13 d

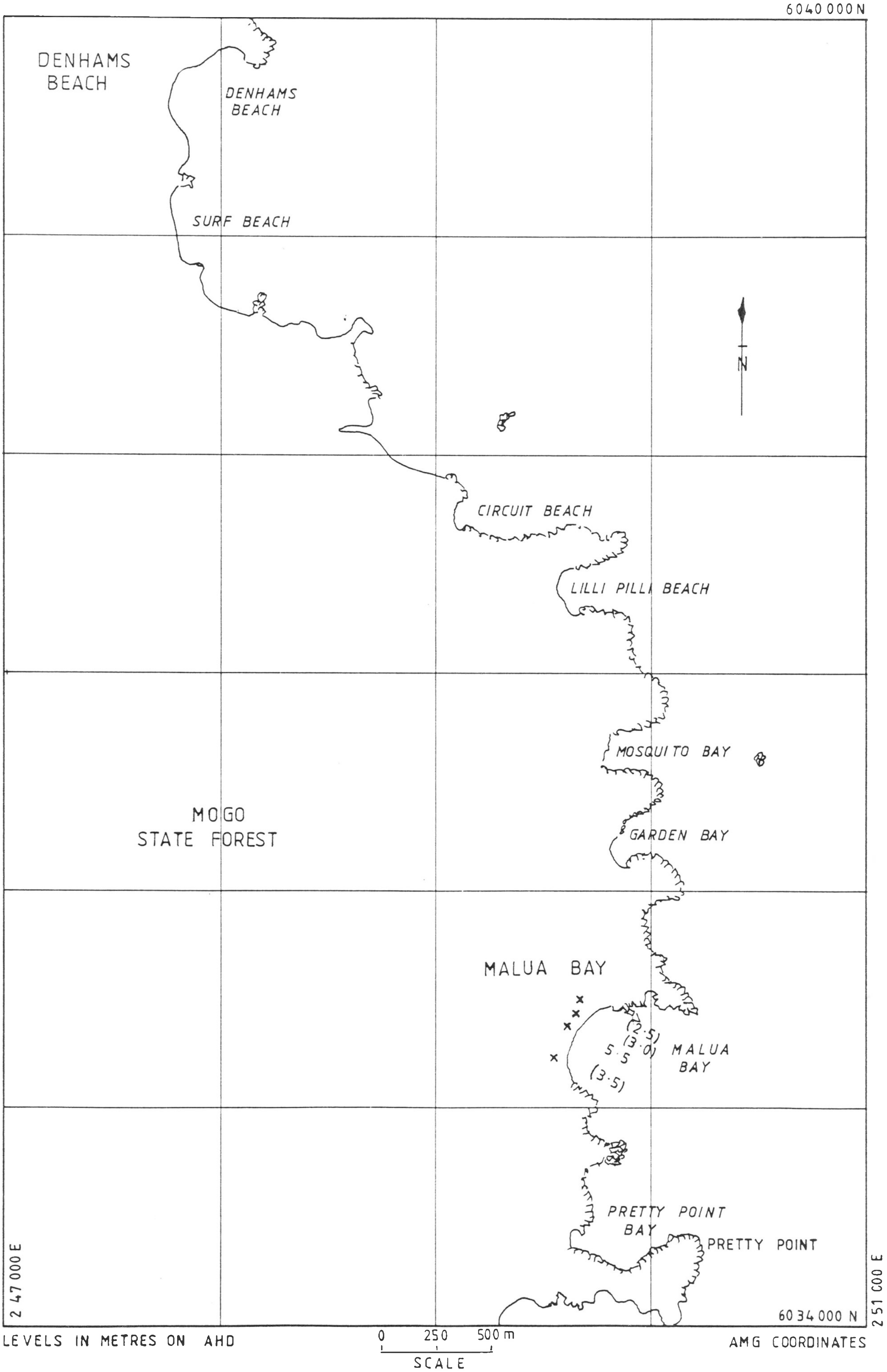


MAXIMUM RUN UP LEVELS, BATEMANS BAY WEST
AUGUST 1986 (NOVEMBER 1986) FIGURE 14 a

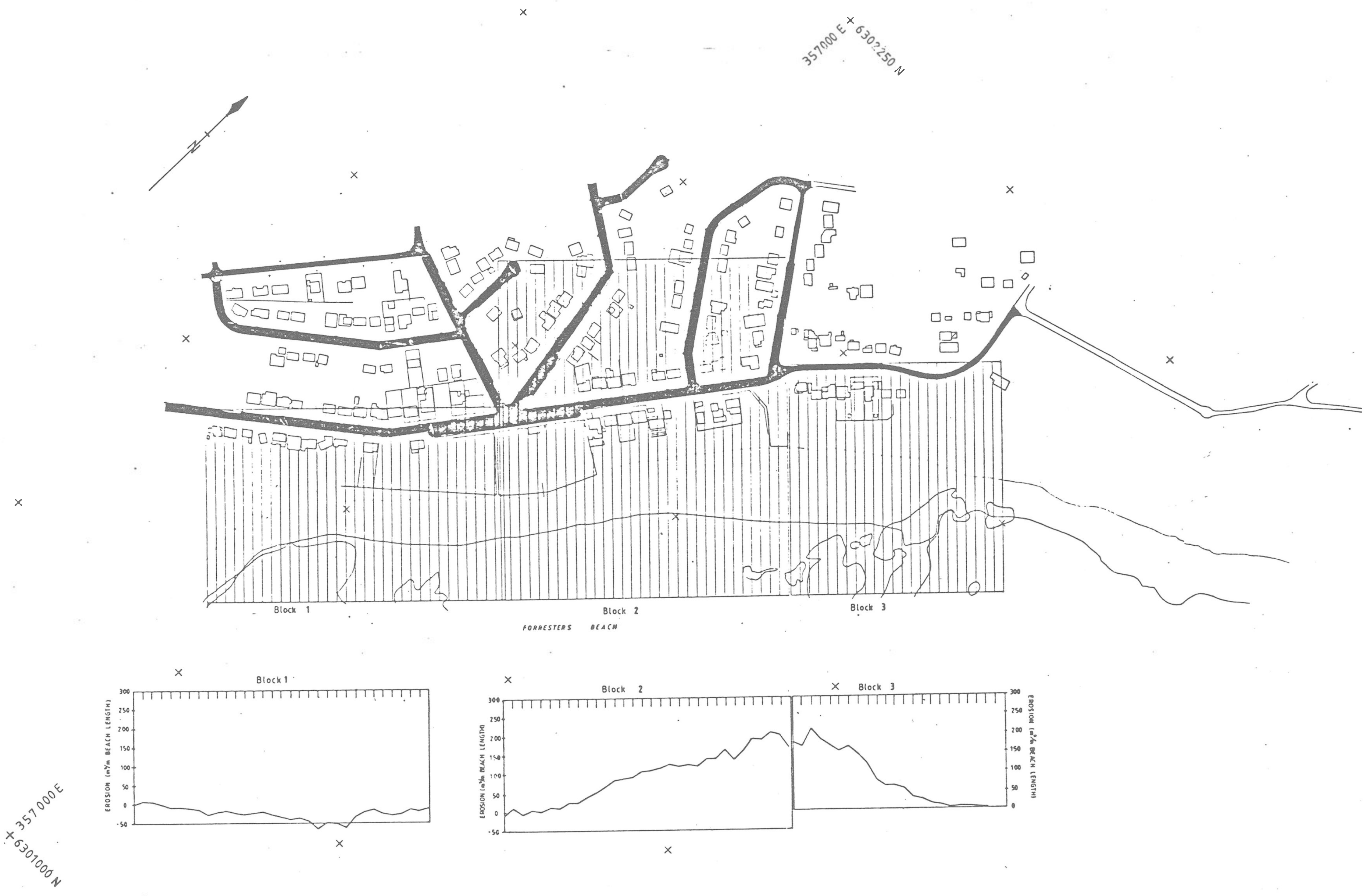


MAXIMUM RUN-UP LEVELS, BATEMANS BAY EAST
AUGUST 1986 (NOVEMBER 1986)

FIGURE 14 b



MAXIMUM RUN UP LEVELS, BATEMANS BAY SOUTH
AUGUST 1986 (NOVEMBER 1986) FIGURE 14c



0 50 100 m

SCALE

NOTE: PLANIMETRIC INFORMATION OBTAINED PHOTOGRAMMETRICALLY FROM AUG. 1984 C.M.A. AERIAL PHOTOGRAPHY; AUSTRALIAN MAPPING GRID

Key to plan of beach

—·—·—·— Top of back beach escarpment

—·—·— Water line

▨ Road formation

▥ Location of beach profiles

Key to graph

Difference in sand volumes between surveys:

——— 23/8/84 - 18/8/86

AMG Coordinates

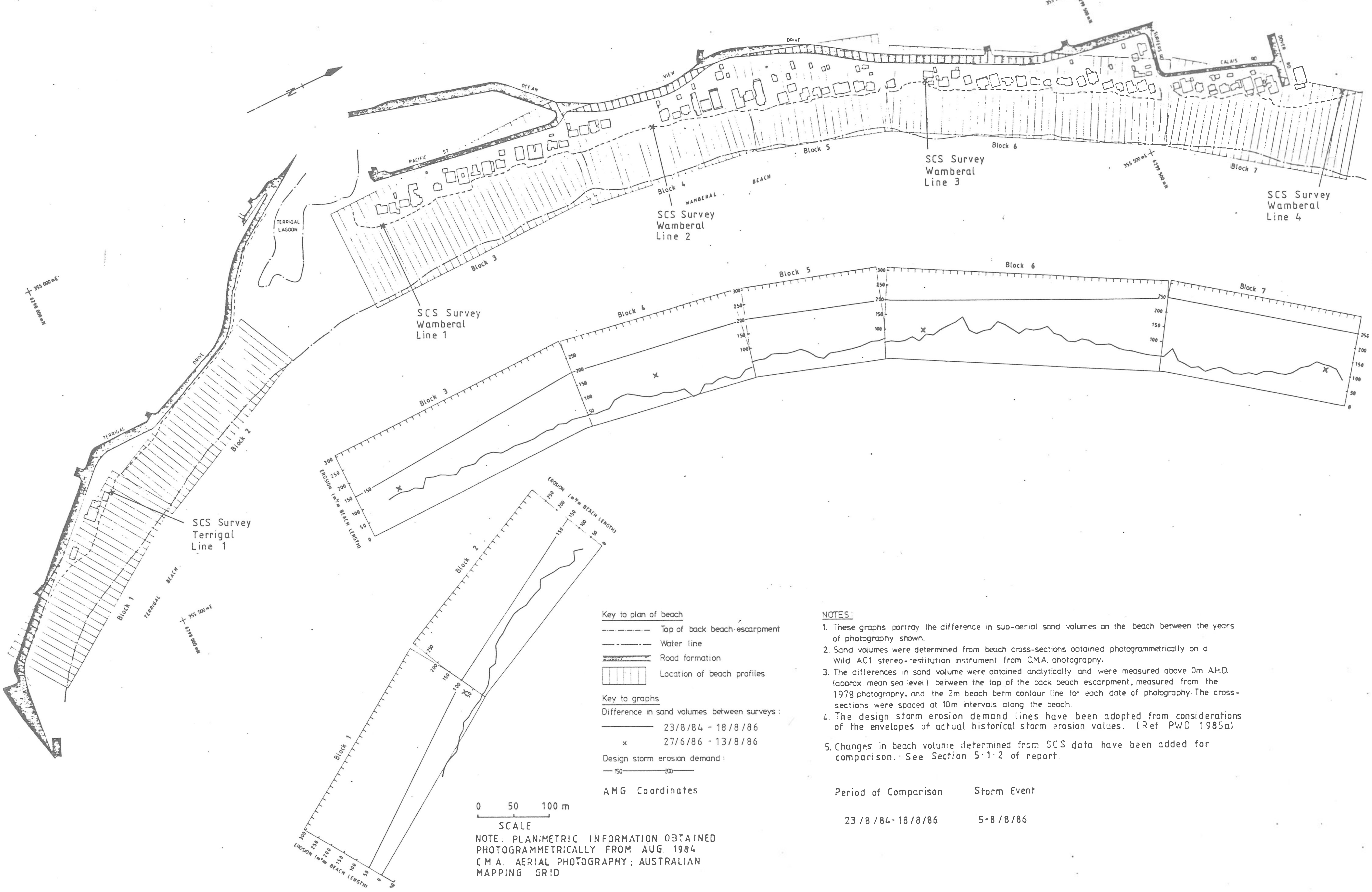
NOTES:

1. These graphs portray the difference in sub-aerial sand volumes on the beach between the years of photography shown.
2. Sand volumes were determined from beach cross-sections obtained photogrammetrically on a Wild AC1 stereo-restitution instrument from C.M.A. photography.
3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between the toe of the back beach escarpment, measured from the 1979 photography, and the 2m beach berm contour line for each date of photography. The cross-sections were spaced at 10m intervals along the beach.

Period of Comparison	Storm Event
23/8/84-18/8/86	5-8/8/86

BEACH CHANGES, FORRESTERS BEACH

FIGURE 15



NOTES:

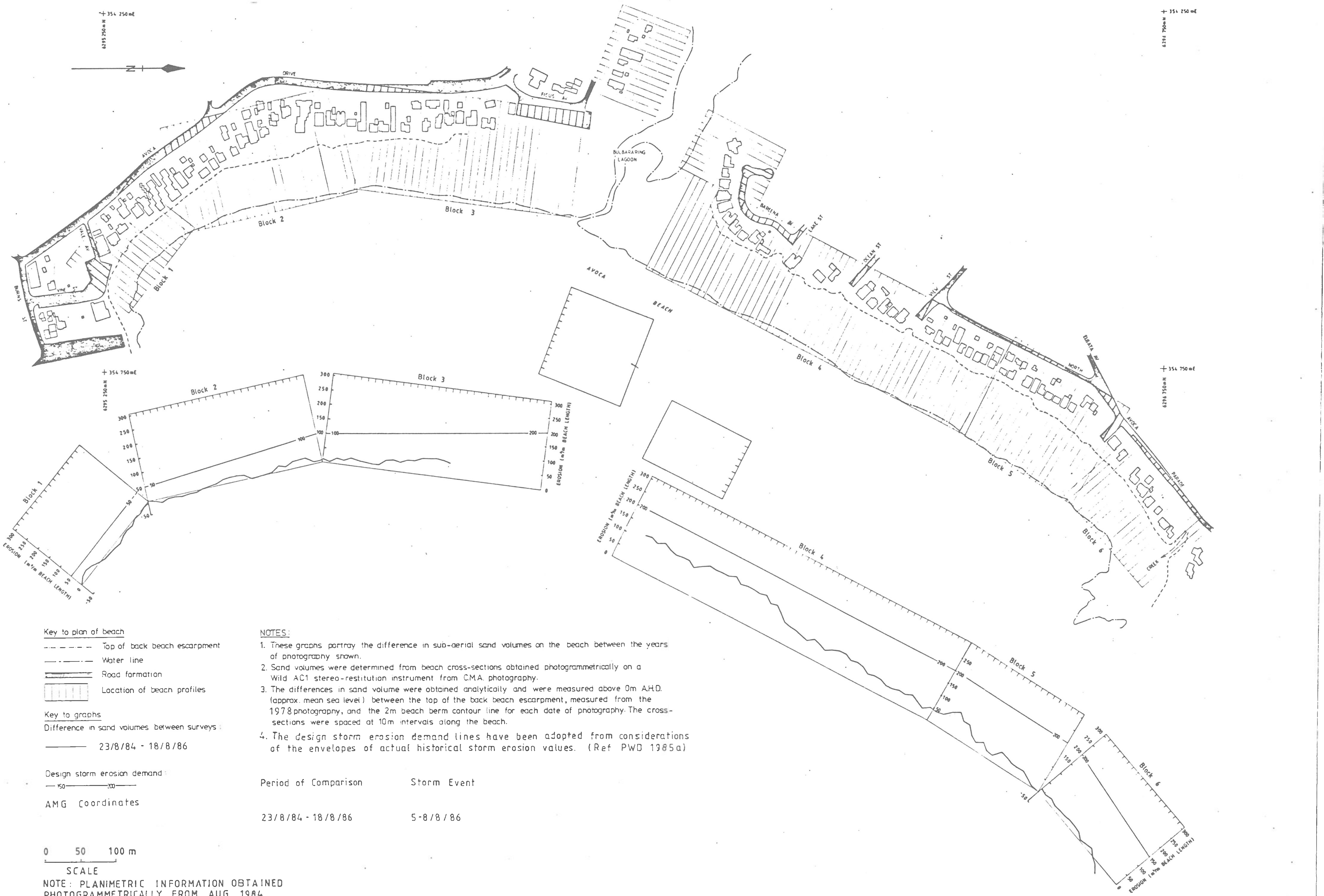
1. These graphs portray the difference in sub-aerial sand volumes on the beach between the years of photography shown.
2. Sand volumes were determined from beach cross-sections obtained photogrammetrically on a Wild AC1 stereo-restitution instrument from C.M.A. photography.
3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between the top of the back beach escarpment, measured from the 1978 photography, and the 2m beach berm contour line for each date of photography. The cross-sections were spaced at 10m intervals along the beach.
4. The design storm erosion demand lines have been adopted from considerations of the envelopes of actual historical storm erosion values. (Ref PWD 1985a)
5. Changes in beach volume determined from SCS data have been added for comparison. See Section 5·1·2 of report.

