THE HISTORY OF DREDGING IN CLEVELAND BAY, QUEENSLAND AND ITS EFFECT ON SEDIMENT MOVEMENT AND ON THE GROWTH OF MANGROVES, CORALS AND SEAGRASS

TOWNSVILLE PORT AUTHORITY

Great Barrier Reef Marine Park Authority
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THE HISTORY OF DREDGING IN CLEVELAND BAY, QUEENSLAND AND ITS EFFECT ON SEDIMENT MOVEMENT AND ON THE GROWTH OF MANGROVES, CORALS AND SEAGRASS.

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EXECUTIVE SUMMARY

Aims

The aims of this project on Cleveland Bay were to investigate:

1) the history of dredging using all available Townsville Port Authority records and records from other relevant sources; attention was to be focussed on the location of dredging and dumping and the types of material involved,

2) coastal changes as revealed by aerial surveys between 1941 and 1988 and a more limited number of replicate ground surveys,

3) processes influencing sediment movement both in the coastal catchments which supply sediment to the bay, and in the marine zone,

4) the relationship between dredging and the coastal changes identified on the aerial photographs and ground surveys, taking into account processes in the coastal catchments and the marine zone.

Dredging Records

These are examined chronologically from the small scale beginnings of dredging in 1883 when the port of Townsville was starting to emerge, through its important role in the port's subsequent development. For further consideration the records were grouped into two time periods:

1883-1964 Only intermittent data are available concerning localities, depths and quantities dredged. Additional problems arise from the use of different volume units which proved impossible to convert, and a severe shortage of dump site information. The only written records relate to dumping near Cockle Bay, Magnetic Island in 1883 and 1893, and verbal information suggests that dumping south of Middle Reef occurred before the mid 1960's. More lithified dredge spoil from developmental dredging especially in the harbour area would be less liable to redistribution from the dump sites than is the unconsolidated finer sediment from subsequent maintenance dredging. Some of the latter has probably been moved by currents (although only a partial knowledge of these exists at present) onto the south-west Magnetic Island coral reef flat.

1965-1988 From 1965 onwards Townsville Port Authority dredging records give details of each dredged load including source. The data have been tabulated to show monthly and annual totals dredged from different parts of the port and approach channel; graphs have been drawn also from this data. During a massive programme of developmental and maintenance dredging in the early and mid 1970's the annual maximum reached 2,112,879 tonnes in 1973-74. A shallow draft dump site south-east of Magnetic Island has been used since the 1960's and a deep draft dump site east of Magnetic Island since the early 1970's. Fine sediment from the 1970's developmental dredging which was dumped mainly at the latter site was probably extensively redistributed by currents.

Coastal and Nearshore Zone Changes

Vertical aerial surveys at various scales and time intervals between 1941 and 1988 were analyzed to determine coastal and nearshore zone changes. The longer time intervals, up to a 17 year maximum, during the 1940's, 1950's and 1960's contrast with the regular 3-4 year interval between surveys in the 1970's and 1980's. The surveys selected for analysis were those which provided an extensive cover of the Cleveland Bay area, most commonly at a scale of 1:12,000 and which show clearly coastal and nearshore features. The Cleveland Bay and Magnetic Island coasts were divided into segments for analysis and assessment of change in the physical features, mangroves, fringing coral reefs and seagrass beds. Several of these segments showed relatively little change during this period. The most marked changes occurred along the Ross River delta segment; at localities where seagrass beds are found in the intertidal and subtidal zones off Shelly Beach-Cape Pallarenda, Sandfly Creek-Cape Cleveland and the south-west coast of Magnetic Island; and in the mangrove fringe of this same Magnetic Island segment.

Coastal ground surveys have been much more limited in scope and frequency than the aerial surveys. Replicate surveys by the Beach Protection Authority in 1982 and 1983 along the Cleveland Bay coast west of Townsville Harbour and along parts of the south-east and north coasts of Magnetic Island were studied, as were 6 replicate surveys by the Townsville Port Authority between 1978 and 1983 along cross profile lines between Townsville Harbour and Cape Pallarenda. Only small scale vertical changes (0.1-0.2m accretion or erosion) were revealed by these surveys.

Processes Influencing Sediment Movement

In order to assess the possible effect of dredging on these coastal and nearshore zone changes the processes influencing sediment movement are reviewed. Within the coastal catchments, geology, climate and river regime are considered as the main influences on natural sediment supply to the coast. Man's intervention through engineering works, such as dams and weirs and by pollution are examined also. Marine processes relating to wind, wave and tidal effects are assessed in so far as they influence sediment movement over the sea bed and in suspension.

