THE UNIVERSITY OF NEW SOUTH WALES
water research laboratory
Manly Vale N.S.W. Australia

SAND BYPASSING AT THE TWEED RIVER ENTRANCE
DATA COLLECTION AND ASSESSMENT

VOLUME I - INVESTIGATIONS (TEXT AND FIGURES)

by

R.B. Tomlinson and D.N. Foster

Research Report No. 167
July 1986

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8. ABSTRACT

This report details an investigation of the natural sand bypassing processes which control the development of the ebb tidal delta at the trained entrance of the Tweed River. The training of this entrance has had a major impact on the longshore supply of sand to the beaches to the north of the entrance. The study has entailed the collection and assessment of existing data pertaining to the Tweed River - Lower Gold Coast Region. In addition, field investigations have been undertaken including offshore drogue tracking, side-scan sonar and seismic profiling, bed sediment sampling and stream gauging.

The results have shown that there is a complex interaction between the ebb jet, littoral, offshore currents at the entrance influencing the formation of a dynamically stable ebb tidal delta and the bypassing of the littoral sand supply. This and other factors make inadequate the use of commonly used procedures to investigate the effect of training walls on beach stability.

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1. INTRODUCTION

The movement of sediments in the coastal zone can be both onshore - offshore, generally in response to storm attack and recovery, and alongshore due to littoral currents driven by a predominant wave climate. The interruption of this longshore sediment movement, or littoral drift, at any given location along the coastline will result in an imbalance in the sediment budget for that region. The most significant implication of such an imbalance is usually the erosion of beaches downdrift of the interruption.

Littoral drift may be interrupted naturally by headlands jutting out past the zone of littoral transport. However, in terms of human history, the presence of headlands can be considered permanent features and coastal processes occurring around them are in a state of `dynamic equilibrium'.

Similarly, at tidal inlets or river mouths the interaction between the entrance discharge and the littoral currents results in an interruption to the littoral drift. Quite substantial short term fluctuations can occur depending on the natural bypass mechanisms operating at the entrance. However at natural entrances a long term sediment budget balance is achieved.

The tidal inlet represents an interruption to the continuity of beach processes along the coast. Waves and longshore currents that modify the beach are in constant interaction with the tidal currents in the inlet. The movement of sediment associated with these processes is a major concern in most engineering endeavours. The most common engineering problems are related to erosion and deposition in the vicinity of an inlet, and to inlet migration. In order to understand more about these mechanisms it is necessary to evaluate both the short term and long term history of changes at a given location.

Early observations of tidal inlets established that sediment was being exchanged through tidal inlets between the bay and nearshore marine environments. The path of sand being carried along-shore past the mouth of the inlet would be altered by flood and ebb currents in a similar fashion, such that deposition would occur in the bay and ocean side of the inlet respectively (Brown, 1928). More recently, research has indicated that there appears to be a balance between scouring actions of tidal currents, which tend to keep the channels open and the longshore transport of beach sand, which tends to close them. As a result of this balance or dynamic equilibrium, the inlet and associated tidal deltas develop a characteristic size and shape. On the ebb tidal delta, sand is redistributed by tidal forces, predominantly transporting sand offshore; and wave forces, predominantly transporting sand onshore (Oertel, 1972). The inlet therefore acts as an effective sand trap. In a situation where these two forces are exactly balanced, the shoal has achieved an equilibrium condition in which, over some time period, there is neither growth nor reduction in shoal volume (Dean & Walton, 1975). This equilibrium volume would be attained by the flood-tidal delta and ebb-tidal delta during a period of inlet stability.

Similar processes are applied to estuaries with low fresh water river flows which behave as a tidal inlet. The occurrence of high fresh water flows periodically will modify the estuary dynamic balance. Flood tidal deltas manifest themselves as river channel shoals in the lower reaches of the estuary.

Historically, inlets have been utilised by man as a link between land based activities and the ocean going transport systems. This was particularly true prior to the development of road transport as an economically viable means of moving the resources of the coastal areas. The ever increasing pressures on the limited number of coastal features providing access to the open sea resulted in difficult problems for coastal engineers. Tidal inlets are an integral part of a larger system of coastal processes, however, and conventional approaches to modify tidal inlets generally involve a gross change or interruption of the natural condition. At times such modifications may change the processes substantially and result in a new set of problems. The most common modification at a tidal inlet is to construct training walls which are designed to:- stabilise the location of the inlet; increase the governing depths in the channel, thus improving navigability; minimise the amount of sediment transported into the inlet and control tidal currents.

The efficiency of the training walls (or jetties) to block the littoral drift of sand into the inlet depends upon the length of the walls in relation to the bottom slope, wave exposure and the magnitude of the drift. Where two walls are constructed the important parameter is the length. The works can act as a partial or complete littoral drift barrier. A complete littoral barrier may not continue as such if the sedimentary processes change resulting in a new natural bypassing mechanism. For example, if a pair of training walls is constructed out to a depth below the prevailing limit of littoral transport then the updrift wall will initially act as a complete littoral barrier. However as accretion occurs on the updrift side, a bypassing path can be re-established which allows a modified version of the previously outlined sedimentary processes at the inlet.

Associated with the blocking of littoral drift past a tidal inlet, the presence of training walls will cause erosion on the downdrift side. This erosion will continue until bypassing has been re-established either by a return to a natural dynamic equilibrium or by artificial means such as a sand transfer system. The new naturally occurring bypassing mechanisms may be different from those operating previously and result in modified bypassing rates. Of course, a return to a natural dynamic equilibrium negates the reason for constructing the training walls, which was to improve the navigability of the entrance.

Investigations of sedimentary processes at tidal inlets in the past have shown that each inlet behaves differently due to the different physiographic setting, the variation in wave climate and hydraulic character of the inlet and bay - river system. Studies undertaken into various aspects of inlet behaviour are too numerous to reference here, but those of particular interest will be mentioned in the following text. Most studies tend to be of a site specific nature. It has been shown however that inlets, and in particular their sediment deposition patterns, can be categorised depending on the wave climate and the tidal flows (Per Bruun, 1978).

The purpose of this study is to examine the various aspects of tidal inlet behaviour, with particular reference to the modifications to the sediment bypassing mechanisms brought about by the construction of training walls.

There are numerous locations along the Australian coastline where tidal inlets of various types occur. A general investigation of the behaviour of all these inlets is beyond the scope of a study of this type. The procedure adopted here is to make a site specific investigation and then develop analytical techniques applicable to inlets in general. The site chosen is the Tweed River Entrance in northern New South Wales.

1.1 Study Location

The Tweed River catchment is in the far north eastern corner of New south Wales, Figure 1. The river mouth has been stabilised by the construction of training walls and enters the Pacific Ocean at a location which is only a few hundred metres south of the Queensland-New South Wales border. Although in New South Wales, this proximity to Queensland results in the influence of the natural processes occurring at the entrance being felt in both states. This means that the construction and subsequent effects of coastal works undertaken at the Tweed Entrance, are within the areas of responsibility of two State governments and two local government bodies, the Tweed Shire Council in New South Wales and the Gold Coast City Council in Queensland.

1.2 Scope of this Study

The main aim of this study is to gain a better understanding of the hydrodynamic and sedimentary processes which control the bypassing of sediments being transported alongshore past a trained tidal entrance. The Tweed River Entrance was chosen as there is a large data base for the region due primarily to the commercial importance of the downdrift beaches. It is hoped that a system for modelling the bypassing mechanisms can be obtained.

The first phase of the study was to search the literature and records to obtain all the available data pertaining to this region. For the purposes of the study, the area of interest was taken to extend from Fingal Head approximately 3 kms south of the Tweed River Entrance, to the Currumbin Creek Entrance which is about 7 kms to the north. The source of this data and an outline of the relevant details are presented in this report.

In addition to the collation of existing data, a part of this study has been to conduct field data collection exercises to determine the coastal processes which are operating at present. Also, longer term data collection programs have been planned and initiated to fill in gaps in those programs which are currently underway and to provide the kind of information necessary to calibrate the mathematical coastal process models which will be developed in a later phase of the study.

The collection of coastal process data to date has mainly been carried out by the New South Wales Department of Public Works (PWD), the Gold Coast City Council (GCCC) and the Queensland Department of Harbours and Marine, Beach Protection Authority (BPA). Prior to the 1970's the responsible Queensland authority was the Co-ordinator General's Department (COG).

1.3 Brief Historical Outline

The New South Wales government authority responsible for river works is the Public Works Department (PWD). Records held by the PWD detail the commercial development of the lower reaches of the river (PWD, 1957).

The Tweed River was discovered in 1823 by Lieut. Oxley and explored in 1828 by Captain Rouse. Cedar cutting was commenced about 1844 and farming in 1865. Sugar cane was introduced in 1869 and the Condong Mill was opened by the Colonial Sugar Refining Company in 1880. The town of Murwillumbah was established in 1894 and in that year the railway line from Lismore to Murwillumbah and Condong was opened.

The development of the river by the PWD for shipping by dredging and the construction of training walls was commenced in 1891.

The entrance to the Tweed River is 372 nautical miles north of Sydney. Attention was first drawn to the condition of the river in 1872 when very little was known in Sydney about the area and there were only a few settlers. The trade consisted chiefly of cedar export. Official papers show that in 1882 the entrance and lower reaches of the river were shoaled with steamers drawing only 4'6" to 4'9" grounding on the bar, while craft drawing 3' to 3'6" could cross the flats within the entrance.

A survey made upstream to Byangum in 1884 and urgent requests by residents for the construction of works to improve navigation resulted in a dredge being sent to the river in 1891, followed by a grab dredge in 1894. The work on the training walls was commenced in 1892 and were all but complete by 1904 with some minor work on a spur wall being carried out during 1916-1918. Removal of indurated sand in the entrance was carried out during 1919-21.

Apart from dredging in the lower reaches, the next major construction was that of the new breakwaters during 1962-1964. For many years prior to this work being commenced, great difficulty was experienced by trawlers in negotiating the river entrance and at times of unfavourable seas, passage in and out of Tweed Heads was particularly dangerous. There were numerous cases of vessels grounding on the bar.

Dissipation of the concentrated flow passing between the training walls resulted in a shallow bar and a navigational problem, with vessels entering the river frequently having to negotiate areas of breaking waves. There was also much difficulty in finding the channel, the location of which was constantly changing.

During 1961 observations were made of sand movements and the river entrance generally in connection with the proposed new works. The design called for the construction of two walls extending approximately 1500 feet from the existing shoreline, with a clear width between walls of 500 feet. Work was commenced toward the end of 1962 and was completed in February 1965.

The construction of these walls has resulted in major changes in the patterns of sediment deposition in the region. As expected, there was rapid accretion of the updrift beach to the south. This has continued at a reduced rate to the present. As the new walls extend into deeper water, the desired effect of increased navigability was achieved. Coupled with the accretion along the updrift beach was the erosion of the downdrift beaches. This would be expected as the training walls are acting as a littoral drift barrier.

The erosion of the downdrift beaches has been of great concern to the Gold Coast City Council. The beaches are the basis of the tourist industry from which the city derives the majority of its income. The extent of the erosion attributed to the construction of the Tweed training walls and other groyne structures at Coolangatta and Kirra had reached a point about 5 kms downdrift of the Tweed Entrance by 1983. Erosion of these beaches has been exacerbated by a series of cyclones in the late 1960's and early 1970's and has been the subject of a number of previous investigations.

A detailed description of beach erosion on the lower Gold Coast beaches has been compiled by Chapman (1978) and this will be used as a main data source for historical information of this nature.

Theoretical calculations made as part of a major study by the Delft Hydraulics Laboratory (Delft, 1970) indicated that the new Tweed Entrance would be fully bypassing by 1985. It would appear that this is not the case at present and it is this point as well as a concern over the erosion to the Gold Coast beaches that led to the initiation of this study. Added urgency is given to understanding the processes operating at the Tweed Entrance by the fact that following a period of around 20 years of relatively safe navigation of the river and entrance, the ebb-tidal delta and entrance shoals have grown to an extent where navigation has again become difficult under certain conditions.

1.4 Previous Studies

Numerous studies have been carried out by the government departments mentioned in Section 1.2 as well as the following authorities: the University of New South Wales Water Research Laboratory (WRL), the University of Queensland, the Queensland Institute of Technology, the University of Sydney, the Delft Hydraulics Laboratory (Delft), the Bureau of Mineral Resources (BMR) and various private companies involved in the commercial development of the area. Chapman (1978) gives a comprehensive bibliography of the studies of the region. This will not be repeated here, but a brief outline of the more relevant studies will now be given.

The first major investigation into the problems of beach erosion on the Gold Coast was done by the Delft Hydraulics Laboratory of the Netherlands, Delft (1970). This report addressed the general problem of erosion along the entire length of the Gold Coast, which had taken on new significance following the rapid development of the coastal strip in the early 1960's. The report includes: estimates of the littoral transport rates at a number of locations along the coast, the first reported analysis of the wave climate, a study of the offshore currents and an assessment of the relative importance of long term erosion trends, storm wave erosion and erosion due to man-made structures. Delft assessed the expected total accretion updrift of the Tweed Entrance to be $1.53 \times 10^6 m^3$ and suggested that disruption to the supply of sand to the lower Gold Coast beaches would last for a period of 20-25 years. After this time littoral transport near Point Danger would be re-established and no remaining detrimental effects for the Gold Coast were to be expected.

The most significant finding of the Delft Report in the light of more recent studies is that there is a nett littoral drift differential along the coastline. The estimated transport rate along Letitia Spit was 478 000 m^3/year, at Tugun - 176 000 m^3/year and at Surfers Paradise - 486 000 m^3/year. These figures implied that there is a sand loss to the system near Point Danger of some 300 000 m^3/year.

Having stated that after the littoral supply was re-established past the entrance, there would no longer be sufficient depth in the river mouth, Delft recommended a co-operative study between Queensland and New South Wales of the future of the Tweed Entrance.

In the early 1970's, two students from the University of Queensland (Haydock, 1973 and Grimstone, 1974) studied the offshore area near Point Danger using seismic and side-scan ponar profiling techniques.

During the early 1970's a series of cyclones caused severe erosion problems along the entire length of the Gold Coast. The beaches to the north, although badly damaged, recovered following the passage of the cyclones. To the south, at Kirra in particular, the damage was greater and the beaches did not recover. This prompted a number of engineering actions. A groyne was built at Kirra Point to trap sand and reform Coolangatta Beach. This exacerbated the erosion further to the north and another smaller groyne was built at Miles Street, Kirra. Associated with these structures was the construction of a boulder seawall along this section of the coast.

It is apparent that the significance of the blocking of the littoral supply by the construction of the new training walls at the Tweed Entrance in 1962-64 had not been fully appreciated until the early 1970's.

The BPA (Robinson and Patterson, 1975) reported on the construction of the Kirra Point Groyne and subsequent erosion problems and suggested that the littoral transport rate to the north of Point Danger was higher than that given by Delft (1970) for Tugun.

A further response to the cyclone erosion was a beach replenishment program conducted in 1974-1976. This involved dredging from the Tweed River and pumping to Kirra Beach. As part of this program a sand tracing study was carried out using dyed sand. This has been reported by Chapman (1978), who also compiled a comprehensive data base of coastal process information as has been referred to earlier. Chapman's assessment of littoral transport at Kirra beach was based on data obtained over a short period and was different again from Delft (1970) and the BPA (Robinson and Patterson, 1975).

The dredging of the Tweed River led to complaints from users of the Tweed estuary of changes in its hydraulic character. This prompted the PWD to undertake a study of the hydrodynamic and sedimentary character of the lower reaches of the river in order to be able to predict its response to any future dredging, PWD (1979). It was found that the immediate response to the dredging in 1974-1975 of $765\,000\,m^3$ was infilling with sand of marine origin. This is continuing to date and is having the effect of removing an equivalent quantity from the active littoral system and delaying a return to natural bypassing of the Tweed Entrance. The deposited sand also was dispersed very quickly downdrift providing no long term benefit to Kirra Beach.

The BPA produced a series of reports in the early 1980's specifically dealing with the littoral transport of sand along the Gold Coast. The littoral drift estimates published by Delft (1970) were revised by the BPA (1981) using updated wave statistics from their coastal monitoring program. They calculated a nett transport rate at Tugun of around $500\,000\,m^3$/year. In 1983 the BPA (Patterson & Pattearson, 1983), estimated a total erosion due to the Tweed training walls of $3.5 \times 10^6 m^3$ based on a limited number of beach surveys. This estimate was revised using a greater number of beach surveys to be $5.7 \times 10^6 m^3$ (MacDonnald and Patterson, 1984). The total expected accretion at the Tweed Entrance was also estimated to be greater than $7 \times 10^6 m^3$.

From these results the BPA has stated that there cannot be a loss of littoral sand from what can be called the nearshore active zone around Point Danger as suggested by Delft (1970). They argue that the nett littoral transport differential suggested by Delft does not exist because the measured accretion updrift of, and at the Tweed Entrance, is approximately equal to the measured downdrift erosion.

In his discussion of the BPA (1983) report, Foster (1983) has argued that the permanent offshore loss of sand near Point Danger as suggested by Delft (1970) had not been disproved by the BPA and that calculations of littoral transport in the region are very difficult due to the irregular bottom topography.

The question of littoral transport differentials became very important in the mid 1980's as the options for a replenishment of the $5.7 \times 10^6 m^3$ of sand lost to the Gold Coast beaches were being considered. If long term artificial bypassing of the Tweed Entrance is to be adopted then the required annual dredging rate depends on the littoral transport potential to the north of Point Danger. Simply stated, the BPA suggests that 500 000 m^3/year is required and other studies indicate 200 - 300 000 m^3/year.

Foster (1984) examined the short and long term management options for Kirra Beach and found that a return to a fully natural bypassing conditions at Point Danger required the presence of extensive shoaling off Rainbow Bay and Coolangatta Beaches. As this is not evident at present, a considerable time will be needed before this condition is met, particularly as Point Danger bypassing follows from Tweed Entrance bypassing.

1.5 Outline of this Study

This leads to the present study the aim of which is to gain an understanding of the overall natural bypassing processes at the Tweed Entrance. In particular, an attempt will be made to quantify the 'loss' of sand from the study area. For this study a loss is defined as the average long-term removal of sand from the littoral zone transport system. This includes sand trapped by the construction of the training walls; depostion of sand within the active zone to satisfy hydrodynamic requirements, for example, the build-up of ebb and flood-tidal deltas to a state of dynamic equilibrium; and the permanent deepwater loss of sand.

The study has been prompted both by the failure of existing predictive models to estimate the time scale of the influence of the construction of the walls and also by the differences in estimates of the littoral transport rates. This study commenced in 1985 with funding from the Marine Sciences and Technologies Grants Scheme. This support was obtained for one year.

This report details the first phase of the planned study which involved the collection and collation of all the available data concerning the region. Initial assessments have been made and will be stated where appropriate.

The second phase of this study was to be the development of mathematical modelling techniques for all or part of the bypassing processes. This may not be commenced however due to the withdrawal of full financial support.

The report is set out as follows.

The source of the available existing data will be referred to and results of particular relevance to this study will be presented. The data obtained during field exercises carried out in 1985 will be included as part of the relevant section in the discussion.

The emphasis placed on the data collection was two-fold. Firstly a sediment budget for the Point Danger/Tweed Entrance was required. This can be obtained by considering the measured changes in beach profiles using land and sea based survey techniques.

Secondly, in order to develop mathematical modelling techniques, a physical understanding of the coastal processes is needed. For this, a description of the following is required: wave statistics, offshore currents, Tweed River fresh water flows, hydraulic characteristics of the lower reaches, sediment transport capacity of the ebb and flood tidal flows, longshore transport potential, bottom sediment distribution, ebb jet discharge patterns, ebb tidal delta formation and entrance shoaling behaviour. The data base searched for this type of information included the records of the government departments and the numerous reports published by the various sources listed earlier. In cases where analyses have been made of data by other authorities, these will be presented and in some cases used to form part of the data assessment of this study.

It should be noted at this point that, unless otherwise stated, the conclusions or inferences drawn from the data presented in this report are those of the authors and not necessarily those of the various authorities and departments from which the data were obtained.

2. SEDIMENT BUDGET

The survey coverage of the region comprises a number of hydrographic surveys of the Tweed River Entrance and lower reaches made since 1873 (PWD, 1979) and beach and offshore shore-normal profile surveys along the coastline from Fingal Head to Currumbin. These surveys fall into the following categories: the regularly surveyed ETA, OMEGA, BETA and GAMMA profile lines established in 1966; the Letitia Spit Survey profile lines established to monitor the updrift accretion at the new Tweed Entrance training walls in 1962; the soundings of the lower reaches of the Tweed and its entrance taken since 1873; the PWD Ebb-Tidal delta surveys commenced in 1978; the PWD Tweed Dynamics Study river sounding lines surveyed since 1976 and the shore normal profiles surveyed by the GCCC at various times as part of their coastal engineering works program.

These categories will be detailed separately and then will be discussed as a whole in reference to the sediment budget in the study area.

2.1 Gold Coast Beach and Offshore Sounding Lines(ETA OMEGA BETA and GAMMA)

The Delft Hydraulics Laboratory was commissioned in the early 1960's to prepare recommendations for an investigation of coastal erosion problems (Delft 1965). The establishment of a set of shore normal sounding lines to be surveyed at regular intervals was part of these recommendations. The location and spacing of these lines was based on a preliminary survey undertaken by the COG in the early 1960's (Goetsch, 1985). In the study area these soundings were presented as COG Plan Number Wd. 2721.

The survey lines were coded ALPHA, ETA, GAMMA, BETA and OMEGA in the region of interest and their location is shown on Figure 2. ETA lines are spaced at 400 metre intervals and are usually surveyed to around RL -20m AHD. [Australian Height Datum (AHD) - see Appendix 5 for discussion on survey datum.] OMEGA lines are ETA lines extended into deep water. GAMMA, ALPHA and BETA lines are closely spaced sets of lines at specific locations as shown on Figure 2. The survey of these lines is now the responsibility of the BPA although the GCCC uses some of these lines as part of their survey program. Surveys commenced in 1966 and continued at regular intervals to 1974. There was an hiatus in surveys until 1983, with yearly surveys since then.

Requests have been made to the BPA for the profile data but as yet they have not been made available. It a comprehensive data set and would be an invaluable tool in assessing both the sediment budget and in particular, provide site specific information on coastal processes.

Since 1983 even numbered ETA lines have been surveyed by the GCCC and surveys south of Point Danger held by them are shown on Figure 3. The reference datum to which these surveys are plotted is the Australian Height Datum established in 1974.

The BPA has used the ETA line data to calculate accretion and erosion trends for the Point Danger area. The results presented by them (Macdonald & Patterson, 1984) are reproduced as Figure 4. Total accretion to the south of Point Danger up to 1983 has been calculated as $6.4 \times 10^6 m^3$. This represents the accretion on Letitia Spit (updrift fillet) and on the ebb tidal delta since 1962. The 1962 reference survey for these calculations is not referred to by the BPA, but it is assumed by this writer that it is a composite of soundings taken for the initial Delft (1965) report as mentioned above and the PWD Letitia Spit surveys to be discussed later. The use of these surveys for comparison with the ETA line surveys which commenced in 1966 is difficult however, as the coverage of the earlier surveys was only to around RL -6m AHD. The methods used by the BPA in extrapolating these data have not been detailed in any of the BPA publications.

2.2 Letitia Spit Surveys

The Tweed River training walls were extended seawards between 1962 and 1965. The PWD established 11 survey lines to the south of the entrance to monitor beach changes during construction. The location of these lines relative to other surveys is shown on Figure 5 and in detail on Figure 6. The lines are coded by the distance in feet from the southern wall to the profile base point. The surveys began on 20 November 1962 and continued until 1971. A full listing of the survey dates can be found in Appendix 1, as well as data source and plan numbers. In all, there were 17 surveys during this period including a number done by the COG. Two lines were added along Duranbah Beach in 1966.

In general each profile was surveyed from around RL +6m AHD to RL -6m AHD. The profile nearest the wall, Line 100, was not surveyed as regularly as the others due to it intersecting the wall alignment. The profiles were surveyed again in 1985 by the GCCC as part of this study. The profiles are shown on Figure 7 for the following survey dates: 20 November 1962 - commencement of construction; 21 October 1964 - completion of southern wall; July 1966; March 1971; and 8 May 1985.

2.2.1 Letitia Spit Accretion

These surveys have been used by the various investigators to determine the rate of accretion at the Tweed Entrance and to calibrate theoretical littoral transport models. The analysis techniques have differed between the various investigations and a brief outline of these differences and the results obtained will now be given.

2.2.1.1 Letitia Spit Accretion - Delft, BPA

The methods by which Delft (1970) analysed the Letitia Spit survey data were not reported. The quoted average accretion rate during construction is 359 300 m^3/year. The BPA have adopted this figure without any reference made as to whether independent accretion calculations have been carried out.

2.2.1.2 Letitia Spit Accretion - PWD

PWD internal records (PWD, 1972) detail as follows the accretion calculation methods used by the department. The accreted volume per unit length of beach was calculated by measuring the area of water below RL +10ft ISLW (later referred to as Tweed River Hydrographic Datum - see Appendix 5 of this report) and above RL -15ft ISLW, bounded by the beach and profile chainage 2 400 ft. The total volume of water was determined by using an average end-area summation between Line 400 and Line 5200. [Note - in all analyses Line 100 (which intersected the southern wall) is not used due to inadequate survey coverage.] The line of best fit average accretion rate during construction determined in this manner was 355 700 m^3/year.

This method does not account for any accretion on the back beach or the change in survey baseline direction as shown on Figure 6 at Lines 1300 and 2200.

2.2.1.3 Letitia Spit Accretion - WRL

The accretion rate was determined as part of an internal study by the WRL in the late 1970's. Part of the internal report has been reproduced in Appendix 1. This report highlights some of the difficulties encountered with the analysis of beach profile surveys.

The accreted volume per unit length was calculated by measuring the sand area below a profile using RL-15ft ISLW as a base line. To this was added a triangular area between RL-15ft and RL-30ft which represented the assumed limit of sediment movement - see Figure 5, Appendix 1. The total volume from Line 400 to Line 5200 was determined with an average end-area summation with allowance for the change in the survey baseline direction. The average accretion rate during the period of construction of the walls was calculated to be 437 000 m^3/year.

2.2.1.4 Letitia Spit Accretion Rate - Summary of Previous Studies

Letitia Spit - Line 400 to Line 5200

Authority	Accretion Rate 20.11.62 to 21.10.64
Delft	359 300 m^3/year
BPA	360 000 m^3/year
PWD	355 700 m^3/year
WRL	437 000 m^3/year

2.2.1.5 Letitia Spit Accretion - This Study

Accretion calculations were again done as part of this study. The procedures adopted were as follows.

PWD and COG plans listed in Appendix 1 were digitised and the levels were adjusted to refer to AHD. The area under each profile above RL-15ft ISLW

(RL -5.41m AHD) and seaward of the profile zero chainage was determined numerically and the change in area with time referred back to the 1962 survey. The total volume was determined as for the previous WRL calculations with allowance for the change in baseline direction at Line 1300 and Line 220. Profiles which did not extend to the limits of the computations were completed by linear extrapolation to the RL -15ft level or by linear interpolation or horizontal projection to the zero chainage.

The change in the volumes of sand above RL -5.41m AHD between Line 400 and Line 5200 is shown on Figure 8. The following results can be obtained from this analysis.

Accretion from 20.11.62 - 21.10.64	=	652 500 m^3
Accretion rate from 20.11.62 - 21.10.64	=	371 700 m^3 /year
Accretion from 20.11.62 - March 1971	=	1 241 400 m^3
Accretion from 20.11.62 - 9.5.85	=	1 845 200 m^3
Accretion from March 1971 - 9.5.85	=	603 800 m^3

Average accretion rates were determined by linear regression analysis. It can be seen from Figure 7 that survey to around RL -6m AHD was inadequate as a measure of the limit of beach changes. By 1964 the offshore limit of all profiles had moved seaward indicating accretion at greater depths. In addition substantial accretion has been measured by 1964 at Line 5200 which is approximately one half distance along Letitia Spit indicating that a substantial quantity of accretion has not been accounted for further updrift.

It is interesting to note that following the initial rapid accretion during construction, there has still been a continual build up of the back beach area, particularly since 1970.

Also shown on Figure 8 is the accretion between Line 400 and Line 2200 and between Line 1000 and Line 2200. As can be seen in Table 2, Appendix 1, all lines were not surveyed on each date. The most comprehensive data set is for the section of beach between Line 1000 and Line 2200. The data set for the beach between Lines 400 and 2200 is complete except for one survey in May-June 1967. For Line 400 to Line 5200 there are six incomplete survey dates. The different accretion curves are shown to give an indication of the short term variability in volume changes.

2.2.2 Littoral Drift Estimates

The PWD and COG survey data have been used by the various investigators to calibrate littoral drift estimates for Letitia Spit. The most commonly referred to value in the literature is 500 000 m^3/year. This was initially suggested by the BPA (1981) based on the assumption that the measured accretion quoted by Delft (1970) of 359 300 m^3/year did not represent the total transport as a portion (28%) was bypassing the southern wall during construction. This is supported by the sediment transport calculations made by Delft (1970) which give the nett transport rate to the north of 478 000 m^3/year. As was shown in Section 2.2.1.4 the measured accretion rates by the various authorities are similar except for that calculated by the WRL. The minor variations are due to the different calculation procedures. The WRL value is higher because of the allowance made to account for accretion beyond the offshore limit of the profile surveys.

In addition, the accretion between the southern wall and Line 400 is unaccounted for. An estimate for this quantity has been obtained by considering the change in Line 100 profile to the point where it intersects the wall - see Figure 6. Between 20.11.62 and 21.10.64 this was equal to 445 m^3/m. An estimate of the accreted volume between Line 100 and Line 400 over this period is obtained by calculating the profile change at Line 400 (545 m^3/m) to a point opposite the end of the southern wall. Thus the volume change is given by the average end area multiplied by the distance between the two profiles (91.4 m). This gives:

$$\Delta V_{100-400} = \frac{445 + 545}{2} \times 91.4$$
$$= 45\,240 \text{ m}^3$$

Also unaccounted for by the Letitia Spit Accretion Surveys is the accretion on the southern end of the beach between Line 5200 and Fingal Head, a distance of some 1 600m. Calculations at Line 5200 give an accretion per unit length of beach between 1962 and 1964 of 380 m^3/m. An estimate of accretion for the southern end of Letitia Spit is thus given by assuming a linear reduction in accreted beach volume from 380 m^3/m at Line 5200 to zero at Fingal Head. This gives an accreted volume of $1/2 \times 380 \times 1600 = 304\,000\ m^3$.

Thus an average accretion rate from the southern wall to Fingal Head can be determined by considering the total accretion and dividing the time period from 20.11.62 to 21.10.64.

Estimated Accretion Line 100 - Line 400	=	45 240 m^3
Measured Accretion Line 400 - Line 5200 (From Appendix 1)	=	849 500 m^3
Estimated Accretion Line 5200 to Fingal Head	=	304 000 m^3
TOTAL	=	1 198 740 m^3
Average Accretion Rate 20.11.62 - 21.10.64	=	624 300 m^3/year

This figure is presented as a possible upper limit on the actual accretion rate during the period of construction of the walls and highlights the problems encountered in adopting a measured accretion and relating this to a potential transport rate.

As the measured accretion rates underestimate the littoral transport, it can be taken that the commonly referred to transport rate of 500 000 m^3/year is a reasonable estimate for the nett littoral transport rate during the two year period of construction. This rate represents a long term average transport rate only if the wave climate during that period was representative of the long term average conditions. During that time there were no major recorded meteorological events such as cyclones. However, no reference is made in any report to the general wave climate as automatic wave recording facilities were not available at that time. A study of the meteorological records has not been made at this stage.

2.3 General River and Offshore Soundings

A listing of the available hydrographic survey plans for the Tweed River and its entrance is given in Section 3, Appendix 1. These early surveys have been used by the PWD (1979) and are discussed in a later section. The

1960 sounding plan prepared by Mr.R.M. Engel has been used in this study as a reference survey to compare the more recent river soundings. Similarly, the PWD 1971 Tweed River Hydrographic Survey offshore soundings have been used as a reference survey for the more recent ebb-tidal delta surveys.

2.4 PWD Ebb-Tidal Delta Survey

Detail surveys of the ebb-tidal delta have been conducted regularly since 1978 by the Public Works Department, NSW (PWD). Prior to this period, the delta surveys were sporadic and usually did not have a broad coverage. The ebb delta formations prior to the 1960's training wall construction have been examined from aerial photographs and hydrographic survey by the PWD (1979).

The earliest survey of the area was in 1873. At this time the inlet had stabilised its position against Point Danger to the north. As discussed elsewhere in this report, evidence exists to suggest that the Tweed Inlet was once located further to the south and has migrated northward.

The geomorphology of the ebb delta has been determined by PWD (1979) and their sketch sequence of the development of the delta is shown as Figure 9. The salient features of their description of the ebb delta formation are outlined as follows.

The earliest survey in September 1873 indicated a northward prograding beach bar which forced the river entrance to flow almost due north against Point Danger. The ruling depth was -1.5m ISLW. Some time during the next six years a major flood scoured the beach bar resulting in the channel running due east with an approximate depth of -3m ISLW. By 1883 the depth had reduced to -0.9m ISLW due to strong littoral supply. However, the channel was still oriented to the east.

The internal training walls were constructed between 1900 and 1903. The entrapment of sand on Fingal Beach during construction and a flood prior to 1903 resulted in a ruling depth of -3.2m ISLW in 1903.

By October 1920 the entrance had re-established pre-construction conditions with a northerly orientation of the channel; outflanking of the southern breakwater by Fingal Beach and a bar depth of 2m.

By January 1932 the entrance conditions had worsened and were similar to those in 1873. The channel took a north easterly course with a depth of -1.0m ISLW. There was a continuous and shore parallel bar across the river mouth which dried at low water. The conclusion is made that the delta configuration was close to the maximum bypassing condition of 1873.

By 1947 there had been little change except for the forcing of the ebb to flow north around Point Danger. The next survey was in 1960 following the largest flood on record in 1954. This had scoured an easterly channel through the delta to a recorded depth in 1960 of -1.5m ISLW.

The new training walls were constructed between 1962 and 1965. Surveys between 1960 and 1971 indicate the effects of the interception by the breakwaters of the littoral supply resulting in the delta re-establishing itself further seaward. By 1971 the bar depth was -3.5m ISLW.

After an initial period of near complete trapping of sand to the south, bypassing of the southern breakwater has been increasing. The delta continued to grow until March 1978 when a flood scoured it to a depth of -3.0m ISLW. At present sand is being supplied to the ebb delta as well as the estuary shoals.

In June 1978 a series of regular ebb delta surveys were commenced and these will now be discussed in detail as they provide the only available data set from which sediment budget quantities can be derived. The ebb delta has been surveyed by the PWD (and more recently the GCCC) as part of their Tweed Estuary Dynamics Study which has been outlined in another section.

2.4.1 PWD Tweed Dynamics Ebb Delta Surveys, 1978 to Present

As a continuation of the Tweed River Dynamics Study (PWD, 1979) the ebb tidal delta has been surveyed on the dates shown in Table 1 below.

Table 1 - Tweed Ebb Delta Surveys

Survey Date	Surveyed By	Accretion/Erosion Calculations
July 1971	PWD	PWD
1/ 6/1978	"	"
17/ 1/1979	"	"
26/ 4/1979	"	"
8/10/1979	"	"
2/ 6/1980	"	"
23/ 9/1980	"	"
23/ 4/1982	"	"
15/ 3/1983	"	"
19/ 2/1984	"	This Study
9/ 5/1985	"	"
11/12/1985	GCCC	"

The PWD (unpublished) has analysed the survey data for surveys up to that of 15th March 1983. Subsequent surveys have been analysed as part of this study. To ensure continuity of results, the same procedures used by the PWD have been adopted.

The area covered by the surveys is shown in Figure 10. Nine profile lines are surveyed covering a length of coastline from 394m to the north of the channel centreline to approximately 280m south of the centreline. Profile lines are generally surveyed from the low water mark (RL 0m TRHD = -0.86m AHD) to the 20m depth contour using echo sounding equipment. The three lines within the channel are surveyed from near the western bank of the river bend providing details of the entrance shoals.

For the purposes of analysis, a control area was arbitrarily defined by the PWD for the initial survey which approximated the offshore area from RL 0m to RL -18m TRHD. The control area does not include the channel section between the training walls. This is marked on Figure 10.

Accretion/erosion calculations proceed by determining the profile section area and using an average end-area summation to calculate the volume. For the PWD calculations this area was taken as the area of water above the profile and below RL 0.9m TRHD.

For analyses subsequent to the 15.3.83 survey the area of sand below the profile was used. The base line was taken as the reduced level corresponding to the control area cut off chainage used by the PWD. The results obtained from these analyses are summarised graphically on Figure 11. The reference point for the delta surveys is the July 1971 PWD hydrographic survey. This was not part of the current series, but had sufficiently detailed coverage for the sand volume to be determined accurately over the control area. The sand volume for the 1971 survey is taken to be zero on Figure 11, and the plot represents the change in volume since that time. Positive values represent accretion within the control area.

Since the commencement of regular surveys in June 1978 the average accretion rate in the control area has been 110 300 m^3/year. Between the July 1971 survey and June 1978, the change in volume represented an average accretion rate of 39 800 m^3/year. The total increase in the measured quantity of sand within the control area between July 1971 and December 1985 is 945 200 m^3.

It is difficult to obtain a pre-construction bathymetry within the control area due to a lack of comprehensive survey data at that time. However, attempts are being made to compile a pre-construction bathymetry from the available survey data. These include the 1962 Letitia Spit survey, a RAN sounding chart for 1960 and the ETA line reference surveys of the early 1960's discussed previously. At the time of publication of this report, this had not been completed.

2.4.1.1 Discussion

The contour plan of the ebb-tidal delta is shown on Figure 12 for each of the surveys since 1978. The form of the bar is generally crescentic in shape as is clearly shown in the photograph taken on 10.2.83 shown as Figure 13.

The growth of the bar can be demonstrated by plotting the seaward migration of selected depth contours. This is shown on Figure 14 for the 5m, 10m, 15m and 20m (TRHD) contours. The distance is measured from an imaginary line drawn between the lead lights at the end of the training walls.

There is an indication that the growth rate of the bar is reducing as shown by the change in the rate of seaward migration of the 10m, 15m and 20m contour around 1981. Also shown on Figure 14 is the seaward migration of these contours at the northern ebb-tidal delta survey line, using a projection of the same baseline as a reference. The continued growth demonstrated on Figure 11 may indicate that the ebb delta is expanding along the coast to the north under the influence of increased entrance bypassing.

Periods of high freshwater runoff in the catchment in the years 1971, 1972, 1974 and 1976 would have scoured the delta in the same manner as discussed earlier for the March 1978 flood. This would have limited the growth of the delta and explains the relatively slow growth between 1971 and 1978 shown in Figure 14 when compared to that from 1978 to 1981 during which time river flows were less significant.

The pattern of erosion and accretion demonstrated by Figure 11 will be discussed in more detail in the next section in relation to the river surveys, the wave climate and the river discharge.

2.5 Tweed River Surveys

An investigation of the hydraulic character and sediment carrying capacity of the Tweed River has not been included within the scope of this report as it has been the subject of a major study by the PWD (1979). The report on this study has been used as the major reference for this study.

The PWD study was initiated as a response to evidence that the hydraulic character of the estuary had changed following the dredging of approximately 765 000 m^3 of sand from near the entrance between August 1974 and October 1975. This sand was used as beach nourishment material for Kirra Beach. A comprehensive hydrographic survey was undertaken.

As part of the study a program of regular river soundings was commenced in December 1976. Regularly spaced river cross-section profiles are surveyed from a section 580m upstream of the seaward end of the training walls to a section 2745m upstream. In addition, 275m of Terranora Inlet are surveyed upstream of its confluence with the Tweed. The extent of the dredging and the survey program is shown on Figure 15. The behaviour of the shoals in the lower reaches has been discussed at length in the Tweed River Dynamics Report and will not be considered here other than in relation to the ebb delta surveys.

The PWD has analysed the survey data obtained since 1976. A copy of their working file has been made available for this study. The changes in river cross-section are determined below RL 0.9m TRHD, being approximately mean sea level. The total channel volume is calculated using an average end-area summation.

The changes in channel volume since 1976 are presented in graphical form as Figure 16. Results are presented for the total area surveyed, the total dredged area and the dredged area in Terranora Creek. PWD channel volume changes are related back to the hydrographic survey of July 1971 prior to the commencement of the beach nourishment dredging.

A better understanding of the response of the estuary to dredging can be obtained by considering a schematic history of dredging and river response as shown in Figure 17. As part of this study the channel volume in the surveyed area was calculated from the December 1960 sounding plan prepared by Mr. R.M. Engel. The 1960 survey is used as a reference and the dredged quantities are shown as changes from the previous surveyed volume. Since 1960 approximately 1 581 000 m^3 (PWD, 1979) have been dredged from the survey area as shown below in Table 2.

Table 2 - Tweed River Dredged Quantities 1960-1983

Date	Quantity (m^3)	Location
Jan 1966	77 000	Eastern Training Wall - near spur wall.
- May 1968	486 000	Survey Area
May 1971	18 000	Terranora Inlet
Mar 1973 - Nov 1976	235 000	Terranora Inlet - northern bank near confluence.
Aug 1974 - Oct 1975	765 000	Survey Area - Figure 15

The channel volume at the end of October 1975 as shown on Figure 17 corresponds closely to a volume which would be obtained if the 1976-1983 trends were extrapolated back to that date.

The results shown in Figure 16 indicate an infilling of the surveyed area between 1976 and 1983 at an average rate of 79 400 m^3/year. The total volume change being 491 000 m^3. The analysis of sediment samples taken in the late 1970's as part of the PWD study showed that the source of the infilling sand was almost solely from the active beach sand system. Samples taken in November 1985 as part of this study confirm that this is still the case. Records held by the GCCC (1979) indicate that during the 1974-1975 dredging operation near the entrance, the dredged hole was infilling at a maximum rate of 350 m^3/hour.

Further examination of Figures 16 and 17 indicates that prior to the commencement of dredging in 1973 the river Entrance shoal regime may have been in a state of dynamic equilibrium. The PWD (1979) state that the river entrance was in a similar condition prior to the construction of the new training walls in 1962, with the entrance at or near its maximum bypassing condition. The construction of a new entrance would act to reduce the frictional resistance to flow and consequently modify the sediment movement in the entrance. The nett effect of the new conditions would likely to be similar to a dredging operation with infilling occurring. Between the 1960 and 1971 survey dates there was a nett erosion of the channel which may be due to the major flooding that occurred in 1963 and 1967. Between 1971 and 1976 the dredged volume approximately equalled the change in channel section indicating that scour associated with the high river flows in 1972 and 1974 was balanced by infilling from the ocean.

It has been found that a correlation exists for the measured river channel and ebb-tidal delta volume changes with both the wave climate and freshwater discharges during the period of surveys. Wave records obtained by the Queensland Department of Harbours and Marine, and Tweed River flow records obtained by the NSW Water Resources Commission have been plotted on Figure 18 along with the surveyed volume changes for the river and the ebb delta.

The mean monthly wave height and wave direction data were obtained from the BPA's Coastal Observation Program records at Surfers Paradise (BPA, 1984). Also shown on Figure 18 are dates when significant wave heights of 3.5m or greater have been recorded at the Point Lookout automatic wave recording site (BPA, 1985). The river flow data presented is for the Oxley Arm of the Tweed River system, for which a complete record is available covering the period of hydrographic survey.

The infilling rate into the dredged area from the entrance is nearly constant. High river flows in early 1978 appear to have resulted in erosion of the river channel and ebb-tidal delta. Similarly, scour of the dredged area occured in early 1977. As reported by the PWD (1979), the March 1978 flood did not significantly alter the infilling pattern.

The period of accelerated accretion, both in the river and on the ebb delta in 1979, corresponds to a period of low river flows and predominantly high south-easterly wave activity.

It should be noted that the mean wave statistics presented on Figure 18 tend to mask the occurence of major storms. Foster and Higgs (1981) have shown at Currumbin that over a few days of storm attack a slug of sand comparable in volume with the annual mean littoral transport can be mobilised.

2.6 Lower Gold Coast Surveys

Beach and offshore profile surveys within the area of interest from Point Danger to Currumbin Creek have been carried out at various times by the BPA and the GCCC. As mentioned in Section 2.1 the ETA line surveys provide a comprehensive cover of this stretch of the coastline. This data set is not available for analysis at present. In addition to ETA lines, the BPA program includes a set of more closely spaced BETA lines at Coolangatta. These were primarily established to monitor the effect of the construction of the Kirra Point Groyne in 1972.

The ETA line program does not cover that portion of the offshore region near Point Danger given as an arc from ETA13 at Point Danger to the BETA lines at Greenmount Hill. This section of the coast is of considerable importance to an understanding of the bypassing mechanisms operating at Point Danger. Deep water OMEGA lines 7, 9, 10 and 11 off Point Danger have been surveyed in 1967 and 1983, but this data is not available.

The GCCC established survey lines in the early 1970's which extend from Rainbow Bay to North Kirra. The location of those which have been surveyed on a number of occasions are shown on Figure 19. These lines were originally surveyed in the period from 1972 to 1975 following which there was an hiatus in surveys until 1983.

The survey work in the early 1970's was in response to the major erosion and subsequent coastal structure construction following the 1972 and 1974 cyclones. The renewed interest in the erosion problems in the early 1980's prompted a reestablishment of the survey program. The survey coverage of the Kirra (K) lines has been extensive since 1985 to monitor the offshore dredging program for beach replenishment at North Kirra.

Appendix 2 contains a list of the survey dates for each of the GCCC Survey Lines. A representative sample of the profiles is given as Figure 20. Shown is Greenmount-Coolangatta Line 9, Rainbow Bay Line , Kirra 1 and Kirra 11A.

As these surveys have not been continuous, their usefulness in sediment budget considerations is limited and consequently the profile changes have not been analysed as part of this study. A number of these GCCC lines as well as other lines are however to be surveyed regularly as part of the proposed continuation of this project as will be discussed later.

A program of regular sub-aerial beach and surf zone profile surveys was commenced by the GCCC in December 1983 at COPE stations at Rainbow Bay, Coolangatta, Bilinga (ETA20) and Currumbin (ETA27). Initially these surveys were done on a weekly basis, but this has since become less regular. At each survey, a note is made of wave height, type and direction; sea condition; sand suspension; wind direction and speed; longshore drift direction and strength and the state of the tide.

2.7 Discussion of Survey Errors

All survey data referred to in the above sections are subject to errors both in the survey and the analysis. The magnitude of the error will vary from survey to survey and for the earlier surveys may be impossible to quantify. Generally, surveying authorities such as the PWD quote a vertical survey error of up to 0.3m. An indication of the significance of an error of this magnitude on accretion rate calculations can be shown by a simple calculation for Letitia Spit.

The average accretion between the 1971 and 1985 Letitia Spit surveys (see Figure 8) was approximately 43 000 m^3/year. The worst possible case is taken to be for a +0.3 m error systematically applied to all 1971 survey profiles and -0.3 m applied to the 1985 data. Letitia Spit survey lines cover approximately 600 m offshore and 1 600 m alongshore, thus the maximum error in the accreted volume between the two surveys would be 576 000 m^3. Over the 14 year period the error represents 102 percent of the quoted accretion volume. Similar percentage errors can be determined for accretion/erosion estimates for other surveys and over different survey periods.

Although this example represents the upper limit of the error band, it clearly demonstrates that absolute accretion/erosion volumes calculated from beach and offshore surveys must be used with caution. However, given the systematic nature of error, the calculated accretion/erosion rates - and consequently, littoral drift rates - can be used with greater confidence.

The vertical error is usually introduced in the interpretation of a mean water depth from the echo trace, which due to wave activity can be relatively wide compared to the water depth. Another source of vertical error is datum error. This is usually evident during the profile checking stage of data analysis, however, in the case where a line has been surveyed over a long period and over different distances datum errors may be impossible to detect.

In light of the above comments, the inherent inaccuracies of offshore survey work would normally preclude a confident use of the data. However, as the errors are generally systematic in nature, and as the data is checked for obvious error, it is used in this report at face value and no detailed error analysis is undertaken, or for that matter, considered necessary.

2.8 Literature Review - Littoral Transport

The following is a compilation of the results reported elsewhere concerning the longshore transport of sand on the lower Gold Coast beaches.

Delft (1970) estimated the littoral transport potential at two locations within the study area. At Letitia Spit, as discussed earlier, and at Tugun. Theoretical computations of littoral transport were made using Eagleson's (1965) formula to determine the littoral current for various wave directions, heights and periods. The calculated current velocities agreed rather well with the littoral currents measured by Delft. Using Bijker's (1968) theory, the bed load and suspended transport were calculated. Delft obtained the frequencies of occurrence of wave heights, periods and directions from The Royal Dutch Meterological Institute (KNMI) observations. The result of this analysis for Tugun was a nett northerly littoral transport of 176 000 m^3/year. As this is less than the transport capacity to the south of Point Danger, Delft concluded that the excess of sand passing Point Danger does not lead to accretion of the beaches, but is deposited offshore in an area in front of Greenmount Beach. This conclusion was supported by the shape of the offshore profile in comparison to a shore normal profile at Tugun as shown on Figure 21. [More recent seismic profile data have shown however, that this lobe consists of a relatively thin layer of sand underlain with bedrock or other hard strata.] The pattern of erosion/accretion at beaches such as Kirra prior to the 1960's suggested that this section of the coast was dynamically stable with major erosion being caused by storm events.

Delft also considered a 30 year shoreline change history as a measure of erosion/accretion quantities with the cause of the erosion or accretion being due to differences in littoral transport. A GCCC reference plan was used in this analysis and the results are reproduced and shown as Figure 22. Summation of erosion/accretion quantities estimated from these changes gave a nett littoral transport rate in good agreement with that theoretically calculated at Tugun. Based on these shoreline changes, Delft also estimated that the nett littoral transport rate immediately to the north-west of Point Danger (Rainbow Bay to Kirra) was 208 000 m^3/year.

Chapman (1978) has estimated the littoral drift for Kirra Beach using a number of techniques. His investigation was part of the beach replenishment program for Kirra during 1974 and 1975.

- Wave angle data obtained from a study of vertical and oblique aerial photos and waverider records were used with the Komar (1977) sediment transport model. Ninety five values of the wave breaking angle were obtained for a period from 1971 to 1978. This data yielded a transport rate of 338 000 m^3/year.

- Wave records and observed wave breaking angles during the months of May and June 1975 were used with the Komar model to obtain a rate of 228 000 m^3/year.

- Analysis of the beach profile changes during the beach replenishment program during May and June 1975 indicated a rate of 284 000 m /year.

- A sand tracer exercise was conducted using dyed sand. The rate of downdrift dispersion of this sand indicated a transport rate of 252 000 m^3/year.

- Analysis of the profile changes at Coolangatta Beach during the construction of the Kirra Point Groyne gave an accretion rate of 153 000 m^3/year.

Chapman concluded that during the six week period of his study, the most credible estimate of the littoral transport rate was that derived using high resolution wave data, i.e. 228 000 m^3/year.

2.8.1 Beach Protection Authority - Littoral Transport Estimates

The BPA have investigated the littoral transport question for the lower Gold Coast and have recently concluded that the transport rate for Tugun is 500 000 m^3/year and that consequently there cannot be any littoral transport differential between Letitia Spit and Tugun. The results of BPA studies which led to this conclusion will now be outlined.

Robinson and Patterson (1975) studied the effects of the construction of the Kirra Point Groyne. Construction commenced in May 1972 and was completed by December 1972. The measured average accretion rate during construction was 340 000 m^3/year. During the same period the downdrift beaches eroded at a rate of 130 000 m^3/year. The changes in profile were found to occur above approximately RL -6m AHD. Over a two year period following commencement of construction, 306 000 m^3 had accumulated. During that same two year period 503 000 m^3 eroded along a 1.8km stretch of coastline to the north.

Using the Delft (1970) estimate of littoral transport on this section of coast of 208 000 m^3/year and assuming that the groyne would trap 65% of that transport, the estimated accretion rate was 135 000 m^3/year. This was less than the measured initial accretion rate. From this, Robinson and Patterson suggested that the nett littoral transport rate may be higher than Delft reported and that the imbalance between erosion and accretion at the Kirra Point Groyne was due to the effect of the Tweed training walls.

The BPA (1981) reassessed the longshore transport rates. Using the surveys of Coolangatta Beach from 1972 to 1974 the estimate of the transport rate during those years was given as 350 000 to 500 000 m^3/year. The theoretical nett littoral transport rate at Tugun was calculated using two methods to be :- 475 000 m^3/year using the Bijker (1968) equation and 526 000 m^3/year using the CERC (1977) equation. The wave climate used was based on wave heights, periods and directions recorded over a six year period. The difference between the calculated transport rates at Tugun and that quoted by Delft are primarily due to the revised wave climate which results in a greater upcoast component of the total transport from south easterly wave activity. The report concluded that there can be no nett longshore transport differential near Point Danger.

Patterson and Pattearson (1983) reported on the above reassessment of the nett longshore transport rates. It was also stated that the estimate of uninterrupted longshore transport at Coolangatta was 500 000 m^3/year. This was derived by assuming that the measured 230 000 m^3 that accreted updrift of the Kirra Point Groyne in a year represented a groyne trapping efficiency of 80% of the available transport. In addition, the available transport was taken to equal the amount which would be bypassing the Tweed Entrance at that time (53 to 57% of the Letitia Spit transport rate, Delft (1970)). Thus the uninterrupted nett transport rate at Coolangatta would be $230\,000 / 0.8 \times 0.55 = 500\,000\ m^3$/year.

MacDonald and Patterson (1984) consider the total erosion downdrift and accretion updrift of the Tweed training walls. They state that the estimate for total erosion given by Patterson and Pattearson (1983) of $3.5 \times 10^6\ m^3$ was based on profile changes at only four locations. This was updated to give a downdrift erosion of $5.7 \times 10^6 m^3$ by 1983 based on profile cnanges at 21 locations. The results presented in their paper are reproduced here as Figure 4. The erosion downdrift of the Tweed Entrance was found to have extended to about 4.5 km downdrift by 1983. The measured downdrift erosion was found to have occurred across some 1200 metres width of the nearshore profile out to depths of about 15m. The pumping of approximately $1 \times 10^6 m^3$ of sand from the Tweed River in 1974-1975 was found to have had no lasting effect, as the rate of longshore supply of sand at the time was less than the transport potential. This resulted in rapid distribution of the pumped sand to the north. Also, as the source of the sand was within the active sand transport zone, the river has responded by infilling, resulting in small long term benefit to the nourished beaches. It was concluded that $7 \times 10^6 m^3$ may ultimately be trapped by the Tweed training walls and that natural bypassing of the entrance will be restored to 90% of its original rate by 1990.

2.8.2 Discussion

The estimated littoral transport rate for Coolangatta (500 000 m^3/year) and the theoretical transport rate at Tugun (500 000 m^3/year) have been used by the BPA to show that there is no nett littoral transport differential at Point Danger. The following aspects should be noted however.

As shown in Section 2.1 the measured accretion rate following the construction of the Tweed training walls in 1962-1964 is not likely to represent the actual nett transport rate during that period. It is possible, for instance, that the transport potential for Letitia Spit may be much higher than 500 000 m^3/year due to the wave climate being expceptionally calm during the period of construction (McGrath, 1967).

The use of conventional wave refraction techniques at a location such as Letitia Spit is not considered reliable because of the extensive reefs to the south-east (the predominant wave direction) and the generally irregular bathymetry off Letitia Spit.

The sediment transport formulations also require an empirically calibrated coefficient which has been derived using the measured accretion rates mentioned above. As stated before, these are also not considered sufficiently reliable.

The coefficient derived empirically at Letitia Spit has been used for all transport calculation locations by Delft (1970) and BPA (1981). It has been shown by other investigators however that the coefficient is dependent on beach slope and wave steepness which must also vary along the coastline due to the varying offshore bathymetry along the Gold Coast and the observed differences in wave characteristics between Letitia Spit and other areas (Kirra in particular).

MacDonald and Patterson (1984) point out that the change in beach alignment has resulted in a reduction of the littoral transport potential along Letitia Spit. The main purpose of the present study is to determine whether the change in sedimentary characteristics at the entrance itself has further reduced the littoral supply to Point Danger and beyond. As will be discussed in a later section this is likely due to interaction between the ebb jet and offshore currents and wave refraction around the ebb tidal delta.

Recent evidence by Nielsen and Gordon (1984) has implied that the use of waverider buoy records may greatly overestimate the bed movement, thus making littoral transport calculations of questionable value.

The estimated nett littoral transport rate of 500 000 m^3/year at Coolangatta (Patterson and Pattearson, 1983) has been derived using somewhat limiting assumptions and cannot be relied upon to provide confirmation of the revised calculated theoretical transport rates at Tugun.

The figure of 500 000 m^3/year is primarily derived from the accretion rate during the first year after construction of the Kirra Point Groyne. It should be noted however that in January and February 1972 just prior to the commencement of construction of the groyne, the coast was hit by a number of cyclones. The normal onshore movement of sand following such erosion events may have contributed to the high accretion rate measured in that year. This beach recovery process may also have accounted for the initially low erosion rate downdrift of the groyne. The erosion rate subsequently increased and the accretion rate decreased.

The BPA's estimate that 53 to 57% of the littoral drift was bypassing the Tweed Entrance was based on Delft (1970) calculations using the Pelnard-Considere method of determining beach changes at shore normal structures. This however has little relationship to bypassing of a tidal entrance and it is now considered that the amount bypassing north to Point Danger would have been much less at that time.

In addition, the diffraction of waves from the east and south-east sectors in the lee of Point Danger result in a markedly different wave field than that along Letitia spit. The erosion in the Kirra area since the 1960's would affect these characteristics to the extent that the littoral transport potential would be continuously changing.

It has been proposed by Smith (1979) that the littoral transport across an embayment such as at Rainbow Bay, Coolangatta, and Kirra Beaches, is along a path diagonally across the embayment and not along the beach. The cause of this is uncertain but is probably explained by wave energy considerations. This transport mechanism was clearly shown in early aerial photographs of the area such as shown as Figure 23 and has been discussed by Foster (1984). The erosion of the shoals that make up the bypassing path would have changed the transport potential along this stretch of coastline.

The aspects raised in the above discussion are to be investigated in the next stage of this study. In particular it is proposed to model the wave refraction/diffraction characteristics at the Tweed ebb delta and around Point Danger.

2.9 Littoral Supply to the Study Area

It has long been known that the nett longshore transport of sand on the northern NSW coastline is to the north. Studies at Byron Bay, Dreamtime Beach and Bogangar Beach by the PWD as well as observations at other locations have confirmed this. The magnitude of the nett littoral drift is found to vary along the coastline. Roy and Crawford (1977) state that, based on geological evidence, the long term erosion evident on the northern NSW coastline is due to this littoral drift differential. The supply of sediments from rivers to the south is insufficient to counter this trend. Chapman (1978) has presented an assessment of the sources of, and sinks for, the sediment supply and suggests that the beaches within the study area have been protected from extensive erosion of their outer beach ridge systems by the longshore transporet of sand from eroding systems further updrift which acted as stores in late Holocene times.

Littoral transport rates have been estimated at a number of locations to the south. As part of a major study of coastal erosion at Byron Bay, the PWD (1978) has calculated the littoral transport rates at Cape Byron, Byron Bay and Hastings Point. The results of their analysis for that stretch of coastline is shown on Figure 24. The study concluded that the erosion of the shoreline in the Byron Bay area is mainly due to two factors.

- Less sand is moving around Cape Byron into the study area than is moving north around Hastings Point, out of the area, mainly due to the overall coastal alignment. (Tallow Beach to the south of Cape Byron being near perpendicular to the dominant wave approach direction experiences far less drift than the Cape Byron-Hastings Point region whose increases obliquity enhances drift rates.)

- A long term loss of material to the offshore region at Cape Byron, due to the offshore current interception of the littoral zone.

The above two factors result in a demand for sand by the longshore drift processes in the Byron Bay area; this demand being satisfied by the shoreline erosion. It was further implied that the demand situation has been generated by natural processes which have operated over an extended period of time and which it can be assumed will continue to exist in the foreseeable future.

As part of a study of Bogangar Beach between Norries Head and Kingscliff, the PWD (1982) calculated the beach recession rates using photogrammetric techniques. From these results a recession rate of 110 000 m /year was obtained. Considering the erosion required to satisfy the differential in transport rates between Hastings Point (195 000 m^3/year) and Letitia Spit (500 000 m^3/year) to be evenly distributed over the length of coastline, then the resultant loss on Bogangar Beach would be of the order of 110 000 m^3/year. It was thus implied that the erosion experienced on Bogangar Beach was due to the nett littoral drift differential.

3. OFFSHORE SEDIMENT DISTRIBUTION

3.1 General Discussion

The distribution of sediments in the offshore region of the study area can be used to determine both long term deposition patterns and short term changes to deposition patterns. As such, a study of the sedimentary distribution compliments the results of sediment budget considerations. As has been discussed earlier, the sediment distribution within the Tweed River Entrance confirmed infilling as a response to the dredging for beach replenishment in 1974-75. The offshore region in the study area has not been extensively studied. There have been a limited number of surveys carried out in search of heavy minerals (Cifali et al, 1968 and Jones 1973), offshore grain size determination by Delft (1970) and more recently sampling of a proposed offshore dredging source area.

In the study area, bedrock is frequently exposed, but generally the inner continental shelf is surfaced with sand to a thickness of 6m or more. Delft (1970) inferred that there was a universally deep sand cover in the Point Danger region resulting from deposition of the imbalance in the littoral drift at that location - see Figure 21. Seismic profiling by Haydock (1973) did not prove this however. The Delft assumptions were based almost entirely on the data of Cifali, et al (1968), which by the latter's own admission were somewhat poor in the study area. The BPA (1981) also quote GCCC offshore bore logs which indicate that in the embayment at Kirra there is only a thin layer of sand above a peat substrate. This evidence is used by the BPA to support the assumption that there is no differential in nett longshore transport rates at Point Danger.

Chapman (1978) has given the following general description of the offshore sediment distribution.

Sands of the inner continental shelf are generally fine and similar to those on adjacent beaches. The distribution of mean grain size in the study area is shown on Figure 25 which is a reproduction of the data presented by Delft (1970). Whilst surface sands tend to decrease in size seaward to about 15m water depth and then to become coarser, with poorer sorting, core sample sands show a tendency to increase in mean diameter with distance from the shore. Outer shelf surface materials are typically coarse with coarse shell, gravel, coarse sand and canal fragments reported from RAN hydrographic surveys in 1954 and 1975.

Observations by Chapman of the colour of samples recovered from sea-bed cores enabled three vertical zones to be distinguished. The upper zone, extending up to 2.5m below sea bed in 6m water depth and up to 0.75m in 10m and 15m depths, was similar to beach sand in colour and is interpreted as having been recently or periodically disturbed by normal or cyclone wave activity.

Bedforms on the inner continental shelf also indicate wave activity. The RAN hydrographic survey of 1954 detected well defined ripples in 60 to 80 metres of water off the study area. Similar features have been observed in shallower depths.

The known details of the sediment distribution in the study area will now be discussed for the following areas: Fingal Head to Point Danger (including the Tweed ebb-tidal delta), Point Danger to Kirra, and special reference to the Norries Head - Fingal Head region.

3.2 Norries Head to Fingal Head

Although this region is outside the general study area, a survey has been made of the sediment distribution along three shore normal lines as shown on Figure 26. The execution of a survey in this area was suggested by Stephens (1985) who proposed this area as the possible location of a sink for sediments which are jetted offshore at the Tweed Entrance and are carried southward by the offshore currents to be deposited south of the Tweed in the form of a lobe.

The lobe hypothesis is supported by studies of similar current dominated sediment deposition patterns along the NSW coastline by Gordon (1982), at Indian Head, Fraser Island and Point Lookout, North Stradbroke Island (Stephens, 1983) and at Cape Byron (PWD, 1978). At these locations narrow lobes of inner nearshore sand stretch down current to the south for some distance. It was proposed by Stephens that such a lobe may exist south of Fingal Head. Examination of measured currents in the study are (Delft

[1970] and this report) indicates that the southward flowing current flows along a path which passes close by Point Danger and is slightly deflected seaward over the extensive reefs to the east of Fingal Head. These reefs (and Cook Island) create a current shadow in the embayments to the south.

In their study of beach recession on Bogangar Beach (Norries Head to Kingscliff), the PWD (1982) also suggested that the convex upwards features shown on RAN hydrographic charts approximately 2km offshore may represent a lobe of sand which is an active sink.

To test these hypotheses the three lines shown on Figure 26 were sounded to a depth of 50m in February 1986 as part of this study. Bed surface samples were taken at approximately 5m depth intervals. Sampling in the offshore direction was limited by difficulties in communication with the shore based position fixing teams. The location of the samples is shown for each profile on Figure 26. Samples were collected using a bed drag sampler. The analysis of these samples has not been completed at the time of writing. Expert microscopic examination to determine sediment type is under way, but at present only the preliminary assessment which follows has been made of the sediment distribution.

At Norries Head sampling commenced at the 10m depth with fine outer nearshore sand being fawn grey in colour. Similar sand was sampled out to the 25m depth. From this depth out to the 40m contour the samples were an orange brown colour and contained some shell fragments. The grain size was coarser with a D_{50} grain size of 0.22mm on average. At depths greater than 40m, the grain size became finer with a D_{50} of 0.13mm. The colour of the samples was grey - light brown.

At the Cudgeon line the fine fawn grey coloured outer nearshore sand extended from 10m to around 30m depths. A band of orange - brown coarser sand with a D_{50} = 0.2mm then extended to around the 35m depth. Beyond this was the finer grey - light brown sand to a depth of 45m.

At the Kingscliff line the fawn grey sand extended out to the 35m depth and merged with coarser light brown sand.

A summary of the preliminary assessment of the properties of the samples is given in Table 3. Generally speaking changes in sample colour corresponded to changes in mean grain size. The shell content was less than 5% in all samples.

Table 3 - Sediment Properties : Norries Head to Fingal Head

Sample No.	Colour	D_{90} mm	D_{50} mm	Depth m	Shell/Grit %	Fines %	$CaCO_3$ %
Norries							
1	1	0.20	0.13	49	1.27	0.17	
2	1	0.21	0.17	45	0.62	0.04	9.15
3	2	0.32	0.20	40	0.98	0.1	
4	2	0.35	0.22	35	1.23	0.11	
5	2	0.32	0.21	30	0.81	0.07	
6	3	0.21	0.17	25	0.40	0.02	3.59
7	3	0.25	0.17	20	0.27	0.11	
8	3	0.21	0.17	15	0.32	0.06	2.18
Cudgeon							
1	1	0.20	0.15	45	1.84	0.53	10.15
2	1	0.20	0.13	42	1.03	0.01	
3	1	0.21	0.15	39	0.42	0.04	
4	2	0.36	0.23	34	0.83	0.07	
5	2	0.30	0.20	31	0.59	0.02	
6	2	0.35	0.21	30	0.88	0.09	
7							
8	3	0.25	0.17	19	0.58	0.14	
9	3	0.29	0.18	15	0.54	0.14	2.07
10	3	0.27	0.18	11	0.63	0.02	2.91
Kingscliff							
1	2	0.35	0.22	34	1.22	0.03	
2	3	0.25	0.18	31	0.31	0.06	
3	3	0.30	0.18	30.5	0.96	0.04	
4	3	0.23	0.17	24	1.61	0.12	
5	2	0.23	0.16	19.5	1.17	0.06	
6	3	0.23	0.16	15	0.52	0.04	
7	3	0.27	0.17	10	0.77	0.05	

Colour
1 - grey - light brown
2 - orange brown
3 - fawn grey

There are two possible interpretations of the sediment distribution. The broad platform (around 4km wide) of outer nearshore sand to the northern end of the sampling area may represent the finer component of nearshore sand which has been jetted offshore at the Tweed Entrance and been carried to the south by the offshore currents. Deposition has occurred in the 'current shadow' created by the reefs off Cook Island. Secondly, the lobe may represent a relict beach, left over from earlier times when the sea level was much lower and the coastline had a more northerly orientation. The orange-brown sands are typical of the sediments found in similar features elsewhere (Roy and Stephens, 1978). At the time of writing this report, a comprehensive sampling exercise is being undertaken by the Queensland Geological Survey for which results are not yet available.

3.3 Fingal Head to Point Danger

A portion of this area was sampled for the Delft (1970) study of Gold Coast erosion. The grain size distribution is reproduced as Figure 25. Delft does not present an analysis of sediment type in their report. The Delft results have been examined by Stephens (1985) who has attempted to broadly classify sediment type based on grain size distribution. This has been reproduced here as Figure 27, but it is to be stressed that this is very much an intuitive assessment.

The lack of any recent sediment sampling off Letitia Spit and the Tweed Entrance prompted the undertaking of a major sampling exercise together with side scan sonar and seismic profiling. This work was done by the University of Queensland, Department of Geology, and the results have been written up by Lloyd (1985) as an undergraduate thesis. Part 1 of Lloyd's thesis forms a major part of this study and as such has been directly reproduced as Appendix 3. Those chapters which present the results directly related to this study are included. The details of Lloyd's report will now be summarised.

The distribution of sediments from Point Danger to Fingal Head is given on Map 6 (Appendix 3) and is shown here as Figure 28. All samples within the surveyed area consisted of various forms of nearshore sediment.

[The sampling conducted in June 1985 was to depths of 25m. This was extended in February 1986 to 30 - 35m depths. On preliminary analysis, these samples are of the same type as described by Lloyd and do not define the seaward boundary of the outer nearshore sand zone as was hoped for.]

The main features of the sediment distribution can be seen on Figure 28. Near the rocky outcrops off Point Danger and the reefs near Cook Island, the sediments contain a large amount of shell fragments as would be expected. The narrow band of inner nearshore beach sand extends seaward into approximately 10m water depths to the south of the entrance. To the east and north east of the entrance a large lobe of inner nearshore sand extends seaward into 25m depths of water. This lobe corresponds to the ebb-tidal delta and to the ebb jet - offshore current interaction deposition zone for the coarser inner nearshore sediments. The remainder of the surveyed area consists of outer nearshore sands. There is no lobe of inner nearshore sand extending to the south. Comparison can be made between this present day distribution and that interpreted from the Delft study sampling as shown on Figure 27. The seaward extent of the inner nearshore sand lobe is much greater at present than is indicated by the late 1960's sediment distribution.

Side-scan profiling of the area revealed a number of instances of sand ripples of varying wavelengths. Although not conclusive, these may give an indication of sediment transport direction. In June 1985 the side-scan profiling lines were scheduled to retrace those reported by Haydock (1973) and Grimstone (1974) near Point Danger as well as to the south off Letitia Spit. The salient features which were noted are shown as Map 9, Appendix 3 and are reproduced as Figure 29.

The exposure of rock to the north of Point Danger is greater than that reported by Grimstone (1974). The sediments near the rocky outcrops, and those to the south, consist of coarse sand - fine gravel. Sand ripples of 1m wavelength orientated to the north west are evident in these sediments.

Directly off the Tweed Entrance, bedforms with 18m wavelengths are evident. The orientation of these features indicates a possible wave induced shoreward sand movement under the influence of the predominant south-easterly wave climate. Around Point Danger ripples of 3m wavelength were also observed orientated so as to suggest littoral transport with wave diffraction around the headland.

However the presently exposed submarine outcrop off Point Danger indicates that contrary to the Delft (1970) conclusions, the present day nearshore sand bypassing is not yet at the level which existed prior to the construction of the Tweed River training walls.

Other features noted by Lloyd (1985) were the submarine outcrop off Kirra and the planar geometry of the coarse sediments near rocky outcrops.

3.4 Point Danger - Kirra

The offshore sediment distribution in this area in the late 1960's has been inferred by Stephens (1984) from the records reported by Delft (1970) and shown as Figure 27. Although this represents an intuitive interpretation of grain size data, the use of present day sediment classification systems developed by Roy and Stephens (1978) provide a useful reference for comparison.

The main features of the Delft distribution are: the small lobe of what is apparently inner nearshore sand off Rainbow Bay and Greenmount; a broad band of outer nearshore sand to the northwest of Point Danger extending to Bilinga; north of Bilinga, a more typical offshore grading occurs with a narrow inner nearshore band and then outer nearshore sands grading into coarse inner shelf sand and then muddy mid-shelf sands.

Sampling in this area since 1970 has been done exclusively by the GCCC. Initially in the early 1970's and then in recent years, samples have been taken to prove offshore sources of beach replenishment sand. The results of these surveys have been reported elsewhere by Grimstone (1974), Chapman (1978), Lloyd (1985) and Jackson (1985).

Core samples taken by the GCCC off Kirra Beach in 1973 indicated a layer of sand up to 3m thick overlaying hard substrata. This varied from peat to rock to clay. The details of sampling along three survey lines at Kirra are shown on Figure 30. Chapman (1978) has analysed numerous samples in an attempt to statistically classify the sediment characteristics. Chapman also detailed the sediment variation with depth along line ETA20 at Bilinga.

A core sample taken in June 1985 in 17m water depth off North Kirra was analysed by Lloyd (1985). The surface layer represented outer nearshore sand facies. The complete analysis is given in Appendix 3.

Jackson (1985) summarised the recent GCCC sampling in the North Kirra area.

The size, shape and shell grit content was found to vary with distance offshore as did the thickness of the sand layer. Offshore surveys indicate little or no bed changes beyond RL-20m with only minimal movements at RL-15m. Preliminary analysis of the grain size distribution indicates that in 16m and 21m depths the D_{50} grain size is smaller than the beach sand, with large percentages of shell grit increasing seaward of RL-16m.

4. REGIONAL ENVIRONMENT

The proposed second stage of this study will involve the mathematical modelling of coastal processes. To this end the physical environment of the study area, and coastal processes operating are now described. Various aspects of the physical environment have been discussed in detail by other investigators and will only be given a cursory treatment here.

4.1 Geology

The various investigations of the geology of the study area and the Tweed catchment have been summarised by the PWD (1979) as part of the Tweed River Dynamics Study and by Chapman (1978). The sedimentary geological features have been interpreted by the PWD from aerial photography and their results are reproduced here as Figure 31. In addition, Chapman (1978) has described the offshore bedforms based on his own work and that of others referred to in his report.

Of particular relevance to this study is the thickness of the offshore sand layer thickness above the underlying bedrock. This has been discussed earlier in relation to the possible bypassing mechanism at Point Danger.

4.2 Offshore Currents

The presence of a persistent southward flowing current along the length of the Gold Coast has been observed by local residents and been reported in the various studies of the region.

It is now taken that this current is a flow induced by the presence of the East Australian Current (EAC). The EAC is known to flow with varying intensity to the south along the coastline from north of Brisbane to a point near Newcastle where it breaks down into a series of large eddies off the southern NSW coast. The eddy features in the southern ocean have been studied by the CSIRO at length in recent years. In the study area the current is less well documented and the important data previously obtained will now be considered.

A major study was conducted by the CSIRO and reported by Greig (1974).

This involved the collection and analysis of the logs of shipping travelling along the coastline over a two year period. The presence of the current is known by ships' captains and is used to advantage. As the current varies in intensity with distance offshore, the majority of ships travelling to the south steam around 15 nautical miles offshore at Fingal Head. Ships travelling to the north steam only 5 miles offshore, taking advantage of the lesser magnitude of the current further inshore. The results of Greig's study are shown on Figure 32. Along-coast currents for north bound ships were found to vary up to 2m/s.

On RAN charts of 1954 and 1975 currents of 1m/s in 55m water depths are marked near the study area.

The Admiralty of Great Britain (PWD, 1978) have prepared average three monthly direction velocity and percentage occurrence of the current and these are presented on Figure 33.

The currents measured inshore at the study area are considered to be induced by the EAC. Delft (1970) made a number of measurements of both surface and sub-surface currents up to a distance of 4kms offshore. This data shows a predominantly southerly current with velocities of up to 0.5m/s. Measurements were taken of both surface currents using drift cards and surface drogues, and of vertical velocity profiles using `Planeta' Pendulum current meters. The vertical profiles revealed no noticeable trend and were approximated by a constant velocity from just below the surface to just above the bed. Delft (1970) concluded that - "the facts found may well fit the hypothesis that the currents are induced by the EAC, being in fact part of the general current but diminishing in value as the coast is approached in the case of down coast currents. In the case when up coast currents are observed, these may be due to eddies from the EAC."

Selected results from the Delft Report are presented here for the study area. The sub surface currents were measured using vaned float poles at sites 1, 6 and 8 and the results are given as Table 4. The surface currents were measured by releasing drift cards at sites 1 and 6 and the results are reproduced as Table 5. Site 1 was located approximately 1km offshore at Tugun in 5m water depth; Site 6 was 1km NNE of Point Danger in 25m water depth and Site 8 was 3km due north of Point Danger in 40m depth.

Probability analysis of the average up and down coast velocity measurements by Delft indicated that currents capable of transporting sand by their own strength occurred 8% of the time.

Similar current measurements were made at Cape Byron as part of the Byron Bay Erosion Study (PWD, 1978). South flowing currents of 0.6m/s were measured.

4.2.1 Offshore Current Measurements - This Study

Current measurements using drogues were carried out in May 1985 and February 1986 to qualify the interaction between ebb jet currents and the offshore currents. The significance of this interaction was suggested at by a review of the aerial photographs held by the PWD in Sydney and the GCCC. Photographs taken prior to the construction of the training walls in 1962-1964 generally showed an ebb jet development to the north or northeast of the old entrance. Since 1964, the photographs indicated a predominance for the ebb jet to spread to the east and southeast. A hypothesis was made, that this change was caused by the training of the ebb-tidal flow resulting in an ebb jet-like discharge into deeper water where it would be influenced by the south flowing offshore current to a greater extent than before.

The offshore current data obtained in May 1985 is shown on Figures 34 to 38 for the various releases. A summary of the wind, wave, tide level and ebb discharge conditions during the exercise is given on Figure 39.

The drogues used in this study consisted of a vane made of aluminium suspended by rope below a surface float. The vane was 580 mm long and was in the shape of a cross with a distance of 580 mm across. The surface float was a plastic bottle 330 mm long and 100 mm diameter. Attached to the float was a coloured marker made of 50mm square plastic mesh rolled into a cylinder. The top of the float sat at water level and the mesh marker presented a minimal area to the wind. The vane was attached at different depths below the surface depending on the available water depth at the measurement area. These attachment depths are shown as 10m, 5m, etc on Figures 34 to 38. Drogues with the vanes attached directly to the float are marked as SURFACE. Offshore releases during both phases of the tide

TABLE 4: RESULTS OF SUB-SURFACE CURRENTS MEASUREMENTS

(DELFT, 1970)

Date	Average Velocity (ft/min.)			Net Current		Ratio	Remarks
	Longshore x)	On/Offshore xx)	Net	Angle to Coast xxx)	True Bearing	Av. longsh. Vel. / Av. Net Vel.	xxxx)
Sites 1 + 1A							
25 April 1967	-14.4	-0.8	14.5	3°	137°	0.99	
26 April 1967	+ 4.5	0	4.5	0	320°	1.00	
17 Aug. 1966	+11.3	-0.9	11.4	4°	324½°	0.99	
27 Mar. 1968	+27.5	+2.8	27.6	5°	314½°	0.99	
4 July 1967	-12.7	-4.5	13.4	19½°	120½°	0.95	
5 July 1967	+17.5	+4.8	18.3	15½°	304½°	0.96	
Site 6							
29 Aug. 1967	-51.8	- 3.8	51.8	4°	116°	1.00	
30 Aug. 1967	-80.0	+30.6	85.6	21°	141°	0.93	
27 Mar. 1968	- 4.0	+19.2	19.5	78½°	198½°	0.21	
Site 8							
15 July 1969	-47.1	+15.4	49.6	18°	138°	0.95	
16 July 1969	-39.5	+12.3	41.3	17½°	137½°	0.96	
22 July 1969	-41.7	+17.1	45.0	22½°	142½°	0.93	
23 July 1969	-31.8	+20.1	37.6	32½°	152½°	0.85	
2 Sep. 1969	-72.2	+ 6.0	72.5	5°	125°	1.00	
3 Sep. 1969	-99.0	+22.3	101.4	12°	132½°	0.98	

x) + is upcoast direction.
- is downcoast direction.

xx) + is onshore direction.
- is offshore direction.

xxx) "Angle to Coast" given is the Angle < 90° from upcoast or downcoast direction as appropriate.

xxxx) O is outflow tide.
I is inflow tide.

TABLE 5: RESULTS OF DRIFT CARD MEASUREMENTS (DELFT, 1970)

Site : 1 No. of Releases : 9 No. of Results : 9 + 1[F]

Release day				Av. Travel		Surface Vel.		Av. Sub-Surf. Vel.		Note
		Wind								
Date	Time hrs.	Speed m.p.h.	Dir^n (from)	Distance miles	Dir^n	Max. (feet per min.)	Mean (feet per min.)	Vel. ft/min	Dir^n	
17 Aug. 66	0915	6-8	S	3.3	310°	46.5	12.0	11.34	324°	
17 Aug. 66	1600	6-8	S	1.75	305°	7.2	6.2	11.34	324°	
25 Apr. 67	0830	10-15	NW-N	1.45	157°	28.4	22.2	14.45	137°	
25 Apr. 67	1500	10-15	NW-N	1.15	169°	67.5	59.5	14.45	137°	
4 July 67	0815	0-5	variable	176.0	355°	37.4	28.8	13.5	120½°	
4 July 67	1130	0-5	variable	176.0	355°	37.4	28.8	13.5	120½°	
4 July 67	1445	0-5	variable	176.0	355°	37.4	28.8	13.5	120½°	
27 Mar. 68	0730	6-10	SSE-SE	18.0	344°	19.4	16.8	27.7	314°	67% *
27 Mar. 68	0730	6-10	SSE-SE	5.0	318°	47.5	30.7	27.7	314°	33% *
27 Mar. 68	1400	6-10	SSE-SE	16.8	342°	29.8	18.8	27.7	314°	

* 67% of cards found travelled in av. dir^n 344°, and 33% in av. dir^n 318°

F. This means that on 9 experiments cards were recovered, but 1 experiment gave two "separate" results-see .

Site : 6 No. of Releases : 4 No. of Results : 3[L] + 4

Release Day				Av. Travel		Surface Vel.		Av. Sub-Surf. Vel.		
		Wind								
Date	Time hrs.	Speed m.p.h.	Dir^n (from)	Distance miles	Dir^n	Max. (feet per min.)	Mean (feet per min.)	Vel. ft/min	Dir^n	Note
29 Aug. 67	1430	6	SSW-SE-N	3.0	152°	5.5	-	51.8	116°	
27 Mar. 68	0730	6	SW-E	2.2	172°	20.8	-	19.5	198°	
27 Mar. 68	1400	6	SW-E	4.0	290°	4.0	3.8	19.5	198°	15%
27 Mar. 68	1400	6	SW-E	14.0	327°	16.2	14.6	19.5	198°	15%
27 Mar. 68	1400	6	SW-E	37.0	350°	12.3	9.7	19.5	198°	38%
27 Mar. 68	1400	6	SW-E	16.0	160°	17.5	9.7	19.5	198°	23%
27 Mar. 68	1400	6	SW-E	38.0	160°	20.6	9.7	19.5	198°	8%

L: No cards found from one release.

were made on 8th, 9th, 15th and 16th May 1985. These indicated a current flowing in a southerly direction. The measured speed averaged 0.5m/s but was variable.

Of particular interest were the paths of drogues released near Cook Island (see Figure 40). Releases to the southeast of Cook Island were seen to be deflected around the island to the east and to speed up over the reefs in that area. Releases to the north west of Cook Island moved to the south between the island and Fingal Head. Currents measured with 5m and 10m drogues released at the same location were of similar magnitude. The wave conditions, and wind speed and direction were recorded during each exercise and have been tabulated on Figure 39. Current direction on the days listed above was in opposition to the predominant wind and wave direction.

Offshore drogue releases on 10th May 1985 at similar locations to those just discussed gave current direction to the north at speeds of around 0.1 m/s. Currents measured on 9th and 15th were to the south. This reversal is consistent with the hypothesis that the offshore current is induced by the EAC which meanders perpendicular to the shore thereby causing a fluctuation in the magnitude of the current and also an occasional current reversal as an eddy forms. It would seem reasonable that direction reversal due to this mechanism would be less frequent at a prominent point on the coastline such as Point Danger or Cape Byron.

Drogue releases were again made on 26th February 1986 in the southern end of the study area. These releases are plotted as Figure 40. These measurements were part of the sediment sampling exercise carried out to the south of Fingal Head discussed earlier.

The current direction on this occasion was to the south east with speeds of 0.75m/s recorded near Cook Island. Of particular interest in Figure 40 is the presence of a large eddy in the Kingscliff embayment which appears to have been triggered by the current `shadow' effect of the line of reefs to the east of Cook Island. The separation zone between the main stream of the offshore current and the eddy was very distinct with a foam line being visible and with the sea state being very choppy in the current and calm in the eddy. The current reversal inshore was measured around 1km from the beach and is not considered to be part of the littoral drift current.

Drogues released between Cook Island and Fingal Head moved to the south.

This current shadow effect is considered to be a possible explanation for the deposition of nearshore sands to the south of Cook Island. It is also hypothesised that the presence of a southerly flowing current between Cook Island and Fingal Head during times of strong SE swell and wind conditions (and hence strong littoral transport conditions) must influence the littoral bypassing processes at Fingal Head. The presence of the extended Tweed training walls is not considered to influence the path of the offshore current and hence the bypassing mechanism at Fingal Head is in a state of dynamic equilibrium and is unaffected by the changes at the Tweed Entrance.

4.2.2 Tweed Ebb Jet - Offshore Current Interaction

During the May 1985 field exercise the behaviour of the ebb jet in the nearshore region was controlled by the ebb delta formation. Prior to and during this exercise the predominant wave activity was from the south east with observed wave heights of the order of 1m to 2m. As a result an offshore storm bar had formed. Under these conditions there was a strong littoral supply from the south. The presence of the offshore bar welded to the ebb delta provided ideal conditions for transport of sand to the north around the delta to be deposited as an extension of the ebb delta off Duranbah Beach. Consequently the extension of the delta to the north provides a path for littoral sand to bypass Point Danger. The bar formation at 9th May 1985 is shown on Figure 41. The aerial photograph shown as Figure 42 was taken on 6th May and clearly shows the features discussed here.

With reference to Figures 41 and 42, a number of features can be seen. Firstly, the ebb discharge (clearly defined due to the suspended fine sediment load carried downstream by the moderate freshwater flow at that time) is being deflected to the north at the end of the training walls by a shoal just inside the entrance formed by the magnitude of sand drifting around the end of the southern wall being greater than the transport capacity of the ebb flow to clear it.

Drogue tracking (Figures 34-38) showed that at the commencement of the ebb, flow would be contained within the gutter formed by the extension of the ebb delta to the north.

Figure 42 shows that sand was bypassing Point Danger at that time as evidenced by the build up of a shoal off Rainbow Bay. Although the ebb jet was initially deflected to the north under strong littoral transport conditions, the overall development of an ebb jet under the conditions existing in May 1985 was more complex.

Generally, an ebb spring tide discharge commenced with a weak flow to the north along the gutter formed off Duranbah Beach. As the flow rate increased the ebb developed to the north east. The flow was strong enough not to be influenced by the littoral drift current, but still be deflected to the north by the shoal at the end of the southern wall. The flow constriction created by this shoal resulted in ebb exit velocities of the order of 2.5 m/s. At the ebb flow peak, discharge was generally to the ESE being deflected to the south in deeper water by the offshore current.

As the water level fell, the influence of the ebb delta and littoral currents became more pronounced, and towards the end of the ebb phase the jet was discharging again along the gutter to the north.

The drogue tracking was complimented by stream gauging in the entrance. The measured discharge has been shown where revelant on Figure 39.

Ebb discharges for neap tides were generally confined completely to the channel to the north, having insufficient strength to counter the littoral currents. However, such discharges were still influenced by the offshore current which was measured close in to shore during May 1985. The interaction between the north flowing ebb and the south flowing offshore current resulted in the formation of eddies being shed in the shear zone. The eddies are advected with the current out to sea and are dispersed. The presence of these is shown on Figure 38 for drogue tracking on 16.5.85 and have been recorded photographically on many occasions both at Point Danger and at other locations and are prominently shown on the photograph shown as Figure 43 taken on 19th July 1963 during the period of construction of the training walls. The photograph was taken on the ebb tide and the suspended sediment laden eddies are clearly visible. Similar features at Cape Byron are caused by the interaction between the northerly littoral current and the southerly offshore current. Such features are the subject of research at present and will be considered in Stage 2 of the study as part of the overall offshore transport mechanism.