Period of Comparison	Storm Event
23/8/84- 18/8/86	5-8/8/86

NOTE: PLANIMETRIC INFORMATION OBTAINED PHOTOGRAMMETRICALLY FROM AUG. 1984 C.M.A. AERIAL PHOTOGRAPHY; AUSTRALIAN MAPPING GRID

BEACH CHANGES, WAMBERAL AND TERRIGAL BEACHES

FIGURE 16



Key to plan of beach

— - — - — Top of back beach escarpment

—— · —— · — Water line

Road formation

Location of beach profiles

Key to graphs

Difference in sand volumes between surveys :

———— 23/8/84 - 18/8/86

Design storm erosion demand :

— 150 ———— 200 ———

AMG Coordinates

NOTES:

1. These graphs portray the difference in sub-aerial sand volumes on the beach between the years of photography shown.
2. Sand volumes were determined from beach cross-sections obtained photogrammetrically on a Wild AC1 stereo-restitution instrument from C.M.A. photography.
3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between the top of the back beach escarpment, measured from the 1978 photography, and the 2m beach berm contour line for each date of photography. The cross-sections were spaced at 10m intervals along the beach.
4. The design storm erosion demand lines have been adopted from considerations of the envelopes of actual historical storm erosion values. (Ref PWD 1985a)

Period of Comparison	Storm Event
23/8/84 - 18/8/86	5-8/8/86

0 50 100 m

SCALE

NOTE: PLANIMETRIC INFORMATION OBTAINED PHOTOGRAMMETRICALLY FROM AUG. 1984 C.M.A. AERIAL PHOTOGRAPHY; AUSTRALIAN MAPPING GRID

BEACH CHANGES, AVOCA BEACH

FIGURE 17

0 50 100 m

SCALE

NOTE: PLANIMETRIC INFORMATION OBTAINED PHOTOGRAMMETRICALLY FROM AUG. 1984 C.M.A. AERIAL PHOTOGRAPHY; AUSTRALIAN MAPPING GRID

Key to plan of beach

— - — - — -	Top of back beach escarpment
——— - ——— -	Water line
▬▬▬	Road formation
▥	Location of beach profiles

Key to graphs

Difference in sand volumes between surveys :

——— 23 / 8 / 84 - 18 / 8 / 86

AMG Coordinates

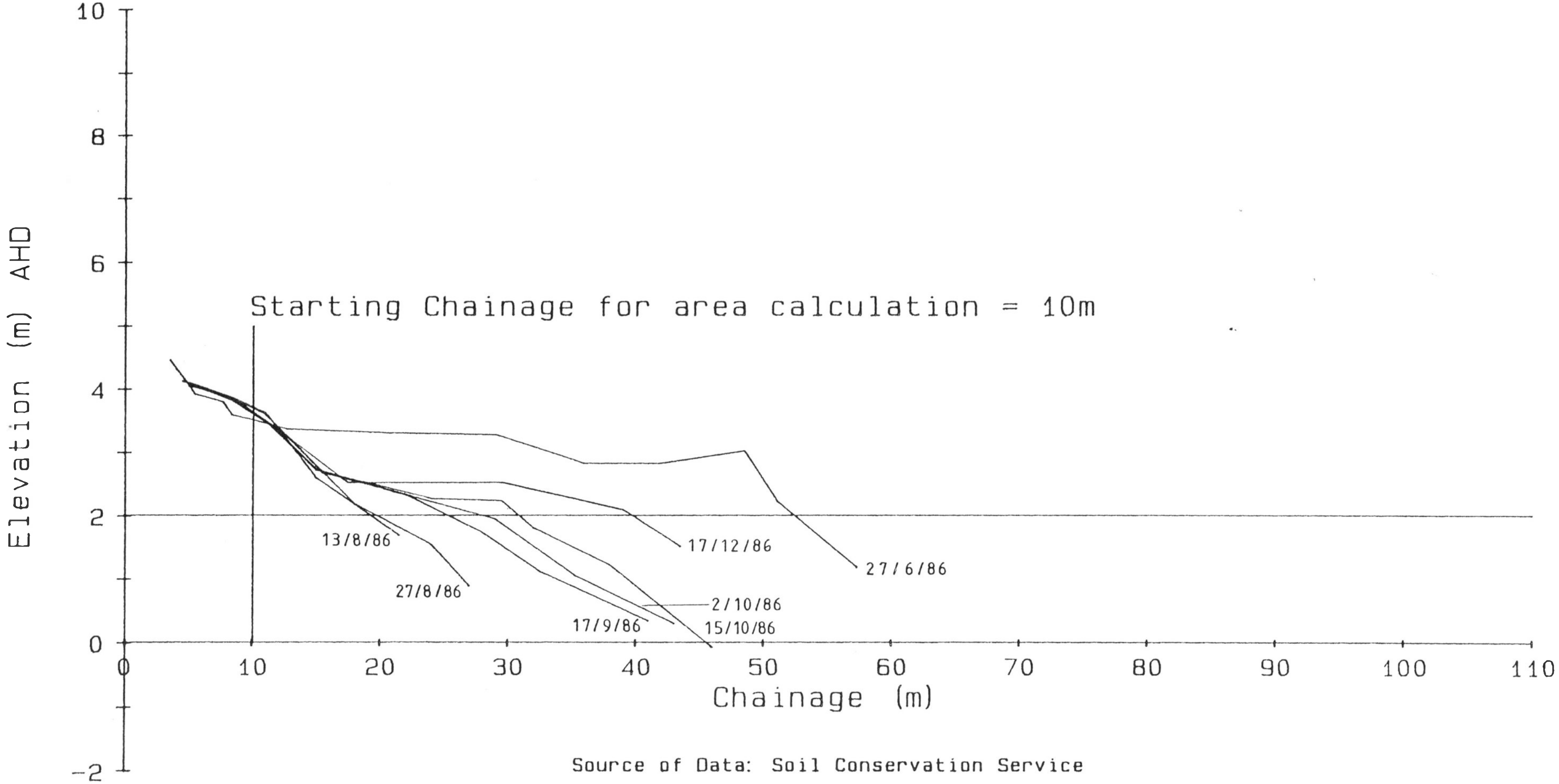
NOTES:

1. These graphs portray the difference in sub-aerial sand volumes on the beach between the years of photography shown.
2. Sand volumes were determined from beach cross-sections obtained photogrammetrically on a Wild AC1 stereo-restitution instrument from C.M.A. photography.
3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between the toe of the back beach escarpment, measured from the 1978 photography, and the 2m beach berm contour line for each date of photography. The cross-sections were spaced at 10m intervals along the beach.