Relationship between Dredging and Coastal Change

The most direct effect of dredging has been shown near the mouth of Ross River. Here 2,319,660m^3 of sand were removed from the intertidal sandbanks between 1968 and 1970 and a further 400,000m^3 were removed from the nearby Ross River bed in 1979-80 for adjacent land reclamation. More sand was removed during developmental dredging in the Ross River channel between 1977 and the early 1980's and during subsequent maintenance dredging. Two effects have resulted. Firstly the channel has been moved westwards from its previous natural route across the intertidal zone, which has affected the sedimentation pattern. Secondly this sediment which has been shown to be heavily polluted from the former sewage outfall on the east side of the Ross River mouth has been used in land reclamation and some has been carried to the shallow draft dump site south-east of Magnetic Island from where it will have been redistributed in response to current movements.

Dredging probably produced its greatest and most widely felt effect in the early to mid 1970's, although this is more difficult to demonstrate as it occurred at the same time as major natural events. During this period there was a massive programme of developmental as well as routine maintenance dredging. The highest monthly peak rose to over 118,000 tonnes in October 1972. The maximum annual peak of over 2,000,000 tonnes in 1973-74 is equivalent to nearly two thirds of the Burdekin River's estimated averge washload plus bedload of 3.45 million tonnes. The predominantly fine dredged sediment was dumped mainly in the deep draft dump site, but with some in the shallow draft dump site, and after redistribution by currents, it probably had a marked adverse effect on the Cleveland Bay seagrass beds. The aerial surveys showed a moderate seagrass cover in 1959 and 1961, almost no seagrass in 1974, but recovery beginning by 1978 and continuing through 1981 to 1985. A gap in appropriate aerial surveys in the 1960's and early 1970's makes pinpointing the time of the seagrass destruction difficult. However it is likely to have occurred in the early 1970's when the massive dredging programme coincided with the occurrence of Cyclones 'Althea' and 'Una' and subsequent periods of heavy rain. These produced major floods down the rivers leading into Cleveland Bay and down the Burdekin River which also can affect the bay at such times. The massive influx of sediment from dredging and river floods probably produced extensive burial of seagrass beds. It also may have contributed to mangrove deaths noted along the south-west Magnetic Island coast during this period.

Future Assessment of Dredging Effects

To assess dredging effects in Cleveland Bay more precisely in the future further monitoring and research is proposed:

- detailed recording of localities of dredging, amounts and types of material dredged and localities of dumping; further observation of dredge spoil plumes under different wind, wave and tidal conditions,

- more detailed instrumental measurements of tides, tidal currents, regional winds and waves to provide a better understanding of processes affecting sediment movements,

- monitoring of all major types of coastal change considered in this report and analysis of the recorded changes in the light of the controlling processes and the dredging programme.

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INTRODUCTION

Aims

This report investigates the history of dredging in Cleveland Bay and aims to assess its influence on sediment movement and on the growth of mangroves, fringing coral reefs and seagrass. The history of dredging will be traced from its small scale beginnings in 1883, when the port of Townsville was starting to emerge, through its important role in the subsequent development of the port. Attention will be focused on the location of dredging, the amount and types of material dredged and the dump sites used for its disposal. All available Townsville Port Authority records have been used, together with records from the Queensland Department of Harbours and Marine (and its predecessors) and Port of Brisbane Authority, in so far as they relate to dredging in the Port of Townsville.

Assessment of the influence of dredging will be made in relation to changes identified on a series of aerial surveys flown between 1941 and 1988. Changes shown on a limited number of replicate coastal ground surveys, carried out by the Beach Protection Authority and the Townsville Port Authority, will be considered also. Such an assessment must take into account the natural processes operating in the area. Here the processes operating in the coastal catchments relating to geology, climate, and river regime will be examined in so far as they influence fluvial sediment supply to the coast. Man's intervention in the natural sediment supply system and his pollution of parts of it will be considered as well. Marine processes relating to wind, wave and tidal conditions will be examined, concentrating especially on their effects on sediment movement both over the sea-bed and in suspension.

Because of limitations in the earlier dredging records between 1883 and 1964 only a broad general assessment of the effects of dredging can be made for this period. The existence of much more detailed dredging records and data relating to processes enables a more detailed assessment to be made for the subsequent period between 1965 and 1988. Separate consideration will be given then to coastal and intertidal zone changes, and changes to the mangrove coasts, the fringing coral reefs and the seagrass beds, which extend from the intertidal zone into adjacent parts of the subtidal zone.