Larger scale eddies are also formed by the separation of the ebb discharge at the end of the training walls. Under ideal conditions with no longshore currents, Tomlinson (1985) has predicted that a pair of counter rotating eddies will form at the front of the jet and migrate seaward away from the entrance. Under the influence of a strong longshore current, only one will form on the downcurrent side of the entrance. This is shown on the photograph presented as Figure 42 and taken at the commencement of the ebb phase. The drogue tracking indicated that although the updrift eddy was suppressed initially a large circulation eventually formed due to the deflection of the ebb jet by the south flowing offshore current. Tomlinson has shown experimentally that under such conditions, this large eddy is maintained by the ebb discharge and will move away along-shore under the influence of the offshore current even during the flood tide. At the Tweed Entrance this movement to the south would be limited by the presence of the reef structures off Cook Island.

Current measurements taken in February 1986 were under different conditions. The ebb-tidal delta had a shape more consistent with tidal flow domination and reduced littoral supply. The drogue tracks are shown as Figure 44 for measurements on 26th February 1986. On this day, the offshore current was measured near Cook Island at between 0.6m/s and 0.8m/s as has been discussed earlier.

Weaker littoral drift currents to the north result in the ebb discharging directly to the east of the entrance, then deflecting to the south under the influence of the offshore current. During this exercise, surface drogues were released at the end of the training walls at three locations across the entrance. Drogues were tracked through the wave-break on the bar and then retrieved and the exercise repeated at the next location. Drogues at 2.0m depths were then released outside the wave-break directly offshore from the initial release locations. In this way a composite picture of the current development in the early stages of the ebb tide was developed.

4.3 Tweed River Dynamics

A major study of the behaviour of the lower reaches of the Tweed was carried out by the PWD (1979). This was in response to the changes reported following the dredging of 765 000 m^3 of sand from an area shown on Figure 15 for beach replenishment by the GCCC in 1975-1975. This report has been a valuable source of data for this study and the major relevant finding will now be outlined.

4.3.1 Impact of Dredging

Whilst the estuary behavioural changes due to the extensive dredging commenced in the middle 1960's went undetected, the magnitude of the 1974-1975 dredging was such that its estuarine impact was immediately apparent. It caused: a 15% increase in tidal range, a reduction in tidal lags by 30 minutes, a reduction of low water by 300mm in the Boyd's Bay area, an increase in peak tidal discharge, a pronounced increase of sediment movement downstream towards the dredged area and a pronounced increase of sediment movement upstream onto the tidal delta of the Terranora Broadwater.

The estuary is extremely sensitive to dredging in the immediate vicinity of the entrance. The Terranora arm is more responsive to major dredging than the main arm of the Tweed River. Hence the proliferation of changes observed in the Terranora arm after the 1974-1975 dredging. There is negligible hydraulic transference between the main arm and the Terranora arm associated with any dredging upstream of the confluence.

4.3.2 Estuarine Shoal Dynamics

The lower Tweed estuary has a strong propensity towards the establishment of a unique and predictable pattern of tidal shoals. This shoal regime was attained approximately 30 years after the initial river training at the turn of the century. Major dredging activity, and to a lesser extent, floods, retard the establishment of a regime. In order to achieve a tidal regime there must be a slight nett sediment movement upstream throughout both arms of the estuary. The orientation of bedforms was found to reverse at locations in both the Tweed River and Terranora Inlet. Seaward of each point, the nett sediment movement was downstream. The 1974-1975 dredging brought about an upstream shift in the location of these reversal points of up to 500m. The existence of these points is symptomatic of non-regime conditions.

The natural recovery of the 1974-1975 dredged area is dominated by sand supplied from the ocean with infeed during 1977-1978 being 93 000 m^3/year. Sand supply from upstream areas during 1977-1978 was 5 000 m^3 from the main arm and 3 000 m^3 from the Terranora arm.

4.3.3 Estuary Hydraulics and Sediment Transport

The main arm and the Terranora arm represent distinctly different estuary types. The two broadwaters at the end of the Terranora arm function as tidal nodes exaggerating tidal gradients. The inlet cannot attain a shoal regime whilst the lakes remain as a tidal control, thus the broadwaters will continue to shoal. A state of balance between tidal and fluvial regimes has been attained in the main river arm downstream of Barney's Point Bridge. This reach consequently demonstrates a strong resilience to external disturbance.

The tidal flow is fully mixed within Terranora Inlet and varies from mixed to transiently stratified in the main arm. In general, the ebb velocities exhibit pronounced surface exaggeration, whilst the flood velocity tends to be uniform with depth. Sediment transport was found to vary with spring tides transporting up to five times more sediment than neap tides. It was found that since peak velocities and maximum hydraulic gradients generally occur simultaneously in tidal situations, the sediment transport for a half tidal cycle can be well represented by a triangular distribution.

4.3.4 Ebb Delta Dynamics

The development of a tidal shoal regime is associated with the deterioration of the ebb delta to a configuration which is conducive to maximum littoral bypassing. Large scale dredging within the lower estuary increases sand feed through the entrance, and retards delta build up. Thus use of sand dredged near the entrance as beach nourishment does not supply any new sand to the littoral system. The proportion by which the prevailing littoral bypassing is reduced is unknown. The delta will continue to shoal at an accelerating rate.

4.4 Stream Gauging - 1985

As part of this study full-cycle stream gaugings were carried out near the entrance. The location of the gauging stations is shown on Figure 10 and the details of the river cross-section at this location are shown on Figure 45.

The gaugings were done primarily to establish head loss characteristics for flow across the ebb-tidal delta. Use was to be made of ocean tide records from a tide recorder at Snapper Rocks operated by the Queensland Department of Harbours and Marine, however, this instrument malfunctioned during the period of the exercise due to the covering of the sensor with sand. Ocean tide records can be obtained from an offshore recorder at Fingal Head operated by PWD, however, the datum for these has not yet been established. Head loss analysis has consequently not been done.

Tide records have been obtained for the Tweed Regional Tide Recorder operated by the PWD and those for the May 1985 field exercise have been obtained. The location of this recorder is shown on Figure 10.

The results of stream gauging done on the 13th and 20th May 1985 are shown on Figures 46 and 47. Flow was confined to the north part of the channel due to the shoals which formed on the inside of the bend. The results of these gaugings are summarised in Table 6 below. Limited gaugings were done in conjunction with drogue tracking and the results of these are given elsewhere. Comparison with PWD (1979) data is difficult as the Regional Recorder was not in operation during the PWD March 1977 stream gauging exercise.

4.5 Salinity Structure

As part of the entrance stream gauging exercises, the salinity structure was measured over the full tidal cycle. The salinity structure at the mid channel gauging station is presented diagramatically on Figures 48 and 49 for the two gauging dates. A similar structure is evident on both days. During the weeks preceding these gaugings, there had been moderate rainfall

Table 6 - Tweed Entrance Stream Gauging Results

Parameter	Full Cycle Gaugings 13.5.85	20.5.85	Partial Cycle Gaugings 10.5.85	15.5.85
R_f	0.55	1.28	0.46	0.77
R_e	0.37	0.83	0.39	0.87
Q_f	428.00	1 020.00	-	-
Q_e	420.00	638.00	-	730.00
V_{sf}	0.90	1.80	-	-
V_{se}	0.90	1.28	-	1.35
V_{bf}	0.70	1.50	-	-
V_{be}	0.80	1.05	-	1.35
Slack H	95.00	95.00	100.00	100.00
Slack L	120.00	115.00	-	-
P_f	5.933	16.339	-	-
P_e	5.153	9.248	-	-

LEGEND

R_f - Tide range (m) for gauged flood tide - Tweed Regional Recorder.

R_e - Tide range (m) for gauged ebb tide - Tweed Regional Recorder.

Q_f - Peak discharge (m^3/s) flood tide.

Q_e - Peak discharge (m^3/s) ebb tide.

V_{se}, V_{sf} - Peak surface velocity (m/s) ebb, flood.

V_{be}, V_{bf} - Peak bottom velocity (m/s) ebb, flood.

Slack H/L - Delay from High/Low water to slack water, min.

P_f - Flood flow tidal prism, million m^3.

P_e - Ebb flow tidal prism, milliion m^3.

in the catchment and although the peak freshwater discharge had occurred earlier, there was still a significant freshwater component to the flow. At the time of writing the discharge records for the Tweed catchment were not available.

At high water the water column is completely saline. As the water level falls the salt water mixes uniformly with the freshwater, until at low water, the water column is well mixed with recorded salinity of 26 to 28 parts per thousand (ppt). At the commencement of the flood tide salt water intrudes on the bottom with a continued brackish flow on the surface. Apparently this stratification is very unstable and rapid mixing occurs and the salinity uniformily increases to ocean salinities.

4.5.1 Offshore Salinities

As part of the drogue tracking exercises during May 1985 the salinity in the ebb jet was measured. On 15th May salinity profiles were taken inside the north flowing jet at two locations shown on Figure 37 at the end of the ebb phase. The measured salinities indicated that the ebb discharge is a surface flow with ocean salinities of around 34 ppt recorded in 5m depths at 500m from the entrance and in 3m depths at 1.5km from the entrance.

Measurements taken on 16th May in the entrance during the ebb flow indicated a uniform salinity of 26 ppt. The ebb jet was discharging to the north past Point Danger and the salinity in the jet measured off Point Danger was 32 ppt and off Snapper Rocks, 34 ppt. Ocean salinities were generally 34-35 ppt.

4.6 Tweed River Hydrology

The available evidence suggests that high freshwater runoff from the Tweed catchment will result in erosion of the estuary entrance shoals and the ebb-tidal delta (PWD (1979) and this study).

Daily flow records have been obtained from the NSW Water Resources Commission for the following gauging stations.

No.	Station	A (km^2)	Record (Years)
201002-5	Rous R. at Boat Harbour 1,2	117	32
201001	Oxley R. at Eungella	213	37
201003	Tweed R. at Braeside	298	16

Annual flood series were extracted from the record and flood frequency curves plotted. These have been tabulated and are presented in Appendix 4. The occurrence of major recorded flood events is shown on Figure 50. WRC records have been used elsewhere in this report in relation to the erosion of the entrance shoals and ebb delta.

4.7 Wave Climate

The sources of wave data in the study area prior to 1968 were visual shipboard observations or lighthouse observations. In 1968 the Queensland Department of Harbours and Marine installed a wave measuring and recording system. This Datawell waverider was in operation providing digital records more or less continuously from 1968 to 1971. These records have been analysed by McGrath and Patterson (1973). Analogue records are available for 1974 and these have been analysed by Chapman (1978). Chapman also obtained digital records in 1975.

Since October 1976, digital records have been available from a wave rider installation off Point Lookout at the northern tip of North Stradbroke Island. These records have been analysed and the results published by the BPA (1985).

4.8 Storm Surge

The occurrence of elevated ocean levels on the northern N.S.W. coastline has been examined by the PWD (1985, 1986). The results of these studies has shown that the surge component for cyclones and other severe storms is significantly lower than the potential component due to breaking wave set-up. Storm surge has been specifically examined in the Tweed Estuary for a storm in April 1984 (Higgs and Cox, 1985). The major contribution to the increased water levels in the lower Tweed during this storm was wave set-up resulting from waves breaking across the entrance channel.

5. DATA ASSESSMENT

At this stage of the project the available data are being assessed in relation to their usefulness in developing mathematical models for various aspects of the coastal processes operating in the study area.

A consequence of the assessment of available data is the recognition of areas where data coverage is inadequate or missing completely. This will now be discussed as well as the proposed data acquisition programs which have been implemented or need to be implemented in the future.

5.1 Implemented Data Acquisition Programs

Shore normal beach surveys have been conducted in the area since 1962. However an hiatus in the late 1970's and early 1980's has resulted in much of the collected data being of limited value. This is particularly valid when considering the re-establishment of the ebb-tidal delta and bypassing of Point Danger. It is fortunate, and of significance, that during that period there were no major erosional events.

The established survey lines do not cover all of the coastline. In particular, a section from ETA13 to Greenmount Hill has very poor coverage. The OMEGA lines radiating from Point Danger have been surveyed only twice and a line at Rainbow Bay established by the GCCC has not been surveyed since 1974.

In order to provide a complete coverage of the study area in the future, a program of regular (if possible, 3 monthly) surveys of the following lines has been commenced: ETA 4,6,8,10,11,11A,12,13,20,22,24,26,28 (see Figure 2); PWD Ebb Delta Survey lines (see Figure 10); and extra GCCC lines which are marked on Figure 51. The Point Danger to Rainbow Bay area has been singled out for extra coverage considering the significance placed on this area in terms of Point Danger bypassing.

The survey work to be undertaken by the GCCC as part of this study is planned to compliment survey work by the PWD and the DHM. Consequently, the more these state government authorities can contribute to the survey program, the greater will be the survey coverage.

Wave data is continually being obtained by the DHM at the Point Lookout wave recorder. However wave direction data and local sea conditions are also required and the BPA's COPE program is in operation at beaches at the southern end of the Gold Coast.

The general condition of the beaches in the study area is being monitored by regular oblique aerial photography as well as occasional vertical photography.

Tide levels are being continuously recorded (except during periods of instrument malfunction) by the PWD inside the Tweed Entrance and offshore at Fingal Head. The DHM also records tide level at Snapper Rocks. These records are available as required.

Meteorological data is recorded within the study area at Coolangatta Airport.

5.2 Proposed Monitoring Programs

In addition to improving the survey coverage, it is proposed to implement a more comprehensive current monitoring program, thereby gaining a better understanding of current interactions and hence the sediment transport capacity of these currents.

A qualitative understanding of the interaction between the ebb jet and the offshore current can be obtained by visual observation on a daily basis, however it is proposed to automatically record this by installing a video camera at the top of the Captain Cook Memorial Light on Point Danger. The camera would be programmed to record the scene looking across the entrance out to sea every three hours for a minute or so. This would record:- the sea state (and with suitable reference marks, the wave direction); Duranbah Beach and Letitia Spit beach conditions and the development of the ebb discharge. In particular, the presence and magnitude of the offshore current can be assessed by the deflection of the ebb jet. With regular maintenance by GCCC staff, it is proposed to monitor the entrance for six months or more.

Quantitative current measurement is also proposed using a bottom mounted electromagnetic current meter installed at various locations. The data obtained could be used for various aspects of the mathematical model calibration including: assessment of wave direction, sediment carrying capacity of offshore current, offshore development of ebb jet velocity profiles, and the assessment of the significance of nearshore current features such as eddies.

5.3 Assessment of Bypassing Processes Prior to 1962

The following is an assessment of the sediment transport processes which were operating prior to the construction of the Tweed River entrance training walls in 1962-1964.

The PWD (1979) have presented a history of ebb delta and river entrance shoal evolution since 1873, based on examination of old aerial photographs and early hydrographic surveys. This has shown that the delta and shoal system reached a regime state approximately every 30 years. Regime was achieved when the entrance was in a state of dynamic equilibrium, with the ebb and flood tidal forcing being in balance. Under these conditions the entrance was choked with sand and there was an extensive ebb delta. The bypassing rate at the entrance was at a maximum due to there being negligible loss into the river system. Bypassing occured across the ebb delta which extended to the north near Point Danger. Sand transported across the delta was then bypassed around Point Danger by littoral transport processes. This maximum bypassing condition is shown schematically on Figure 52(a).

Major flood events scoured the lower reaches and the ebb delta. The ebb channel broke through the bar to the east and suspended sediments were carried much further out to sea, presumably to be lost in an offshore sink, Figure 52(b). The scouring of a new channel isolated the portion of the ebb delta to the north.

Recovery from major scour events involved both the establishment of the entrance regime and the bypassing path to the north. A portion of the littoral transport from the south was then taken up by the infeed into the river system. The ebb channel would then gradually migrate to the north under the delta building influence of the littoral supply, Figure 52(c).

During this period of delta build up the slug of sand isolated to the north by the ebb channel relocation could bypass Point Danger under the influence of the predominant wave climate. Littoral transport along the coastline to the north-west of Point Danger is maintained during the interruption of full Tweed Entrance bypassing by the store of sand which was evident off Rainbow Bay and Greenmount beaches prior to 1962. These shoals would initially be depleted, but would be resupplied by the slug of isolated delta sand. The cycle of re-establishment of maximum bypassing conditions following a major scour event has been estimated to be around 30 years (PWD, 1979).

As has been discussed in Section 1 of this report, this type of inlet bypassing mechanism is typical of naturally occurring tidal inlets on high littoral drift coastlines (Per Bruun, 1978). The indications are that the Tweed Entrance/Point Danger system was fully bypassing in 1962. The photograph presented as Figure 23 was taken in August 1962 just prior to the commencement of construction of the training walls. This photograph clearly shows offshore shoaling at the Tweed and to the north west of Point Danger.

The maximum bypassing condition at the Tweed Entrance is perhaps better represented by the photograph taken in September 1959 shown as Figure 53. This photograph shows the extension of the ebb delta to the north and indeed around Point Danger. Presumably under this condition the ebb jet will discharge to the north throughout the ebb cycle, further enhancing the wave induced bypassing of the entrance. This enhancement of wave dominated processes by tidally induced flow seems to characterise the maximum bypassing condition.

5.4 Assessment of Bypassing Processes After 1962

The construction of the extension to the entrance training walls in 1962-1964 has dramatically altered the hydrodynamic and sedimentary processes acting in the area.

To the south of the entrance the immediate influence was the build-up of an accretion fillet. Reports during the two years of construction indicated that the beach build-up kept pace with the construction progress. At various times build-up was faster and sand began to infill the entrance. Once the southern wall was completed the nett littoral drift was effectively blocked as it extended to a water depth seaward of the existing zone of littoral transport. Initial build up was followed by an extended period of accretion below mean sea level until the beach alignment readjusted along the length of Letitia Spit.

The last of the regular surveys following the construction was in 1971 and no more were done until 1985. The main feature of the build up between those dates has been that little change has occurred below mean sea level, with the majority of the surveyed accretion taking place in the back beach area with the formation of dunes. This would imply that the beach alignment has reached some kind of equilibrium. Overall accretion in the surf zone can be expected to continue, however, until the ebb delta has reached its equilibrium size. This accretion results from the groyne effect of the delta.

The change in beach alignment would result in a change in the littoral transport potential. A reduction in nett littoral transport would be expected, as the alignment becomes more in line with the predominant wave front direction. Recent theoretical calculations of Letitia Spit littoral transport potential have also indicated this trend (Patterson and Pattearson, 1983).

The blocking of the littoral drift resulted in a safe navigable entrance for many years. It has been suggested earlier that the river shoals were in a regime around the early 1960's. The unblocking of the entrance by the construction of the walls initially caused a change in sediment transport directions within the entrance. However, as the supply of littoral sand was blocked and so the river was in a near-regime state, the entrance was relatively stable during the first five years after construction.

By May 1967 however, it appears that the entrance was again being supplied with sand from the beaches. This was balanced however by the commencement of dredging activities in the lower reaches around this time. With continued dredging throughout the 1970's there was an overall reduction in the entrance shoals despite the observed infilling from the ocean.

During the late 1960's and early 1970's the ebb delta was continuing to grow despite there being little evidence to suggest that there was any significant bypassing across the delta. It has been estimated by the WRL (1983) that 75-80% of the littoral transport potential was bypassing the southern wall. Although more recent analysis suggests that this figure may be an overestimate, it still represents a large quantity of sand which was being trapped by the tidal flow induced transport mechanisms.

Delta growth was minimal up to 1974 as can be seen from the ETA 10,11 and 12 line profile data obtained from the BPA, Figure 54. It is also considered that in the mid 1970's the majority of sand transport past the southern wall was lost inside the Tweed Entrance in response to the 1974-1975 dredging.

Ebb delta growth has been significant during the late 1970's and early 1980's. Sand build up sufficient to deflect the ebb to the north east was observed as early as April 1977. The growth of the delta and hence the bypassing rate to the north is expected to increase with the decreasing requirements of entrance infilling. The PWD (1979) predict that the infilling of the lower reaches from the ocean will reduce to around 31 000 m^3/year by 1992.

Averaged over approximately the last ten years, the measured losses of sand to the sinks associated with the Tweed Entrance (i.e. infilling of lower reaches, formation of ebb delta and continued accretion of Letitia Spit) account for around 232 000 m^3/year. This suggests that at present about 55% of the littoral drift potential of 500 000 m^3/year is bypassing the Tweed Entrance and/or is being lost offshore.

Foster (1984) has suggested that an indication of Point Danger bypassing is the formation of the shoals in the lee of Snapper Rocks and Greenmount Hill. These features are in evidence in early photographs and were still present to a lesser extent in the photograph taken on 21st May 1967, shown as Figure 55. Although four years had elapsed since commencement of construction and hence blocking of supply from the south, the existence of the shoals at this time is probably due to the store of original ebb delta sand isolated from the Tweed tidal flow by the construction of the walls. This store was maintaining the supply of sand around Point Danger. Assuming that the transport potential along this section of coastline immediately to the west of Point Danger is of the order of 200 000 m^3/year, then a store of sand to the north of the entrance would only need to be of the order of $1 \times 10^6 m^3$ to maintain the Snapper Rocks and Greenmount shoals until 1967. Once this store was depleted, however, the shoals quickly disappeared and the severe erosion problem along the lower Gold Coast became evident.

Observations made during 1985 and early 1986 suggest that the shoal formations are being re-established (see Figure 42). It is considered however that pre-1962 transport rates will not be re-established until the pre-1962 offshore bathymetry between Point Danger and Kirra Point has re-established. The existing bathymetry and the presence of the two groynes at Kirra result in a modified wave pattern to that typical of pre-construction conditions. It is considered that this may significantly change the shoal rebuilding process. However, evidence of sand waves given by Haydock (1973), Grimstone (1974) and Lloyd (1985) suggests wave induced sand movement around Point Danger.

Survey and photographic evidence suggests that Point Danger bypassing is occurring in a slug fashion. Such a condition was evident during May 1985 following an extended period of south east swell as is shown on Figure 42.

The offshore loss of sand at the Tweed Entrance has been suggested by previous investigations. Delft (1970) proposed a sink of sand to the north west of Point Danger in order to explain the nett littoral transport differential. The BPA (1981) has refuted this by showing that flattening of the bed profiles here does not represent the store of beach sand required but is a thin layer of sand overlaying peat and gravel. Gordon (1982) and Stephens (1984) have suggested that the influence of the East Australian Current is such that sediments discharged at the Tweed Entrance and at Point Danger will be carried to the south.

The data obtained in this study to date has supported the view that sediments can be lost to the south and that a sink of sand to the north west is part of the overall bypassing mechanism at Point Danger. However, the first of these losses is nearly impossible to quantify, although qualitative evidence can been obtained. The second loss can be quantified, however insufficient data is available at present to do so.

The post-entrance construction sediment budget for the study area is summarised schematically on Figure 56. Firstly, the initial period after 1962 before large scale dredging commenced in the late 1960's is shown. Secondly, the situation at present is shown based on the available data, and thirdly the situation which can be expected in the future is given.

By training the entrance, the ebb jet now has a changed hydrodynamic character and will discharge generally to the east as a stronger jet with greater sediment carrying capacity. Thus the entrance bypassing mechanisms will be different from those at the untrained entrance and consequently the supply rate of sand to the Lower Gold Coast will also be changed.

6. REFERENCES

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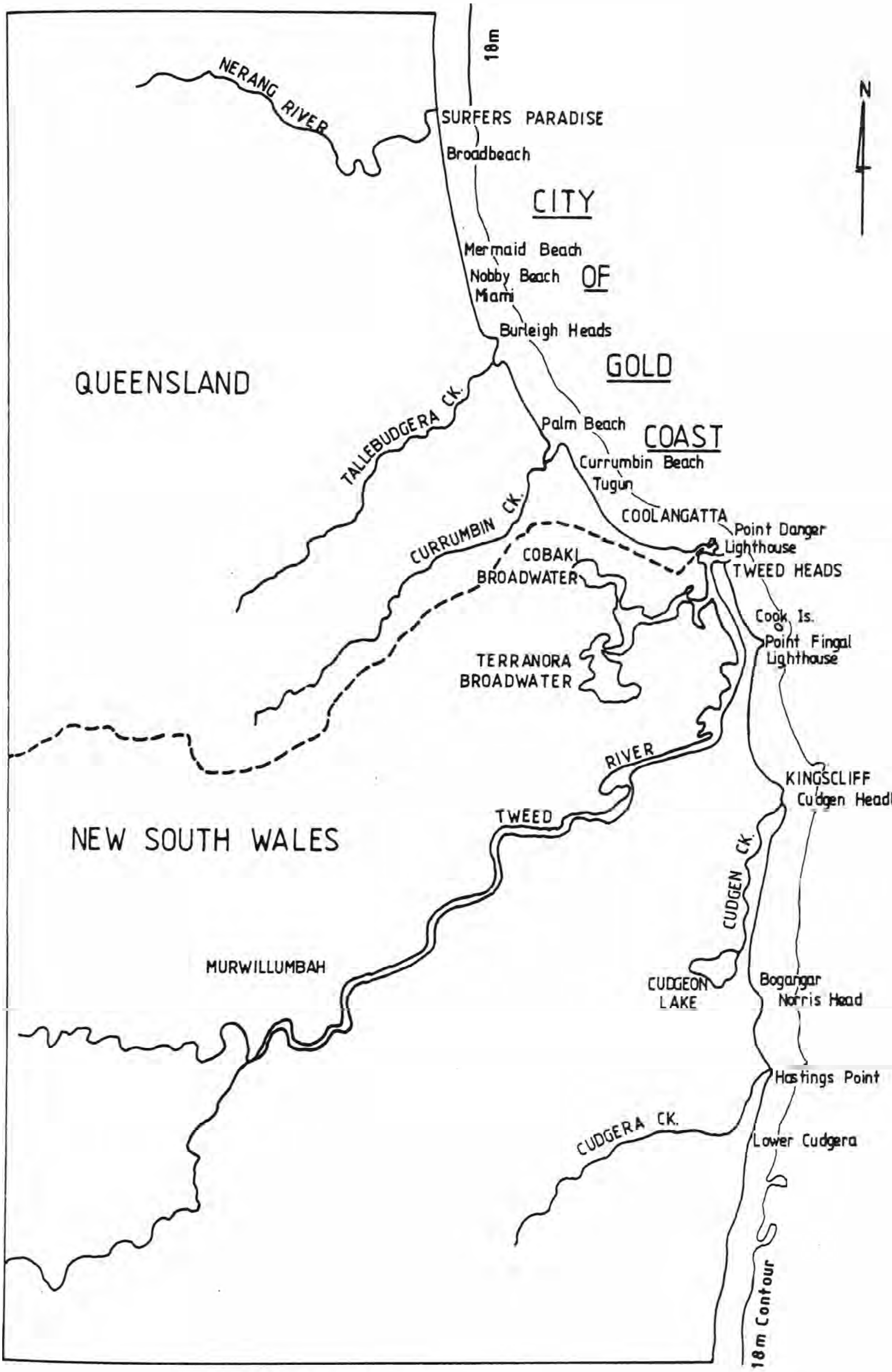
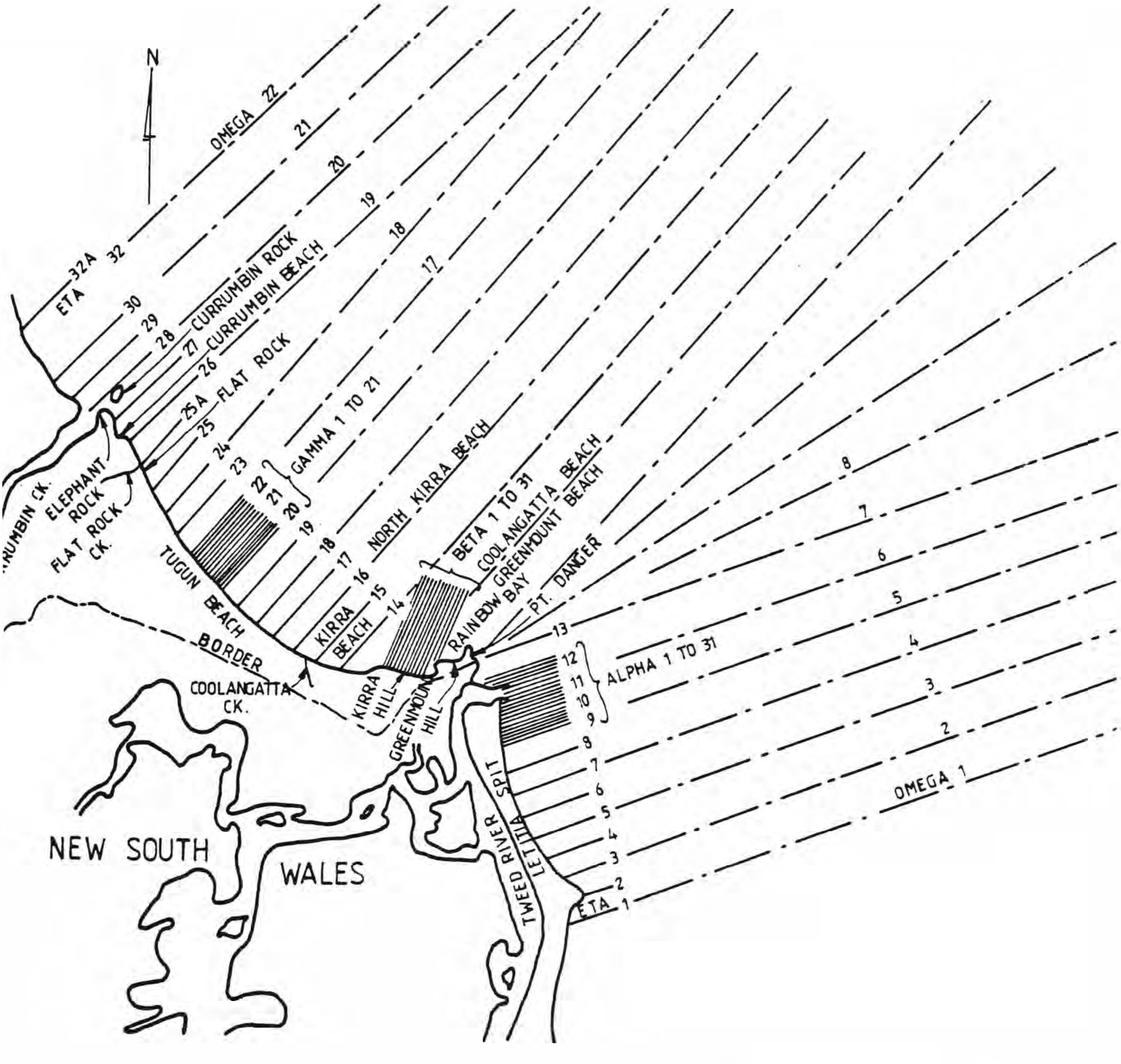


SCALE 1:250,000

LOCALITY SKETCH

FIGURE 1



LOCATION OF ETA, BETA, GAMMA AND OMEGA
BEACH AND OFFSHORE LINES
(DELFT, 1970)

FIGURE 2

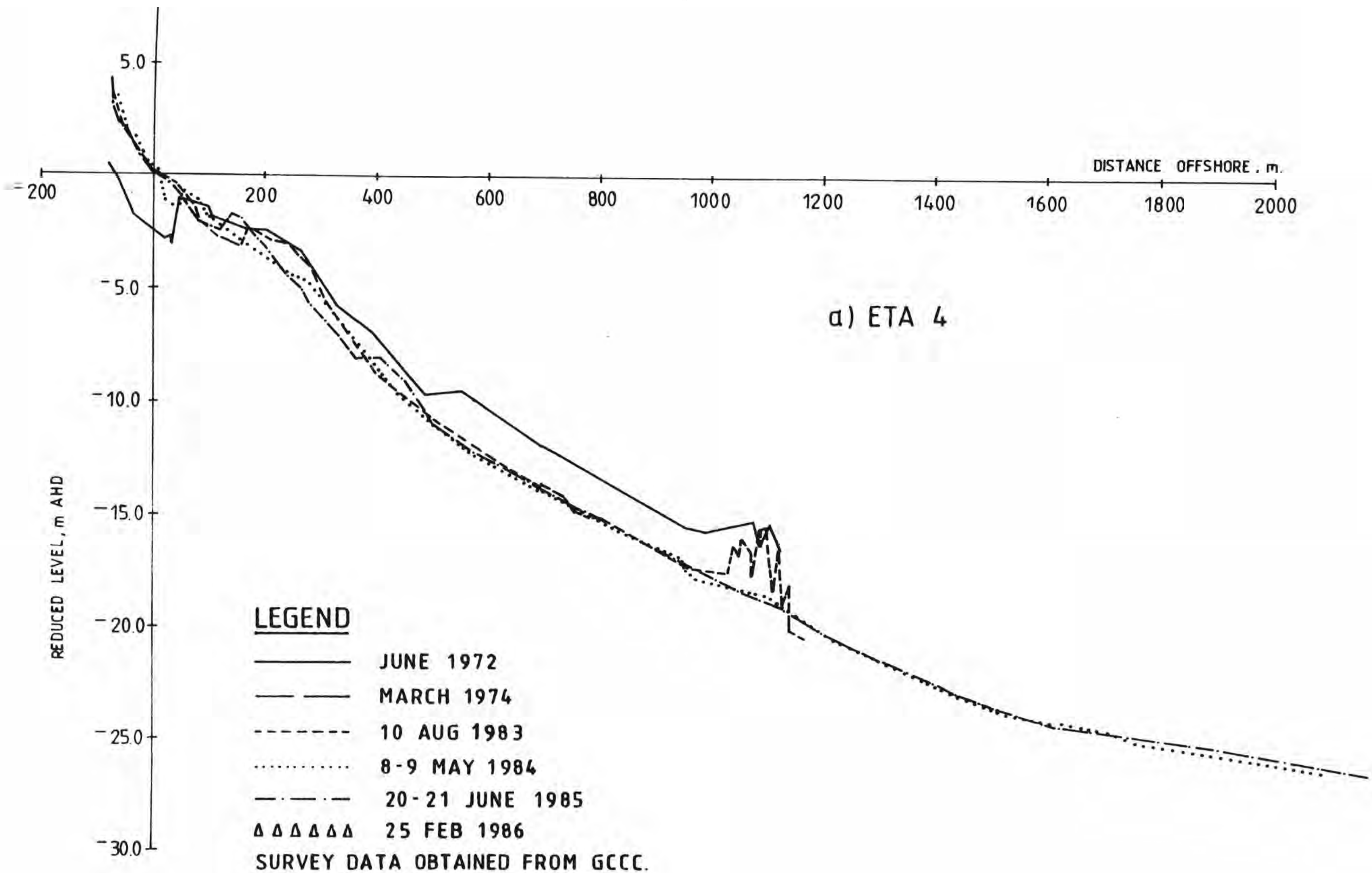


FIGURE 3

ETA LINES SOUTH OF POINT DANGER

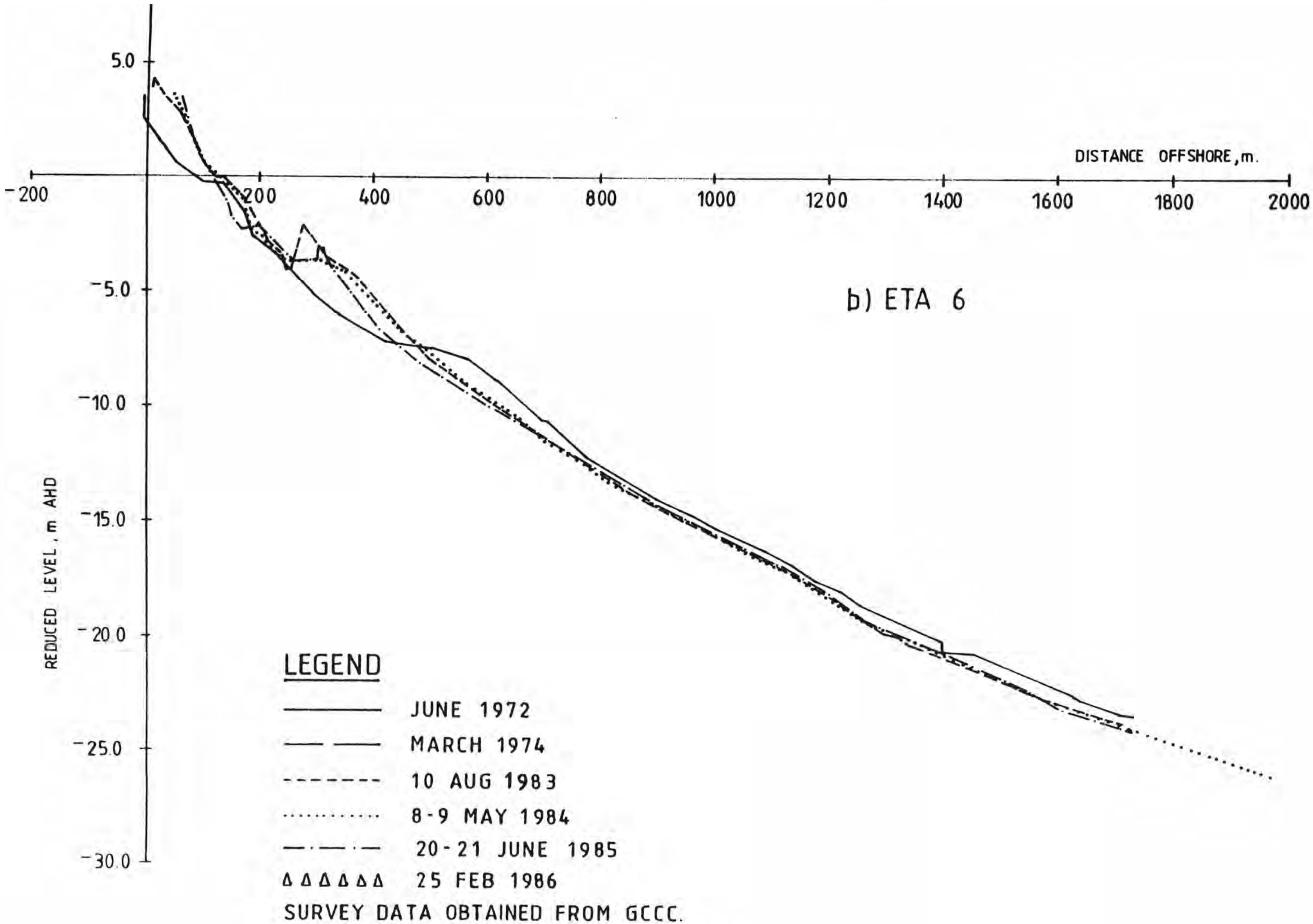
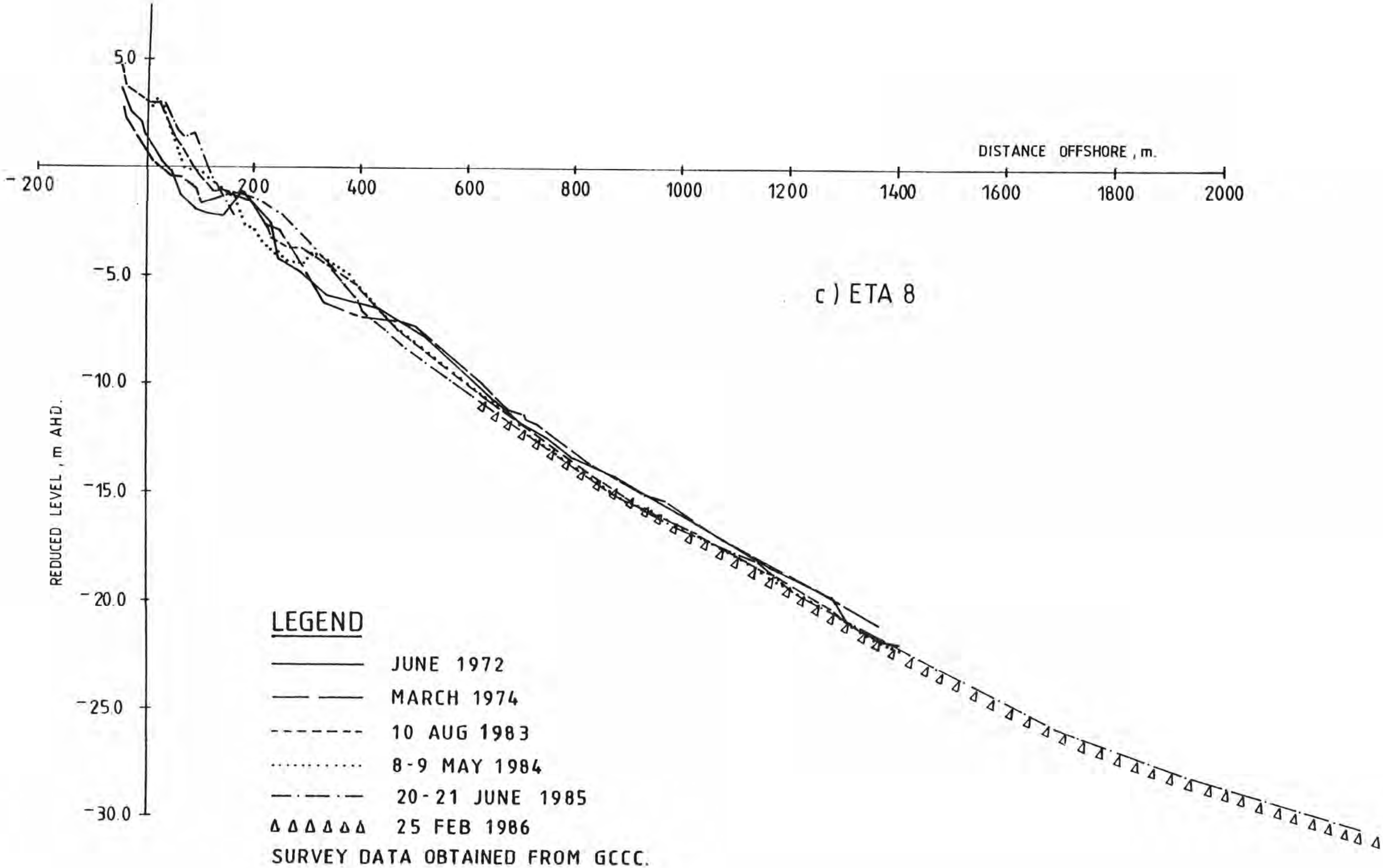


FIGURE 3 CONTD.



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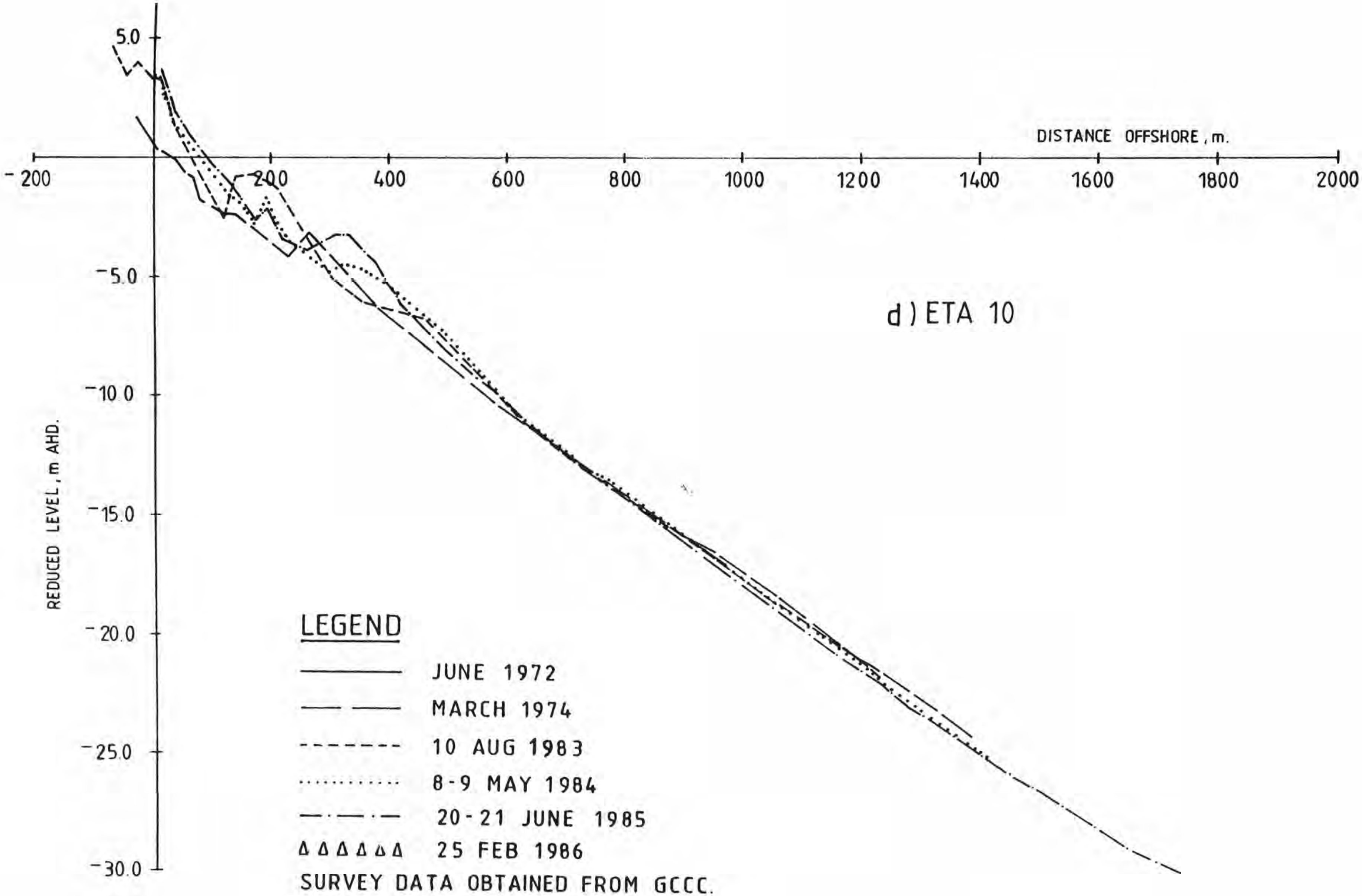

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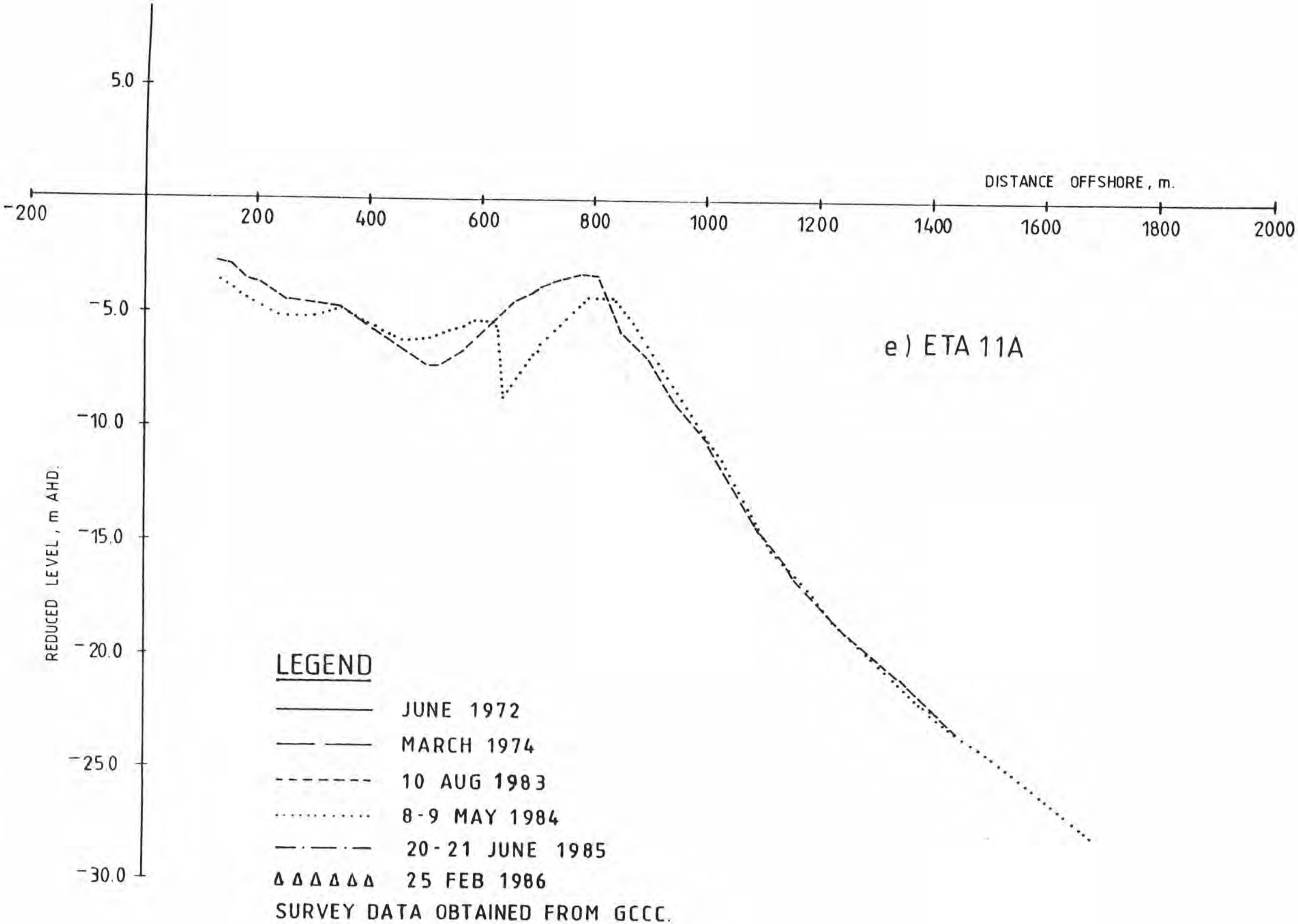

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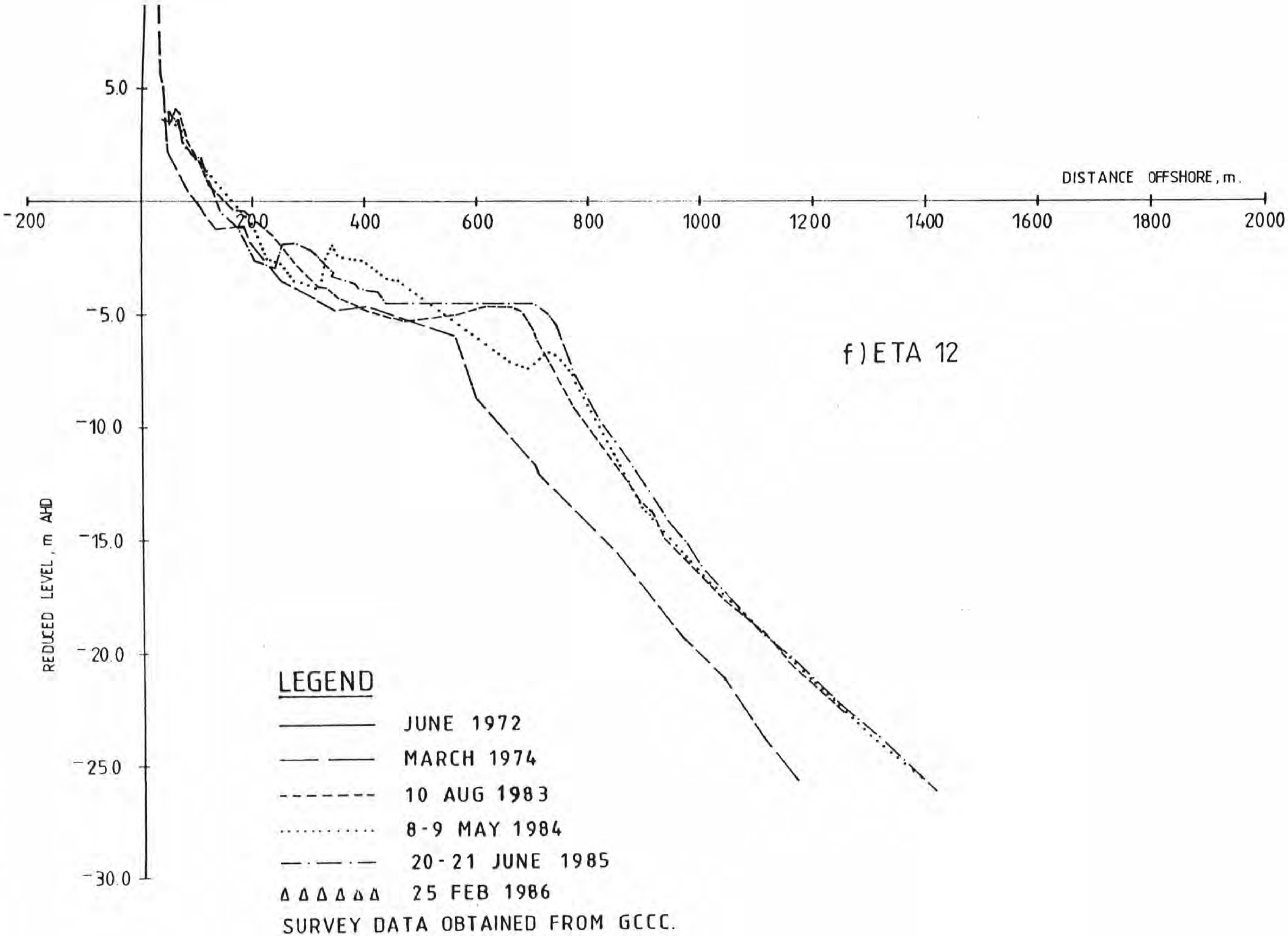

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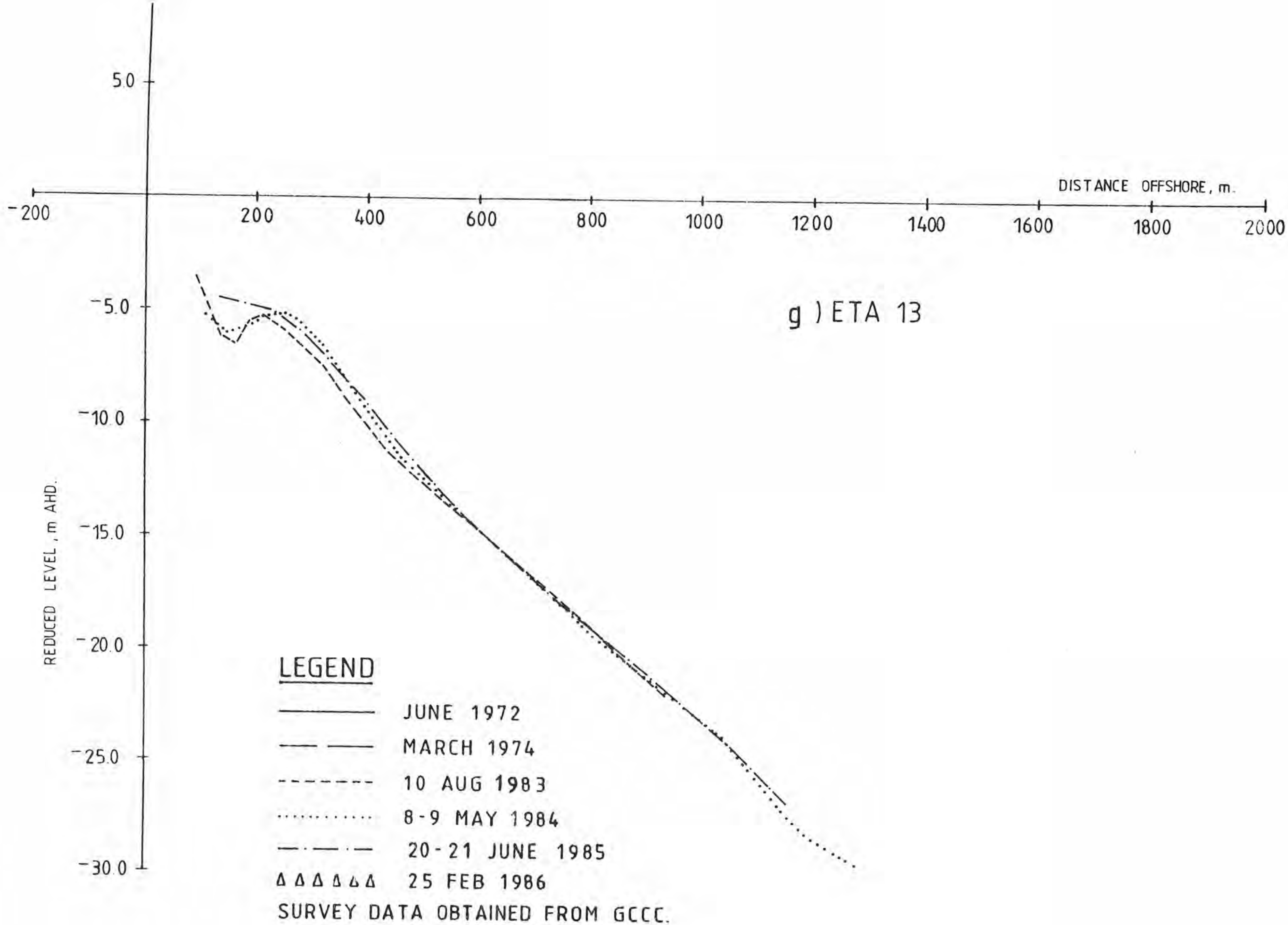

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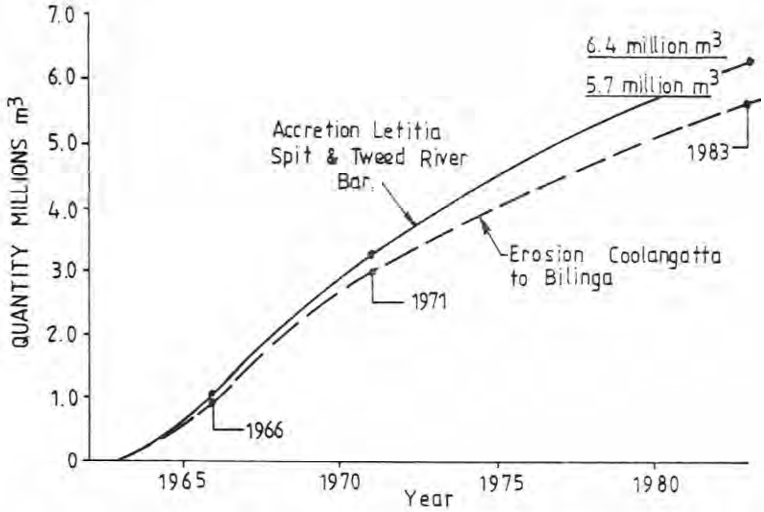
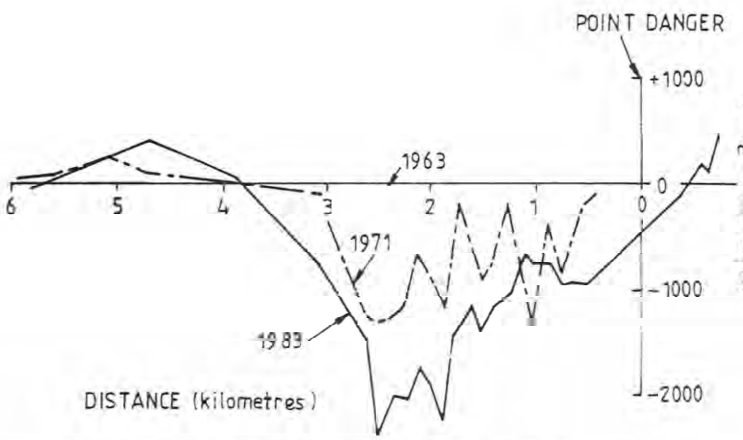
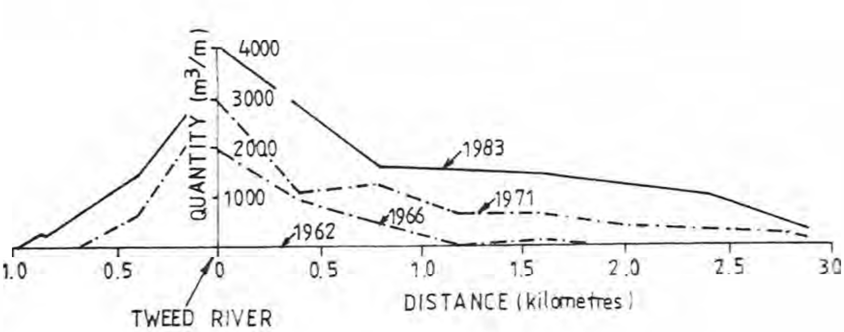


TIME HISTORY OF UPDRIFT ACCRETION AND DOWNDRIFT EROSION.



EROSION DOWNDRIFT OF THE TWEED.

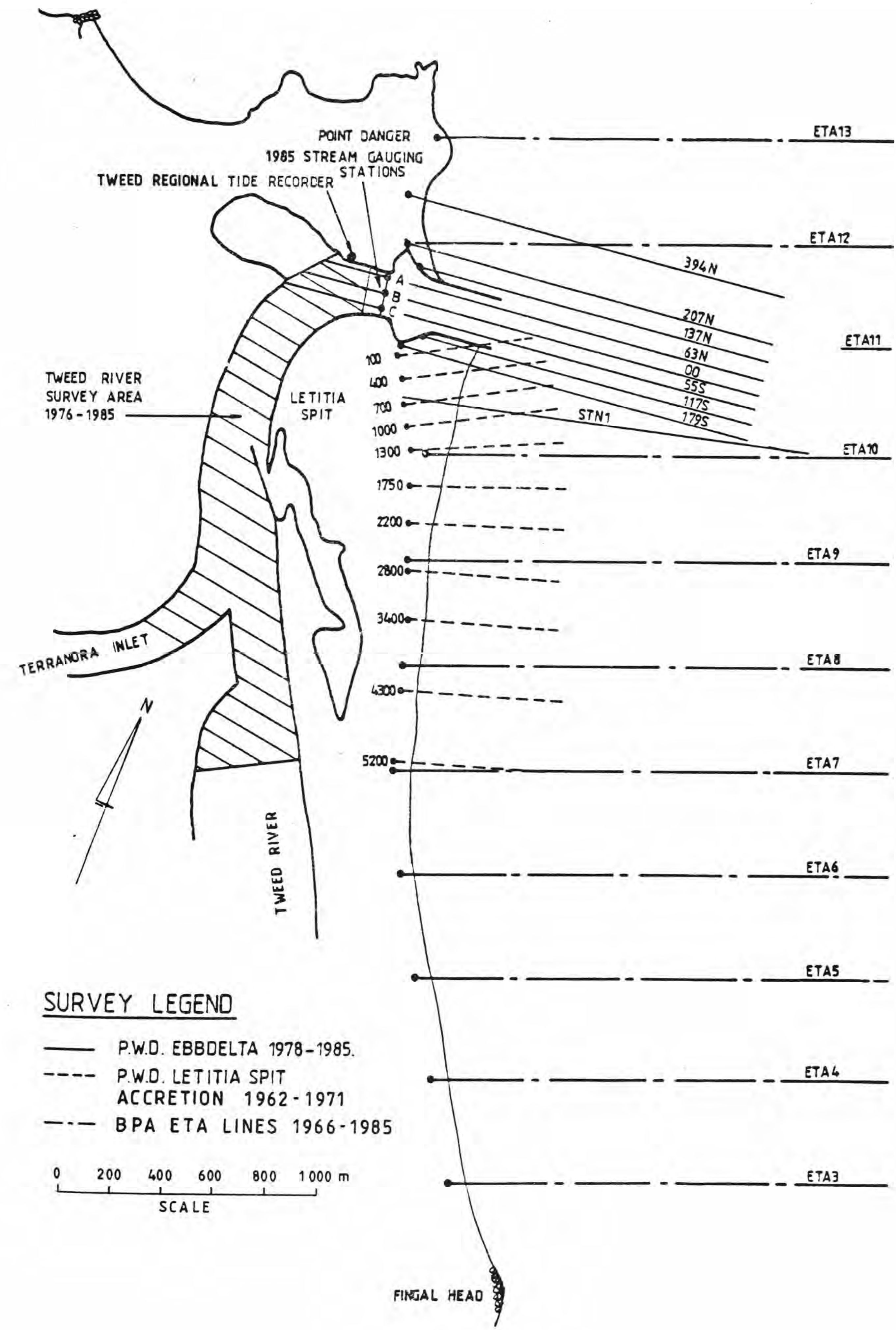


UPRIGHT ACCRETION ALONG LETITIA SPIT.

BEACH CHANGES DUE TO TWEED TRAINING WALLS

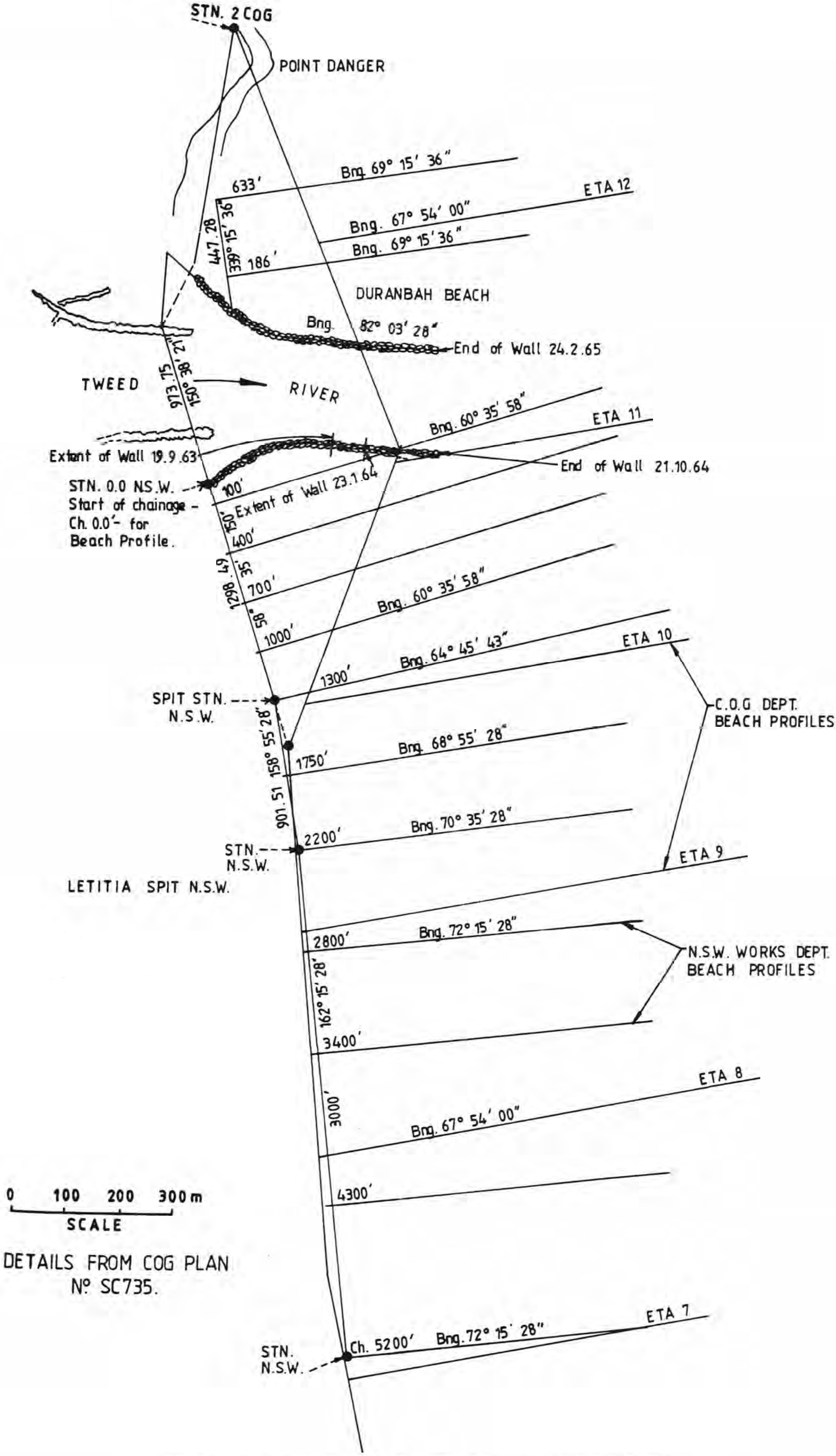
(REPRODUCED FROM MACDONALD AND PATTERSON, 1984)

FIGURE 4



LOCATION OF SURVEY LINES

FIGURE 5



LOCATION OF LETITIA SPIT ACCRETION SURVEY LINES

FIGURE 6

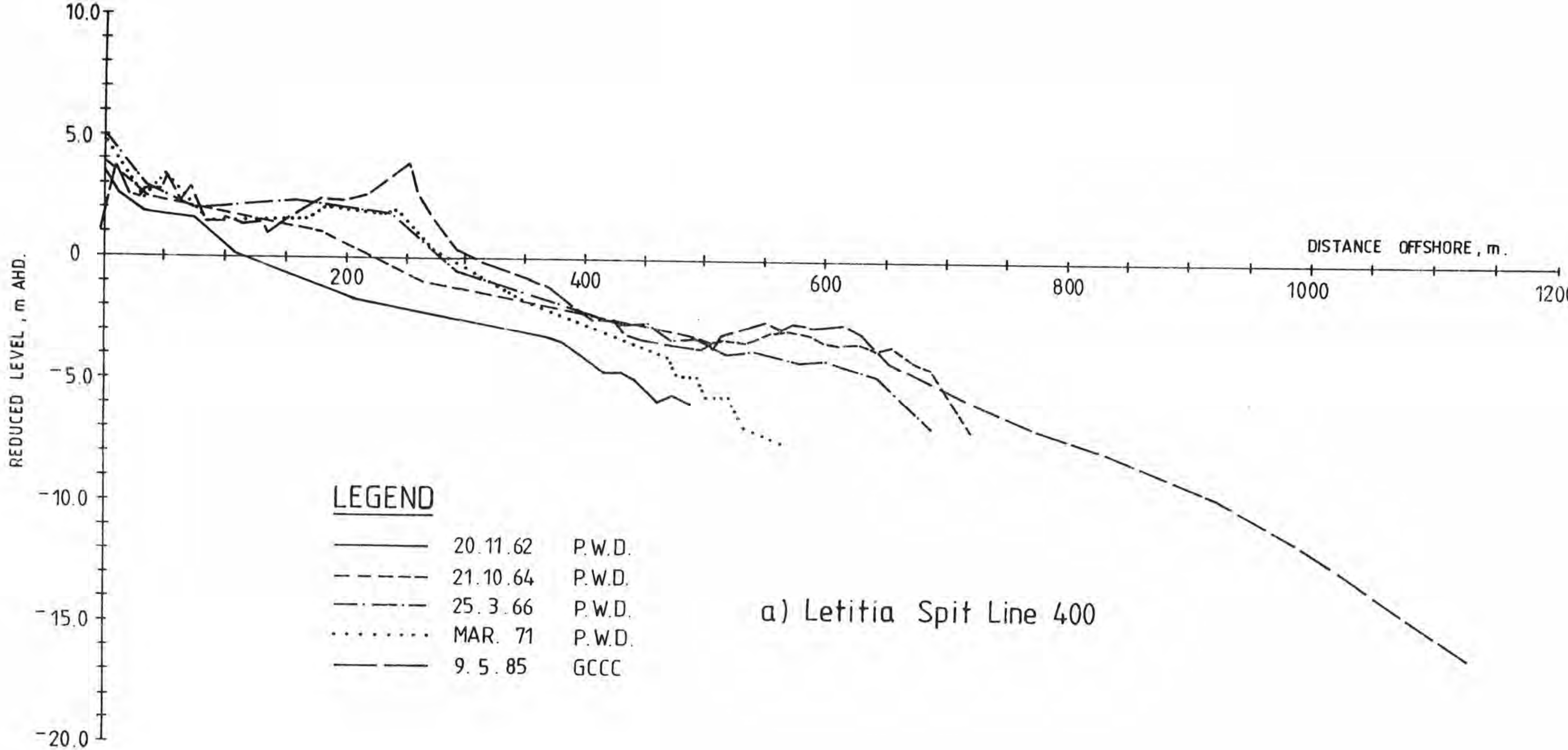
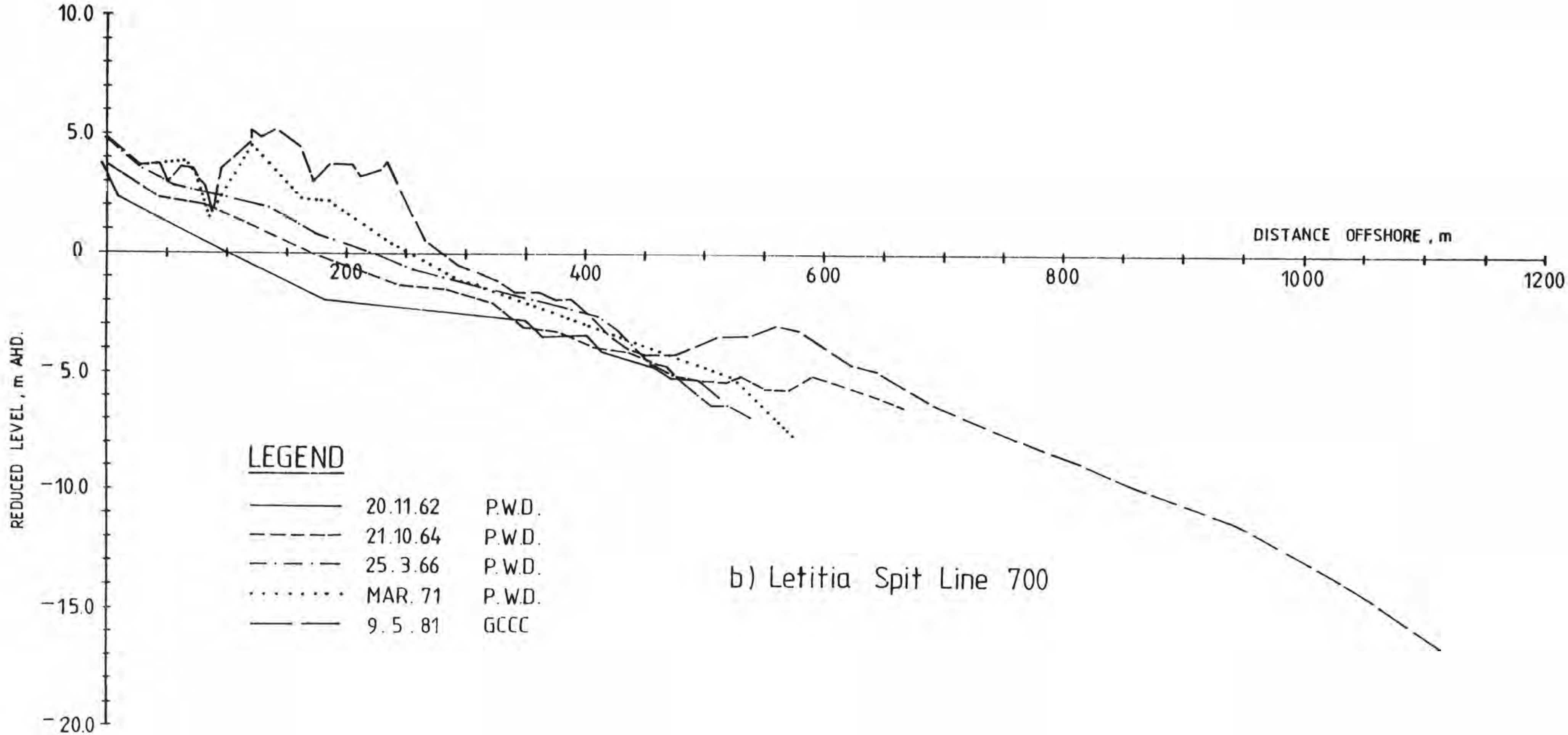


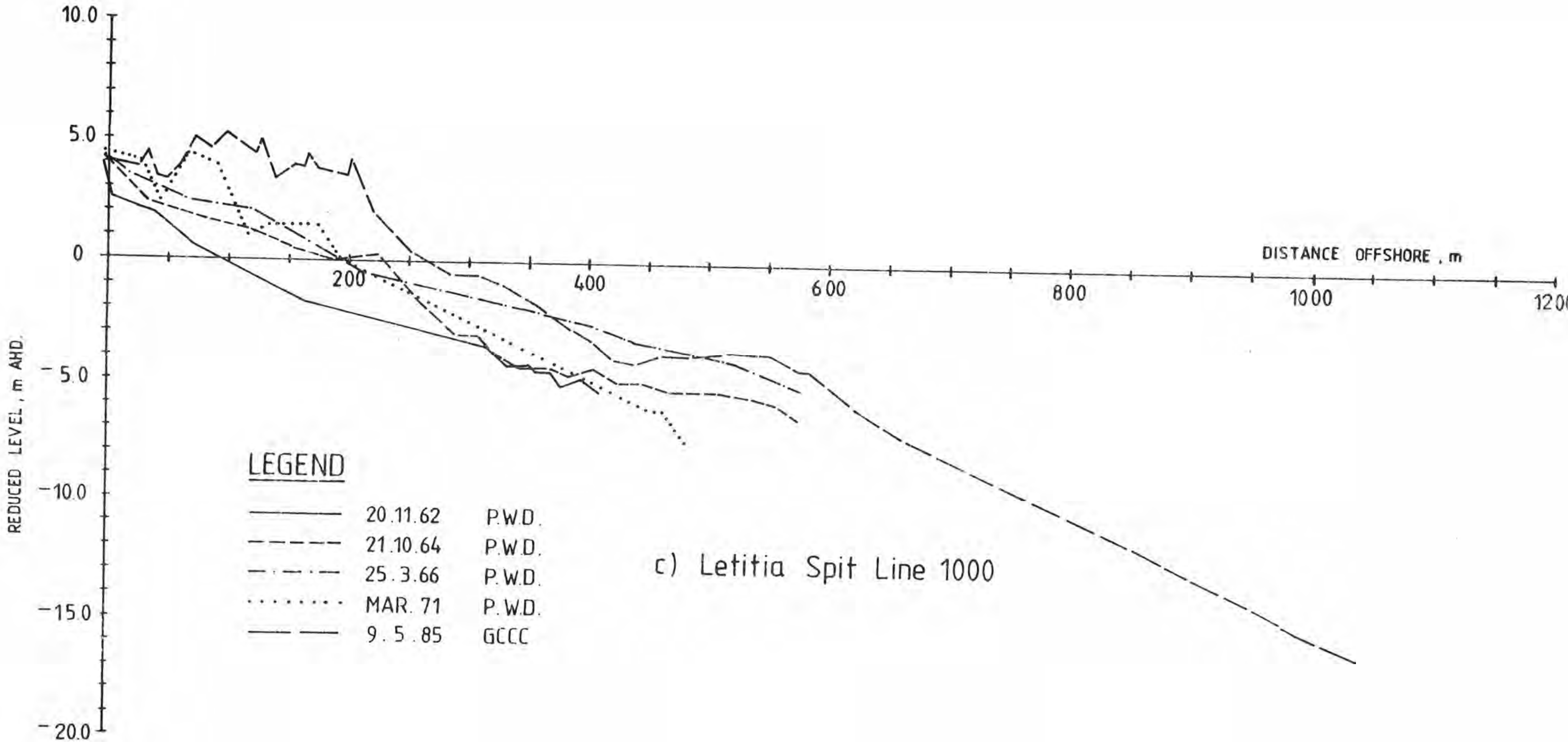
FIGURE 7

LETITIA SPIT ACCRETION SURVEYS



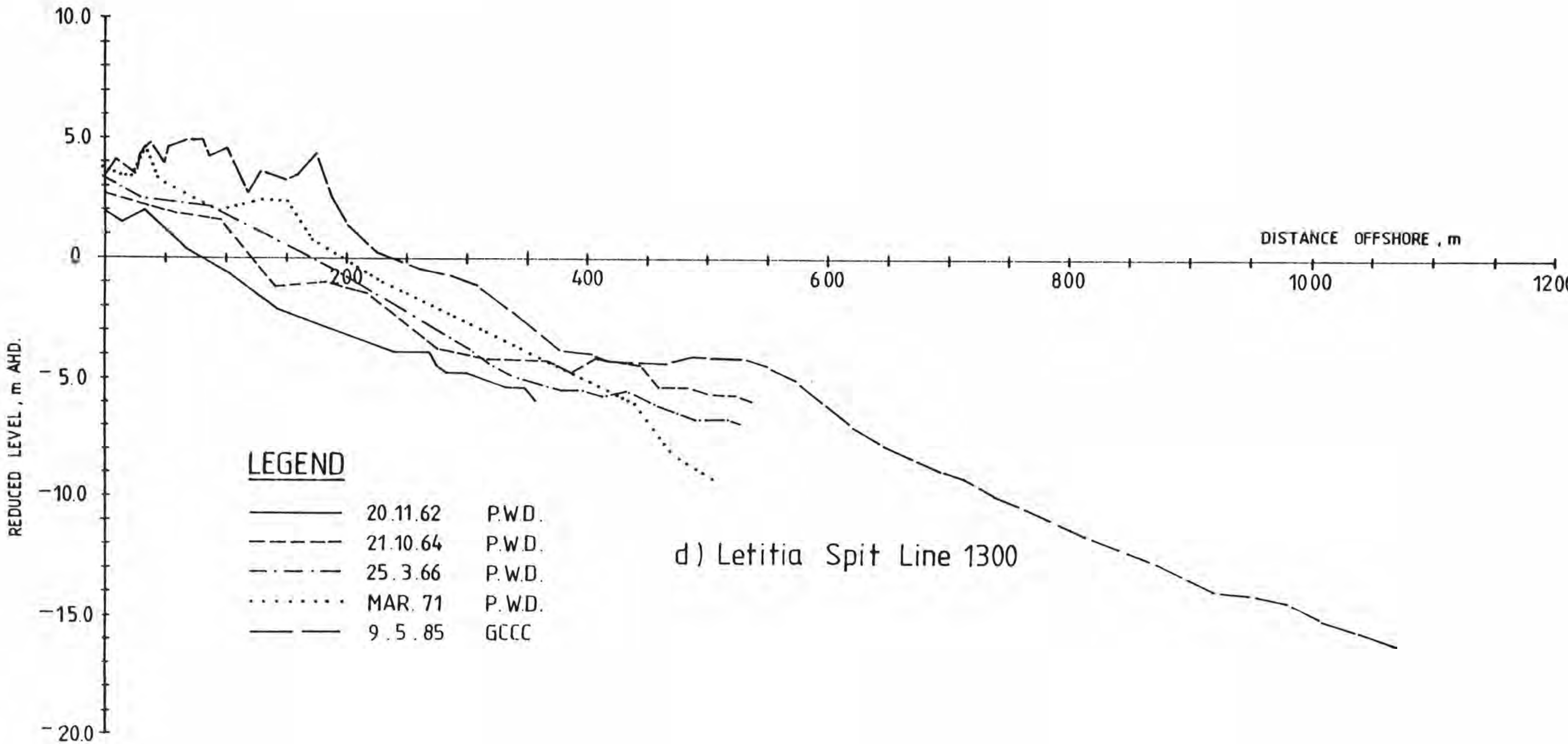
b) Letitia Spit Line 700

FIGURE 7 CONTD.



c) Letitia Spit Line 1000

FIGURE 7 CONTD.