Period of Comparison	Storm Event
23/8/84 - 18/8/86	5 - 6 / 8 / 86

BEACH CHANGES, COPACABANA AND MacMASTERS BEACHES

FIGURE 18

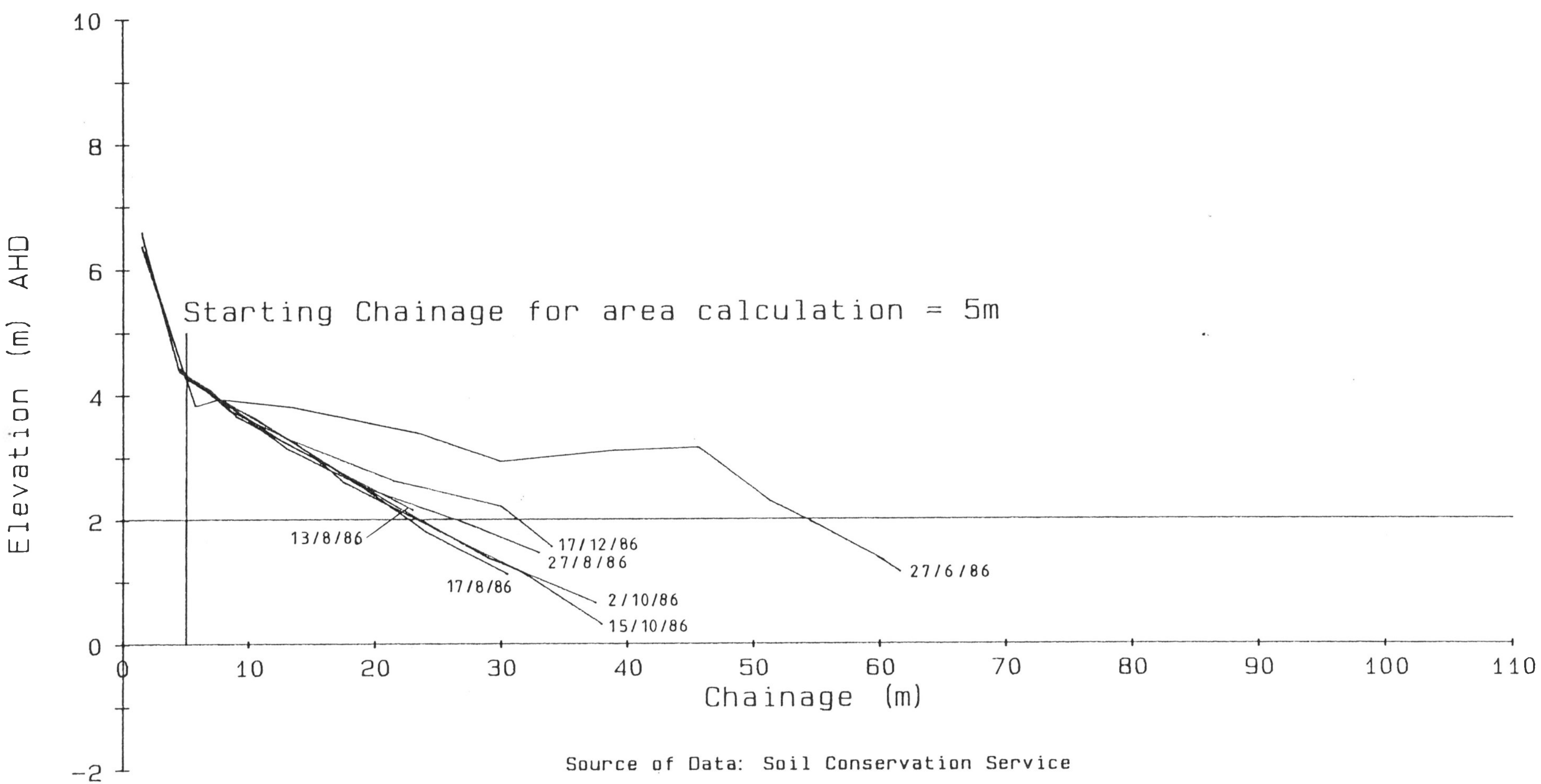


Source of Data: Soil Conservation Service

Beach Profiles, Gosford Area

Wamberal Beach, Line 1

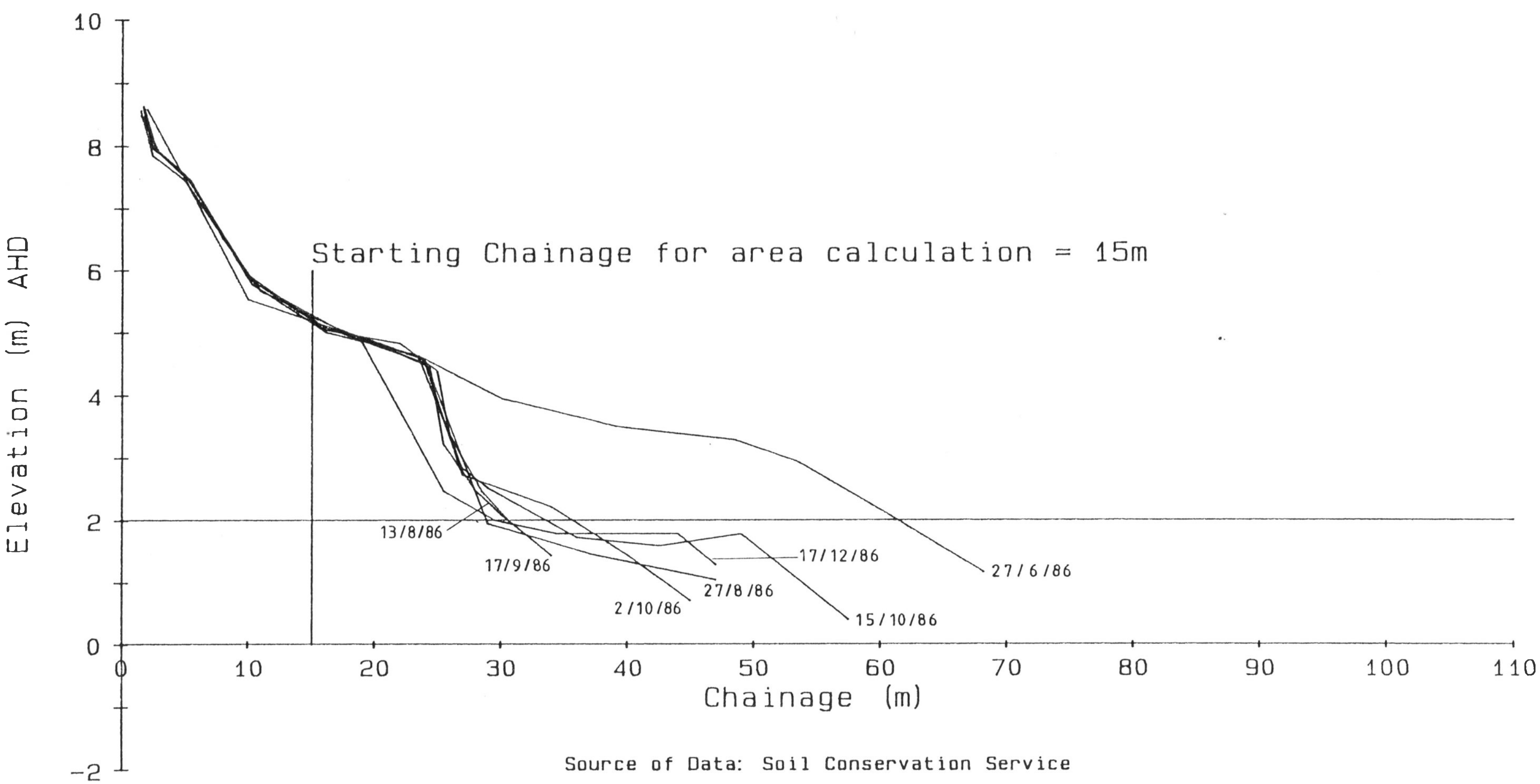
FIGURE 19a



Source of Data: Soil Conservation Service

Beach Profiles, Gosford Area
Wamberal Beach, Line 2

FIGURE 19b

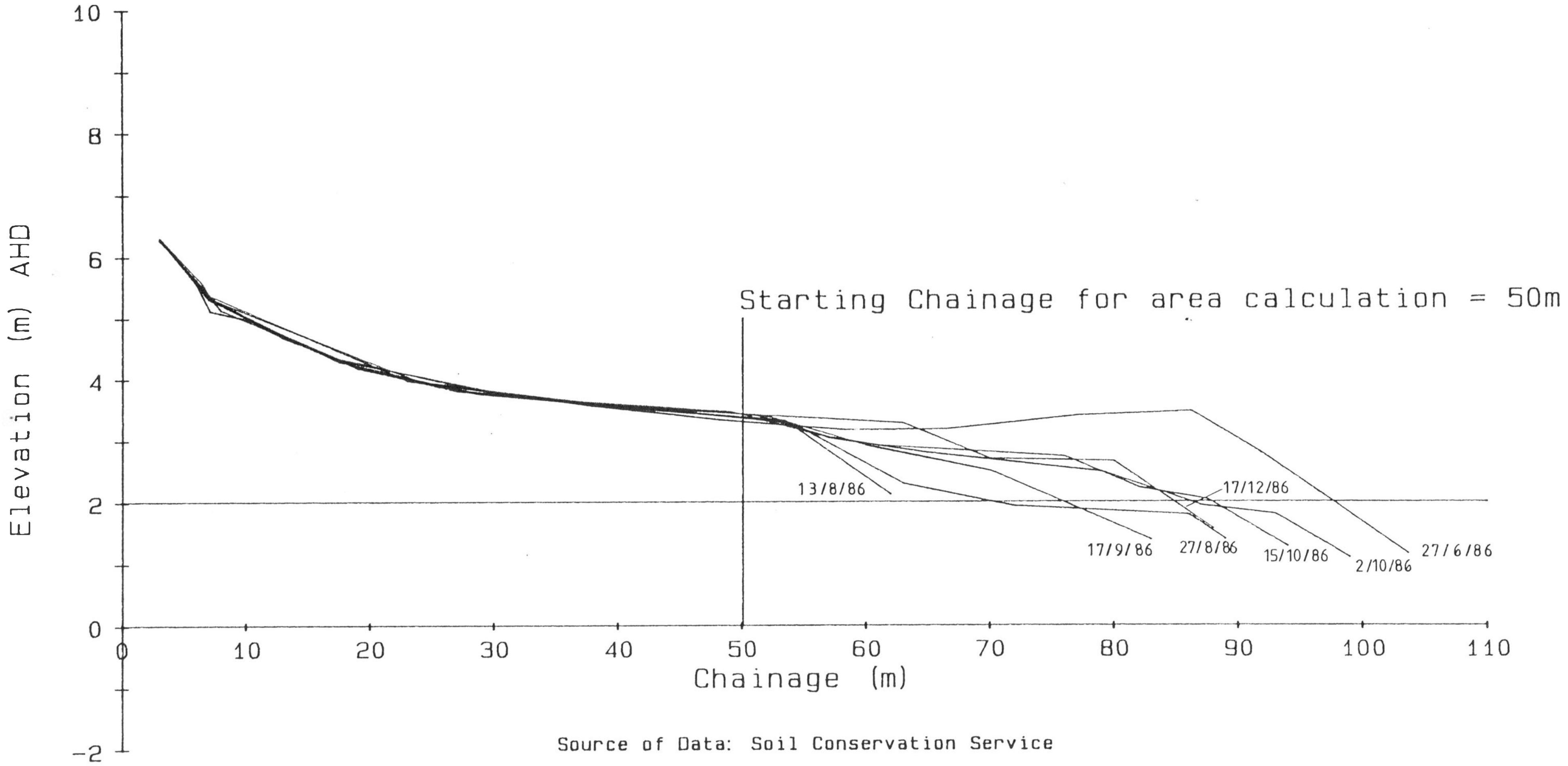


Source of Data: Soil Conservation Service

Beach Profiles, Gosford Area

Wamberal Beach, Line 3

FIGURE 19c

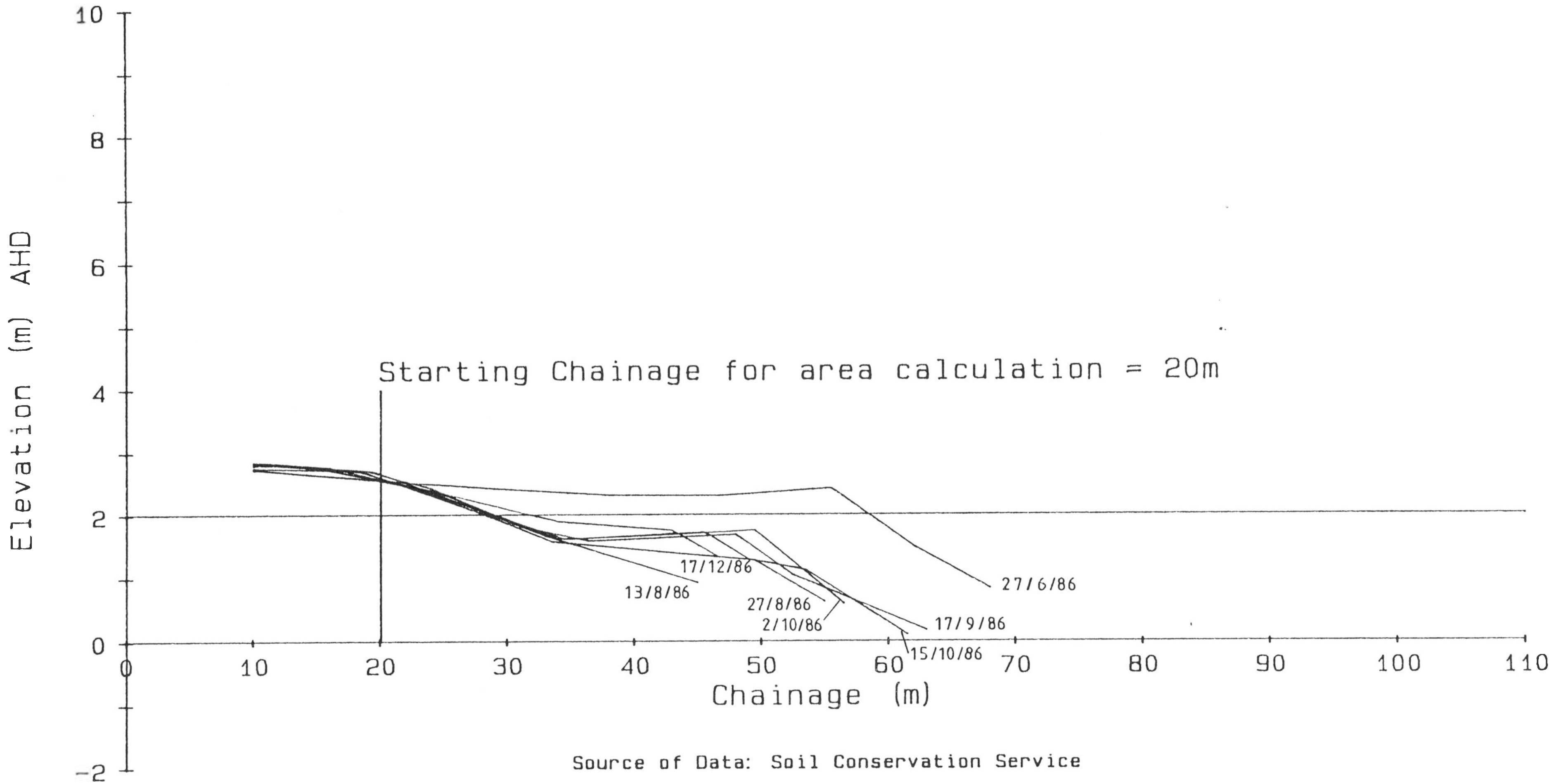


Source of Data: Soil Conservation Service

Beach Profiles, Gosford Area

Wamberal Beach, Line 4

FIGURE 19d

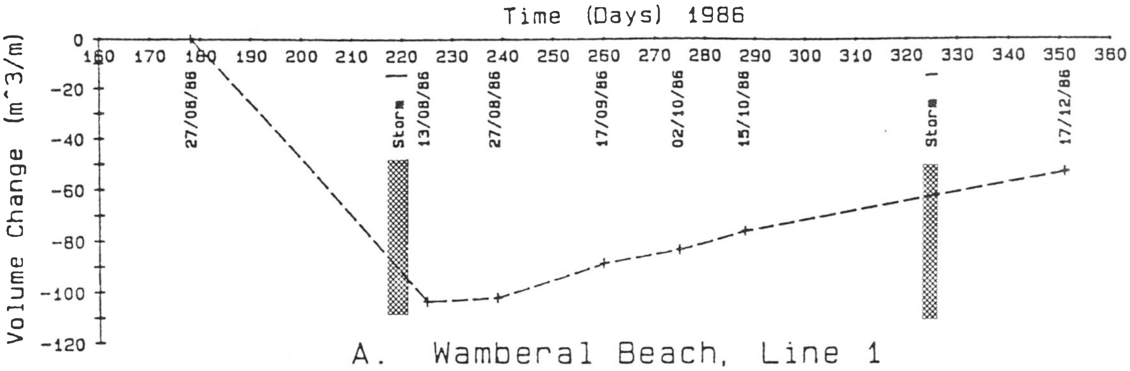


Source of Data: Soil Conservation Service

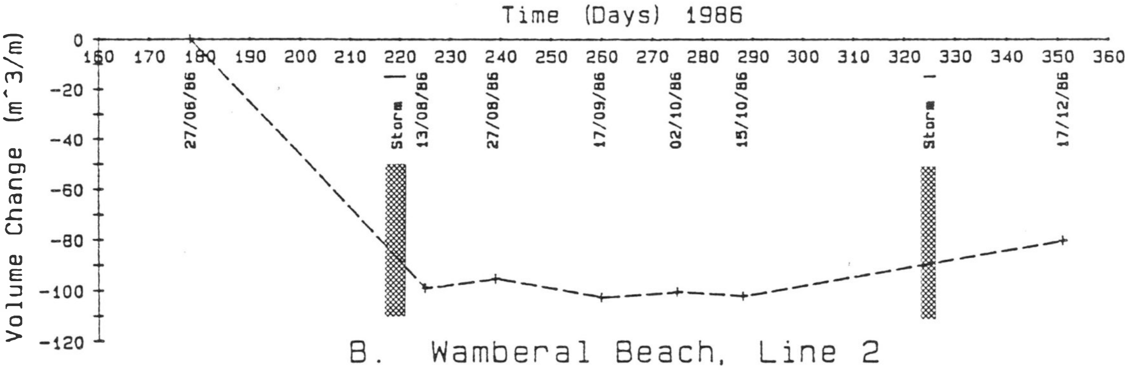
Beach Profiles, Gosford Area

Terrigal Beach, Line 1

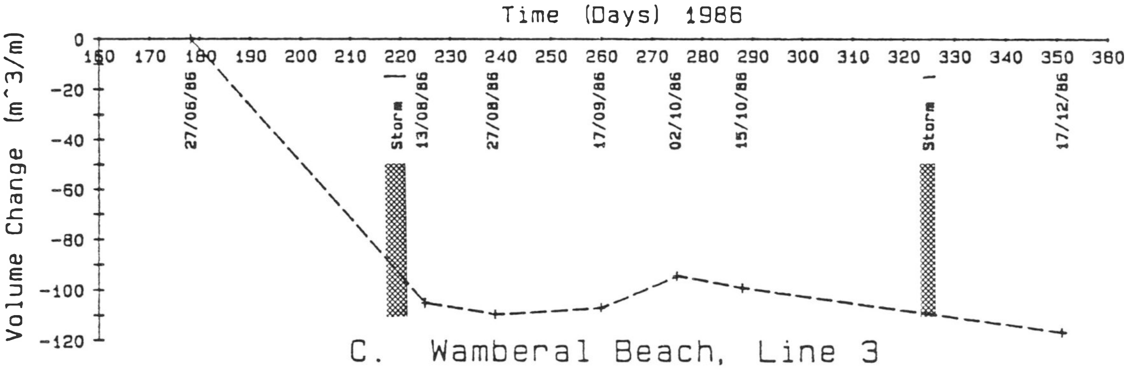
FIGURE 19e



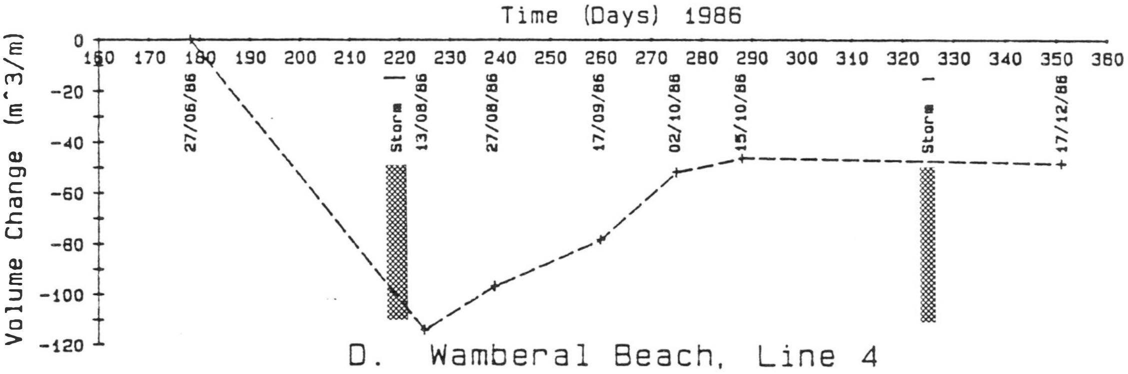
A. Wamberal Beach, Line 1



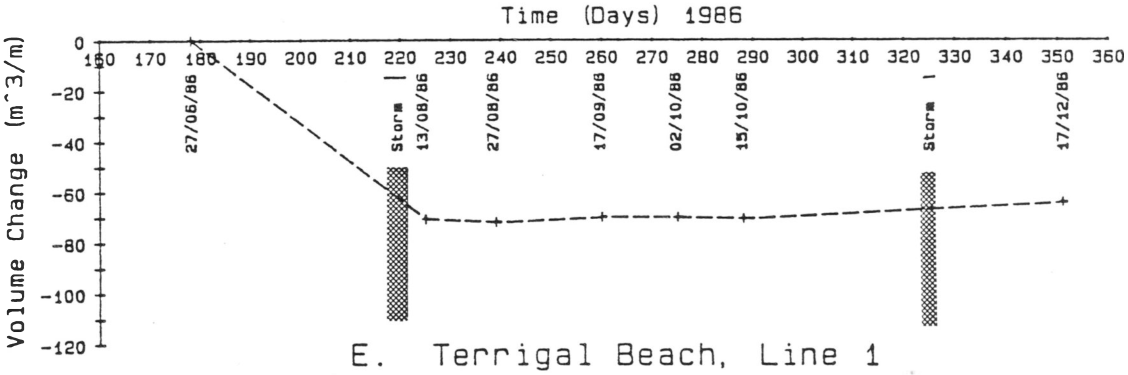
B. Wamberal Beach, Line 2



C. Wamberal Beach, Line 3



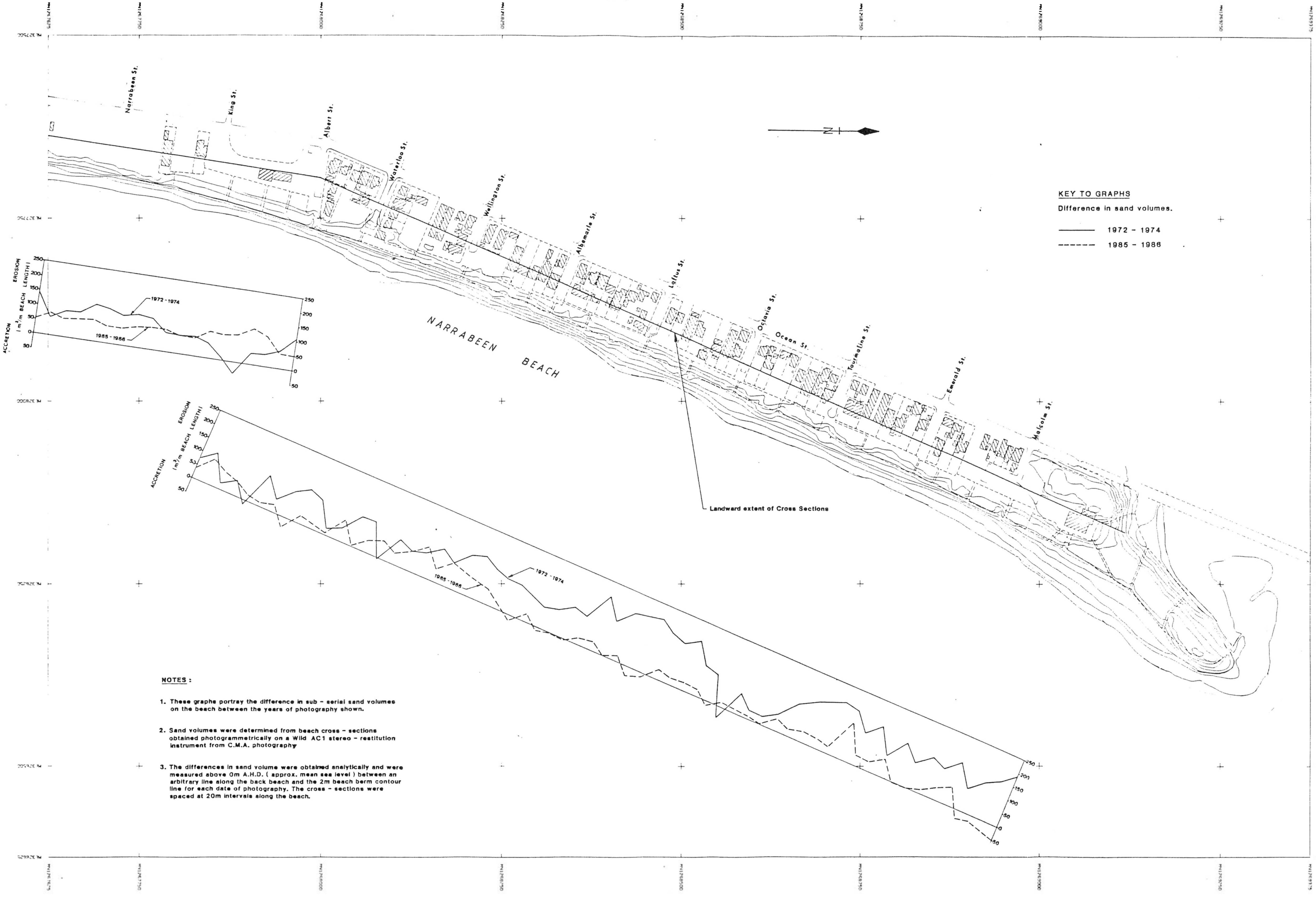
D. Wamberal Beach, Line 4



E. Terrigal Beach, Line 1

Change in Beach Volume Vs Time,
Wamberal and Terrigal Beaches

FIGURE 20



KEY TO GRAPHS

Difference in sand volumes.

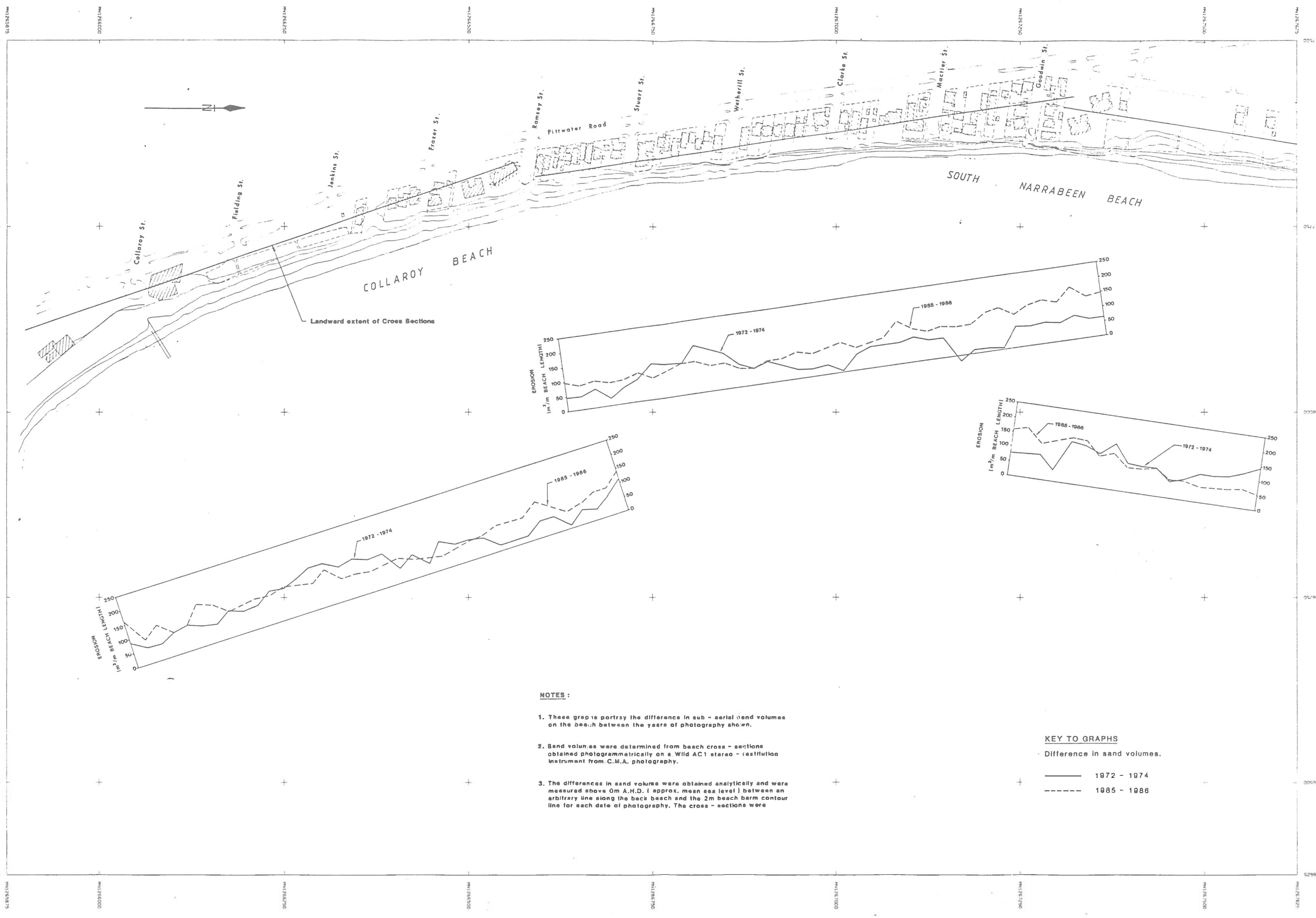
———	1972 - 1974
- - - - - -	1985 - 1986

NOTES :

1. These graphs portray the difference in sub - aerial sand volumes on the beach between the years of photography shown.
2. Sand volumes were determined from beach cross - sections obtained photogrammetrically on a Wild AC1 stereo - restitution instrument from C.M.A. photography
3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between an arbitrary line along the back beach and the 2m beach berm contour line for each date of photography. The cross - sections were spaced at 20m intervals along the beach.

BEACH CHANGES, NARRABEEN BEACH

FIGURE 21



NOTES :

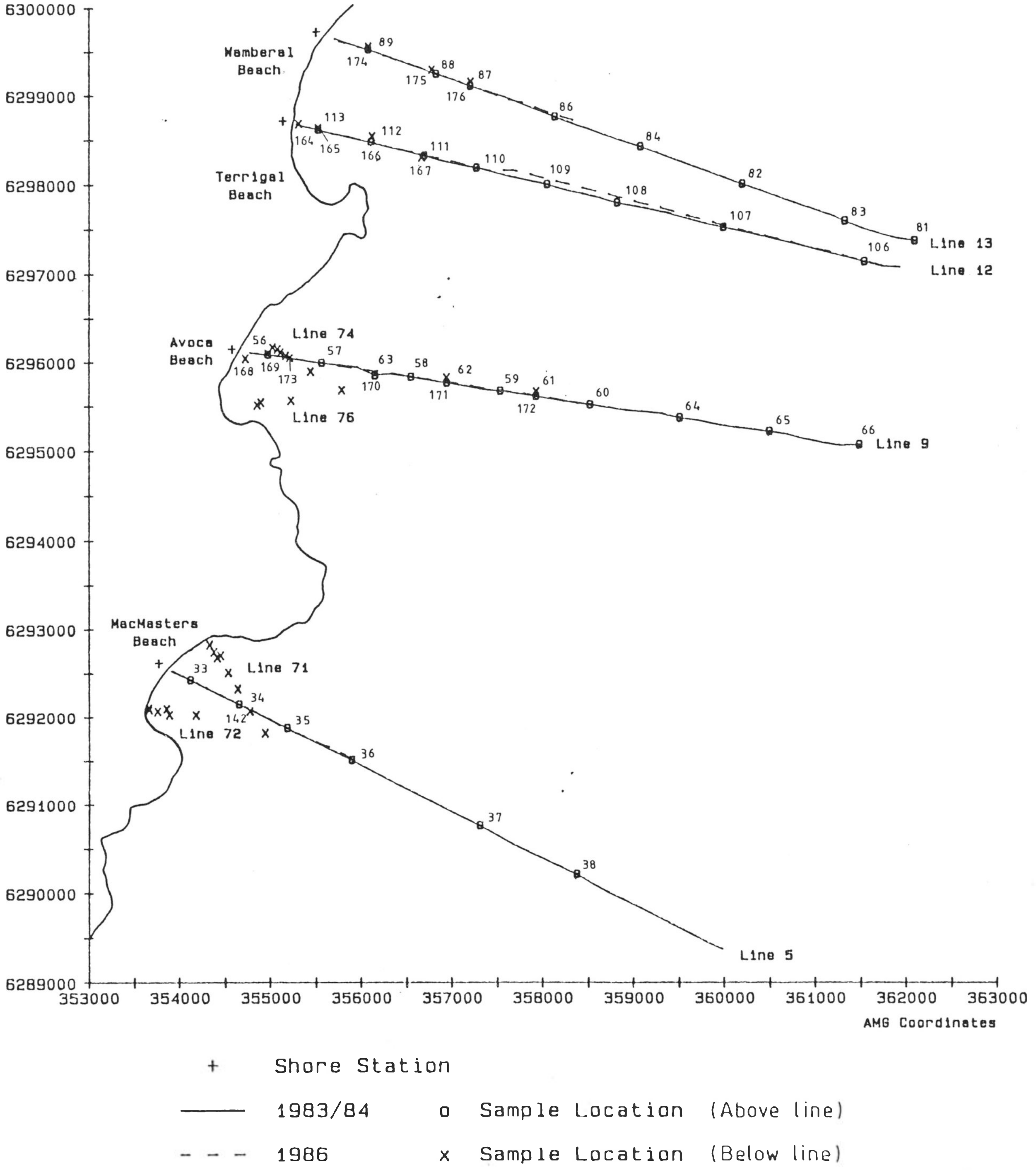
1. These graphs portray the difference in sub - aerial sand volumes on the beach between the years of photography shown.

2. Sand volumes were determined from beach cross - sections obtained photogrammetrically on a Wild AC1 stereo - restitution instrument from C.M.A. photography.