Cleveland Bay Area

Cleveland Bay located at about latitude 19°S, is approximately 17km square and faces north-eastwards to the Coral Sea (Figure 1). On its north-west side is Magnetic Island which is separated from the adjacent mainland by the narrow and shallow West Channel. The 15m isobath lies across the entrance to the bay with the 10m isobath approximately parallel to it on its landward side. A channel, which Carter and Johnson (1987) named Orchard Channel, runs parallel to the north-east coast of Magnetic Island and these isobaths swing south round it. The central and southern parts of the bay slope gently landwards. West Channel in its shallowest central part is under 4m depth with the elongated Middle Reef rising above Low Water Mark (LWM) on its south side. Townsville Harbour has been sited on the south-west coast of Cleveland Bay with the artificial Platypus Channel, the main approach channel for shipping, extending northwards from it and terminating in the dog-leg Sea Channel off the south-east coast of Magnetic Island.

The coast of Cleveland Bay is mainly depositional in type but with the granite and volcanic rock headlands of Cape Pallarenda and Cape Cleveland bounding it on its western and eastern sides repectively, and Kissing Point forming a low granite promontory on the south-west coast. Seagrass has colonized on an intertidal and subtidal foreland north of Cape Pallarenda. A series of beach ridges flank the west coast of the bay, which has a narrow sand beach backed by low sand dunes. The south-east coast between Kissing Point and

Townsville harbour is backed by an artificial wall of large rocks to protect The Strand in Townsville from coastal erosion, and only a narrow sand beach lies at its foot. The mouths of Ross River and its distributary Ross Creek now form part of the Port of Townsville with the harbour extending seawards between them. Previously this area was part of the aggrading Ross River delta, which extends westwards to the mouth of Sandfly Creek. A series of beach ridges have developed here as the coast extended seaward. Further east, along the south coast of Cleveland Bay a beach ridge and chenier plain has formed north of the Muntalunga Range, with narrow sand ridges interspersed by salt flats with saltmarsh along their margins. Alligator, Crocodile and Cocoa Creeks flow in meandering courses across this plain. Along the whole coast eastwards from near the Ross River mouth to the southern end of Cape Cleveland a strip of mangroves straddles High Water Mark (HWM) and is flanked by an intertidal zone of fine silty sand. Along the west coast of Cape Cleveland, rock headlands separate sandy bayhead beaches, with mangroves colonizing in the most sheltered localities. In the lower part of the intertidal zone and the adjacent part of the subtidal zone along the south and east coasts of the bay, extensive seagrass beds have developed.

The triangular shaped Magnetic Island is formed mainly of granite with volcanic rocks outcropping near West Point. The north and south-east facing coasts consist of rock headlands, with bays between containing sandy bayhead beaches. In the most sheltered localities fringing coral reefs have formed and these are best developed in Geoffrey, Nelly and Picnic Bays on the south-east coast. The south-west coast flanks West Channel and gains maximum shelter from the prevailing south-east winds and waves. Here the largest fringing coral reef is found and landwards a belt of mangroves has developed near HWM. Seagrass grows in sediment on the reef flat.

Units of Measurement

Inevitably in records such as those relating to dredging which span a period of over 100 years, different units have been used at different times. In addition to imperial and metric units which may be converted readily, other units, eg barge yards, were used, the precise meaning of which has proved impossible to determine. For uniformity of treatment within Chapter 1 concerned with the 'History of Dredging in Cleveland Bay' the original units are retained as used in the Townsville Port Authority records and in the various reports and books referred to. This also should assist those readers who wish to refer back to the source material. Elsewhere in the report, in the text, tables and figures metric measurements are used except where conversion proved impossible.

CHAPTER 1

History of Dredging in Cleveland Bay

The history of dredging in Cleveland Bay is closely linked to the development of the Port of Townsville. In 1864 (Department of Harbours & Marine Queensland,1986) J.M. Black, North Queensland Manager of the Sydney firm of Robert Towns and Company selected a site on Ross Creek for a harbour needed in the development of pastoral properties in the hinterland. However, a sand bar at the mouth of Ross Creek and a rock bar inside allowed only shallow draught vessels to enter at H.W. The amount of shipping in Cleveland Bay doubled between 1867 and 1868 with the opening up of the Cape River goldfield. It was subsequently proposed in 1876 that, in the absence of a suitable site on Ross Creek, a jetty should be built from Magazine Island to form the basis of a good harbour for Cleveland Bay and also to protect the entrance to Ross Creek. The difficult work on this progressed slowly in the late 1870's and early 1880's. At the same time a western breakwater was being constructed seaward to protect, and stop sand moving into, Ross Creek from that side. The extent of the harbour works in 1885 are shown on Nisbet's Plan (Taylor, 1980) (Figure 2).