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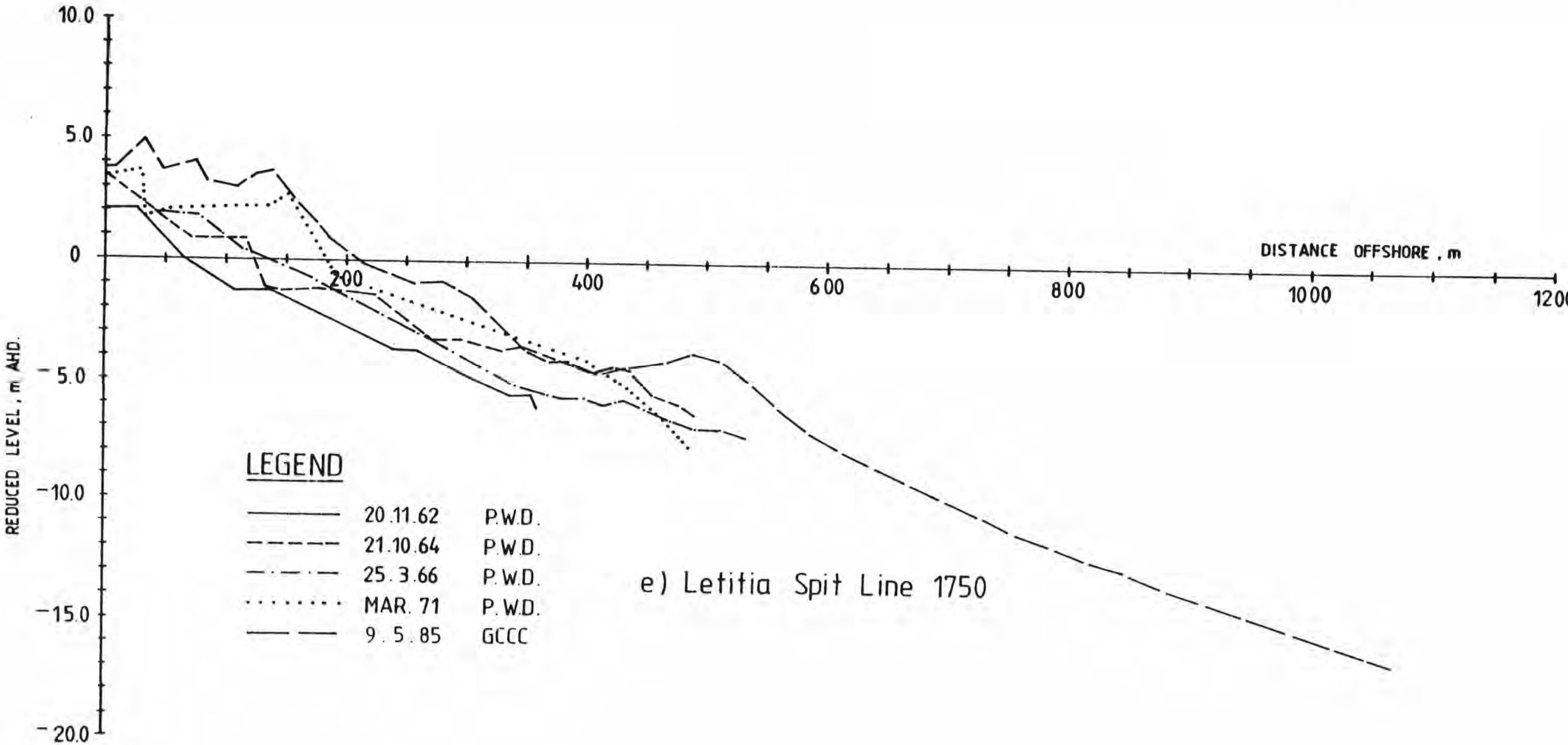
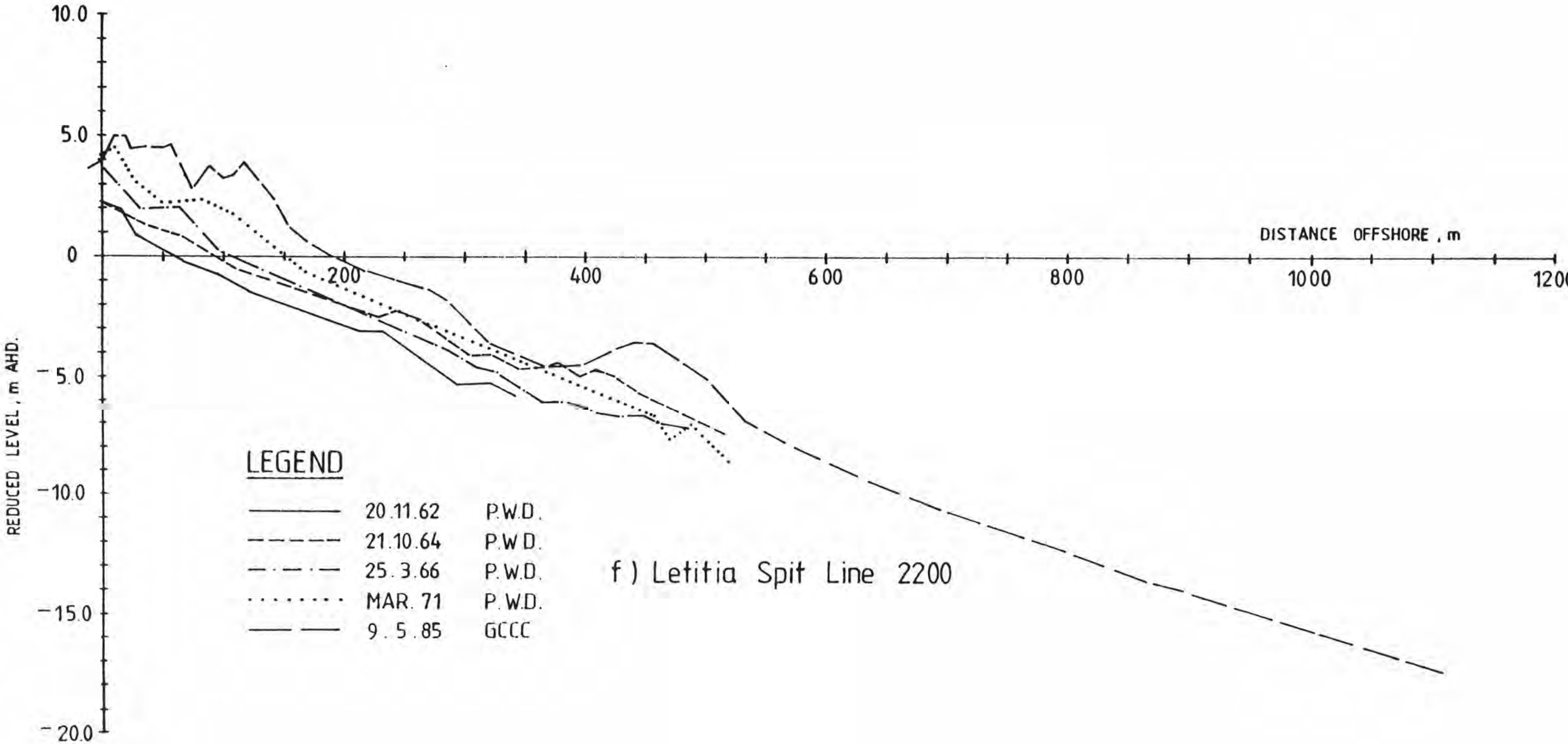
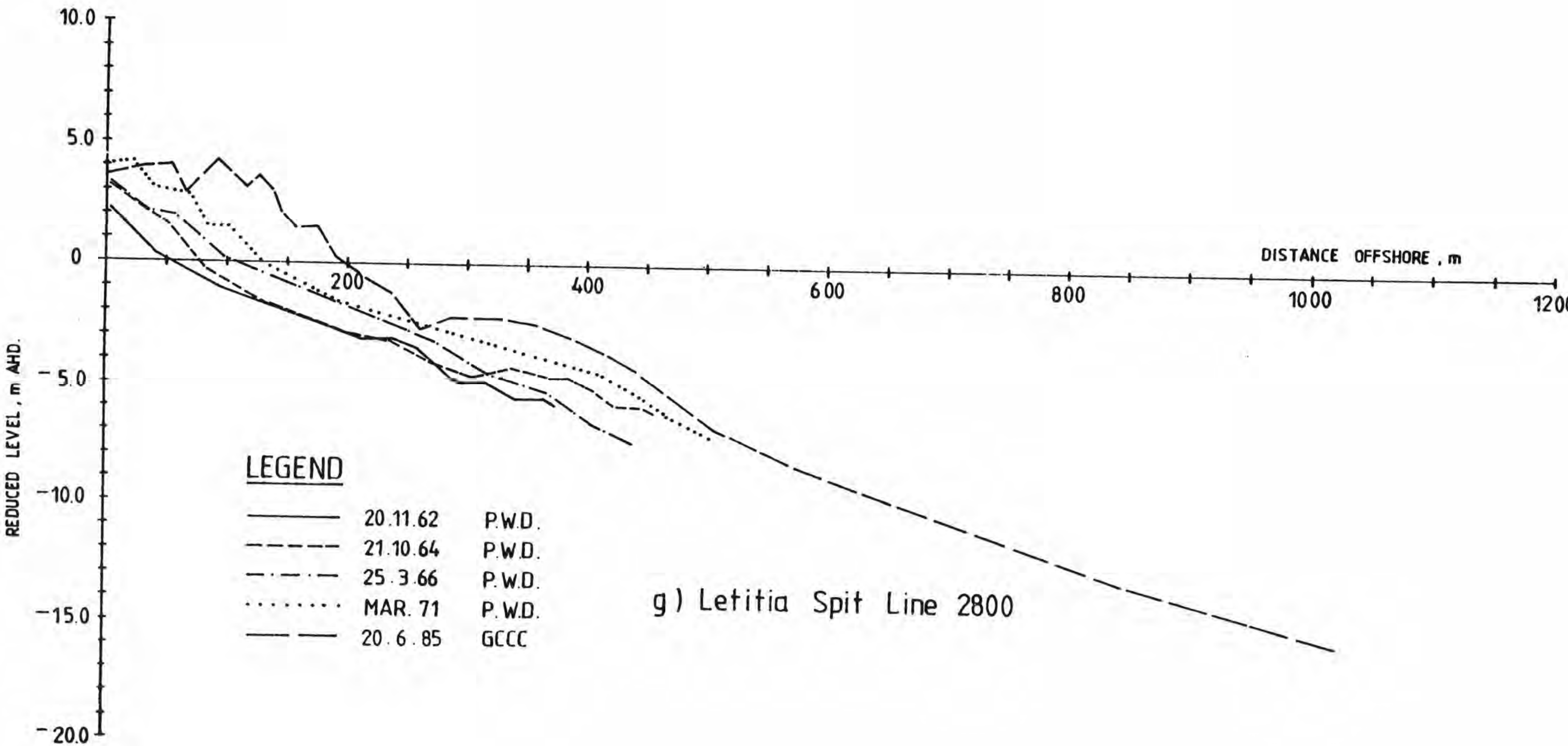


FIGURE 7 CONTD.



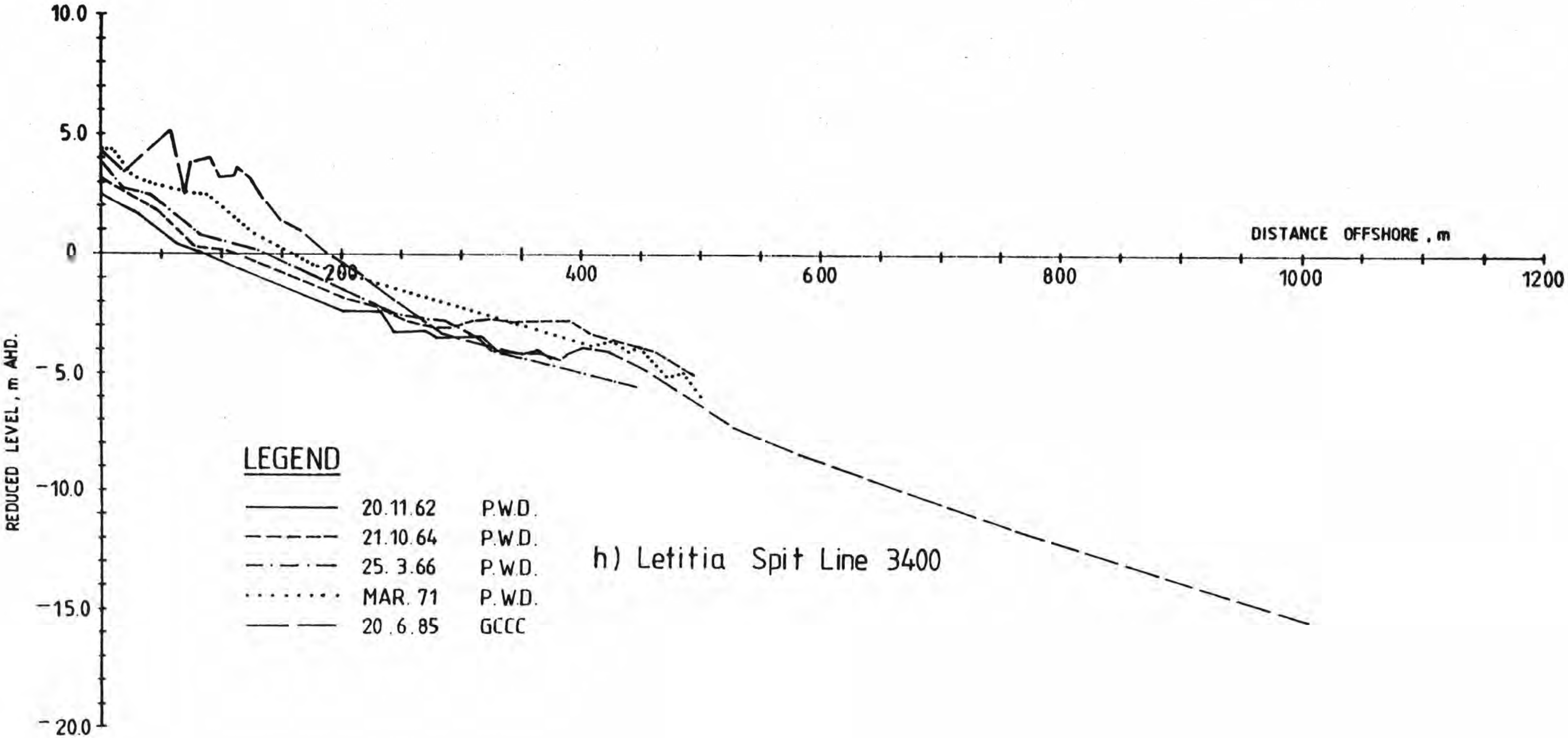
f) Letitia Spit Line 2200

FIGURE 7 CONTD.



g) Letitia Spit Line 2800

FIGURE 7 CONTD.



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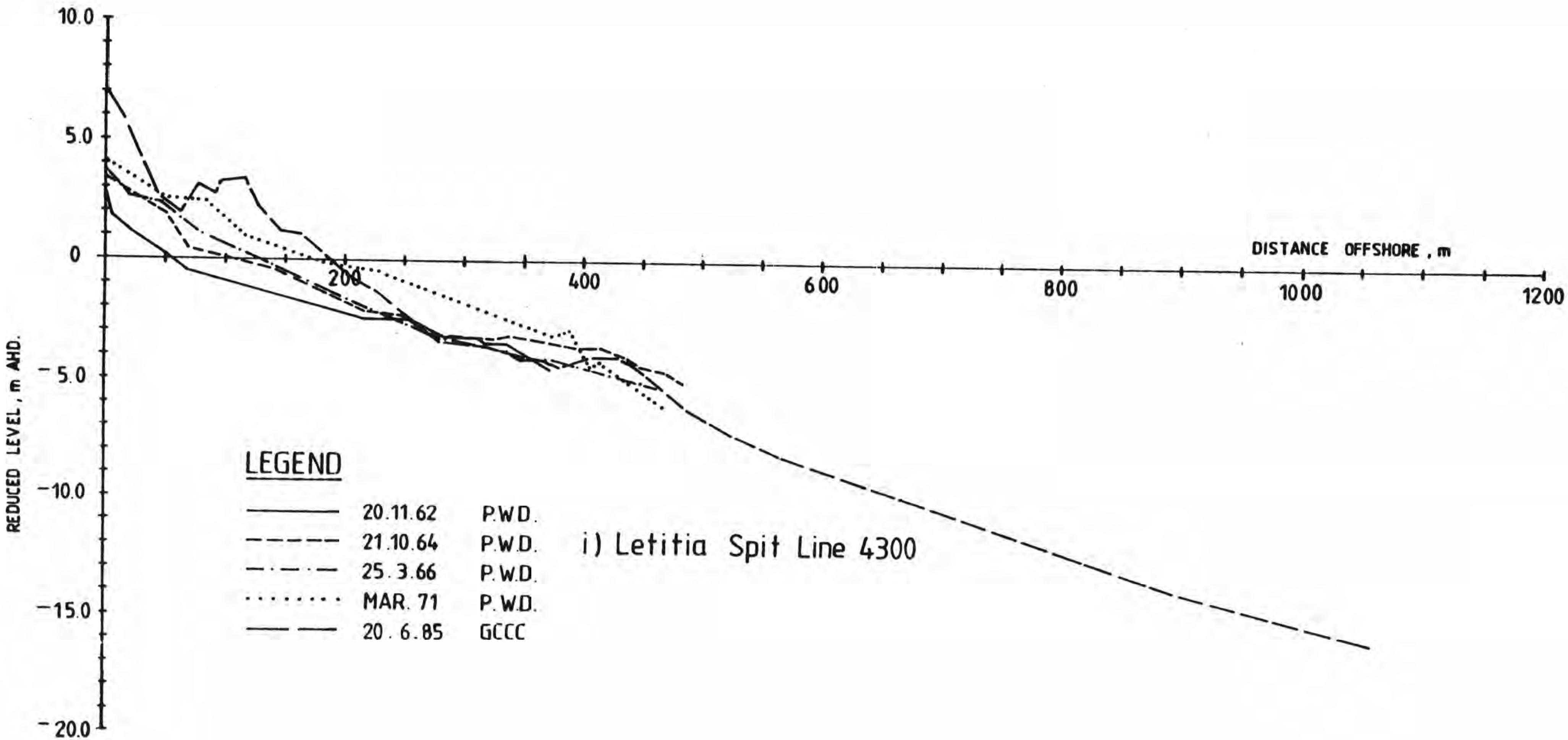

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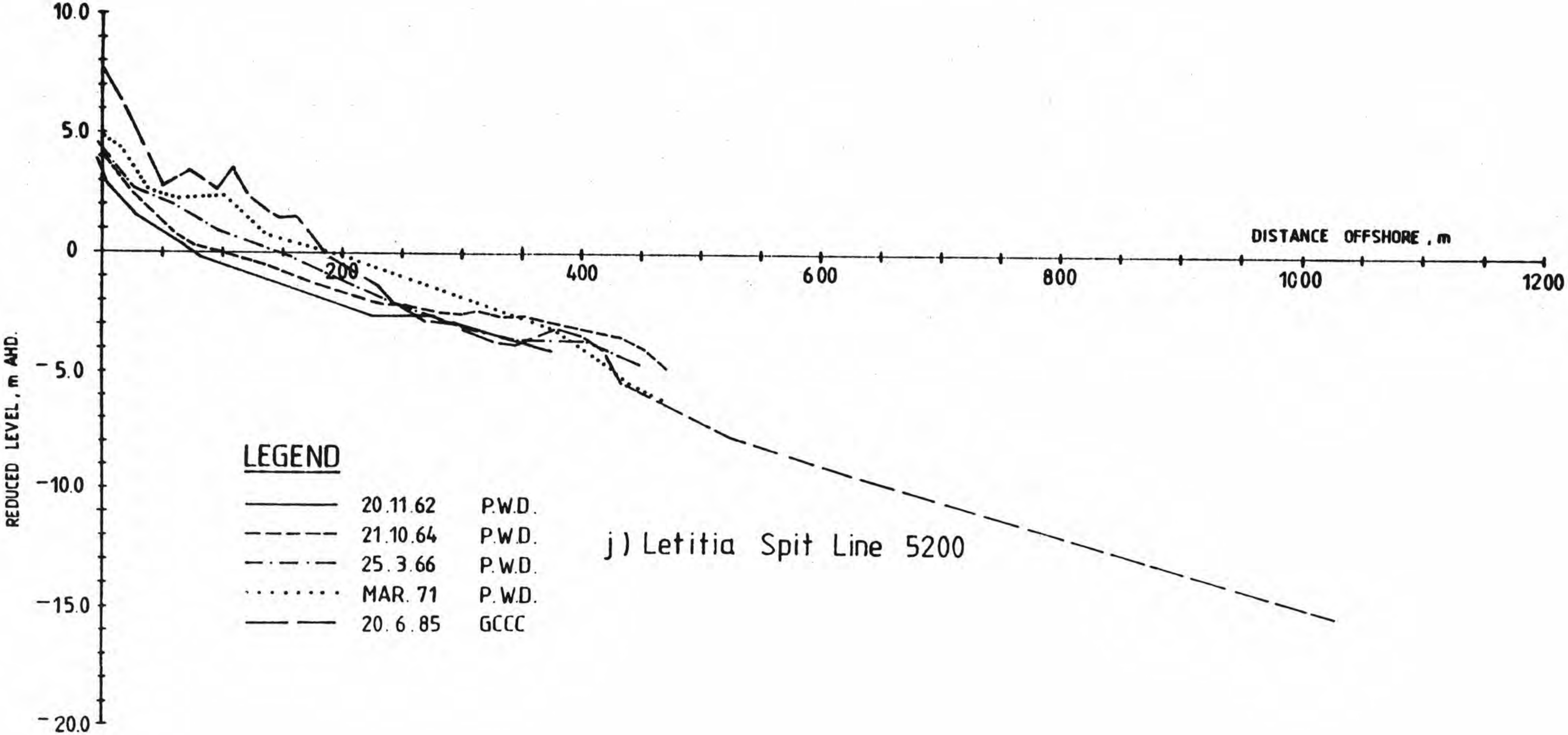

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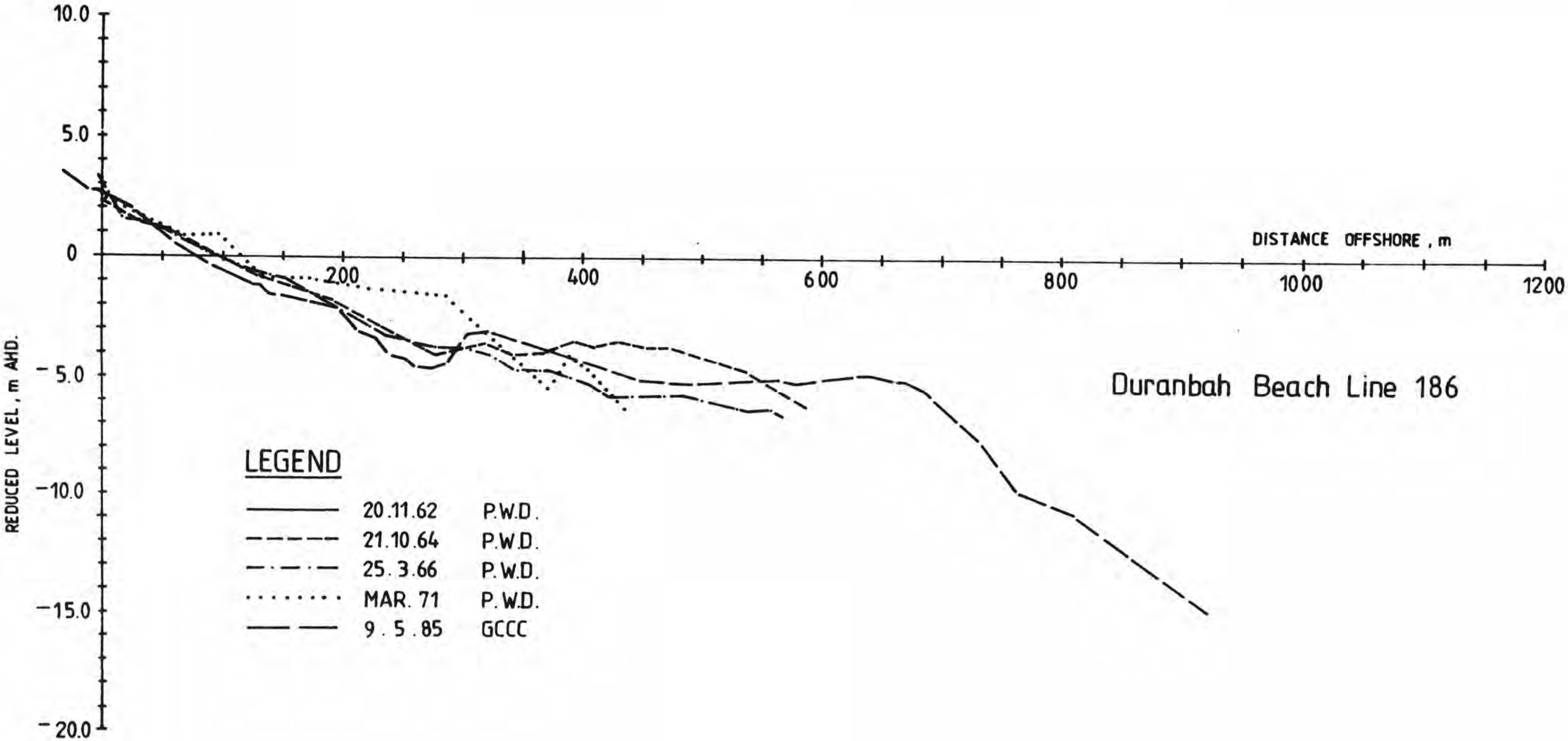

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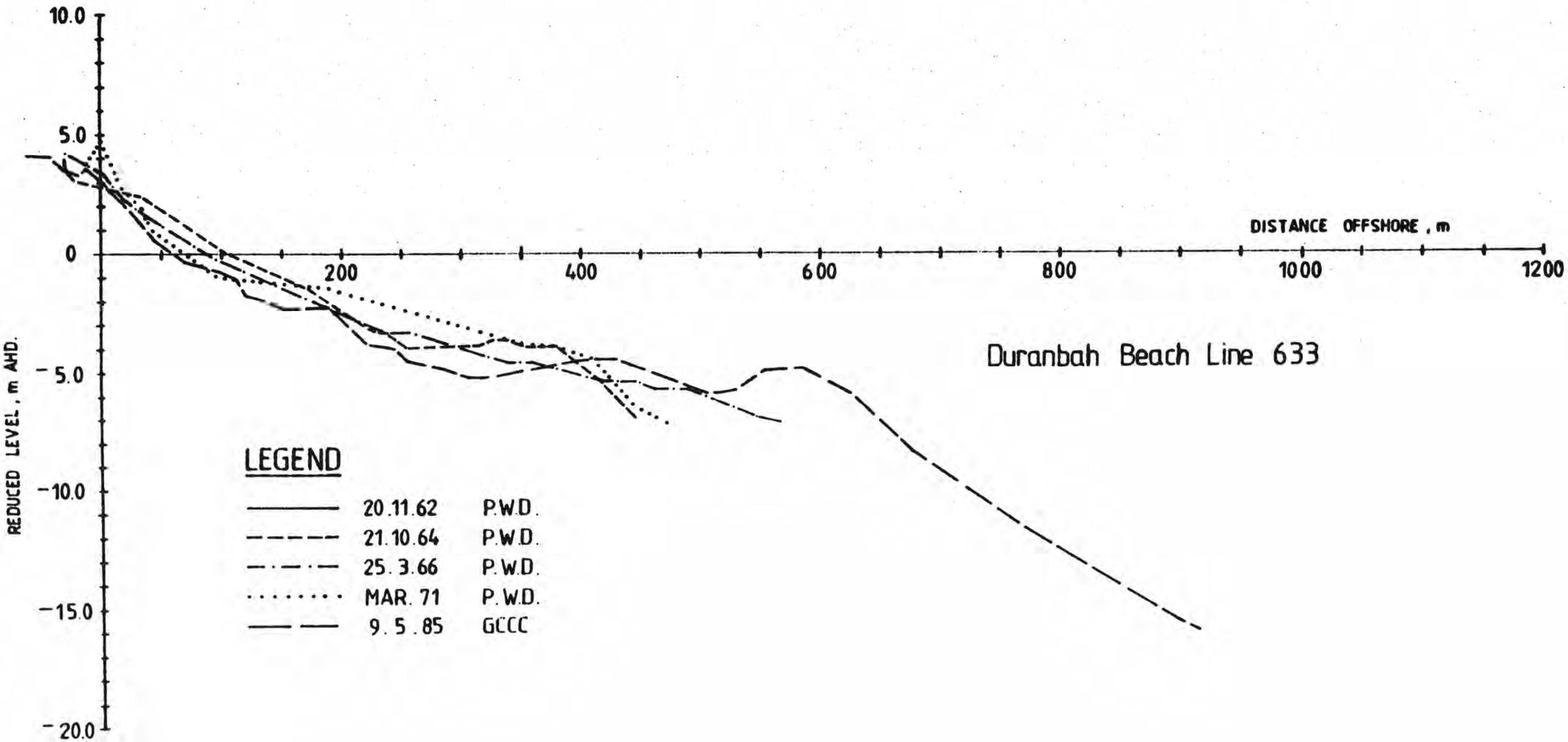


FIGURE 7 CONTD.

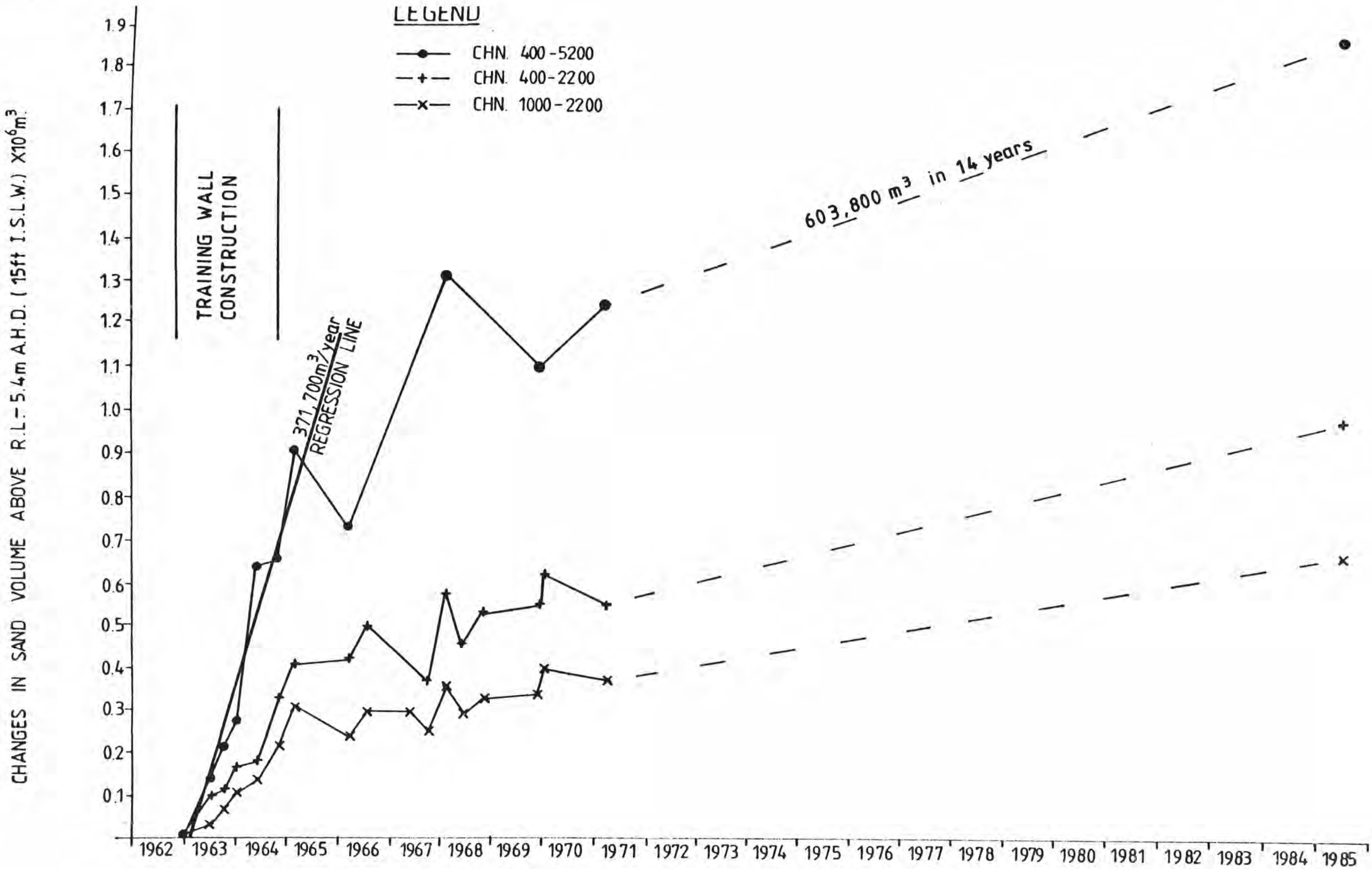
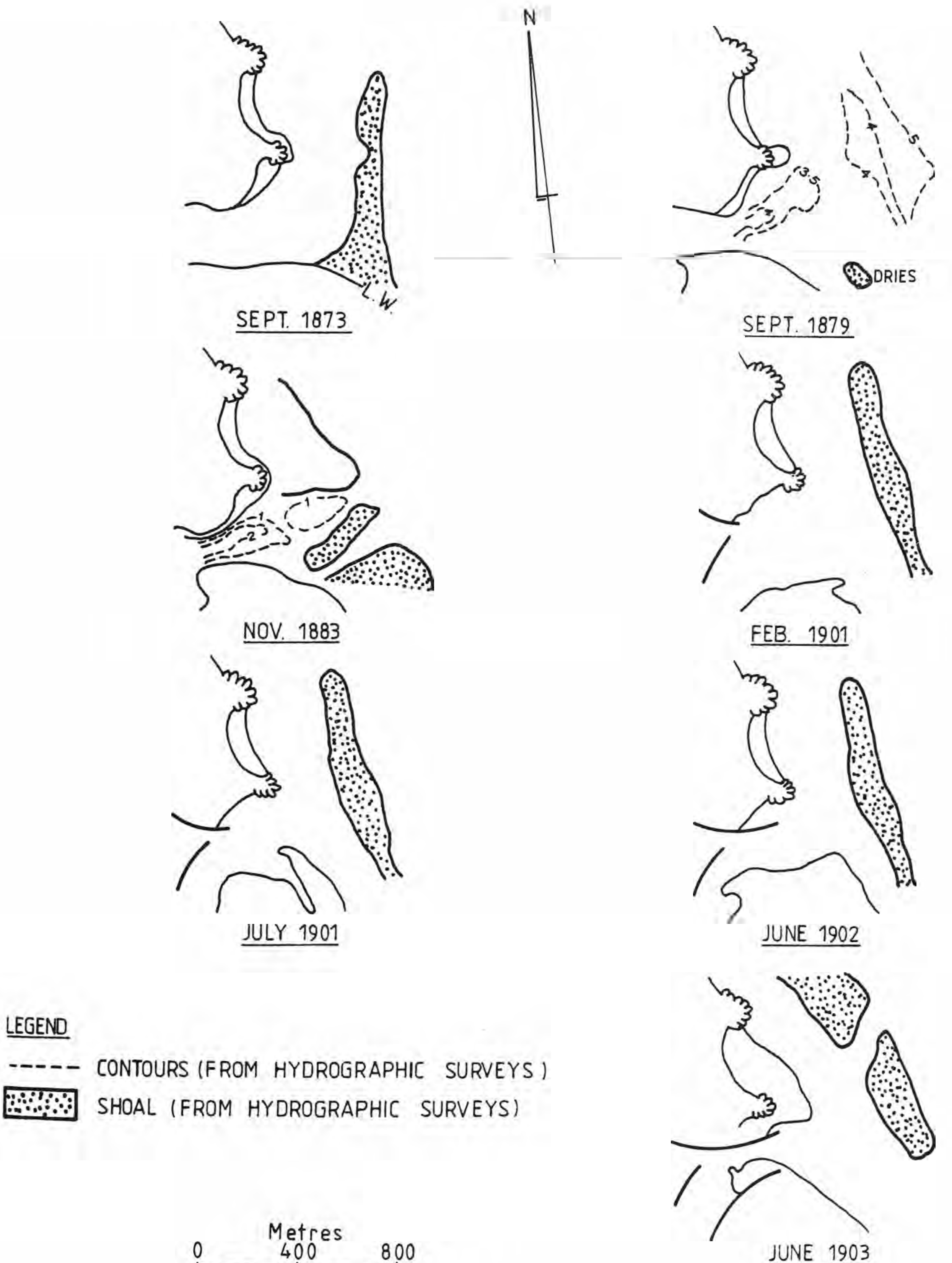


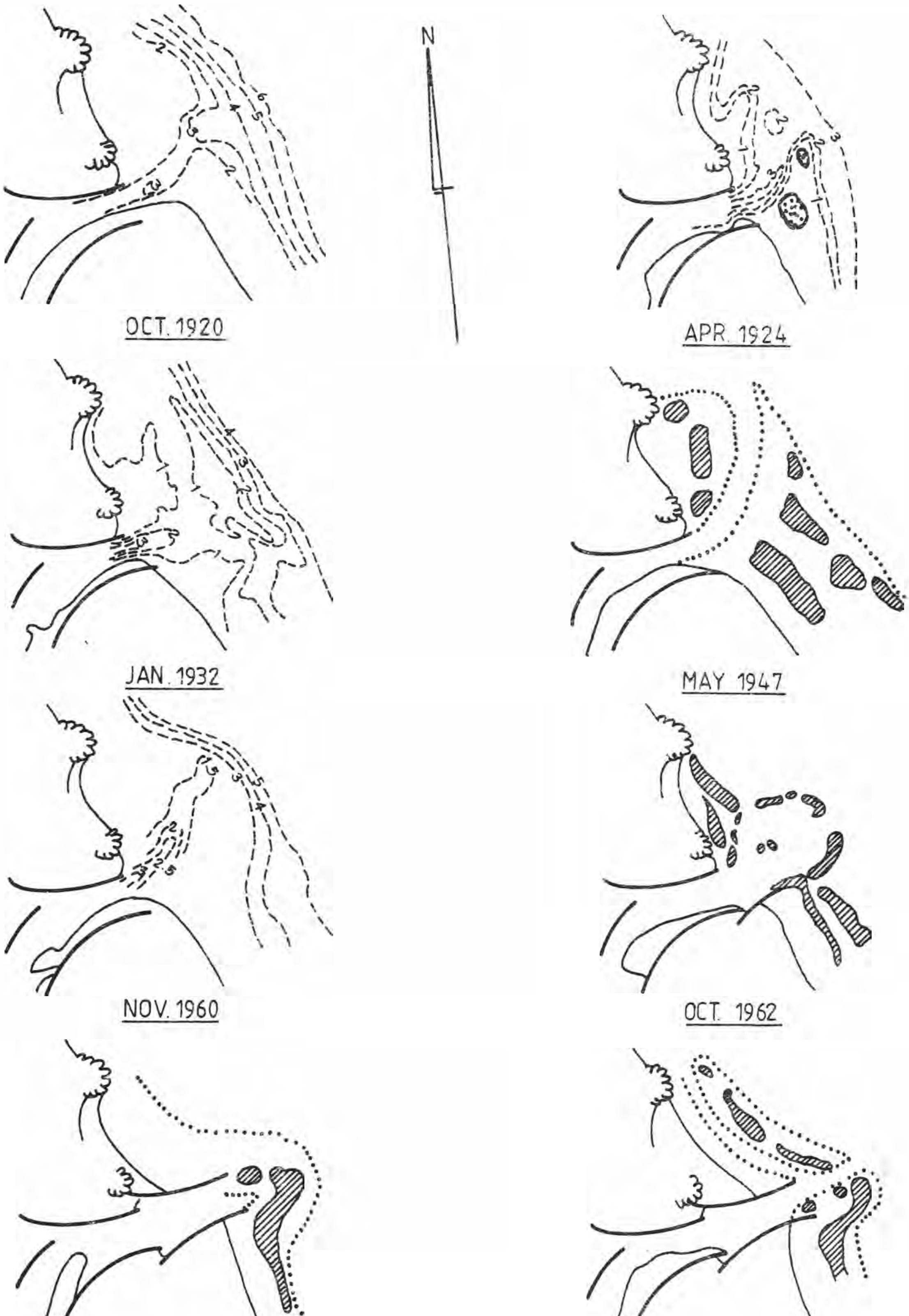
FIGURE 8

LETITIA SPIT ACCRETION SURVEYS
– BEACH VOLUME CHANGES 1962-1985.



GEOMORPHOLOGY OF ENTRANCE BAR
(REPRODUCED FROM TWEED RIVER DYNAMICS STUDY (P.W.D., 1979)).

FIGURE 9



LEGEND

- - - - - CONTOURS (FROM HYDROGRAPHIC SURVEYS)

SHOAL (FROM HYDROGRAPHIC SURVEYS)

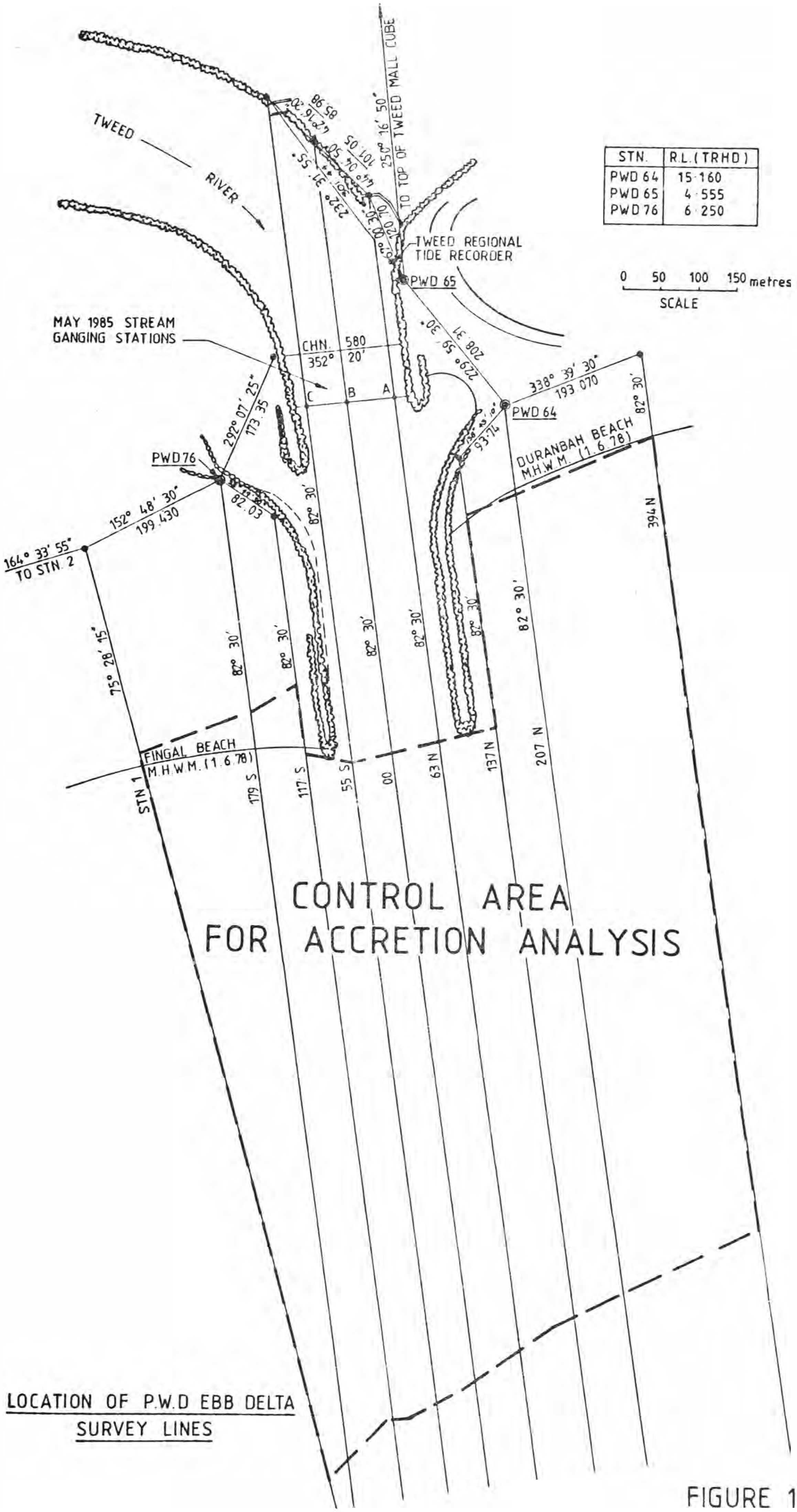
WAVES BREAKING (FROM AERIAL PHOTOGRAPHS)

·········· SHALLOW REGION (FROM AERIAL PHOTOGRAPHS)

Metres
0 400 800

ENTRANCE BAR

FIGURE 9 CONTD.



STN.	R.L. (TRHD)
PWD 64	15.160
PWD 65	4.555
PWD 76	6.250

LOCATION OF P.W.D EBB DELTA SURVEY LINES

FIGURE 10

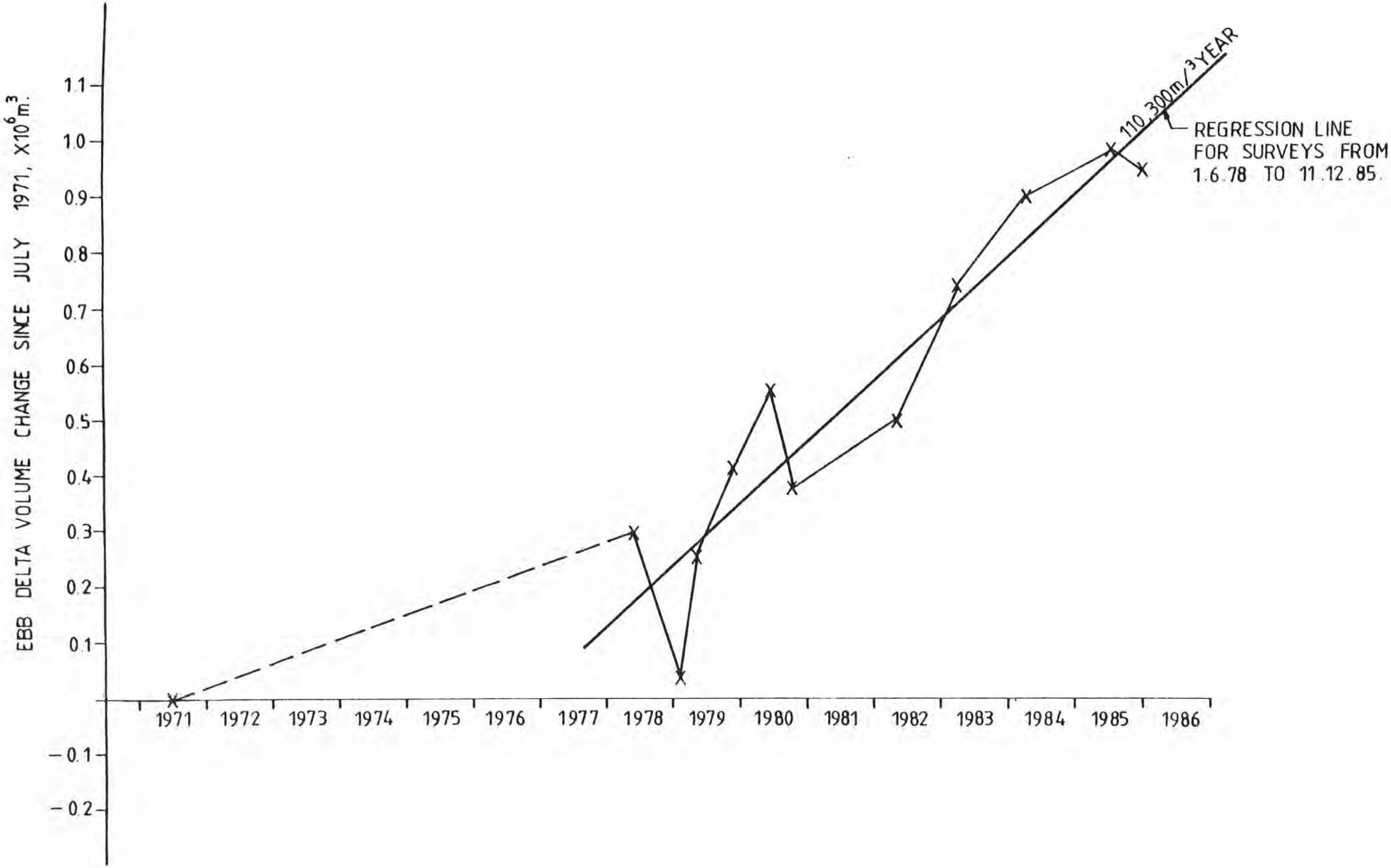


FIGURE 11

EBB DELTA VOLUME CHANGES SINCE 1971
P.W.D. SURVEY LINES SHOWN ON FIGURE 10

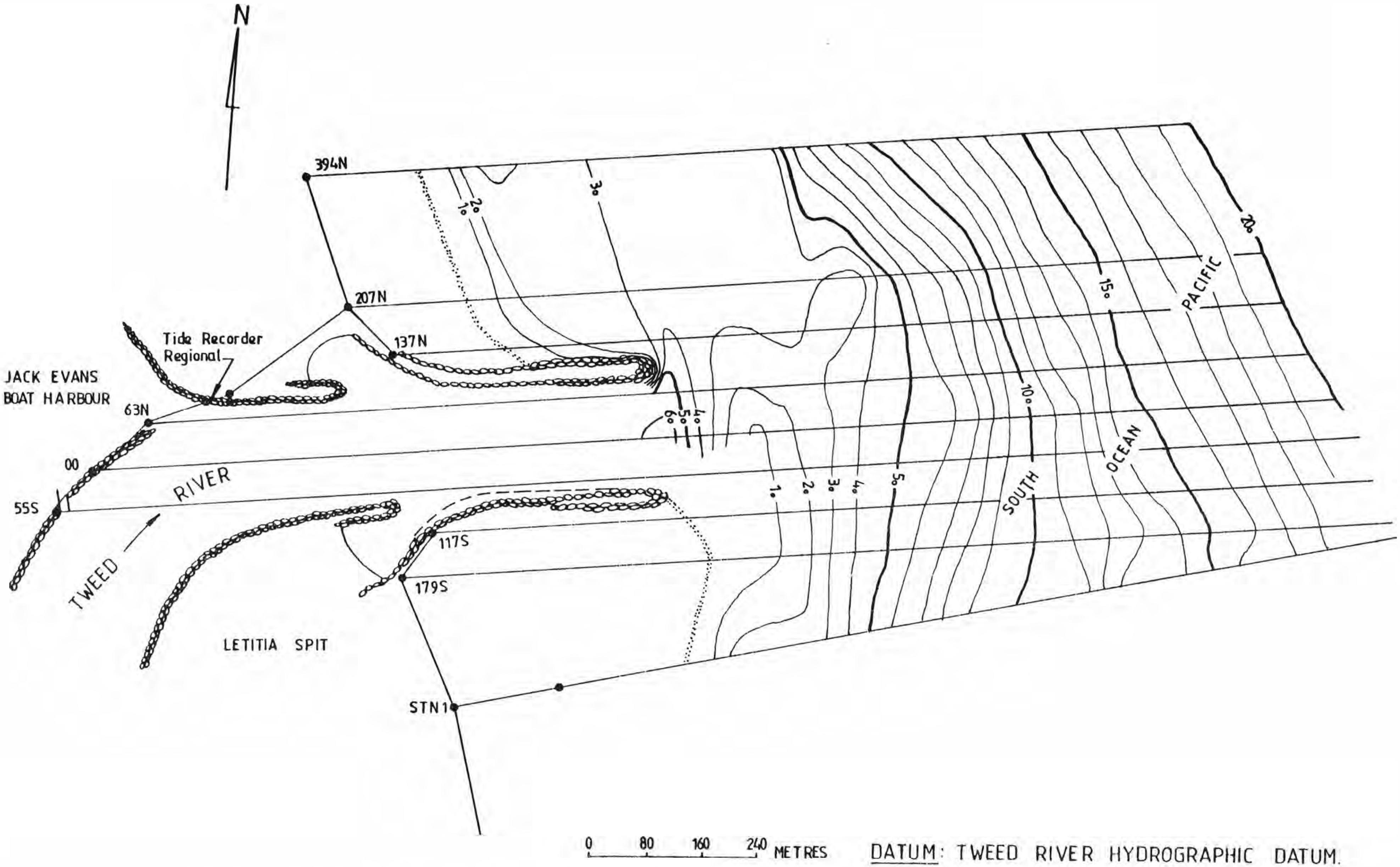
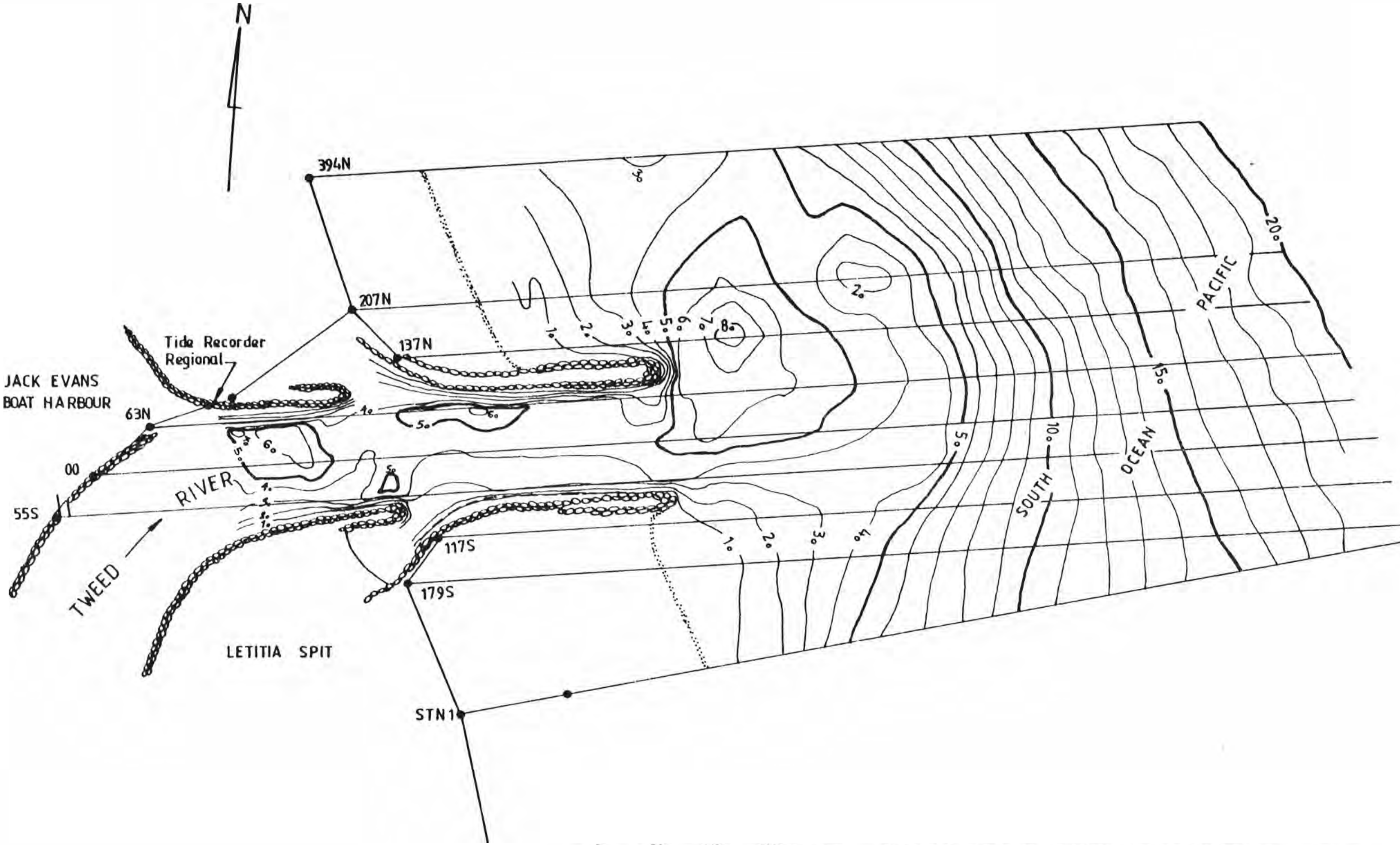


FIGURE 12

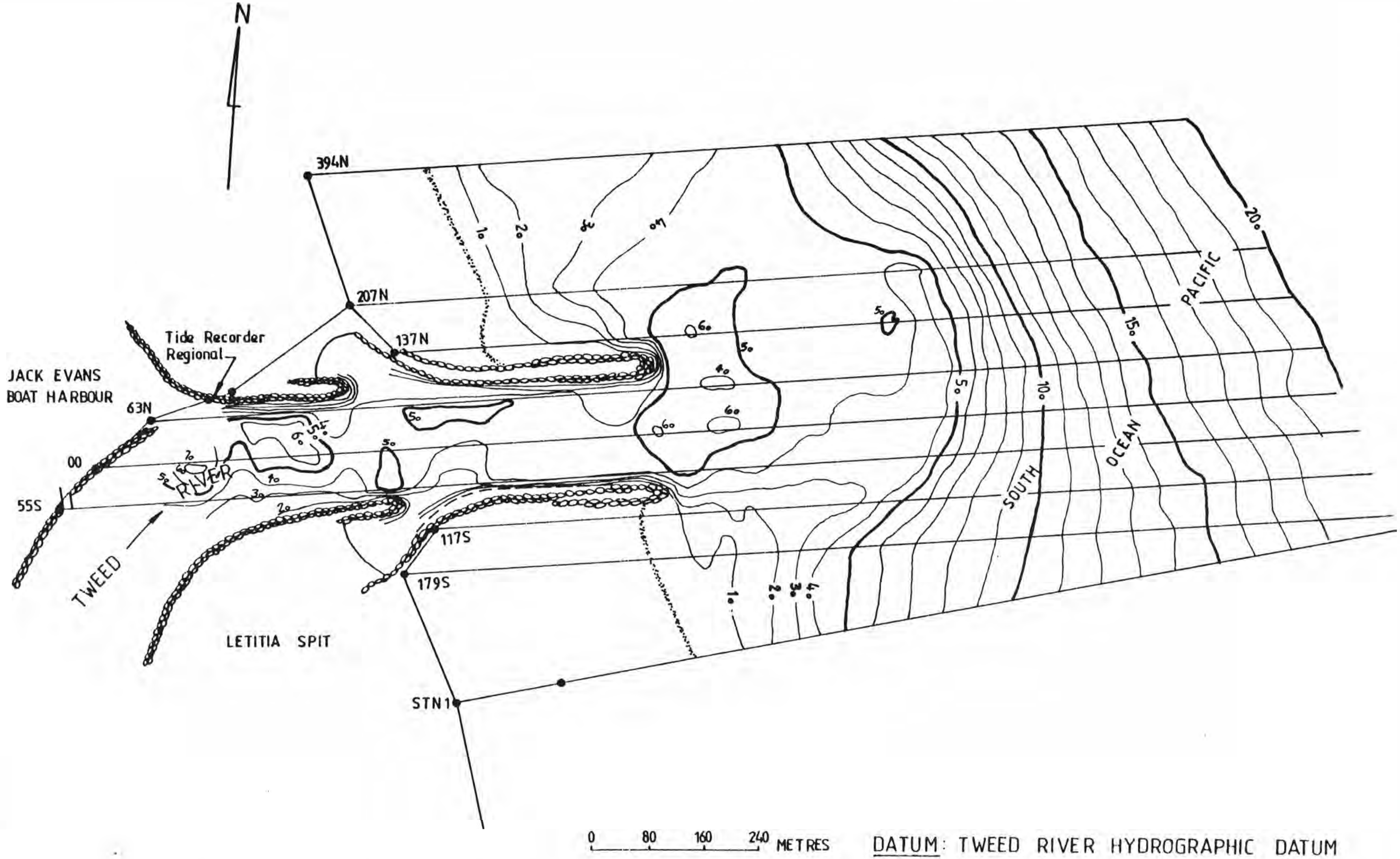
TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 1st JUNE 1978



0 80 160 240 METRES   DATUM: TWEED RIVER HYDROGRAPHIC DATUM

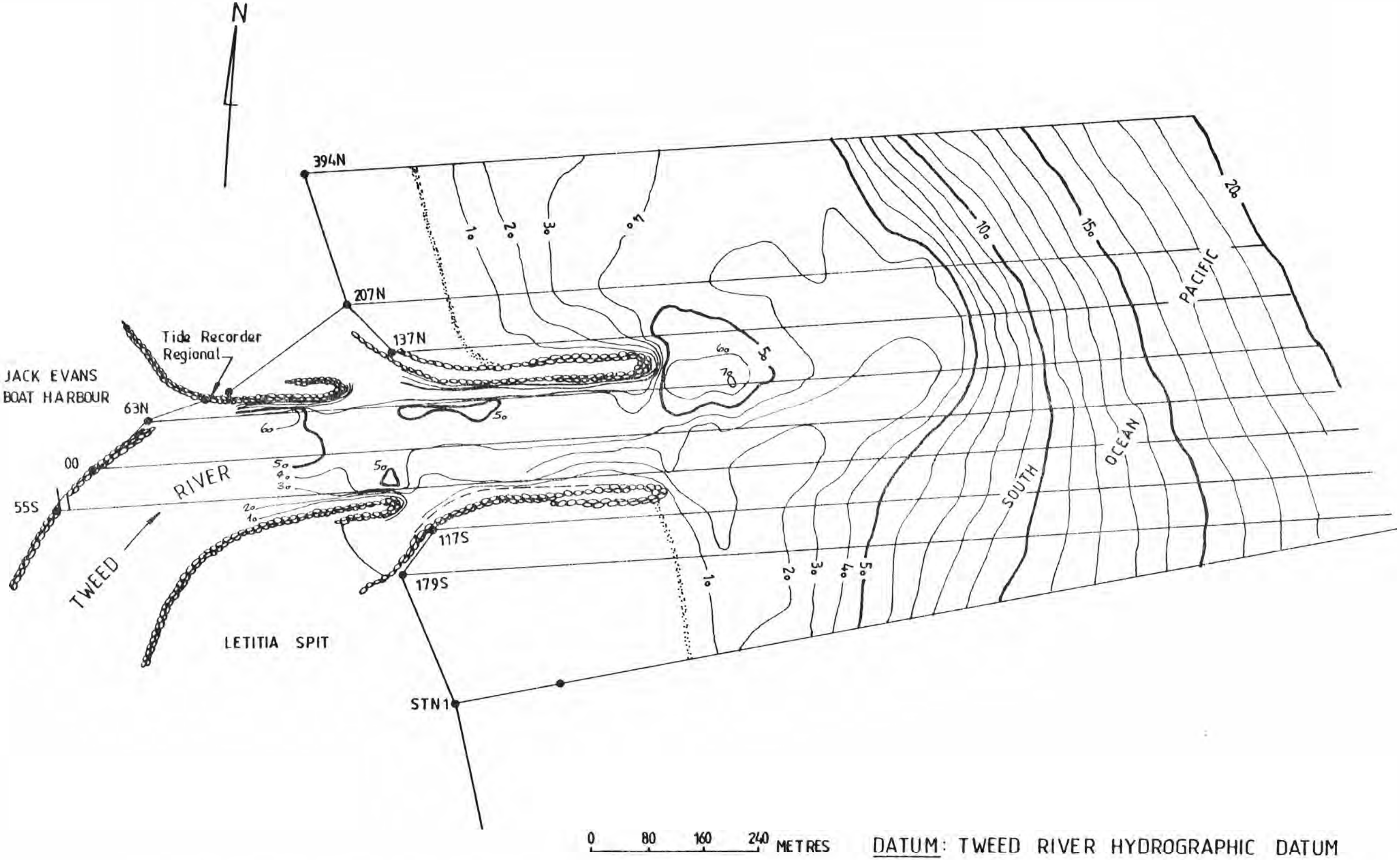
TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 17th JANUARY 1979

FIGURE 12 CONTD.



TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 26th APRIL 1979

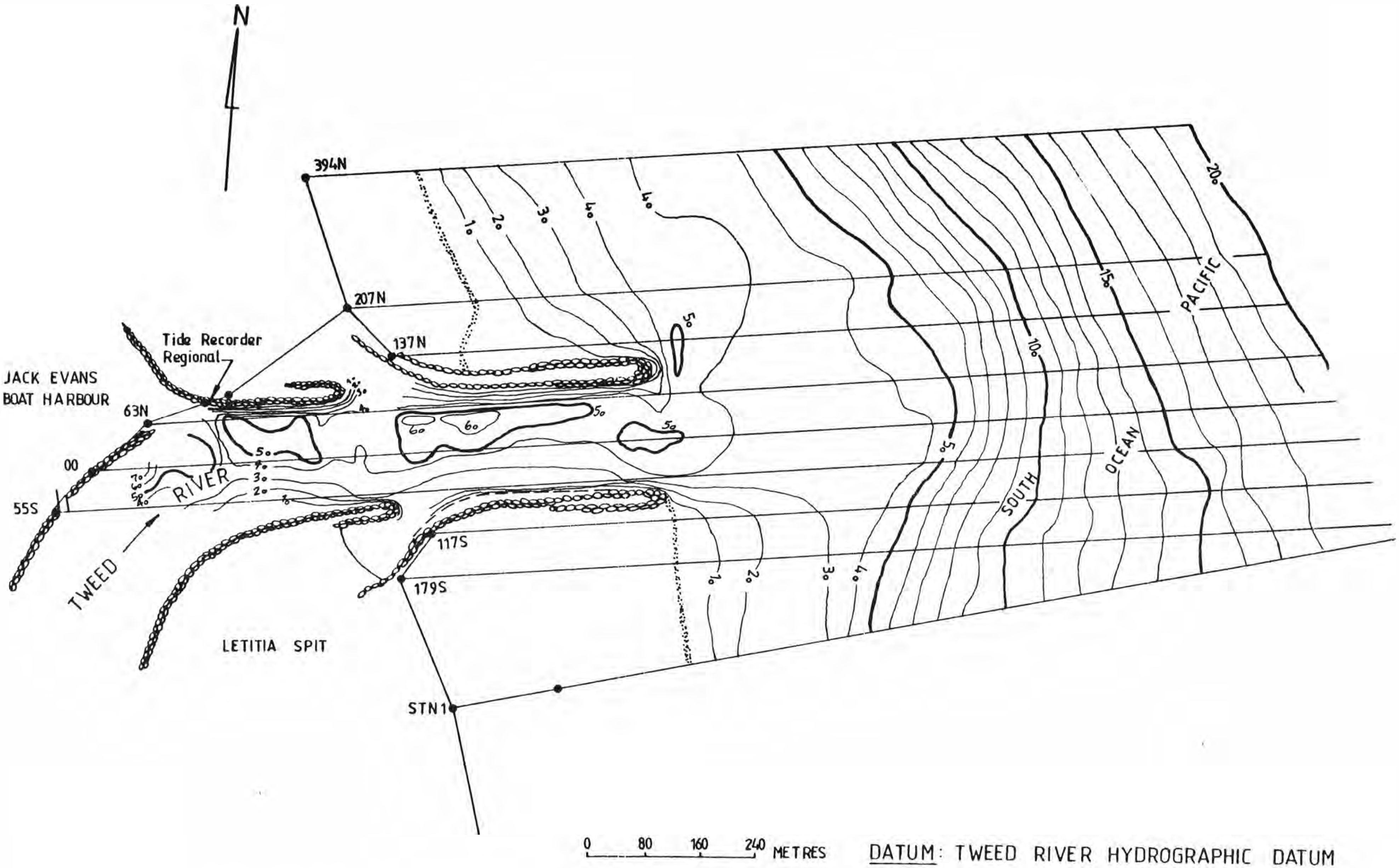
FIGURE 12 CONTD.



DATUM: TWEED RIVER HYDROGRAPHIC DATUM

TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 8-9th OCTOBER 1979

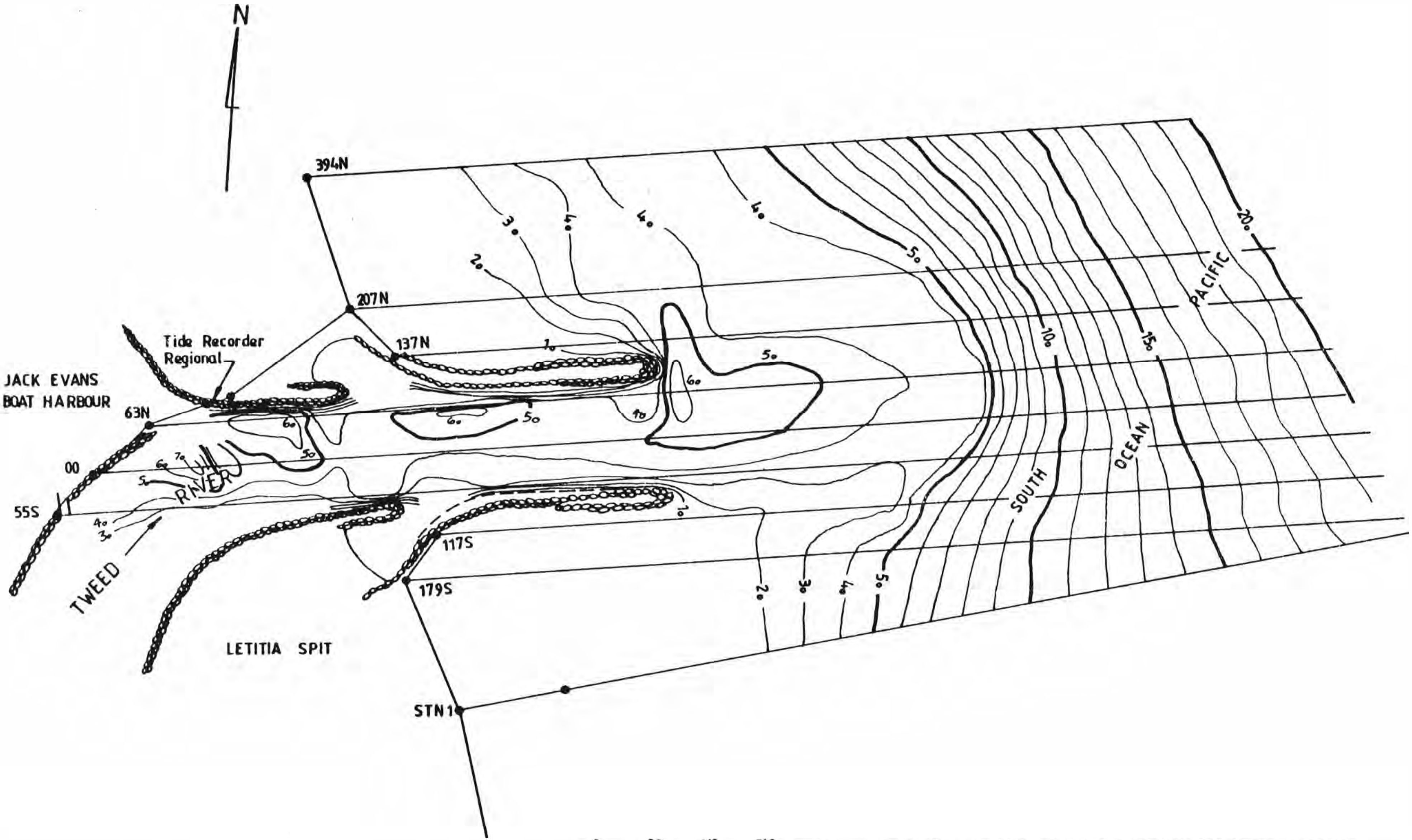
FIGURE 12 CONTD.



TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 2-3rd JUNE 1980

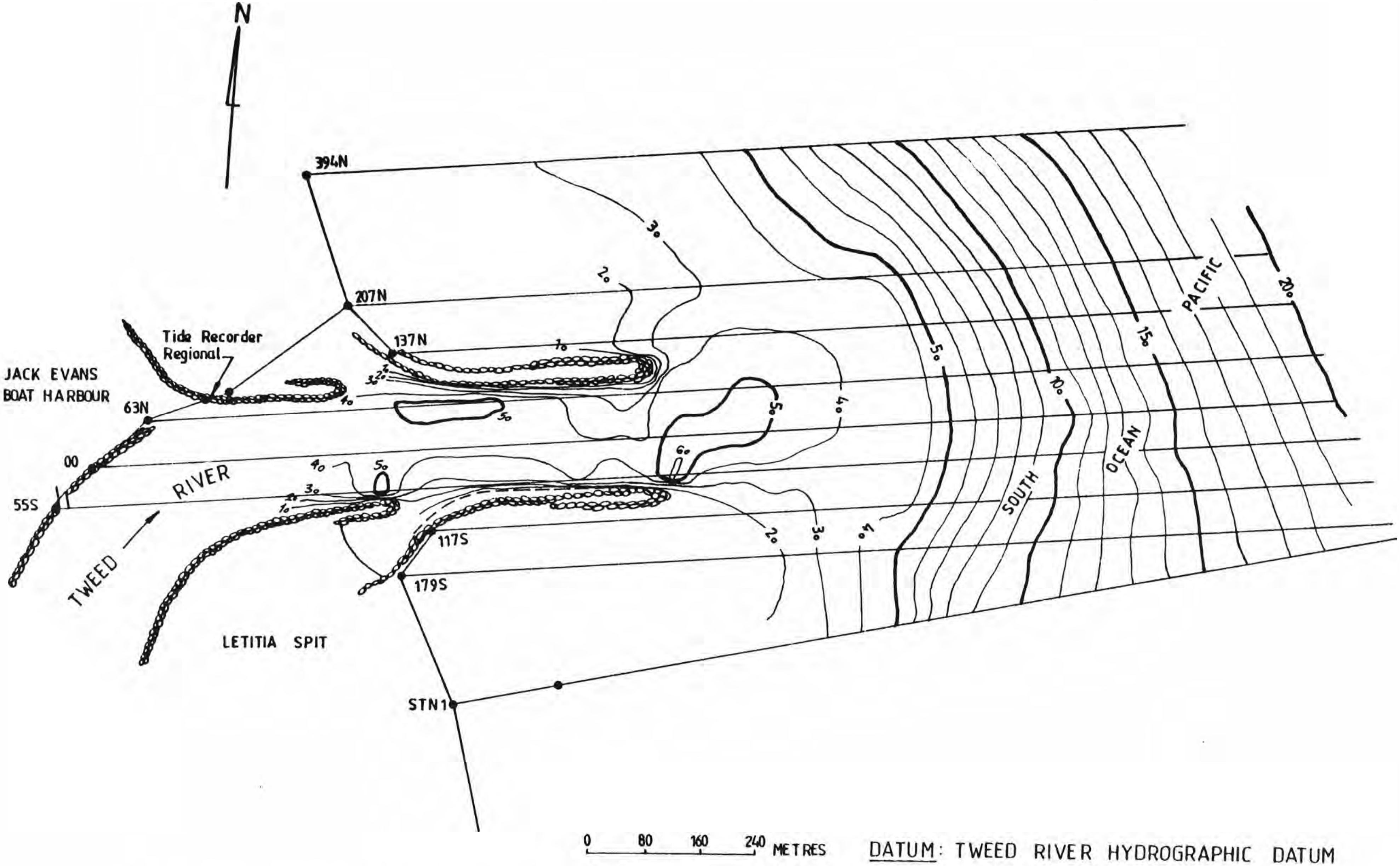
FIGURE 12 CONTD.

FIGURE 12 CONTD.



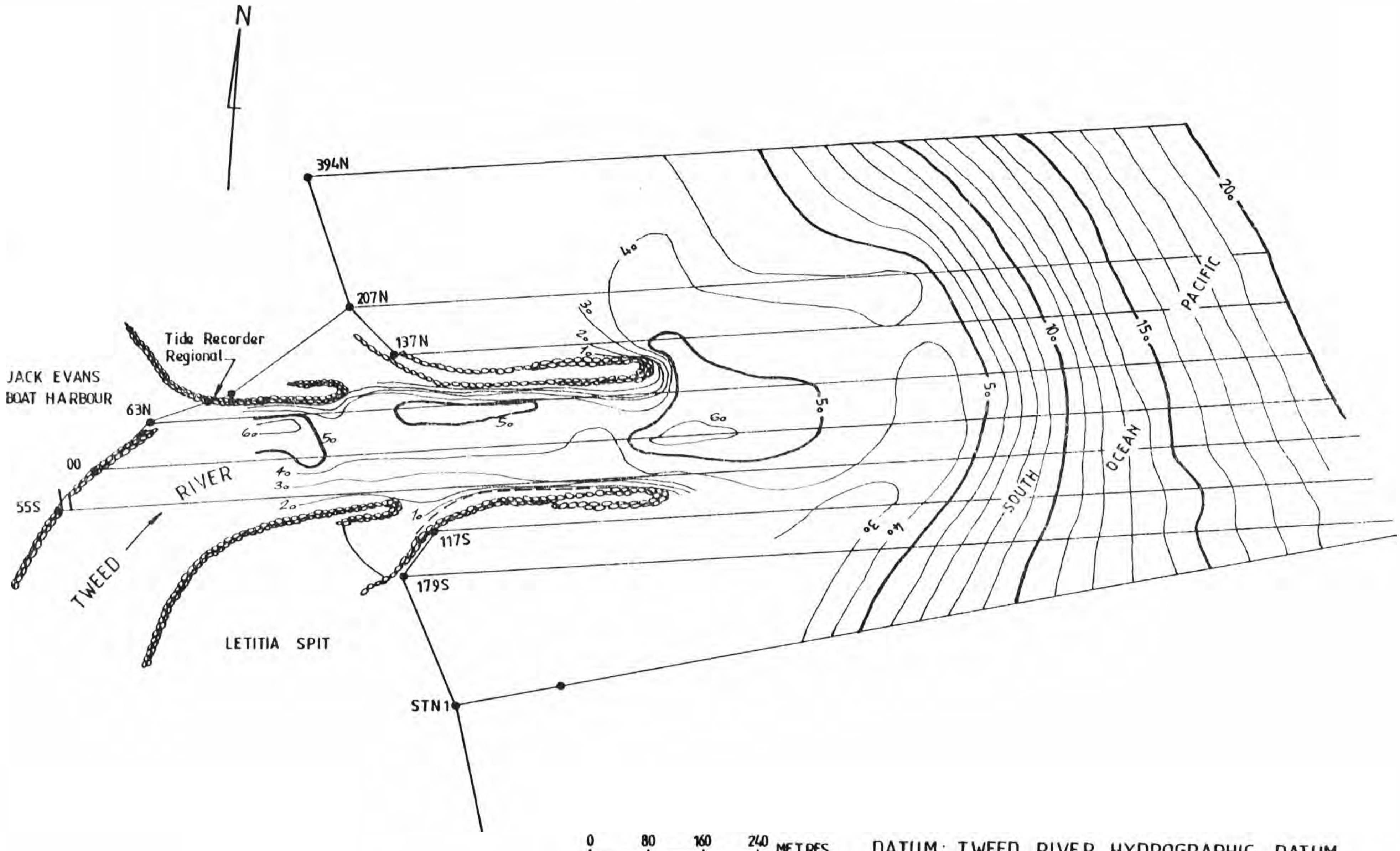
0 80 160 240 METRES DATUM: TWEED RIVER HYDROGRAPHIC DATUM

TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 23rd SEPTEMBER 1980



TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 23rd APRIL 1982

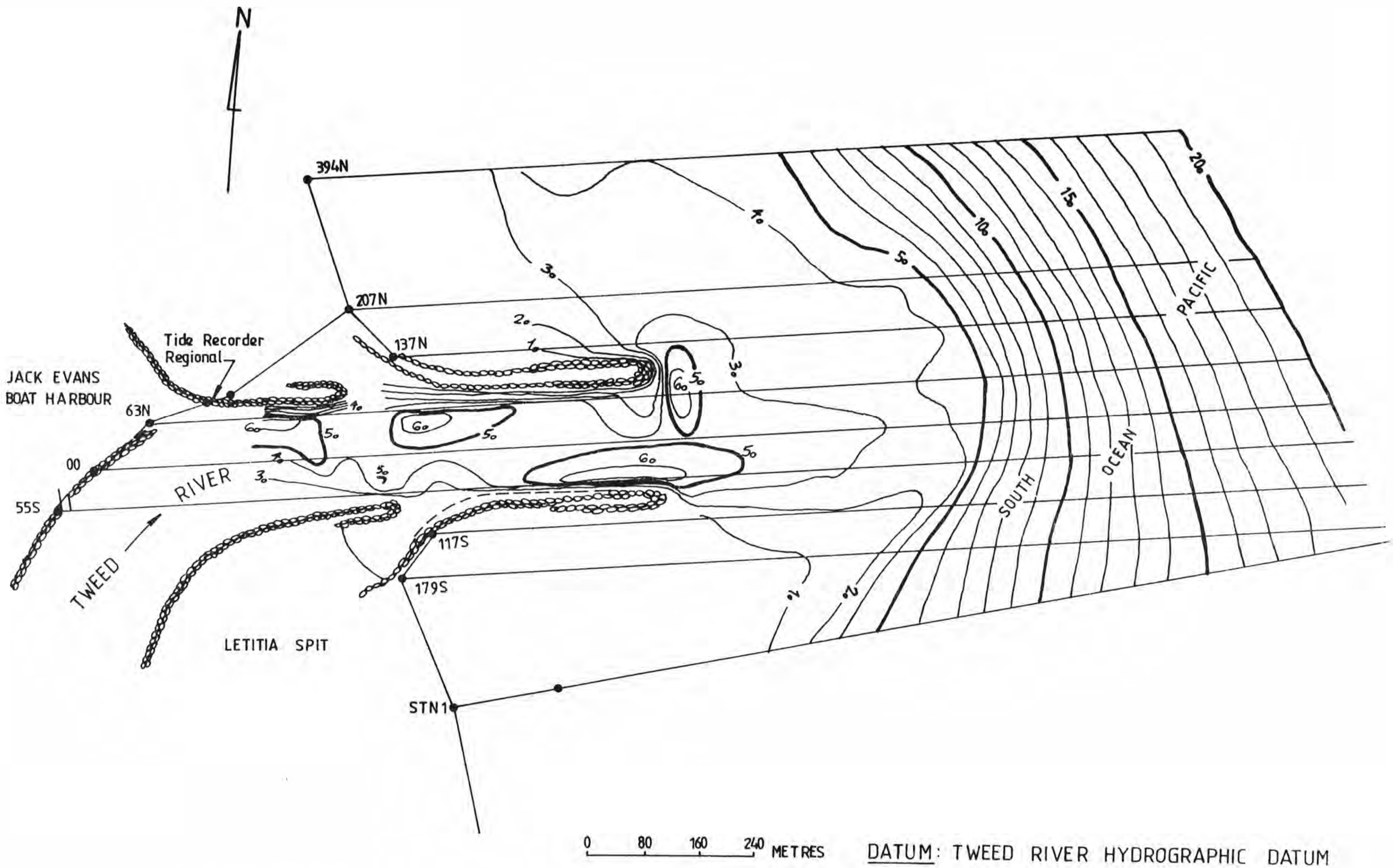
FIGURE 12 CONTD.



DATUM: TWEED RIVER HYDROGRAPHIC DATUM

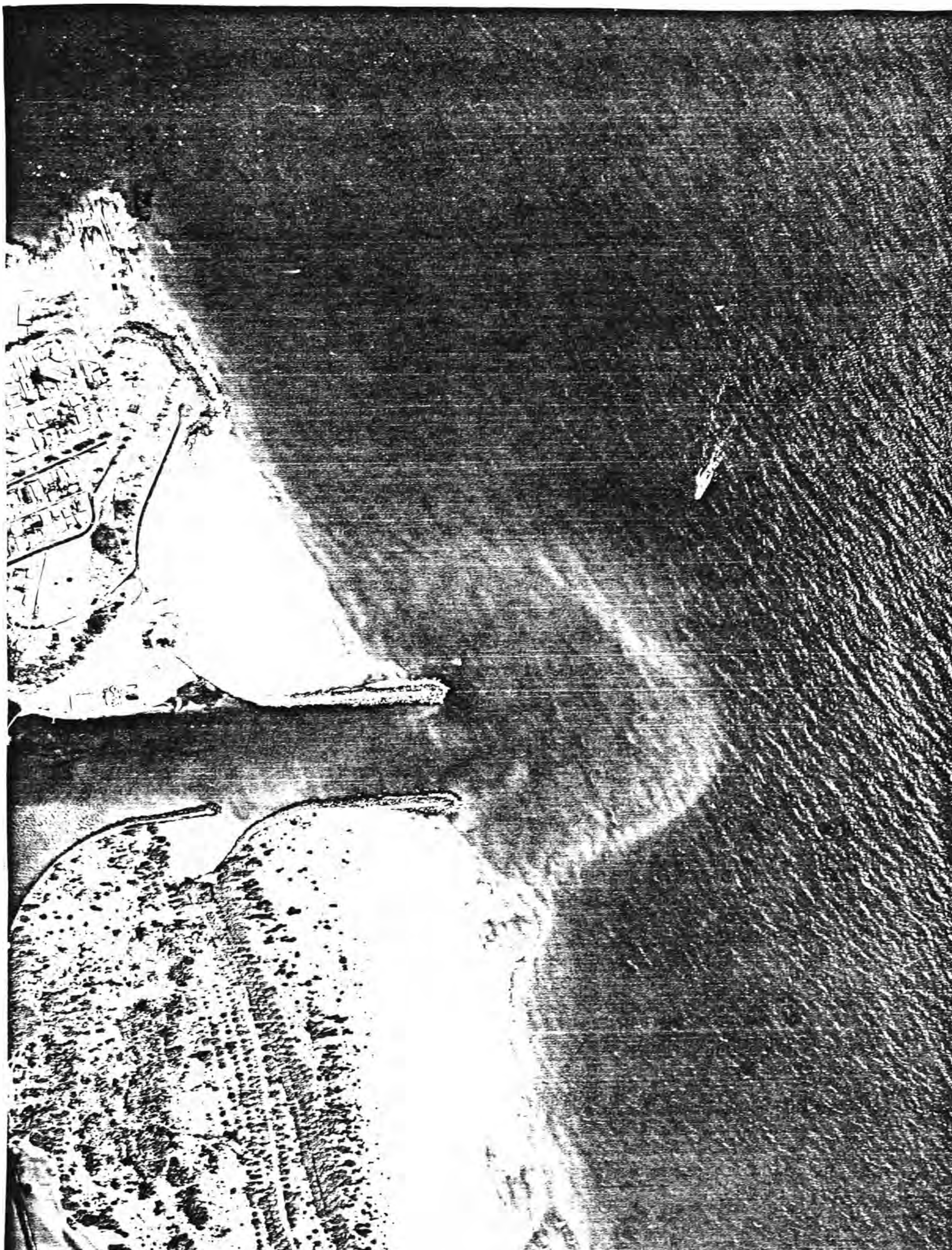
TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 15-16 MARCH 1983

FIGURE 12 CONTD.



TWEED RIVER EBB DELTA BATHYMETRY - SURVEYED 17th FEB 1984

FIGURE 12 CONTD.