3. The differences in sand volume were obtained analytically and were measured above 0m A.H.D. (approx. mean sea level) between an arbitrary line along the back beach and the 2m beach berm contour line for each date of photography. The cross - sections were

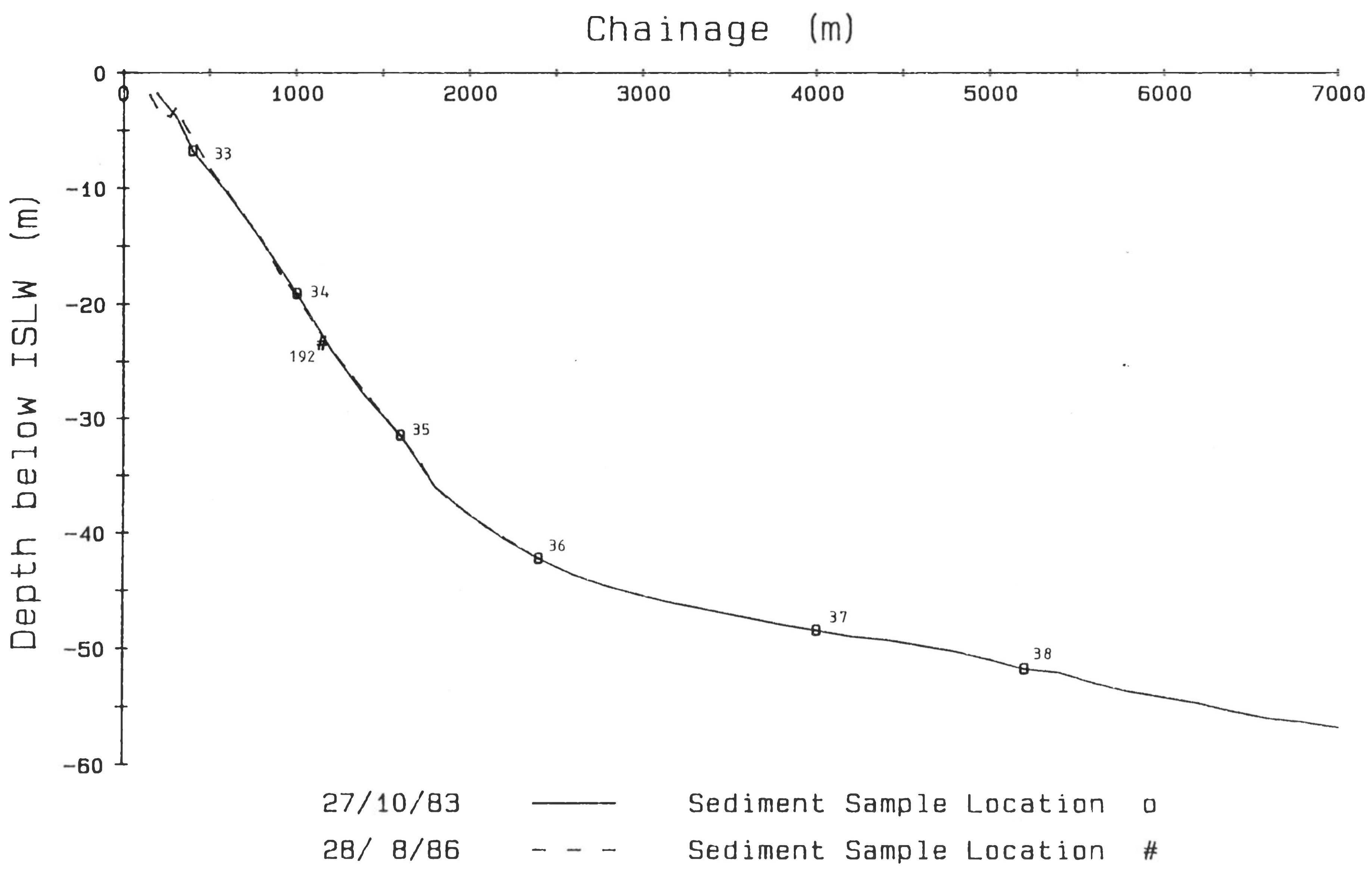
BEACH CHANGES, COLLAROY AND SOUTH NARRABEEN BEACHES

FIGURE 22



Location of Gosford Offshore Profiles and Samples

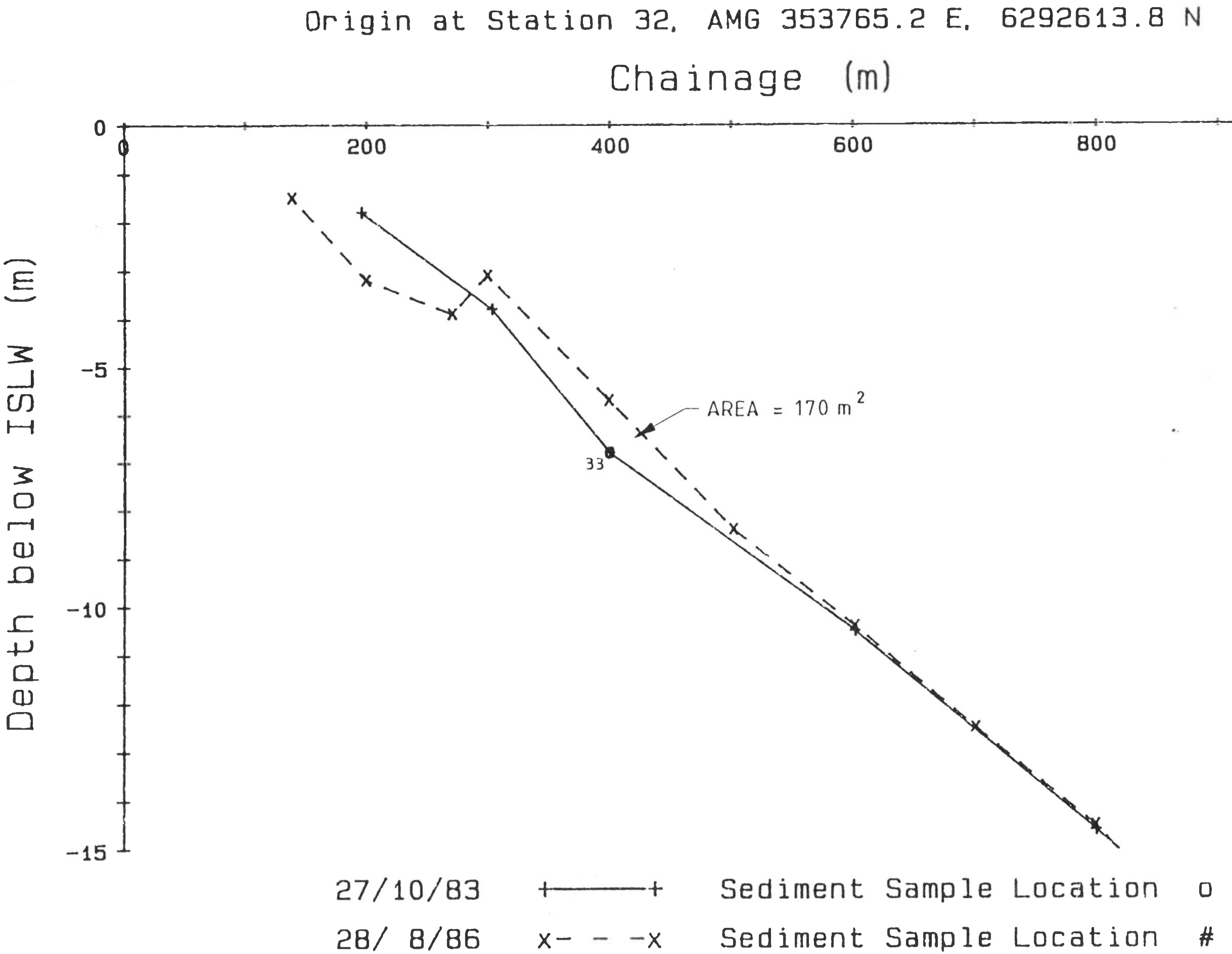
FIGURE 23



Origin at Station 32, AMG 353765.2 E, 6292613.8 N

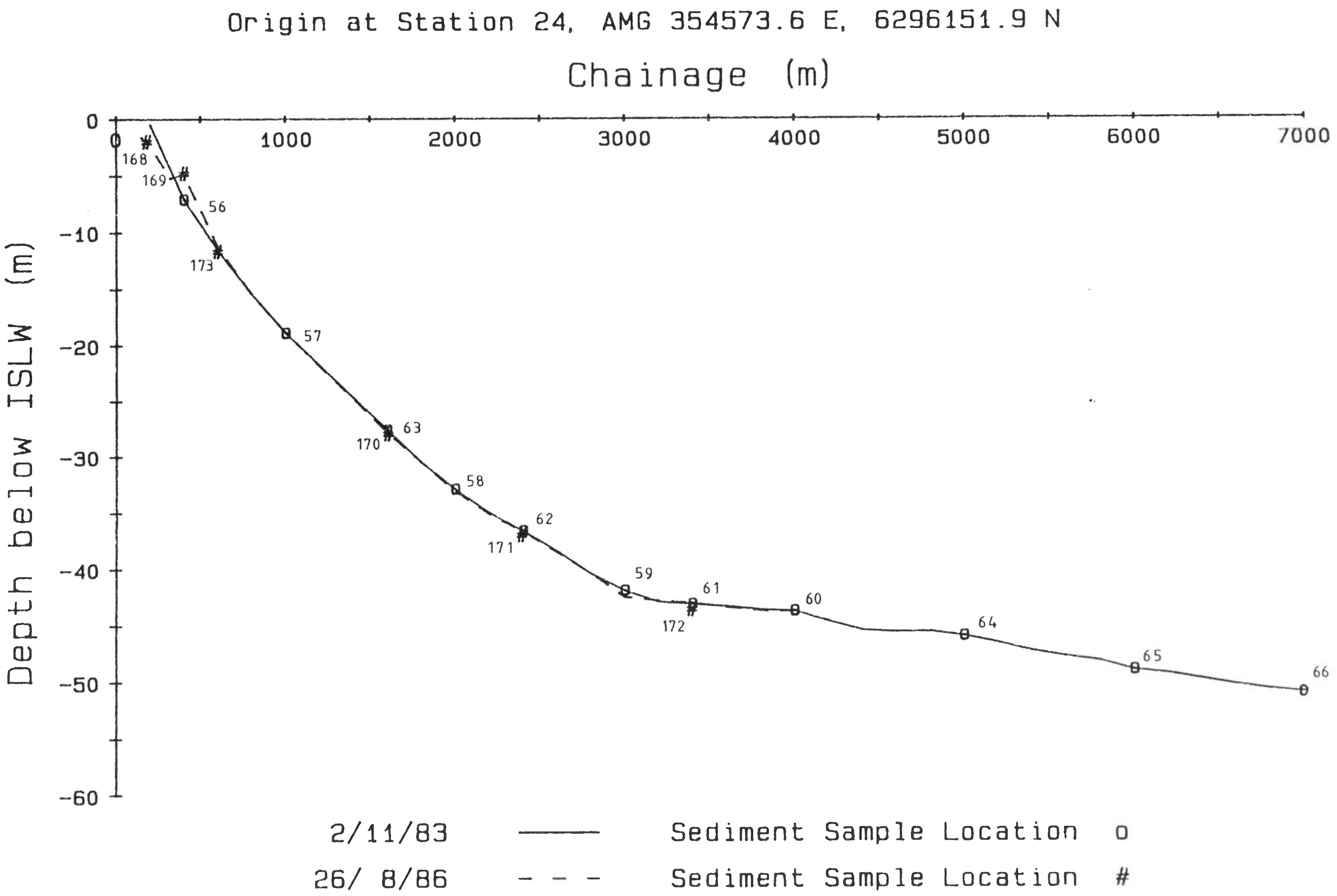
OFFSHORE PROFILES, GOSFORD LINE 5
MacMasters Beach

FIGURE 24a



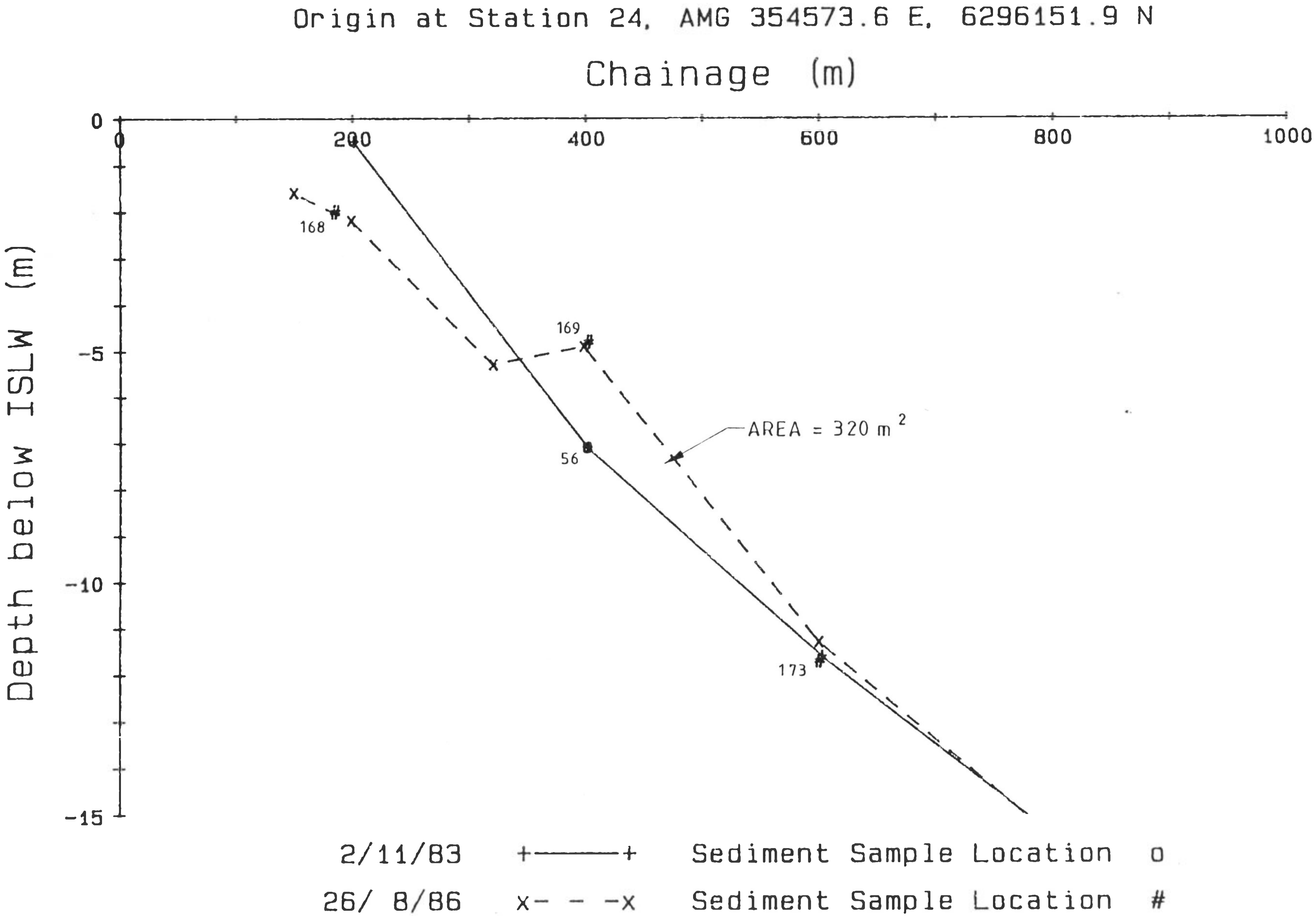
OFFSHORE PROFILES, GOSFORD LINE 5
MacMasters Beach

FIGURE 24b



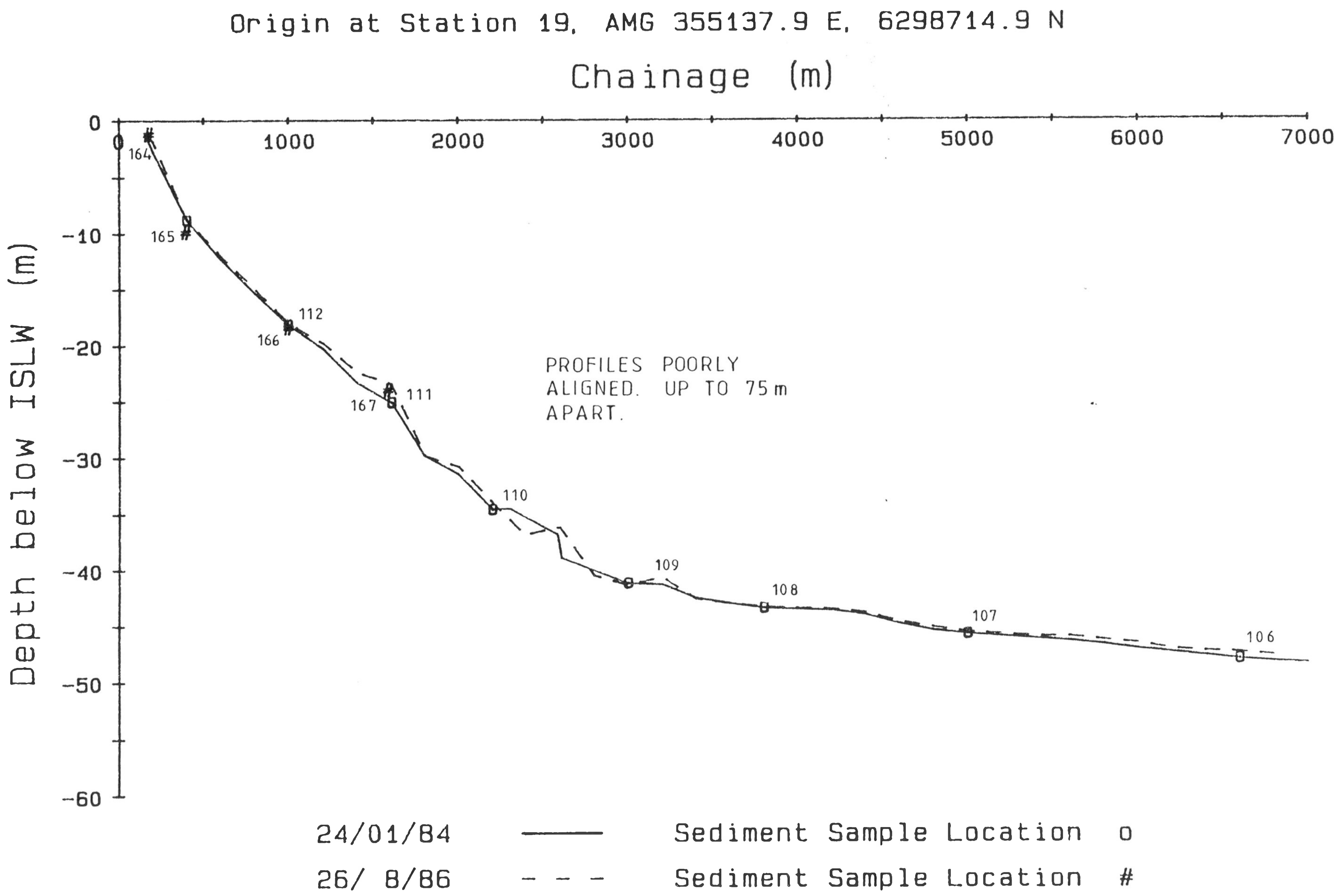
OFFSHORE PROFILES, GOSFORD LINE 9
Avoca Beach