1878-1890

Dredging was first proposed in 1878 (Annual Reports of the Engineer of Harbours and Rivers on Works, 1876-1928) to 15-16ft below L.W. along the inside of the jetty and seaward. In 1879 dredging was proposed in the Outer Harbour and also to 18ft below L.W. in an approach channel 3,000-4,000ft long aligned north to south. No silting was observed along the jetty between 1880 and 1883 but dredging to increase the water depth was again suggested. On 13 November 1883 the dredge 'Platypus' from Brisbane began cutting a channel into

Ross Creek from Magazine Island Jetty in 12 ft of water at L.W. "The material dredged is deposited close to Magnetic Island, about $5^1/2$ miles distant from where it is raised". The material was mainly clay with sand and mud on top. The 'Platypus' continued to dredge this channel to 13ft below L.W. from 1883 to 1887 and it was named the Platypus Channel. In 1885 it was noted that a "light coating of sludge accumulated" after dredging but no sand was deposited. In November 1887 the 'Platypus' was sent to Cairns and replaced by the dredge 'Octopus' from Brisbane, which continued dredging the channel towards the rocks in the mouth of Ross Creek through"extremely hard material".

After completing the channel in 1889 the 'Octopus' began excavating a mooring basin in the shelter of the Eastern Breakwater in "hard material", but soft sandstone gave way to clay with increasing depth. In Ross Creek in 1890, 14,154cu yards of material dredged from the planned swing basin was transferred landwards for reclamation of the Palmer Street frontage. A cyclone in March 1890 caused the deposition of an "appreciable quantity" of silt over the dredged areas, and a subsequent flood down Ross River carried much sand and "levelled and distributed sandbanks" at the inner end of the dredged channel.

1891-1900

In May 1891 the 'Octopus' continued excavating the basin in the lee of the Eastern Breakwater. The earlier dredged areas had silted up considerably with "sludge and soft mud", but it could be removed relatively easily. The near completion of the Western Breakwater caused accelerated scour in the dredged channel and no further silting occurred there. On 24 January 1892 a gale (probably associated with a cyclone) produced "heavy seas" followed by "heavy floods" down Ross Creek, which caused rapid siltation between the breakwaters and east of the Eastern Breakwater. The previously dredged channel depth of 10ft below L.W. was reduced to 4ft, for a "considerable length". Dredging of the basin in "difficult material" (sandstone, very tenacious clay and mud) was almost complete in 1892 but re-dredging of the channel was needed. In 1892 it was noted that "The cost of carrying has ... been less, but this item will possibly be slightly greater in the coming year as all the dredgings will be carried to Cockle Bay, in Magnetic Island, it not being advisable to deposit any eastward of the Eastern Breakwater". The dredging plant in commission in June 1892 was the dredge 'Octopus', the two steam hopper barges 'Nautilus' and 'Dugong' and three side-delivery barges. The berth at the railway wharf was excavated that month to 18ft below L.W.

Both developmental and maintenance dredging were carried out between 1893 and 1901 (Annual Reports of the Marine Department, 1894-1933; and Report of the Portmaster on the Department of Ports and Harbours of Queensland 1882-1883). In 1894 the basin near the railway wharf was deepened, but gales in April led to floods which caused silting. Further developmental dredging in all parts of the harbour was undertaken in 1894-95, but between January and August 1885 maintenance dredging was necessary to remove soft mud which had accumulated in all the previously dredged areas. The Inner Harbour, in Ross Creek, had been subject to rapid silting of 6in/month at the wharf and 2-3in/month in the entrance channel; 25% of the dredge's time was taken up in clearing this. In 1895, the 'Octopus' was altered to enable her to dredge to 30ft instead of 24ft as previously.

On 18 December 1896 the Queensland Department of Harbours and Rivers formally handed over the dredge 'Octopus', the two steam hopper barges 'Nautilus' and 'Dugong' and silt punts numbers 26, 29 and 30 to the Townsville Harbour Board, which thereafter was responsible for dredging at the port. A considerable amount of maintenance dredging was necessary during 1896-97, following Cyclone 'Sigma' in January 1896 and a subsequent flood down Ross Creek, which deposited much sediment in the harbour especially towards the outer end of the Eastern Breakwater (Department of Harbours and Marine Queensland, 1986).