PHOTOGRAPH OF TWEED ENTRANCE
TAKEN ON 10TH FEBRUARY 1983

FIGURE 13

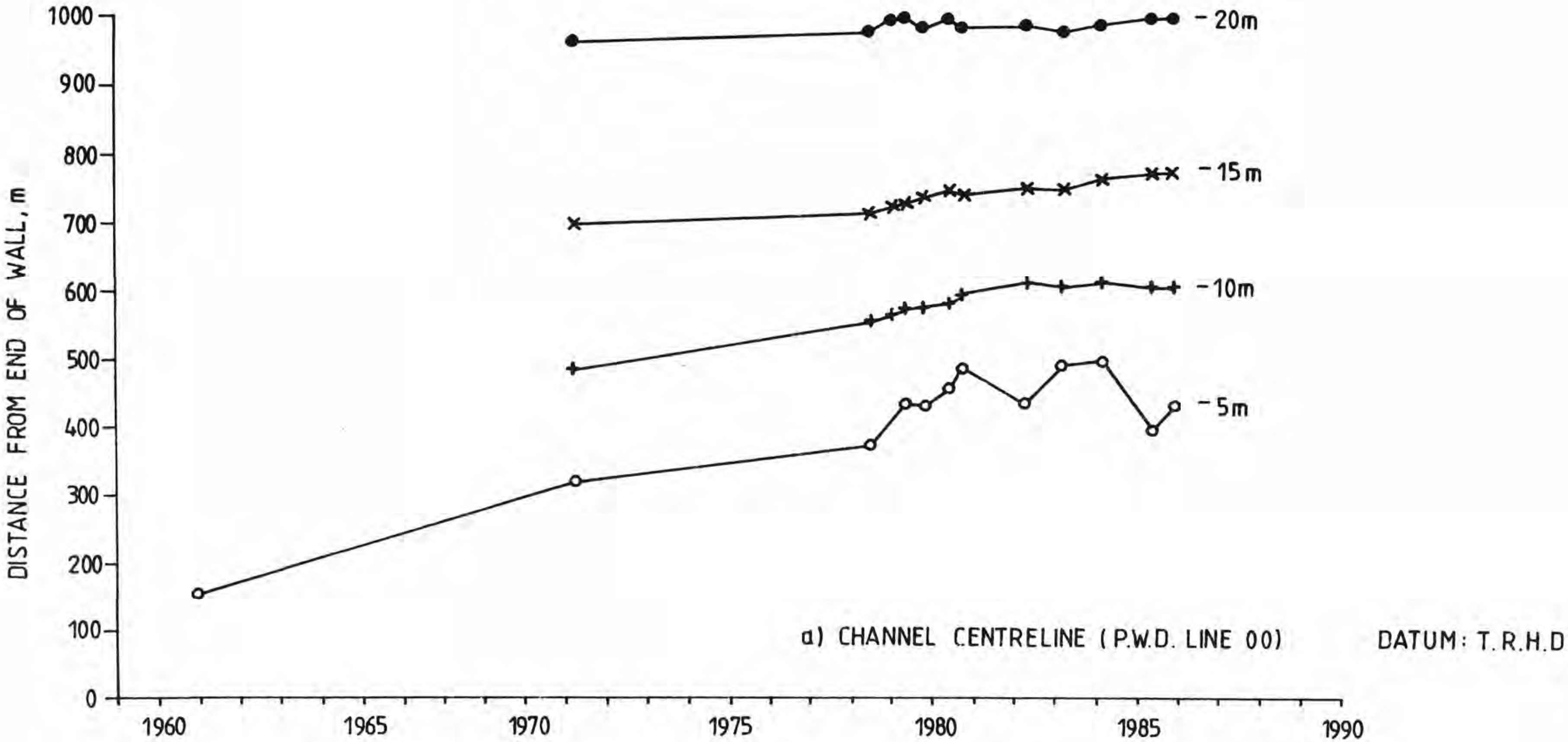
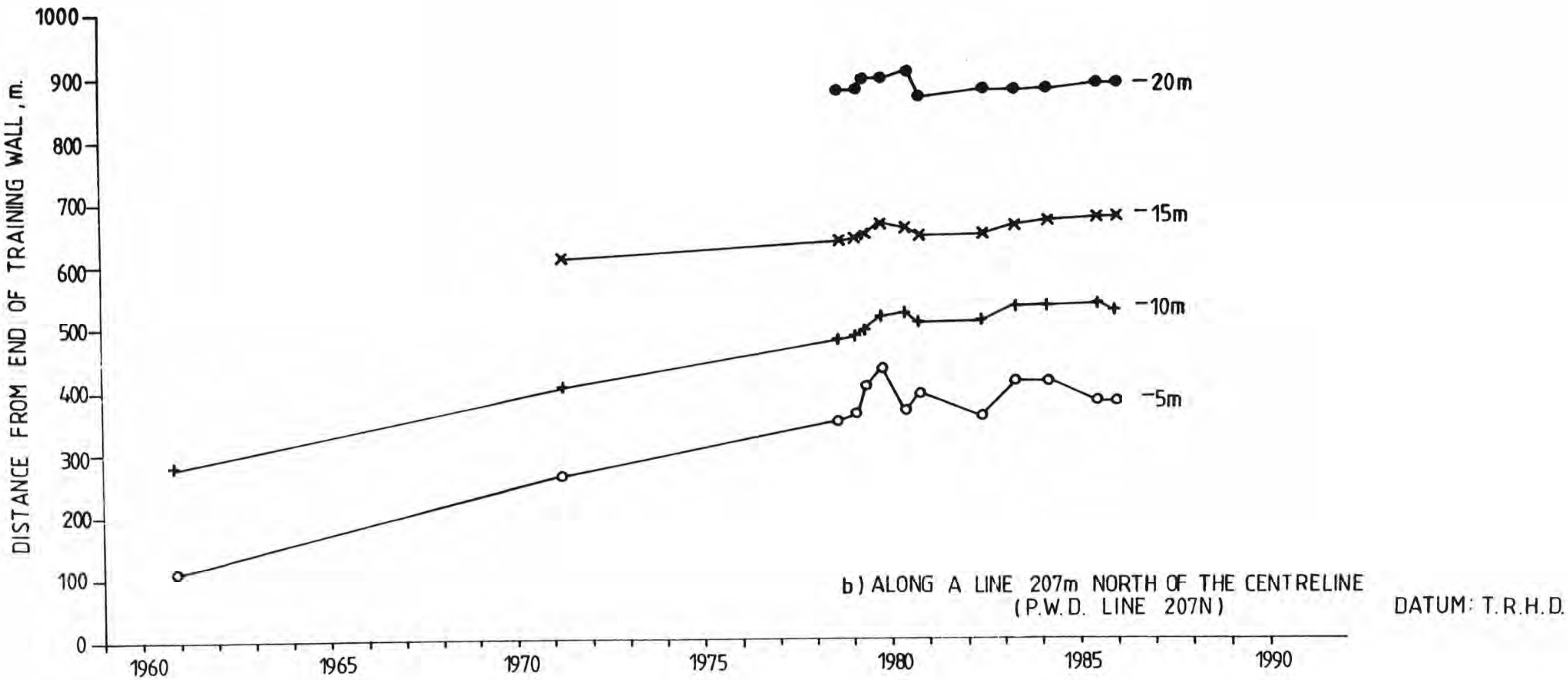


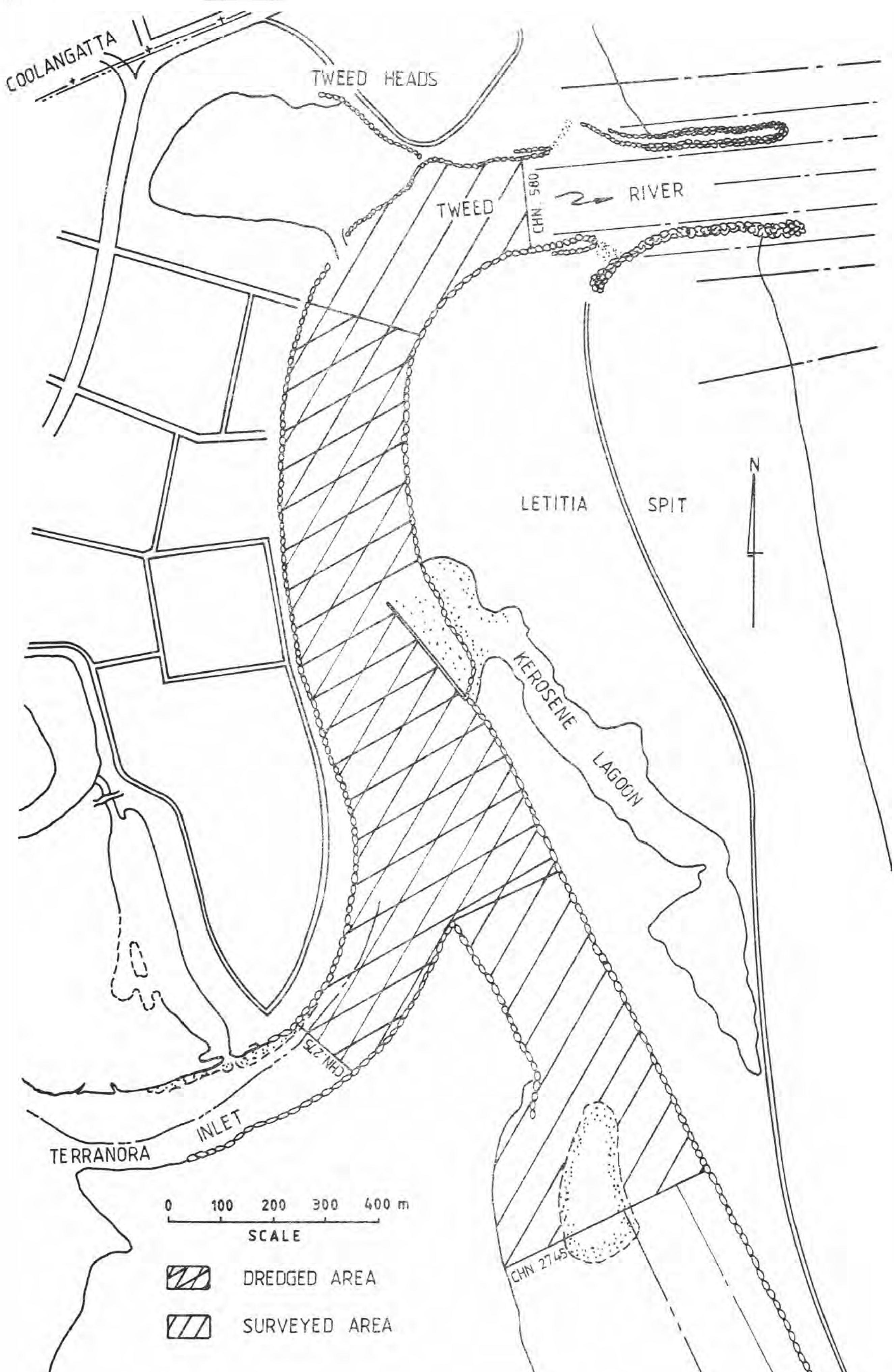
FIGURE 14

GROWTH OF EBB DELTA EXPRESSED AS THE LOCATION OF THE 5, 10, 15, 20m WATER DEPTH CONTOURS



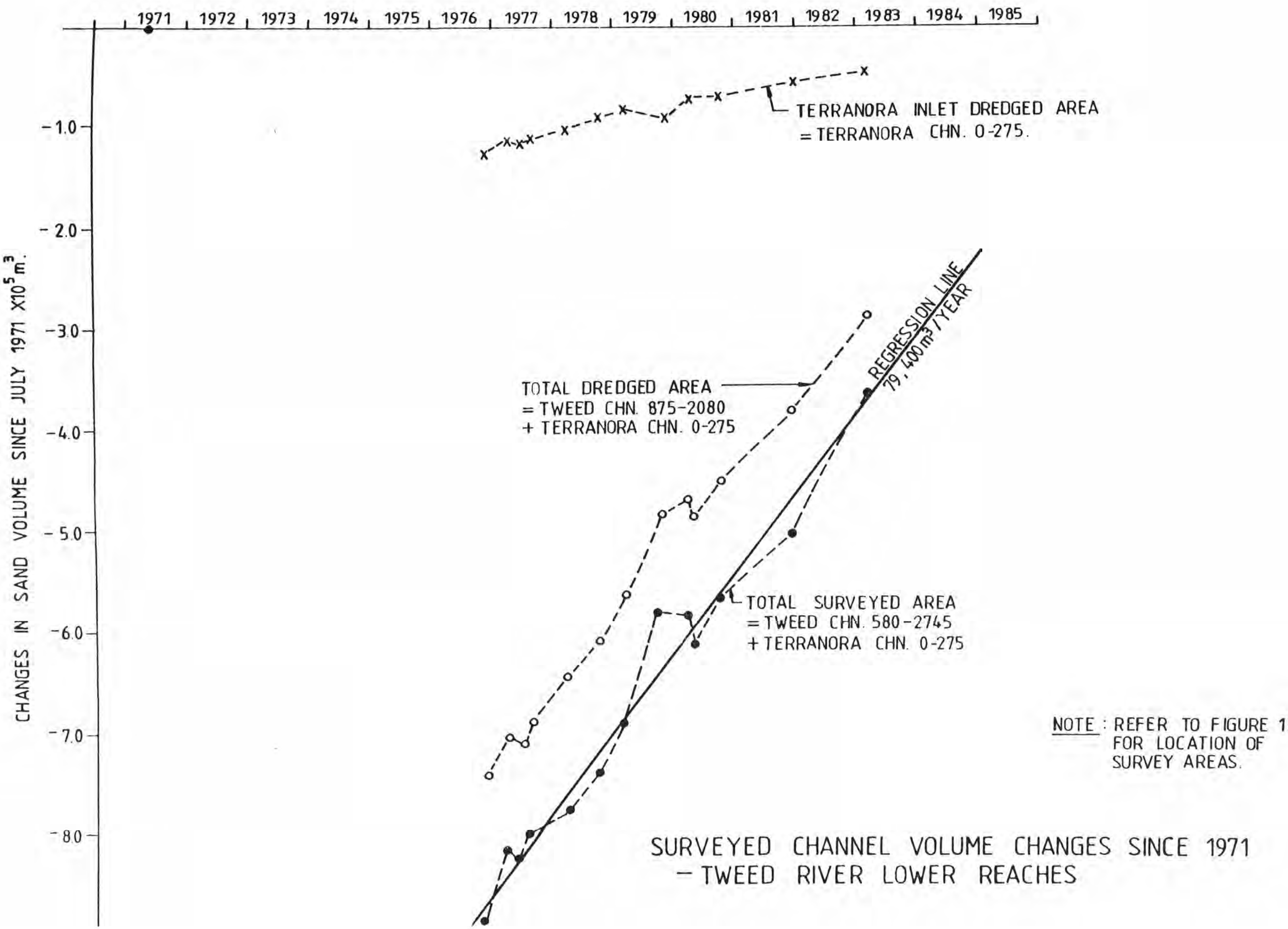
GROWTH OF THE EBB DELTA EXPRESSED AS THE LOCATION OF THE
5,10,15,20m WATER DEPTH CONTOURS

FIGURE 14 CONTD.



GOLD COAST BEACH RE-PLENISHMENT DREDGED AREA
AND TWEED RIVER DYNAMICS STUDY SURVEY AREA

FIGURE 15



SURVEYED CHANNEL VOLUME CHANGES SINCE 1971
– TWEED RIVER LOWER REACHES

FIGURE 16

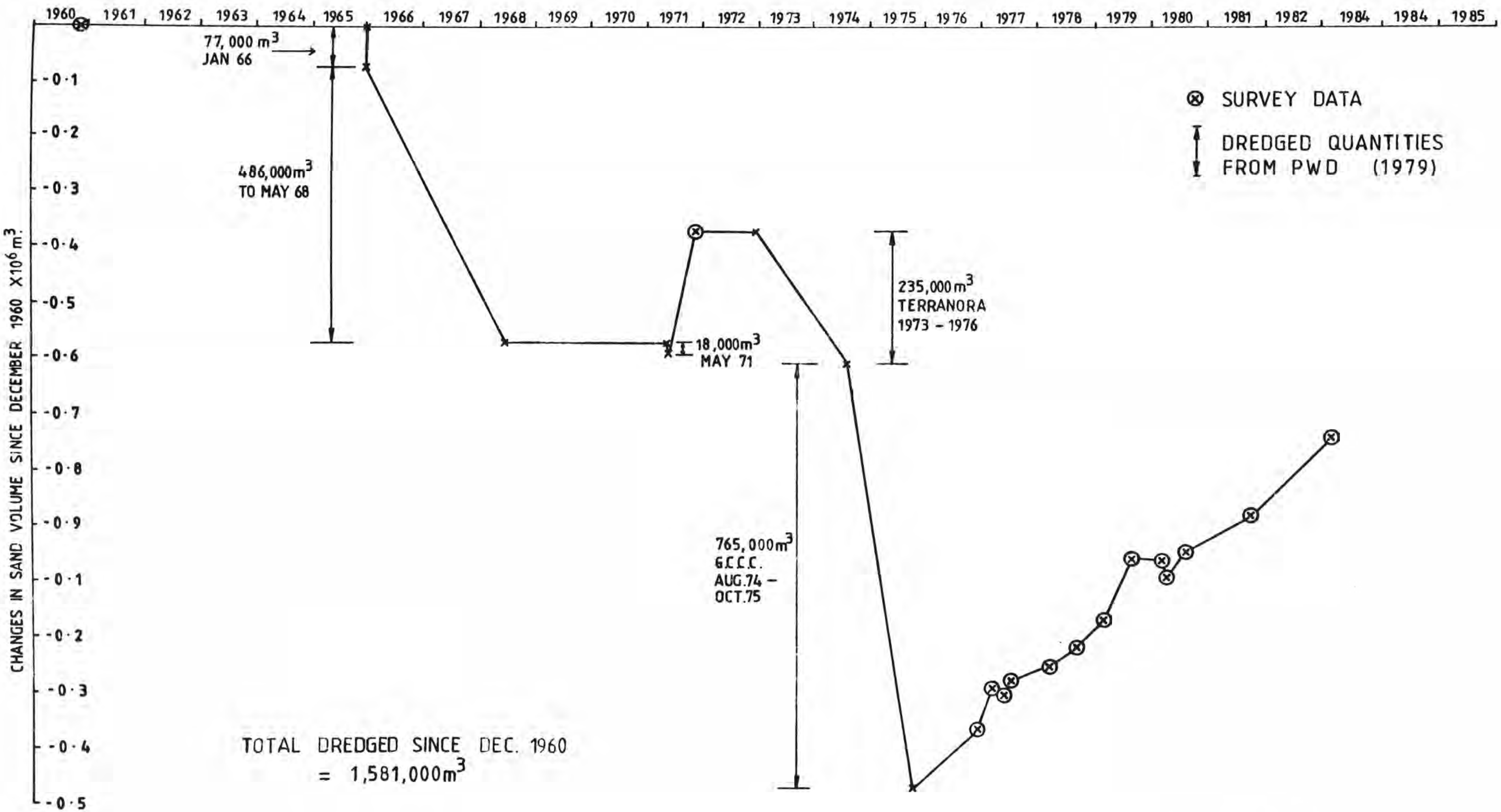
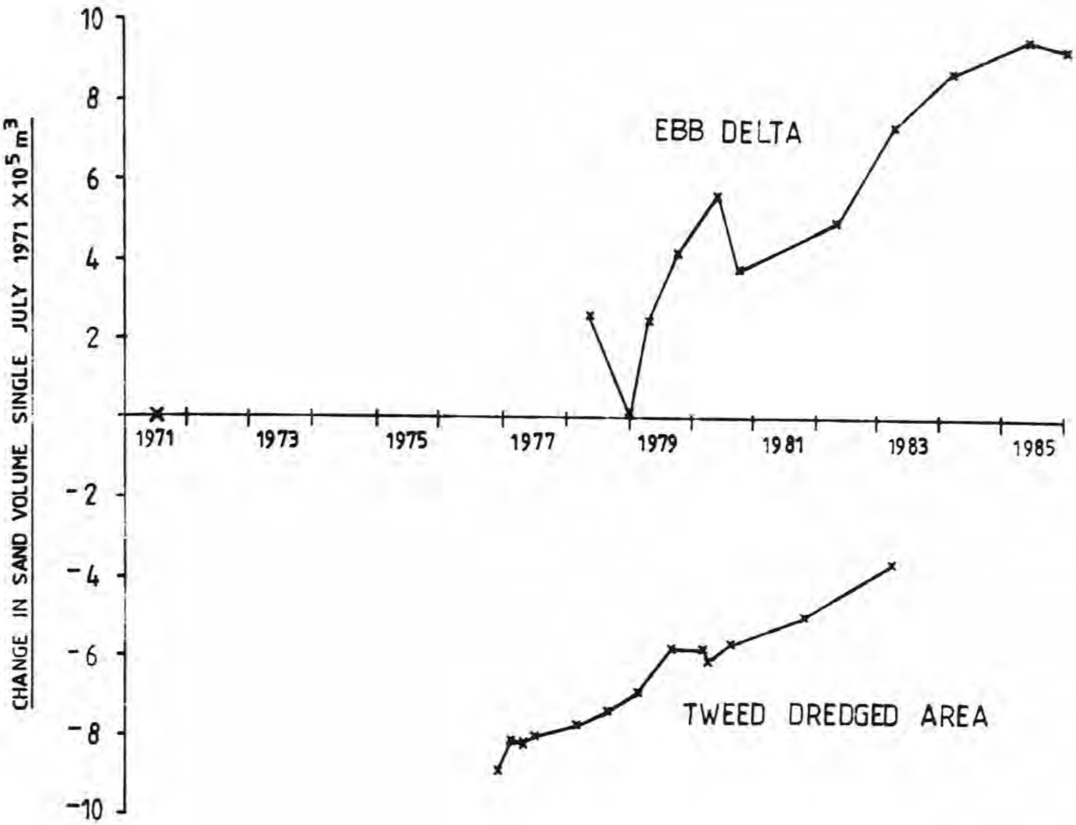
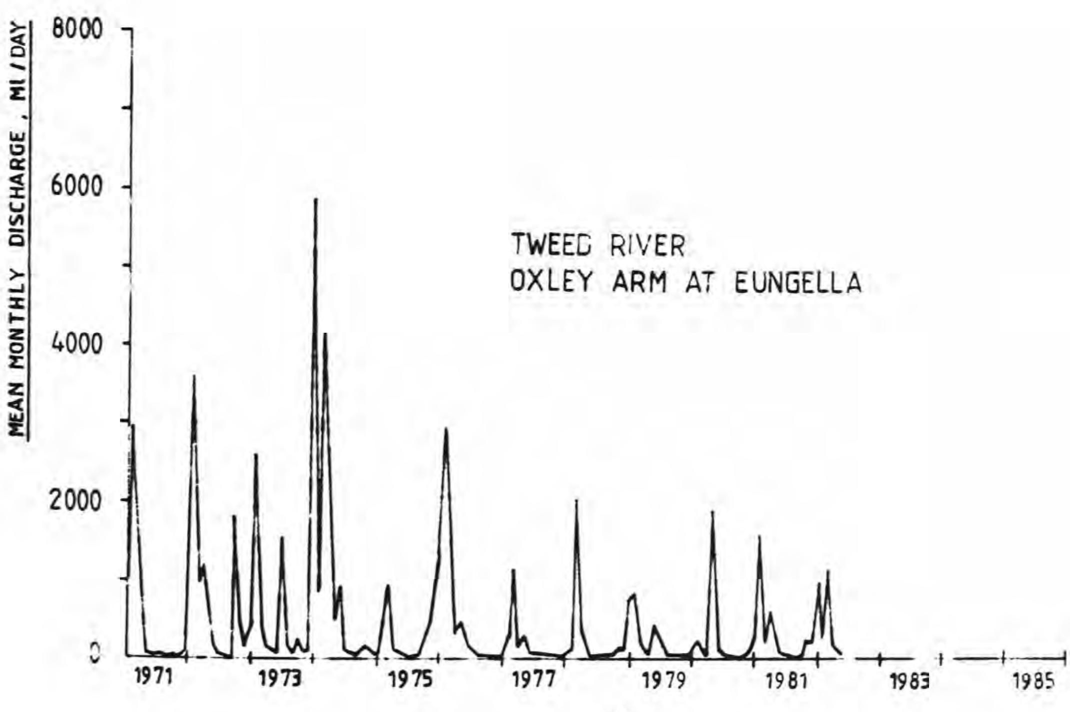


FIGURE 17

SCHEMATIC REPRESENTATION OF THE CHANGES IN THE TWEED RIVER CHANNEL CAPACITY DUE TO DREDGING AND SUBSEQUENT INFILLING

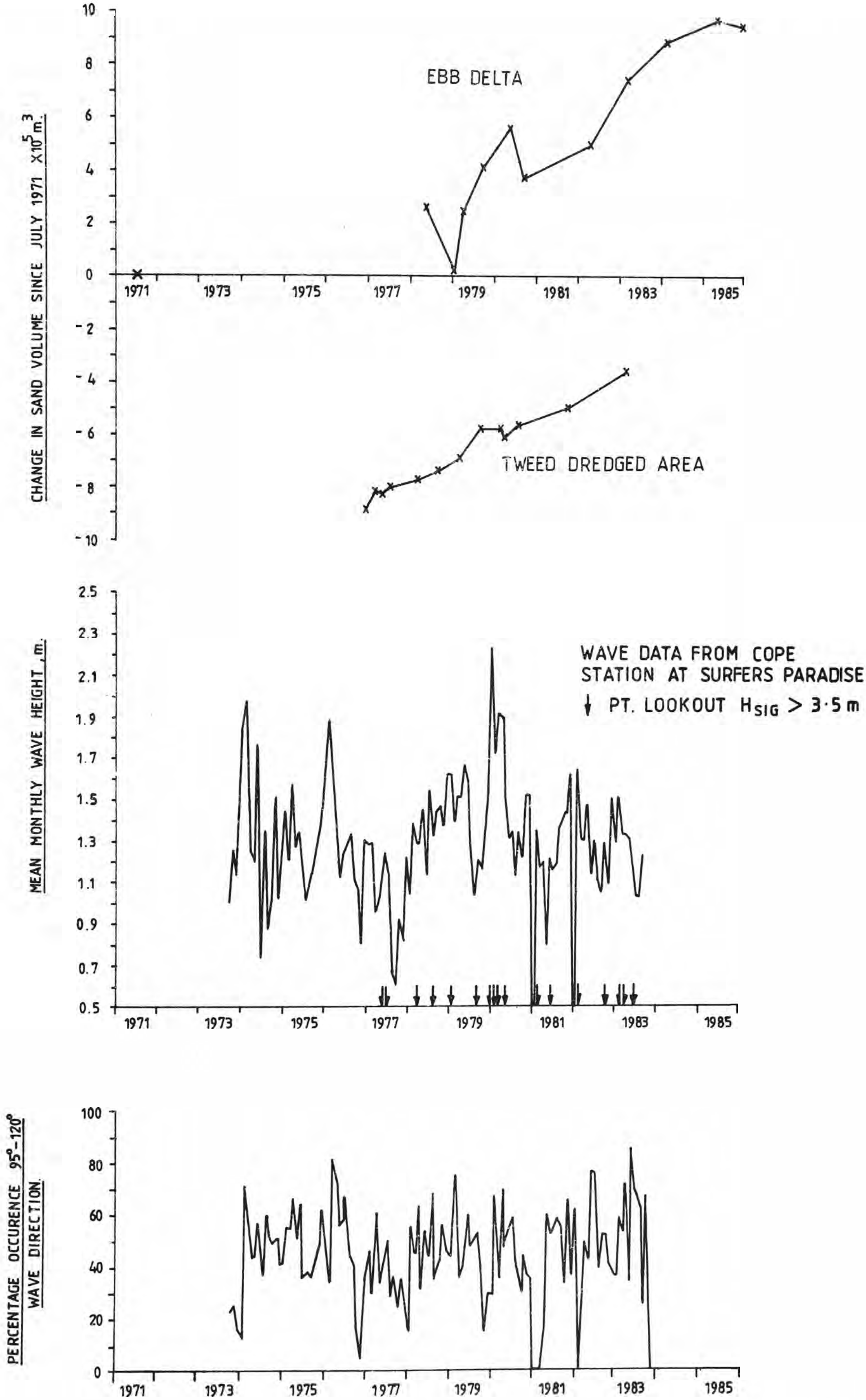




a)

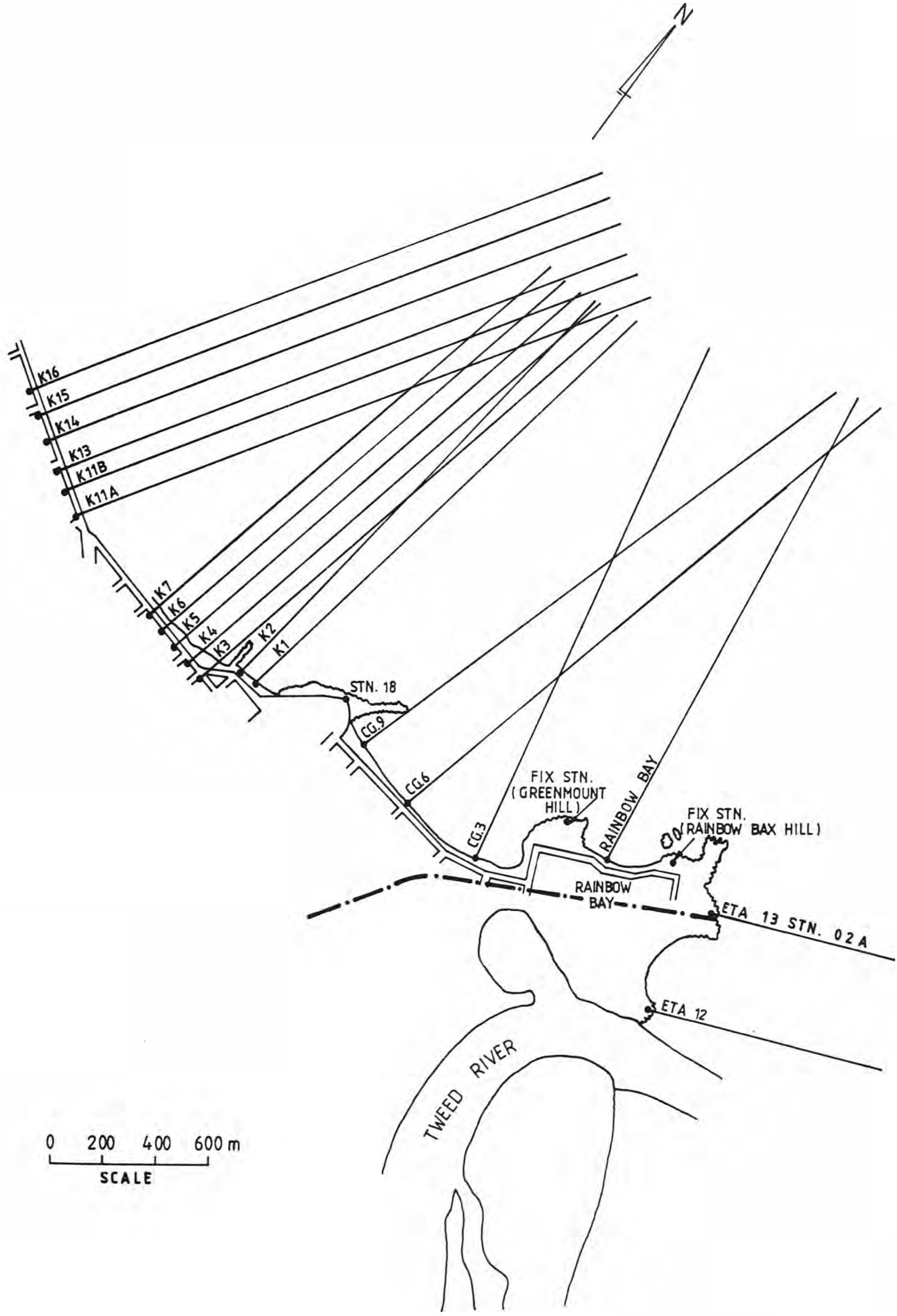
CORRELATION BETWEEN EROSION / ACCRETION EVENTS
AND a) TWEED RIVER DISCHARGE
b) WAVE CLIMATE

FIGURE 18



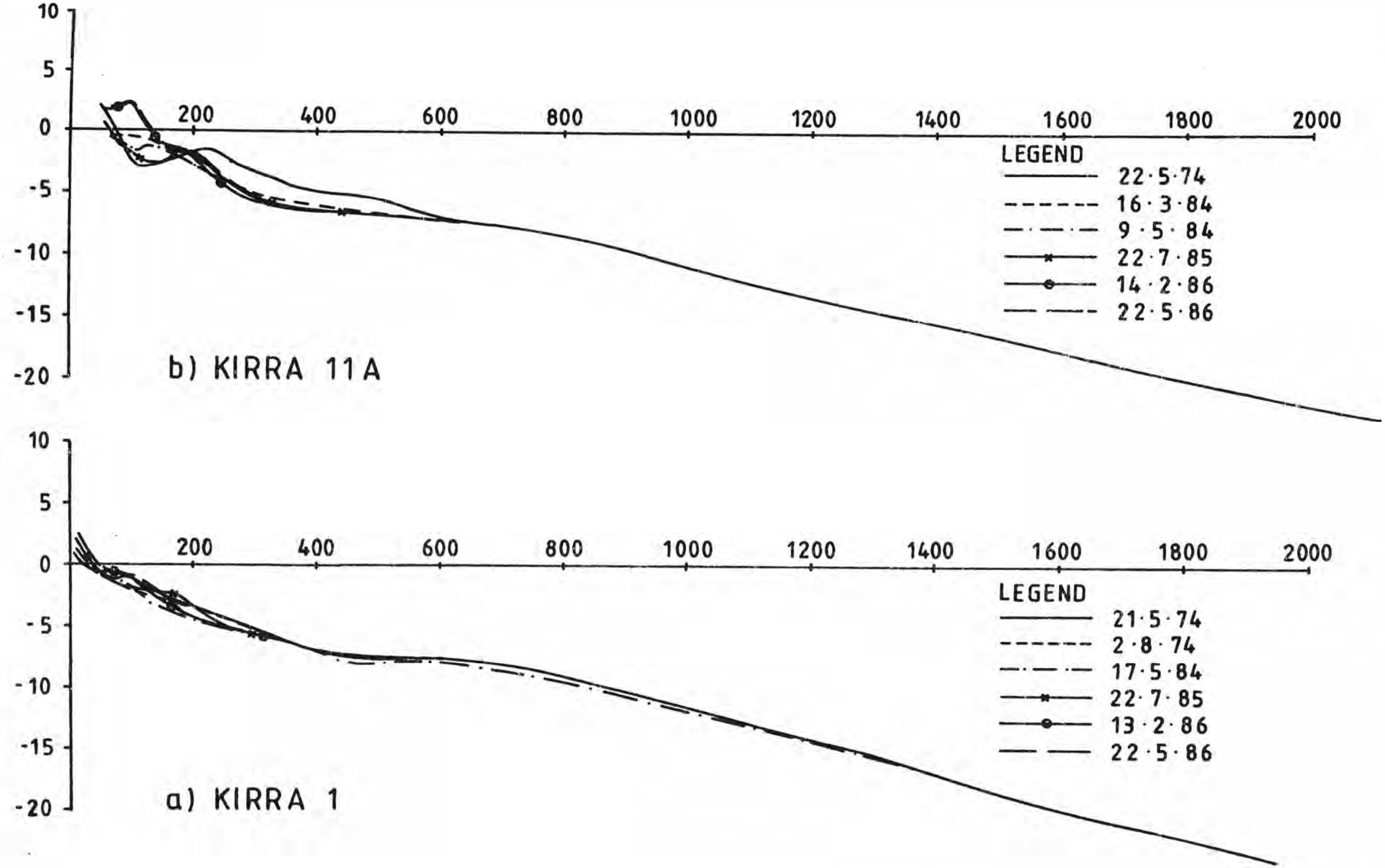
b)

FIGURE 18 CONTD.



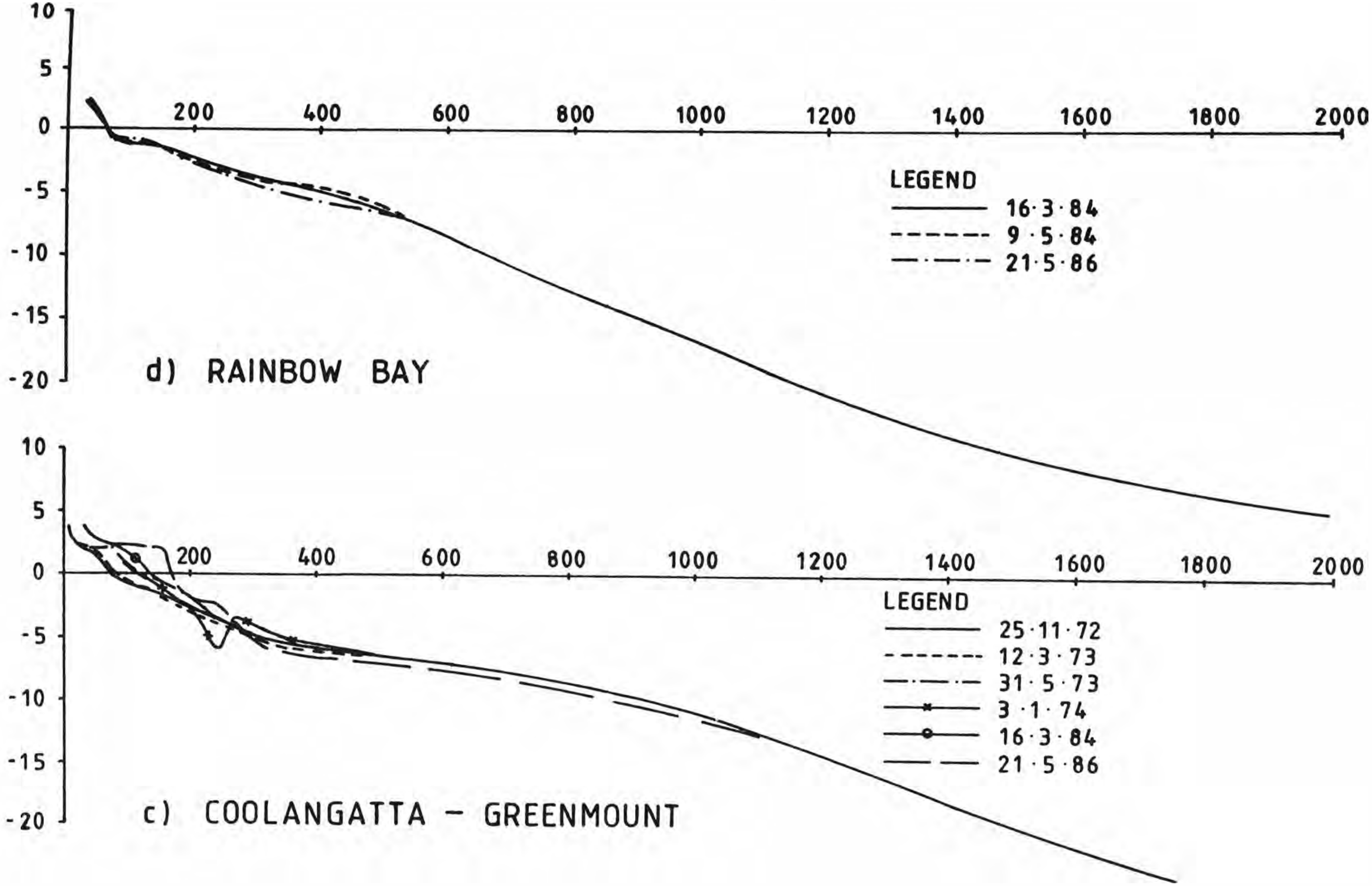
LOCATION OF LINES SURVEYED BY THE GCCC

FIGURE 19



BEACH PROFILES SURVEYED BY THE GCCC

FIGURE 20



BEACH PROFILES SURVEYED BY THE GCCC

FIGURE 20 CONTD.

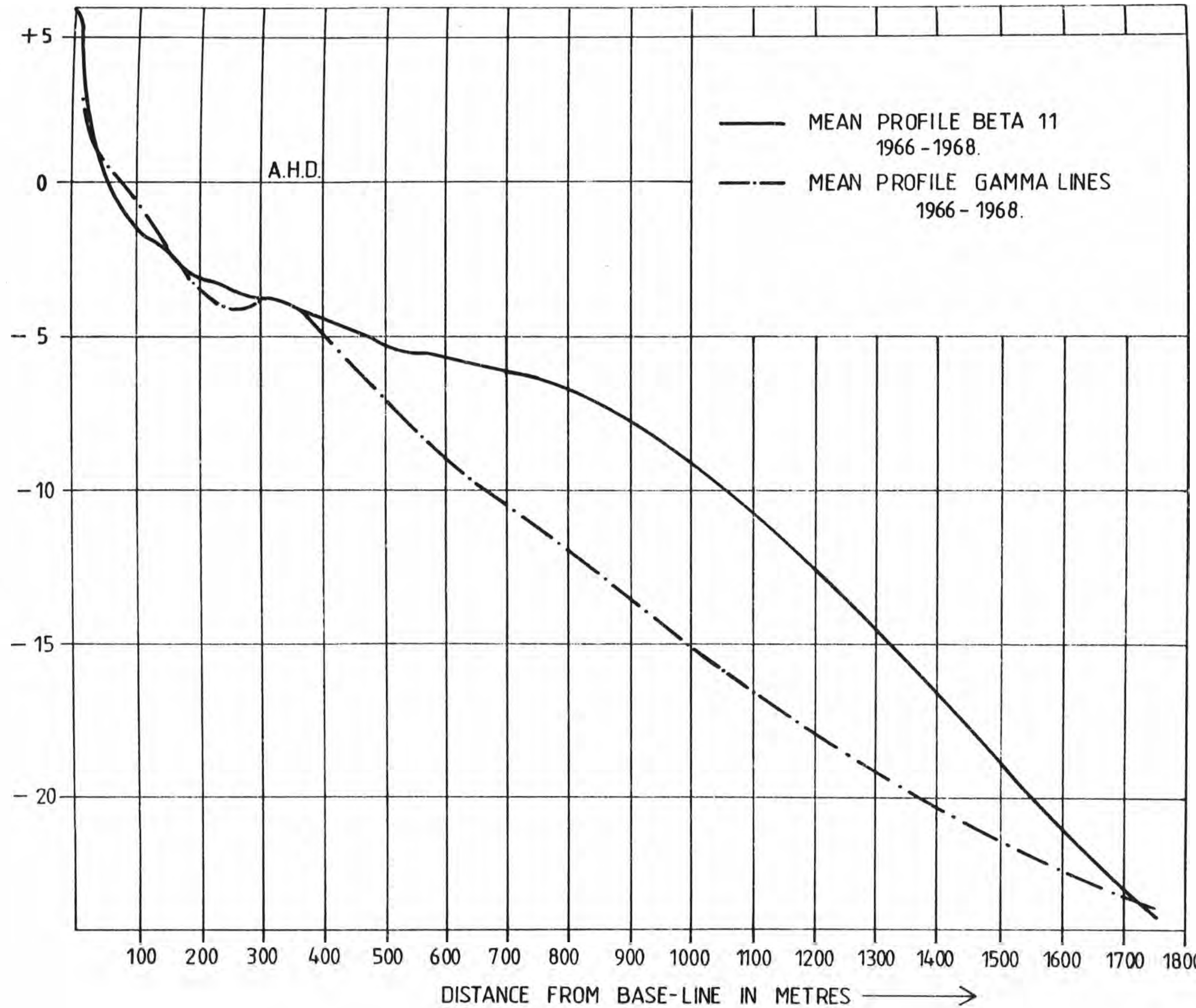


FIGURE 21

OFFSHORE PROFILE FROM GREENMOUNT BEACH
(FROM DELFT, 1970)

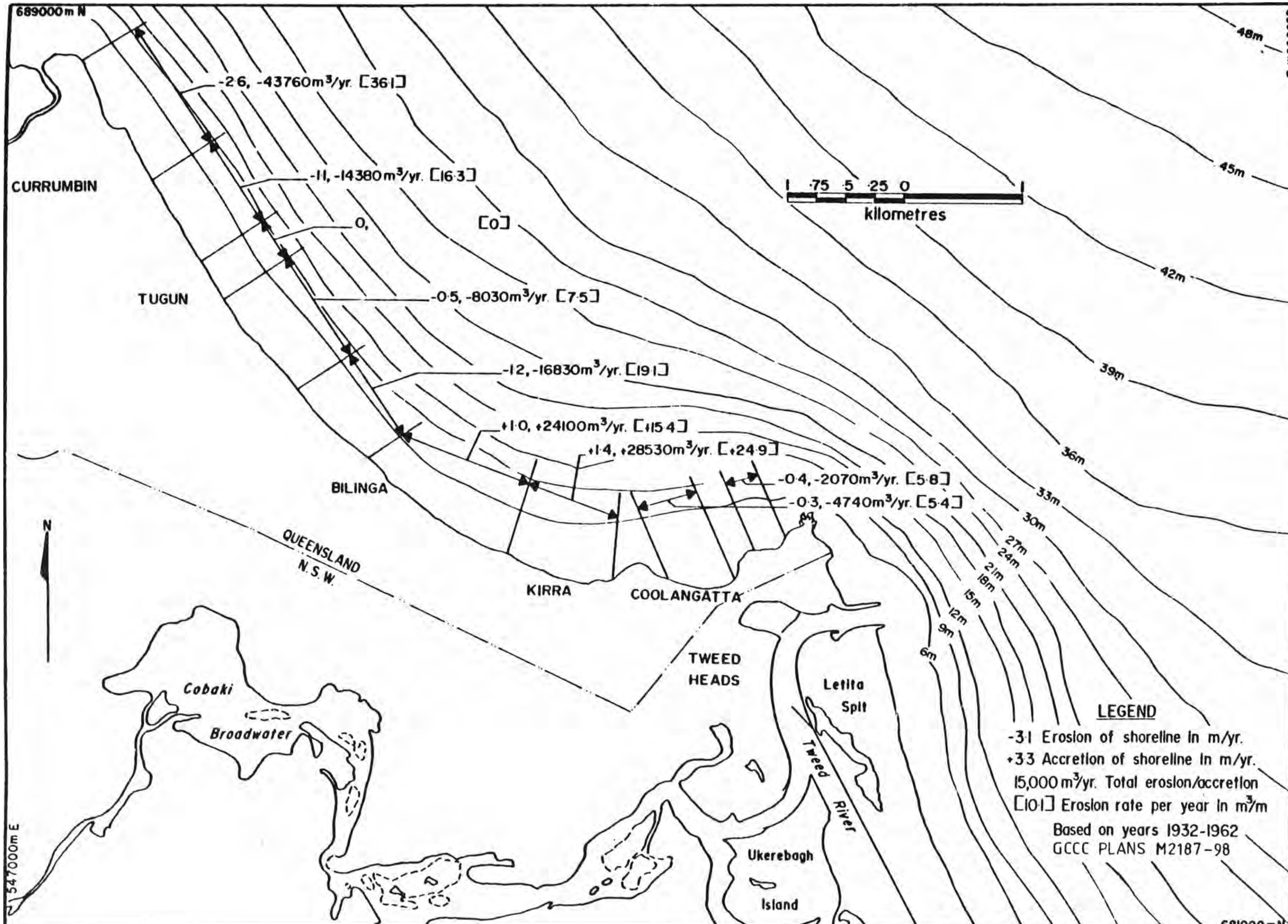


FIGURE 22

EROSION / ACCRETION QUANTITIES 1932 – 1962

FROM DELFT (1970) FIGURE 86

PHOTOGRAPH OF TWEED ENTRANCE
TAKEN IN AUGUST 1962

FIGURE 23

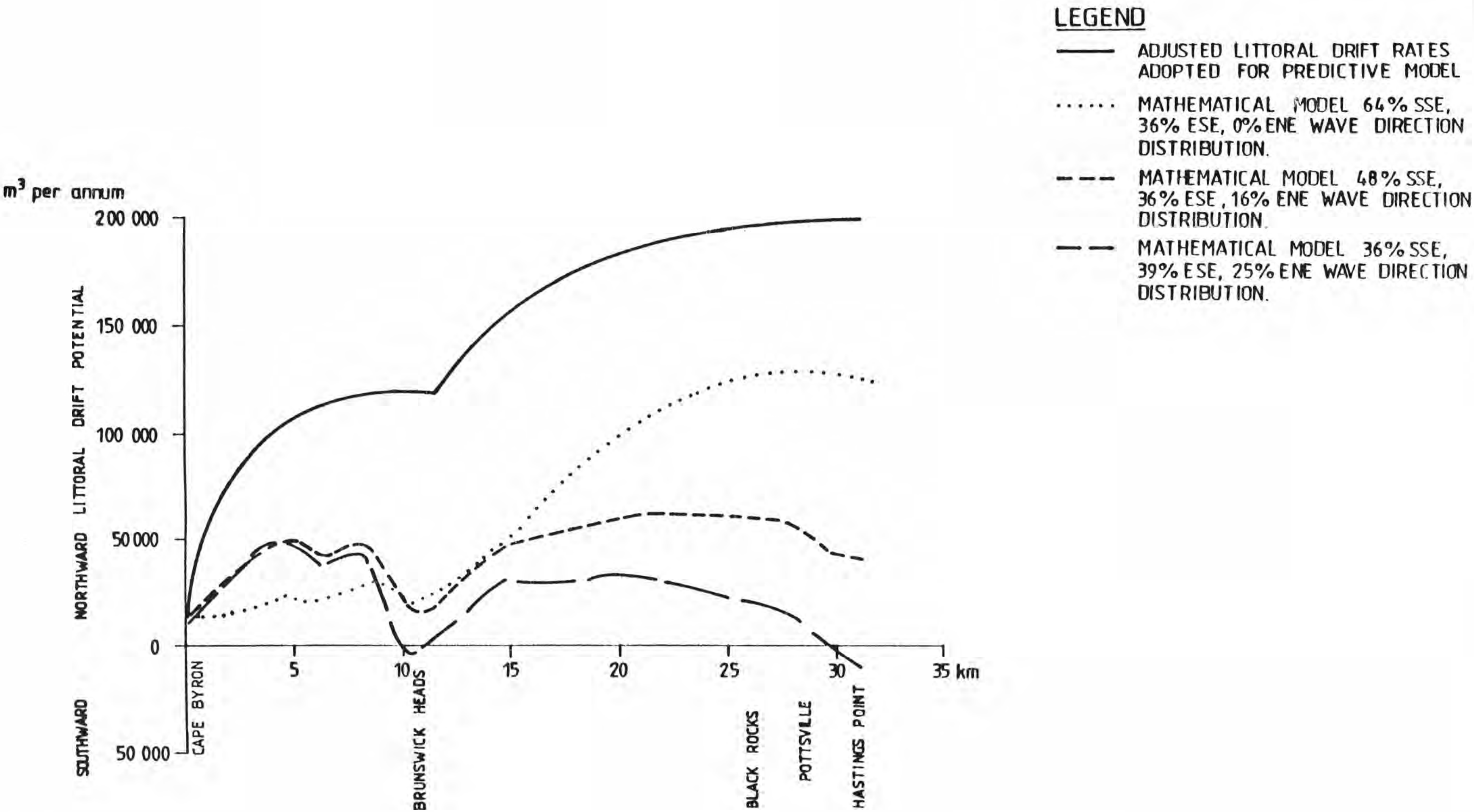
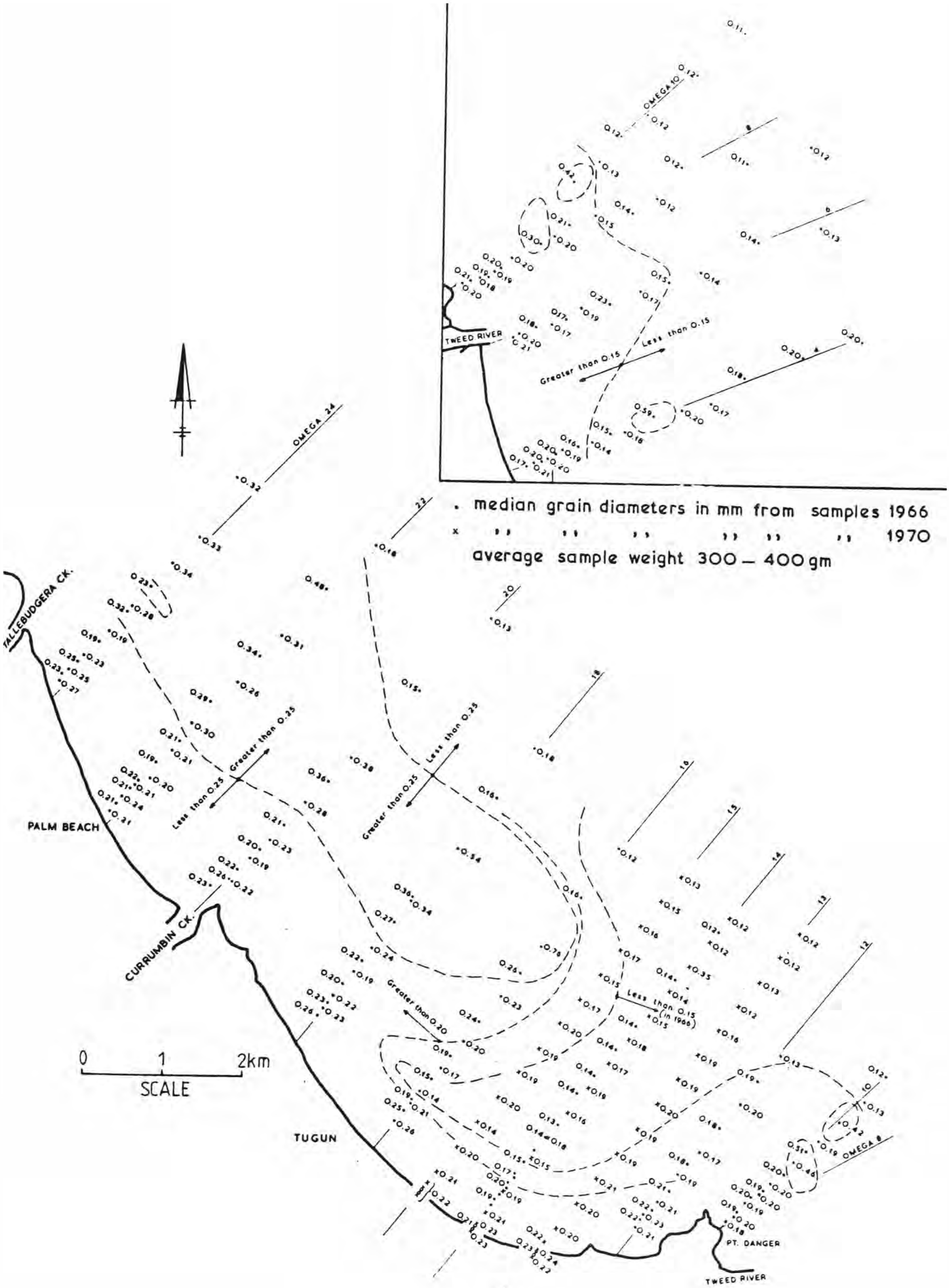


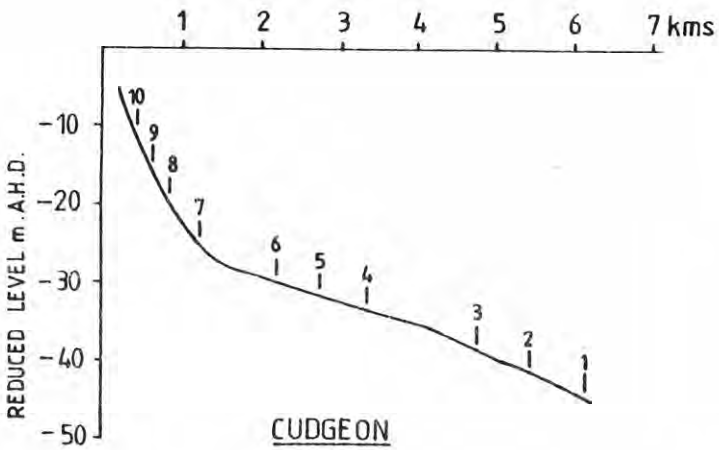
FIGURE 24

AVERAGE NETT LONGSHORE TRANSPORT RATE
CAPE BYRON TO HASTINGS POINT
(REPRODUCED FROM P.W.D. (1978) FIGURE 12.4)



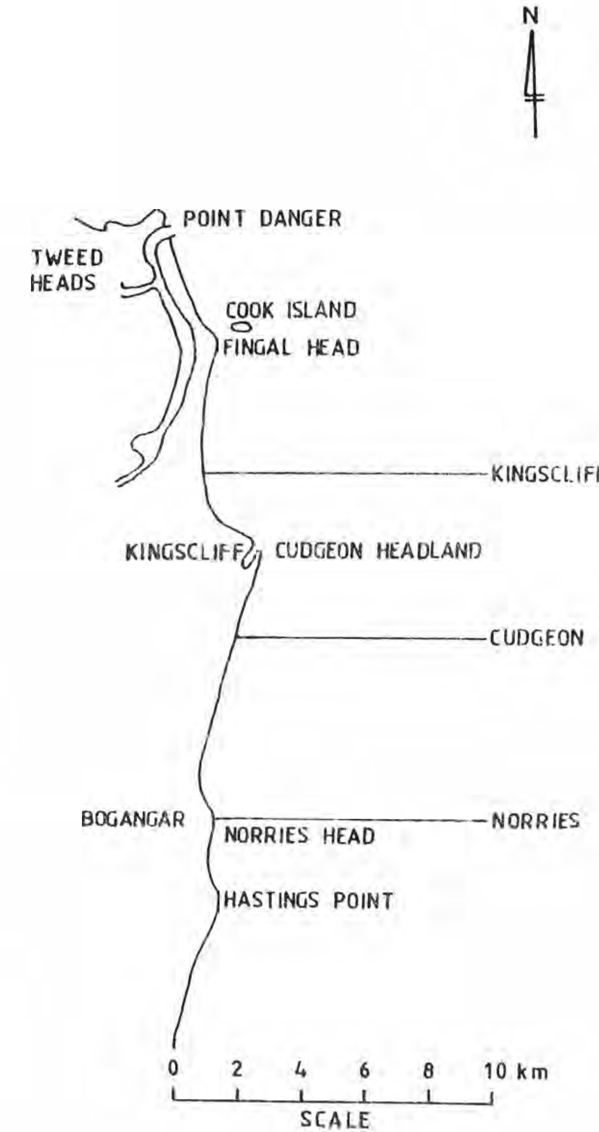
MEDIAN GRAIN SIZE DISTRIBUTION
FROM DELFT (1970)

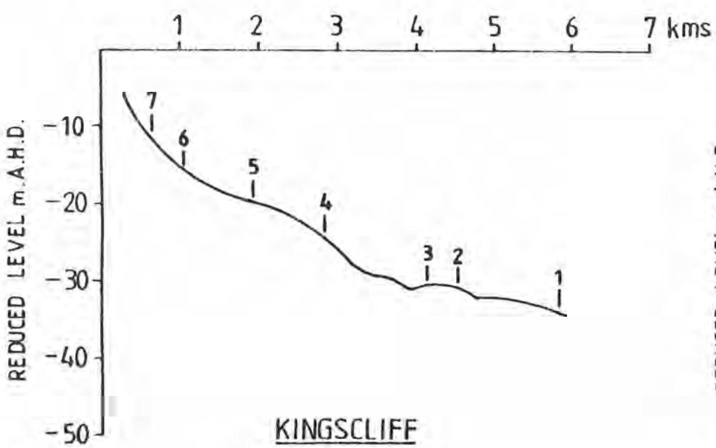
FIGURE 25



D50 GRAIN SIZE, mm

SAMPLE Nº	KINGSCLIFF	CUDGEON	NORRIES
1	0.22	0.15	0.13
2	0.18	0.13	0.17
3	0.18	0.15	0.20
4	0.17	0.23	0.22
5	0.16	0.20	0.21
6	0.16	0.21	0.17
7	0.17	—	0.17
8		0.17	0.17
9		0.18	
10		0.19	





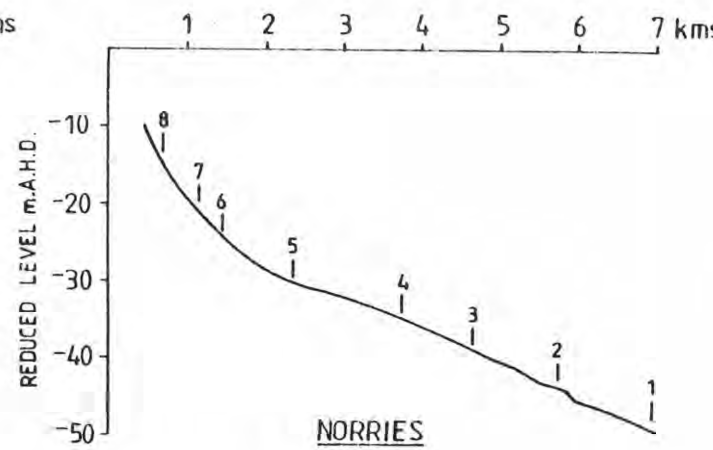
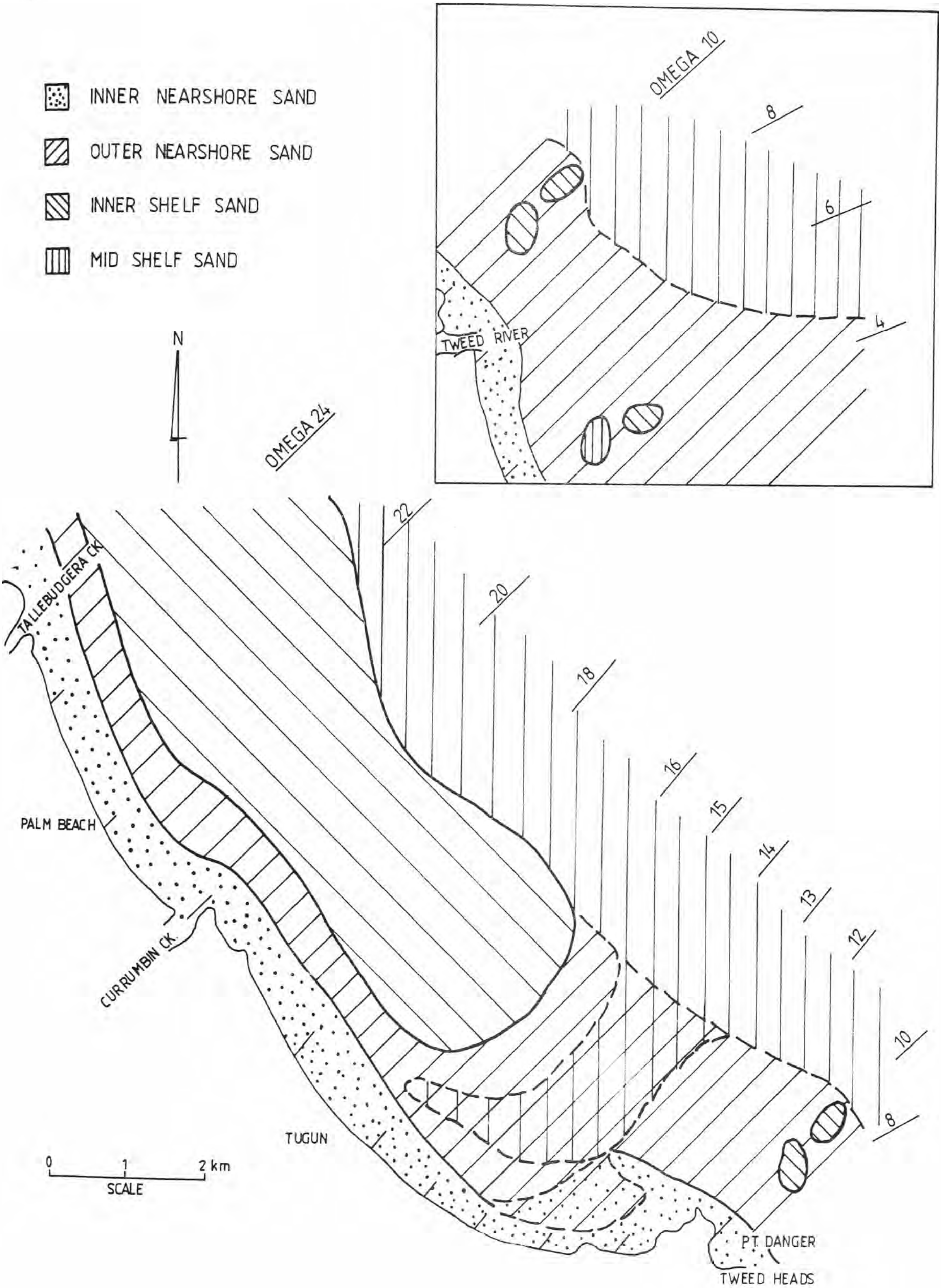


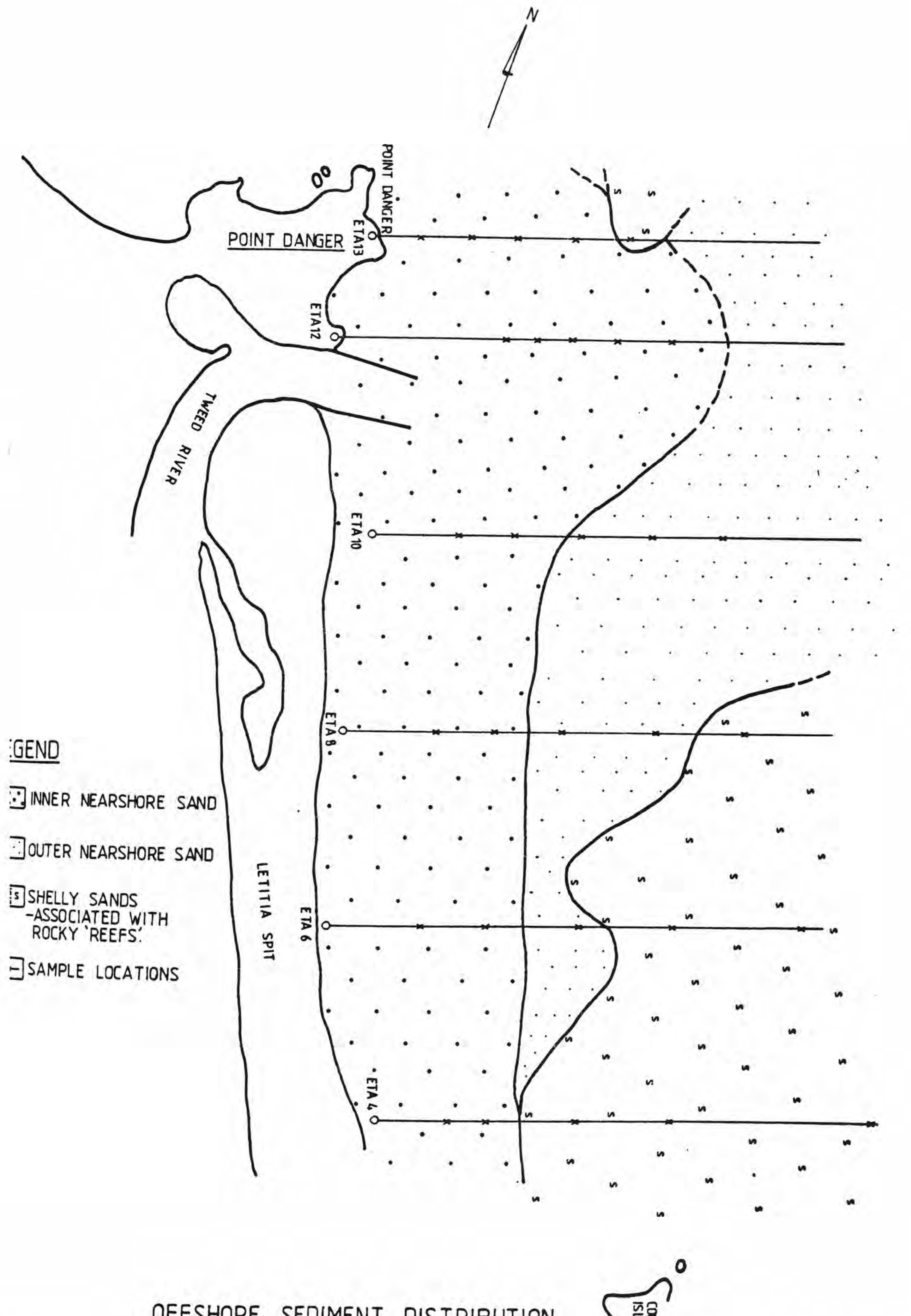
FIGURE 26

OFFSHORE SOUNDINGS AND SEDIMENT SAMPLING
— FINGAL HEAD TO NORRIES HEAD



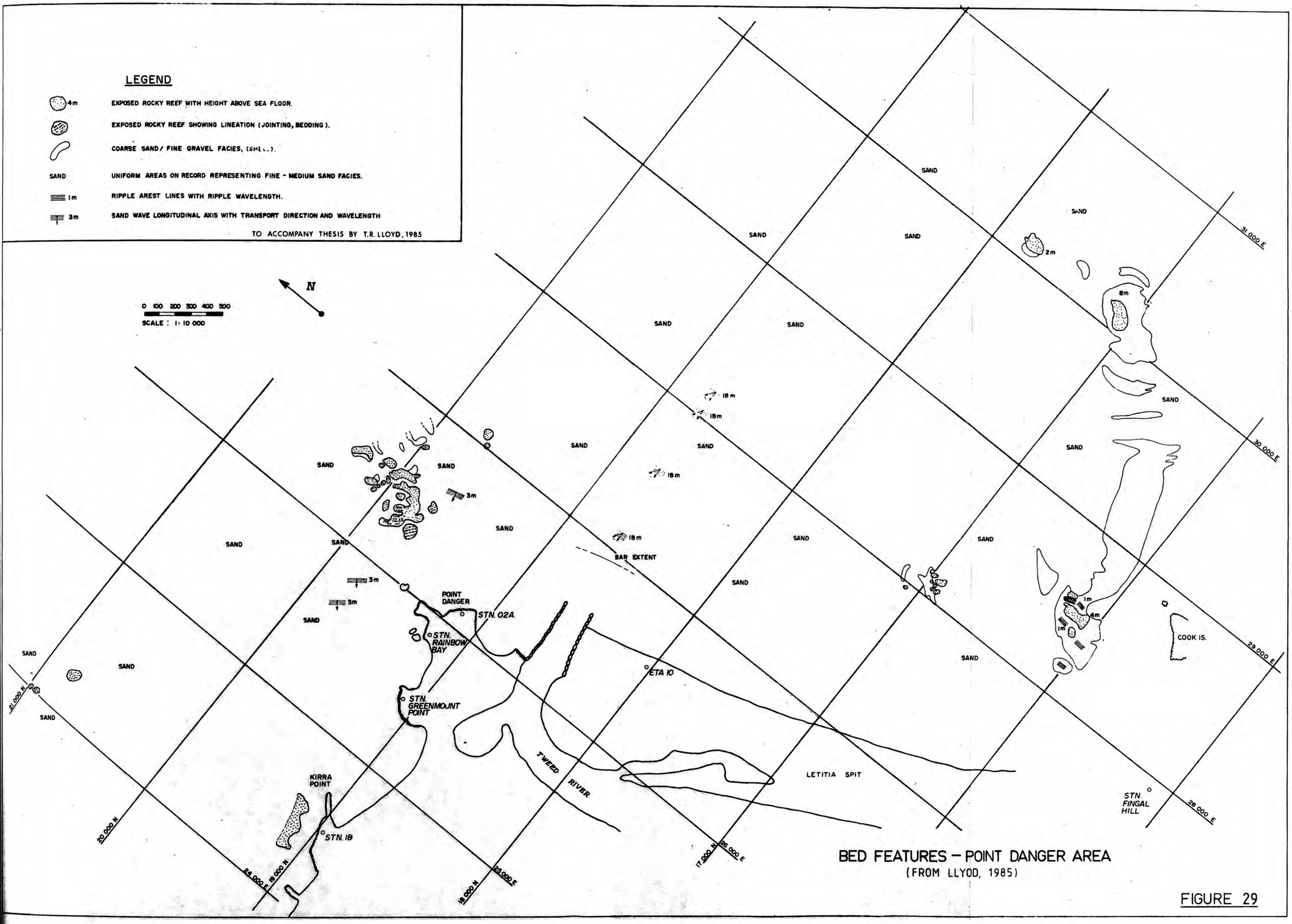
OFFSHORE SEDIMENT DISTRIBUTION - INTERPRETATION OF DELFT (1970) SAMPLING BY STEPHENS (1984)

FIGURE 27



OFFSHORE SEDIMENT DISTRIBUTION
– LETITIA SPIT 1985

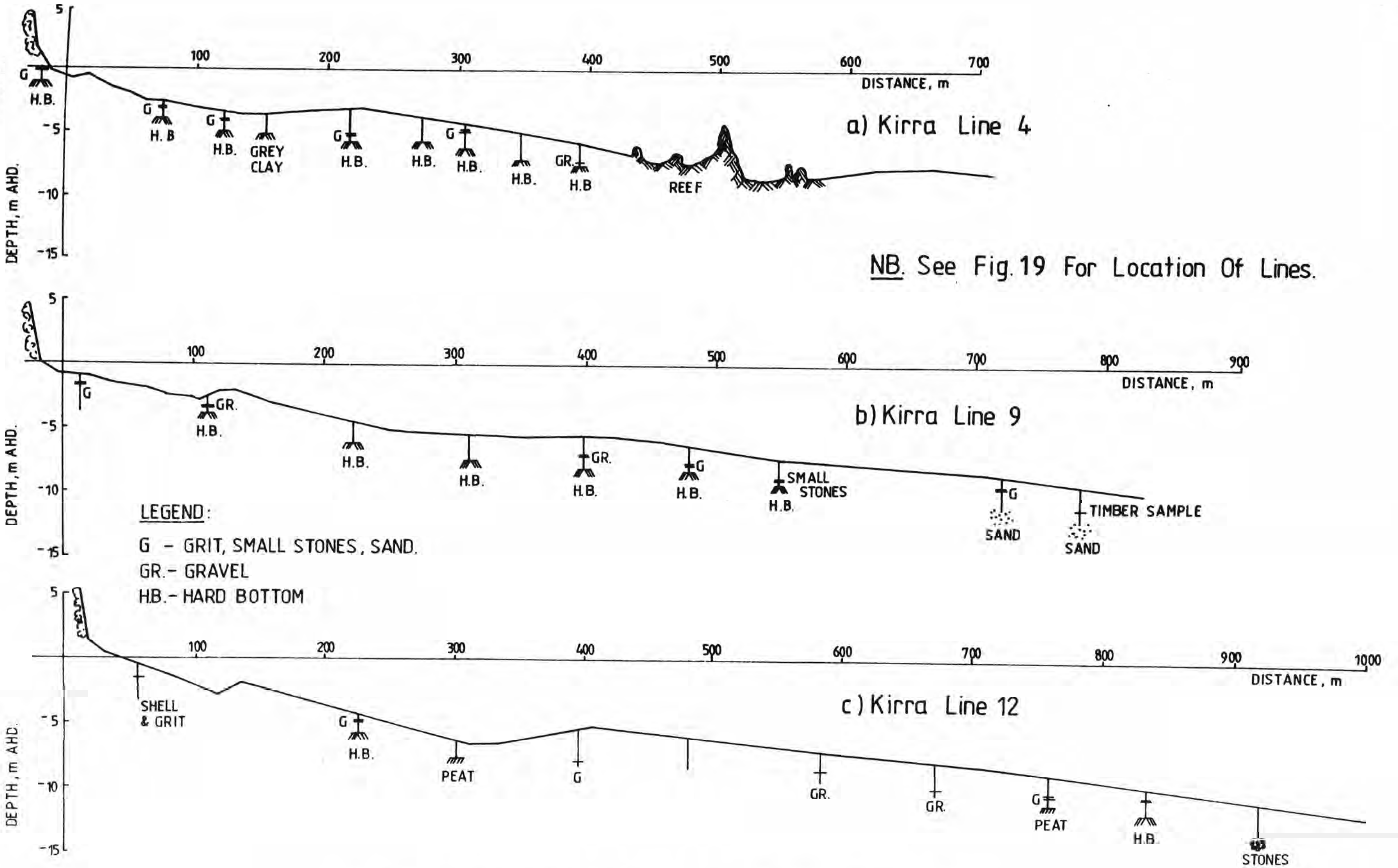
FIGURE 28



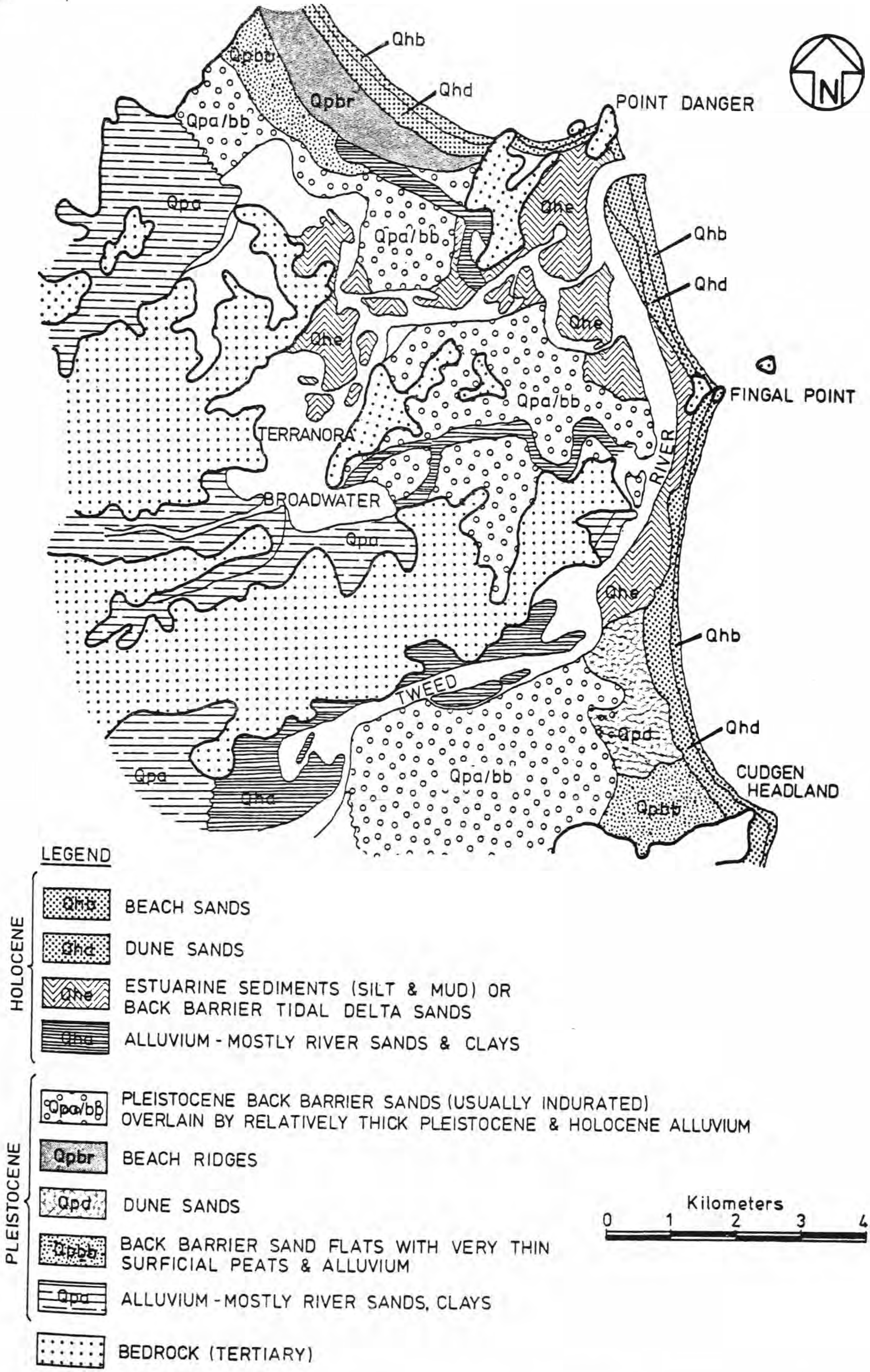
BED FEATURES – POINT DANGER AREA
(FROM LLYOD, 1985)

FIGURE 29

FIGURE 30

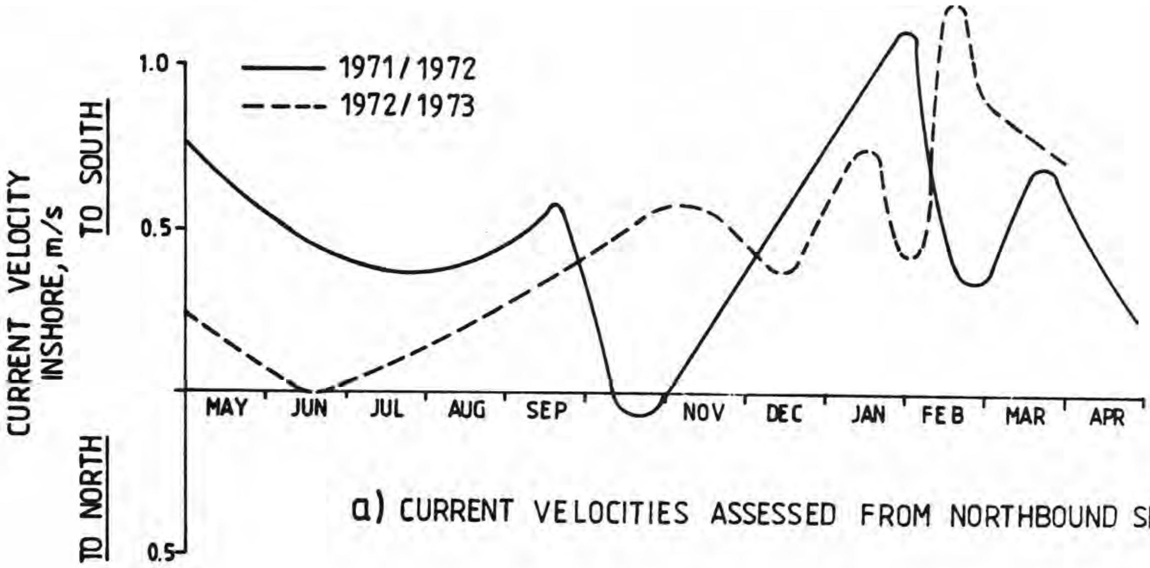


GCCC OFFSHORE KIRRA CORE SAMPLING OCTOBER 1973

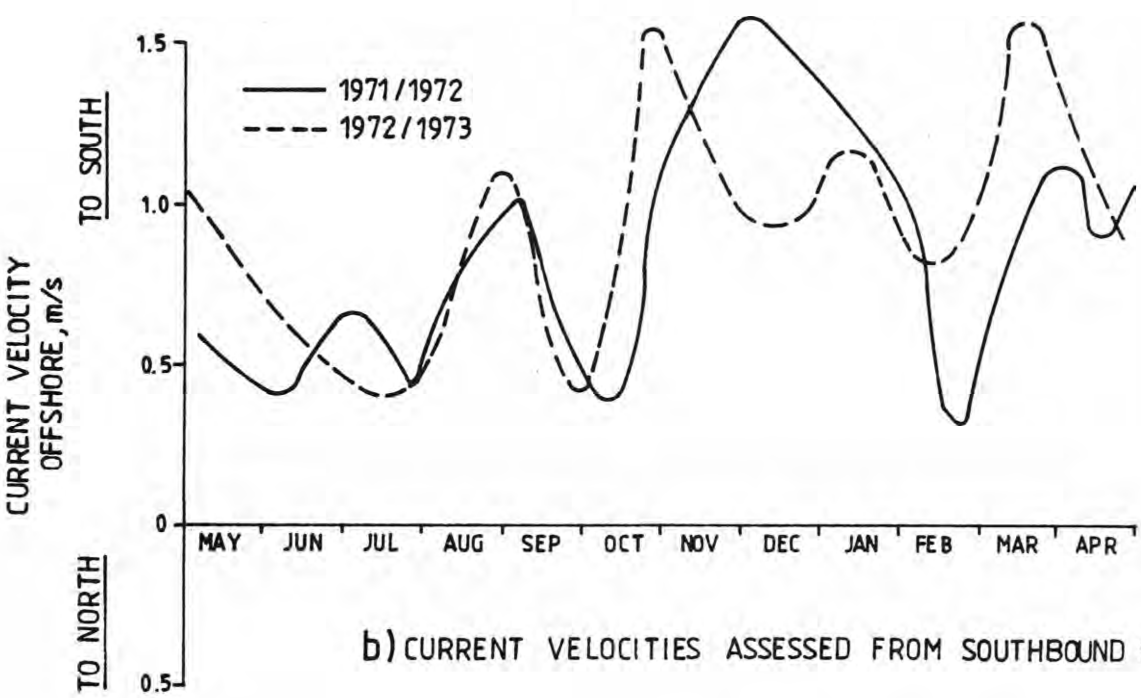


TWEED RIVER SEDIMENTARY GEOLOGY
FROM P.W.D. (1979)

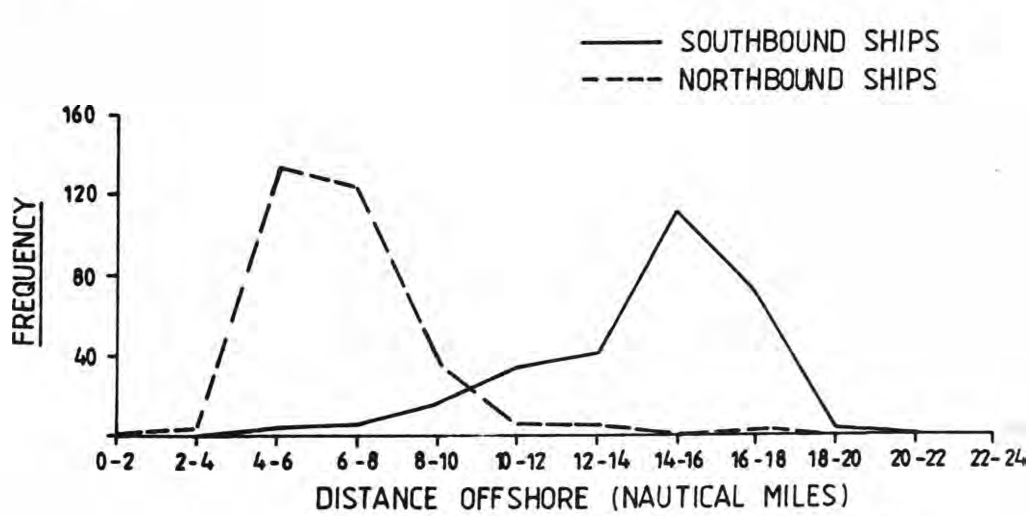
FIGURE 31



a) CURRENT VELOCITIES ASSESSED FROM NORTHBOUND SHIPS.



b) CURRENT VELOCITIES ASSESSED FROM SOUTHBOUND SHIPS.

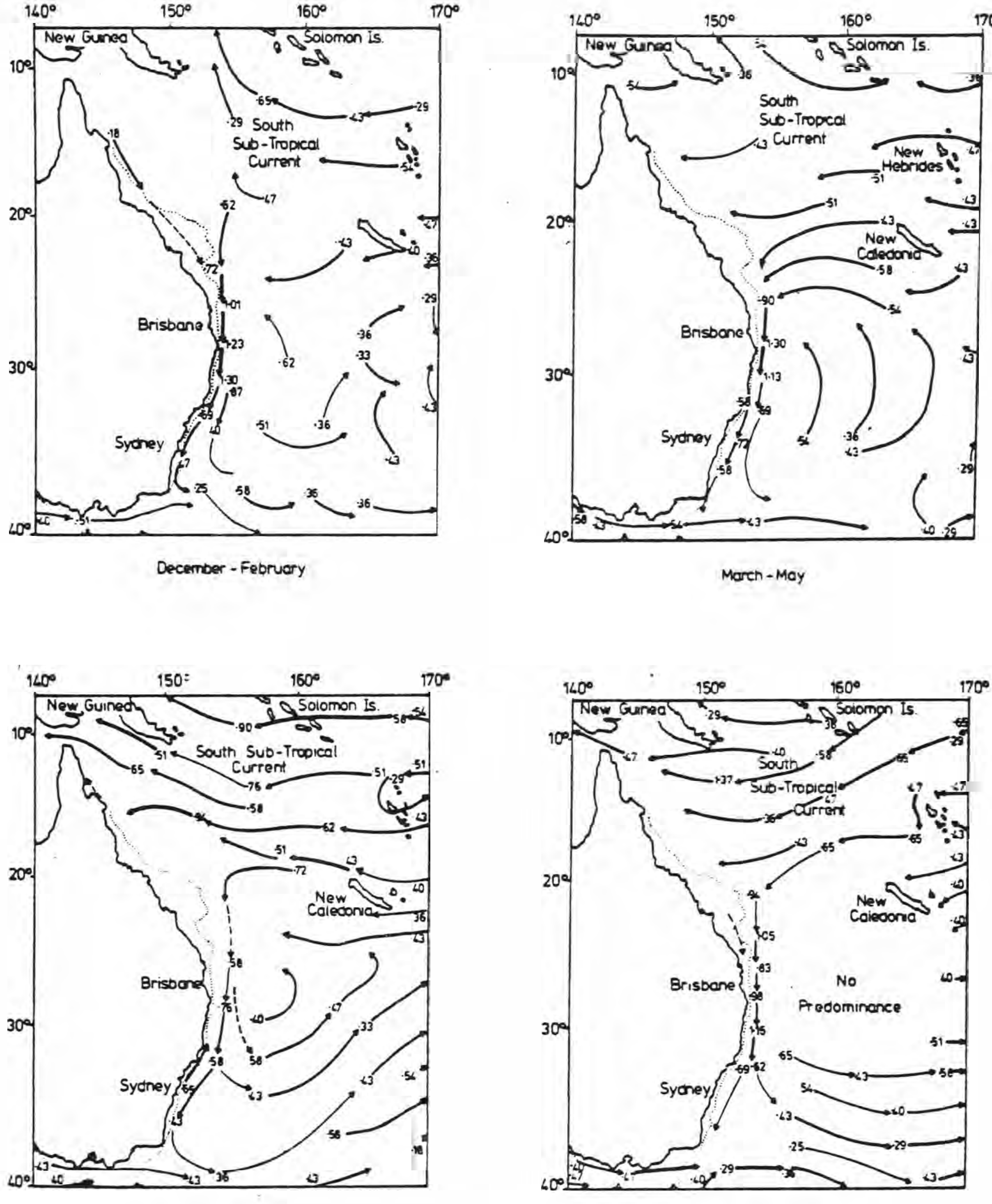


c) FREQUENCY OF READINGS OF NORTHBOUND AND SOUTHBOUND SHIPPING.