FIGURE 25a



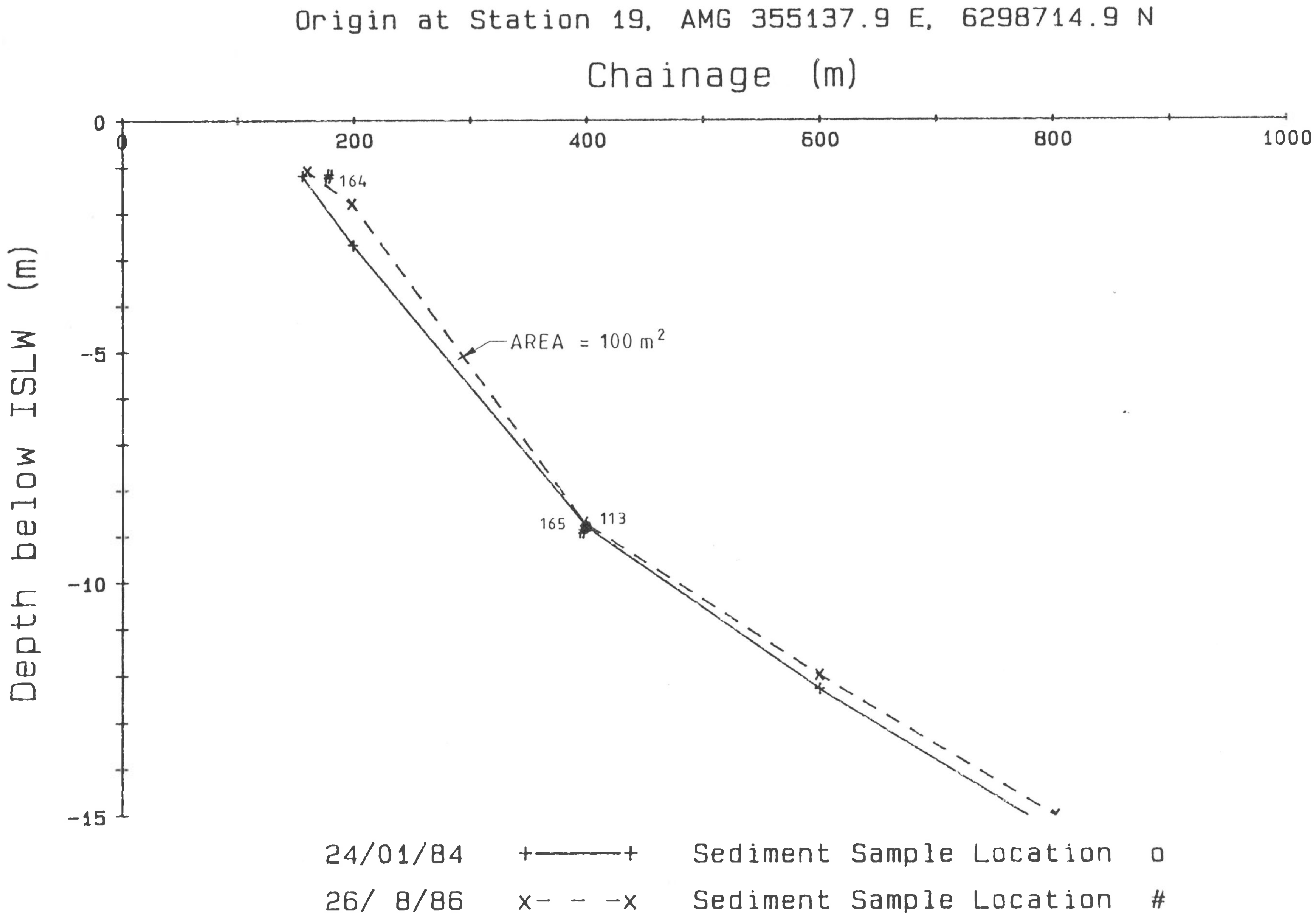
OFFSHORE PROFILES, GOSFORD LINE 9
Avoca Beach

FIGURE 25b



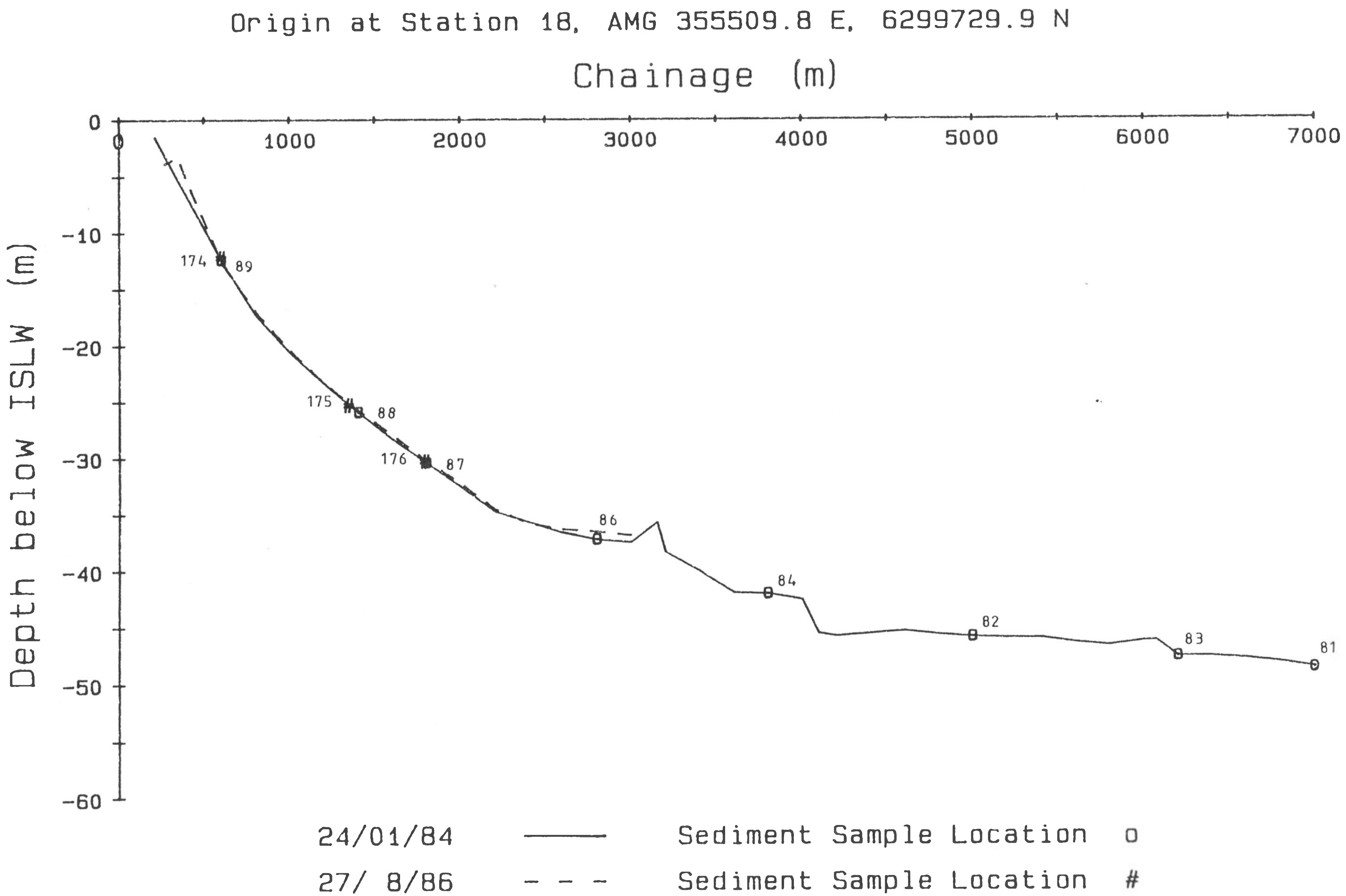
OFFSHORE PROFILES, GOSFORD LINE 12
Terrigal Beach

FIGURE 26a



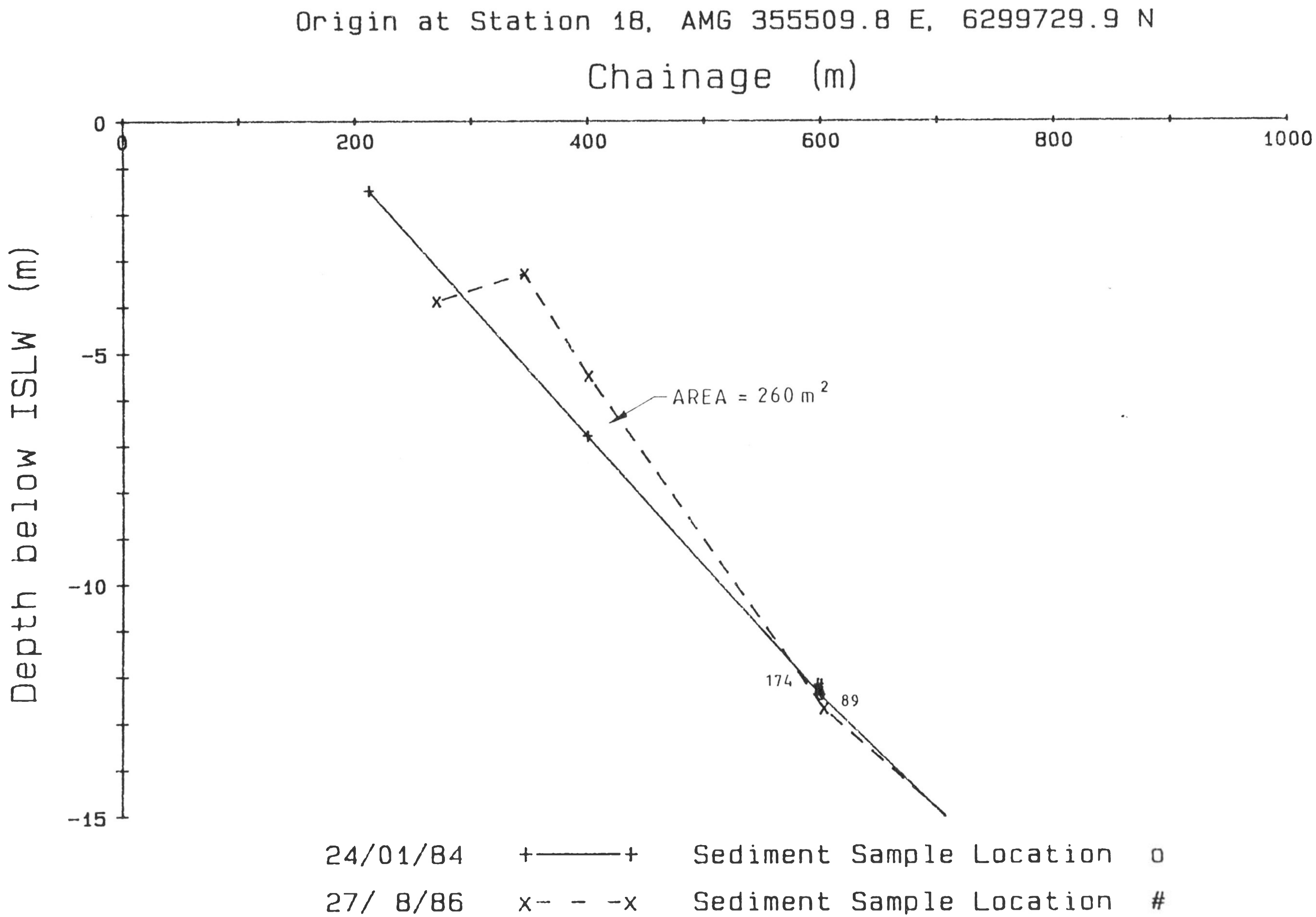
OFFSHORE PROFILES, GOSFORD LINE 12
Terrigal Beach

FIGURE 26b



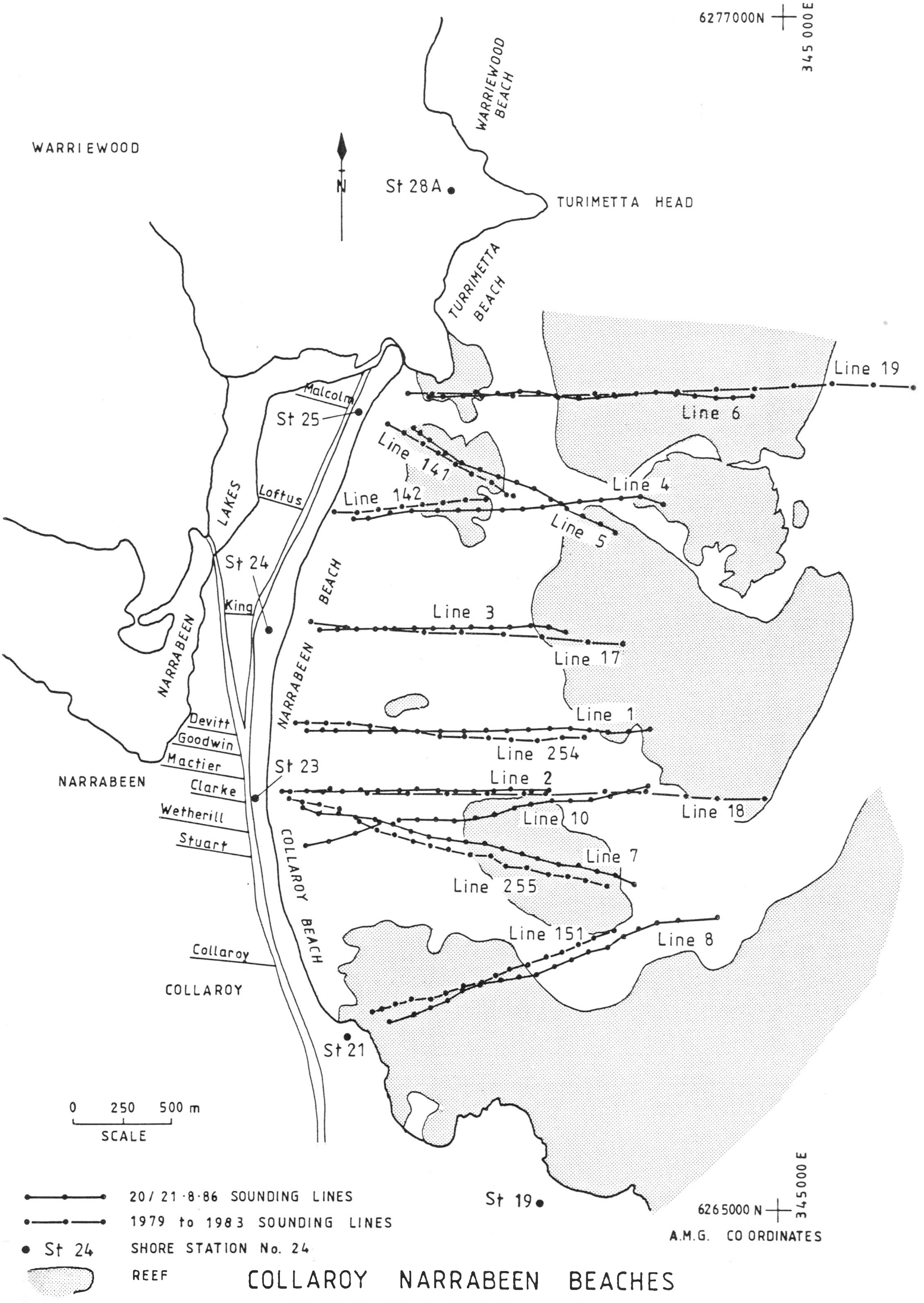
OFFSHORE PROFILES, GOSFORD LINE 13
Wamberal Beach

FIGURE 27a



OFFSHORE PROFILES, GOSFORD LINE 13
Wamberal Beach

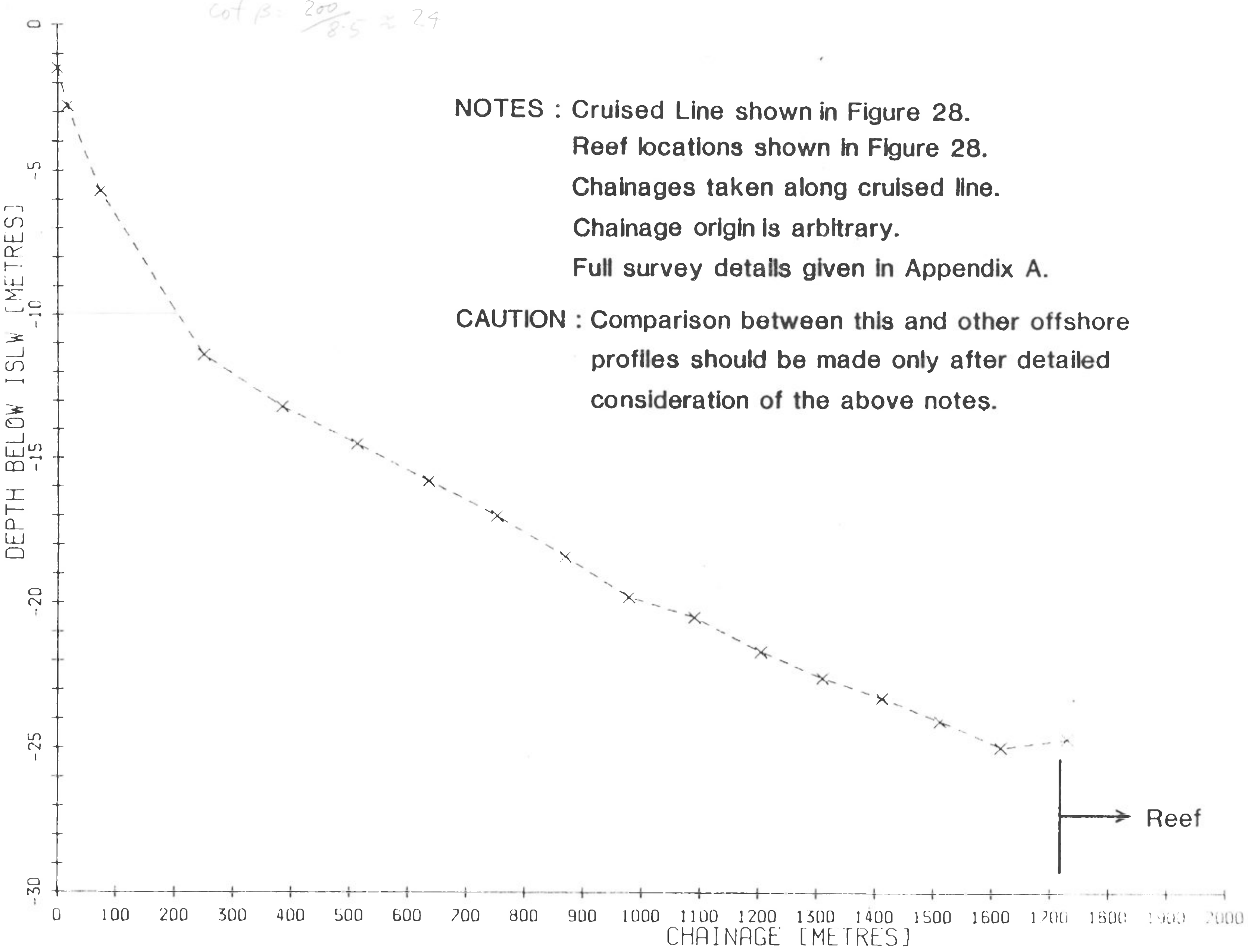
FIGURE 27b



COLLAROY NARRABEEN BEACHES
OFFSHORE SOUNDING LINES

FIGURE 28

$\cot \beta = \frac{200}{8.5} \approx 24$

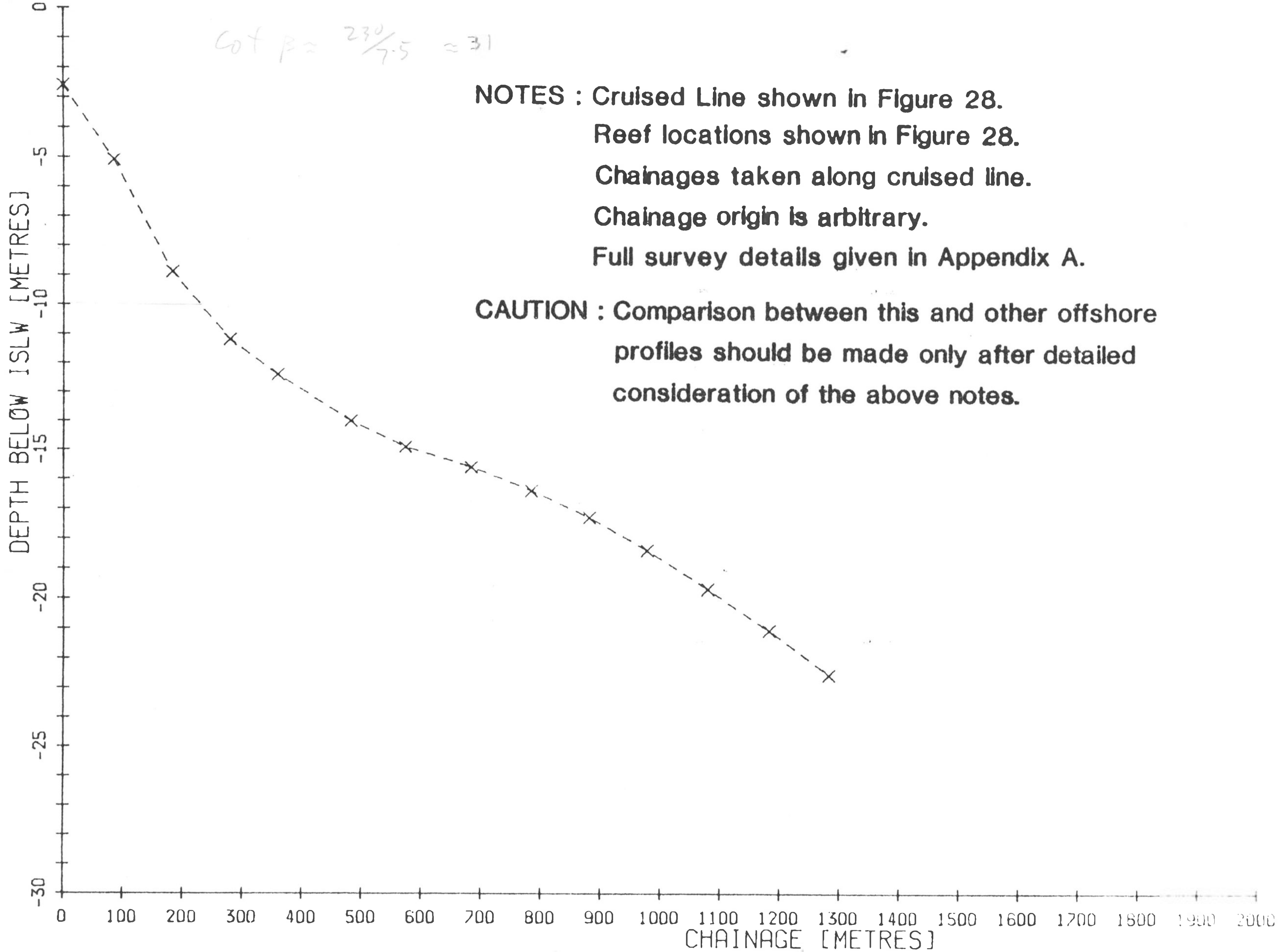


NOTES : Cruised Line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 1 [20.08.86-21.08.86]