In 1897, a scheme was put forward for harbour improvements (Taylor 1980) (Figure 3) and was approved the following year. By October 1899 the Platypus Channel had been dredged to 17ft below Low Water Ordinary Spring Tides (LWOST) and then the two bucket dredges 'Octopus' and 'Crocodile' were used inside the breakwaters and by 1900 had dredged 58 acres down to this depth, with 4 acres along the Eastern Breakwater wharves dredged to 26ft below LWOST. 656,000cu yards of spoil was removed during 1900. Excavation of the Inner Harbour in Ross Creek also began in 1900 with dredged material being tipped on the beach west of the Western Breakwater for later reclamation there.

The sources used for the preceding review of dredging in the 19th century give scattered information on quantities removed and dredged depths, some of which have been incorporated into the review. For easier reference and subsequent analysis, this data is presented in full in tables showing dredged depths in various parts of the Port of Townsville (Table 1) and quantities dredged (Table 2). Measurement of dredged depths were taken more systematically in the 20th century as shown in Table 1. Quantities dredged were recorded annually in the late 19th century, but no records could be found for the period 1901-1941 and only intermittent records could be found for the 1940's and 1950's (Table 2). From September 1965 detailed records were kept by the Townsville Harbour Board, later the Townsville Port Authority, relating to its own dredge, (Table 3) and by the Queensland Department of Harbours and Marine relating to its dredges which were employed from time to time at Townsville (Tables 2 & 4). Before these tables are considered in detail, the history of dredging in Cleveland Bay in the 20th century will be reviewed generally.

1901-1910

During the first decade of the 20th century developmental and maintenance dredging occurred simultaneously. The development of the Inner Harbour in Ross Creek took 10 years, including the blasting of the rock bar near the entrance to Ross Creek, the removal of the rubble by dredge, and the dredging of the swing basin and berths (Taylor, 1980). The Platypus Channel was steadily extended and improved and the Outer Harbour swing basin and berths were deepened. Maintenance dredging was vital to maintain the depths of the cuttings. A cyclone in March 1903 led to 1-3ft of silting in the Platypus Channel and wharf approaches. Another cyclone in 1908 caused siltation problems and two floods in Ross Creek early in 1910 caused deposition of large quantities of silt in the recently dredged entrance to the Inner Harbour and in the Outer Harbour (Department of Harbours and Marine Queensland, 1986). The dredges 'Octopus' (Plate 1) and 'Crocodile', aided by a Priestman grab dredge from 1904 onwards, were working at near full capacity during this decade and in 1910 a new dredge was ordered. In 1906 quarterly soundings were instigated in the Platypus Channel and the Outer Harbour and the annual June data is given in Table 1.

1911-1920

On 7 July 1911 the new dredge 'Cleveland Bay' arrived in Townsville from Paisley, Scotland, where it had been designed and built with the capability of dredging to 38ft and raising 500 tons of stiff clay per hour (Taylor, 1980). The

'Crocodile' and 'Octopus' were in poor condition and the latter was disposed of; the 'Crocodile' however was repaired and refitted to upgrade it between 1913 and June 1914. In 1911 and 1912 the 'Cleveland Bay' which had electric light worked two shifts in an 18 hour day to deepen berths in the Outer Harbour. Developmental dredging in this part of the port and in the Platypus Channel continued until 1919, with "hard sandstone and stiff clay" making dredging difficult in the Channel. Both dredges were involved in the developmental and maintenance dredging the latter of which continued to be important in retaining depths. In April 1919 all the dredging plant was laid up due to the low revenue received by the port, but in September the 'Cleveland Bay' was recommissioned and undertook maintenance dredging in the Platypus Channel until July 1920, aided by the 'Crocodile' in the harbour approach channel in July 1919.

1921-1930

By 1921 the two bucket dredges had dredged the Platypus Channel to 25.5ft, the swing basin and approach channel to 26ft and the berths in the Outer Harbour to 30ft below LWOST (Taylor, 1980). However in June 1921 the 'Crocodile' was finally taken out of commission due to the financially depressed times. As Taylor observed "Dredging has always been and forever will be the most essential of maintenance works required at Townsville Harbour" yet for the following 30 years the 'Cleveland Bay' with its attendant barges and tug was the one major plant to undertake this. Maintenance dredging became of prime importance as the channel and berths deteriorated due to silting. The Platypus Channel, especially its inner east side, was subject to more siltation than the rest of the harbour. Taylor argues that this was because of the prevailing south-east winds and the discharge of several creeks into Cleveland Bay on the east and south-east side of the constructed harbour. Maintenance dredging was therefore concentrated in the Platypus Channel. The dredge's operations were limited during the summer cyclone season and the policy was adopted of the plant being laid up for overhaul, or operating inside the harbour, at this time of year. Some developmental dredging was carried out during the 1920's. The Outer Harbour swing basin was extended and deepened although the dredging was described as the hardest undertaken at Townsville because of the "stiff clay, sandstone and boulder clay, impregnated with granite boulders". Between 1923 and 1925 the dredging plant worked to capacity on this and widening the Platypus Channel. Between 1926 and 1929 the only new work involved dredging an approach channel and berth for the Jetty Wharf extension. The Inner Harbour was dredged for 3 months in 1926-27. Up to 1925 there was some confusion over the declared depths in various parts of the Port of Townsville, with some being maximum, some minimum and some being between the two. From 1925 onwards only minimum depths were declared and these are listed in Table 1.