OFFSHORE CURRENT DATA - FINGAL HEAD

FROM GREIG (1974)

FIGURE 32



December - February

March - May

June - August

September - November

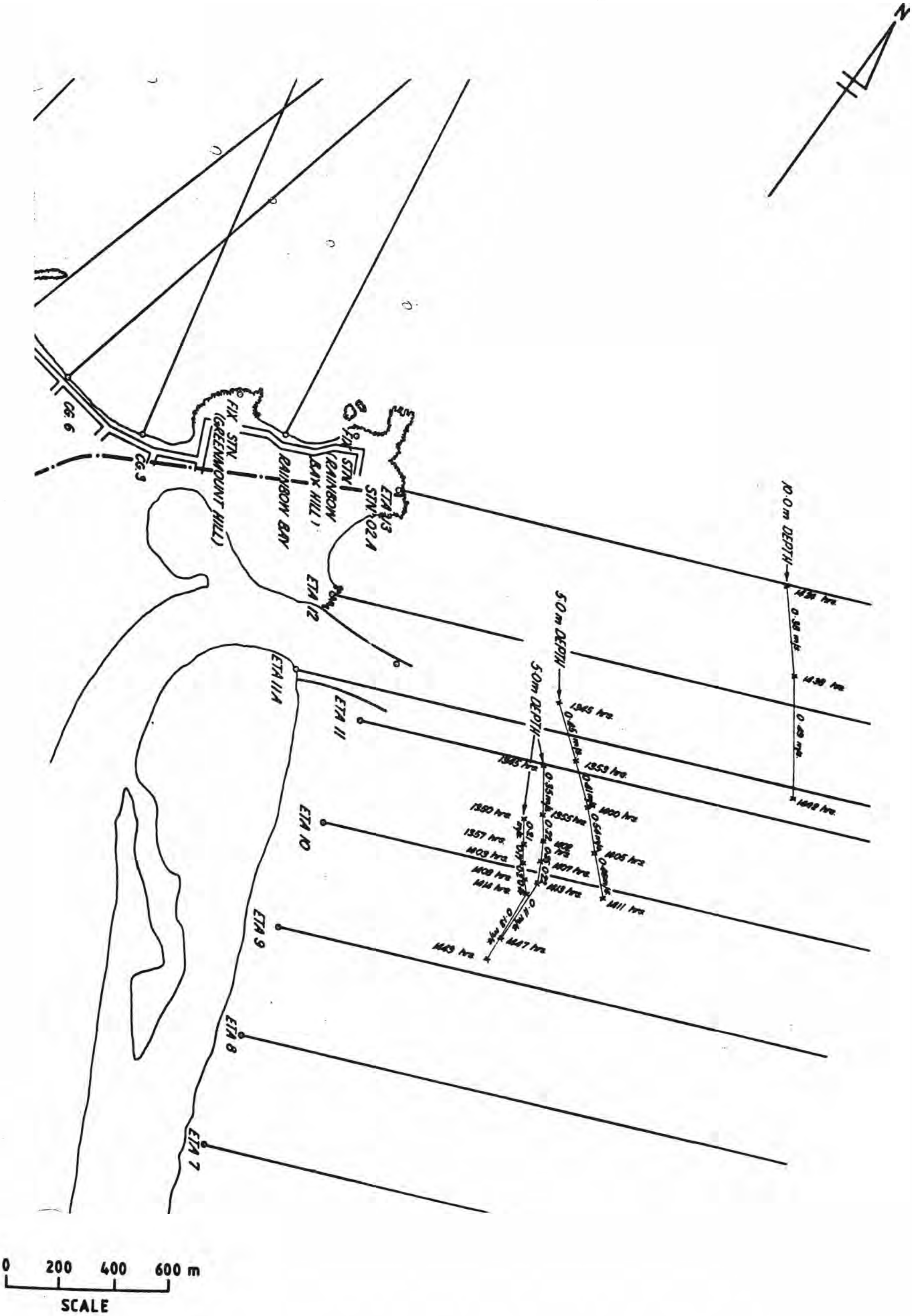
NOTE:-

- Current velocities shown in knots
- The currents are subject to significant variation.
  The arrows represent the predominant flow, the thickness of the arrow indicating the constancy of the current in direction shown :- 25% - 50% ⟶
  51% - 74% ⟶
  75% - 100% ⟶
  Constancies of under 25% are not shown.
- In regions where insufficent observations are available the generally accepted direction of flow is shown by a broken arrow :- - - - - - →

SPATIAL AND TEMPORAL DISTRIBUTION OF OCEAN CURRENTS OFF THE EAST COAST OF AUSTRALIA

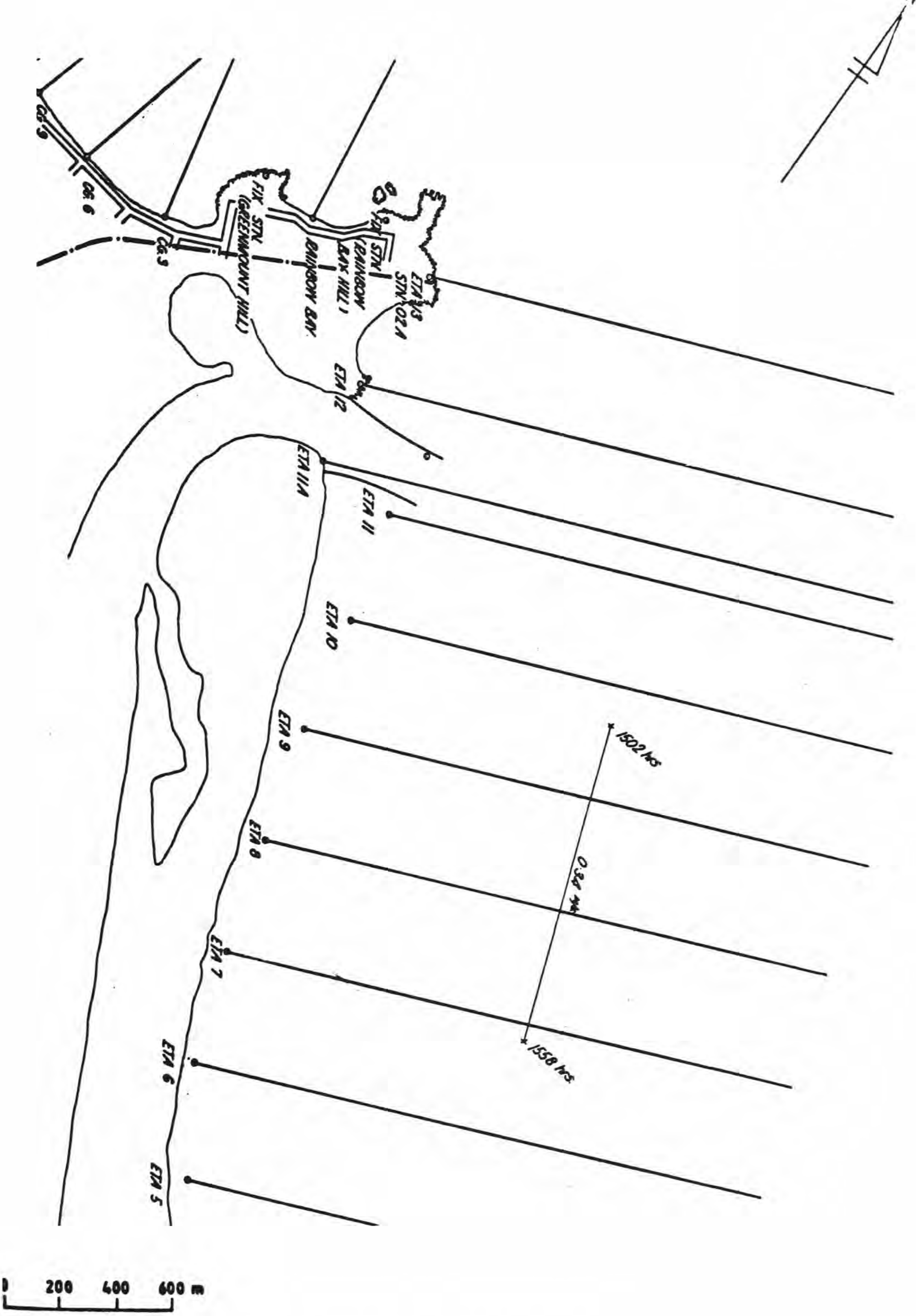
FROM P.W.D. (1978)

FIGURE 33



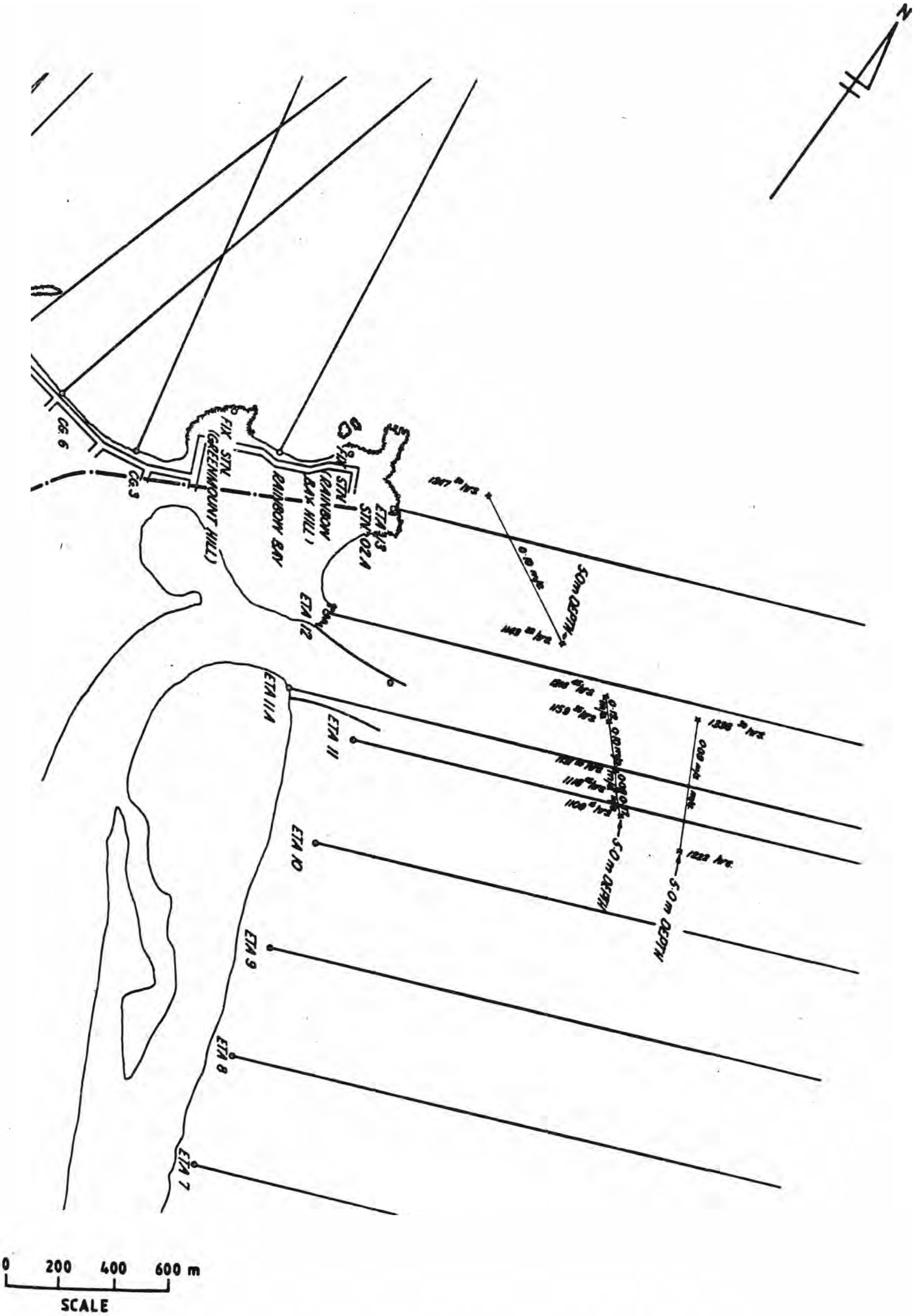
OFFSHORE CURRENT DROGUE TRACKING
8 TH MAY 1985

FIGURE 34



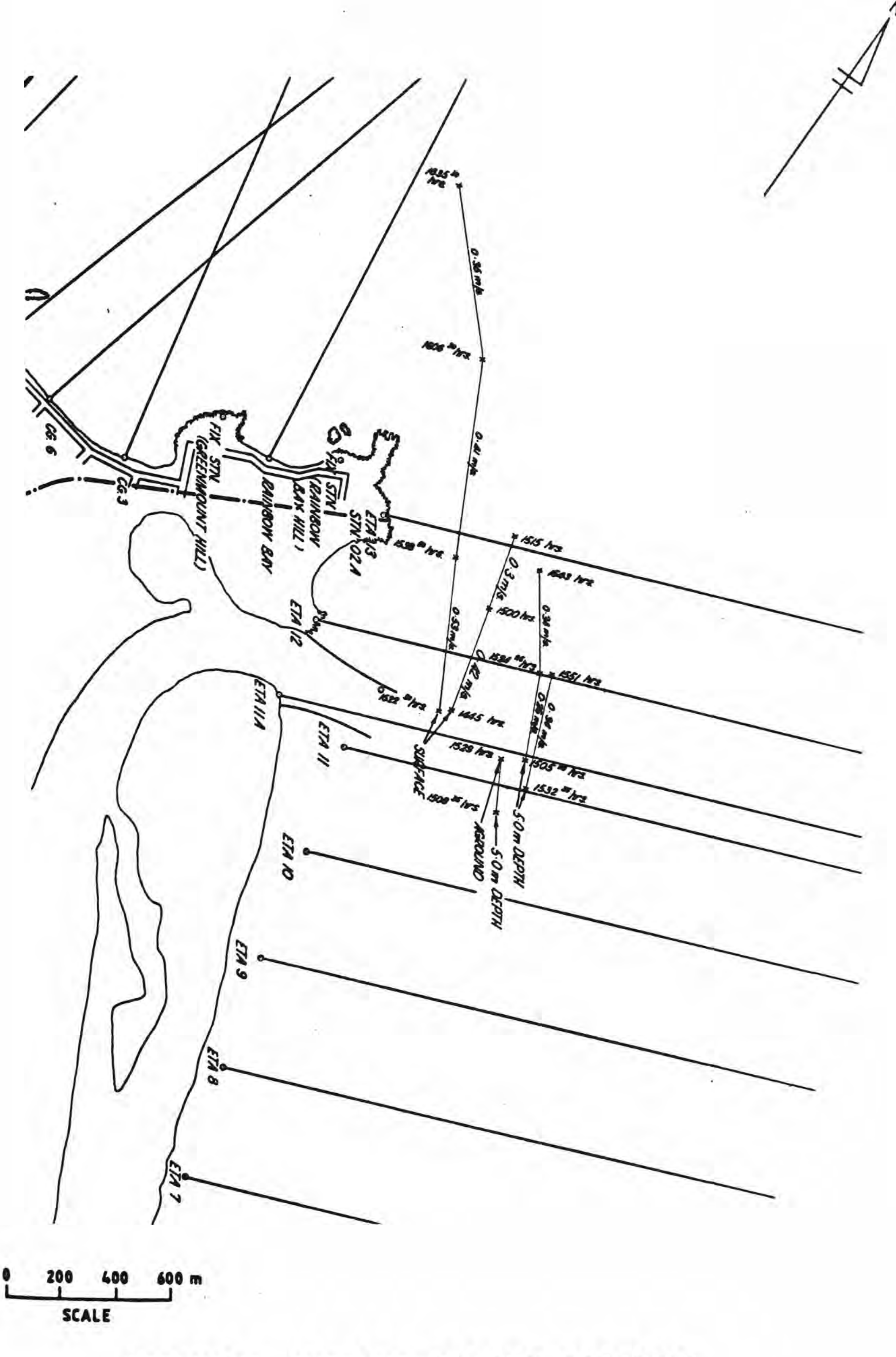
OFFSHORE CURRENT DROGUE TRACKING
9TH MAY 1985

FIGURE 35



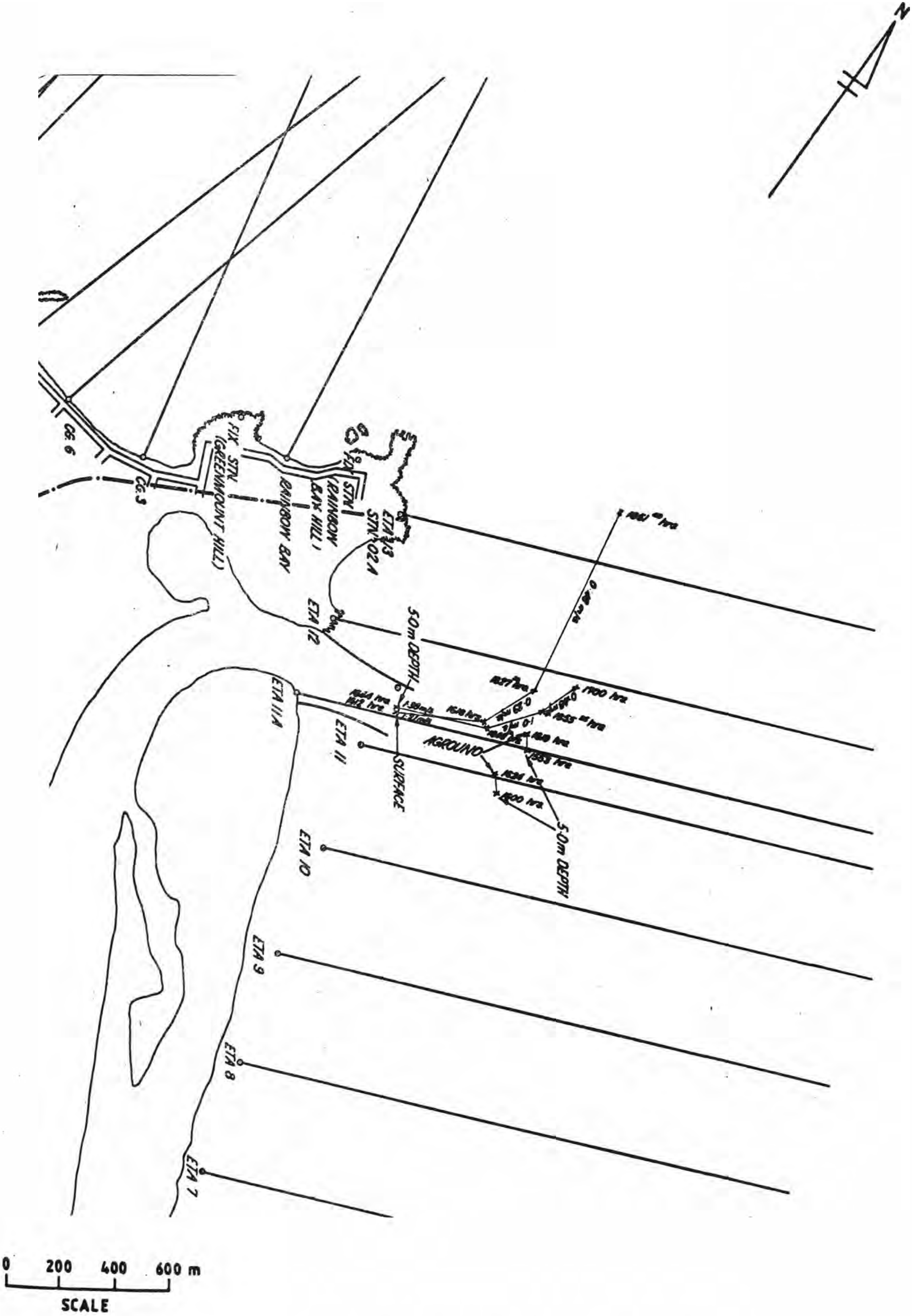
OFFSHORE CURRENT DROGUE TRACKING
10 TH MAY 1985

FIGURE 36



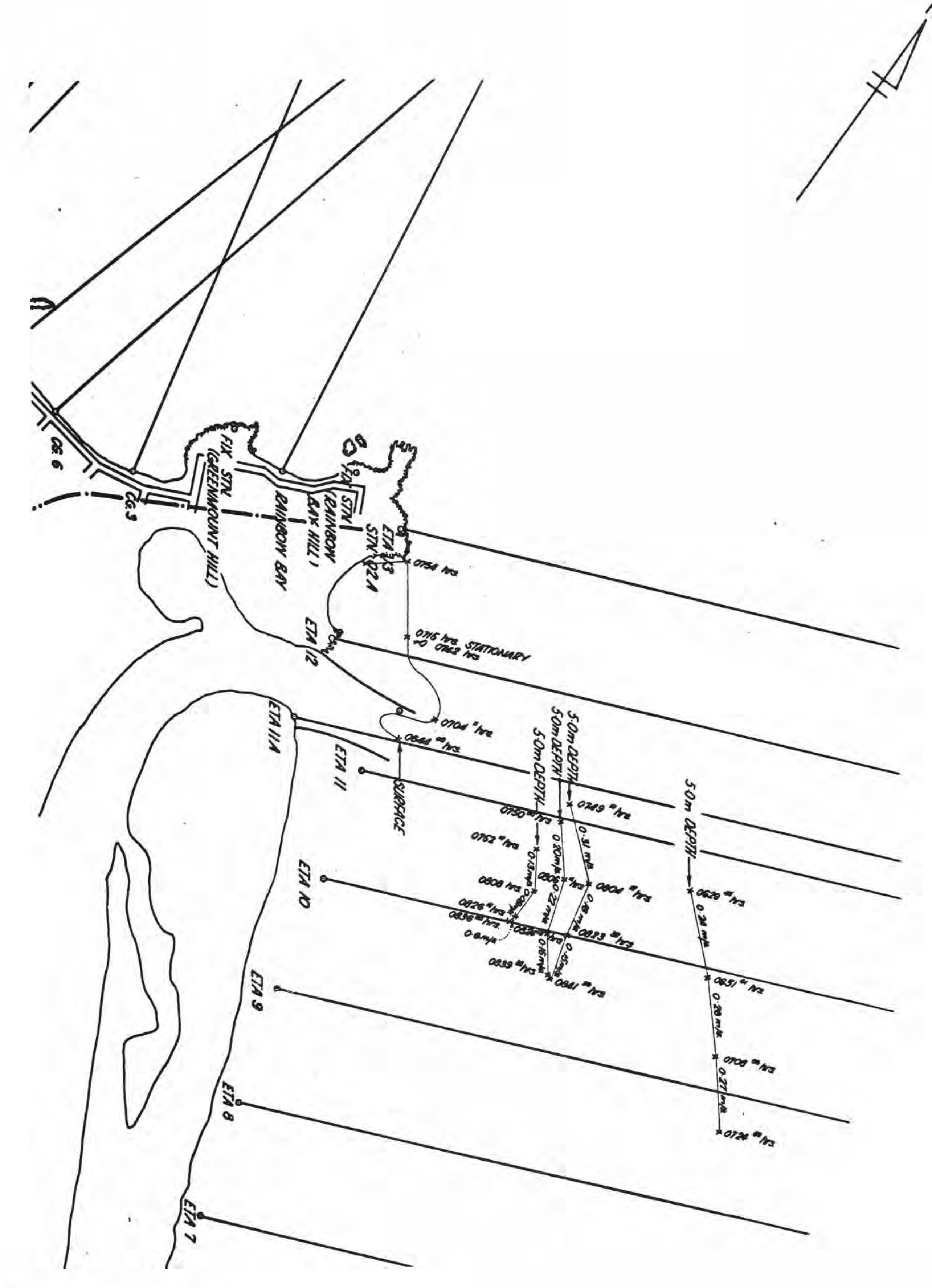
OFFSHORE CURRENT DROGUE TRACKING
10TH MAY 1985

FIGURE 36 CONTD.



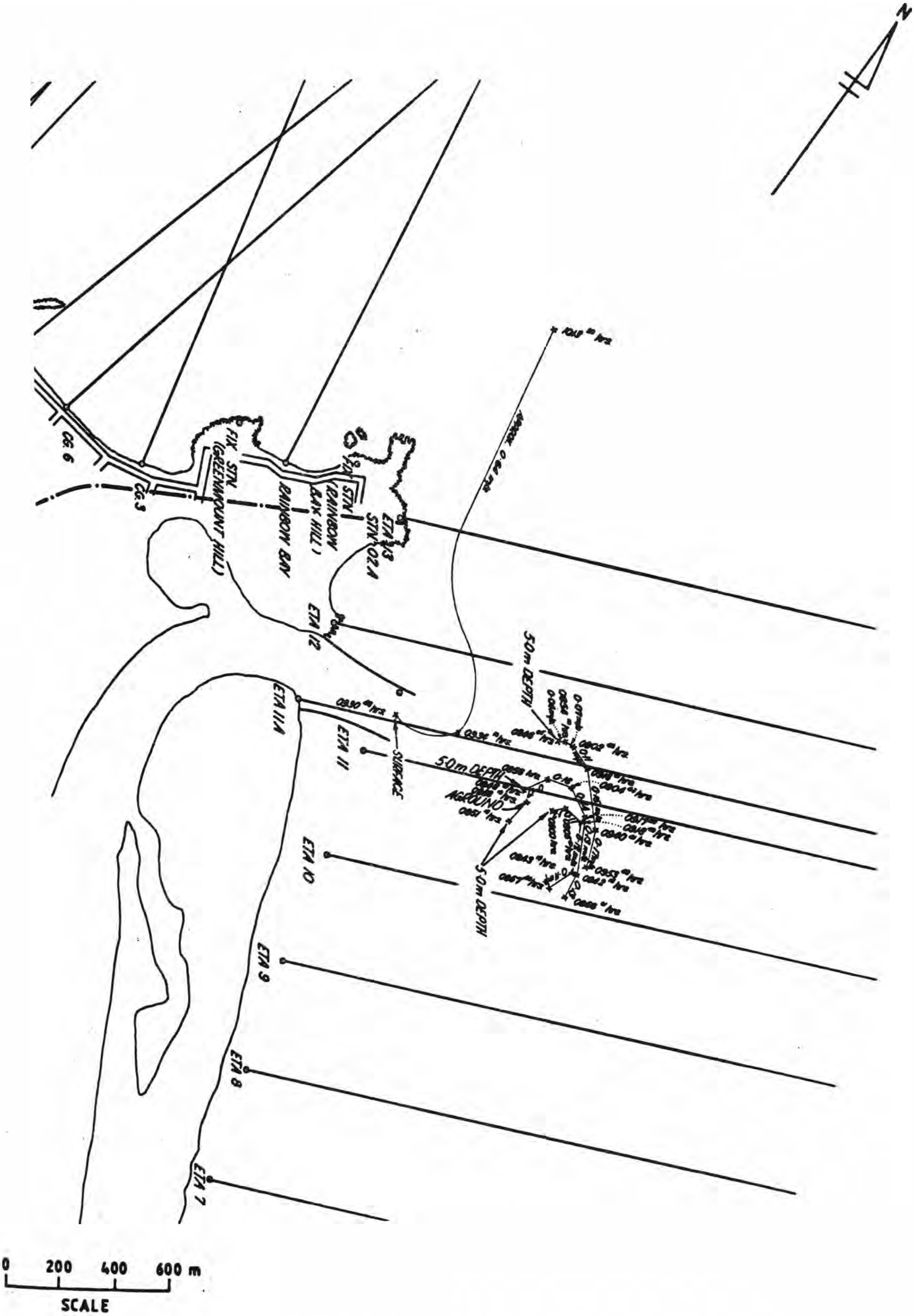
OFFSHORE CURRENT DROGUE TRACKING
10 TH MAY 1985

FIGURE 36 CONTD.



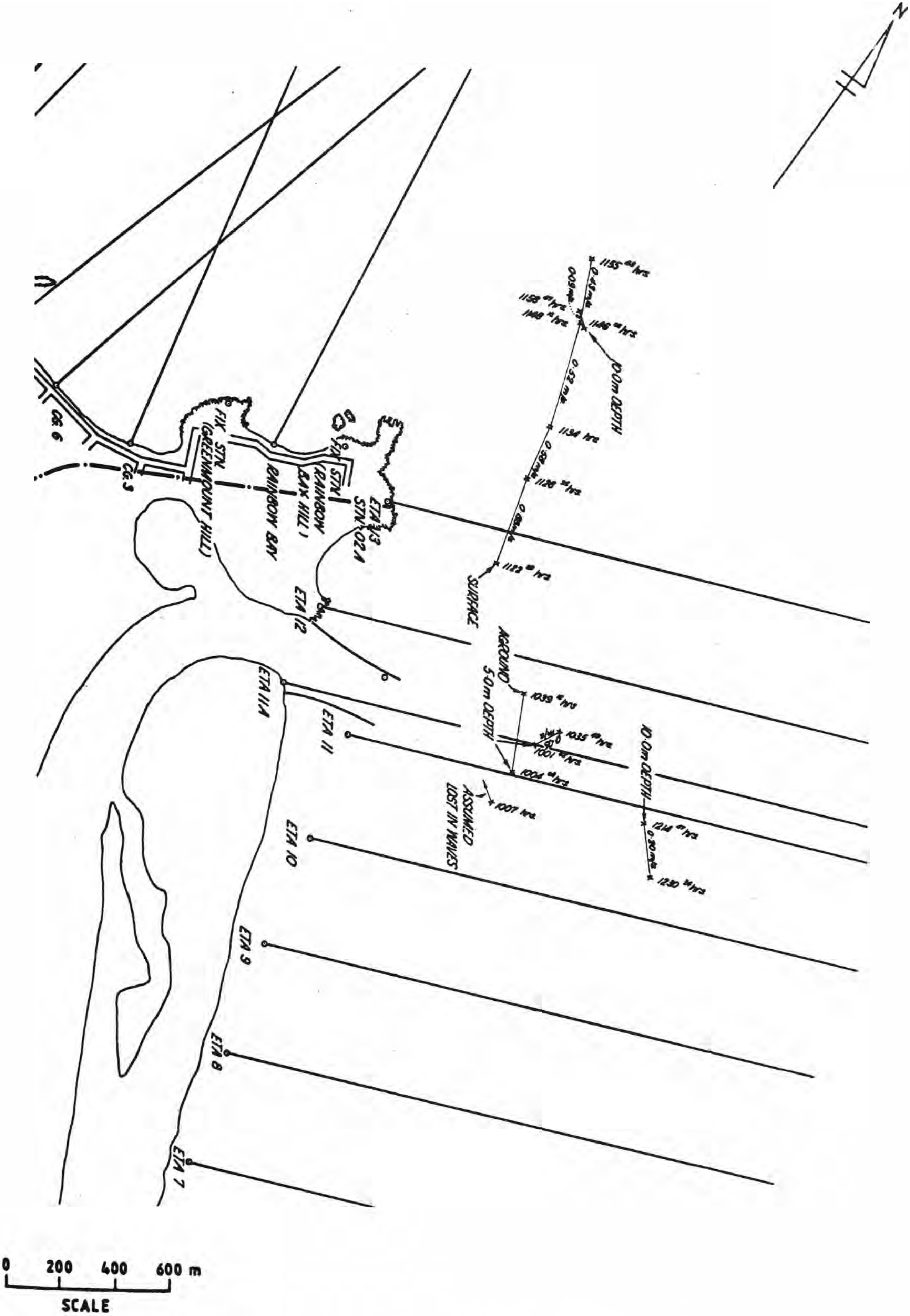
OFFSHORE CURRENT DROGUE TRACKING
15TH MAY 1985

FIGURE 37



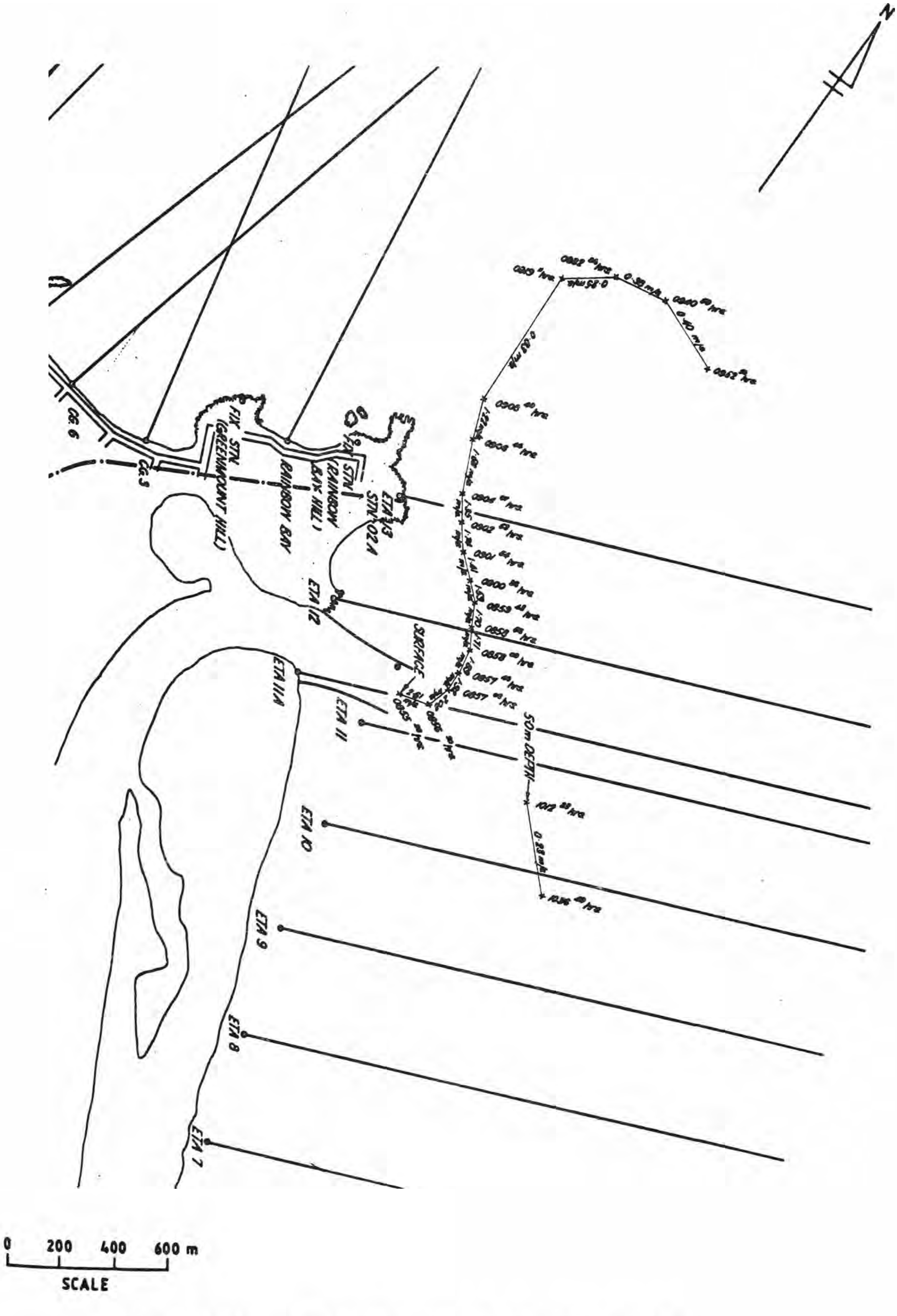
OFFSHORE CURRENT DROGUE TRACKING
15TH MAY 1985

FIGURE 37 CONTD.



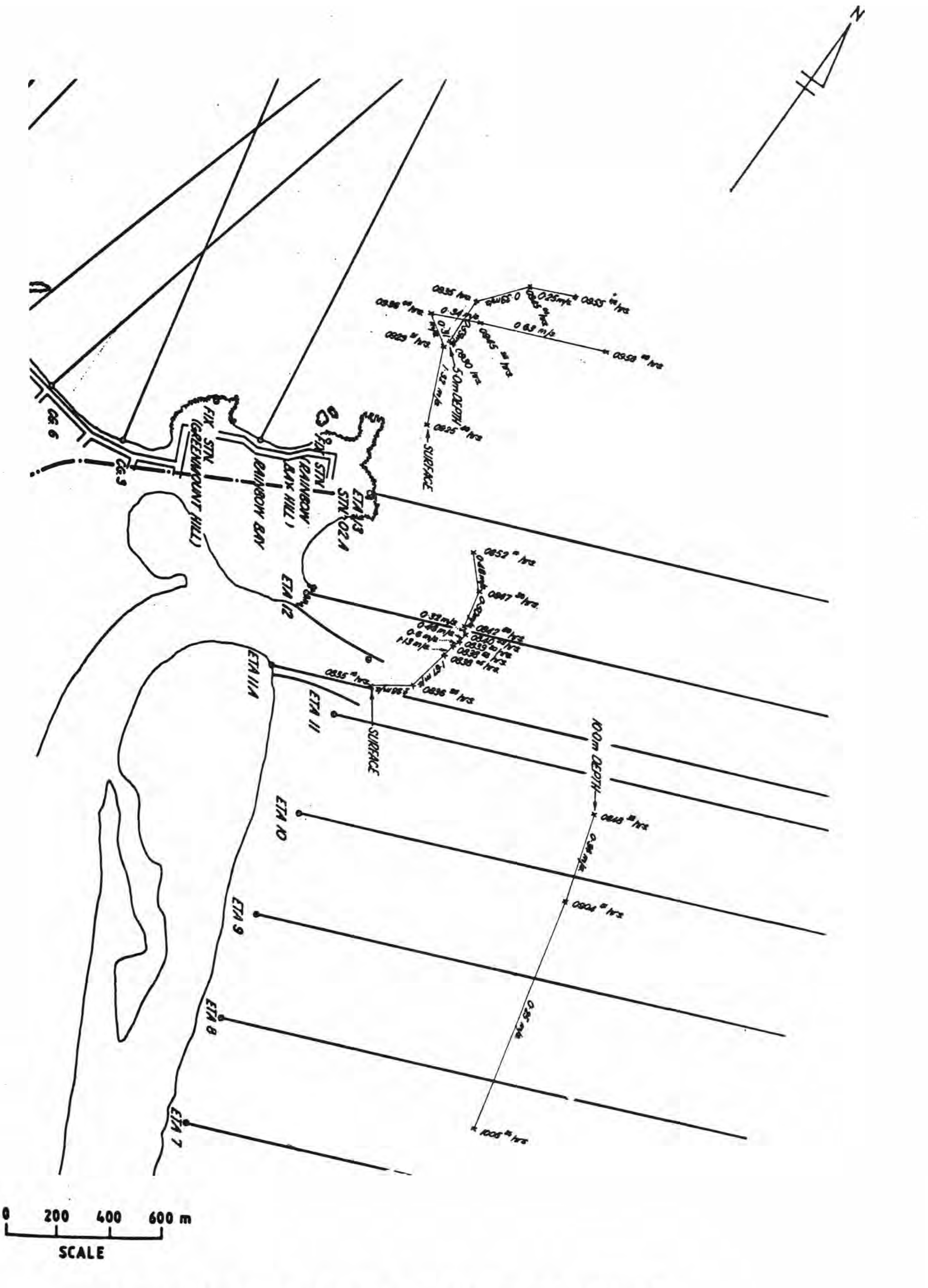
OFFSHORE CURRENT DROGUE TRACKING
15 TH MAY 1985

FIGURE 37 CONTD.



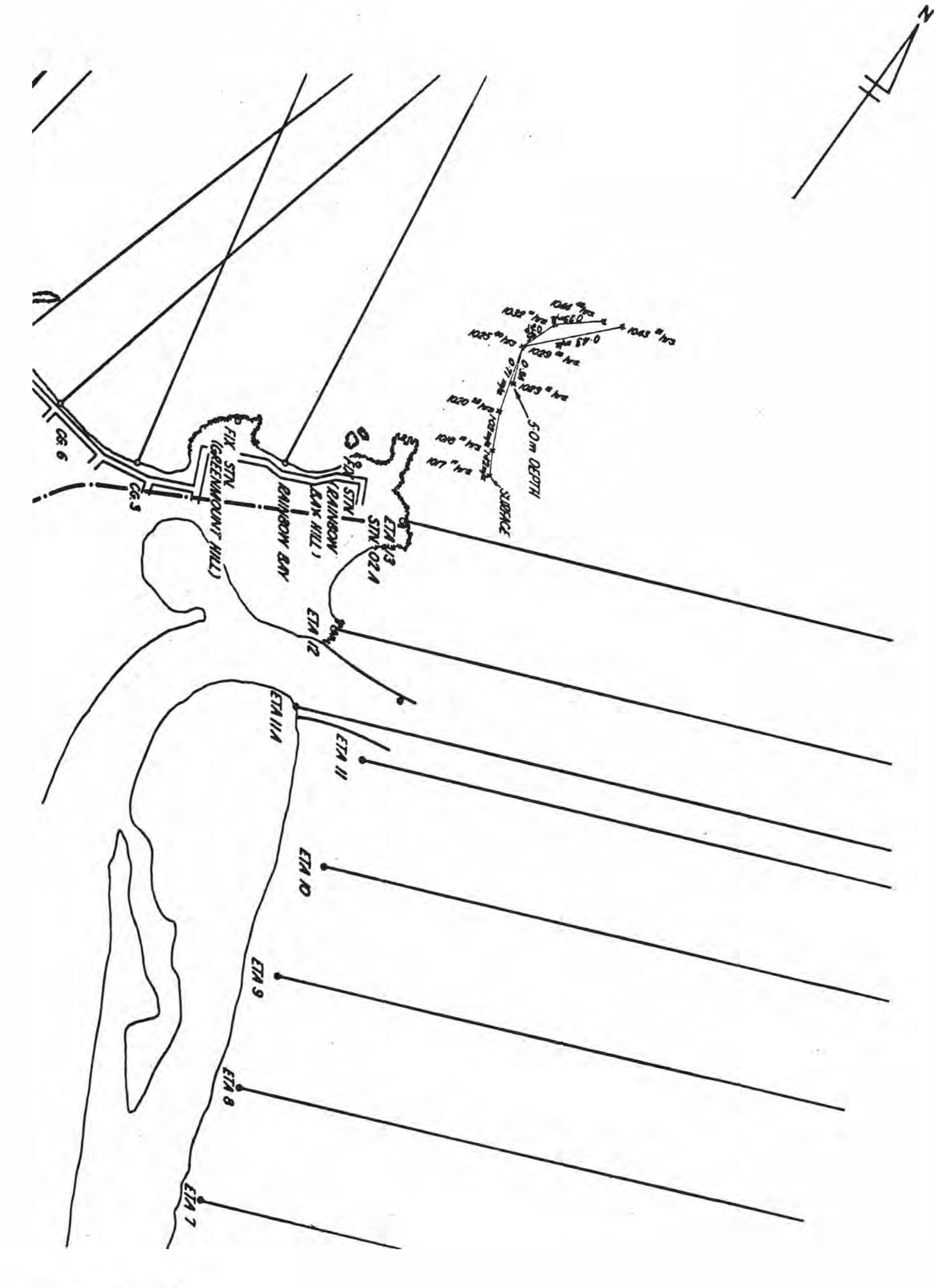
OFFSHORE CURRENT DROGUE TRACKING
16TH MAY 1985

FIGURE 38



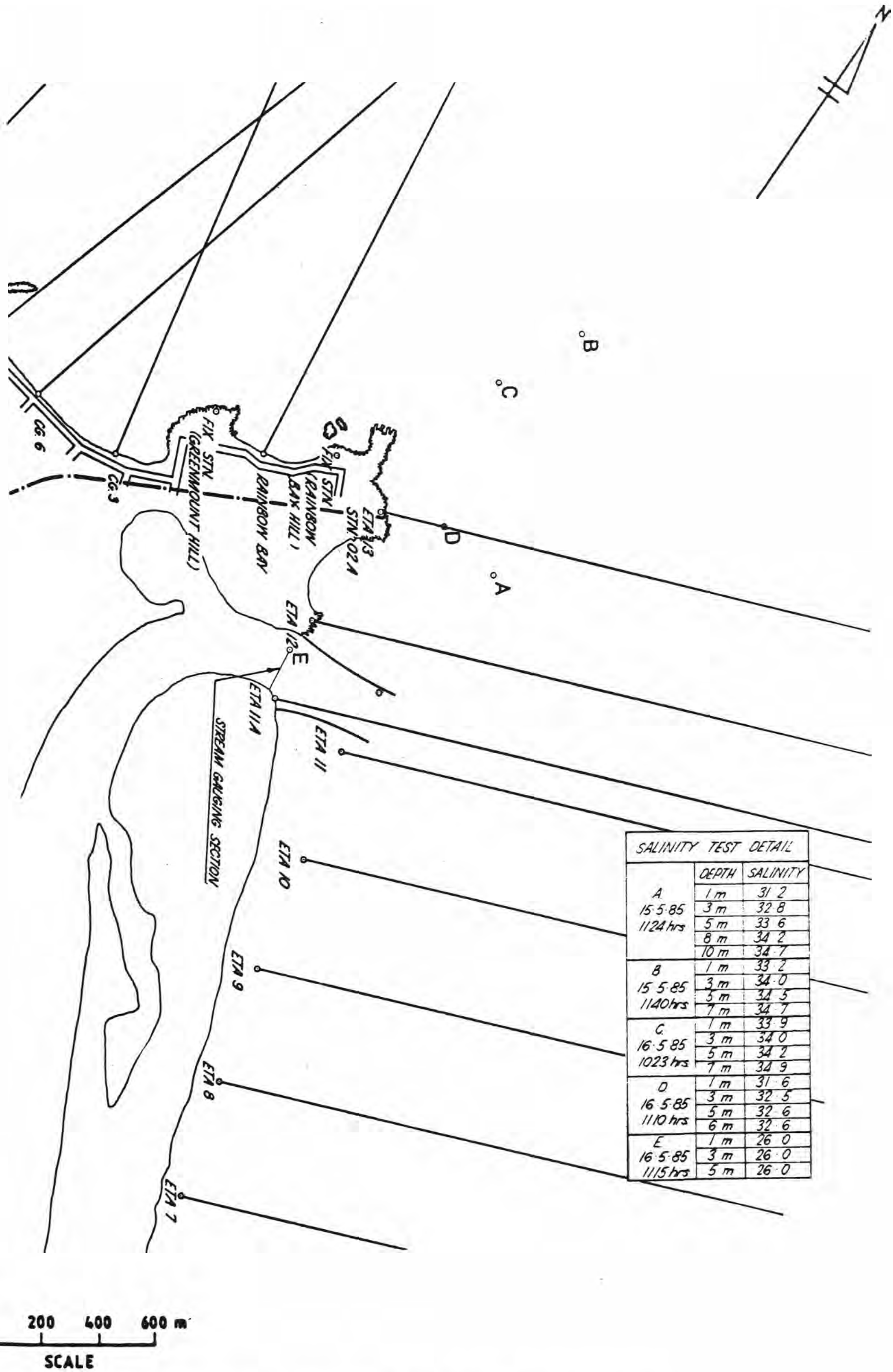
OFFSHORE CURRENT DROGUE TRACKING
16 TH MAY 1985

FIGURE 38 CONTD.



OFFSHORE CURRENT DROGUE TRACKING
16 TH MAY 1985

FIGURE 38 CONTD.

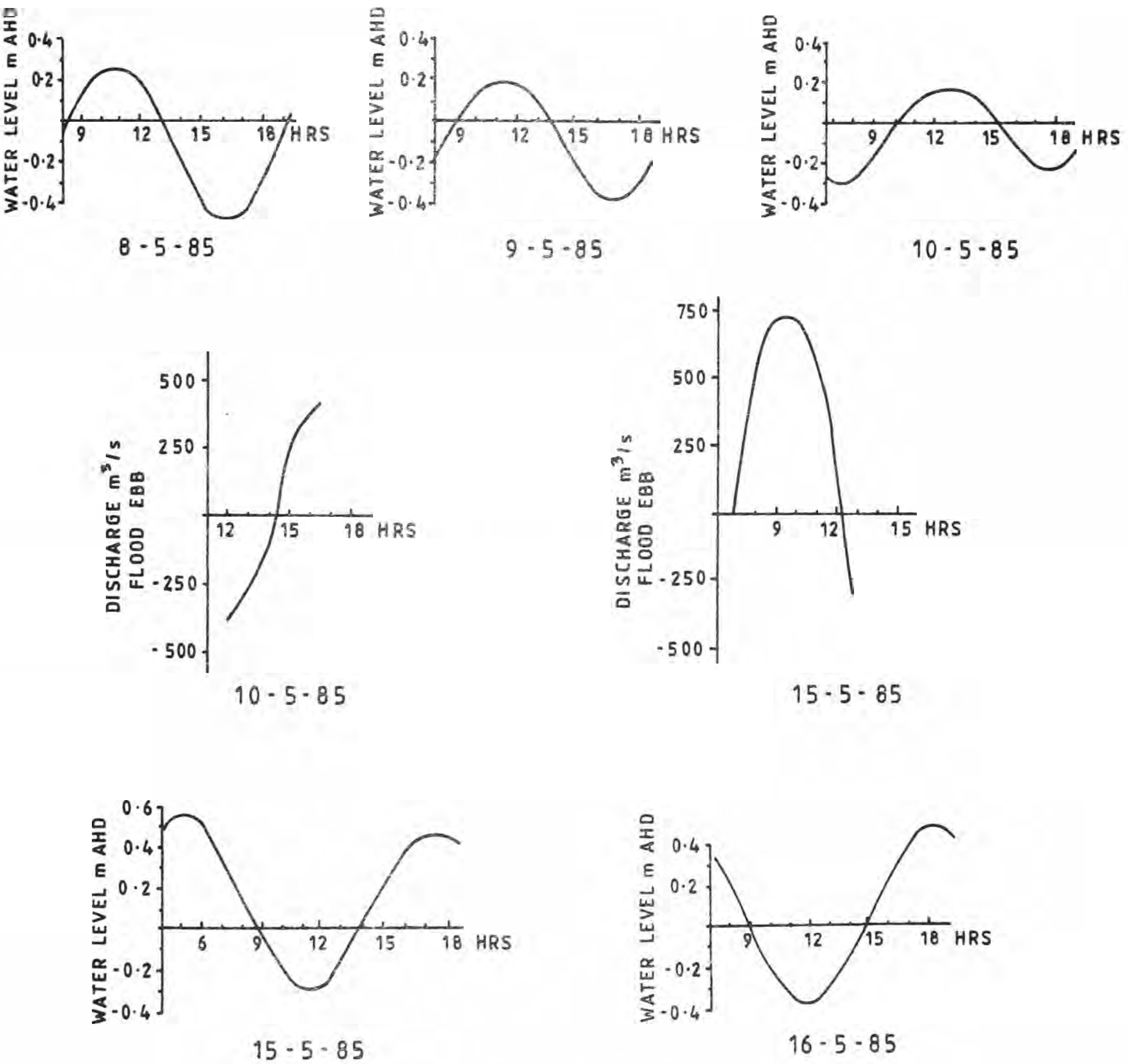


SALINITY TEST DETAIL		
	DEPTH	SALINITY
A 15.5.85 1124 hrs	1 m	31.2
	3 m	32.8
	5 m	33.6
	8 m	34.2
	10 m	34.7
B 15.5.85 1140 hrs	1 m	33.2
	3 m	34.0
	5 m	34.5
	7 m	34.7
C 16.5.85 1023 hrs	1 m	33.9
	3 m	34.0
	5 m	34.2
	7 m	34.9
D 16.5.85 1110 hrs	1 m	31.6
	3 m	32.5
	5 m	32.6
	6 m	32.6
E 16.5.85 1115 hrs	1 m	26.0
	3 m	26.0
	5 m	26.0

OFFSHORE SALINITY MEASUREMENTS
15TH AND 16TH MAY 1985

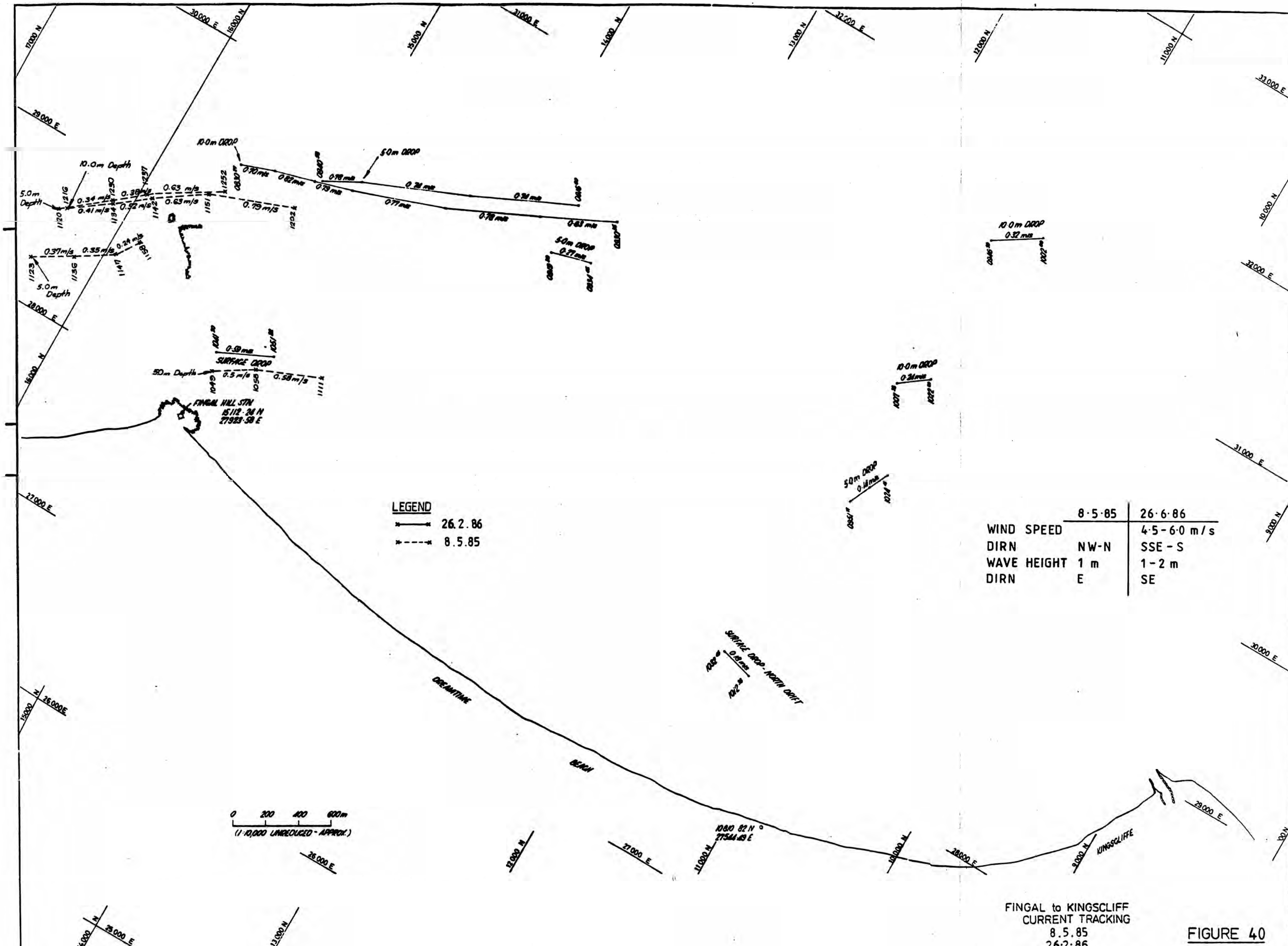
FIGURE 38 CONTD.

DATE	TIME	WIND SPEED, m/s	DIRN	WAVE HEIGHT, m	DIRN
9-5-85	1040	5·1	SE	1	E
9-5-85	1205	6·7	SE		
9-5-85	1606	6·1	SE		
10-5-85	1055	8·1	SE	1-2	SE
10-5-85	1335	9·6	SE		
10-5-85	1450	7·5	SE		
10-5-85	1550	6·5	SE		
15-5-85	0650	3·7	S	1 - 2	SE
16-5-85	0850	2·3	S	1 - 2	SE



SUMMARY OF WIND, WAVE, TIDELEVEL AND TWEED DISCHARGE CONDITIONS DURING DROGUE TRACKING EXERCISE - MAY 1985

FIGURE 39

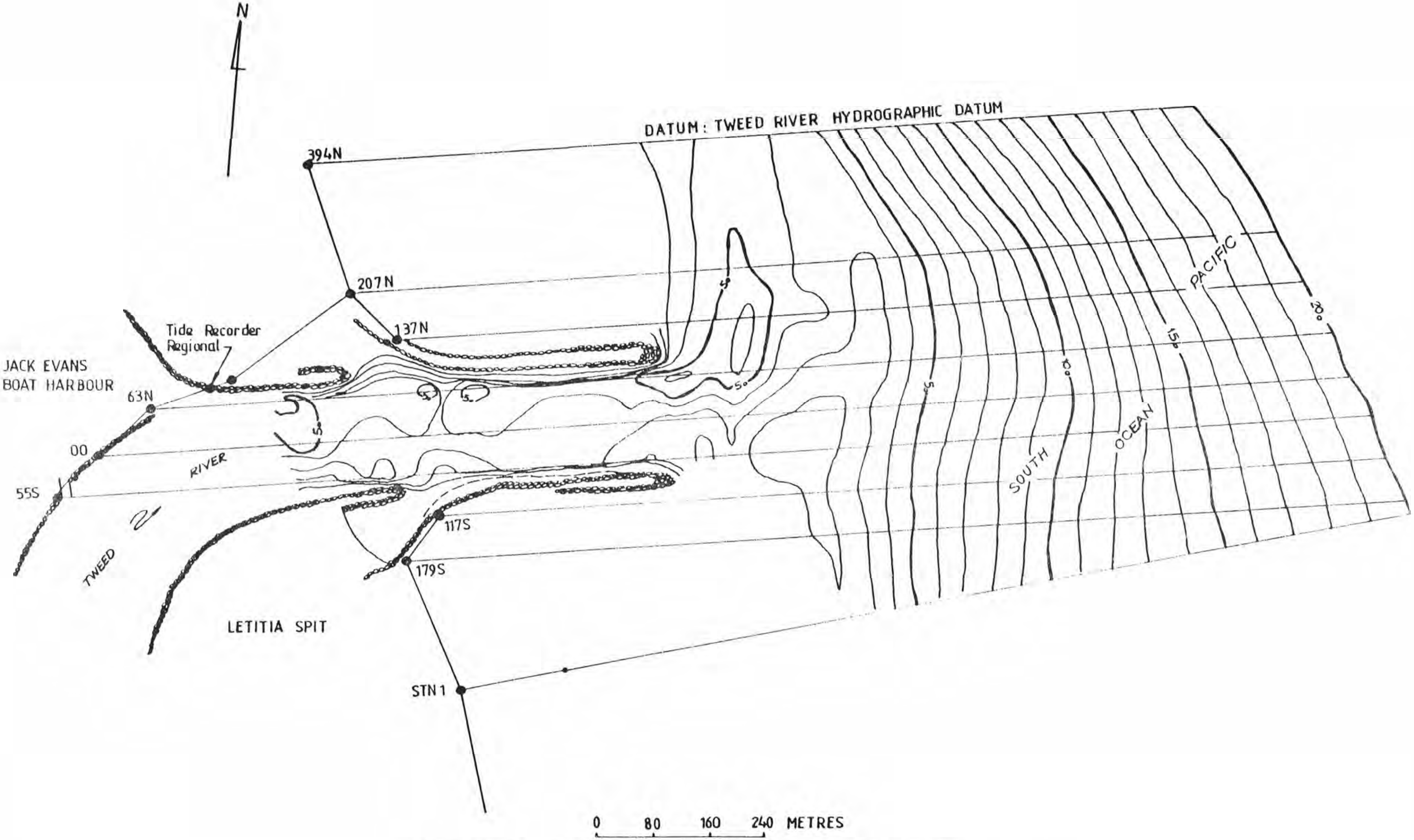


	8·5·85	26·6·86
WIND SPEED		4·5-6·0 m/s
DIRN	NW-N	SSE-S
WAVE HEIGHT	1 m	1-2 m
DIRN	E	SE

FINGAL to KINGSCLIFF
CURRENT TRACKING
8.5.85
26·2·86

FIGURE 40

FIGURE 41



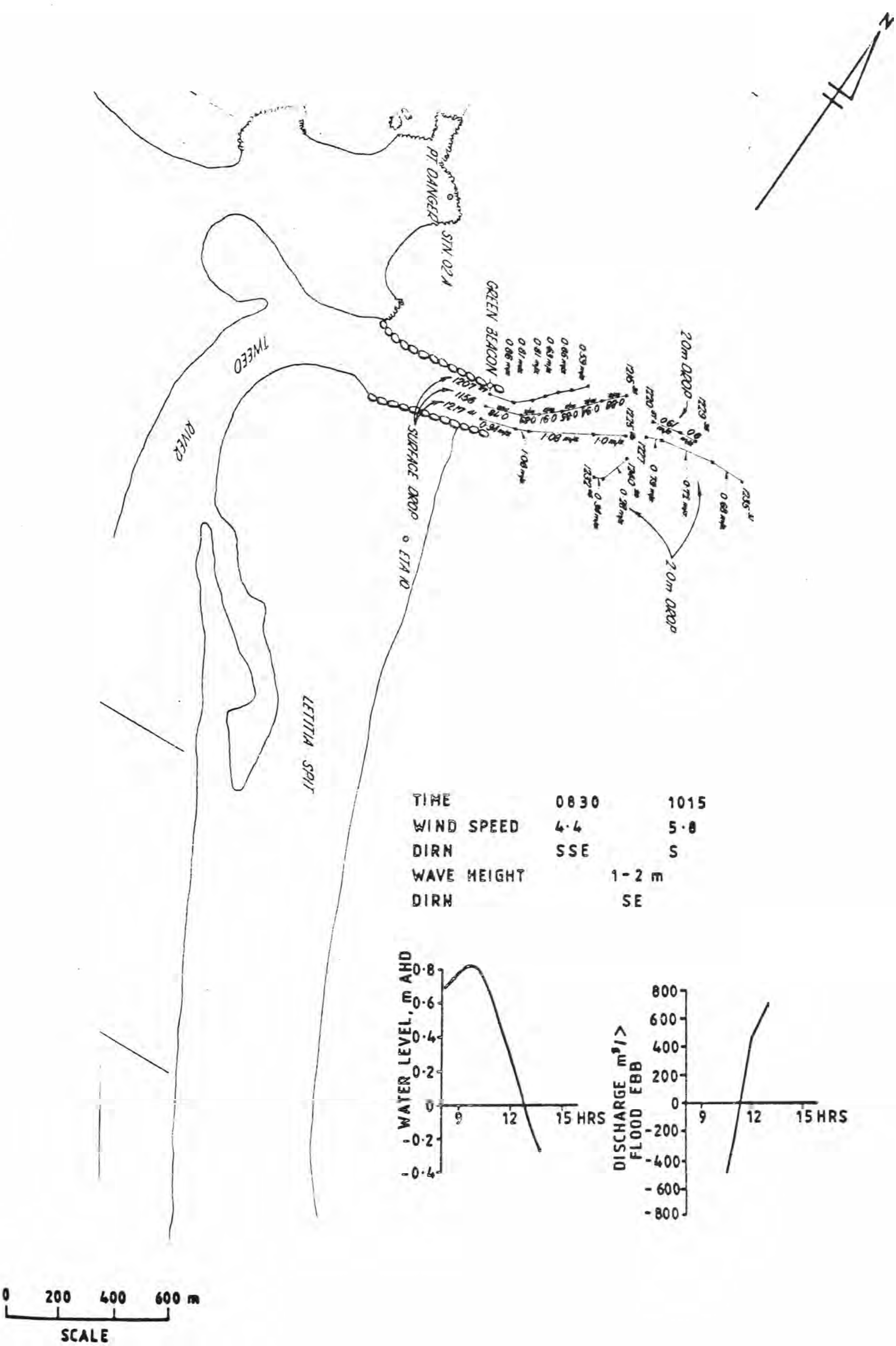
TWEED RIVER EBB DELTA BATHYMETRY
- SURVEYED 9th-10th MAY 1985

PHOTOGRAPH OF TWEED ENTRANCE
TAKEN ON 6TH MAY 1985

FIGURE 42

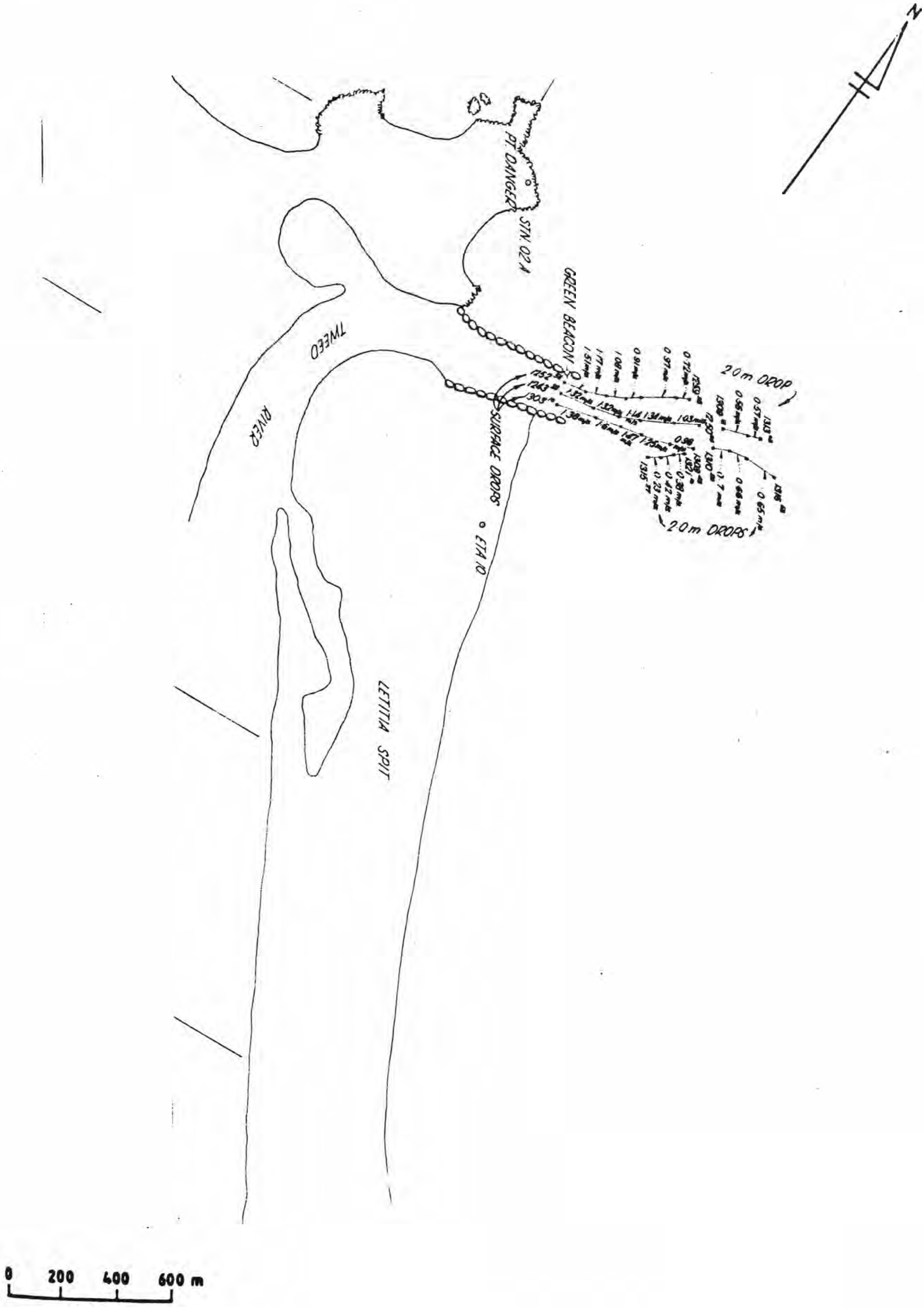
FIGURE 43

PHOTOGRAPH TAKEN ON 19TH JULY 1963 SHOWING
SEDIMENT LADEN EDDIES OFF POINT DANGER



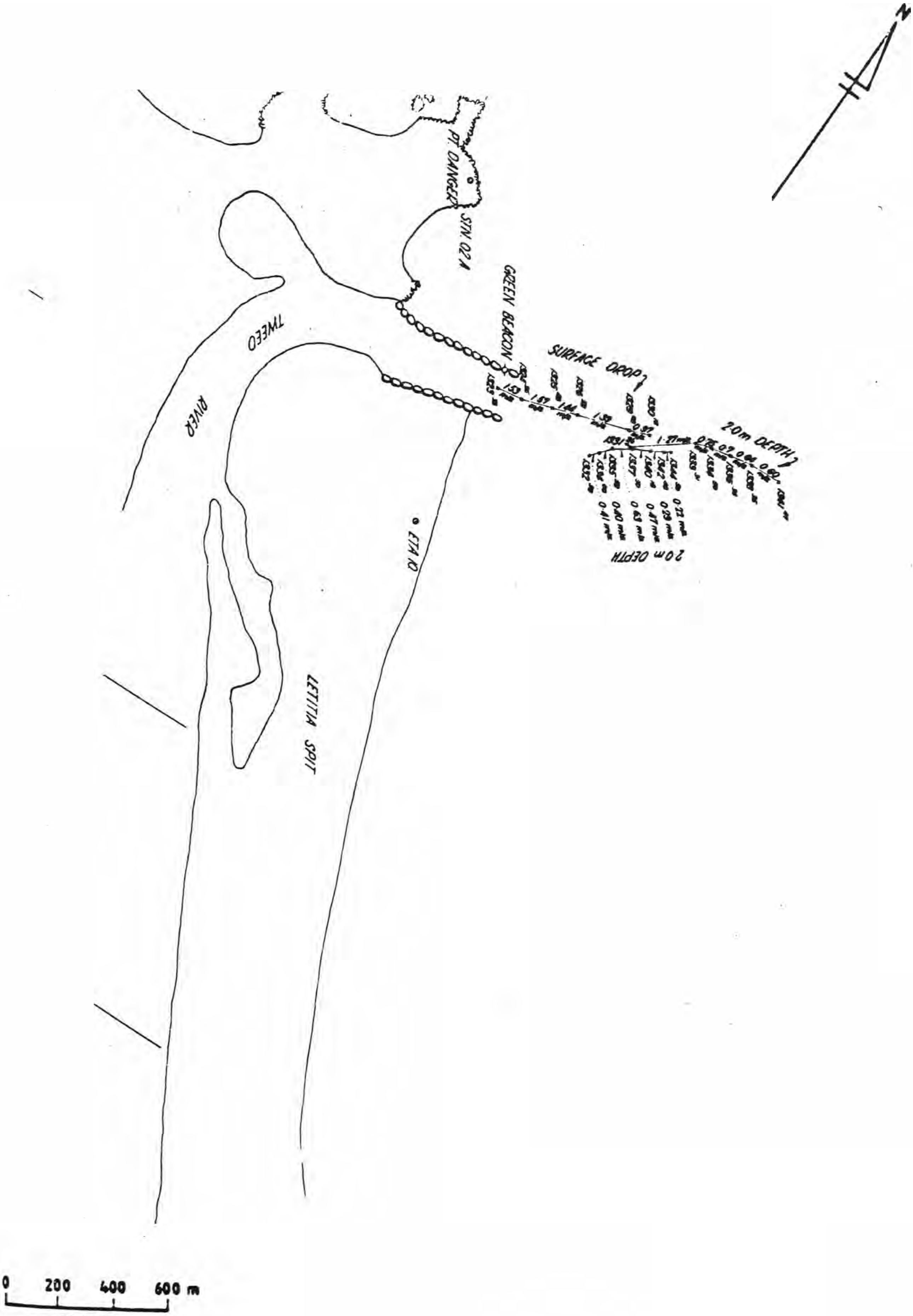
OFFSHORE CURRENT DROGUE TRACKING
26TH FEBRUARY 1986

FIGURE 44



OFFSHORE CURRENT DROGUE TRACKING
26 TH FEBRUARY 1986

FIGURE 44 CONTD.



OFFSHORE CURRENT DROGUE TRACKING
26 TH FEBRUARY 1986

FIGURE 44 CONTD

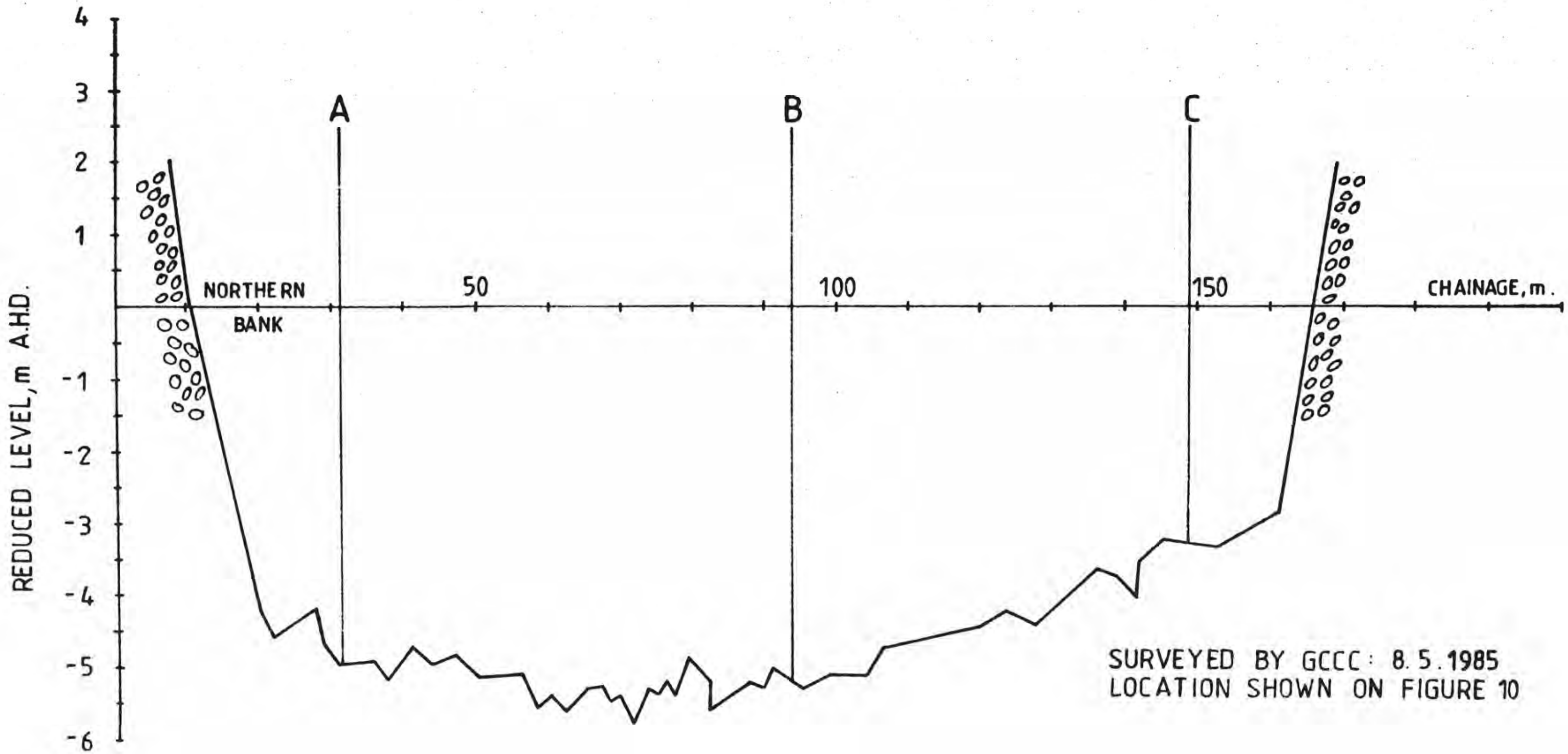
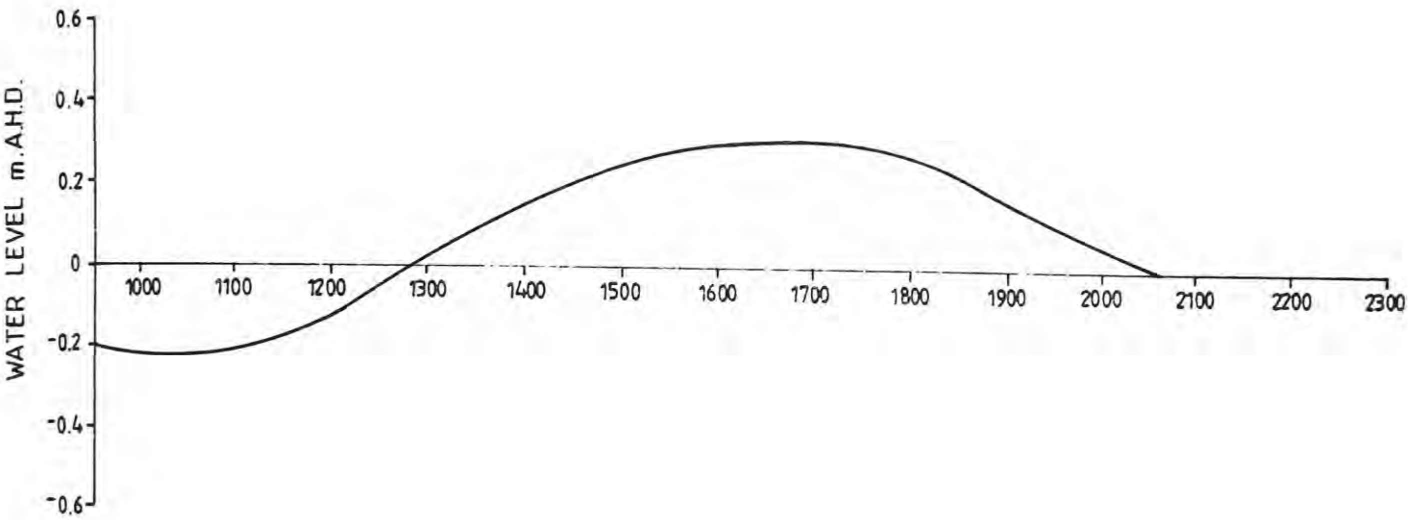
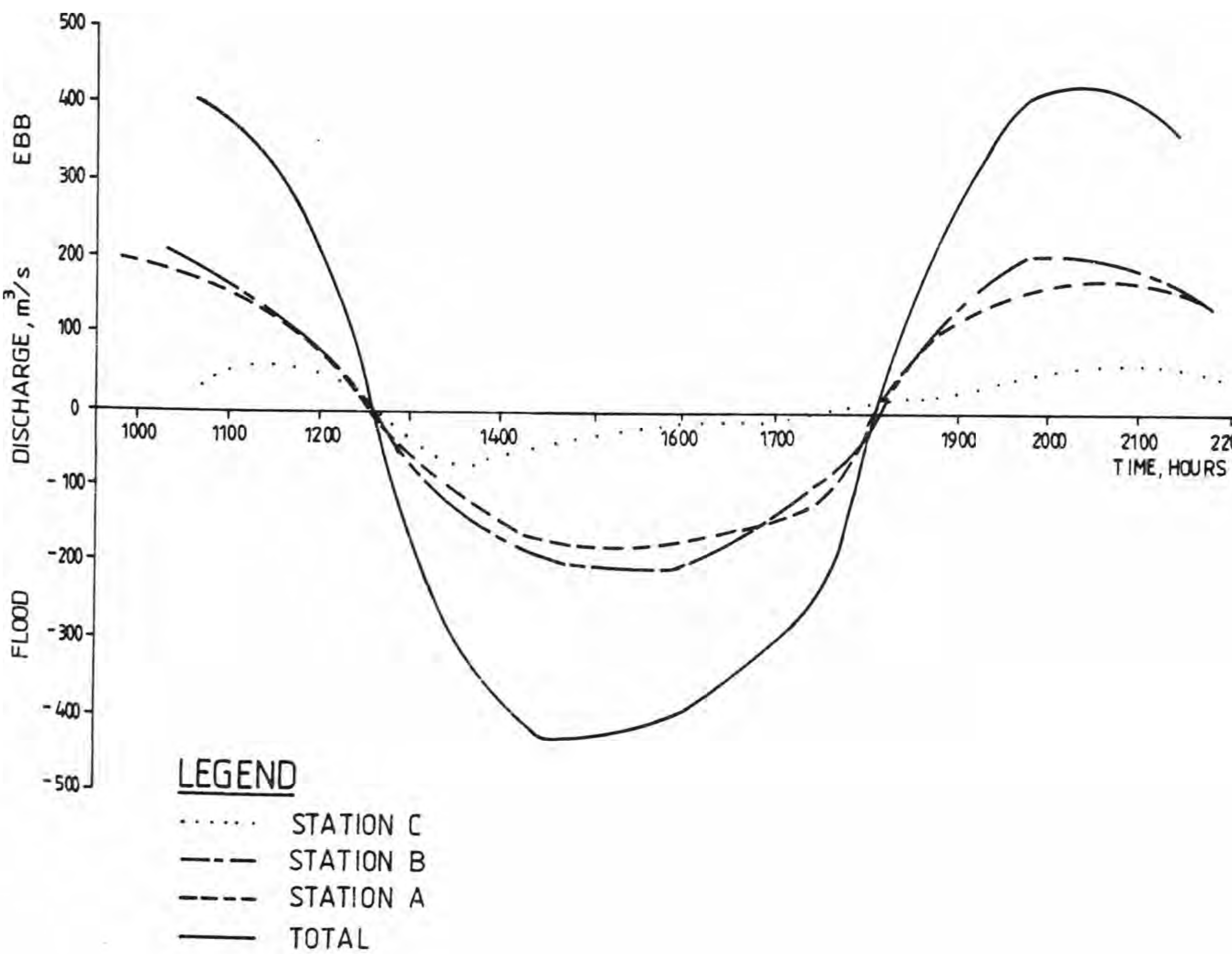


FIGURE 45

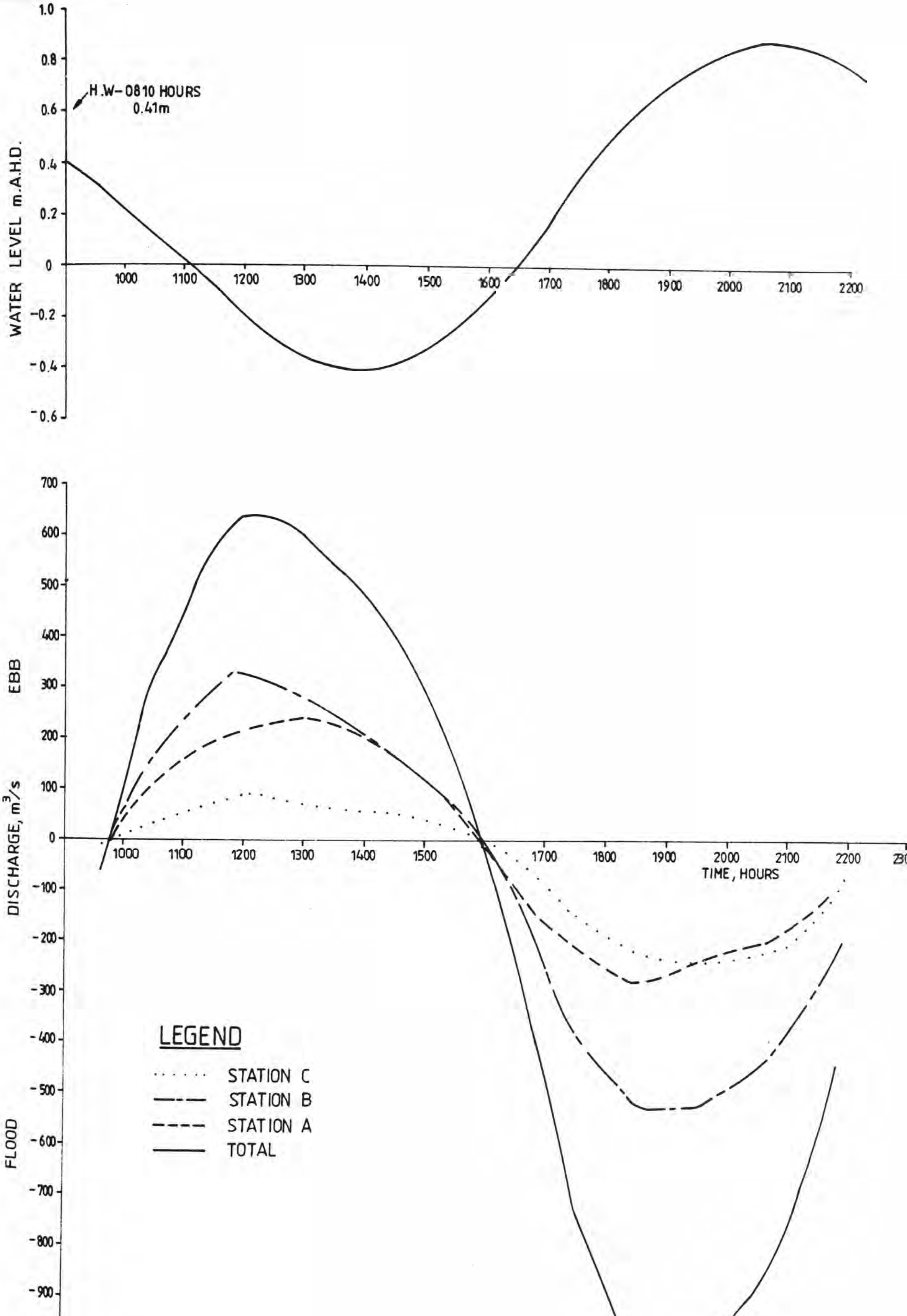
TWEED ENTRANCE CROSS-SECTION SHOWING STREAM GANGING STATIONS





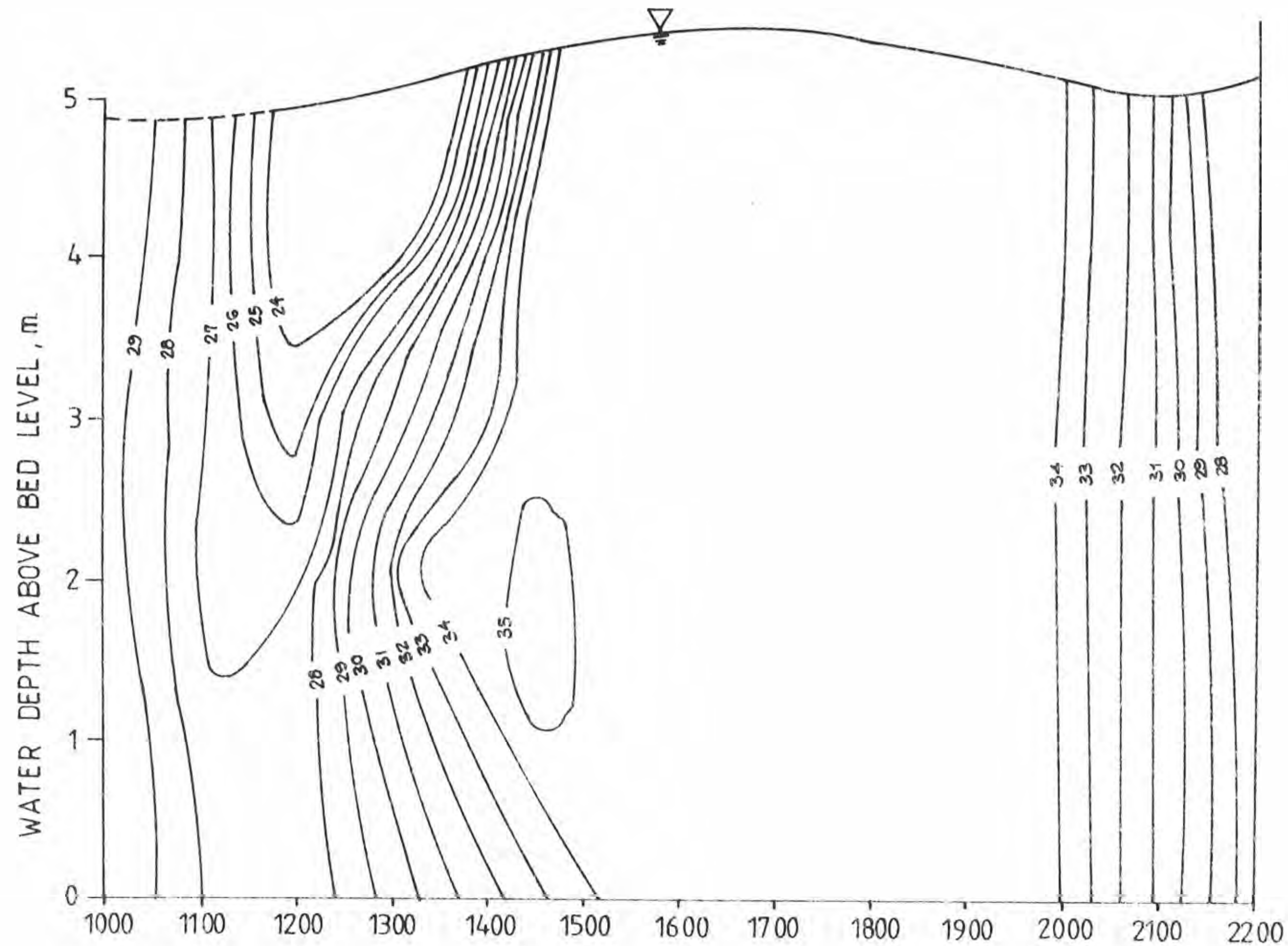
STEAM GAUGING - TWEED ENTRANCE
13TH MAY 1985