Figure 29



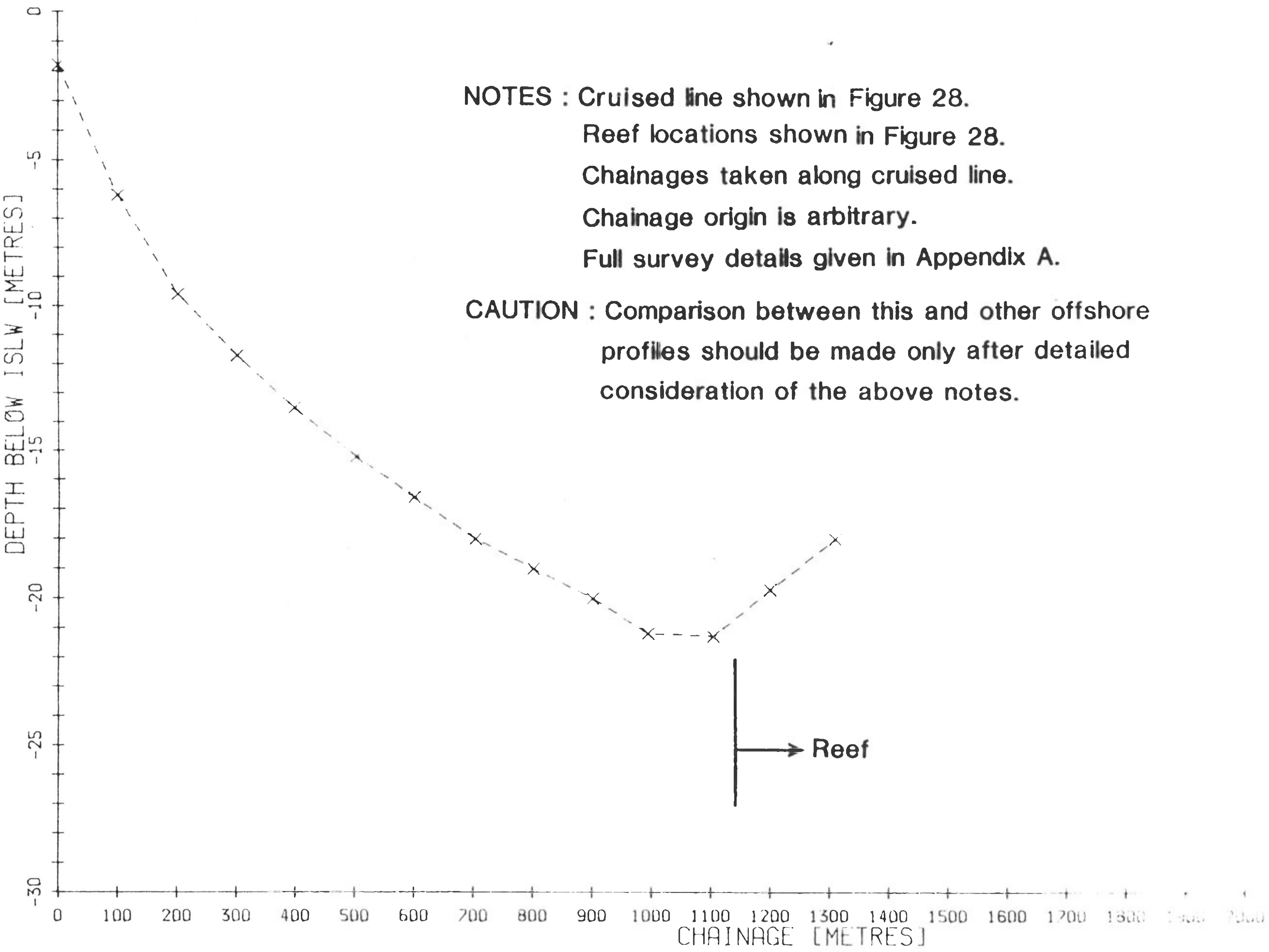
$\cot \beta = 230/7.5 \approx 31$

NOTES : Cruised Line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 2 [20.08.86-21.08.86]

Figure 30

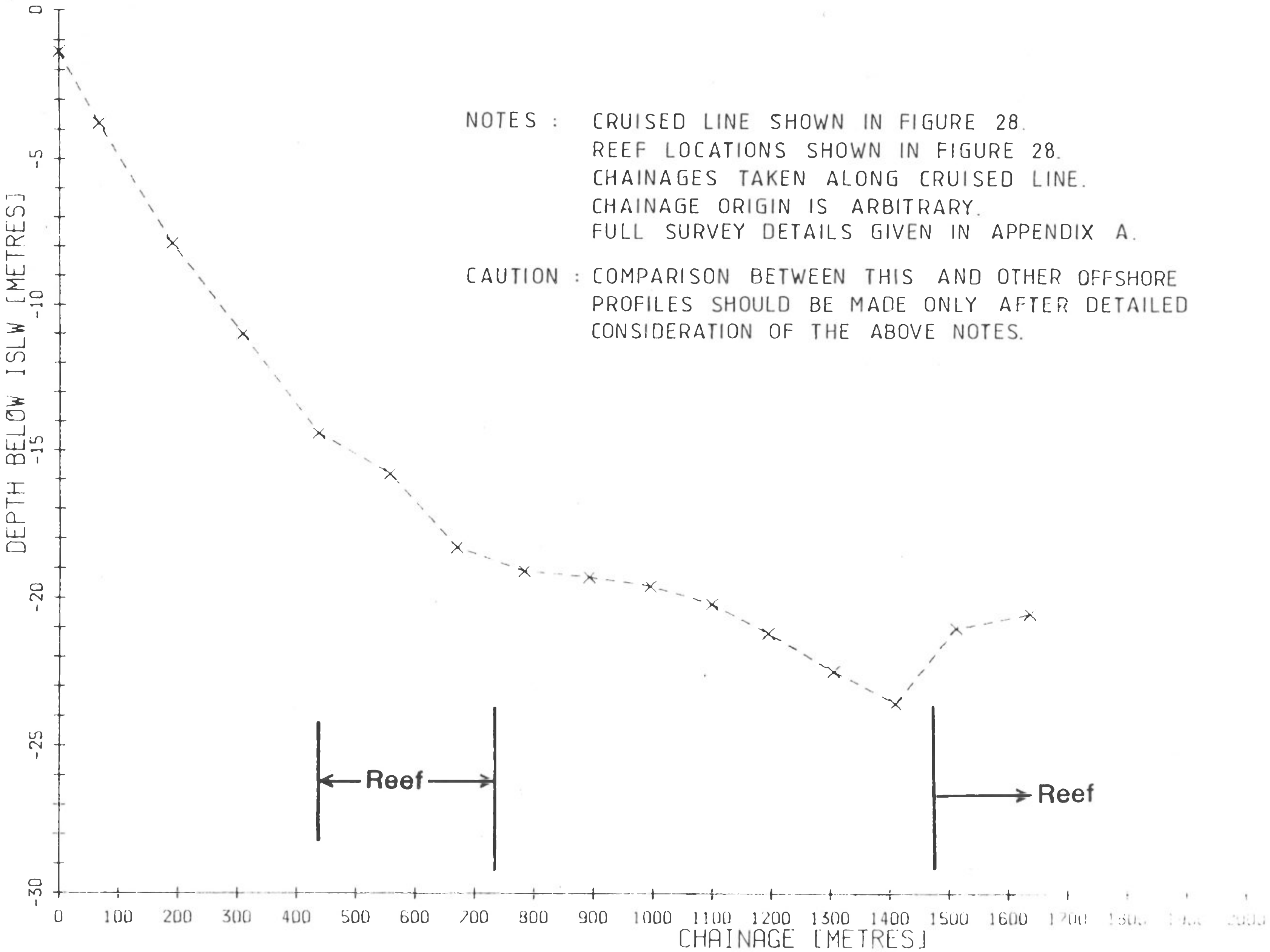


NOTES : Cruised line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 3 [20.08.86-21.08.86]

Figure 31

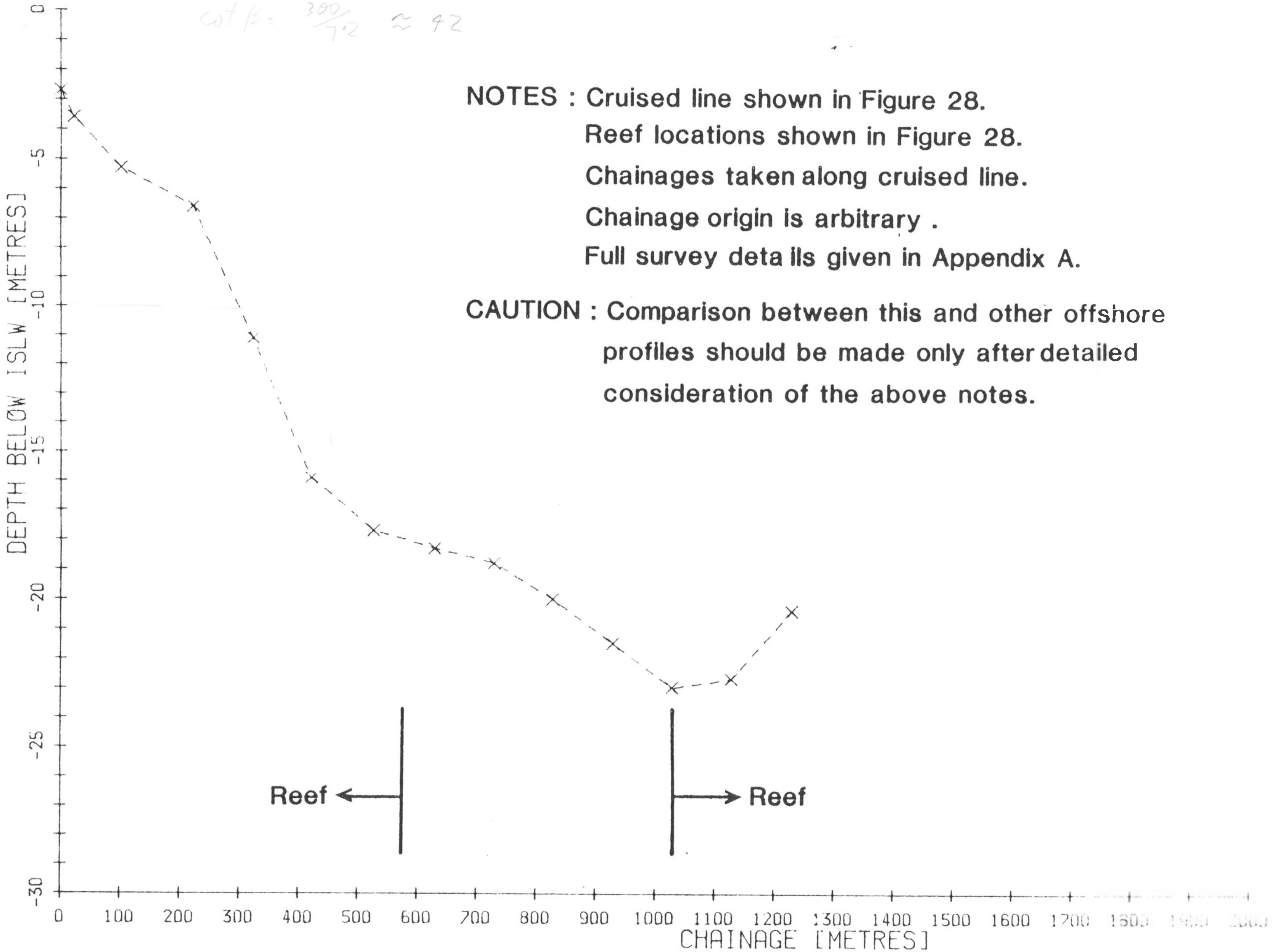


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

0FFSHØRE PRØFILE CØLLARØY-NARRABEEN LINE 4 [20.08.86-21.08.86]

Figure 32



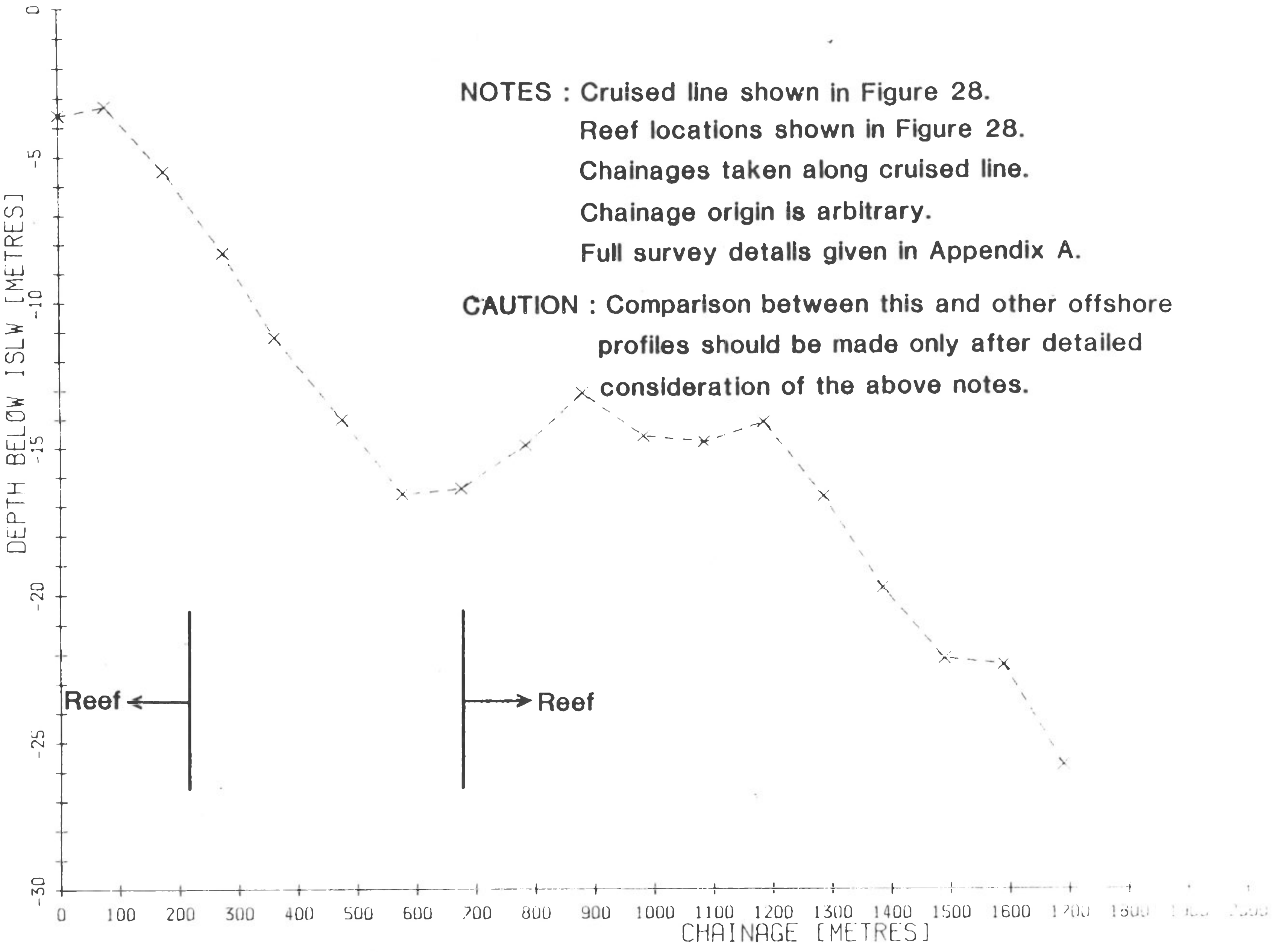
cot β = 300/7.2 ≈ 42

NOTES : Cruised line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary .
Full survey deta ils given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 5 [20.08.86-21.08.86]

Figure 33

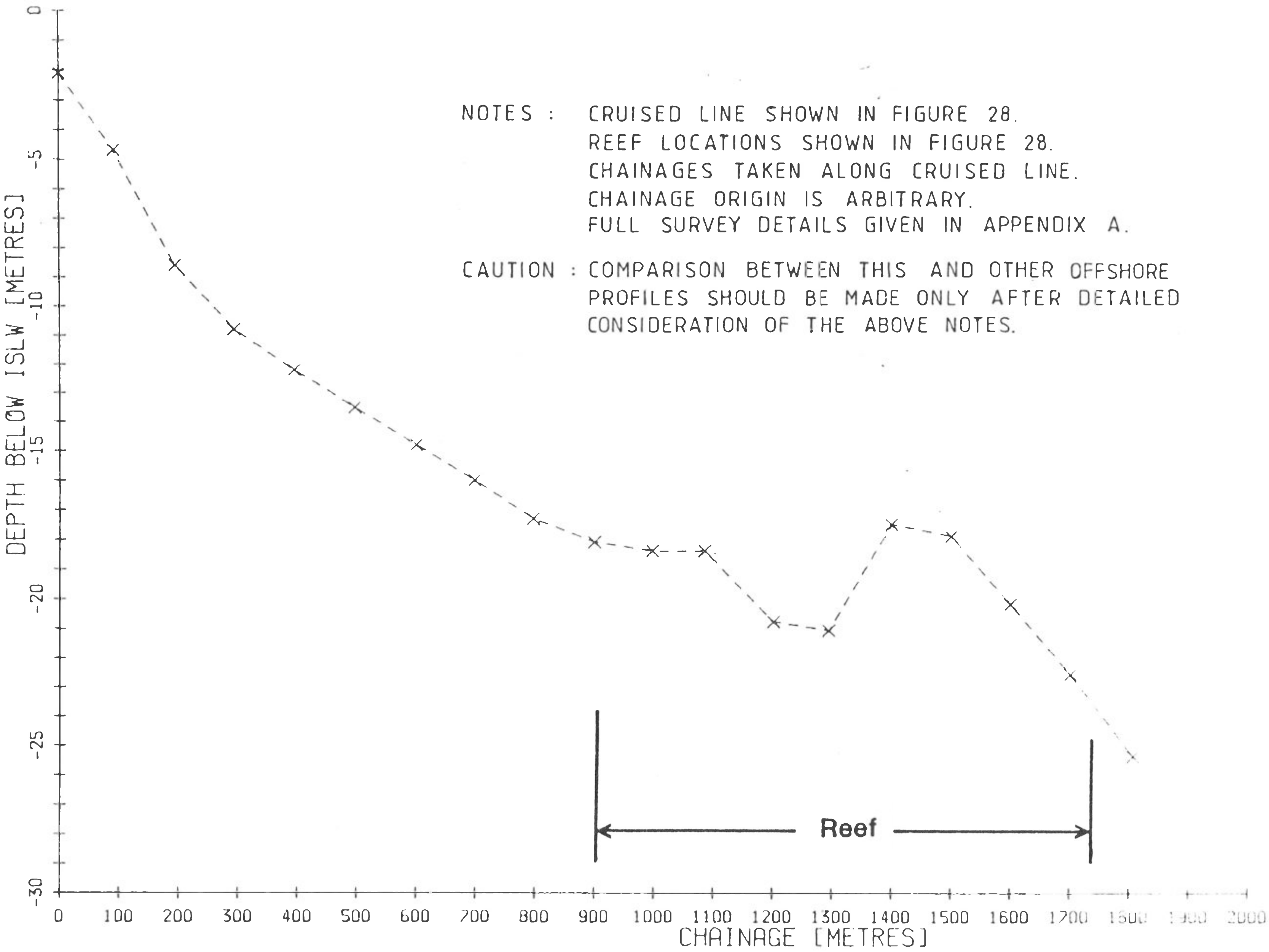


NOTES : Cruised line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 6 [20.08.86-21.08.86]