1931-1940

During most of the 1930's the 'Cleveland Bay' was employed in maintenance dredging, primarily in the Platypus Channel but also in the swing basin and berths of the Outer Harbour. For 4 months in 1936 dredging was carried out in the Inner Harbour to remove large silt deposits from the channel into Ross Creek and in the swing basin and slipway approach (Taylor, 1980). In 1938 the 'Cleveland Bay' operated two shifts in the Platypus Channel, berths and west of the channel and undertook some developmental dredging in the Outer Harbour for the Empire Flying Boat moorings (Annual Reports of Queensland Department of Harbours and Marine 1934-1987). Two cyclones affected Cleveland Bay in 1940, on 18 February and a less severe one on 7 April. Considerable damage was caused on Magnetic Island to bathing enclosures, ferry landings and approaches especially at Alma and Nelly

Bays and to a slightly lesser degree at Picnic Bay and Arcadia. Depths in the Platypus Channel were reduced to a minimum of 22ft below LWOST on 18 April and 20 ft on 13 June, with 20.5 ft being the minimum elsewhere in the dredged areas of the Outer Harbour on 18 April (Taylor, 1980).

1941-1950

During World War II, Townsville was a very busy port. The bucket dredge 'Cleveland Bay' operated two shifts of maintenance dredging in 1941 in an attempt to obtain and maintain the Platypus Channel and swing basin to 28ft below LWOST, dredge the berths and keep the entrance channel to Ross Creek open (Department of Harbours and Marine Queensland, 1986). During part of 1941, the suction dredge 'Trinity Bay' owned by the Cairns Harbour Board assisted in dredging the Platypus Channel. Between February and May 1942 an Allied Works Council Scheme was commenced to provide extensive improvements to Townsville Harbour and the Platypus Channel, but this was abandoned before completion. Between 1942 and 1945 the 'Cleveland Bay' continued maintenance dredging as well as developmental dredging for a proposed naval and lighter wharf. The Queensland Department of Harbours and Marine's suction dredge 'Morwong' assisted with maintenance dredging in the Platypus Channel and Outer Harbour in November and December 1943 and raised 135,000 barge yards of material (Table 2). On 28 March 1944 the port was affected by a cyclone, resulting in subsequent siltation problems, but by 11 June 1945 the minimum LWOST depths were reported as Platypus Channel 22ft, Outer Harbour swing basin 23ft and berths 1-7, 28.5-29ft.

Between September 1945 and March 1948 the 'Cleveland Bay' was out of commission for major repairs including fitting a new boiler and bucket ladder. Another cyclone and major flood occurred in March 1946 and produced considerable silting in the dredged areas. Maintenance dredging was undertaken by the 'Trinity Bay' and 'Morwong' (Plate 2) in 1946-47 and by the former in 1947-48 (Annual Reports of the Queensland Department of Harbours and Marine, 1934-87). The 'Morwong' dumped spoil at sea, prior to completion of the wharf pumping station at the reclamation site in front of Pilot Hill on 13 September 1946 (Taylor, 1980). The spoil which was subsequently pumped ashore from the 'Morwong', and in April 1949 on a smaller scale from the 'Trinity Bay', was subsequently (c.1950) claimed by the Townsville Harbour Board's Chief Engineer to be unsuitable for reclamation because of its silt-laden character. (Several years later the area was filled with sand from the land). After the 'Cleveland Bay' was recommissioned in March 1948 it worked double shifts of maintenance dredging but experienced difficulty in maintaining depths in the port.