FIGURE 46



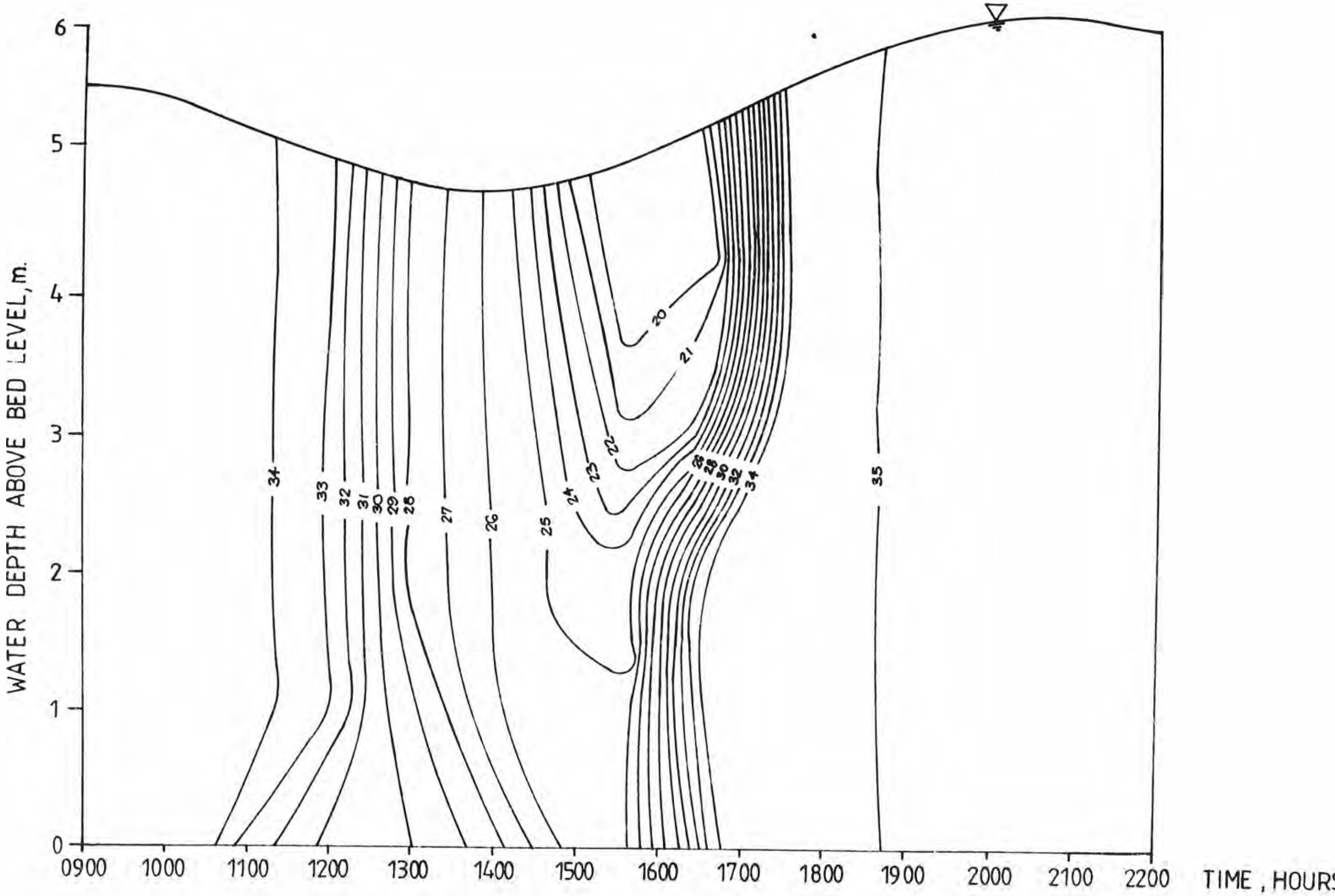
STREAM GAUGING – TWEED ENTRANCE
20TH MAY 1985

FIGURE 47



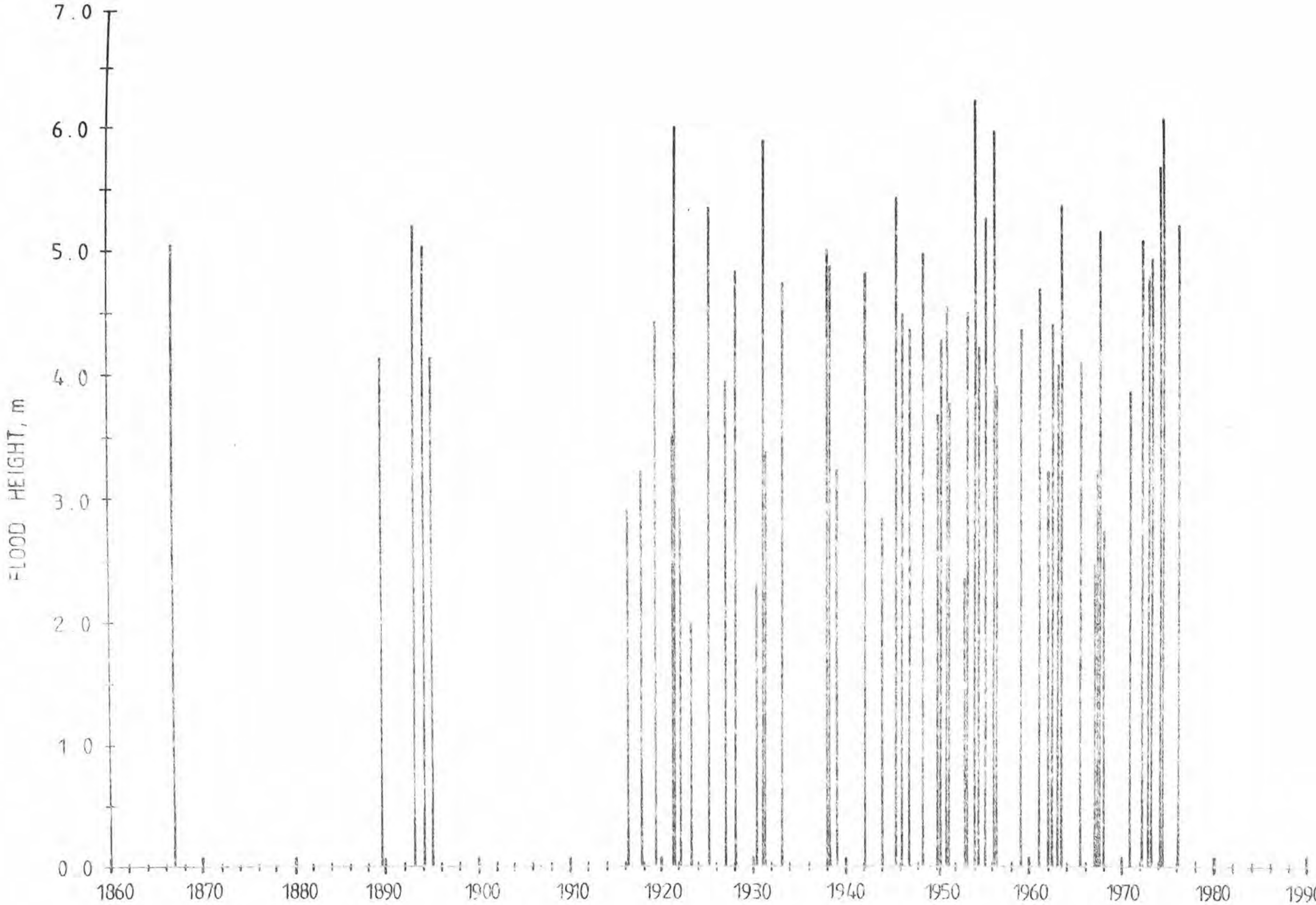
SALINITY DISTRIBUTION (IN PARTS PER THOUSAND) AT THE MID-CHANNEL GAUGING STATION SHOWN ON FIGURE 10 -13TH MAY 1985

FIGURE 4.8



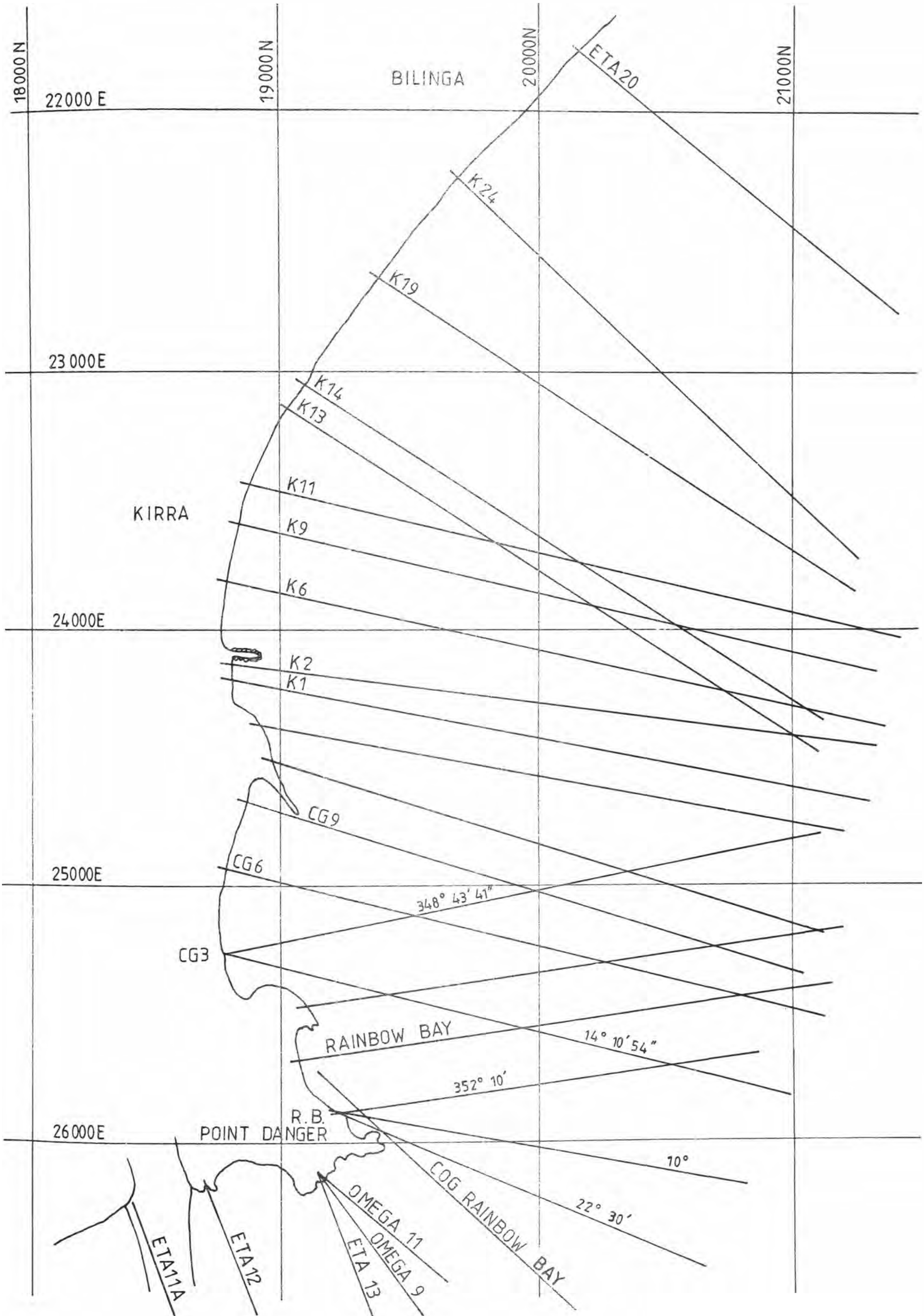
SALINITY DISTRIBUTION (IN PARTS PER THOUSAND) AT THE MID CHANNEL GAUGING STATION SHOWN ON FIGURE 10 - 20TH MAY 1985

FIGURE 49



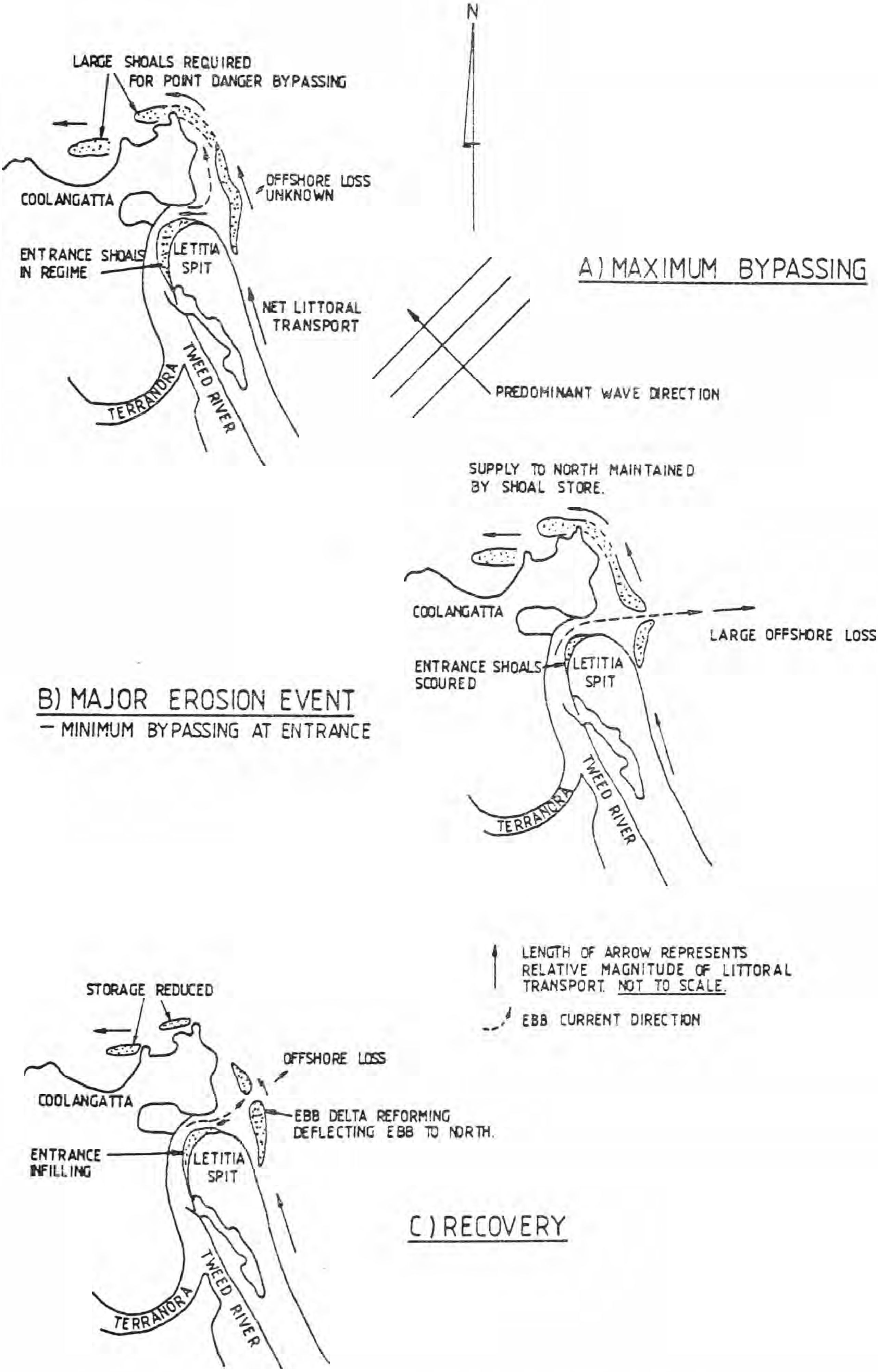
FLOOD RECORDS FOR THE TWEED RIVER AT MURWILLUMBAH

FIGURE 50



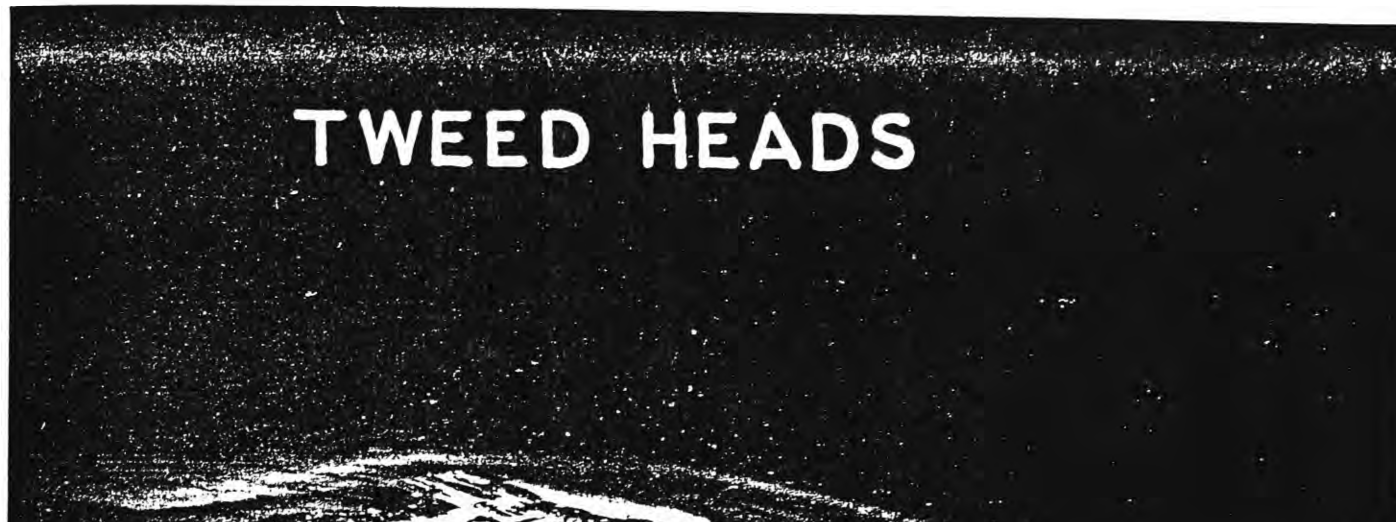
LOCATION OF SURVEY LINES FOR THIS STUDY
POINT DANGER TO CURRUMBIN

FIGURE 51



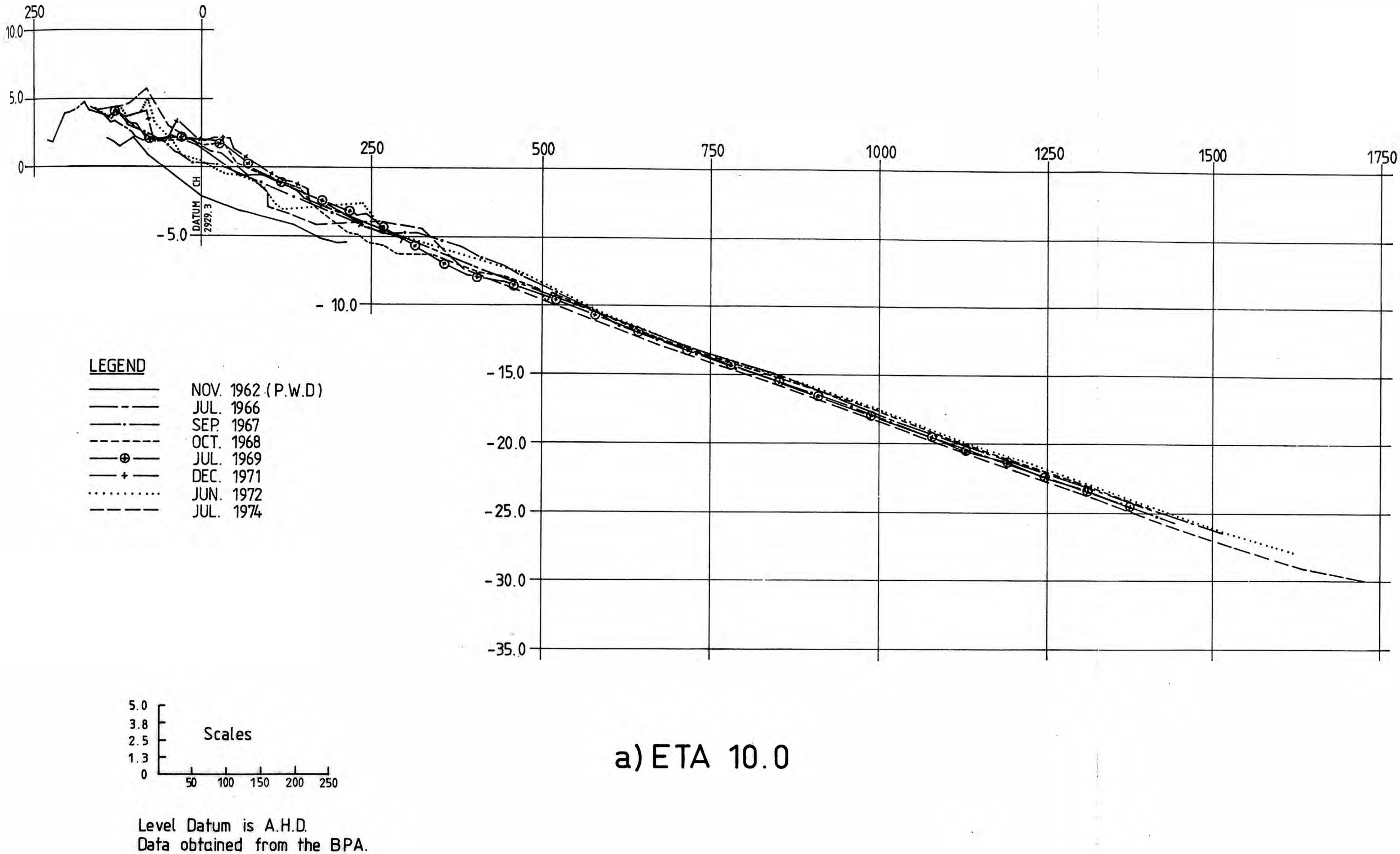
SCHEMATIC REPRESENTATION OF SAND BYPASSING PRIOR TO 1962.

FIGURE 52



PHOTOGRAPH OF TWEED ENTRANCE
TAKEN IN SEPTEMBER 1959

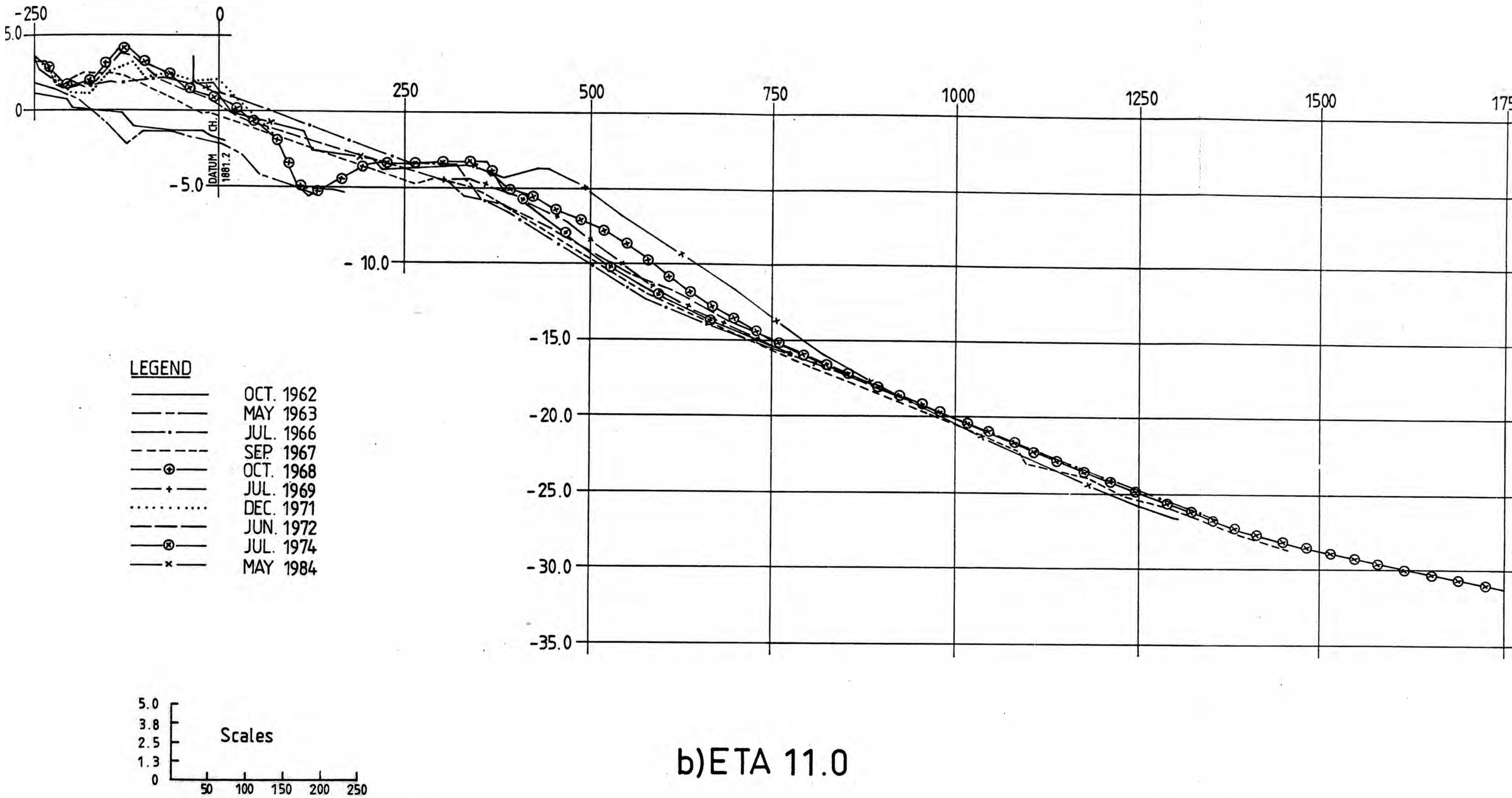
FIGURE 53



a) ETA 10.0

ETA LINE SURVEYS 1962-1984

FIGURE 54

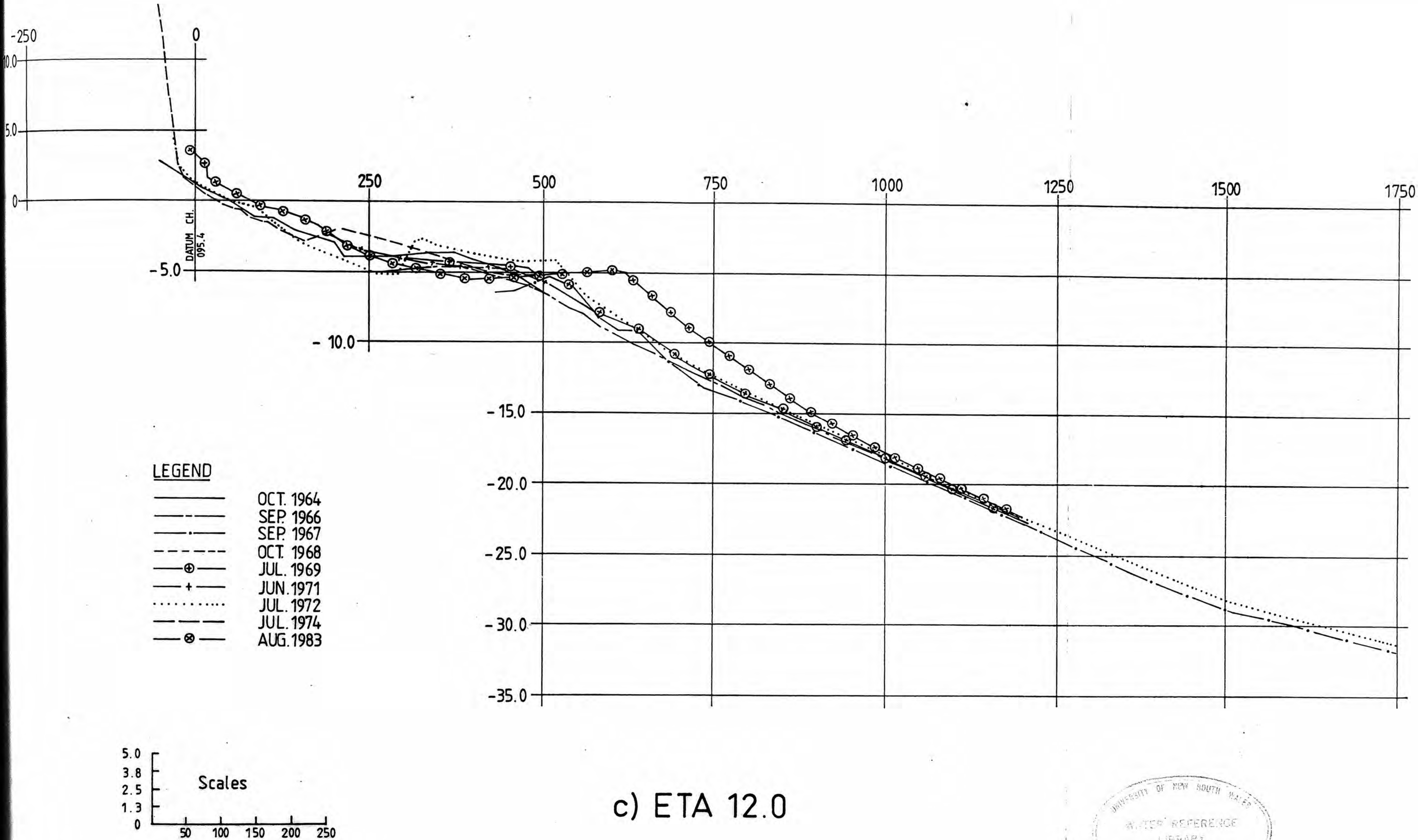


b)ETA 11.0

Level Datum is A.H.D.
Data obtained from the BPA.

ETA LINE SURVEYS 1962-1984

FIGURE 54 CONTD.



c) ETA 12.0

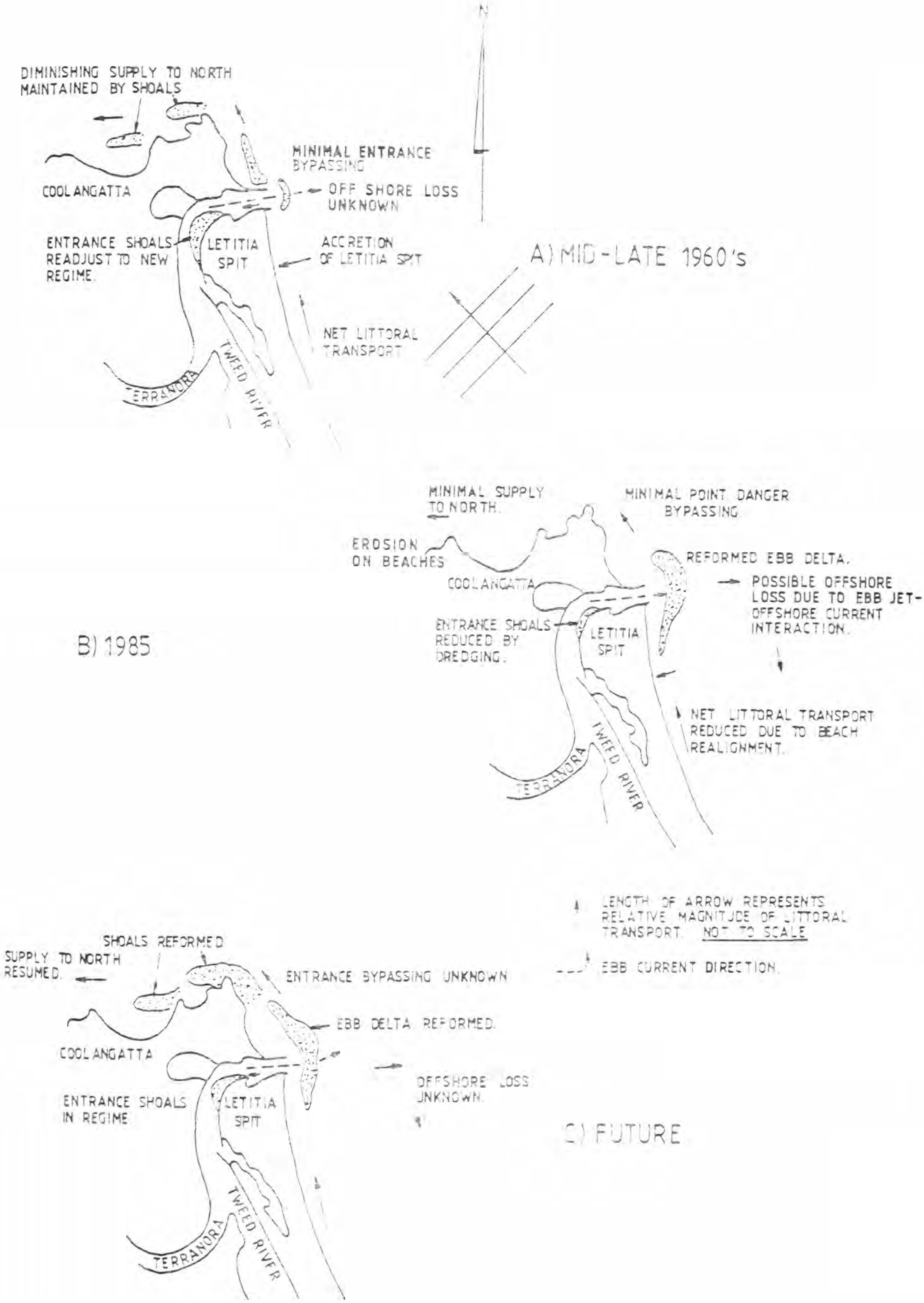
Level Datum is A.H.D.
Data obtained from the BPA.

ETA LINE SURVEYS 1962-1984

FIGURE 54 CONTD.

PHOTOGRAPH OF THE POINT DANGER AREA
TAKEN ON 21ST MAY 1967

FIGURE 55



SCHEMATIC REPRESENTATION OF SAND BYPASSING SINCE 1962-1964

FIGURE 56

THE UNIVERSITY OF NEW SOUTH WALES

water research laboratory

Manly Vale N.S.W. Australia

SAND BYPASSING AT THE TWEED RIVER ENTRANCE
DATA COLLECTION AND ASSESSMENT

VOLUME II - APPENDICES

by

R.B. Tomlinson and D.N. Foster

Research Report No. 167

July 1986

THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

SAND BYPASSING AT THE TWEED RIVER ENTRANCE

DATA COLLECTION AND ASSESSMENT

VOLUME II - APPENDICES

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https://doi.org/10.4225/53/5797fb12cf9db

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8. ABSTRACT

This report details an investigation of the natural sand bypassing processes which control the development of the ebb tidal delta at the trained entrance of the Tweed River. The training of this entrance has had a major impact on the longshore supply of sand to the beaches to the north of the entrance. The study has entailed the collection and assessment of existing data pertaining to the Tweed River - Lower Gold Coast Region. In addition, field investigations have been undertaken including offshore drogue tracking, side-scan sonar and seismic profiling, bed sediment sampling and stream gauging.

The results have shown that there is a complex interaction between the ebb jet, littoral, offshore currents at the entrance influencing the formation of a dynamically stable ebb tidal delta and the bypassing of the littoral sand supply. This and other factors make inadequate the use of commonly used procedures to investigate the effect of training walls on beach stability.

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Enquiries re purchase of report should be directed to the Librarian, Water Reference Library, The University of New South Wales, King Street, Manly Vale, NSW, 2093.

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CONTENTS - VOLUME II

LIST OF APPENDICES

APPENDIX 1

COASTAL CHANGES AT LETITIA SPIT

by

B. Davis, Water Research Laboratory

The following is a reproduction of part of a Water Research Laboratory Internal Report which was compiled in 1977. It has been included here as the results obtained and the listings of survey plans and aerial photographs are relevant to this study. Also an indication is given of the difficulties encountered in analysing beach profile survey data.

In addition to the survey dates listed for the Letitia Spit and Duranbah Beach lines, all lines were also surveyed in March 1971 and May - June 1985.

3. DATA

3.1 Maps, Plans and Charts

The area was first surveyed in 1883 by Commander Howard and since then the beach adjacent to the river entrance and the river have been charted numerous times. The most accurate and complete surveys are as follows.

1883	Howard, R.N.
1903	Tweed River Entrance
1915	S.R. Mallorky
1924	G. Brooks
1932	Moody
1960	R.M. Engel

A complete list of maps of the area is given in Table 1. These were produced between 1883 and 1968 and are available as dye lines or microfilms from the Public Works Department, NSW. The Public Works Department has been responsible for maintaining the entrance and they still hold all the relevant charts with the exception of those beach surveys done by the Co-ordinator General's Department, Qld.

There are also Admiralty Charts of the area but these do not show the beach area in detail. They are available from the Australian Navy.

3.2 Beach Profiles

Profiles of Letitia Spit have been made by the Public Works Department, NSW, and the Co-ordinator General's Department (Qld). Both surveys cover basically the same area. The profiles were first surveyed in 1962 and the most recent listed here was in 1970. They are scattered over about 1 mile of beach and are drawn from a depth of -20ft ISLW to about 10ft or 20ft ISLW. These do not cover the whole width of the active beach, so at the landward and seaward limits of the profiles there is still a considerable amount of sand movement.

The Public Works Department has surveyed five sections more than the Co-ordinator General's Department, four at the southern end of Fingal Beach

TABLE 1 - PLANS, MAPS & CHARTS OF TWEED RIVER ENTRANCE

Date	Title	Surveyed By	Scale	Comments
1883-1884	Tweed River	Howard, R.N.	1":2000′	Shows beaches south of entrance
1883-1884	Tweed River	Howard, R.N.	1":2000′	Shows entrance and beaches
2/4/1890	Tracings of Tweed River Entrance	Not Known	1":400′	
30/6/1897	Tweed River Entrance	" "	1":800′	
10/5/1898	Tweed River Entrance	" "	1":1500′	
13/9/1899	Tweed River Entrance	" "	1":1500′	Very little detail
1900	Tweed River Improvements	" "	Not Given	
12/3/1900	Tweed River Entrance	" "	Not Given	
12/3/1900	Tweed River Entrance	" "	Not Given	
12/3/1900	Tweed River Entrance	" "	1":400′	Near entrance
12/3/1900	"	" "	"	Near entrance
12/3/1900	"	" "	"	Upstream of entrance
12/3/1900	"	" "	"	" "
12/3/1900	"	" "	"	At entrance
9/9/1903	Tweed River Entrance	" "	1":400′	Includes high and low water lines for the previous three years
1903	Tweed River Entrance	" "	Not Given	Sounding at March 1900
1912	Dredge Service Surveys	" "	1":400′	
1912	" " "	" "	Not Given	Contours of river bed
1912	Sounding Tweed River Entrance	" "	1":400′	Soundings River
1915	Tweed River	S.R.Mallorky	1":400′	Contours of River
1915	Tweed River	S.R.Mallorky		Sounding in River
1915	Soundings Tweed River Entrance	S.R.Mallorky	1":400′	
1915	Tweed River Entrance	S.R.Mallorky	1":400′	

TABLE 1 CONTD. - PLANS, MAPS & CHARTS OF TWEED RIVER ENTRANCE

Date	Title	Surveyed By	Scale	Comments
1916	Tweed River	S.R.Mallorky	1":400′	Not much detail
1918	Tweed River	Not Known	1":200′	Dredging in River
1920	Tweed River Entrance	Not Known	1":200′	Contours of River and Entrance
1920	Tweed River Entrance	Not Known	1":400′	Soundings in River
1920	Tweed River	Capt. Pasco R.N.	1":800′	General Layout
1921	Tweed River	" "	1":400′	Soundings in River and Entrance
1918	Tweed River	E.B.Mahoneys	1":200′	Soundings of River
1915-1920	Behaviour in Channel	Not Known	1":800′	Some volumes of sediments calculated
1924	Tweed River	G.Brooks	1":400′	River upstream of Entrance
1924	Tweed River	G.Brooks	1":400′	Entrance
1924	Tweed River		1":100′	Details upstream of of Entrance
1924	Tweed River Entrance	G.Brooks	1":400′	Contours of Entrance
1932	Tweed River	Moody	1":400′	Soundings at Entrance
1932	Tweed River	Moody	1":400′	Soundings of River
1932	Tweed River Entrance	Moody	1":120′	Details near Wharf
1932	Tweed River Entrance	Moody	1":400′	Contours of Entrance
Dec. 1960	Tweed River	R.M. Engel	1":200′	Sounding along Beach
1960	Approaches to Tweed Heads	Sanderson	1:25 000	Soundings
14/12/60	Ballina to Tweed Heads	Sanderson	1:50 000	Soundings
14/12/60	" " " "	Sanderson	1:50 000	Soundings
1/3/68	Tweed Harbour Works	D.P.W.	1":400′	To accompany beach cross-sections

and one on Duranbah Beach.

A map showing the location of the profiles is given in Figure 1 and Table 2 lists the profiles that have been surveyed.

3.3 Aerial Photography

The first aerial photography was done in May 1947 by the Army, but is of poor quality. Subsequent runs have been made by The Lands Department of NSW in 1962 and 1971. These are of good quality and can be enlarged to scales of 1:3 000 with little loss of detail. Copies of all aerial photos can be obtained through the Lands Department.

A list of aerial photos is given in Table 3.

TABLE 3 - AERIAL PHOTOGRAPHY OF TWEED HEADS (1947-1971)

Date	Photograph
27/5/47	404 SVY 122 Run 2
"	405 SVY 122 Run 2
"	SVY 122 Run 2
"	407 SVY 122 Run 2
"	408 SVY Run 2
27/8/62	NSW 1161 5196 Run 1
"	NSW 1161 5171 Run 2
12/8/71	NSW 1966 5089 Run 2

4. LONG TERM COASTLINE CHANGES

4.1 Comparison of Maps, Plans, Charts & Aerial Photographs

Commander Howard compiled a chart in 1883-1884 showing the state of the river before any training walls or breakwater were built. The map shows a wide and reasonably shallow river, with the stretch of land between it and the ocean as mostly scrub but thickly wooded in sections. The beach is about 250 feet wide from low water to the vegetation line. Fingal Point was a thickly wooded ridge running eastwards and turning south at its end. The beach runs out to almost meet its tip on the southern side, but on its northern side a rocky shoreline is shown, which indicates a littoral drift to the north. The sand spit between the river and the coast loses its vegetation about 4500 feet south of the river entrance. This northern end

TABLE 2 : SURVEY DATES FOR BEACH PROFILES, FINGAL AND DURANBAH BEACHES

Sections \ Dates	20/11/62 NSW	3/6/63 NSW	19/9/63 NSW	24/1/64 NSW	5/4/64 NSW	21/10/64 NSW	23/3/65 NSW	25/3/66 NSW	June 1966 QLD	May/June 1967 QLD	Sept 1968 QLD	1/3/68 NSW	May 1968 QLD	Oct 1968 QLD	10/12/69 NSW	Jan 1970 QLD
100	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
400	√	√	√	√	√			√	√	√	√	√	√	√	√	√
700	√	√	√	√	√			√	√	√	√	√	√	√	√	√
1000	√	√	√	√	√			√	√	√	√	√	√	√	√	√
1300	√	√	√	√	√			√	√	√	√	√	√	√	√	√
1750	√	√	√	√	√			√	√	√	√	√	√	√	√	√
2200	√	√	√	√	√			√	√	√	√	√	√	√	√	√
2800	√	√		√	√			√				√			√	
3400	√	√	√	√	√			√				√			√	
4300	√	√	√	√	√			√				√			√	
5200	√	√	√	√	√			√				√			√	
186					√		√	√		√	√	√	√	√	√	√
633					√		√	√				√			√	

Note: Those marked as QLD were surveyed by the Co-ordinator-General's Department, Queensland and those marked NSW were surveyed by the Dept. of Public Works, NSW.

of the spit is covered by hillocks and ridges of bare drift sand about 80 feet high. At the transition point where the thick vegetation and hillocks meet, a rock bar is shown to run along the river foreshore. For a short distance south of the river entrance the beach becomes steeper. This is indicated by the convergence of the high and low water marks.

A map entitled "Tracing of Tweed River Entrance" dated 2nd April 1890, shows the river entrance and about one mile of Letitia Spit, before any breakwaters or training walls were built. The river and beaches are not shown in as much detail as on Howard's map, but little seems to have changed since this earlier survey.

The river and beach area as it was in 1897 is shown on a map entitled "Tweed River Entrance". About one and a half miles of beach area is shown. Some construction on the training walls had begun and the river had been deepened by the dredge "Actor", the dredged material being placed behind the eastern training wall. Otherwise the shape of Letitia Spit had changed little.

A map entitled "Tweed River Entrance" was drawn on 12th March 1900, and shows the breakwaters and training walls nearly finished. The map also shows the position of the high and low water marks for a short distance south of the breakwater. Letitia Spit is still shown to have the same general shape as on previous maps.

In 1903 a very comprehensive chart was drawn showing the breakwaters and beach area. The position of high and low water for various dates was given (1900, 1901, 1902). The breakwaters were still not complete. The map showed that the position of high and low water wandered considerably over the three dates.

The 1915 map drawn by S.R. Mallorky has little detail on the beach area except the position of high and low water.

By 1920 work had finished on the breakwaters although they had not been extended as far as was originally proposed. Captain Pasco's map shows the position of low water to have moved out well past the southern breakwater and the existence of a large sand bank on the southern side of the river.

This bank extended downstream from the spur wall which had been built just previously.

Brooks in 1924 surveyed Letitia Spit and the river entrance. His map shows the position of high and low water to be roughly the same as the 1920 survey. Also there is a large sand flat some distance seaward of the southern breakwater. The map is fairly comprehensive having soundings quite close to Fingal Beach. By this time the dunes behind the southern breakwater had built up high enough to overtop the wall in parts.

In March 1932 Moody surveyed the entrance and Letitia Spit. His map covers about half a mile of beach, showing the position of high and low water and gives some good soundings off Letitia Spit. The large sand flat shown in 1924 off the southern breakwater has changed shape and diminished in size. Letitia Spit is shown as "sand dunes" and even more of the southern breakwater has been overtopped by sand.

Aerial photographs taken in 1947 show Letitia Spit to be covered mainly by sand dunes with very little vegetation. The sand dunes seem to have become larger than the earlier plans indicate and the southern breakwater has experienced severe overtopping. Fingal Point has nearly been buried completely by the dunes. In this area the distance from vegetation to low water in 1889 was about 250 feet, but in 1947 it averages at about 500 feet.

The latest map of the area was surveyed in 1960 by R.M. Engel which includes the river entrance and the beach area south for 2 000 feet. The positions of high and low water are marked, and both have moved seaward since the 1932 survey. Letitia Spit is covered with more grass, and sand is not shown to be overtopping the southern breakwater as it was on previous dates.

4.2 Variation of High and Low Water Lines 1883-1969

In an attempt to assess coastline changes in the long term we need to trace the movement of a common feature. The only well documented common feature on Letitia Spit is the position of high and low water marks which have been recorded since 1884.

4.2.1 Data Used

Plans were useful if:

(a) They covered the appropriate area of the beach.

(b) There were sufficient reference points.

(c) They were at reasonably evenly spaced time intervals.

The following plans were acceptable:

Tweed River 1883-1884, Howard
Tweed River Entrance, 1903
Tweed River, 1960
Beach Profiles, 1962
Beach Profiles, 1969

4.2.2 Method

A plan was prepared showing the position of high and low water marks for various dates (see Figure 2). This was done by reducing the above listed plans to a common scale with the use of a pantograph and then superimposing one on the other. Care was required to ensure that correct and accurate reference points were used and verification of the alignment and scaling was made by cross checking as many reference points as were available.

Sections were established across the beach (see Figure 2) and the low water mark for 1900 was chosen as zero chainage for each section. A graph was then drawn which plotted the chainage of the low water line against time (see Figure 3).

4.2.3 Accuracy

The accuracy of Figures 2 and 3 is dependent on the accuracy of the plans, maps, charts and beach profiles and the errors involved in combining these to produce Figure 2. The water lines on Figure 2 should have error bars of $\pm$ 50 feet.

4.2.4 Trends

There is some evidence to suggest that Letitia Spit has been eroding before and between the period of breakwater construction. However during and immediately after the two periods of breakwater construction there is strong evidence that Letitia Spit had accreted considerably. These observations may be made by examining Figure 3.

The beach position and alignment appears to have fluctuated or wandered, especially at the northern end of Letitia Spit. During the pre-breakwater period, this wandering was most pronounced. This is shown in Figure 2 if a comparison of high and low water marks is made. Further south the fluctuations are less pronounced. The construction of the breakwater seems to have stabilised this wandering to an extent, but there are still random fluctuations which make it difficult to determine trends in the sand movement.

Trends in the beach sand movement are best shown by Figure 3 which indicates that between 1883 and 1900 all sections experienced erosion. Between 1900 and 1902 there was accretion which coincided roughly with the construction of the breakwater. By 31st October 1902, the breakwater length was 1320 feet, just beginning its 90 degree sweep to the east (see Figure 1), and on 31st January 1903 it was only 685 feet from completion and was finally completed in 1904 at 2 500 feet. If the accretion in the 1900 to 1902 period was caused by the breakwater, then the beach was very sensitive to the construction of the breakwater, because the low water mark moved out well ahead of the breakwater construction. This apparent premature jump may be just a combination of the normal wandering of the beach and a moderate accretion caused by the breakwater.

Between 1902 and 1960 the coastline eroded in all but one section. In this 58 year period it is possible that there were large fluctuations, but the graph is drawn as a straight line because there were no suitable surveys. In the 1960's the large accretions were almost certainly caused by the construction of the outer breakwater.

There are two different conclusions which could be deduced from the data. Firstly, we could conclude that there were large fluctuations in the position of high and low water, which were largely stabilised by the construction of the inner (or first) breakwater. This would mean that the 1900, 1901 and, maybe, the 1902 beach configurations were not affected by the breakwater, and may be used to estimate the magnitude of these fluctuations. Secondly we could conclude that, together with some large fluctuations in the position of high and low water, the coastline was eroding and that the construction of the first (inner) breakwaters caused the beach to stabilise. This assumes that the erosion shown in Figure 3 from 1883 to 1900 and from 1902 to 1960 reflects a long term trend.

5. SHORT TERM COASTLINE CHANGE - BEACH PROFILES 1962-69

5.1 Introduction

Section 4 of this report has examined the coastline changes since 1983 by comparing charts of the river entrance. This section makes a quantitative examination of the more detailed beach profiles.

5.2 Cross Sectional Areas of Beach Profiles

5.2.1 Definition of Control Areas

An ideal control area is an area under a beach profile which only changes its value as a result of the addition or subtraction of sand by littoral drift. The profiles on Letitia Spit do not extend landward or seaward far enough to define ideal control areas but they are reasonable approximations. Figure 4a is typical of these profiles showing sand moving on and off-shore and to and from the dunes. The profile shown in Figure 4b defines an ideal control area since it extends to stable limits and so all changes in the area are due to littoral drift. The calculations in this section do not take account of aeolian sand movement.

5.2.2 Reduction of Data

Both the PWD and COG profiles were surveyed to a depth of -15 feet ISLW, but sand movement is known to occur below this level. It is considered that all movement should be negligible at and below -30 feet ISLW, so a straight line approximation was used to extend these profiles down to that level. This is shown in Figure 5. The total control area is given by:

$$A_T = A_1 + A_2$$

The area A_1 was measured by the use of a planimeter, and the area A_2 was calculated from

$$A_2 = \frac{(C - 1000)}{2} \times 15$$
$$= 7.5\,(C - 1000)$$

The areas and relevant dimensions were taken from the beach profiles and were reduced to give the cross sectional areas as shown in Table 4.

5.2.3 Accuracy

There are five areas where error may occur:

(1) Original drawing errors.
(2) Distortion of drawings during copying.
(3) Profiles were drawn with straight lines.
(4) Straight line approximation of profiles below -15 feet ISLW.
(5) Use of planimeter in measuring the area.

The last two sources of error are the most significant. In planimetering the areas it was estimated that the error was equivalent to ± 30 feet^2 of beach cross section. If this is expressed as a percentage of the change in beach cross section during the eight years, it is equal to $\pm 3\%$.

It cannot be estimated what error is involved in the straight line approximation but it is likely that it formed the greatest error.

5.2.4 Trends

The variation in cross-sectional area with time for each profile line is shown on Figure 6. All sections show an increase in the cross sectional area (i.e. accretion) during the time of the study, however with this increase there are large fluctuations which are, in some cases, greater

TABLE 4 : CONTROL AREAS A_T, ft^2

Section	20/11/62	3/6/63	19/9/63	24/1/64	5/5/64	21/10/64	25/3/66	July 1966	Sept 1967	1/3/68	May 1968	10/12/69	Jan 1970
400	23600	34400	29900	45800	30800	42100	42900	41700	37700	44700	41700	42200	48400
700	24800	31700	26100	26800	25500	30100	32900	35500	31900	40700	32100	38800	36200
1000	19200	24200	24900	25000	25400	27400	35800	30300	29200	34100	29500	30600	31200
1300	12900	17300	22500	21000	19800	22000	20300	25700	25500	27600	24000	24800	28000
2200	14800	13100	14100	14200	21900	18900	17400	17000	1800	27000	20100	21300	22100
3400	17500	14600	13100	14200	14100	18300	14900			22700		19400	
5200	13400	15600	15800	16200	23400	19000	18800			23900		18000	

than the overall trend. During the period of the outer breakwater construction (1962-1963) there are large fluctuations at Section 400 which was closest to the breakwater.

The survey dated 1/3/1968 reveals a high accretion rate just prior to this date. This accretion is evident on all Sections and indicates how quickly beach sands can accrete and erode.

5.3 Element Volumes

5.3.1 Definitions

An element volume is the product of cross sectional area of a profile and its element length. The element length is the distance between the half way point to a profile on one side to the halfway point to the profile on the other. Where there is a change in direction of the base line, the profiles are not parallel and the element lengths must be calculated. This occurs at Sections 2200 and 1300. The element lengths are calculated by assuming the entire profile is a straight line as shown in Figure 7. The volume generated by rotating the cross-sectional area through the angle change is given by

$$dv = r^2 \theta \, dy$$

where

$r \quad = \frac{-B}{H}Y + B$

θ is in radians.

$$V = \theta \int_0^H B^2 - \frac{2B^2Y}{H} + \frac{B^2 Y^2}{H^2} \, dy$$
$$= \frac{\theta B^2 H}{3}$$

$$\text{Element length} = \ell_1 + \ell_2 + V/A$$
$$= \ell_1 + \ell_2 + \frac{2 \theta B}{3}$$

The value of B cannot be measured directly from the beach profiles as the profiles do not extend below -15 feet ISLW. To overcome this problem the profiles were extrapolated to -30 feet ISLW. Hence the element lengths for Section 2200 and Sections 1300 were calculated as follows:

Section 1300

θ = 8 degrees 19′ 20″ = 0.1453 radians

B = 1350 feet

$$\text{Element Length} = \ell_1 + \ell_2 + \frac{2\theta B}{3}$$

$$= 150 + 450 + \frac{2\times 0.1453\times 1350}{3}$$

$$= 730 \text{ feet.}$$

Section 2200

θ = 3 Degrees 20′ = 0.05818 radians

B = 1300

$$\text{Element Length} = \ell_1 + \ell_2 + \frac{2\theta B}{3}$$

$$= 450 + 600 + \frac{2\times 0.05818\times 1300}{3}$$

$$= 1100 \text{ ft.}$$

5.3.2 Reduction of Data

The element volumes were calculated using the cross sectional areas and the element lengths, and are given in Table 5. A summation of the seven element volumes for various dates using the NSW data, is plotted against time in Figure 8. Similarly, included in this figure is a plot for elements from the breakwater to Section 2200 ft. This second graph was included so that the Queensland data could be used.

5.3.3 Comments on Control Volumes

The element volumes show the same trend as the cross sectional areas, which is expected as they are closely related. They indicate that the elements suffer periods of erosion and accretion, however the total volume shows a more constant accretion rate. These results suggest that although sand is

TABLE 5 : ELEMENT VOLUMES (MILLION FEET^3)

Chainage \ Date	20/11/62	3/6/63	19/9/63	23/1/64	5/5/64	21/10/64	25/3/66	July 1966	Sept 1967	1/3/68	May 1968	10/12/69	Jan 1970
5200	18.1	21.1	21.3	21.9	31.6	25.6	25.4			32.2		24.2	
3400	26.2	22.0	19.6	21.3	21.1	27.4	32.4			34.1		29.1	
2200	16.2	14.4	15.6	15.6	24.1	20.8	19.2	18.7	19.8	29.7	8.8	23.5	24.3
1300	9.4	12.6	16.1	15.3	14.4	16.1	14.8	18.8	18.6	20.1	17.5	18.1	20.4
1000	5.8	7.3	7.5	7.5	7.6	8.2	10.8	9.1	8.8	10.2	8.8	9.2	9.4
700	7.4	9.5	7.8	8.0	7.6	9.0	9.9	10.6	9.6	12.2	9.6	11.6	10.9
400	7.1	10.3	9.0	13.7	9.2	12.6	12.9	12.5	11.3	13.4	12.5	12.7	14.5

transported randomly between elements, the total volume of sand on the beach varies far less.

The survey dated 1 March 1968 gives inconsistent values for the total volumes. These high values can be seen in the cross sectional areas and also by comparing the beach profiles. It appears there are two possible explanations. Firstly that the beach accreted due to unusual swell and sea conditions or, secondly, that the survey is in error.

5.3.4 Effect of Sand Movement onto Dunes

It is likely that a significant quantity of sand is moving into or from the dunes landward of the base line. This would cause changes in the total volumes and could cause inaccuracy in calculating the role of littoral transport.

If the beach profiles had extended further landward, so having stable limits, then there would be no need to take account of this transport. However, given the profiles as they are, the most practical method of assessing this transport is by plotting the surface elevation at the base line against time (see Figure 9).

With the exception of Chainage 1000, all Sections show an increase in surface height at the base line with time. Associated with this are large fluctuations. A linear regression analysis was carried out to determine an average rate of change of elevation and correlation factors. These are shown in Table 6.

TABLE 6

RATE OF CHANGE OF SURFACE ELEVATION AT THE BASE LINE

Section Ch. ft.	Rate ft/day	Correlation
400	0.00263	0.90
700	0.00205	0.88
1000	-0.00046	-0.89
1300	0.00415	0.95
2200	0.00176	0.82
5200	0.00312	0.94

In general it appears that the surface elevations were increasing at about 0.002 to 0.003 ft per day over the years 1962 to 1970. An approximation for the amount of sand deposited landward of the base is thus given by:

$$\text{Volume of sand deposited} = \frac{5400 \times 0.0025 \times d}{2} \simeq 6d$$

where 5400 is the total of all the element lengths, 0.0025 is the average increase in surface elevation at the base line and d is the distance from the base line to where the dunes become stable. The cross section of this deposition area is assumed to be a triangle. This equation is tabulated in Table 7.

TABLE 7

VOLUME OF SAND DEPOSITED LANDWARD OF THE BASE LINE

d (ft)	Volume ft^3/day
10	60
100	600
500	3000
1000	6000

Section 5.3.5 establishes that the littoral transport rate is at best 17 000 ft^3/day, and hence if d was greater than 100 ft then the loss of sand to the dune system would have caused an error greater than 5% in the calculations of the transport rate. Sand movement is known to have occurred well inland of the frontal dune system, as described in Section 4.1.

5.3.5 Littoral Drift

The volume flow rates of the littoral drift can be calculated by using the change in the total volume calculated in Section 5.3.2 with the following assumptions:

(a) Sand moves from south to north.

(b) Initially the breakwater acts to cut transport completely, and that the time when bypass commences is as shown in Figure 8.

(c) No storage of sand south of element 5200.

(d) Sand does not compact.

(e) Sand does not move off shore or into the dune system.

The transport rate was obtained by measuring the initial slope of the total volume versus time graph (see Figure 8). This was done for the two plots of volumes against time giving a transport rate of 11 795 000 ft^3/year for the volume between the breakwater and chainage 2200 feet and 15 432 000 ft^3/year for the volume between the breakwater and chainage 5200 feet.

The storage per foot of beach per day for the smaller volume is given by:

$$\frac{\text{Transport Rate}}{\text{Length of Beach}} = 11795000/(2200 \times 365) = 14.69 \text{ ft}^3/\text{ft day}$$

and for the larger volume is given by:

$$\frac{\text{Transport Rate}}{\text{Length of Beach}} = 1543200/(5200 \times 365) = 8.13 \text{ ft}^3/\text{ft day}$$

These can be compared with the rate of change of element volumes per foot of beach which was as high as 45.21 ft^3/ft day between 23 January 1964 and 5 May 1964 for element 400. This indicates that the fluctuation in the element volumes is large compared to the total trend.

5.4 Beach Alignment

5.4.1 Definition

For the purpose of this report, beach alignment is considered as the general position and bearing of the littoral zone. Beach alignment is difficult to quantify and hence a schematic concept of beach movement will be used. Accretion of the beach is considered as a complete movement of the beach profiles seaward as shown in Figure 10. The change in cross sectional area is given by:

$$\Delta A = (h + 30)\, d$$

where these symbols are defined in Figure 10. Re-arranging this equation gives the section displacement as:

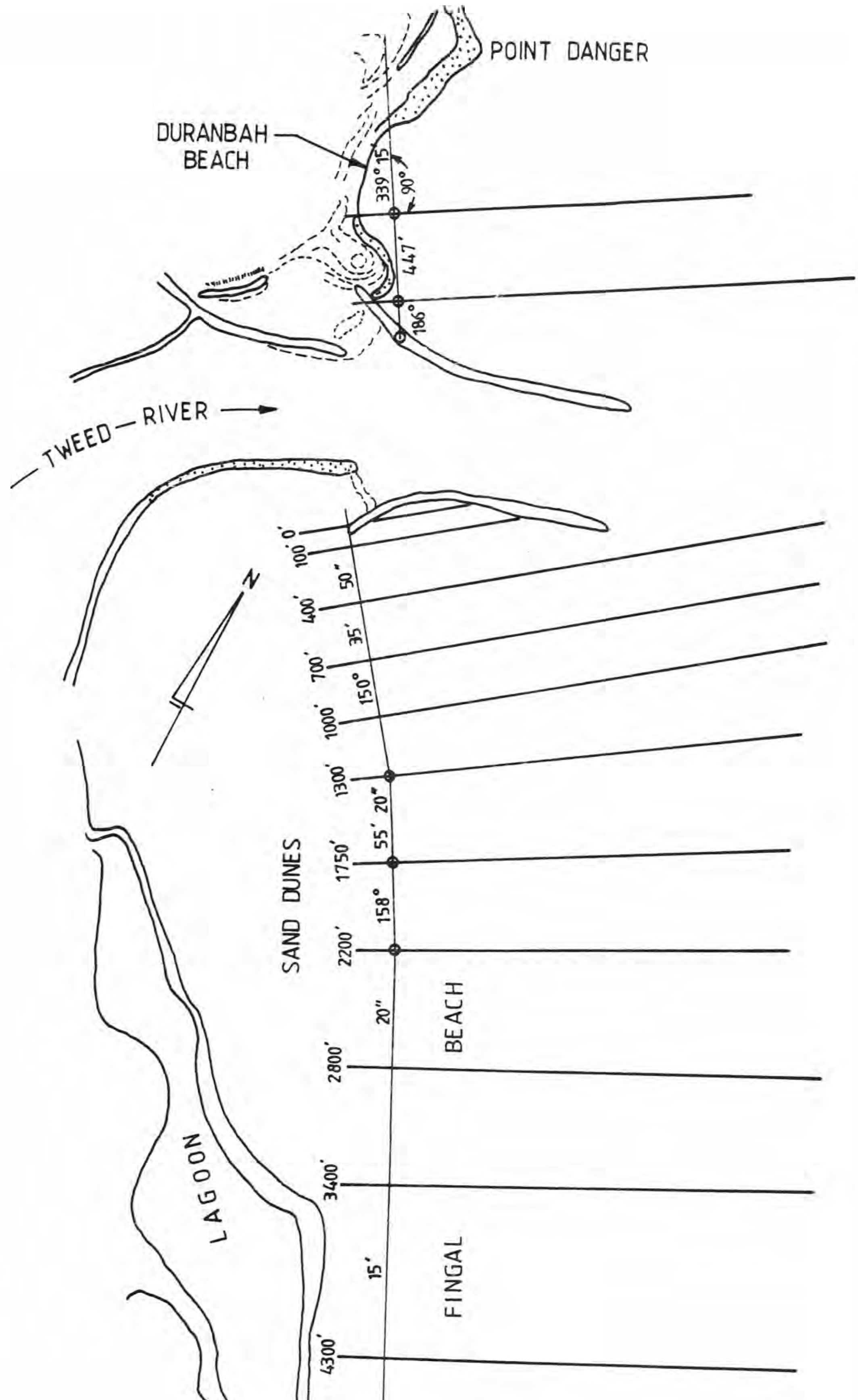
$$d = \Delta A \,/\, (h + 30)\, d$$

5.4.2 Reduction of Data

The data given in Table 4 and Figure 9 were reduced by the use of the above equation to give the Section displacements for the following dates: 3.6.63, 5.5.64, 25.3.66 and 10.12.69. These results are given in Figure 11.

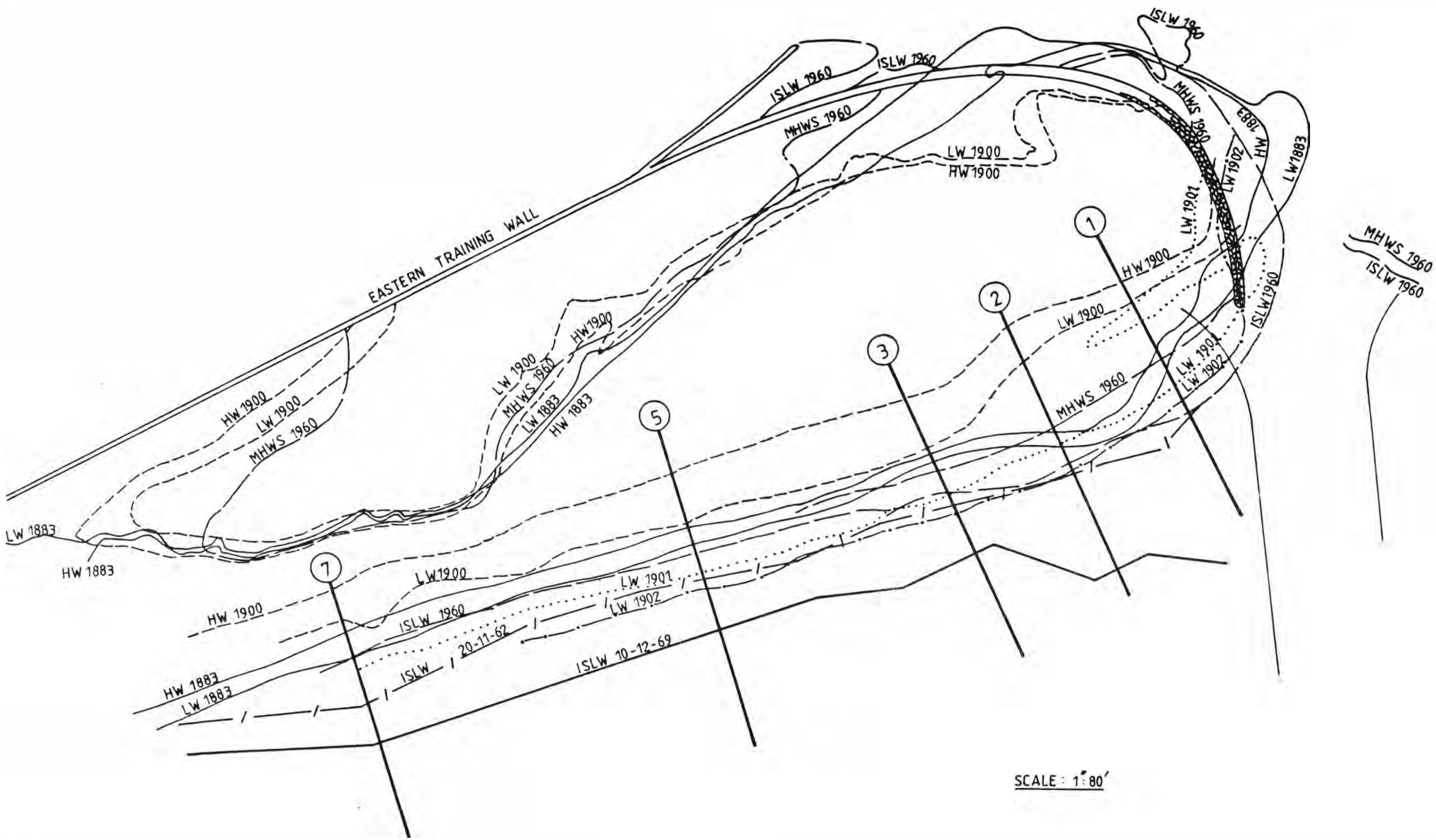
5.4.3 Comments on Alignment

These results show how the beach adjusted its alignment as a result of the breakwater construction. The results may be of use to calibrate computer predictions of beach alignments in such situations.



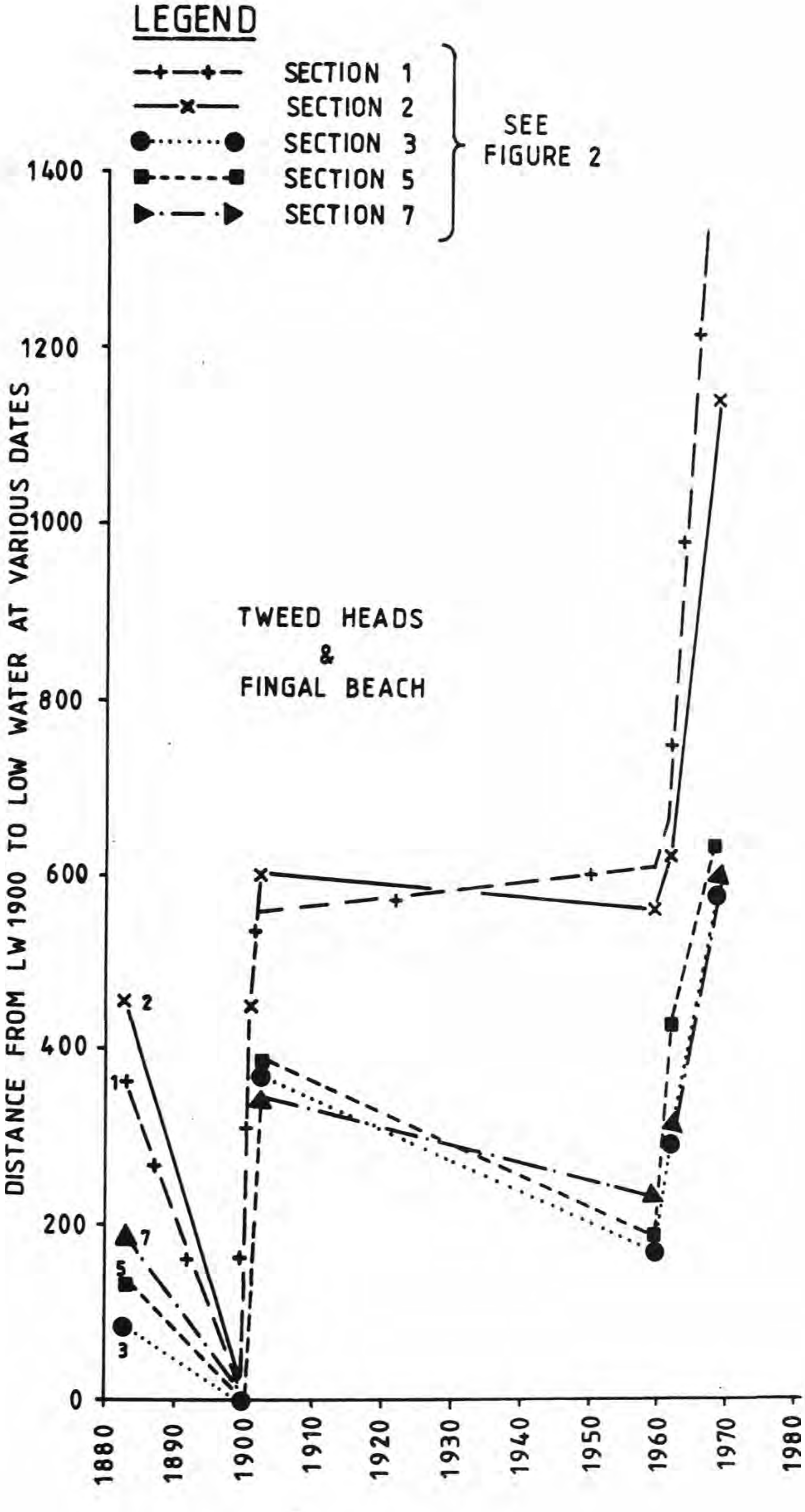
LOCATION OF PROFILES FINGAL AND DURANBAH BEACHES.

FIGURE 1



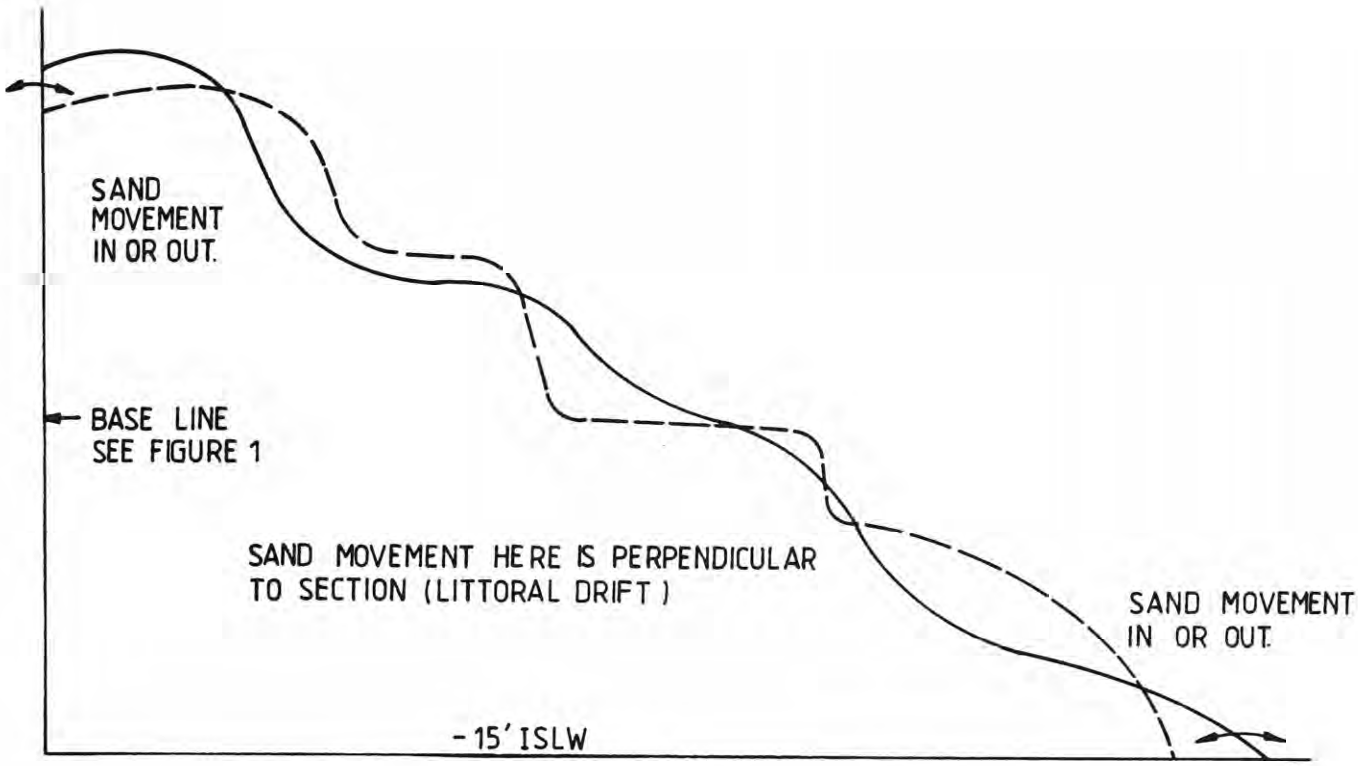
CHANGES IN HIGH AND LOW WATER MARKS SINCE 1883

FIGURE 2

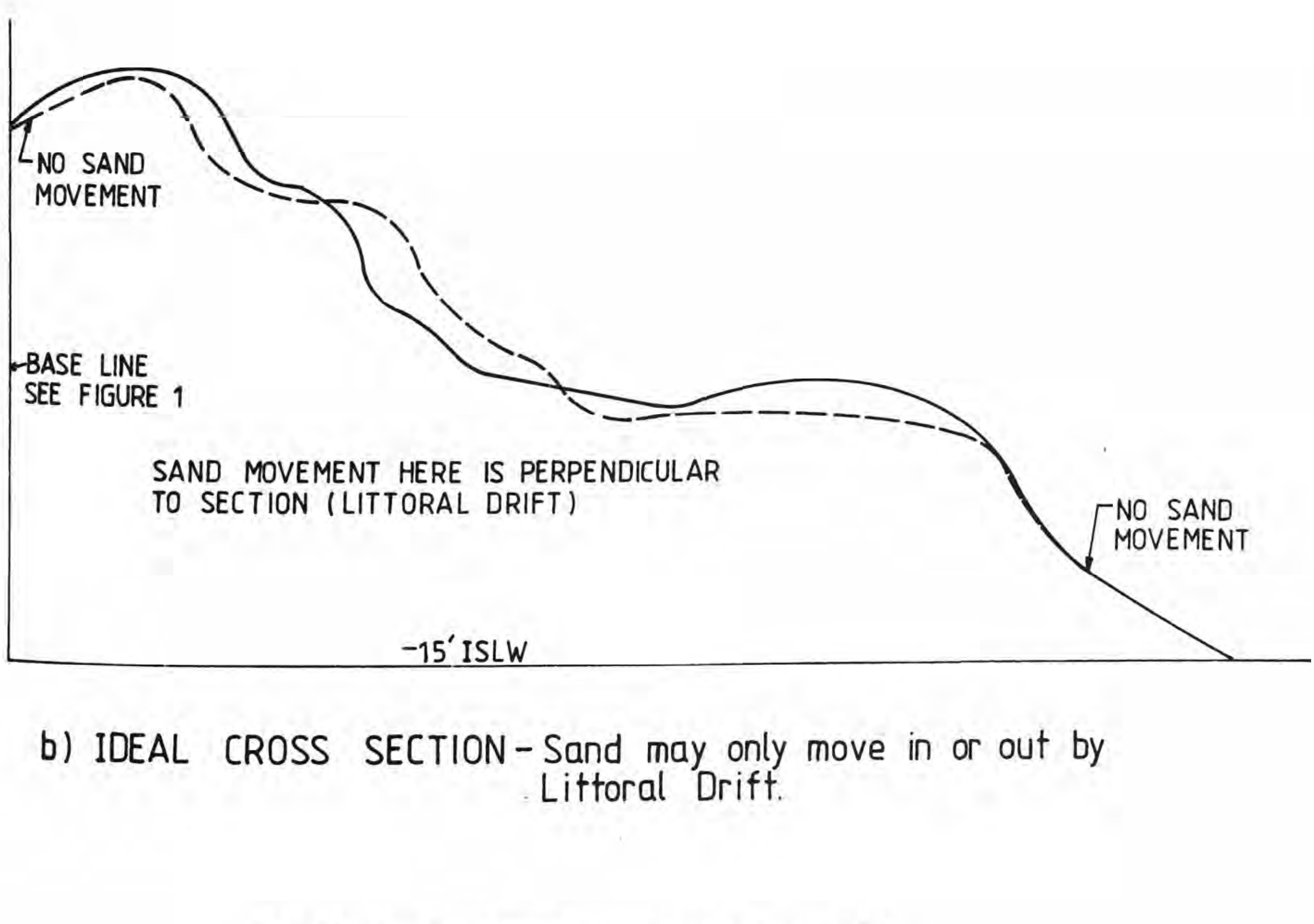


CHANGES IN THE POSITIONS OF LOW WATER MARKS
1883 TO 1969 LETITIA SPIT

FIGURE 3



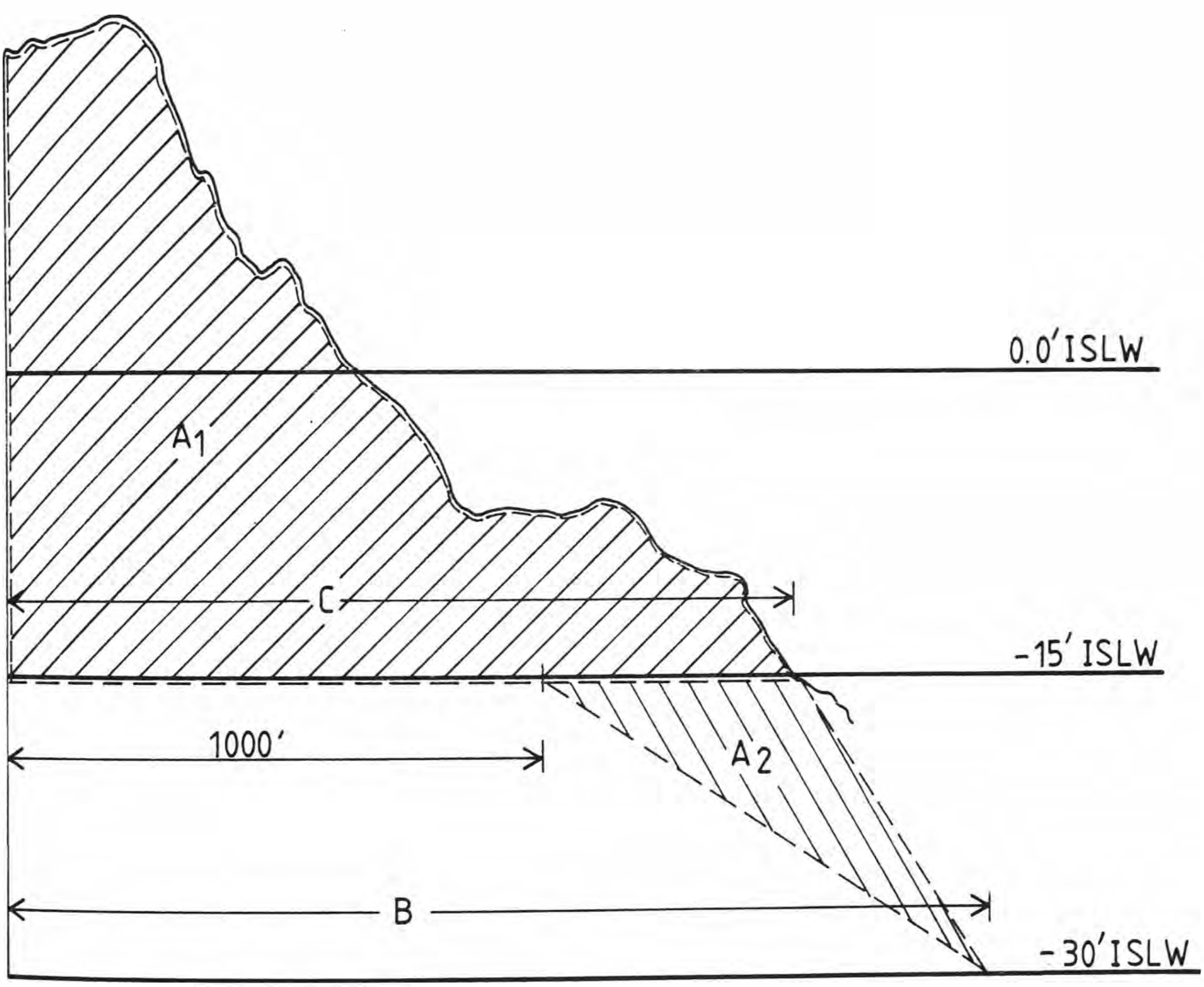
a) TYPICAL CONTROL SECTION – Sand may move in and out other than by Littoral Drift.



b) IDEAL CROSS SECTION – Sand may only move in or out by Littoral Drift.

TYPICAL & IDEAL CONTROL AREAS

FIGURE 4

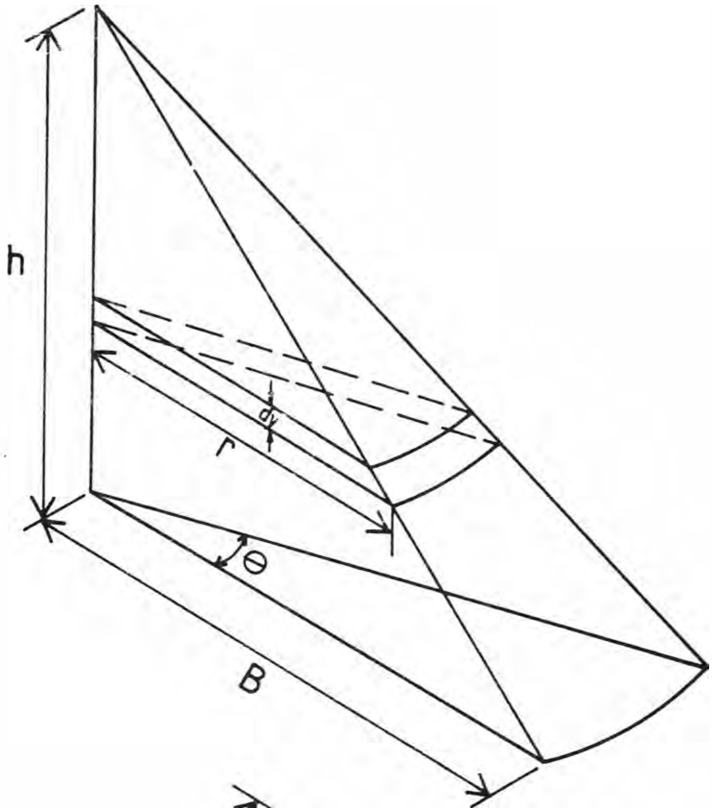


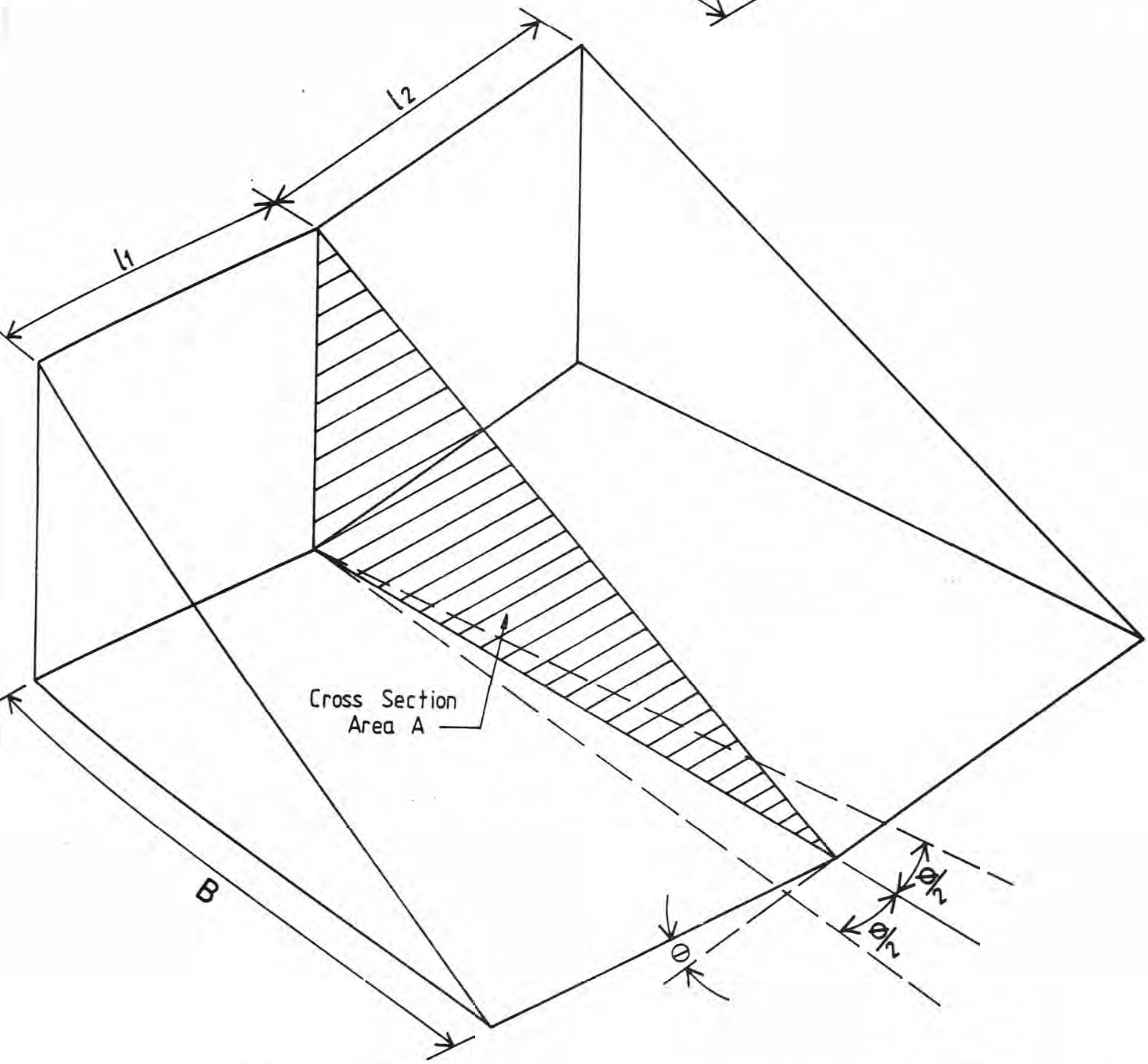
APPROXIMATION OF CONTROL AREAS

FIGURE 5

CROSS SECTIONAL AREA Vs TIME

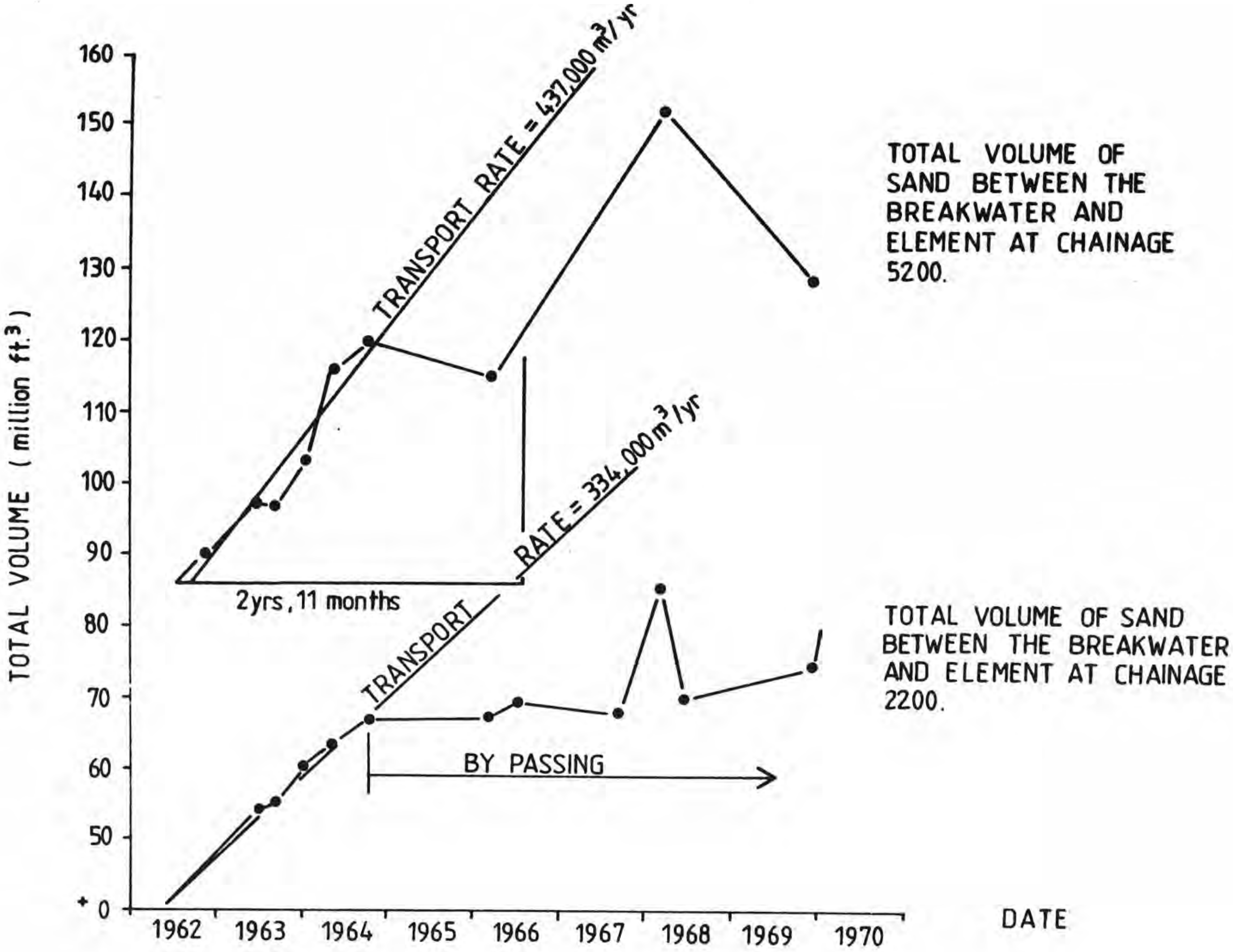
FIGURE 6





ELEMENT VOLUMES AT CHAINAGES 1300 & 2200 ft.