Figure 34

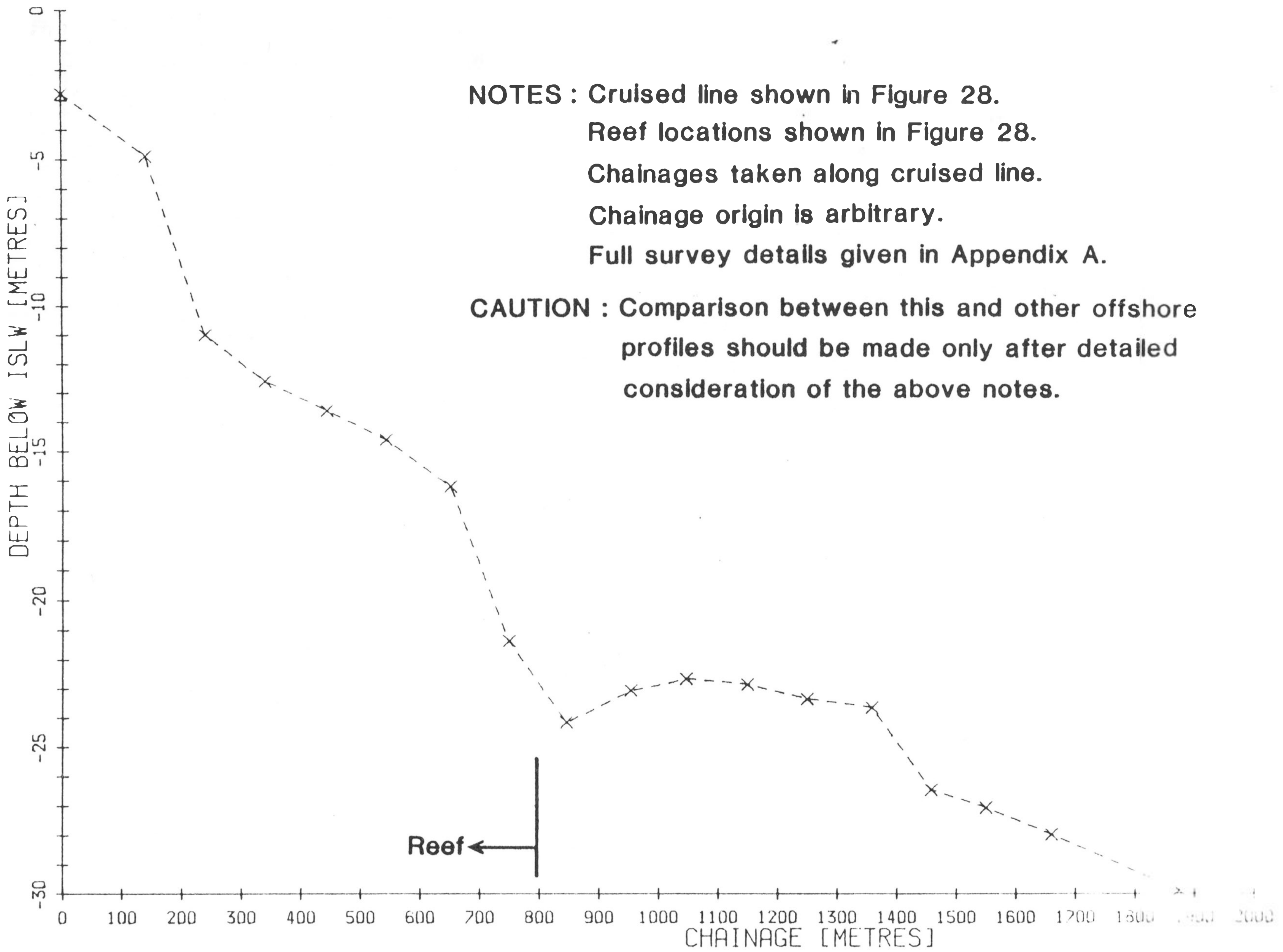


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 7 [20.08.86-21.08.86]

Figure 35

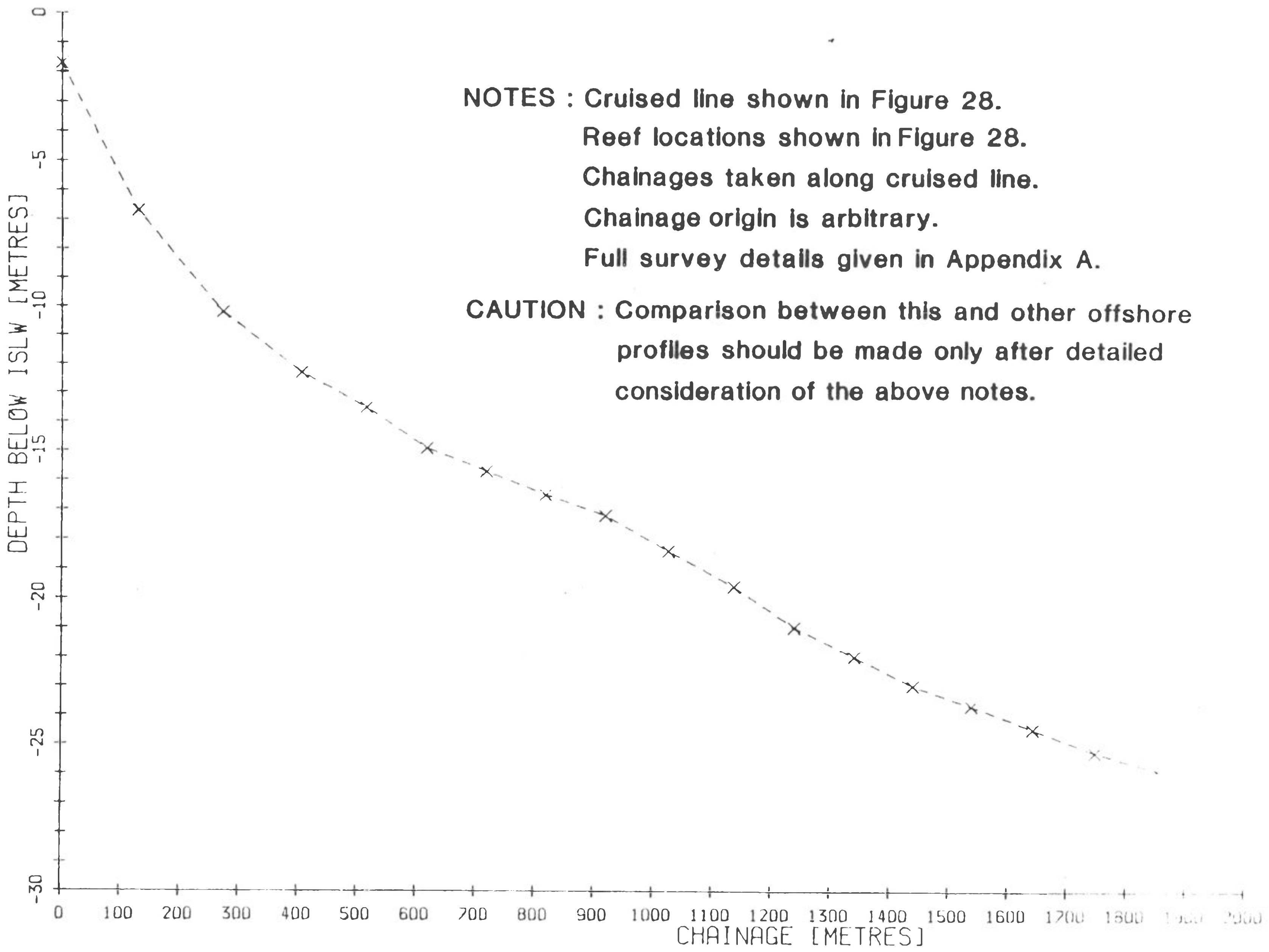


NOTES : Cruised line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

ØFFSHØRE PRØFILE CØLLARØY-NARRABEEN LINE 8 [20.08.86-21.08.86]

Figure 36

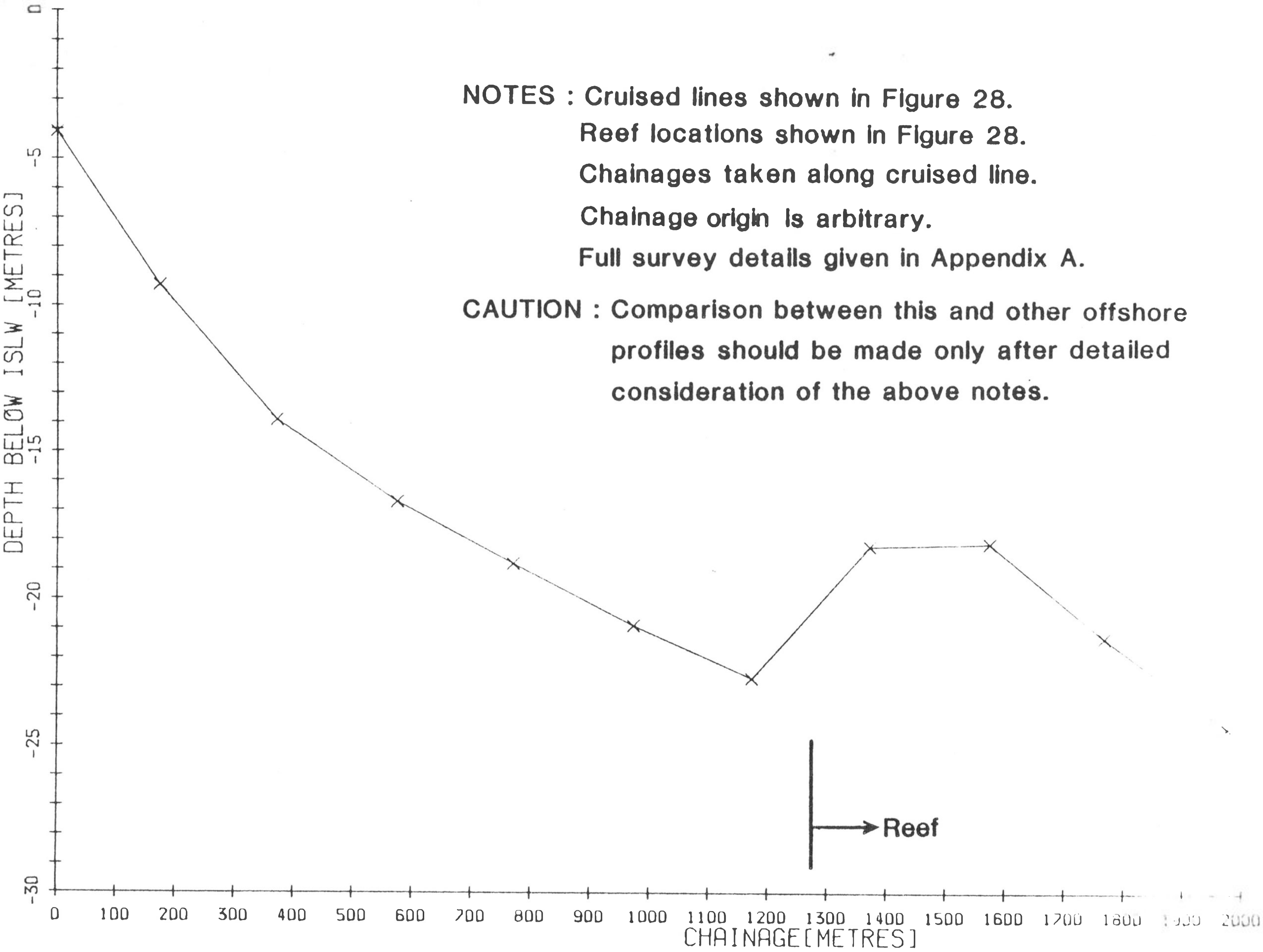


NOTES : Cruised line shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

ØFFSHØRE PRØFILE CØLLARØY-NARRABEEN LINE 10 [20.08.86-21.08.86]

Figure 37

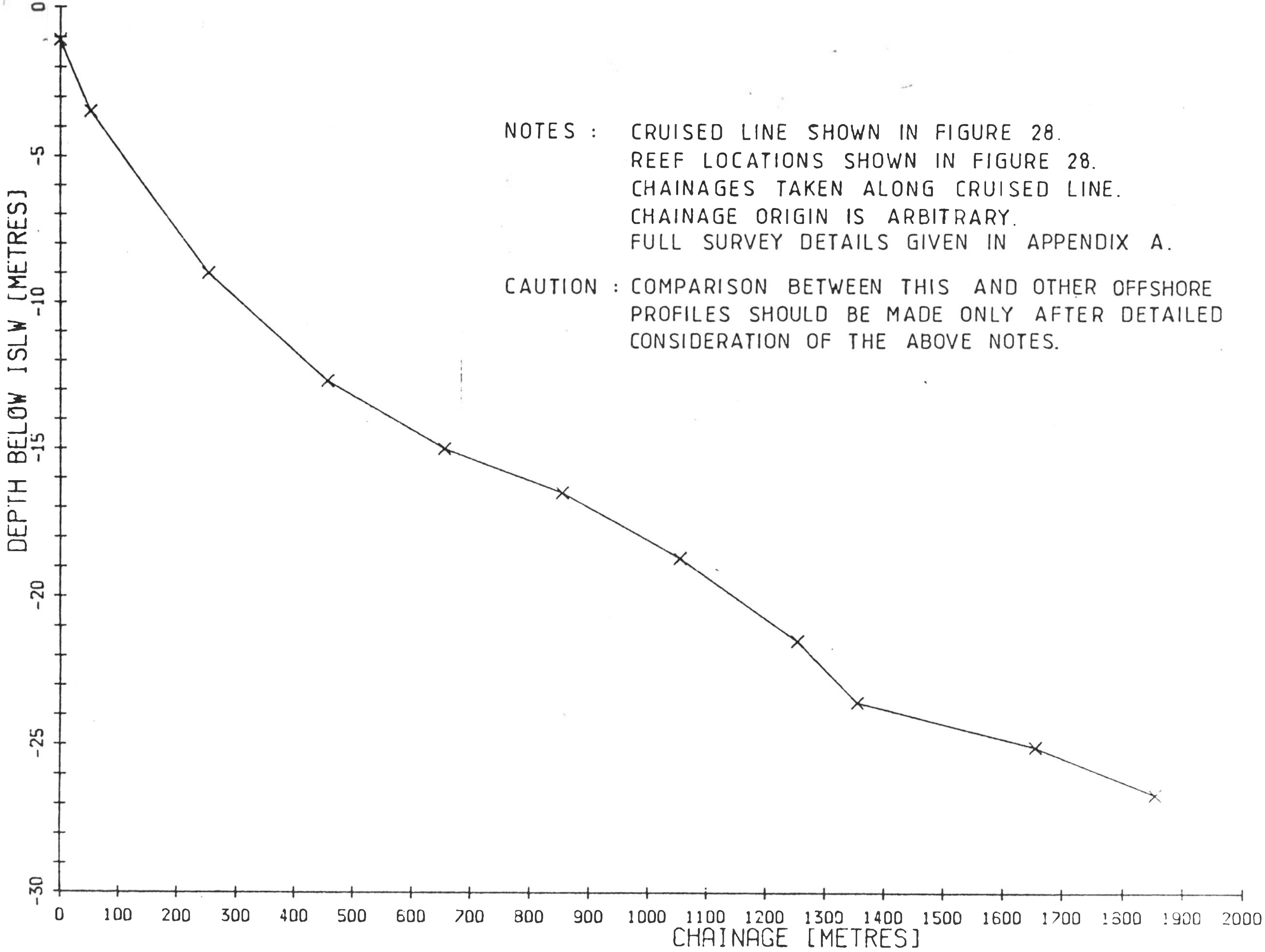


NOTES : Cruised lines shown in Figure 28.
Reef locations shown in Figure 28.
Chainages taken along cruised line.
Chainage origin is arbitrary.
Full survey details given in Appendix A.

CAUTION : Comparison between this and other offshore profiles should be made only after detailed consideration of the above notes.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 17 (25.09.79)

Figure 38

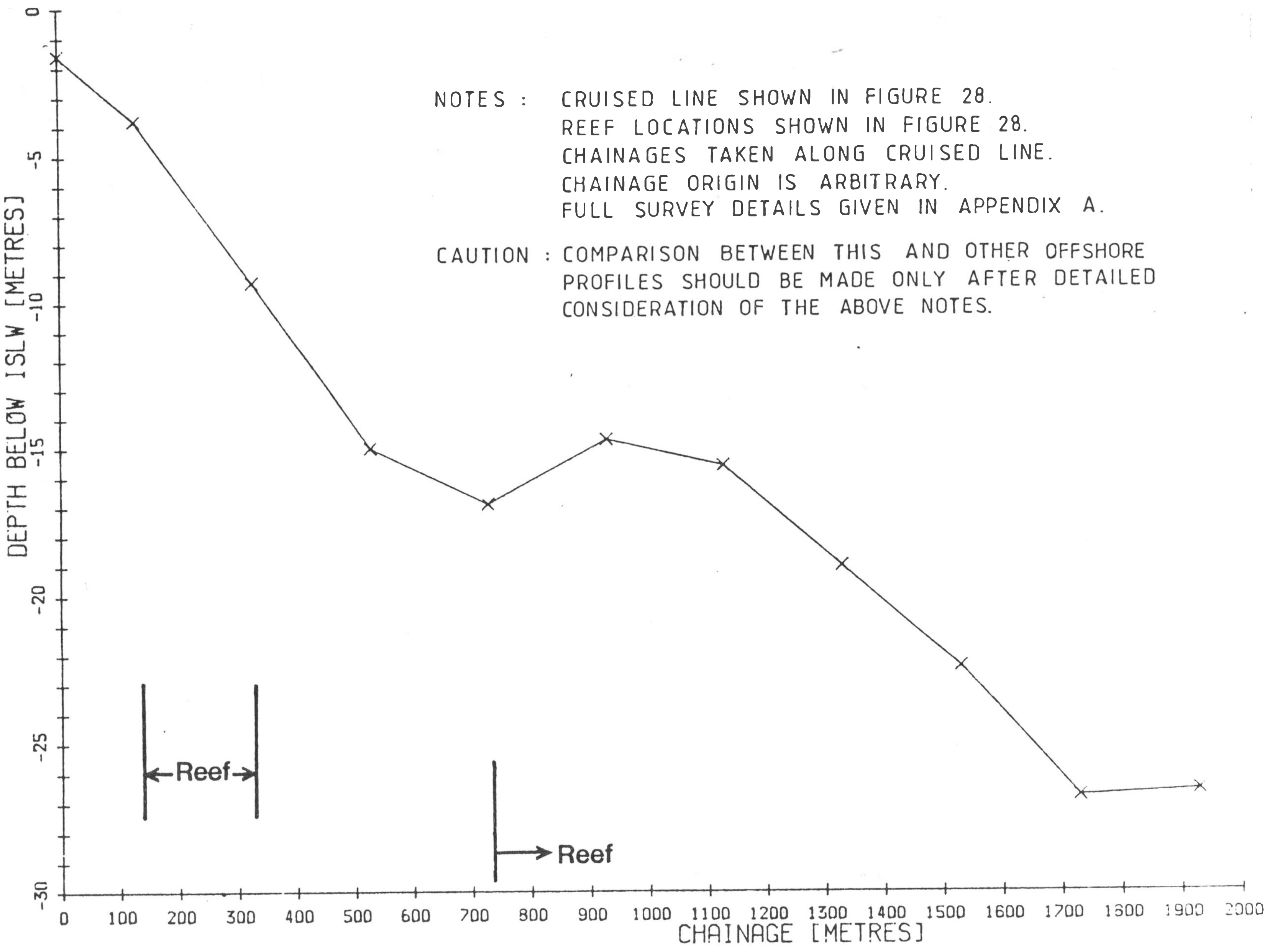


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 18 (19.11.79)