1951-1960

Taylor (1980), in considering future port development in the 1950's, stressed the importance of restoring harbour depths to levels achieved 20 years earlier and forcefully expressed the opinion that "Dredging operations during the complete term of the Townsville Harbour Board's administration of the Harbour, and extending back some twenty years before that, had been the prime and most expensive requirement to keep the port in existence. It has been conclusively proved that the berths of the harbour silt up from three to four feet a year in normal weather conditions, and the siltation of Platypus Channel particularly extending approximately 5,000 feet seawards from the mouth of the harbour, is even greater". In 1951 and 1952 the 'Cleveland Bay' continued to work double shifts carrying out maintenance dredging in the Platypus Channel and Outer Harbour and developmental work to deepen the berths. Sand from Ross River mouth was used in reclamation work near the finger pier. In December 1952 the new suction dredge 'Townsville' (Plate 3) built in Newcastle, N.S.W. arrived in the port and joined the 'Cleveland Bay' in dredging work of all types. By 1954 it was claimed that "dredging is no longer a problem to this port" (Annual Reports of the Queensland Department of Harbours and Marine, 1934-1987). Maintenance dredging was undertaken by both dredges, but the 'Cleveland Bay' was used mainly for developmental work. Cyclone 'Agnes' affected Townsville on 6 March 1956 but with the two dredges the siltation effects in the harbour were soon removed. Developmental dredging for the new Bulk Sugar Terminal was a huge task for the 'Cleveland Bay' which worked 3 shifts from November 1957, and due to its overhaul in 1958, the Queensland Department of Harbours and Marine bucket dredge 'Platypus II' with two barges 'Dugong' and 'Seal' was loaned from November 1958 to May 1959. The 'Cleveland Bay' then resumed 3 shift working so that the terminal was able to handle its first sugar in June 1959 although it was not fully completed until December 1962.

1961-1970

During the 1960's maintenance dredging was carried out mainly by the 'Townsville' in the Platypus Channel, the various parts of the Outer Harbour and for shorter periods in the Inner Harbour. The 'Cleveland Bay' continued developmental dredging to deepen the Outer Harbour, and prepare for the proposed tanker berth, whilst the Queensland Department of Harbours and Marine's clam dredge 'Mourilyan' dredged the Ross Creek boat harbour in 1964 and 1965 to provide a basin and berths. Dredging the oil and tanker berth between March and November 1964 was the final assignment for the 'Cleveland Bay' (Plate 4). Between 1968 and 1970, 150 acres of industrial land was reclaimed on the left bank of the Ross River estuary by pumping ashore

3,034,000 cu yards of sand from the adjacent intertidal zone. An 8 inch cutter suction dredge 'John A Stein' was purchased in 1970 to aid this work (Annual Reports of the Queensland Department of Harbours and Marine 1934-1987), but subsequently the 21 inch cutter suction dredge 'Kembla' (later renamed 'A.C.C.I.') was hired for this and other work (Taylor 1980).

Whilst details of dredging have been recorded in the various sources referred to above, although with limited quantitative data on amounts dredged, very little information is available about dump sites. In 1883 material was deposited close to Magnetic Island and in 1892-93 it was to be dumped in Cockle Bay, Magnetic Island. Before the mid-1960's for an unknown period, dredge spoil was dumped south of Middle Reef (N. Butterworth, personal communication 1988), but then dumping was transferred to a new site north-east of the harbour entrance and south-east of Hawkings Point, Magnetic Island. (This was later defined as the shallow draft dump site shown on Figure 1).

In addition to dredge spoil dumping, in 1963 following the serious fire in the Bulk Sugar Terminal 43,000 tons of burnt sugar had to be disposed of. On 12 June 1963 permission was given by the Queensland Department of Harbours and Marine in Brisbane to the Townsville Harbour Board to dump this approximately 20 miles north-east of the harbour entrance seaward of a line between 19°2'S, 147°13.5'E and 18°55'S,147°E.

In October 1964 a new Australian Naval Chart giving details of soundings in Cleveland Bay was received by the Townsville Harbour Board and the Chairman commented that the depths shown "were virtually now the same in Cleveland Bay as in 1886" (Taylor,1980). He believed this refuted claims being made by various bodies and individuals that the disposal of dredge spoil was having an adverse affect on coral reef growth along the coast of Magnetic Island. In June 1965 the Board's Chief Engineer instituted a change in the calculation of material dredged by the 'Townsville' from measurements in hopper yards to solid yards. The calculation was made by working out the specific gravities of silt and salt water and the vessel's displacement. A draught gauge was fitted to the dredge to indicate that the maximum quantity of solids was aboard before proceeding to the dumping grounds. He reported that "In recent tests the content of spoil in hoppers had varied between 45% and 10%, which meant, at times, a lot of water had been carried out to the dumping grounds" (Taylor, 1980). This must be borne in mind when considering the data in Table 2. The Townsville Port Authority holds detailed dredging records from September 1965 to February 1983 for the suction dredge 'Townsville'. The record sheets show particulars of each dredged load including source. These records were used for the period September 1965 to February 1968 to compile the first part of Table 3. After this, monthly dredging returns were compiled from these records by the Engineer's Department and these formed the basis for the latter part of this Table. This will be examined further later.