FIGURE 7



TOTAL VOLUMES Vs TIME

FIGURE 8

Natural Surface Level at zero offset for Various Chainages Vs time

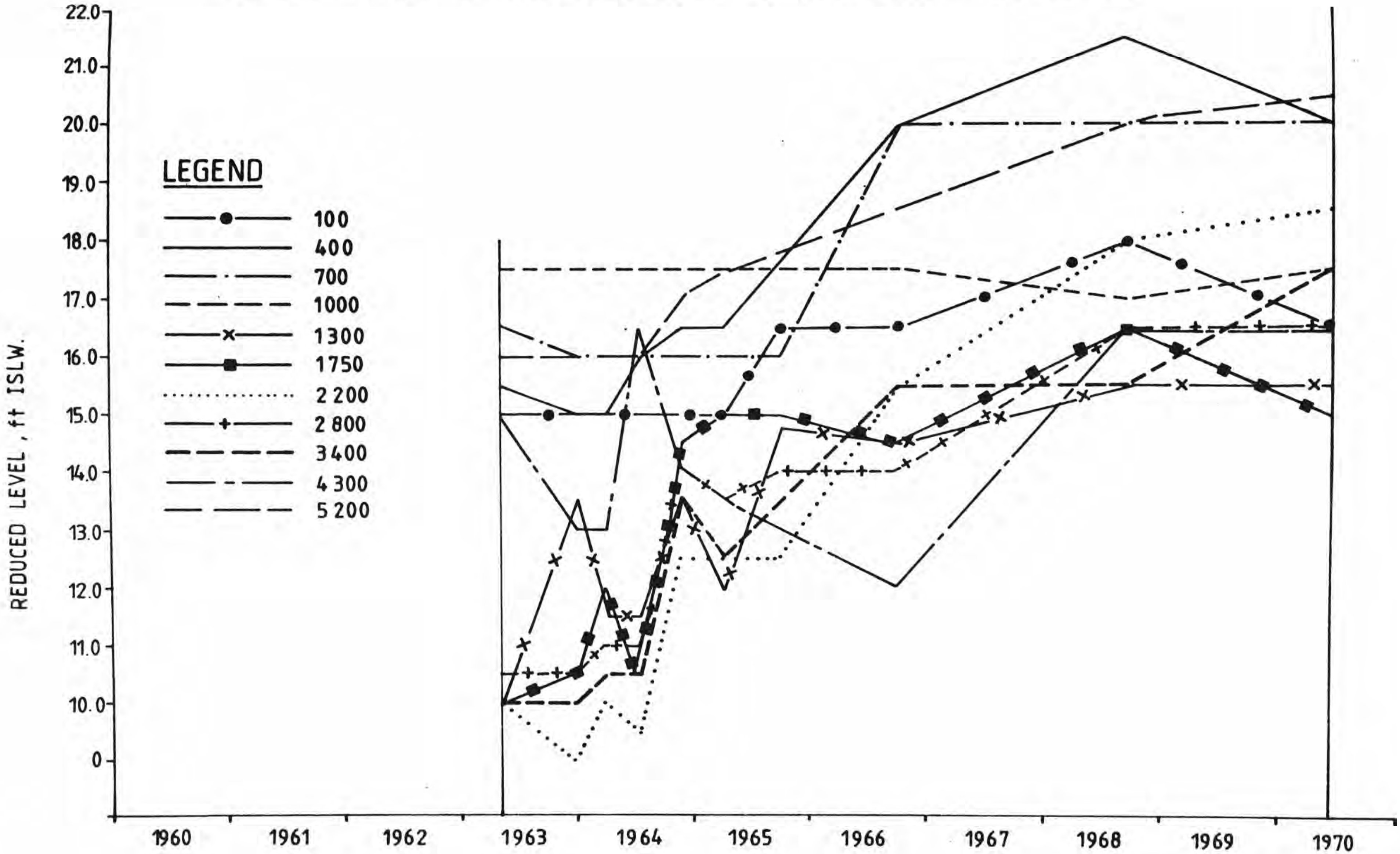
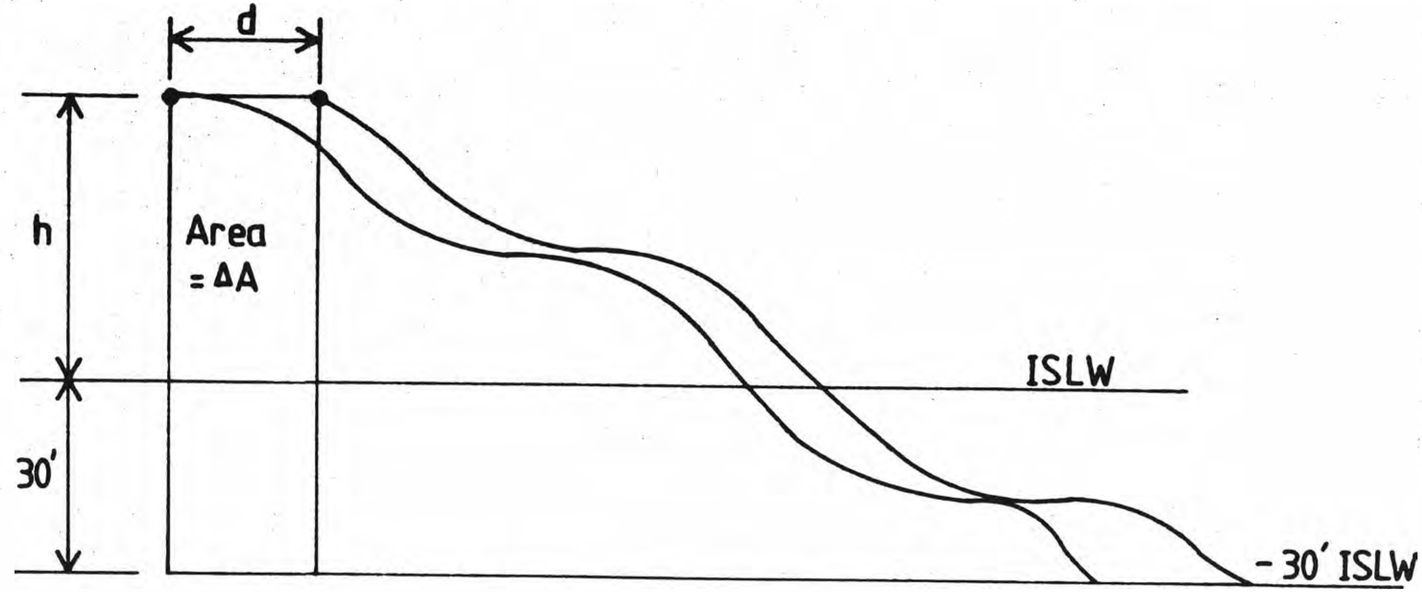
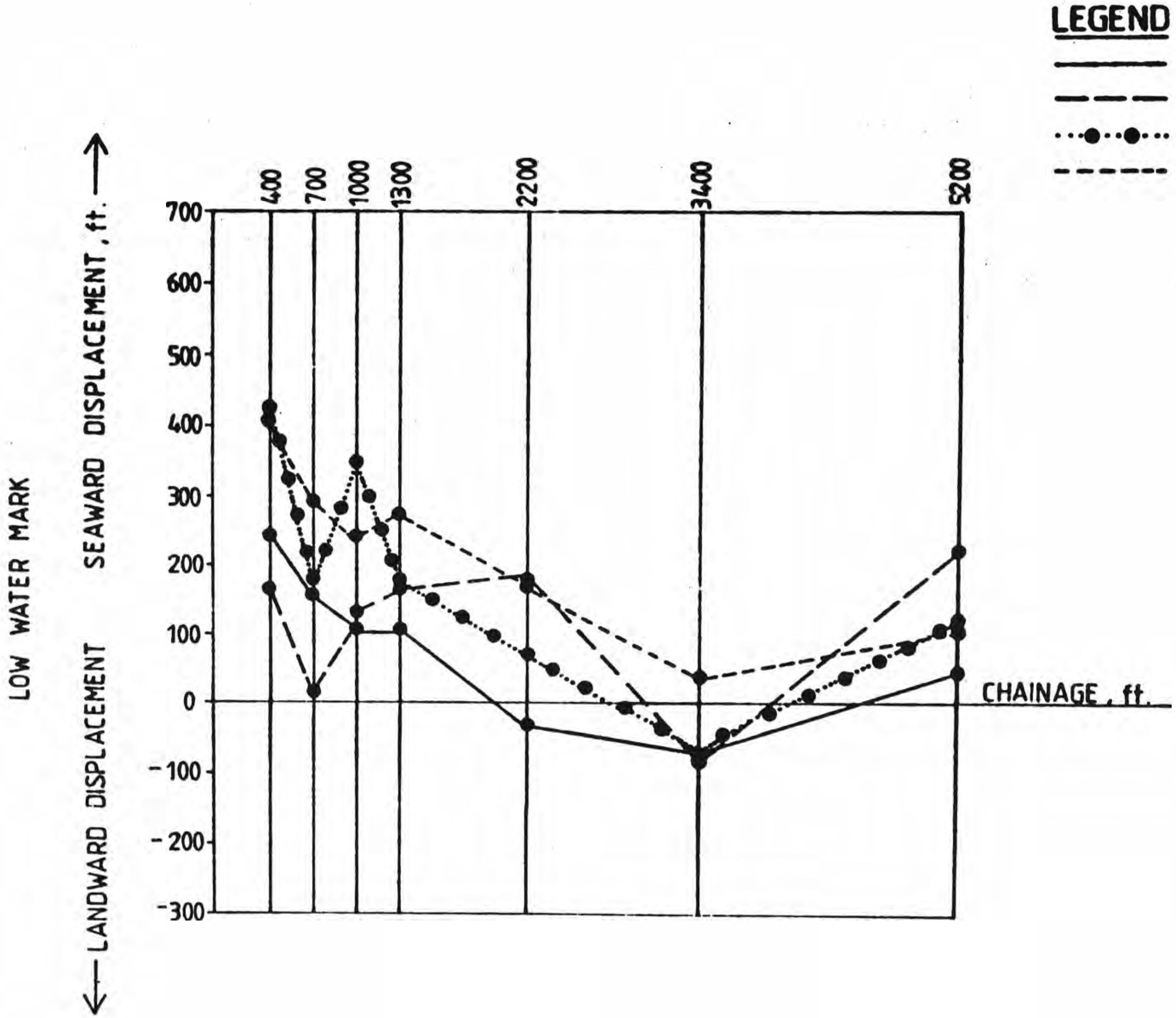


FIGURE 9



IDEALISED PROFILE MOVEMENT DURING BEACH REALIGNMENT.

FIGURE 10



CHANGES IN BEACH ALIGNMENT

FIGURE 11

APPENDIX 2

Listing of River, Beach and Offshore Survey Data

held by the Water Research Laboratory and

the Gold Coast City Council.

Plans used in the analysis presented in this report

are marked with an asterisk.

HYDROGRAPHIC SURVEY DATA.

The following list incorporates the data obtained from the various authorities which are relevant to this study. Those listed have been copied and are held either at the Water Research Laboratory or by the Gold Coast City Council. Plans listed in Appendix 2 are not repeated here.

ROYAL AUSTRALIAN NAVY, HYDROGRAPHIC OFFICE.

Hydrographic Chart - AUS. 813. March, 1962
Oceanic Soundings - July, 1979
North Coast, N.S.W. - River Entrances - AUS. 220.

PUBLIC WORKS DEPARTMENT, N.S.W.

* Tweed River Hydrographic Survey (47 sheets) - July, 1971
* Tweed River Dynamics - Index Plan, 4th August, 1978
  - Survey Control, 4th August, 1978
* Tweed River Dynamics - Entrance Soundings and Bar Sections for Survey No.
  1 - 1st June, 1978
  2 - 17th January, 1979
  3 - 26th April, 1979
  4 - 8th & 9th October, 1979
  5 - 2nd & 3rd June, 1980
  6 - 23rd September, 1980
  7 - 2nd April, 1982
  8 - 15th & 16th March, 1983
  9 - 17th February, 1984.

CO-ORDINATOR GENERAL'S DEPARTMENT, Q'LD (COG)

South Coast Erosion Wd.2721 - Tweed River Mouth, January, 1963
- Kirra to Point Danger.

Gold Coast Beach Erosion - Location of Oceanic Profiles, SC 13, 21st September, 1964
- Point Danger and Tweed Profile, July, 1964, SC 14
- Snapper Rocks 45^{o} Profile, July, 1964, SC 15
- Alpha Lines 1 to 21, Beach Survey Tie, SC 140
- Eta 1 to 89, Beach Survey Tie, SC 154
- Alpha Lines 1 to 31, July, 1966, SC 164
- Eta Lines, October, 1966, SC 219
- Alpha Lines 1 to 31, May-June, 1967, SC 224
- Alpha Lines 1 to 31, September, 1967, SC 328

Letitia Spit Beach Survey, 1966 - 1970, SC 735, 736A, 9th December, 1969.

GOLD COAST CITY COUNCIL.

BEACH PROFILES.

LINE	DATES
ETA 4, 6	10.66, 7.67, 5.68, 7.69, 6.72, 3.74, 10.8.83, 9.5.84
ETA 5, 7, 9	8.5.84
ETA 8, 10, 12	9.66, 6.67, 5.68, 7.69, 6.71, 6.72, 3.74, 10.8.83, 9.5.84.
ETA 11A	10.8.83, 9.5.84
ETA 13	7.72, 3.74, 10.8.83, 9.5.84
ETA 20	22.2.74, 4.7.74, 18.9.74, 21.11.74, 17.12.74, 12.2.75, 16.7.80, 23.2.81, 15.6.83.
RAINBOW BAY	16.3.84, 9.5.84
COOLANGATTA-GREENMOUNT 1-11	25.11.72, 19.12.72, 12.3.73, 31.5.73, 6.11.73, 3.1.74
" " 3,6,9	16.3.84, 9.5.84
KIRRA 1-11	12.3.73, 7.6.73.
" 5	21.5.74, 17.5.84

Tweed River Sand Pumping Cross Sections - 26.7.74, 26.8.74, 30.1.75, 28.2.75,
28.2.75, 1.4.75, 13.5.75, 12.6.75
14.10.75

Beach Replenishment - Kirra Lines 4, 9, 12 Sand Samples - Sieve Analysis Oct. 1973

APPENDIX 3

Reproduction of a portion of a
Bachelor of Applied Science Thesis written in 1985

by

T.R. Lloyd

entitled

Part 1 - Marine Geology of the Lower Gold Coast
Point Danger Area

Part 2 - Morphostratigraphy of the Gold Coast
Southport to Fingal

Reproduced here are Chapters 3, 4, 5

References and Appendix IV

CHAPTER 3.

3. SIDE SCAN SONAR.

3.1 STUDY REQUIREMENTS.

Side scan sonar techniques were used in the mapping of the seabed from offshore at Kirra Beach, past Point Danger, to Cook Island, in the south. This was done to provide some data from which surface sediment patterns and transport influences could be interpreted. Together with hydrodynamic and shallow subsurface data, a model, or models, for inner shelf evolution in this area, incorporating present day sediment dynamics could be synthesised. Such aspects as: the level of submarine bedrock exposure, which provides information on surficial sand cover relative to previously mapped exposure levels; the areal extent of various sediment facies; and the presence, form, and orientation of seabed sedimentary structures which indicate transport type and direction were essential components of modelling.

Haydock (1973) and Grimstone (1974) provide, as mentioned in Chapter 1, the data base with which present study details could be compared. Such areas of overlap, where this procedure was possible, extended from the Tweed River mouth to offshore at Kirra Beach. No previous side scan study had been carried out for the southern area, from the Tweed River to Cook Island, however, and therefore no such sequential considerations were possible.

3.2 MARINE SURVEY.

3.2.1 Equipment and Operation.

The side scan system used in the survey was an E.G.& G. Int., "dual channel side scan sonar system Mark 18." It consists, basically, of two elements, a dual channel graphic recorder and a tow fish, housing the active sensing components. A length of cable joins the two components. The sytem is battery powered and portable. Details of the equipment are given in Appendix II.

The operation of the side scan sonar system is commonplace and a full description of such is here considered superfluous. Fuller detail can be found in Haydock (1973, pages 31 - 34) and Grimstone (1974, pages 164 - 166). Leenhardt (1974) and Flemming (1976) both give a complete treatment of the subject, including both theory of operation and interpretive procedure and the reader is referred to them in the case of general method analysis.

In the field the system was operated as per standard procedures. Prior to the start of survey lines, a calibration procedure was carried out so that parameters such as range and gain setting could be set with respect to the depth of tow fish and general water column depth in which the survey was to be carried out. In general, where survey lines were closely spaced and water column depth low, range was set at either 100 metres or 125 metres and the fish towed close to the water surface. Where survey lines were more widely spaced and water depths greater, range was increased to 200 metres and the fish dropped down a few metres. For each survey run, however, parameters were kept constant in an effort to maintain a systematic, internally consistent record.

Sea conditions throughout all of the surveys were excellent. A slight south-easterly swell operated throughout and there was little surface chop.

3.2.2 Traverses.

Three general areas were surveyed using the side scan system. These are shown in Appendix I, Maps 1,2 and 3. Map 1 shows the systematic coverage of the offshore region at Kirra Beach bounded by the 12 metre and 26 metre (approximately) isobaths, surveyed as part of a dredge site analysis project carried out in June for the Gold Coast City Council. Information gained in this survey provided information contributing to the analysis of downdrift conditions with respect to the "Point Danger system".

The area immediately offshore from Point Danger was surveyed in detail (Map 2) to map the level of bedrock exposure and compare with the results of Haydock (1973) and Grimstone (1974). Similarly, any sedimentary structures could be compared to transport phenomena recognised by the previously-mentioned authors.

The survey shown in Map 3 basically comprised two transect series. Firstly, a shore normal transect was made from the Tweed River mouth out over the "tidal delta". This was done in an attempt to better define the general morphology and internal characteristics of this sediment body. Following this, shore parallel transects were made. These started at about 32 metres water depth offshore east of the Tweed River mouth. In this region, isobaths turned eastwards as the survey moved southwards and therefore, the first shore parallel transect was across somewhat of a shallowing seafloor. Subsequent transects, closer inshore, were made following isobaths (22, 20, 18 metres depth). The outer transect was connected to the inner set by a shore normal transect made from the southern end of the first shore parallel transect towards the area around Cook Island.

3.2.3 Position Fixing.

Tables in Appendix I and Maps 1-3 were compiled based on position fixing from a shore based theodolite system of the Gold Coast City Council. As the fix interval was very short (one minute), sideways extrapolation of data between transects is considered to be reasonably accurate in the plotting of sonograph detail onto maps.

3.2.4 Survey Vessels and Tow Methods.

Surveys shown on Maps 1 and 3 were carried out from the 21foot Shark Cat, "Surveyor II", of Mr. Frank Goetsch of the Gold Coast City Council. The fish was towed from the port side of the stern at a distance of approximately five metres during operation from this vessel. Only the starboard engine was operated during surveys so as to minimise "noise" on the records.

The Point Danger survey (Map 2) was carried out from the wooden hulled prawn trawler used in the seismic work. In this case, the fish was towed close to the sea surface, at a distance of only two metres from the vessel's stern. This was done so as to avoid contact with known submarine rock outcrops in the region, especially in the shallow water areas closer inshore.

Both vessels operated at approximately four knots during survey.

3.3 INTERPRETATION PROCEDURE.

3.3.1 Previous Work.

As mentioned in Section 3.1, work by Haydock (1973) and Grimstone (1974) form the comparative data base for the present work. The more important features described and mapped by these authors include the submarine outcrop exposure level off Point Danger and the large (15 metre wavelength) sand waves mapped by Haydock (1973) in this region, which were not noted by Grimstone (1974). Smaller scale features, specifically sand ripples of about one metre wavelength mapped by Grimstone (1974) around Point Danger were also noted, although their significance seemed less than that of the larger scale structures noted by Haydock (1973).

3.3.2 Record Interpretation

Once again, the reader is referred to Leenhardt (1974) and Flemming (1976) for a detailed account of the interpretation of side scan sonar records or sonographs. Those procedures especially relevant to the present study will be briefly discussed, however an exhaustive treatment is considered unnecessary.

Basically the sonograph consists of a sheet of paper on which a series of marks are made by an electrode. The intensity of the marks (or tone, from light to dark) is a function of the strength of the returning accoustic signal from the seafloor. Therefore, the greater the reflectivity* of an object, the darker the tone that will represent it on the sonograph. Two factors contribute to the reflectivity of any given object. One is the reflectivity of the individual constituents (eg. sand grains), the other the overall texture of an object. In texture, consideration is made of the fact that the coarser the sediment, say, the less scattering of the incident pulse will occur, and hence, the greater will be the strength of the reflected signal, and thus the darker the graphic record mark.

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* note: The reflectivity of an object may be considered to be the fraction of incident energy retransmitted back along the original accoustic path.

Also of note is the effect of topography, in that, depending upon the orientation of a certain feature with respect to the transducer (or tow fish), reflectivity will vary. For example, slopes facing the transducer are better reflectors than slopes lying oblique to the sound beam. It is obvious, therefore, that features such as ripples will be represented on the side scan record to varying degrees of prominence, depending upon their orientation with respect to the tow fish.

An account of the parameters of resolution is given by both Leenhardt (1974) and Flemming (1976), the significance here being that only rocky outcrops are represented as single objects in the study area. Tonal contrast is the consideration, or variable, which distinguishes the sand facies/coarse sand-fine gravel facies distinction made here.

Where accoustic shadow is distinct enough, the calculation of the height above seafloor of submarine rock outcrops can be made. Flemming (1976) shows how the geometry of the situation leads to the construction of the general formula:

$$H_t = \frac{L_s - H_f}{L_s + R_s}, \text{ where}$$

H_t is the height of the object above the seabed.

L_s is the accoustic shadow length (slant range).

H_f is the height of the fish above seabed.

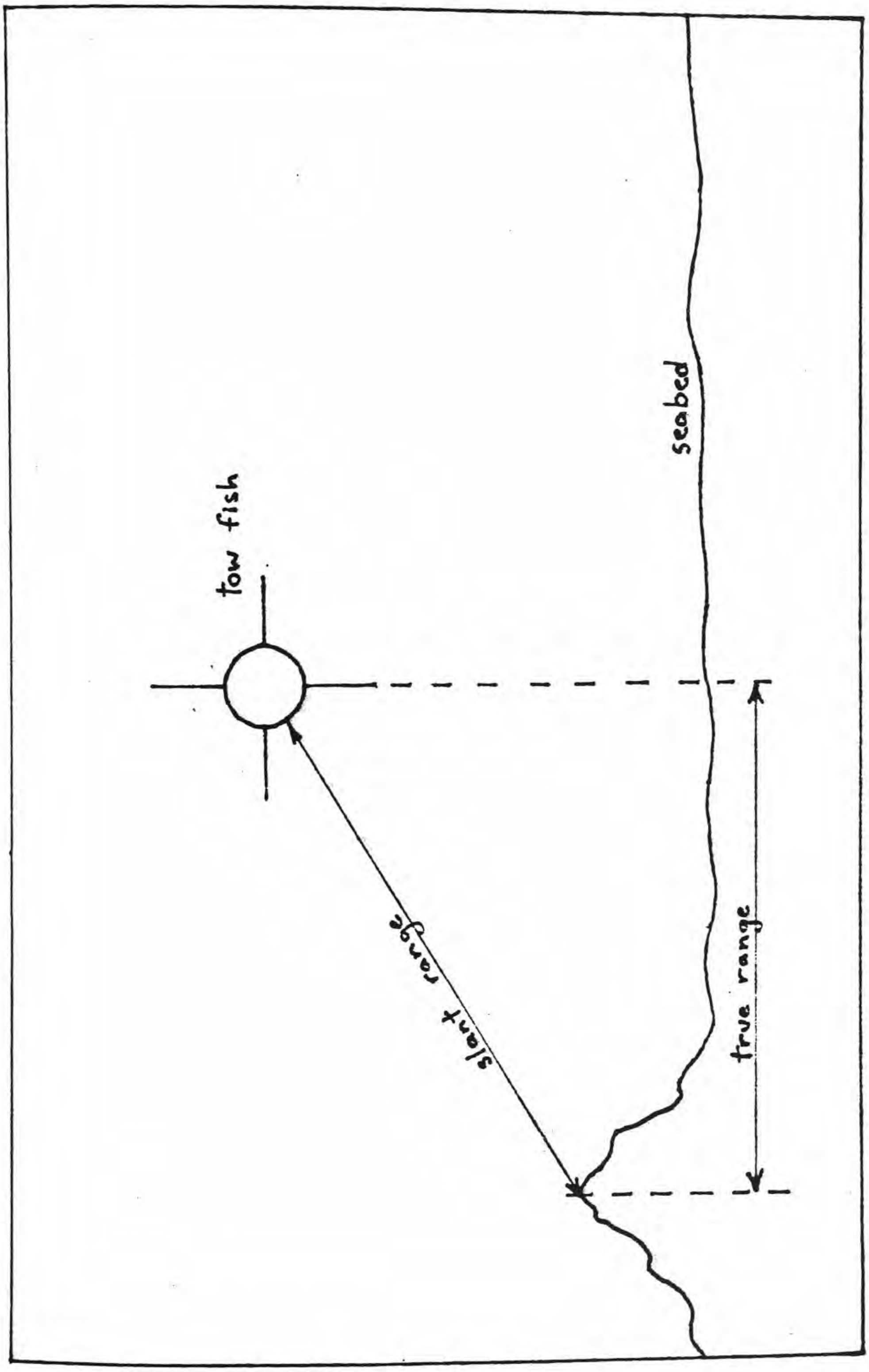
R_s is the slant range of the object.

In calculating planar geometries, both vertical and horizontal distortions must be eliminated. As the water velocity of sound may be taken as constant at 1500 ms^{-1}, time travel markers on the sonograph can be directly correlated to distance. The recorder plots slant ranges, or distances from object to transducer, whereas seafloor maps require distances from object to the point on the seafloor directly beneath the transducer. Figure 3.1 shows this distortion, which decreases in magnitude the farther the object is away from the tow fish. Corrections are carried out using tables as given by Flemming (1976). The horizontal distortion occurs due to the fact that the fix axis represents time and varies with varying boat speed. Transference of spatial data with respect to this axis must then be carried out via simple linear transformation between fix points, from sonograph to map. For this to be successful, boat speed must be kept as constant as possible and fix time intervals be as short as practical.

3.4 STUDY RESULTS AND DISCUSSION.

3.4.1 Map Presentation.

Map 6 (pocket) shows the information obtained from the three side scan sonar surveys (Maps 1,2 and 3 & Appendix I). Lithologically, only one facies boundary was identifiable, delineating areas of coarse sand-fine gravel, generally associated with submarine rock outcrops, from uniform,



<u>Figure 3.1</u>. Side Scan Range Distortion.

light coloured areas, interpreted as fine to medium sand. Distinction between the various sand facies types as described in Section 2.4 was not possible and not expected using side scan techniques. More important data concerned identification of areas of submarine rock outcrop and surface structures.

As transects overlapped sufficiently, detailed plotting of exposed rock was possible. Such outcrop was identified off Point Danger, where expected, throughout the southern survey region, associated with Cook Island which is a similar, very large mass well above sea level, and offshore at Kirra, previously unidentified. The area at Kirra was the least well defined, however supporting evidence from echo sounding (trawler's system) and seismic data existed.

Due to resolution limits only relatively large scale sedimentary structures were observable using the side scan system. Generally, sand areas were totally uniform, showing no surface structure information on the side scan record. The exception was the Point Danger region, where the identification of relatively small wavelength sand waves was possible over a relatively large area. Their asymmetry was recognisable and therefore sand transport direction inferrable. Also shown on Map 6 are much larger scale sand waves offshore from the Tweed River mouth. Identified only from the vertical beam return part of the record, their form can only be approximated. Other obvious features were ripples in the gravelly facies in the southern area. A sense of asymmetry was not obviously determinable here.

3.4.2 Seabed Feature Details.

3.4.2.1 Submarine Rock Outcrop.

In the southern part of the survey area, where rock outcrops ("reefs") take the form, mainly, of single pinnacles, simple, large accoustic shadows allowed simple calculation of outcrop dimensions. Where calculation was possible, the height of the mass from the seafloor is given (Map 6).

Off Point Danger there presently exists a high level of rock exposure. The submarine outcrop here shows prominent lineations on the side scan record which may indicate bedding or jointing direction. Haydock (1973) considers rocky outcrop here to represent Neranleigh-Fernvale bedrock material. The level of bedrock exposure shown in Map 6, east of Point Danger, is greater than that mapped by Grimstone (1974, Map 3), who covered a similar area using side scan sonar techniques. It may then be inferred that the thickness of surficial sand cover in the region was less at the time the present survey was undertaken than when the area was surveyed by Grimstone in 1974.

This conclusion is significant in that Delft (1970) considered that nearshore sand bypass around Point Danger would gradually increase from the time of their study up to 1985, when they considered "full" conditions to apply to the "tidal delta" accumulation off the Tweed River mouth. At this "full" point, they considered sand bypass would reach "pre-wall" rates. "Pre-wall" conditions were observed from old airphotographs shown to the author by Mr. Rodger Tomlinson of the Water Research Lab., University of N.S.W. The development of a large sand shoal which extended northwards, or downdrift from Point Danger could clearly be seen in these photographs. This shoal, which is not observable nowdays would seem to be a required indication of a return to "pre-wall" conditions. If present, it would blanket much of the presently- exposed submarine outcrop off Point Danger. This is not the case, as shown in Map 6, with rock exposure in fact seemingly increasing relative to 1974. Therefore it is concluded from this line of evidence that Delft's conclusion was incorrect and that present day nearshore sand bypass is not yet at the level which existed prior to the construction of the Tweed River training walls.

A small area of submarine outcrop was mapped off Kirra Beach from evidence from the side scan record as well as information from the seismic survey and the survey vessel's echo sounder. The nature of this "reef" was not clear, for seismic records did not show the bedrock reflector intersecting the seafloor clearly in this region. If these bodies represent bedrock pinnacles then they are quite localised in this area, being a consequence of sharp, local rises in subsurface bedrock which could have been masked by the resolution loss associated with highly reflecting bodies on the seismic record. The areas appear as dark, extremely vague areas on the side scan record, but which were consistent in both spatial and temporal terms.

3.4.2.2 Facies Distinction.

Two sediment facies were distinguishable on the side scan record based on the criteria of differential reflectivity. Areas of light tone, which, in fact, comprised most of the sonographs, were interpreted as areas of fine to medium sand. Areas of distinctly darker tone, which were generally associated with areas of submarine rock outcrop, were interpreted as representing coarse sand to fine gravel. This conclusion was reached in light of ripples which appeared commonly in this facies being around one metre in wavelength, which is indicative of a fairly fine grain size in gravelly facies. This is based on the fact that ripple wavelength is controlled in this range, fundamentally by sediment grainsize (Stephens, pers. comm.).

The coarse facies is considered to represent local surface bodies developed in response to the different hydrodynamic conditions associated with areas of submarine rock exposure combined with allochtonous contribution from "rocky reef" dwelling organisms. They are very extensive in the extreme southern part of the surveyed region where such exposures are common. Of significance is the planar geometry of these coarse sediment bodies in this area, which may indicate current-alignment hydrodynamic processes on this part of the inner shelf. As such, this adds a little more weight to the significance of southerly-flowing shelf currents in the area.

3.4.2.3 Sedimentary structures.

In general, the side scan records from the three surveys showed very little in the way of sedimentary structures. Where features were clearly shown, their geometry was analysed and represented by a particular symbol on the map. Map 6 then shows, diagrammatically, the areas of occurrence of sand waves and ripples as could be clearly observed on the side scan records. This method of representation was chosen as features were often so vaguely expressed on the side scan record that their tracing was impractical. Also seabed features such as sand waves are considered mobile and their general area of occurrence, not so much their specific location on the seabed within the region,is of most significance.

Ripples in the coarse sediment facies of one metre wavelength, as mentioned in Section 3.4.2.2, indicate, by their orientation, wave action from a prominently south easterly direction.

Sand waves noted offshore from the Tweed River mouth were not recognised on the lateral sections of the side scan record, but, instead from the vertical bottom reflection (which acts basically as an echo sounder). This was the case because survey direction was perpendicular to the general crest lines of the sand waves (see Map 3).

For this reason, the exact orientation of sand wave crests was not discernible and symbols on Map 6 merely indicate the presence of these features. Measured wavelengths were found to be quite consistent, however, at around 18 metres, and therefore the profiles seen on the side scan record probably represented a view close to perpendicular to crest lines. A distinct asymmetry of the sand waves, in profile, indicated shoreward sand transport under the hydrodynamic conditions which were operating around the time of survey. These conditions could be described as calm to moderate, with slight south-easterly swell dominating.

Sand transport around Point Danger is indicated by the presence of smaller wavelength (three metres) sand waves orientated so as to suggest littoral transport, with waves being refracted around the headland (Map 6). This wave refraction effect may be responsible for the different bedform size in this area with respect to those observed off the Tweed River.

Southard (1975) notes that the characteristic flow velocity associated with sand waves lies, generally, between 0.3 ms^{-1} and 0.8 ms^{-1} and this seems reasonable for "normal" hydrodynamic conditions associated with the area. With respect to the bypass conditions, then, it would appear as though certainly a reasonable level exists, (as is well documented by accretion updrift from the Kirra groyne) although not, apparently, sufficient at present to re-equilibriate the system.

3.4.3 Relationship of Side Scan Results to Drogue Tracer Current Vectors.

Map 7 (pocket) shows the results of a drogue tracer study carried out on the 15th. and 16th. of June, 1985, by Mr. Rodger Tomlinson of the Water Research Laboratory, University of N.S.W. The map shows current vectors constructed from original distance - time plots without regard for local tidal influences, which were considered relatively insignificant when compared to prevailing sea state (waves) and possibly regional East Australian Coast' Current influences. A more detailed analysis of the work will be carried out at a later date by Mr. Rodger Tomlinson. The significance of his drogue tracer results are shown with regards the present study as a tentative or preliminary indicator of what processes may be hydrodynamically important in the study area.

It can be seen from Map 7 that the East Australian Coast Current appears to affect the hydrodynamic regime of the Point Danger offshore region. Its ability to move sediment is questionable and under investigation. Although measured velocities seem as though they may be sufficient in this regard, side scan results indicate the contrary. This conclusion is based on the fact that, of the bedforms observed, all were wave action orientated, indicating that this is the dominant factor with regards sediment transport phenomena in the area. It can be said then, that although prevailing current movement of sediment may occur, indicative bedforms of such are not observable using side scan sonar techniques. Furthermore, such bedforms as were observed within the same study area are indicative of near sea floor currents induced by wave action. Thus wave action is considered to dominate the hydrodynamic regime of the area.

CHAPTER 4.

4. CONTINUOUS SEISMIC PROFILING.

4.1 STUDY REQUIREMENTS.

The use of high resolution continuous seismic profiling was made by Haydock (1973) in the location and delineation, on a reconnaissance basis, of offshore sand resources potentially available for shoreline replenishment. Grimstone (1974) was able to use results from this work in developing a Quaternary history for the Gold Coast region. Part of the area covered by Haydock, off Kirra Beach, was repeated in the present study in confirming viable areas for the winning of such sand for a beach replenishment dredging programme carried out by the City Council in 1985. No work, however, had previously been carried out south of Point Danger, where the emphasis of the present study was placed.

By using the work, to the north of Point Danger, by Haydock, who was able to incorporate some drill data in his interpretation, correlation was attempted, in light of the general scheme of Grimstone, to the southern study area, off Letitia Spit. In so doing, a general stratigraphic scheme for this southern area could be proposed, based upon seismic stratigraphy derived from the present investigations and from work done by Haydock in the northern area. By presenting the resulting inner shelf structure along with information gained in the other aspects of the study, a model for inner shelf development in the region, incorporating present day sediment dynamic considerations, was possible.

4.2 MARINE SURVEY.

4.2.1 Equipment and Operation.

The continuous seismic profiling system used included a High Resolution Boomer transducer supplied by Professor G.E.G. Sargent of the University of Queensland, mounted on a catamaran constructed of P.V.C. tubing. The hydrophone array, recording equipment and power supply were provided by the Geology Department, University of Queensland. The Gold Coast City Council provided shipboard generators for the duration of the survey. Equipment detail can be found in Appendix III.

Operational parameters were consistent throughout both surveys and are shown in Appendix III. Sea conditions were very good and consistent throughout. A south easterly swell of less than a metre was generally maintained with very little chop and there were only short, infrequent periods where any surface "whitewater" was observed.

The recording of seismic data on magnetic tape was carried out throughout the survey. In an effort to avoid gaps in replays, tapes were generally changed between the last fix of a particular survey line and the first fix of the next line. Examples of seismic records shown in Plates I - VI are replays from magnetic tapes, presented at half-scale with respect to the original records.

4.2.2 Traverses.

The seismic survey was carried out in two transects, from Point Danger to offshore from Kirra Beach and from Cook Island to Point Danger (see Maps 4 and 5 & Appendix I). Survey positions were plotted onboard as the survey was being carried out so that ship headings could be obtained and thereby sufficient coverage obtained. The zig-zag pattern, with transects generally shore normal,was chosen as providing the best data collection method, allowing good coverage at optimum orientation, with ship turns being broad enough to maintain consistent trailing of boomer and hydrophone array.

4.2.3 Position Fixing.

Shore based theodolites were used in fixing the vessel's position, five minute intervals being used. Initial and final line fixes were taken as close as possible to the beginning and ends of transects to provide ease of interpretation. This was achieved by beginning the turn about two minutes after the final fix on a particular transect which allowed three mintues or so for the vessel to come around and be on course for the next fix.

4.2.4 Survey Vessel and Tow Method.

The boomer and hydrophone array were trailed from the stern of the trawler used for the geophysical survey, the catamaran on the starboard, hydrophone streamer on the port side, both about 15 metres from the vessel. The trawler operated at close to four knots throughout the survey, the boomer trailing well at all times.

4.3 INTERPRETATION PROCEDURE.

4.3.1 Previous Work.

As noted by Haydock (1973) work by the B.M.R.* (Cifali, et. al., 1967) carried out in conjunction with the Delft study, completed in 1970, provides little in terms of inner shelf stratigraphy. The recognition of shallow sub-surface reflectors necessary for such was achieved by Haydock (1973) who was able to devise an offshore stratigraphic column for the Gold Coast area, north of Point Danger, incorporating some core data. Interpretation of seismic stratigraphic results in the present study rests heavily upon the basic relationships found by Haydock as no drill data was available in the study area, with the exception of a single six metre seaprobe in the Kirra area (see Chapter 5). The sampling programme, in general, was confined to half metre depth surface samples (Chapter 5), and as such only provided limited information with respect to the very top sequence, the most recent sands.

4.3.2 Seismic Records.

Due to the inconsistent nature of sub-bottom reflectors throughout the survey area, record quality, in terms of

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* note: Bureau of Mineral Resources, Australia.

definition of sequences, varied from poor to reasonable. Problems were also encountered as a result of what appeared to be near surface bubble oscillation phenomena associated with the relative position of the hydrophone streamer. A theory pertaining to the origin and effects of such phenomena is outlined by Sargent (1984). The general effect, here, was to mask much of the near surface parts of the seismic records with a series of dark parallel bands as can be observed in Plates I - VI. Also important to note is the fact that the generally seismically similar nature of the various sequences, especially the nearer surface ones, sometimes made delineation of such a rather arduous at best, impossible at worst, task.

An outline of the interpretive procedure in dealing with the seismic data obtained is given in Section 4.4.1. Generally, an attempt is made to provide a seismic stratigraphic scheme for the Point Danger to Cook Island offshore region based on the stratigraphy interpreted for the Kirra Region from present study seismic records, the work of Haydock (1973) for this region and the results of the single seaprobe available here (see Chapter 5).

4.3.3 Map Presentation.

Information obtained from seismic data is shown on Map 8 (pocket). Reflector depths are absolute minimums, based on a seismic propagation velocity of 1500 ms^{-1}. Whereas this is, in all probability, close to the real value for water-saturated, well sorted, fine-medium sands, as constitute most of the uppermost sequence, it will not be accurate with respect to underlying sequences. In this, depths to the Pleistocene surface reflector as shown in Map 8 will be shallow with respect to their true value. As no drill data was available for seismic velocity estimation, it was considered that a consistent seismic velocity value be used for simplicity, in the knowledge that deeper features will appear as a minimum. In depth, that from the seafloor is what is meant, as contours are isopach lines. By presenting the data in this form its direct applicability to aspects of coastal engineering becomes apparent. Contours in fact show, with respect to the shallowest reflectors of a particular area, the thickness of overlying surficial sands, of most interest to the coastal engineer. If a topographic expression of the various surfaces was required, the present seabed topography would need to be subtracted from the isopach lines shown on Map 8.

4.4 STUDY RESULTS.

4.4.1 Recognition of Reflectors and Seismic Sequences.

The two important geophysical parameters of a particular sediment body which are relevant to seismic investigation are bulk density (˚) and seismic velocity (v). The variation of these parameters across the boundary of two such bodies or strata is responsible for the creation of a seismic reflector, the reflection efficiency of which is given by the reflection co-efficient of this boundary given by:

$$\text{reflection co-efficient} = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_2 v_1},$$

where ρ_1 and ρ_2 are the bulk densities and v_1 and v_2 are the seismic velocities of the upper and lower strata, respectively. Therefore, the presence of a recognisable reflector will be the result of a change in accoustic impedence ($\rho.v$) within a sub-bottom sequence. Causes for such a change will then define reasons for the presence and position of a particular reflector. Haydock (1973) lists four categories of possible seismic reflectors, each of which would constitute the necessary change in accoustic impedence. These include lithological discontinuities, lithification or induration within lithologically homogeneous sequences, bedrock weathering surfaces, and "solid" bedrock surfaces. Thus the interpretation of seismic reflectors in a geophysical record can be carried out using this basic understanding.

Seismic sequences, bounded by such reflectors, rely basically on "hard data" from drilling programmes for their interpretation or, as is mostly the case in the present study, correlation from adjacent areas where such data exists. Some level of interpretation is possible purely from the seismic record however. Obvious structural information such as areas of differential compaction and channelling are examples. Also useful is the degree of "seismic transparency" of a sequence. For example, all seismic resolution is lost below solid bedrock reflectors, which is in contrast to areas of unconsolidated and semi-consolidated material.

4.4.2 Seismic Stratigraphy.

The following (Tables 4.1 and 4.2) shows the various seismic reflectors recognised and the seismic sequences interpreted from the continuous profiling records obtained, the stratigraphic scheme of Haydock, data from the seaprobe sample, and the general Quaternary framework of the south east Australian coast, as described in Chapter 2.

SEISMIC REFLECTORS
A , well preserved Holocene transgressive surface defined by lithological variation between recent overlying sands and underlying peats/sands/clays.
A′ , discontinuous expression of A offshore, probably a slight lithological variation and/or induration boundary between overlying recent sands and underlying Holocene transgressive sands, or similar within the latter.
B , well preserved Pleistocene surface, representing lithological variation and induration and weathering (soil profile development?) boundary between overlying Holocene transgressive sediments and underlying Pleistocene sediments, sub-aerially exposed during (Last Glacial) sea levels.
C , lithological and structural/textural variation between overlying sediments and bedrock which may appear at any stratigraphic level.

TABLE 4.1. Seismic Reflectors, Inner Shelf.

Point Danger Area - Kirra to Cook Island.

SEISMIC SEQUENCES

Sequence 1 ,	Recent Paralic Sand Wedge.
	reflector A, (i) Holocene transgressive back-barrier deposits, peats, sands, clays.
Sequence II ,	
	reflector A′ , (ii) Holocene transgressive blanket sands, grading landwards to (i).
	reflector B.
Sequence III,	Pleistocene coastal plain deposits formed under sub-aerial conditions during Last Glacial lower sea levels.
	reflector C.
Sequence IV ,	Bedrock - Neranleigh Fernvale Palaeozoic metamorphics and Tertiary volcanics.

TABLE 4.2. Seismic Sequences, Inner Shelf.

Point Danger Area - Kirra to Cook Island.

4.4.2.1 Sequence I - Recent Paralic Sand Wedge.

This sequence, representing the most recent phase of sedimentation, is defined as having the present-day seafloor as its upper boundary and, in general, reflectors A or A′ as its lower boundary. Where reflectors A or A′ are not represented on the seismic records, Sequence I can be seen to directly overlie reflectors B or C. In many areas where reflector A′ does not appear to be represented on the seismic record, masking by bubble oscillation banding may in fact, be responsible (see Section 4.3.2). In these cases, the presence of reflector A′ is not recorded on Map 8, however, in some of these at least, its presence may be inferred, and its mapped extent considered to thus be somewhat of a minimum.

Except for localised bedrock outcrops, Sequence I blankets most of the mapped region. The sequence appears uniform, structureless, and seismically transparent. Generally, it thickens landward, however, an anomalous region appears off Letitia Spit, as shown in Plate VI, where a thickening of this sequence appears to be associated with a change in the seabed profile.

Sequence I is considered to be the result of Late Holocene barrier progradation which occurred generally along the south east Australian coast, following the cessation of the Postglacial Marine Transgression. Reworking of a non-equilibrium transgressive sand surface by wave action led to the development of the present active sediment wedge of outer and inner nearshore sands which is represented by Sequence I in the seismic stratigraphic scheme. This sequence is thus inferred to be around 6500 years old and to have been undergoing constant development and modification up to the present day due, especially, to littoral drift influences, even after barrier progradation is considered to have ceased, some 3000 or so years ago (see Thom, et al., 1981).

4.4.2.2 Sequence II - Holocene Transgressive Deposits.

Holocene transgressive sequences are bounded above by the base of the recent sand wedge, either reflector A near-shore, or reflector A′, which is generally poorly defined and discontinuous, farther offshore. The lower boundary is generally reflector B, which represents the Pleistocene surface over which transgressive deposition occurred.

Where the transgressive sequence is well preserved, in the area offshore from Kirra Beach (see Map 8), reflector A takes the form of a peaty horizon (see Haydock, 1973, and Chapter 5, this study). Due to the abrupt change in accoustic impedance across this boundary from overlying recent sands, this reflector is extremely distinct and, in fact, produces a return signal reversed in phase to the source signal because of the negative reflection co-efficient resulting from the relatively low bulk density of the peaty layers (see Haydock, 1973).

Associated sands and clays correlated from Haydock (1973) together with the peat layers, constitute a transgressive back-barrier sequence, where such facies are preserved by submergence as sea level rises during the transgression. Nearshore sands, which may have formed barrier systems at phases during the transgression, have been reworked landward during the final stages of the transgression and ensuing stillstand period to form the present-day prograded beach-ridge barrier system which presently overlies this reflector.

Grimstone (1974) obtained a radio-carbon date for a peat sample from such a horizon, of 10500 years B.P. at 20 metres depth below present sea level. The Postglacial Marine Transgression is generally believed (see Chapter 2) to have commenced just after the height of the Last Glacial, some 17000 years ago, and is considered to have ceased at around 7000 years ago. This date, then, is reasonable, considering a rapid, uniform sea level rise.

Map 10 (pocket) shows the onshore morphostratigraphy for the Gold Coast region. The unit designated Qhcw represents the present-day back-barrier swamp associated with the present beach-ridge barrier (Qhcb). It is considered that, as concluded by Haydock (1973) and Grimstone (1974), this present day morphological unit can be correlated with the offshore peaty back-barrier facies sequence, bounded above by reflector A. In this, Sequence II, where delineated by reflector A from overlying recent sands, can be considered to represent a transgressive sequence, ranging from Mid to Late Postglacial Marine Transgressive times to the present day. The major part of the sequence was deposited between around 10500 years and 6500 years B.P., when the transgression ceased, and the most recent barrier progradation began.

Where reflector A, representing this peaty horizon, is absent, Sequence I and Sequence II are vaguely separated by what has been termed reflector A′. On Map 8 this reflector is expressed as areas bounded by dashed lines, with spot thicknesses of overlying surficial sand shown within each area. As can be seen from Map 8, reflector A′ appears discontinuous, however this does not preclude the presence of Sequence II in the areas where this reflector is not obvious. As seismic reflectors only appear on a record where a boundary of sufficiently high reflection co-efficient occurs within the sub-surface, where such geologically significant boundaries occur, where strata may be lithologically similar, and accoustic impedances are similar, and therefore reflection co-efficients low, they may not be expressed by a reflector on the seismic record. Such may well be the case here, where it is considered that Holocene transgressive sands underlie recent paralic wedge sands. The seismic reflector may then be produced due to a variation in the degree of induration between overlying recent sands and relict transgressive sands.

This "transgressive sand sheet" may be considered to be correlatable with the peaty back-barrier deposits which underlie the recent sand cover off Kirra, as described above, and therefore are considered to be part of the same seismic sequence. No correlatable drill data is available with regards to deeper offshore areas and, as such, this sequence interpretation, offshore, must be considered speculative.

In the area immediately around Point Danger reflector A′ is mapped (Map 8) closer inshore, similar to reflector A off Kirra. The characteristic strong reflection is absent around Point Danger, however, indicating the absence of peaty horizons. In this case, sequence II may be represented simply by back-barrier sands, silts and muds (clays) of transgressive nature genetically similar to the deposits off Kirra, but without peat horizons.

The discontinuous nature of reflector A′ may also be attributed to a slightly different depositional style in the area to the south of Kirra Point (see Map 8). Where well defined back-barrier transgressive deposits are not preserved close to shore, it can be postulated that they were removed prior to the deposition of overlying sands, rather than not deposited at all. If this was the case, the transgressive depositional style may be considered to be rather more erosional than in areas such as off Kirra Beach. Where then the recent sand wedge directly overlies Pleistocene sediments, as appears to be the case in the southern part of the study area, an erosional transgressive stratigraphic style (Fischer, 1961; Curray, 1964; Swift, 1975; Roy and Thom, 1981) is postulated (see figure 2.2). The style is not, however, wholely erosional, as the presence of transgressive sediments is indicated by reflector A′ , which discontinuously appears throughout.

There does not certainly, however, appear to be the same degree of preservation as is the case in the north, where the presence of well preserved back-barrier deposits may be described as being part of a depositional transgressive stratigraphic style (Roy and Thom, 1981). More specifically, where such back-barrier deposits are preserved, the sequence may be described as possessing a leading-edge depositional stratigraphic style (Stephens and Murray, 1983), where facies landward of the barrier system are preserved as the sea transgresses over the Pleistocene substrate (see figure 2.2). Stephens and Murray (1983) note that such a depositional style may have been favoured by barrier migration over flat substrates where sediment supply was great in comparison to available inshore wave energy. They describe the system as one where "As barriers rolled landwards in tank-tread fashion by washover processes, the trailing shoreface cut shallowly into the underlying transgressive back-barrier sand sheet".

In the offshore part of the study area, this transgressive sand sheet is proposed to be beneath reflector A′. It must then, be of Mid-Postglacial Transgressive age, and part of the original sand body which was reworked land ward to form Holocene beach ridge barriers. The deepest water surface samples taken were at 25 metres water depth (see Chapter 5). Information with regards surface sediment type beyond this limit was not available, then, and seismic interpretation with regards the character of the uppermost sequence is therefore uncertain in offshore areas in deeper water than this. The transgressive sand sheet can be correlated with the inner shelf sand facies described in Section 2.4 which appears as a surface facies where this sequence intersects the sea floor. Although not observable on the seismic records, bubble oscillation banding may have masked this, and the recognised first reflector A′ may have represented a boundary within Sequence II rather than an upper boundary marker. The character of surficial sands in the deeper water offshore areas is uncertain then and may represent either Sequence I or the upper part of Sequence II as shown on Map 8.

Within Sequence II in the Kirra area, underlying reflector A, seismic structure in terms of differentially compacted channel-infill sediments can be observed. These may represent areas of differential compaction within peat swamp areas which have infilled stream channels which cut through back-barrier areas during Postglacial Marine Transgressive times. In some cases, these channels appear to cut down into the Pleistocene substrate (Sequence III) supporting this conclusion.

4.4.2.3 Sequence III - Pleistocene Coastal Plain Sediments.

This sequence is generally bounded above by reflector B and bounded below by reflector C. Reflector B is considered to define the sub-aerially exposed Pleistocene surface of the Last Glacial and is well defined throughout the entire study area. In some areas, especially where present day bedrock submarine outcrop occurs, reflector C replaces reflector B as defining this surface, indicating bedrock outcrop on the land surface during the Pleistocene in those areas. Map 8 shows this Pleistocene surface, expressed in terms of an isopach map, contours showing depth of this surface (reflector B or C) from the present day seafloor. Areas where sequence III is absent (that is, where reflector C replaces B) can be seen to have been areas of erosion during the Late Pleistocene and as such, no Pleistocene sequence was preserved above bedrock basement there (see Plate IV).

Sequence III can be seen to possess greater seismic structure than overlying sequences in the form of basins, channels and differentially compacted sub-sequences (eg. Plate I) which indicate phases of slow and repid deposition, weathering and erosion. The Postglacial Marine Transgression, which commenced around 17000 years B.P. (see Chapter 2) just after the Last Glacial sea level minimum of around 130 metres below present sea level (see Hopley and Thom, 1983), may be considered to be the boundary between the broad scale Pleistocene depositional environments and ensuing transgress-ive phase which lead to the deposition of Sequence II.

Reflector B, which tops Sequence III, is wholely continuous and well defined due to the nature of the boundary between this and the overlying sequences. Sequence III can be correlated with Sequence 2 of Searle (1982) who notes the development of a soil horizon marking the upper surface (his reflector U1), which was revealed by a coring programme.

As such, accoustic impedance variation across such a boundary from overlying transgressive marine sands, would be of sufficient magnitude to provide a good seismic reflector.

Of significance on Map 8 is the presence of what appear on seismic records to be deep, differentially compacted channel-fill sediments within Sequence III. These areas, which map from one seismic line to the next as a continuous feature, following a linear topographic low or valley, may represent relict river channels which cut across the coast plain during Pleistocene Glacial lower sea levels. As such they may represent old courses of the Tweed River, the present mouth of which is some distance north of the course it would have taken in Pleistocene times. Evidence for this conclusion can be found in the absence of a Pleistocene channel expressed in Sequence III, emanating from the present river mouth. Recent northward deflection by the northward progradation of Letitia Spit has taken the river course north from that which it would have followed during the Pleistocene.

4.4.2.4 Sequence IV - Bedrock Basement.

Reflector C defines the top of bedrock, designated Sequence IV, purely for the reasons of completeness as material below reflector C is not part of Quaternary sedimentary history. Bedrock can be easily delineated in seismic sections (see Plate IV) due to its seismic opaquity. Bedrock is assumed to be Neranleigh-Fernvale metamorphics and Tertiary volcanics which form the structural basement and headlands controlling Quaternary deposition in the Gold Coast region. Reflector C generally shows much greater relief than overlying reflectors and in fact cross cuts all of those above, including the present day sea bed (see side scan sonar, Map 6).

CHAPTER 5.

5. SEDIMENTOLOGY.

5.1 OFFSHORE SEDIMENT SAMPLING.

5.1.1 Seaprobe Sample Method.

Subsurface data was collected offshore at Kirra Beach using a seaprobe designed and operated by the Gold Coast City Council. The device, which is able to penetrate the seafloor to a depth of six metres, is used extensively by the Council is assessing areas proposed as dredge sites for shore line replenishment. To assist in the interpretation of seismic data, one such probe was positioned on one of the seismic lines of the Point Danger to Kirra survey series (at fix number 27).

The seaprobe is basically a penetrometer and collects data from the subsurface by means of measuring the resistance to penetration of the probe as it is forced into the substrate. Collection of disturbed sediment samples by means of the blowing up of material by compressed air to the surface from designated horizons within the substrate is also possible.

5.1.2 Surface Sample Method.

Surface samples obtained from a systematic programme offshore from Point Danger to Cook Island were used in constructing a surface sediment distribution map of the main area of the investigation. Divers were used to take half metre undisturbed samples at 5 metre, 10 metre, 15 metre, 20 metre and 25 metre water depths along the hydrographic survey lines ETA 4, 6, 8, 10, 12 and 13 of the Gold Coast City Council's offshore survey series. Short core samples were taken using a plastic tube plunger arrangement (a kind of piston coring device), whereby the tube could be forced into the substrate as the plunger is drawn upwards. Rubber stoppers were placed at both ends of the tube and the sample brought to the surface where the undisturbed "core" could be examined and any sediment boundaries noted and different layers bagged separately with their position within the core recorded.

The use of such a sampling method over the more conventional ones such as grab sampling was made in the hope that differentiation could be made between the very top surface sediment and more significant underlying material. This concept relies on the fact that the very top surface material will represent the"last-event" affecting a certain seabed area rather than underlying material which should be more indicative of the sediment type which has accumulated over a longer, more significant, period of time. Such differentiation was possible and consistent relationships found in the present study.

5.2 RESULTS.

5.2.1 Seaprobe - Kirra.

Analytical techniques and results for the single seaprobe are given in Appendix IV. The sample point was at approximately 17 metres water depth offshore from Kirra Beach, just offshore from the point along the relevant seismic line where reflector A wedged out (see Map 8). That is, just offshore from the extent of the strong seismic reflector inferred to represent a peaty horizon in the Holocene back-barrier transgressive sequence (II). Results from the probe support this inference.

The penetrometer results (Appendix IV) support the presence of an induration boundary between the overlying surficial sand cover (Sequence I) and underlying transgressive sediments (mainly sands).

The surface sample (A) from the probe represents outer nearshore sand facies (see next Section). It consists mainly of well sorted sub-angular fine quartz sand. Shell content is low (6.3%) and comprises bivalve, foram, and echinoid fragments. A few chert lithics were observed (less than 2%), and the sample contained negligible mud. Granulometric data indicated a coarse skewed, leptokurtic distribution. Sediment colour, which is a most useful discriminatory criteria * with respect to delineating nearshore sands into the inner and outer facies types, was fawn-grey *. This sample represents a mature, quartz

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*note: inner nearshore sands are distinctively fawn to grey-fawn in colour.

sediment considered to occupy a moderate energy environment, part of the recent paralic sand wedge (see Chapter 2).

Sample B, taken across the sediment boundary indicated by the penetrometer results, could be seen to represent mixed outer nearshore sands, as for sample A and peaty transgressive sands. As such, granulometric data (Appendix IV) was considered composite, and non-representative of a particular facies type. Variation from sample A was found in that sample B contained a percentage of coarse, sub-rounded, iron-stained quartz grains and "wood" fragments indicative of a peaty environment. Total organic content (TOC) was measured at 2.0% by weight. Shell content also varied slightly with bivalve, echinoid, foram, bryozoan, and gastropod fragments present, as well as sponge spicules. The sample contained very few lithic fragments (chert) and no mud.

Sample C was taken from 3.2 - 3.5 metres, within the underlying transgressive sequence (II). The sample consisted basically of poorly sorted, medium, sub-angular quartz grains, of which a high percentage (30%) were ironstained. Shell content was relatively high, consisting of whole and fragmented bivalves, gastropods, echinoids, bryozoa, forams and worm tubes. Lithic content was relatively low, comprising both shale and chert fragments. The sample contained 2.6% peaty organic matter and no mud. The grain size distribution was strongly coarse skewed (shelly fragments) and mesokurtic. The sample represents transgressive sand facies at a transistional boundary point, laterally, with peaty transgressive back-barrier sediments, preserved nearer shore.

5.2.2 Surface Samples - Point Danger to Cook Island.

5.2.2.1 Facies Recognised.

The surface sediment samples collected offshore from Letitia Spit were subdivided into three basic facies as shown in Table 5.1. All facies studied could be considered to belong to the broader facies group termed nearshore sands (see Chapter 2). Significant to the present study was the subdivision of this broad facies group into inner nearshore sands which are considered to generally occupy a turbulent, high energy environment and outer nearshore sands, which lie generally seaward of this facies and occupy a moderage energy environment. The resulting surface sediment distributions (Map 9, pocket) could then be used in the interpretation of the nearshore sediment system operating in this region and provide information with regards the sediment budget of Gold Coast beaches, downdrift of the Tweed River mouth.

Inner nearshore sands were best differentiated from outer nearshore sands by sediment colour. Inner nearshore sands were fawn to grey-fawn coloured, outer nearshore sands fawn-grey to grey. Inner nearshore sands were generally well to very well sorted. They were composed

	Inner Nearshore Sand	Outer Nearshore Sand	Shelly Sands* (Shell Grit end member)
Grain Size	fine to medium	fine	medium to coarse
Sorting	well to very well	well to very well	poorly
Angularity of quartz grains	generally sub-rounded	generally sub-angular	sub-angular to sub-rounded
% Carbonate	low (< 5%)	low (< 5%)	high (up to 50%)
Shell fraction constituents	bivalve foram echinoid	bivalve echinoid foram	bivalve gastropod echinoid foram
Lithic fraction	very low to low (chert)	very low to low (chert)	low (chert, large quartz grains)
% Mud	0	0	0
% Ironstained quartz grains	low (< 10%)	low (< 10%)	low (< 10%)
Colour	fawn to grey-fawn	fawn-grey to grey	cream-brown

* note: Shelly inner nearshore sands and shelly outer nearshore sands are transitional types between nearshore quartz sands and shell grit. In Map 9, areas mapped as shelly sands include these three members.

<u>Table 5.1</u>. Sediment Properties of Facies Recognised, Point Danger to Cock Island.

almost completely of sub-rounded quartz grains, very few of which are ironstained. Lithic and shell content were both variable but generally low. Sediment generally varied from medium, where lithic or shell content was high to fine grained which were the best sorted inner nearshore sands, being composed almost purely of clean quartz grains.

Shell fractions generally consisted of bivalve, foram and echinoid fragments with sponge spicules appearing occasionally. Samples contained no mud. Granulometric analysis showed that samples were generally coarse skewed and mesokurtic to very leptokurtic. Coarser samples appeared nearer shore, with inner nearshore sands from deep water off Point Danger (see Map 9) being finer, and somewhat transitional in nature with respect to seaward lying outer nearshore sands.

The outer nearshore facies was distinguished as well to very well sorted, fawn-grey to grey, fine sands. Samples consisted almost wholely of sub-angular quartz grains very few of which were ironstained. Lithic content was generally low, shell content variable, consisting of bivalve, echinoid and foram fragments with sparse sponge spicules also present. Samples contained no mud. Shelly outer nearshore sands were coarser, less well sorted and coarse skewed to strongly coarse skewed. They provide a transitional area between quartz sands and shelly sands in the southern part of the study area (see Map 9). Outer nearshore quartz sands were generally near symmetrical to slightly coarse skewed, leptokurtic to very leptokurtic.

The nearshore sand - inner shelf sand boundary was not observed in the sediment samples taken, indicating that recent "active" sands (those derived from transgressive sands, (see Chapter 4)) extend to a minimum of 25 metres water depth throughout most of the area south of Point Danger.

In the southern part of the study area where submarine outcropping bedrock appears widespread, coarse shell grit facies, which was mapped using side scan sonar (see Map 6), dominated. In the area immediately around rock outcrop, sediment was almost 50% shell. Sediment, consequently, was coarse, poorly sorted and distinctively platykurtic. The boundary between such shell grit material and nearshore quartz sands was placed somewhat artitrarily, generally indicated by points, in the outer nearshore facies areas, where average grain size began to coarsen due to increasing shell content, (see Map 9). Basically, such material was outer nearshore, fine, well sorted, grey sands combined with mottled cream-brown coloured, coarse shell. As such, the same general hydrodynamic regime applies to these "sands" as to the outer nearshore quartz sands.

A similar relationship existed just offshore from Point Danger where an inner nearshore - shelly inner nearshore boundary was noted due to the presence of submarine rock outcrop in this northern area.

5.2.2.2 Surface Sediment Structuring.

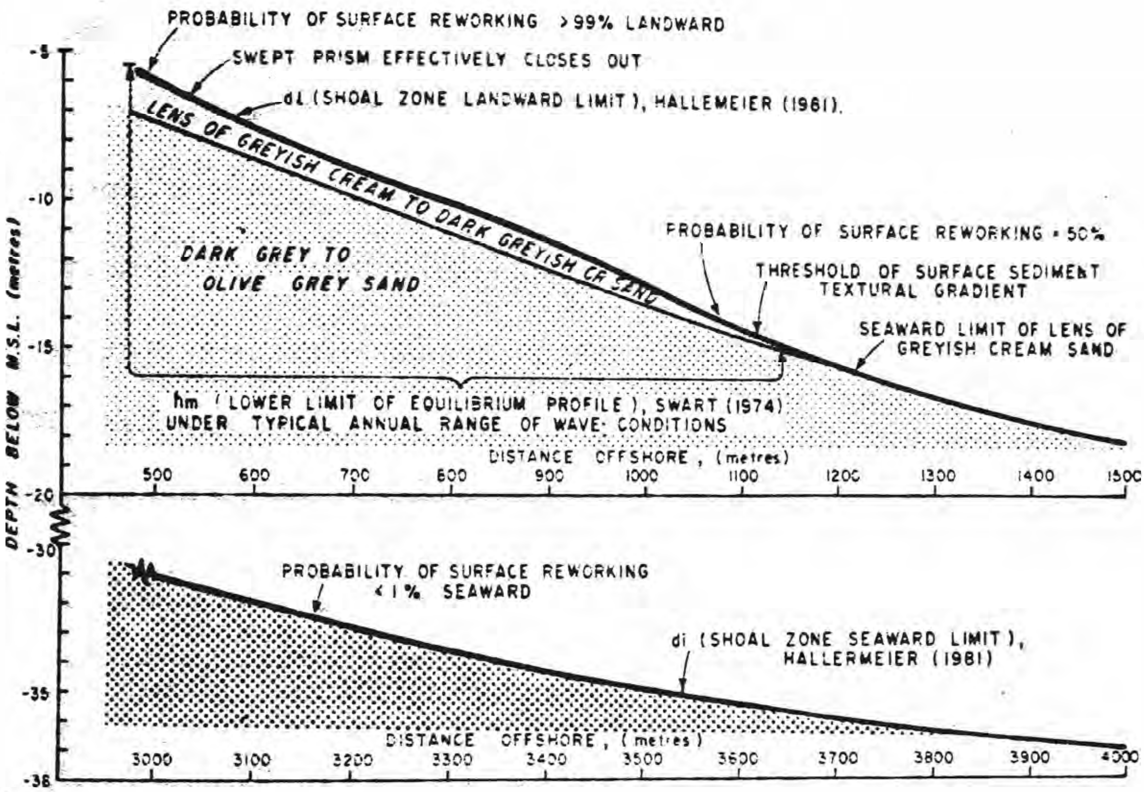
The sampling technique used, where half metre "cores" were collected and sediment layers differentiated, bagged and analysed separately provided information with regards the very top sediment structuring. Reasonably consistently, it could be seen that both the top layers and bottom layers (quartz sands generally, if differentiable, were of two layers), provided the same information with regards to facies categorisation. What was also consistent was the fact that, in general, the upper layer was finer, and in most cases, better sorted than the underlying layer. Also the lower layer tended to be a slightly darker colour, indicating, possibly, a higher organic content (generally very low for all samples). Also significant was that samples taken nearshore, at 5 metres water depth, occupying a high energy environment, did not show such divisions. Furthermore, when such divisions were observable, the upper layers were consistently thicker, the nearer the sample was to the shore, or more correctly, the shallower the water depth of the sample.

The conclusion which can be reached from the above considerations is that, in general, the upper layers, which are finer, better sorted, and contain less organic matter, represent the reworked top of the sediment sample. That is, that part of the sediment body, at that particular point, which posses a high probability of reworking. As this decreases systematically seawards, it provides data towards the indication that waves, the influence of which also decreases systematically seawards, are the major hydrodynamic force operating, with regards to these sediments in this area, offshore from Letitia Spit. This is a significant conclusion with respect to the major sand transport mechanism in the area.

5.2.2.3 Surface Sediment Facies Distribution.

Map 9 shows the distribution of the surface sediment facies in the Point Danger Region. Coarse shell grit facies are shown in Map 6, mapped from side scan sonar. The shelly sand facies shown on Map 9, really represents a transition between the nearshore quartz sands, outer nearshore in the south, inner nearshore in the small area in the north, and this coarse shell grit facies. Hydrodynamically, this shelly sand facies, then, belongs to those respective nearshore sand facies.

From Cook Island up to the Tweed River mouth, nearshore sand facies show the usual relationship for the Gold Coast region. This relationship, which can be correlated with theoretical probability of reworking of surface sediment calculations (see Chapman and Smith, 1983), finds the fawny coloured inner nearshore sands disappearing at about 15 metres with a probability of surface reworking around 50%. This relationship is shown in Figure 5.1.



<u>Figure 5.1</u>. Gold Coast Nearshore Sands - Relationships to Reworking Probabilities (from Chapman and Smith, 1983).

Around the Tweed River mouth region, the inner nearshore sands begin to extend farther seawards. Around the Point Danger region, and immediately offshore from such, the isobaths are close-spaced and deep water exists close to shore. Whilst the surface sediments in this region have been shown on Map 9 as inner nearshore sands, their characteristics were somewhat transitional between inner nearshore and outer nearshore facies. However, sediment colour, which was grey-fawn, as distinct from the grey coloured sands of 25 metres water depth of the southern ETA lines, was used as the discriminating criteria. Inner nearshore sands, therefore, could be seen to extend into relatively deep water off the Tweed River mouth - Point Danger region, indicating, taking reworking probabilities into account, a present day offshore accumulation of this facies. As such, these sands thus presently represent a loss to the Gold Coast nearshore sediment budget.

The fact that the normal fining - seaward relationship applies, with outer nearshore sands lying seaward of inner nearshore sands, no anomolous reversals apparent,is significant to testing the southern offshore sink hypothesis (see Chapter 2). That is, the outer nearshore band parallels the inner nearshore band, appearing to turn around the Tweed River mouth region seawards with the deep water inner nearshore accumulation in this region. It may well be that the outer nearshore band may become very thin offshore from

Point Danger. Inner nearshore sands or the transitional type sediment observed in deep water off Point Danger may almost directly adjoin inner shelf sands, which probably lie in deeper water off Point Danger. The surface sediment distributions shown on Map 9 indicates that no southward redistribution of inner nearshore sands appears to have occurred or is occurring. The deep water offshore inner nearshore sand accumulation around Point Danger indicates a present-day sediment budget deficiency, however. The offshore extent was not able to be shown with confidence and, as such, the volume of accumulated inner nearshore sands was not really quantifiable. As such, the significance of this deep water area, off Point Danger, as an inner near-shore sand sink is unknown in the context of Holocene inner shelf development. Unfortunately, seismic resolution was not sufficient and more significantly the nature and position of the upper sequence reflectors not well enough understood for elucidation of this point (see Section 4.4.2).

More significantly, deep water accumulation of inner nearshore sands indicates that calculations involving present day sediment transport rates and volumes should consider a loss from Letitia Spit to the beaches north of Point Danger.

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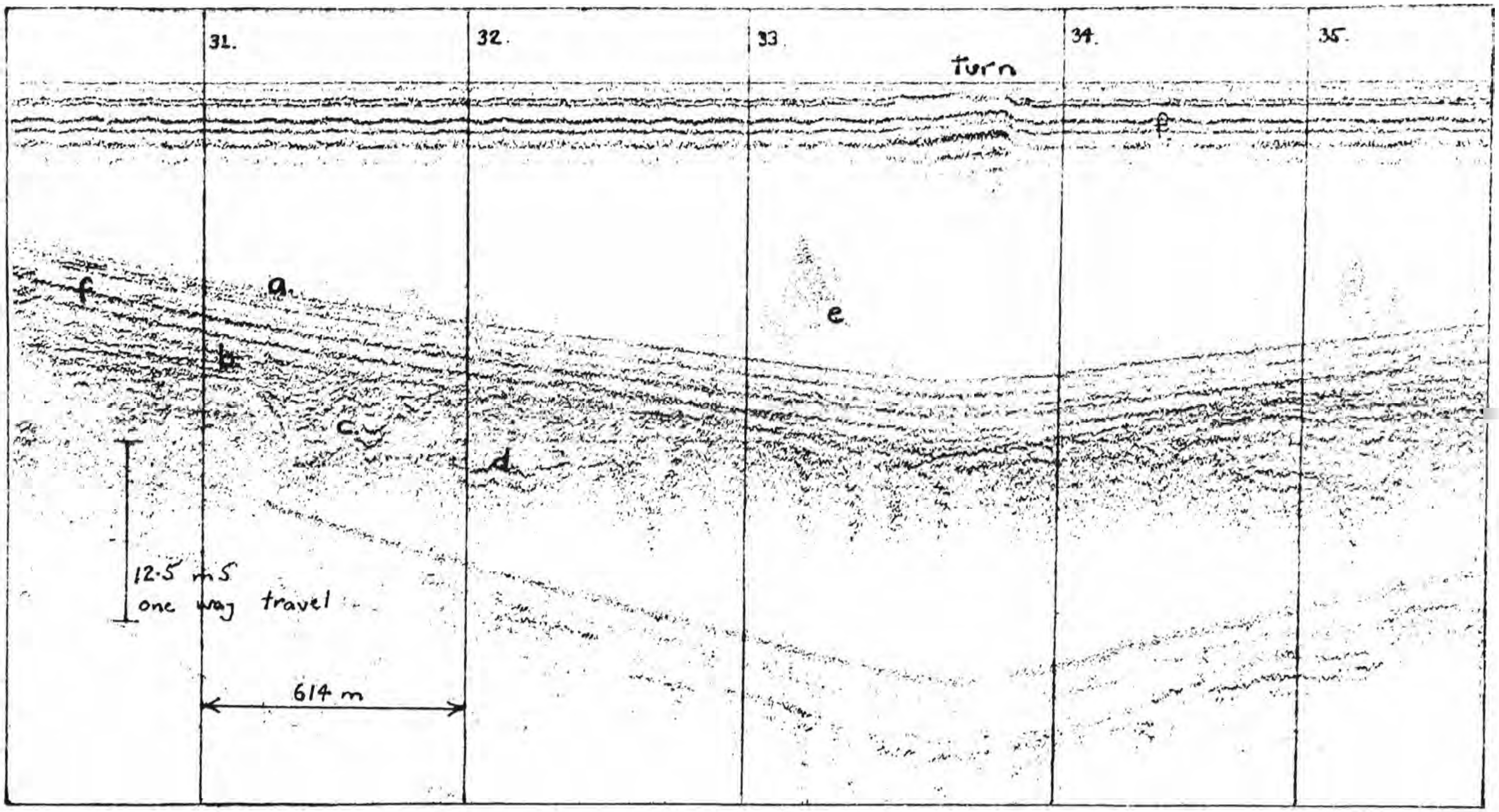


SEISMIC REPLAY RECORD. - KIRRA AREA. - FIXES 31-35.

a. First reflector - sea floor.
b. Reflector B - Pleistocene surface.
c. Structure within Pleistocene sequence (III).
d. Reflector C - bedrock.
e. Fish or prawn schools.
f. Bubble oscillation banding.

PLATE I.

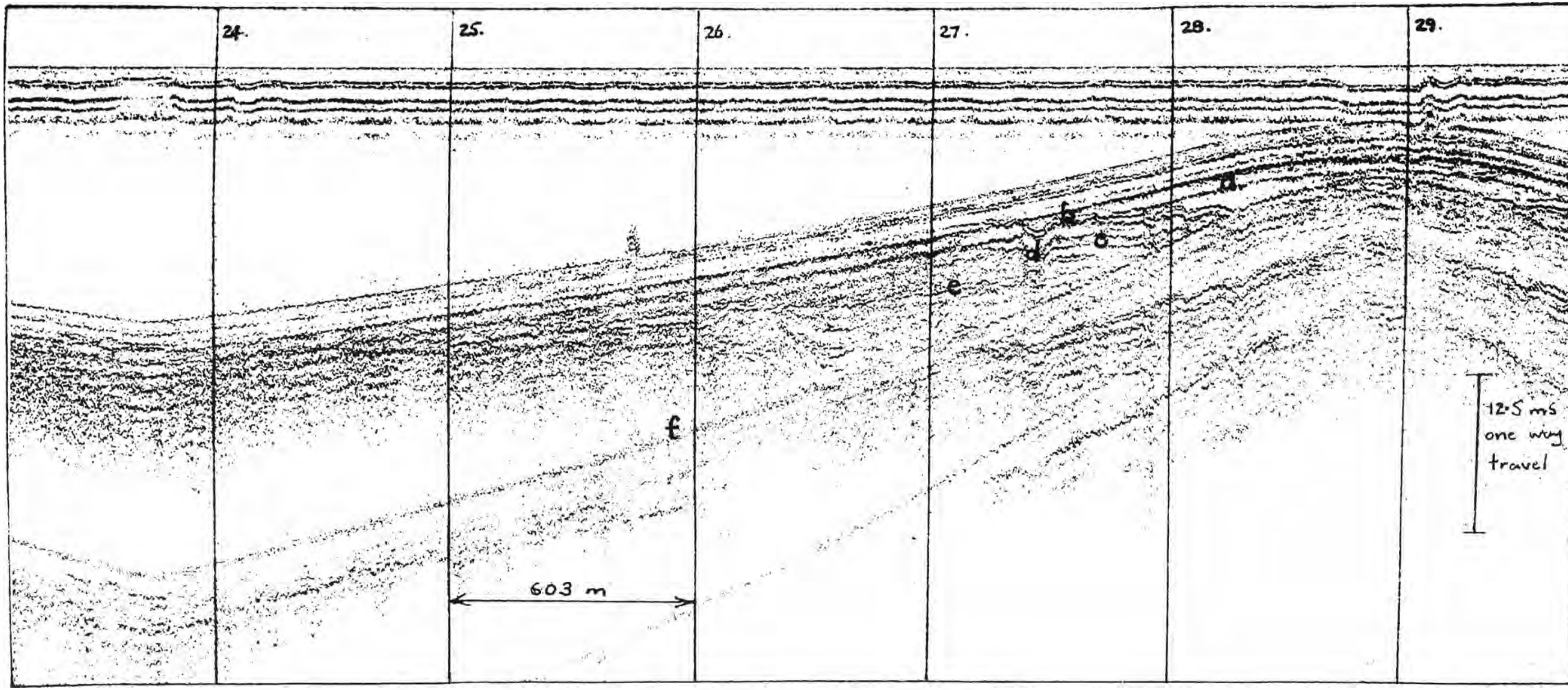
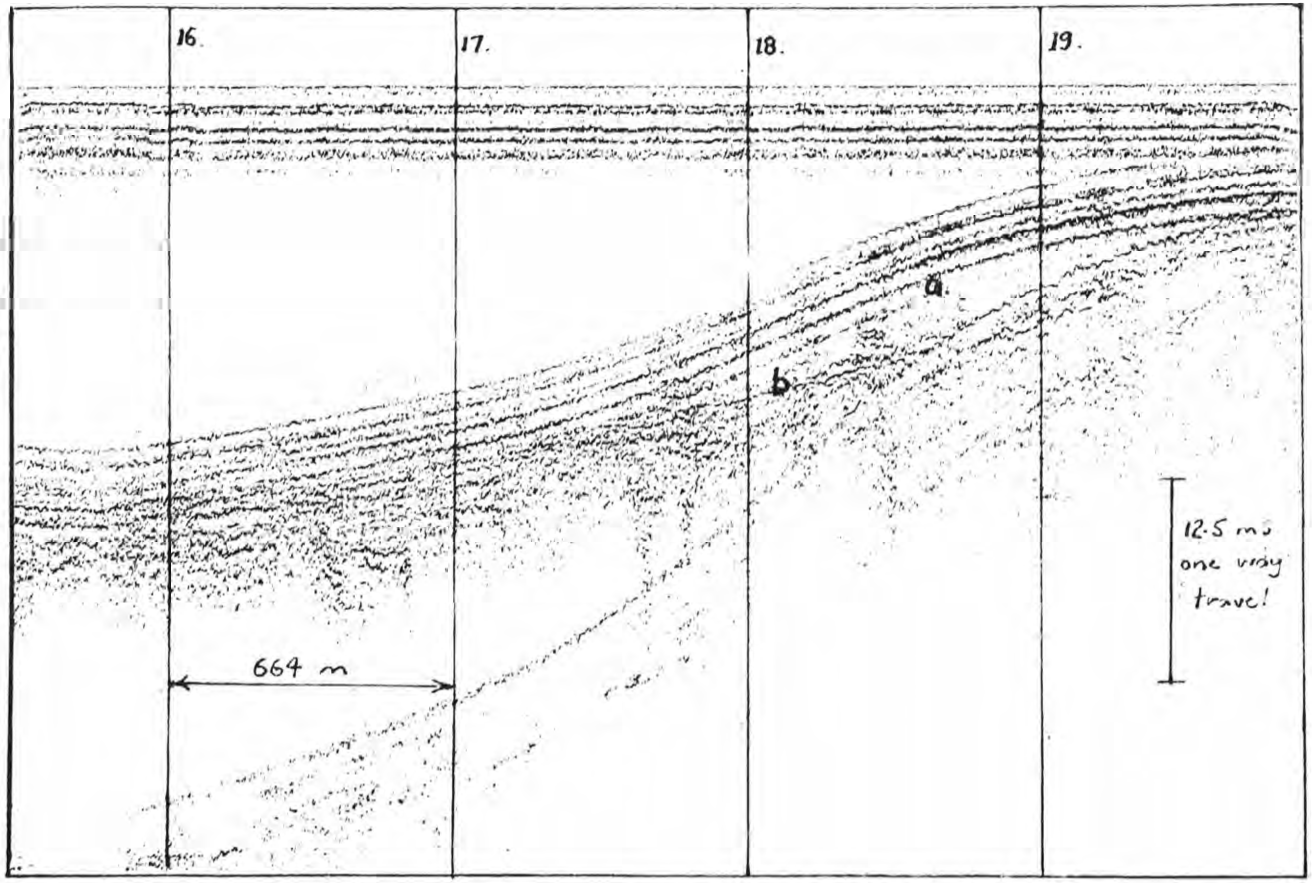


PLATE II.

SEISMIC REPLAY RECORD. - KIRRA AREA. - FIXES 24-29.

a. Holocene surficial sediment wedge - sequence I.
b. Reflector A: Postglacial Marine Transgressive surface.
c. Holocene leading-edge depositional transgressive sequence II.
d. Differential compaction within channelling.
e. Pleistocene - Last Glacial surface - reflector B.
f. First multiple.

PLATE III.



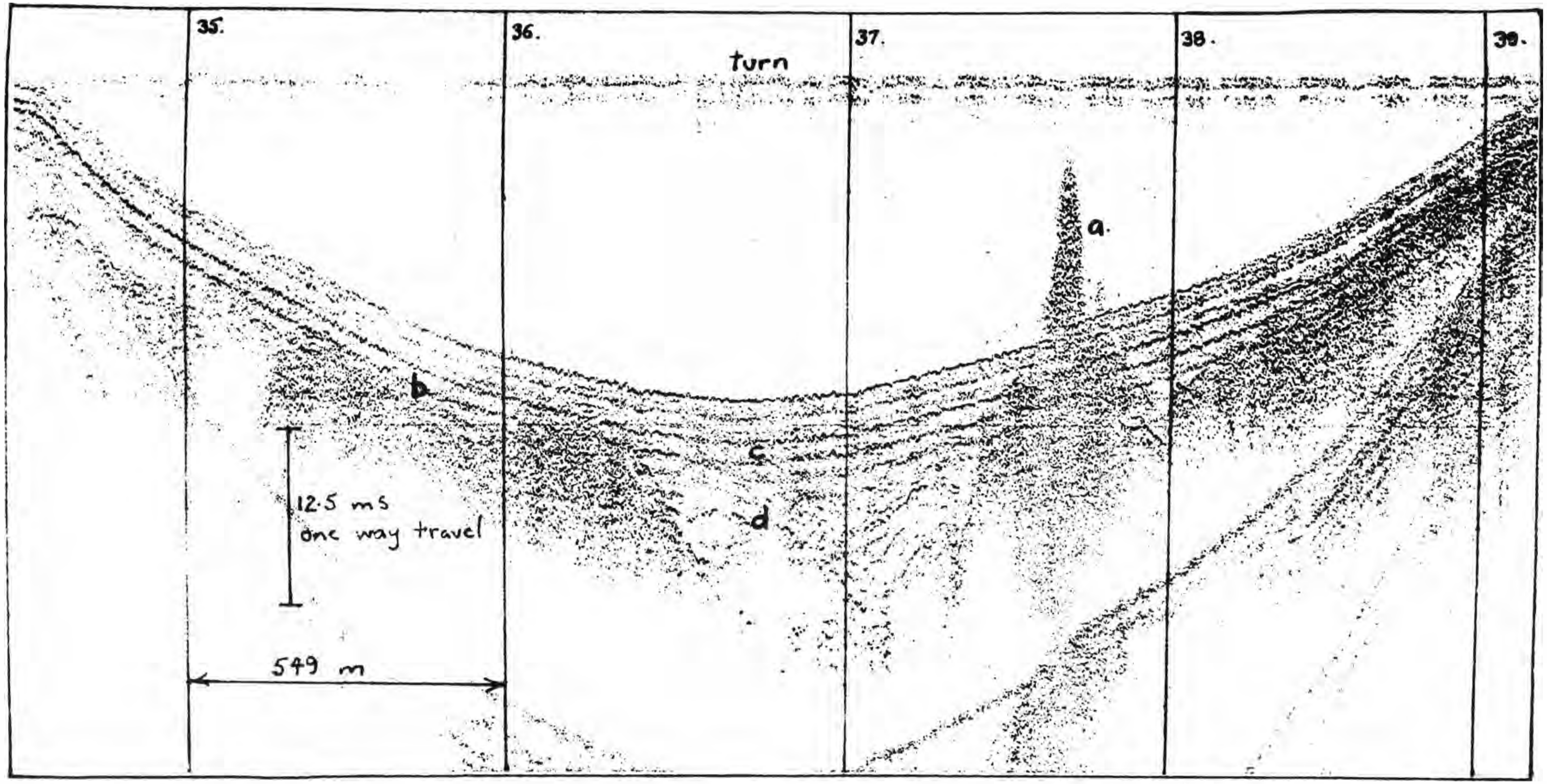
SEISMIC REPLAY RECORD. - KIRRA AREA. - FIXES 16-19.

a. Holocene surficial sediment wedge.