Figure 39

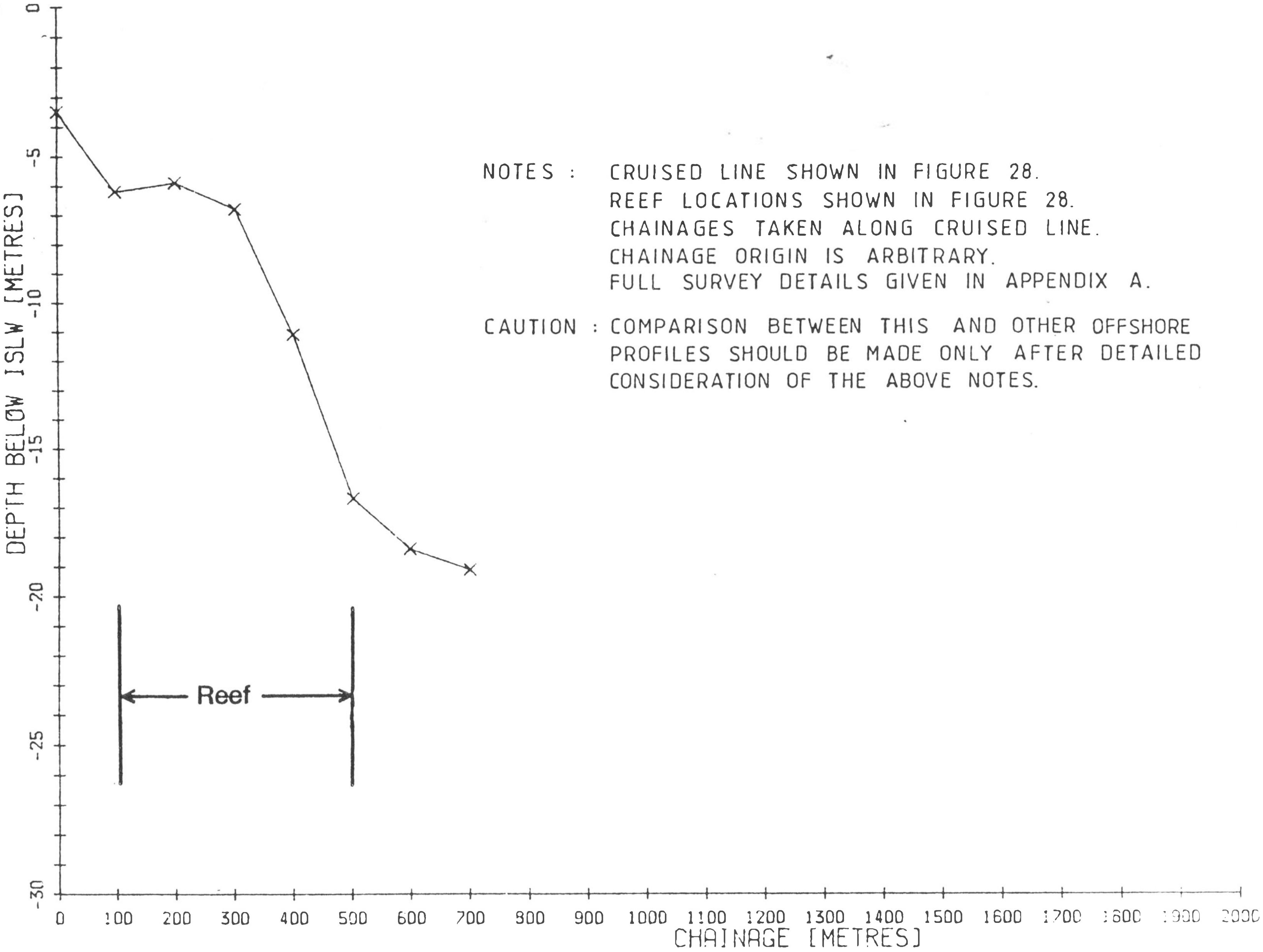


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 19 (19.11.79)

Figure 40

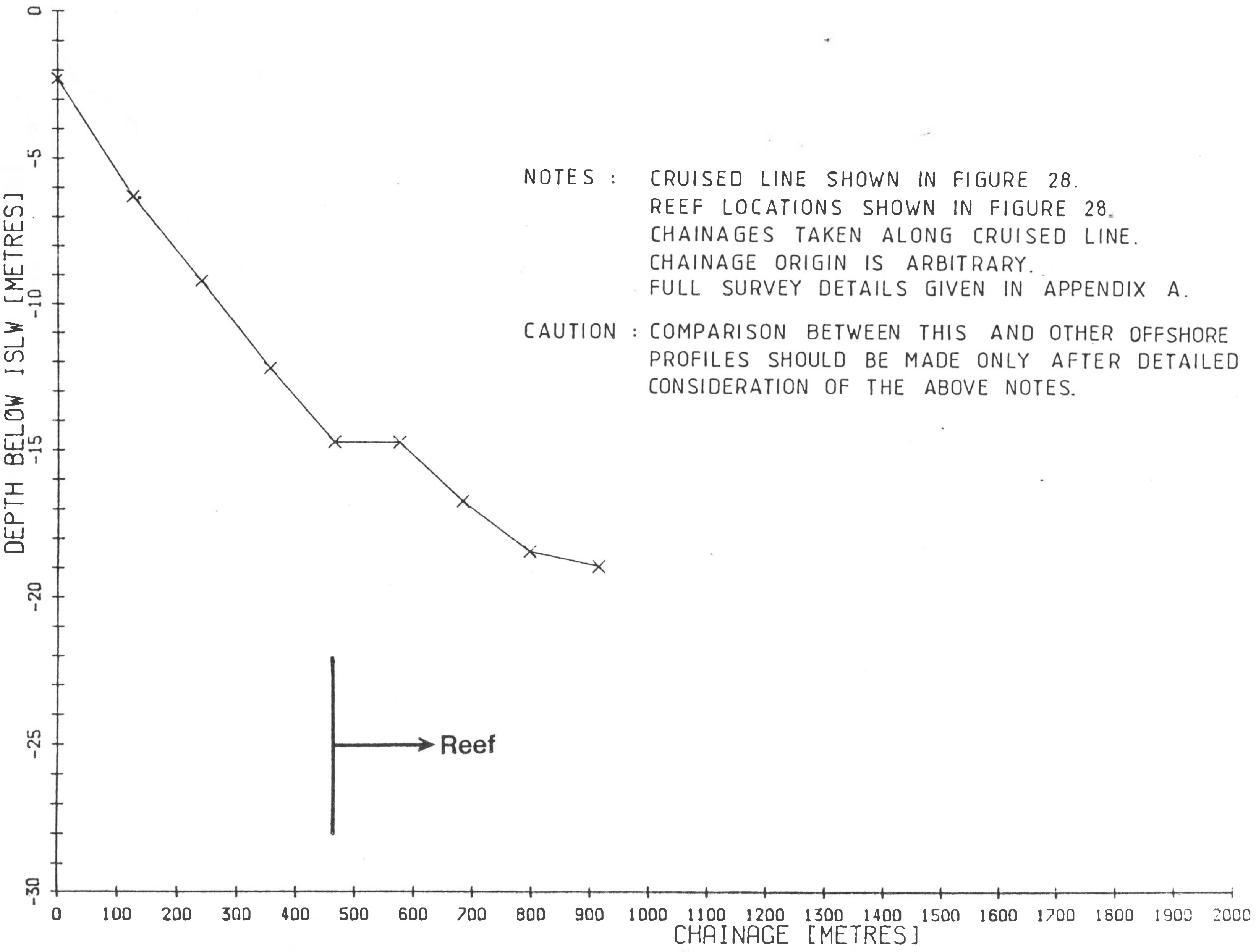


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEN LINE 141 (10.02.83)

Figure 41

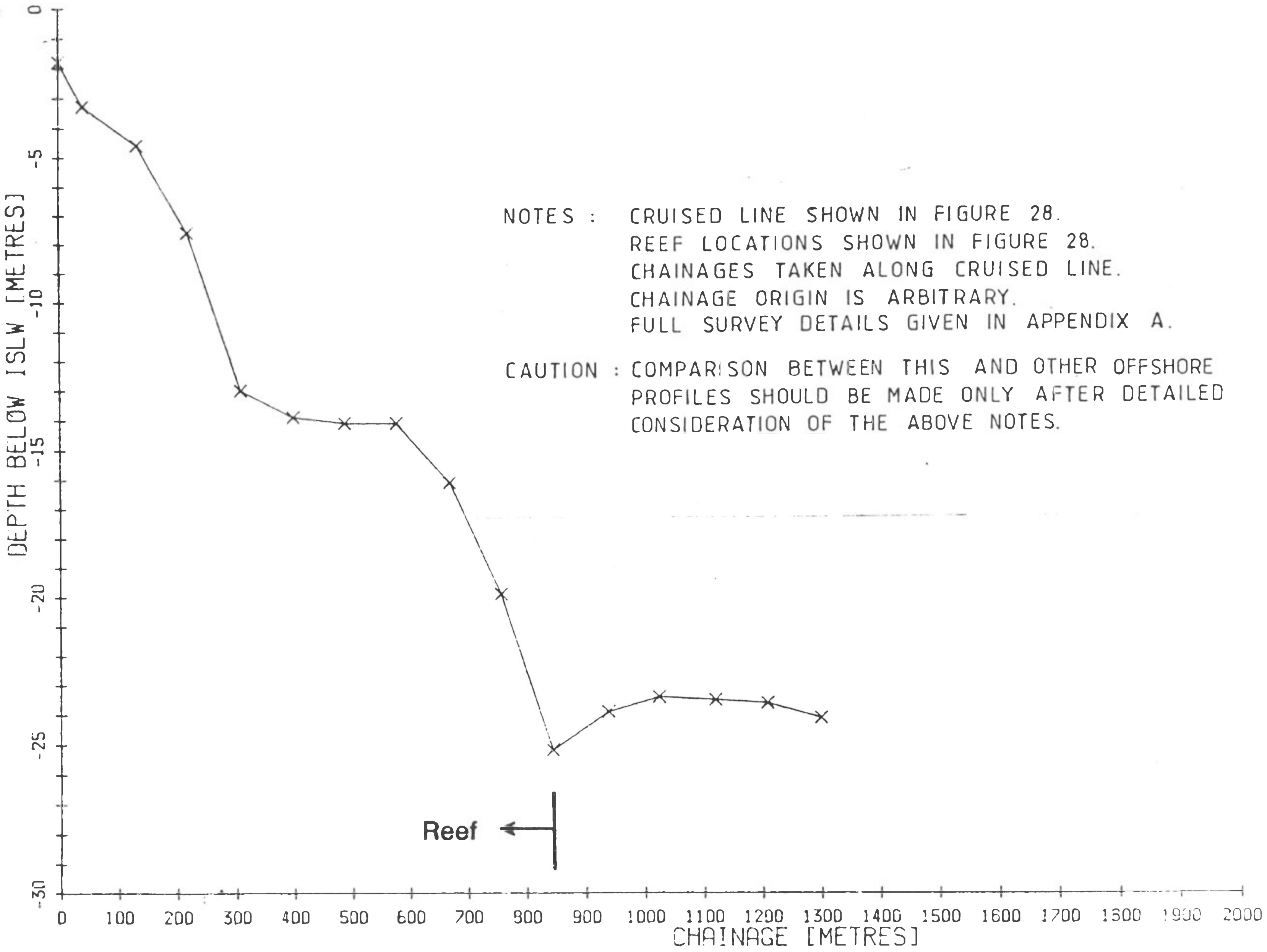


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 142 (10.02.83)

Figure 42

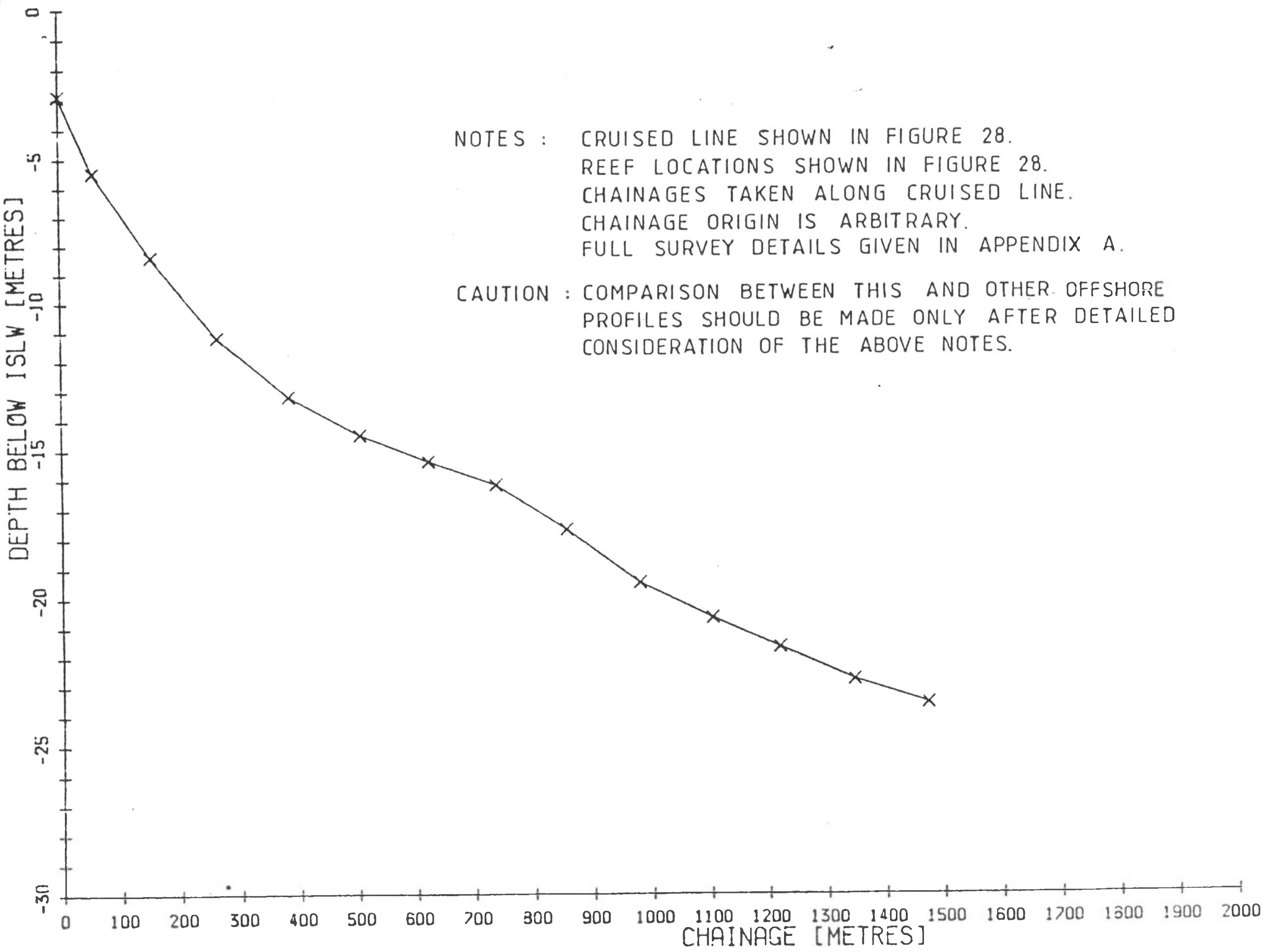


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 151 (10.02.83)

Figure 43

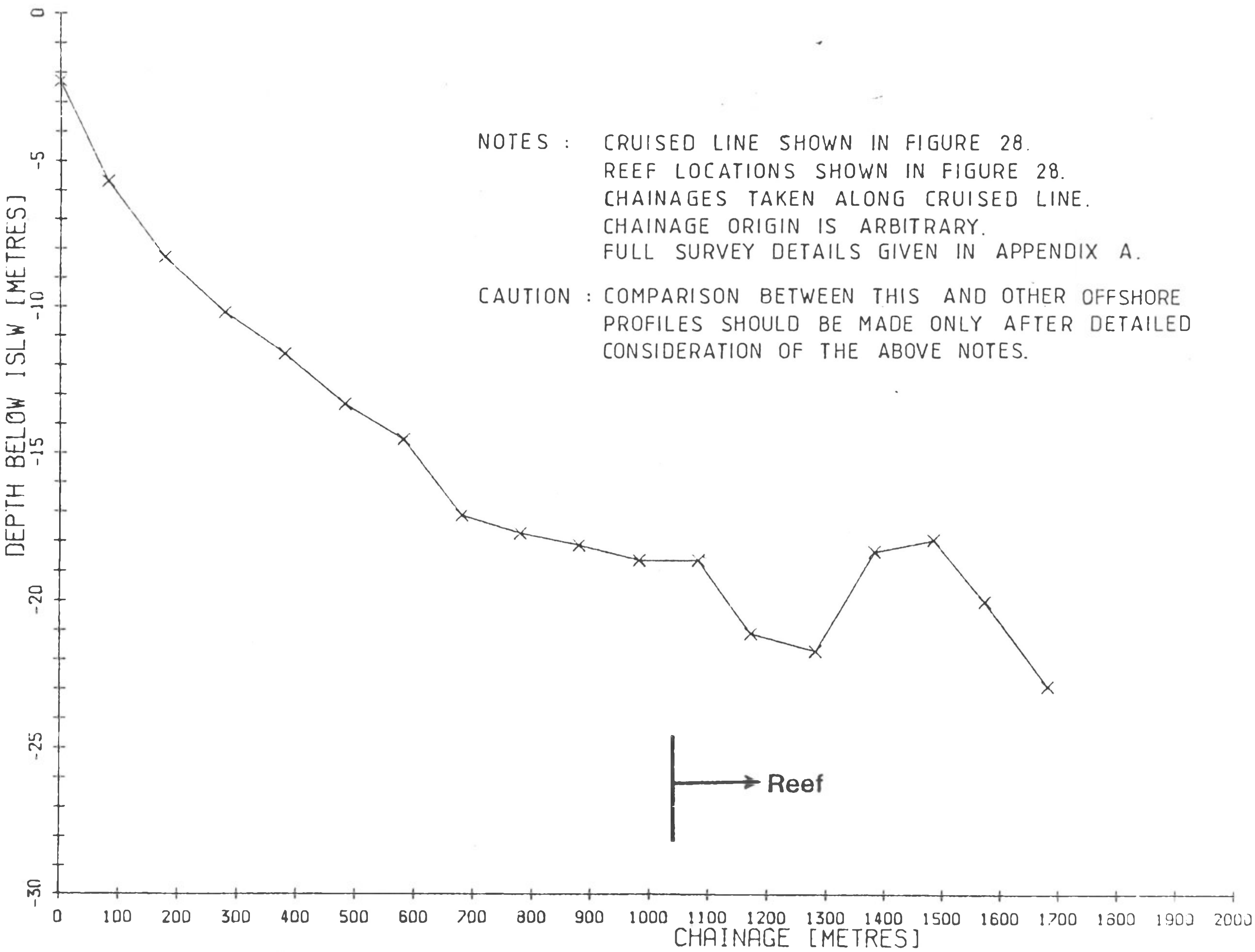


NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 254 (07.04.83)

Figure 44



NOTES : CRUISED LINE SHOWN IN FIGURE 28.
REEF LOCATIONS SHOWN IN FIGURE 28.
CHAINAGES TAKEN ALONG CRUISED LINE.
CHAINAGE ORIGIN IS ARBITRARY.
FULL SURVEY DETAILS GIVEN IN APPENDIX A.

CAUTION : COMPARISON BETWEEN THIS AND OTHER OFFSHORE PROFILES SHOULD BE MADE ONLY AFTER DETAILED CONSIDERATION OF THE ABOVE NOTES.

OFFSHORE PROFILE COLLAROY-NARRABEEN LINE 255 (07.04.83)

Figure 45