Note: absence of reflector A.

b. Reflector B - Pleistocene surface.

PLATE IV.



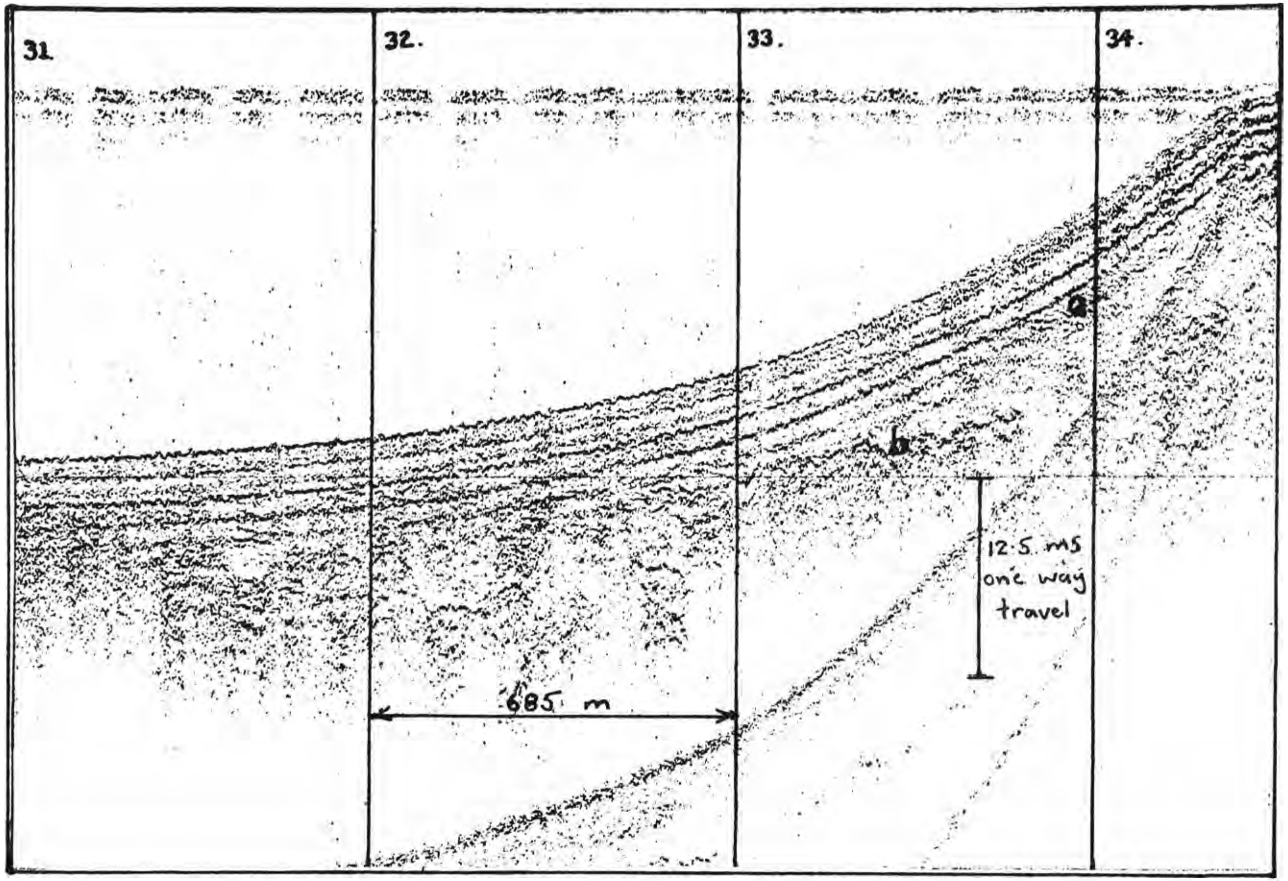
<u>SEISMIC REPLAY RECORD. - POINT DANGER. - KIRRA AREA. - FIXES 35-39</u>.

a. Bedrock submarine outcrop.

b. Bedrock at depth - reflector C.

c. Surficial sediment sequence I.

d. Reflector A - discontinuous first reflector offshore.



SEISMIC REPLAY RECORD. - TWEED TIDAL DELTA. - LETITIA SPIT AREA. - FIXES 31-34.

a. Reflector A - vaguely defined, discontinuous.

b. Reflector B - Pleistocene surface.

PLATE V.

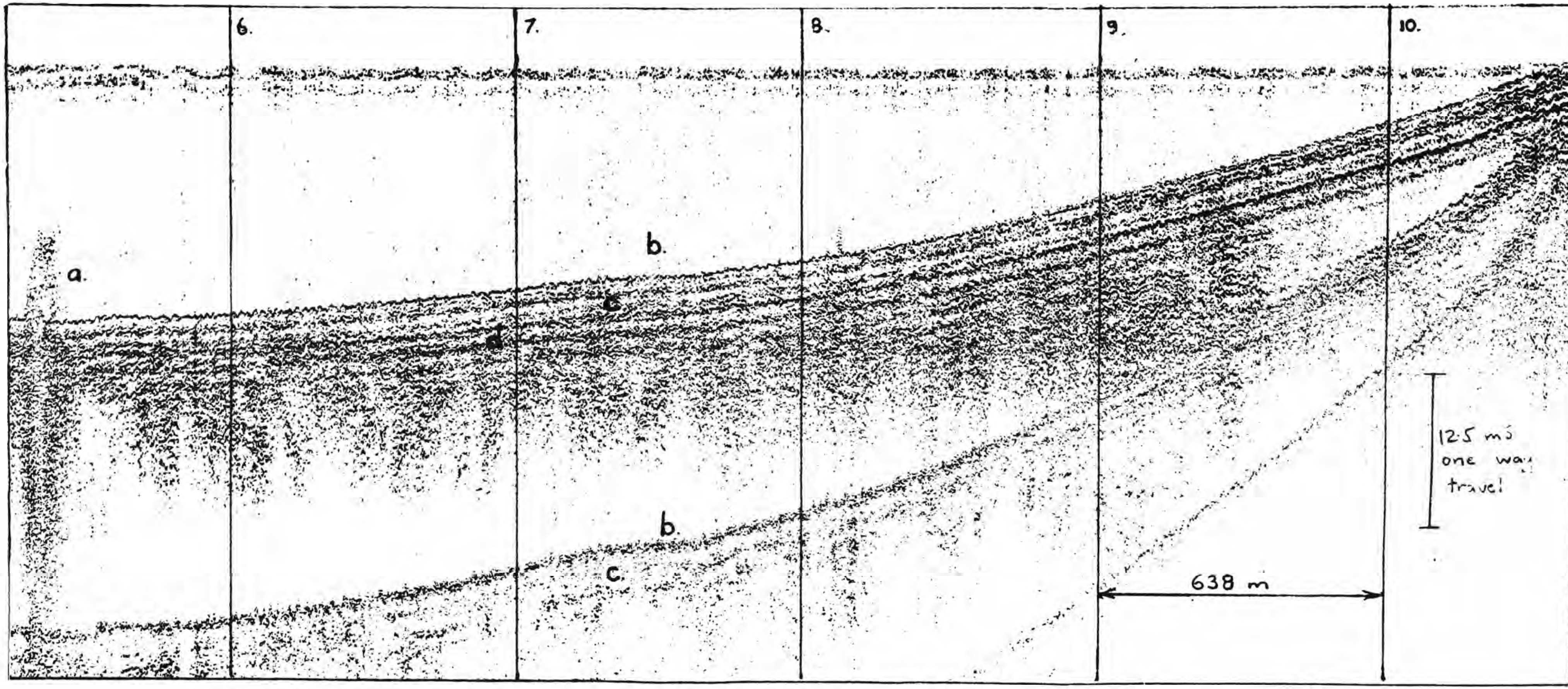


PLATE VI.

<u>SEISMIC REPLAY RECORD. - LETITIA SPIT AREA. - FIXES 6-10</u>.

a. Bedrock submarine outcrop.

b. Seabed profile change (expressed well in exaggerated first multiple).

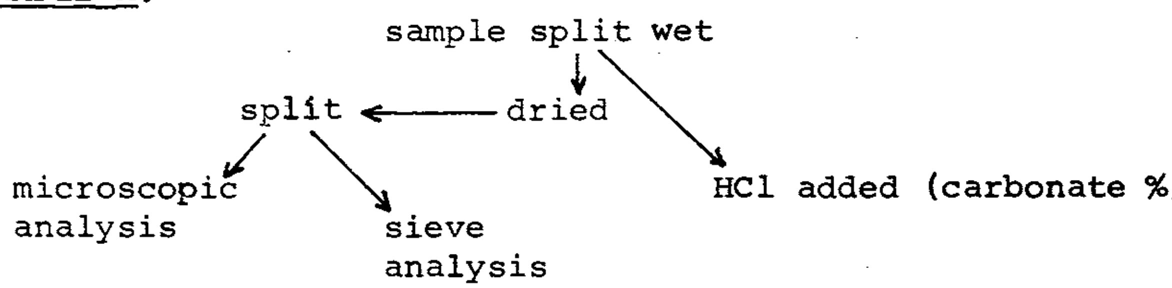
c. Thickening of surficial sediment sequence (I).

d. Reflector A - discontinuous first subsurface reflector - poorly defined.

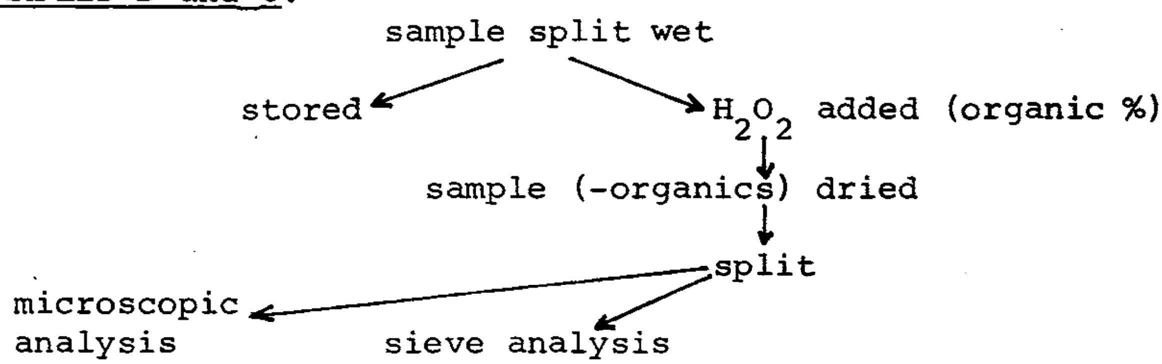
Appendix IV.

SEAPROBE SAMPLE ANALYTICAL TECHNIQUES

SAMPLE A.

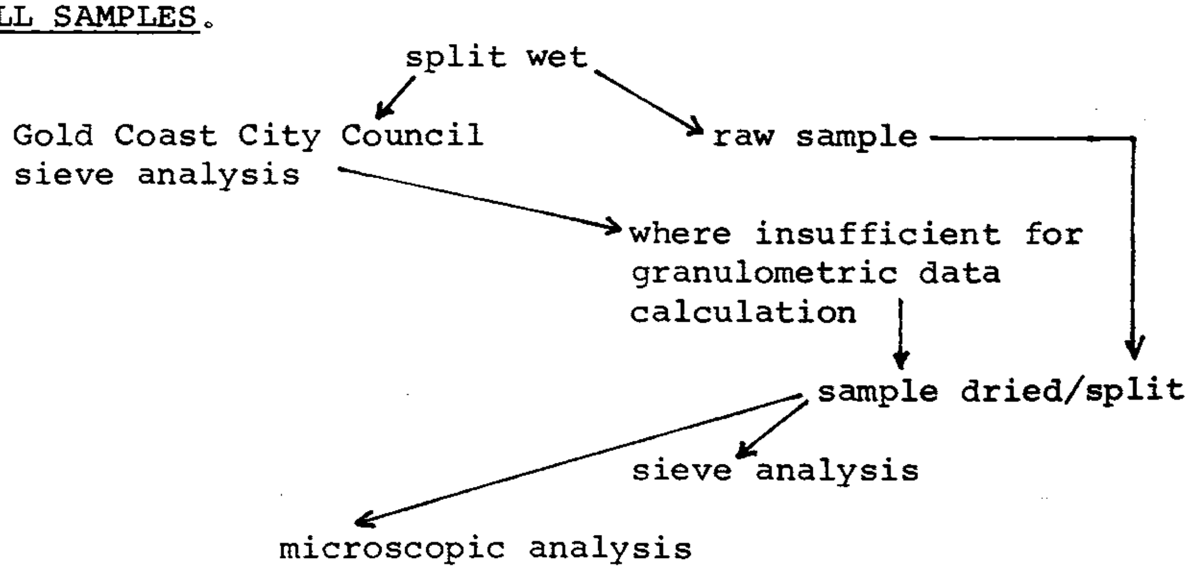


SAMPLES B and C.



SURFACE SAMPLE ANALYTICAL TECHNIQUES.

ALL SAMPLES.



Appendix IV (cont).

SEDIMENT SAMPLE DATA.

SEAPROBE.

PENETROMETER RESULTS.

0 - 3.0m	unconsolidated sands
3.0m - 4.2m	indurated sands with small stones and shell
4.2m - 6.0m	unconsolidated - semi-consolidated sands

DISTURBED SEDIMENT SAMPLES.

Sample and Core Interval	Granulometric Data				Facies
	$M_Z(\phi)$	$\sigma_I(\phi)$	Sk_I	K_G	
A (surface)	2.7	0.4	-0.29	1.19	o.n.s.
B (2.0 - 3.2m)	2.34	0.42	-0.07	1.07	mixed o.n.s. and p.t.s.
C (3.2 - 3.5m)	1.10	1.46	-0.54	1.08	p.t.s.

o.n.s. : outer nearshore sands.

p.t.s. : peaty transgressive sands.

Appendix IV (cont).

SURFACE SAMPLES.

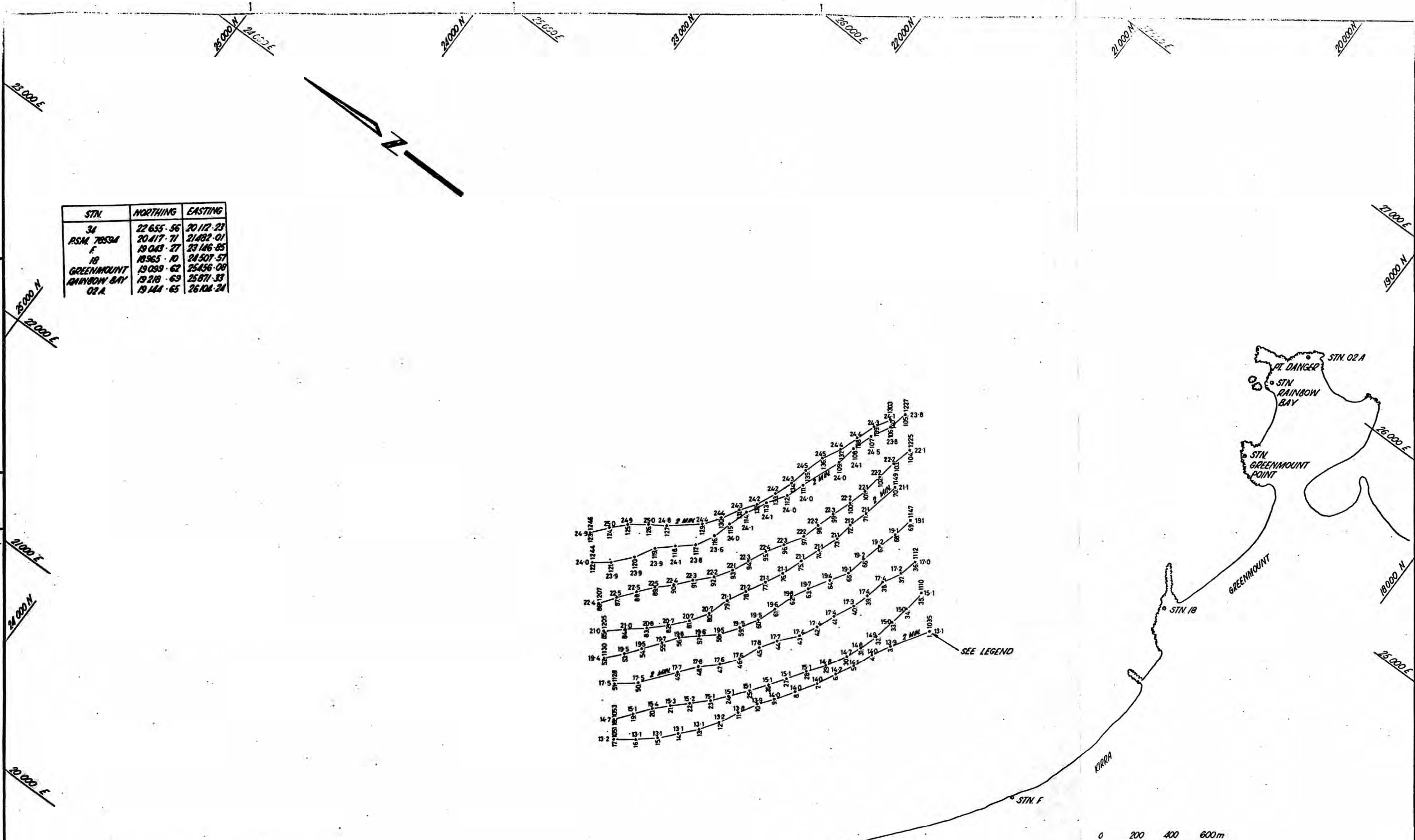
Sample	Granulometric Data				Colour	Facies
	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	K_G		
ETA4/5	1.99	0.41	-0.09	1.04	fawn	i.n.s.
ETA4/10(1)	2.39	0.41	-0.24	1.59	grey-fawn	i.n.s.
ETA4/10(2)		n.a.			grey-fawn	i.n.s.
ETA4/15(1)	1.32	1.36	-0.33	0.80	cream-brown	s.s.
ETA4/15(2)	1.36	1.46	-0.33	0.80	cream-brown	s.s.
ETA4/15(3)	0.82	1.51	0.02	0.82	cream-brown	s.s.
ETA4/15(4)	2.41	0.88	-0.56	1.67	grey	s.o.n.s.
ETA4/20		n.a.			cream-brown	s.s.
ETA4/25	0.37	1.51	-0.37	0.81	cream-brown	s.s.
ETA6/5	2.05	0.67	-0.46	1.39	fawn	i.n.s.
ETA6/10(1)		n.a.			grey-fawn	i.n.s.
ETA6/10(2)		n.a.			grey-fawn	i.n.s.
ETA6/15(1)	2.56	0.45	-0.03	1.75	fawn-grey	o.n.s.
ETA6/15(2)	2.5	0.52	-0.15	1.69	grey	o.n.s.
ETA6/20(1)	2.18	0.63	0.03	1.14	fawn-grey	s.o.n.s.
ETA6/20(2)		n.a.			grey	s.o.n.s.
ETA6/25	1.68	1.51	-0.37	0.81	cream-brown	s.s.
ETA8/5(1)	2.24	0.56	-0.68	1.05	fawn	i.n.s.
ETA8/5(2)		n.a.			fawn	i.n.s.
ETA8/10(1)	2.33	0.48	-0.23	1.31	grey-fawn	i.n.s.
ETA8/10(2)	2.08	0.46	-0.26	1.21	grey-fawn	i.n.s.
ETA8/15(1)	2.62	0.48	-0.23	1.31	grey	o.n.s.
ETA8/15(2)	2.24	0.46	-0.26	1.21	grey	o.n.s.
ETA8/20	2.53	0.36	-0.08	1.74	fawn-grey	o.n.s.
ETA8/25	2.27	0.58	-0.42	1.60	fawn-grey	s.o.n.s.
ETA10/5	1.77	0.67	-0.16	1.0	fawn	i.n.s.
ETA10/10(1)	2.37	0.42	-0.16	1.29	grey-fawn	i.n.s.
ETA10/10(2)	2.08	0.47	-0.19	1.06	grey-fawn	i.n.s.
ETA10/15	2.42	0.35	-0.18	1.61	grey	o.n.s.
ETA10/20	2.5	0.25	-0.01	1.61	fawn-grey	o.n.s.
ETA10/25(1)	2.52	0.27	-0.04	1.20	fawn-grey	o.n.s.
ETA10/25(2)	2.31	0.43	-0.29	1.20	fawn-grey	o.n.s.
ETA12/5	2.0	0.39	-0.12	0.95	fawn	i.n.s.
ETA12/10	2.22	0.36	-0.32	0.93	fawn	i.n.s.
ETA12/15	2.25	0.39	-0.23	1.08	grey-fawn	i.n.s.
ETA12/20(1)	2.4	0.32	-0.06	1.35	grey-fawn	i.n.s.
ETA12/20(2)	2.41	0.32	-0.12	2.09	grey-fawn	i.n.s.

Sample	Granulometric Data				Colour	Facies
	$M_z(\phi)$	$\sigma_I(\phi)$	Sk_I	K_G		
ETA12/25(1)	2.44	0.37	-0.18	1.75	grey-fawn	i.n.s.
ETA12/25(2)	2.23	0.53	-0.39	1.26	grey-fawn	i.n.s.
ETA13/5	1.9	0.49	-0.07	0.88	fawn	i.n.s.
ETA13/10(1)	2.24	0.37	-0.17	1.37	grey-fawn	i.n.s.
ETA13/10(2)	2.12	0.62	-0.36	1.29	grey-fawn	i.n.s.
ETA13/15(1)	2.39	0.33	-0.11	1.39	grey-fawn	i.n.s.
ETA13/15(2)	2.36	0.38	-0.20	1.65	grey-fawn	i.n.s.
ETA13/20(1)	2.38	0.33	-0.09	1.35	grey-fawn	i.n.s.
ETA13/20(2)	2.41	0.32	-0.15	1.40	grey-fawn	i.n.s.
ETA13/25(1)	2.23	0.54	-0.38	1.30	grey-fawn	s.i.n.s.
ETA13/25(2)	2.14	0.60	-0.49	1.29	grey-fawn	s.i.n.s.

i.n.s. : inner nearshore sand.
s.i.n.s. : shelly inner nearshore sand.
o.n.s. : outer nearshore sand.
s.o.n.s. : shelly outer nearshore sand.
s.s. : shelly sand.

$M_z(\phi)$: graphic mean grain size.
$\sigma_I(\phi)$: inclusive graphic standard deviation.
Sk_I : inclusive graphic skewness.
K_G : kurtosis.

n.a. : not analysed (not resieved).



STN.	NORTHING	EASTING
34	22 655 · 56	20 112 · 23
P.S.M. 78594	20 417 · 71	21 482 · 01
F	19 043 · 27	23 146 · 85
18	18 965 · 10	24 507 · 57
GREENMOUNT	19 099 · 62	25 456 · 08
RAINBOW BAY	19 218 · 69	25 871 · 33
02 A	19 144 · 65	26 104 · 24

LEGEND

VESSELL POSITION TAKEN EVERY 60 SECONDS, UNLESS OTHERWISE STATED

1035 — TIME TAKEN
13·1 — DEPTH IN METRES
1 — FIX NO.

MAP 1

DATE OF SURVEY 11·6·85

READ THIS PLAN IN CONJUNCTION WITH:—

40963 .. PT. DANGER - KIRRA PT.
40964 .. TWEED RIVER - COOK ISLAND
40965 .. PT. DANGER - BILINGA
40966 .. PT. DANGER - COOK ISLAND

LEGEND

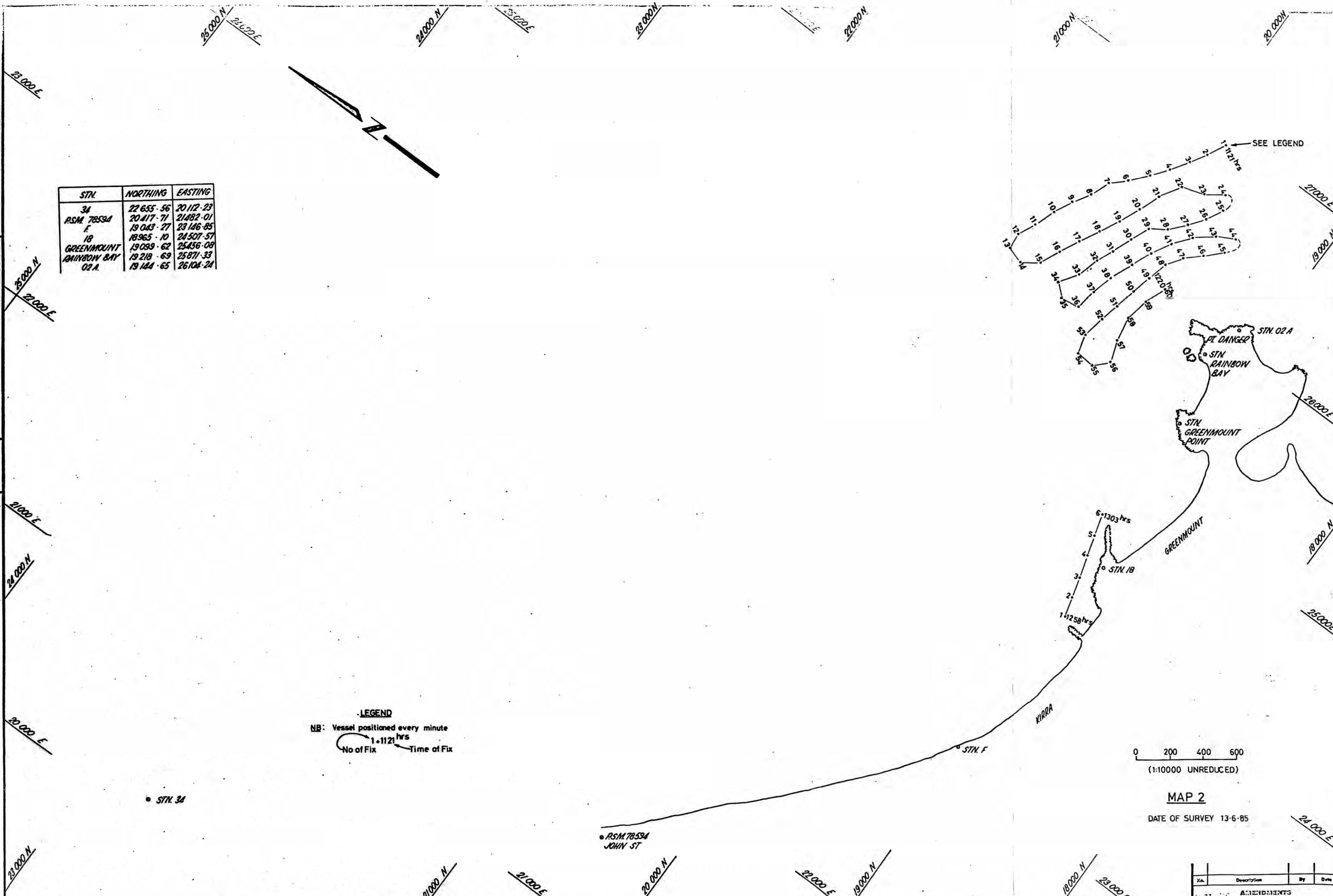
GOLD COAST CITY COUNCIL

JOHN ST—KIRRA POINT
SIDE SCAN
KIRRA

No.	Description	By	Date
AMENDMENTS			

Passed	Date	Approved	Date
[signature]	21/11/85	R.D. Sterling	21/11/85

Drawn	DO.	Lev. Bk.	3080	Job No.	
Traced	W.W.	Fd. Bk.		40962	
Checked	F.L.D.	Cal. No.		Sheet 1 of 5	



STN.	NORTHING	EASTING
34	22 655 · 56	20 112 · 23
P.S.M. 78594	20 417 · 71	21 482 · 01
F	19 043 · 27	23 146 · 85
18	18 965 · 10	24 507 · 57
GREENMOUNT	19 099 · 62	25 456 · 08
RAINBOW BAY	19 218 · 69	25 871 · 33
02 A	19 144 · 65	26 104 · 24

LEGEND

NB: Vessel positioned every minute

1 • 1121 hrs — No of Fix — Time of Fix

MAP 2

DATE OF SURVEY 13·6·85

READ THIS PLAN IN CONJUNCTION WITH:—

40962 .. JOHN ST - KIRRA PT
40964 .. TWEED RIVER - COOK ISLAND
40965 .. PT. DANGER - BILINGA
40966 .. PT. DANGER - COOK ISLAND

LEGEND

GOLD COAST CITY COUNCIL

PT. DANGER & KIRRA PT.

SIDE SCAN SURVEY

AMENDMENTS

Passed	Date	Approved	Date
	21/11/85	R.O. Stuckey	21/11/85
Datum 00	Lev. Bk. 3080	Job No.	
Traced A.O.K.		40963	
Checked F.L.G.		Sheet 2	of 5

STN	NORTHING	EASTING
02 A	19 144 · 65	26 104 · 24
ETA 10	18 032 · 74	26 574 · 59
FINGAL	15 112 · 24	27 923 · 58

READ THIS PLAN IN CONJUNCTION WITH:—

40962 .. JOHN ST - KIRRA PT.
40963 .. PT. DANGER - KIRRA PT.
40965 .. PT. DANGER - BILINGA
40966 .. PT. DANGER - COOK ISLAND

LEGEND

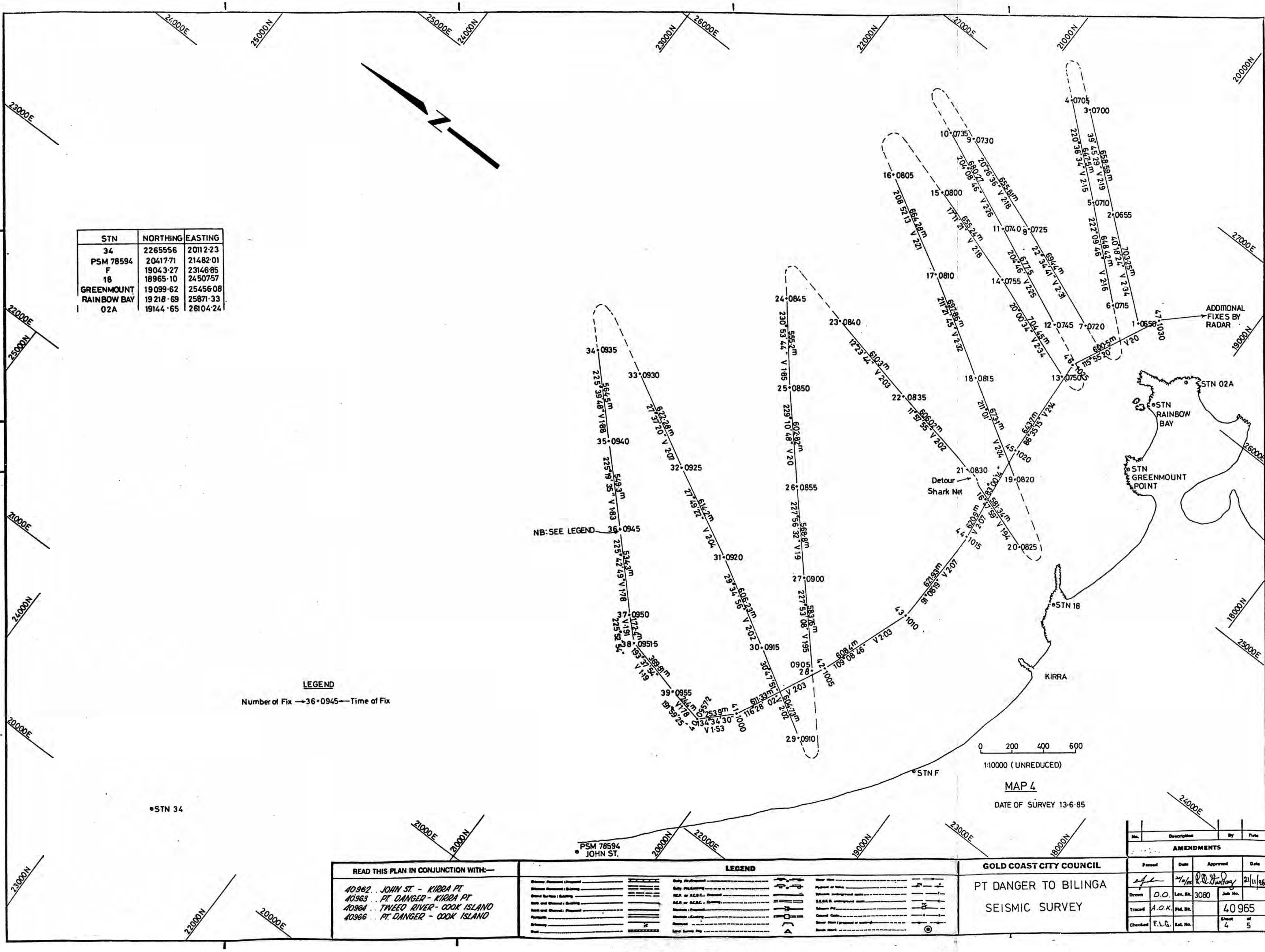
GOLD COAST CITY COUNCIL

TWEED RIVER-COOK ISLAND
SIDE SCAN
LETITIA SPIT

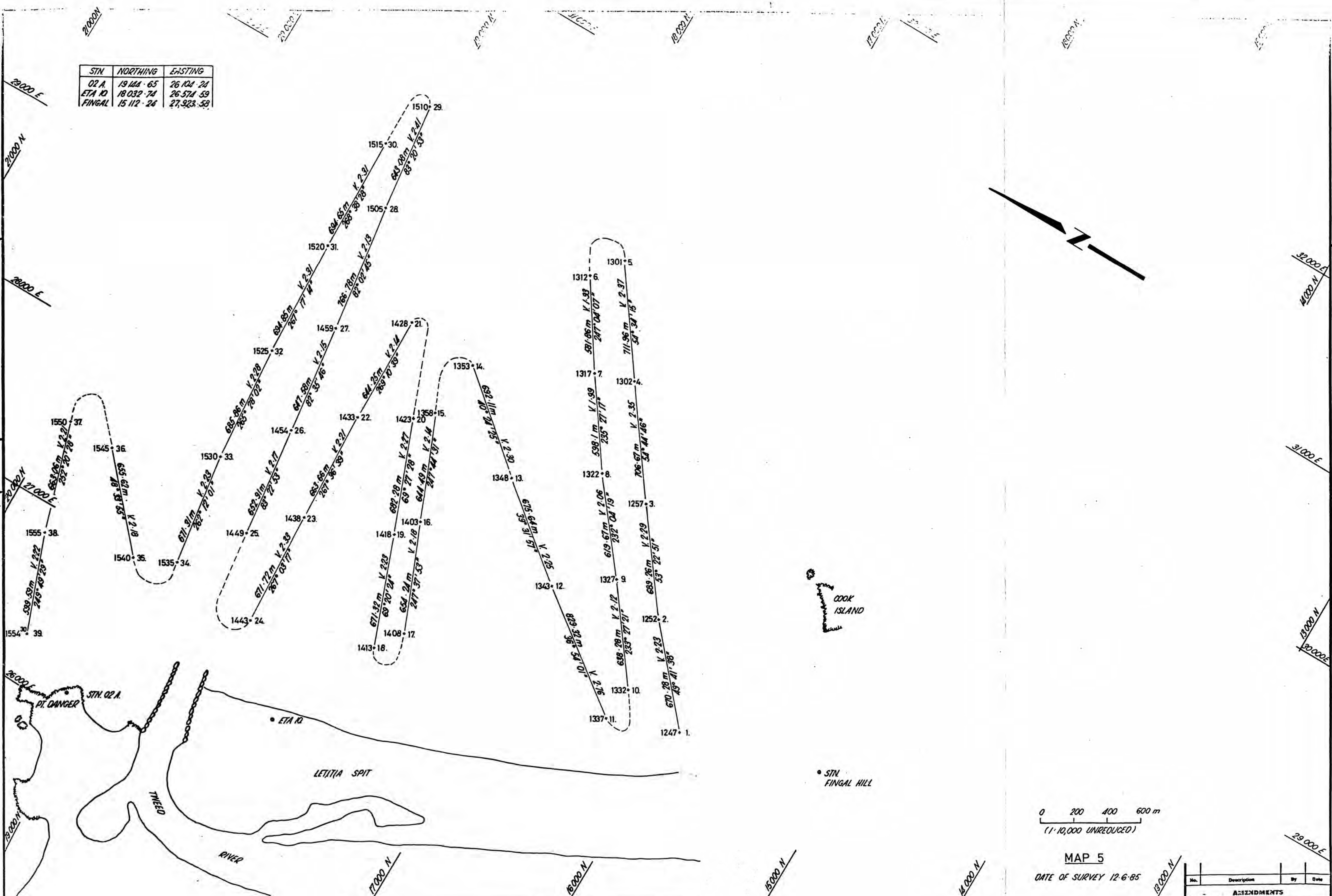
AMENDMENTS

Passed	Date	Approved	Date
	21/11/85	R.D. Stockey	21/11/85

Drawn D.O. Lev. Bk. 3080 Job No.
Traced
Checked F.L.Q.
40964
Sheet 3 of 5



STN	NORTHING	EASTING
34	2265556	20112·23
PSM 78594	20417·71	21482·01
F	19043·27	23146·85
18	18965·10	24507·57
GREENMOUNT	19099·62	25456·08
RAINBOW BAY	19218·69	25871·33
02A	19144·65	26104·24



READ THIS PLAN IN CONJUNCTION WITH:—
40962.. JOHN ST. - KIRRA PT.
40963.. PT. DANGER - KIRRA PT.
40964.. TWEED RIVER - COOK ISLAND
40965.. PT. DANGER - BILINGA

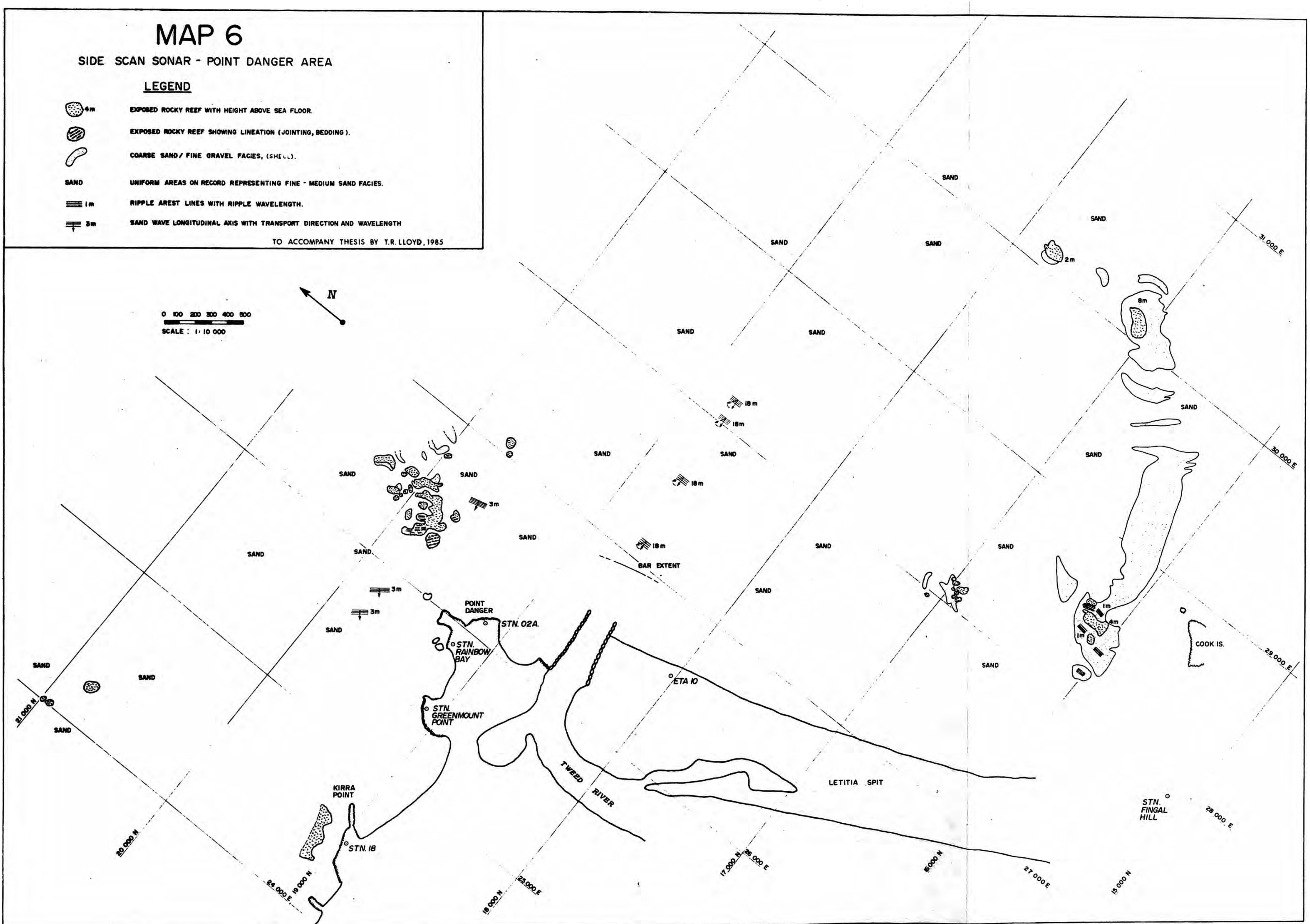
LEGEND

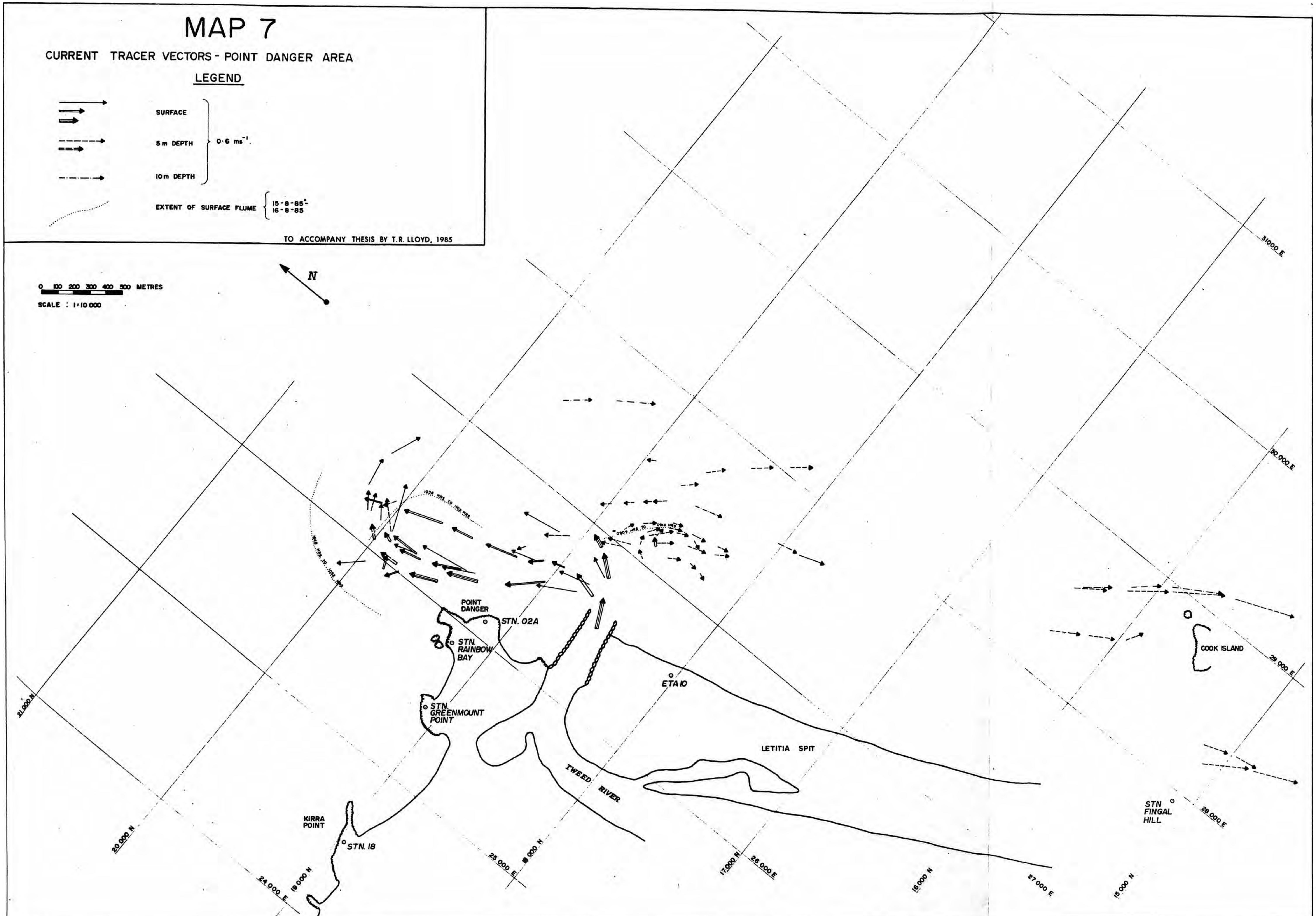
GOLD COAST CITY COUNCIL

PT. DANGER – COOK ISLAND
SEISMIC SURVEY
LETITIA SPIT

AMENDMENTS

Passed	Date	Approved	Date
[illegible]	21/11/85	R.D. Stanley	21/11/85
Drawn DO		Job No.	
Traced			40966
Checked		Sheet	5 of 5


MAP 6
SIDE SCAN SONAR - POINT DANGER AREA
LEGEND
4m
EXPOSED ROCKY REEF WITH HEIGHT ABOVE SEA FLOOR.
EXPOSED ROCKY REEF SHOWING LINEATION (JOINTING, BEDDING).
COARSE SAND / FINE GRAVEL FACIES, (SHELL).
SAND
UNIFORM AREAS ON RECORD REPRESENTING FINE - MEDIUM SAND FACIES.
1m
RIPPLE AREST LINES WITH RIPPLE WAVELENGTH.
3m
SAND WAVE LONGITUDINAL AXIS WITH TRANSPORT DIRECTION AND WAVELENGTH
TO ACCOMPANY THESIS BY T.R. LLOYD, 1985
N
0 100 200 300 400 500
SCALE : 1: 10 000
SAND
18 m
BAR EXTENT
POINT DANGER
STN. 02A.
STN. RAINBOW BAY
STN. GREENMOUNT POINT
KIRRA POINT
STN. 18
ETA 10
TWEED RIVER
LETITIA SPIT
COOK IS.
STN. FINGAL HILL
2m
8m
1m
4m
3m
31 000 E
30 000 E
29 000 E
28 000 E
27 000 E
26 000 E
25 000 E
24 000 E
21 000 N
20 000 N
19 000 N
18 000 N
17 000 N
16 000 N
15 000 N



MAP 7
CURRENT TRACER VECTORS - POINT DANGER AREA
LEGEND
SURFACE
5 m DEPTH
10 m DEPTH
0·6 ms⁻¹.
EXTENT OF SURFACE FLUME
15-8-85 -
16-8-85
TO ACCOMPANY THESIS BY T.R. LLOYD, 1985
0 100 200 300 400 500 METRES
SCALE : 1:10 000
N
POINT DANGER
STN. 02A
STN. RAINBOW BAY
STN. GREENMOUNT POINT
KIRRA POINT
STN. 18
ETA 10
TWEED RIVER
LETITIA SPIT
COOK ISLAND
STN FINGAL HILL
31000 E
30 000 E
29 000 E
28 000 E
27 000 E
26 000 E
25 000 E
24 000 E
21 000 N
20 000 N
19 000 N
18 000 N
17 000 N
16 000 N
15 000 N

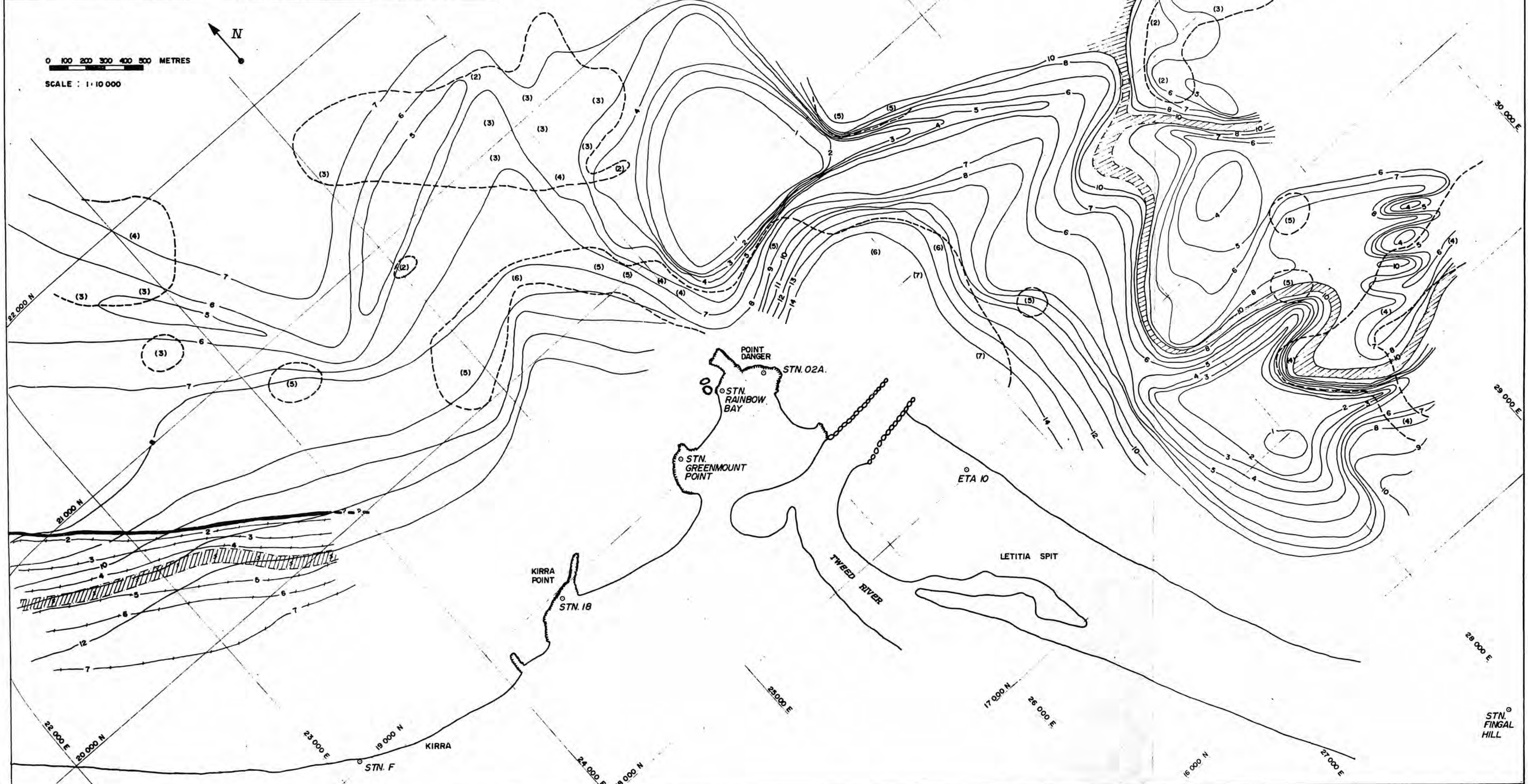
MAP 8

OFFSHORE SEISMIC STRATIGRAPHY ISOPACH MAP - POINT DANGER AREA

LEGEND

- OFFSHORE EXTENT OF REFLECTOR A.
- ISOPACH CONTOURS - REFLECTOR A. (m)
- (5) LOCAL EXTENT OF DISCONTINUOUS FIRST REFLECTOR A', WITH SPOT THICKNESS (m) OF OVERLYING SURFICIAL SAND, (SEQUENCE I OR II).
- ISOPACH CONTOURS - PLEISTOCENE SURFACE - EITHER REFLECTOR B OR C. (m)
- CHANNEL SYSTEM ASSOCIATED WITH PLEISTOCENE SURFACE.
- AXIS OF DIFFERENTIAL COMPACTION / CHANNEL SYSTEM WITHIN SEQUENCE II.
- ONSHORE SURVEY STATIONS.

TO ACCOMPANY THESIS BY T.R. LLOYD, 1985



MAP 9

SURFACE SEDIMENT DISTRIBUTION–POINT DANGER AREA

LEGEND

INNER NEARSHORE SANDS

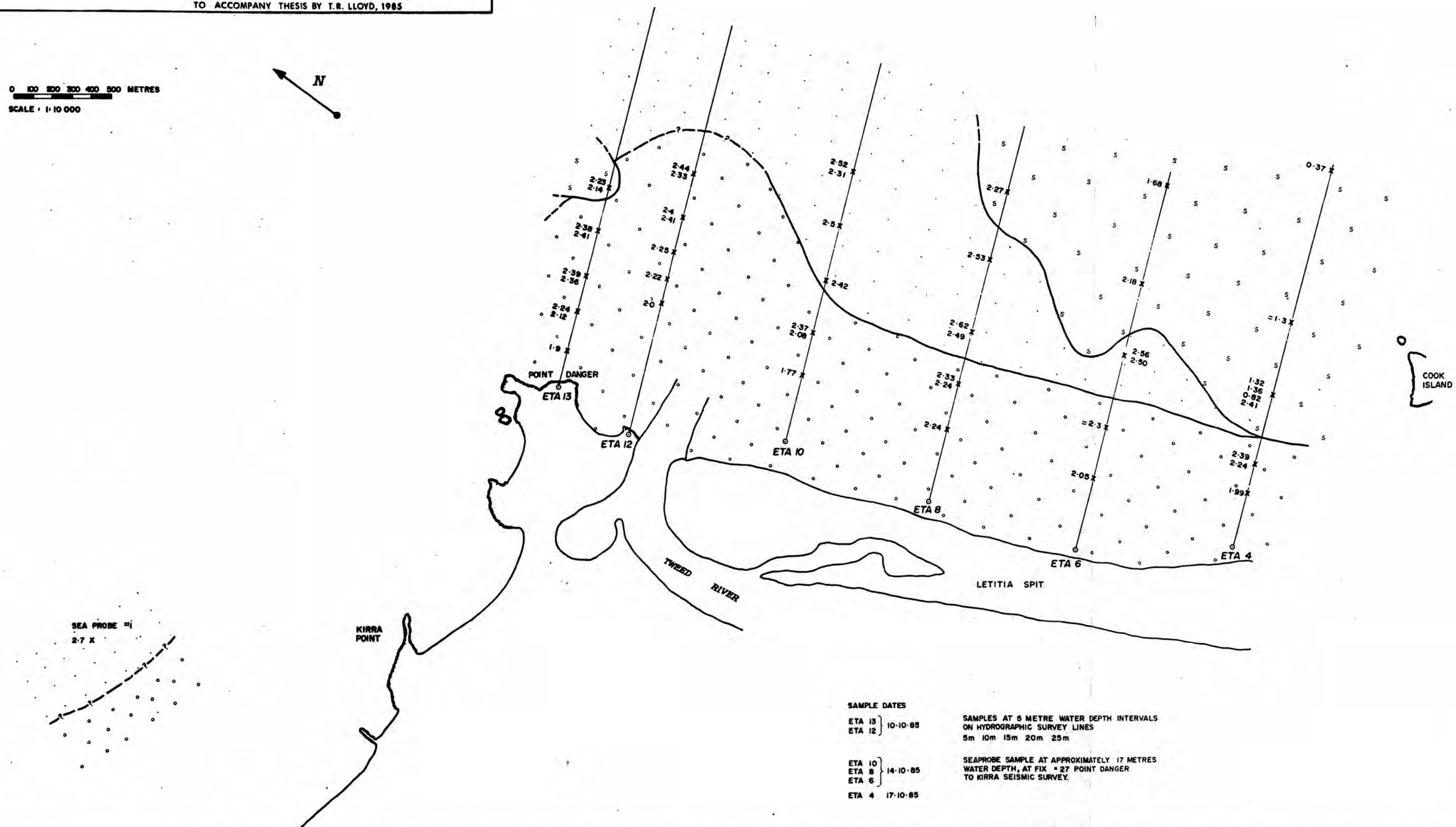
OUTER NEARSHORE SANDS

SHELLY SANDS - ASSOCIATED WITH SUBMARINE ROCKY "REEF"
FOR DISTRIBUTION OF COARSE SHELL FACIES SEE MAP 6.

ETA 10 — HYDROGRAPHIC SURVEY LINES (GOLD COAST CITY COUNCIL).

2·56
X 2·50 — SURFACE SEDIMENT SAMPLE WITH GRAPHIC MEAN OF DIFFERENT SEDIMENT LAYERS. (φ).

TO ACCOMPANY THESIS BY T.R. LLOYD, 1985



SAMPLE DATES

ETA 13, ETA 12 — 10·10·85

ETA 10, ETA 8, ETA 6 — 14·10·85

ETA 4 — 17·10·85

SAMPLES AT 5 METRE WATER DEPTH INTERVALS ON HYDROGRAPHIC SURVEY LINES
5m 10m 15m 20m 25m

SEAPROBE SAMPLE AT APPROXIMATELY 17 METRES WATER DEPTH, AT FIX #27 POINT DANGER TO KIRRA SEISMIC SURVEY.

APPENDIX 4

REGIONAL HYDROLOGY OF THE TWEED VALLEY

Dr. R. Nittim
Water Research Laboratory
The University of New South Wales

January 1983

REGIONAL HYDROLOGY OF THE TWEED VALLEY

Daily flow records were obtained from the Water Resources Commission for the following gauging stations:

No.	Station	Area km^2	Record Yrs
201 002-5	Rous R. at Boat Harbour 1,2	117	32
201 001	Oxley R. at Eungella	213	37
201 003	Tweed R. at Braeside	298	16

Annual flood series were extracted from the record and flood frequency curves plotted. These were extrapolated by eye to give the estimated 50 and 100 year floods.

Multiple regression analysis was attempted to predict discharge from catchment area, median annual rainfall and median catchment height. However, it was found that the last two variables were insignificant. Accordingly, power curves of the type

$$Q = aA^{b}$$

were fitted to the data.

The prediction equations for the 20, 50 and 100 year floods are:

$$Q_{20} = 32.23\ A^{0.73}$$

$$Q_{50} = 38.83\ A^{0.74} \qquad r^2 = 0.86$$

$$Q_{100} = 38.83\ A^{0.76} \qquad r^2 = 0.85$$

Annual flood series are given in Tables 1 to 4 and the flood frequency curves in Figures 1 to 4.

TABLE 1

Oxley River at Eungella No. 201 001

Catchment area	213 km^2
Length of record	37 years
1947 - 1957	Staff gauge
1957 - To date	Recording gauge

Rank	Date	Peak Flow m^3/s	Return Period Years
1	Feb 1954	1412	36
2	Feb 1956	1308	18
3	Mar 1974	1285	12
4	Jun 1967	1157	9.0
5	Feb 1972	1050	7.2
6	Apr 1955	994	6.0
7	Feb 1959	794	5.1
8	Jul 1965	744	4.5
9	Jun 1948	716	4.0
10	Mar 1978	716	3.6
11	Feb 1976	714	3.3
12	Jun 1950	699	3.0
13	Jul 1962	696	2.8
14	Dec 1970	690	2.6
15	Jan 1951	677	2.4
16	Jan 1963	624	2.3
17	Feb 1973	595	2.1
18	May 1980	524	2.0
19	Jun 1958	524	1.9
20	Jan 1968	510	1.8
21	Feb 1961	429	1.7
22	Jan 1982	324	1.64
23	Feb 1971	294	1.57
24	Mar 1949	284	1.50
25	Jan 1979	279	1.44
26	Feb 1952	209	1.38

TABLE 2

Tweed River at Kunghur No. 201 004.

Catchment area	49 km^2
Length of record	27 years
1954 - To date	Recording gauge

Rank	Date	Peak Flow m^3/s	Return Period Years
1	Mar 1974	297	26
2	May 1963	289	13
3	Mar 1955	188	8.67
4	Feb 1976	185	6.5
5	Mar 1978	182	5.2
6	Feb 1971	175	4.3
7	May 1980	156	3.7
8	Jul 1962	155	3.25
9	Feb 1973	152	2.9
10	Dec 1970	141	2.6
11	Jan 1979	128	2.36
12	Mar 1967	122	2.17
13	Mar 1975	113	2.00
14	Jul 1965	110	1.86
15	Oct 1972	94.9	1.73
16	Jan 1968	90.6	1.63
17	Feb 1981	90.3	1.53
18	Jun 1966	86.1	1.44

TABLE 3

Annual Flood Series.

Tweed River at Braeside No. 201 003.

Catchment area 298 km^2
Length of record 16 years
1951 - 1968 Staff gauge

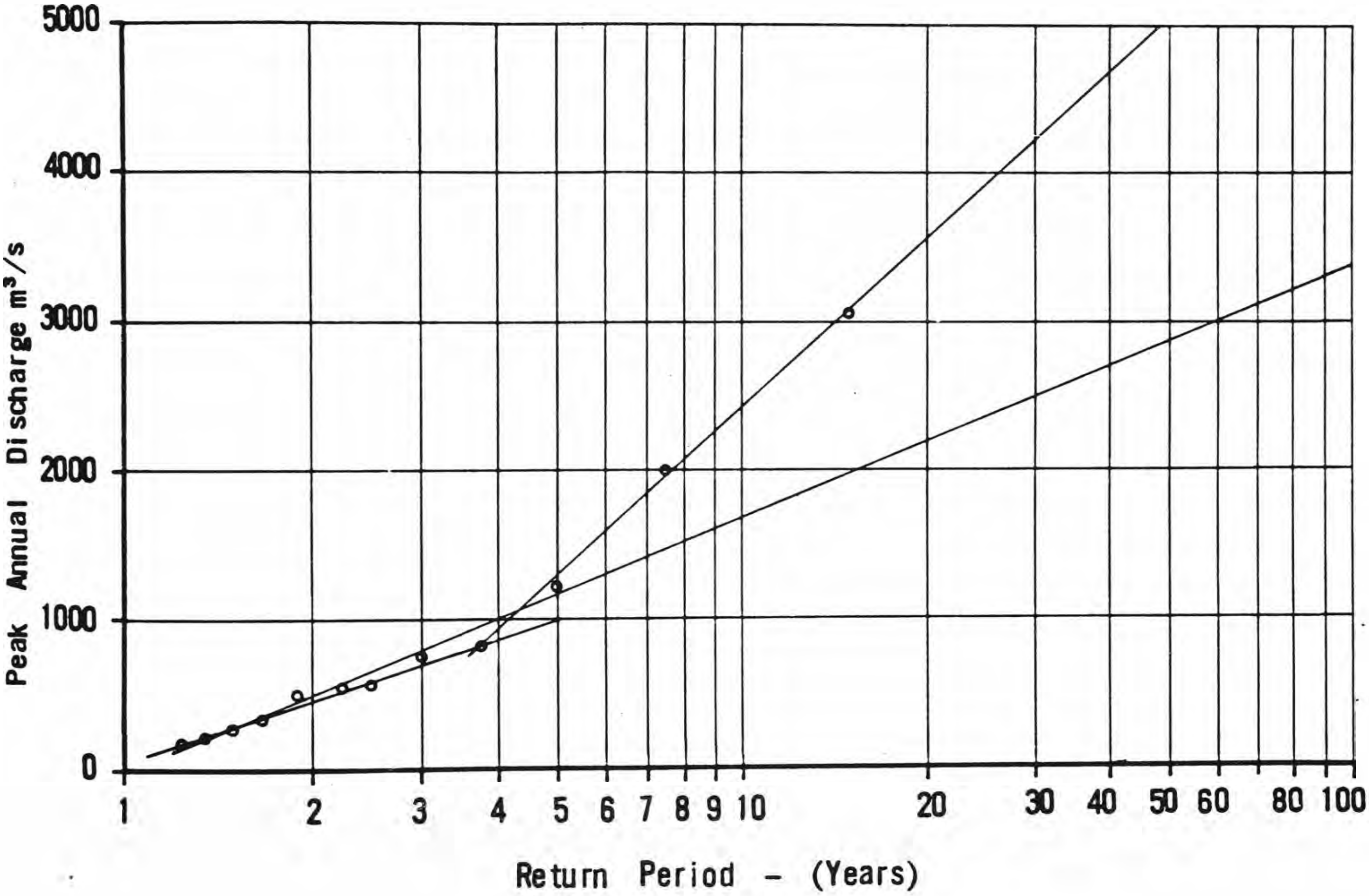
Rank	Date	Peak Flow m^3/s	Return Period Years
1	May 1963	3110	15
2	Feb 1954	1980	7.5
3	Mar 1955	1450	5.0
4	Jul 1962	818	3.75
5	Jun 1967	736	3.0
6	Mar 1959	566	2.50
7	Jul 1965	532	2.14
8	Jan 1968	493	1.88
9	Feb 1961	334	1.67
10	Jun 1966	247	1.50
11	Feb 1953	212	1.36
12	May 1956	172	1.25

TABLE 4

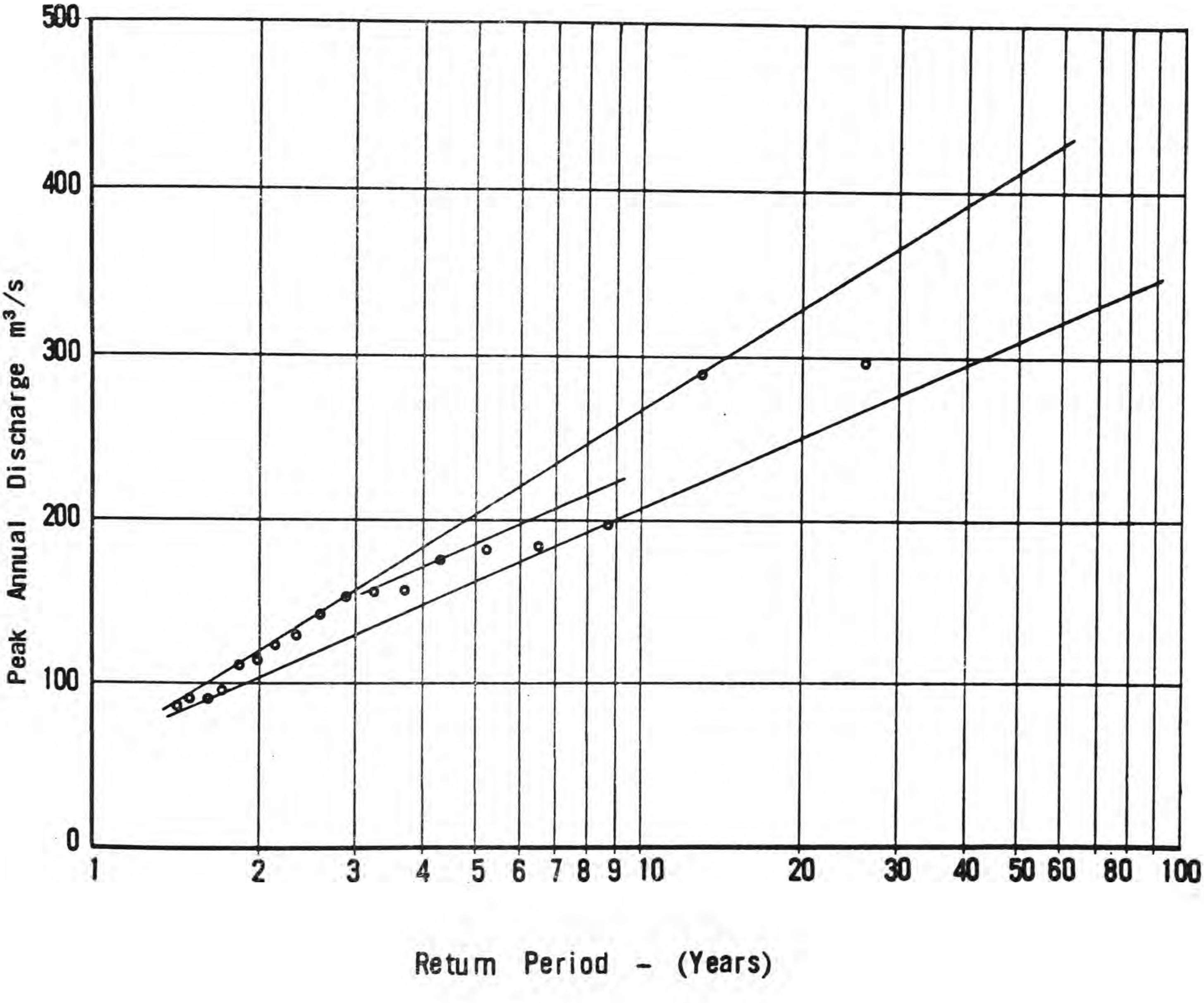
Rous River at Boatharbour 1,2 No. 201 002-5.

Catchment area	117 km^2
Length of record	32 years
1947 - 1957	Boatharbour 1 Staff gauge
1957 - To date	Boatharbour 2 Recording gauge

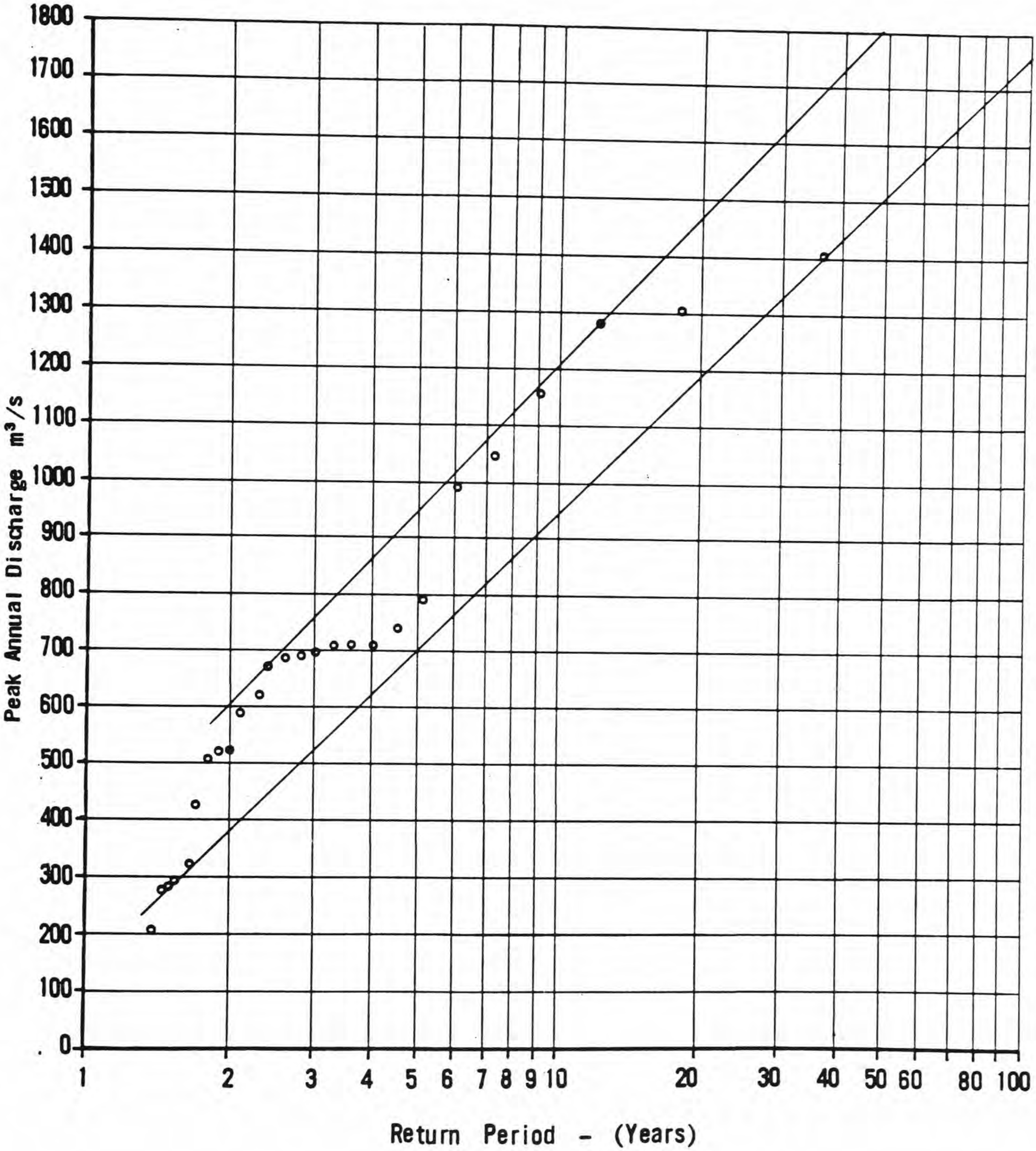
Rank	Date	Peak Flow m^3/s	Return Period Years
1	Feb 1956	1170	31
2	Apr 1955	1110	15.5
3	Oct 1972	904	10.3
4	Feb 1954	850	7.8
5	Mar 1970	834	6.2
6	Jun 1967	795	5.2
7	Mar 1953	773	4.4
8	Jul 1965	750	3.9
9	Mar 1963	731	3.4
10	Jan 1974	670	3.1
11	Feb 1973	620	2.8
12	Feb 1959	617	2.6
13	May 1980	583	2.4
14	Jun 1958	557	2.2
15	Jul 1962	497	2.1
16	Dec 1970	456	1.9
17	Feb 1979	368	1.8
18	Feb 1976	314	1.7
19	Jan 1951	289	1.6
20	May 1981	243	1.55
21	Jun 1950	240	1.48
22	Nov 1961	207	1.41
23	Jan 1956	169	1.35
24	Mar 1977	167	1.29



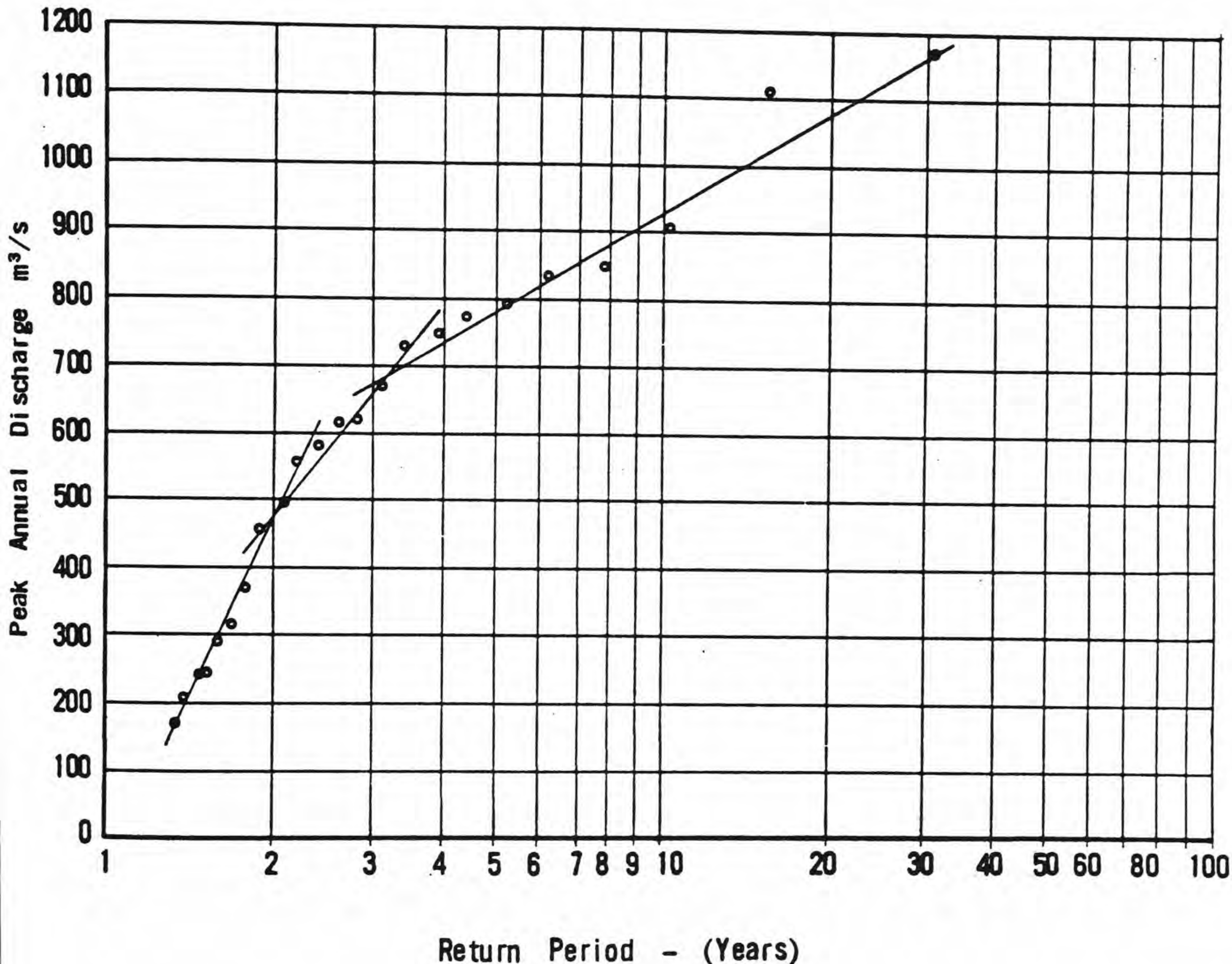
TWEED RIVER AT BRAESIDE. FIG. 1



TWEED RIVER AT KUNGHUR. FIG. 2



OXLEY RIVER AT EUNGELLA. FIG. 3



ROUS RIVER AT HARBOUR 1 & 2 FIG. 4

APPENDIX 5

TWEED REGION DATUM

TWEED REGION DATUM

The datum used traditionally in the Tweed Region has been a low water datum.

The PWD has adopted the Tweed River Hydrographic Datum (TRHD) which is essentially Indian Springs Low Water (ISLW).

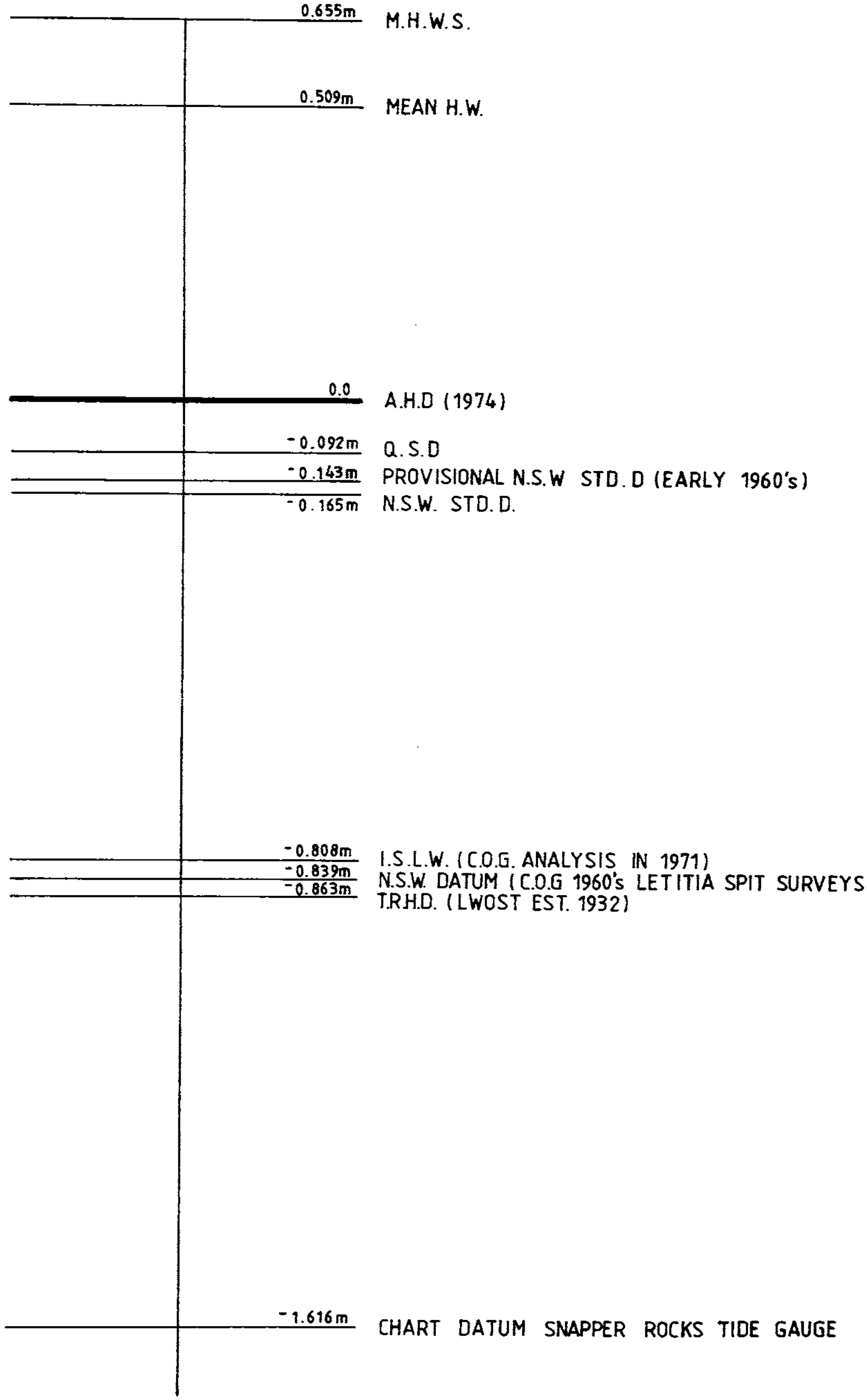
Up until the late 1970's, the GCCC used the Queensland State Datum which is a Mean Sea Level (MSL) datum. Recently they have adopted the Australian Height Datum (AHD) established in 1974.

The BPA also use the Australian Height Datum having previously used the State Datum.

There are a number of areas of uncertainty in the relationships between the various datum. However, the most consistent relationship is that presented as Figure 1. This has been derived from information held by the PWD on their file PWD T/211 and from the various survey plans. There are a number of points to note however.

Tweed Hydrographic Datum was instituted for the 1971 hydrographic survey. This datum is a low water datum set relative to a permanent mark in Tweed Heads (PM3). The level of this mark was transferred from PM5. The level of PM5 was set relative to Low Water Ordinary Spring Tide (LWOST) by surveyor Head in 1955. LWOST was established in 1932 by surveyor Moody. The Local Indian Springs Low Water (ISLW) was established from a 4 month tidal analysis in 1971 by the COG. This set ISLW above LWOST. For a number of surveys in the early 1970's the 0.055 m difference between ISLW and LWOST was ignored.

The Letitia Spit accretion surveys were to either Queensland State Datum (QSD) or a NSW Datum (unspecified). The quoted difference between these on COG plans (SC735) is 2.45 ft. This difference does not correspond to any known NSW datum, and so it has been assumed that the NSW datum referred to was LWOST (or TRHD). The 0.024 m error in this assumption may be due to survey error, but this has not been verified.



TWEED REGION DATUM

FIGURE 1

A tide board recently installed by the BPA at the site of the recorder used in 1971 for tidal analysis (approximately 100 m upstream of the Tweed Regional recorder) was surveyed by the GCCC in 1985 and was found to be at TRHD. The December 1960 Tweed River Soundings by Mr. R.M. Engel show ISLW as the datum, but the levels quoted for the benchmark (PM3) is to TRHD (or LWOST).

The datum used for the various hydrographic surveys are listed below.

Survey	Datum
Letitia Spit Accretion 1962-1970	LWOST (TRHD)
Letitia Spit Accretion (COG)	QSD
1960 Tweed River Soundings	ISLW (TRHD)
1971 Tweed River Hydrographic Survey	TRHD
PWD Ebb Delta (1978-1986)	TRHD
PWD Tweed River (1976-1986)	TRHD
BPA ETA Lines	QSD
GCCC Lines to 1974	QSD
GCCC Lines since 1974	AHD
This Study	AHD

APPENDIX 6

List of aerial photographs covering the study area

In addition to the list of vertical aerial photographs held by the various authorities given below, numerous oblique aerial photographs are held by the P.W.D. (dating from the 1950's), the G.C.C.C. (dating from 1972) and the WRL.

VERTICAL AERIAL PHOTOGRAPHS.

DATE	FLIGHT	RUN	PHOTO No.	SCALE
13. 8.1930	-	21	98 - 99	-
2. 4.1946	Springbrook - Tweed Heads SVY 599	1	20, 23	-
27. 5.1947	SVY 122	2	406, 407	-
30. 8.1950	Springbrook	-	-	-
4. 1.1955	Springbrook - Tweed Heads CAB 14 5087	5	87 - 115	-
21. 4.1956	Eight Mile Plains - Boyds' Pt. Bridge	-	-	-
25. 5.1959	Pacific H'way - Inland Route Mudgeeraba Termora Pt.	-	-	-
18. 5.1961	Jumpinpin - Fingal	-	-	-
1. 9.1961	Springbrook	9	1184 - 29	-
24. 8.1962	N.S.W. 1159	-	5207, 5208, 5237, 5238	1:15,700
12.10.1962	Fingal Pt. - Jumpinpin	-	-	-
31. 8.1963	Springbrook - Tweed Heads CAB 261	5	5132	-
20. 9.1963	Kirra - Jumpinpin	-	-	-
10. 2.1966	N.S.W. 924	1	5067, 5068	1:16,000
17. 6.1967	Gold Coast - Tweed Hds - Southport	-	-	-
1. 7.1967	Erosion	-	-	-
13. 8.1967	Moreton Bay and Adjoining Mainland	-	-	-
18. 1.1969	Harbours and Marine Gold Coast	-	-	-
10. 4.1969	G.C.C.C. Coolangatta	-	-	-
16. 5.1969	M.R.D. Gold Coast H'way, Tamair	-	-	-
11. 1.1970	N.S.W. 1645	6	5185, 5187	1:40,800
10. 5.1971	N.S.W. 1948	1	5182, 5183, 5150, 5151	1:9,700
17. 4.1973	N.S.W. 2138	1	5218, 5219	1:40,000
10. 7.1973	Pt. Dangar - Inskip Pt. Storm Damage	-	-	-
27. 9.1973	BPA Tweed Heads - Urangan	-	-	-
2. 2.1974	South Coast Flooding	-	-	-
13. 2.1974	Noosa - Tweed Coastal Erosion	-	-	-
17. 5.1975	Murwillumbah 9541 1-1V	4	2958	-
18. 6.1975	N.G.M. 211	1	7409 - 7418	1:7,000
2.12.1976	N.S.W. 2422	1	37 - 39	1:40,000
30. 4.1977	QASCO	3	5999 - 6002	1:14,800
1. 6.1977	N.S.W. 2453	1	143 - 153	1:4,000
11. 5.1979	N.S.W. 381	1	6915 - 6916	1:15,000
24. 5.1979	BPA Tweed Heads - Urangan	2	3114	-
17.11.1980	N.S.W. 3035	-	015 - 017	1:15,000
10. 2.1983	Airesearch City of Gold Coast	10	227 - 233	1:10,000
28. 8.1983	Sunmap S.E. Queensland	15-98	-	1:12,500
6. 5.1985	J.A. Harris - Tweed Bar	1	6234 - 6238	1:12,000