<u>1971-1980</u>

On 24 December 1971 Cyclone 'Althea' struck Townsville. Winds gusted to 122 knots, waves of 5ft height were recorded in the enclosed harbour and a storm surge of 9.25 ft was generated. A subsequent survey (Taylor, 1980) revealed that 600,000 tons (600,000 cubic yards according to Townsville Port Authority) of sediment had been deposited in the Platypus Channel, which reduced its depth by 4.5 ft. The S.D. 'Townsville' spent 6 months dredging out this material early in 1972. Later in 1972 the largest dredging programme ever undertaken by the Port of Townsville in a short period began with the 'Townsville' starting to dredge a new 'dog-leg' channel to extend the Platypus Channel seaward and make it suitable for deep draft tankers bringing fuel for the Greenvale Nickel project. It was dredging in comparatively soft material, and the spoil was carried to a dump site relatively nearby between the channel and Cape Cleveland "in depths greater than 6.1m (20 ft) at low water and in a quiescent area of the bay away from tidal currents" (Taylor, 1980). (This was later defined as the deep draft dump site shown on Figure 1). The Queensland Department of Harbours and Marine trailer suction dredge 'Sir Thomas Hiley' was contracted to assist the 'Townsville' with the developmental dredging in the channel and swing basin in 1973, 1974 and 1975. The Townsville Harbour Board's consultants wrote to the Contractor on 30 August 1974 stating that "the excess quantity of silting (in the berths) which has occurred in the period betwen July and October, 1973, has occurred in the period when the 'Sir Thomas Hiley' was dredging the swing basin and is attributed to its operation" (Plate 5). The quantity so deposited was calculated as 31,740 m ^{3} (Taylor, 1980). This is a continuing problem with the 'Sir Thomas Hiley' and is attributed to the way this type of dredge operates (N. Butterworth, personal communication 1988). The 'A.C.C.I.' also played a part in this large dredging programme, which of necessity had to run simultaneously with maintenance dredging in all parts of the harbour and approach channel.

On 15 January 1976 the Department of Harbours and Marine granted formal approval to the Townsville Harbour Board, pursuant to the provisions of Section 86 of the Harbours Act 1955-1972, for the dumping of dredged material in the two areas in Cleveland Bay (Figure 1). This was "subject to the condition that the depth north of a line Mount Marlow in line with Hawkings Point (Magnetic Island) must not be reduced below 8.2m LWOST." These appear to be the same areas which had been in use by the Townsville Harbour Board since the mid 1960's in the case of the shallow draft dump site and the early 1970's in the case of the deep draft dump site. The co-ordinates of these sites are as follows:

Deep draft dump site

Corners of rectangle -	NW	19° 08' 09"S	146° 56' 29"E
	NE	19° 08' 43"S	146° 57' 28"E
	SW	19° 10' 39"S	146° 54' 53"E
	SE	19° 11' 13"S	146° 55' 51"E

Shallow draft dump site

Corners of rectangle -	NW	19° 12' 05"S	146° 53' 01"E
	NE	19° 12' 22"S	146° 53' 30"E
	SW	19° 13' 28"S	146° 52' 07"E
	SE	19° 13' 45"S	146° 52' 36"E

In February 1976 heavy rains resulted in large quantities of silt being deposited in the channel once again. From 1977 to 1980 developmental dredging in the Ross River channel was carried out by cutter suction dredges, which pumped the sediment ashore. In 1979-80 about 400,000m^3 of sand was removed from the bed of Ross River, mainly immediately upstream from the mouth of Goondi Greek. This sand was used to fill an 8ha reclamation on the east side of the Harbour's Eastern breakwater.

1981-1988

From 1981 to the present (1988) most dredging in the Port of Townsville has been to maintain depths, although some developmental dredging continued in the Ross River channel prior to the fishing fleet being moved from Ross Creek to its new base on Ross River in 1983. Subsequently Ross Creek has been used mainly for pleasure boats whereas Ross River is the base for commercial and industrial craft. Maintenance dredging of Ross River channel has involved some sidecasting of material by cutter suction dredge, but most of the material has been pumped ashore. In addition the Townsville Port Authority's grab dredge has removed small quantities of material which has been disposed of mainly in the shallow draft dump site. Until February 1983 dredging elsewhere in the port was carried out by the S.D. 'Townsville' on a regular basis throughout the year. Subsequently however the Queensland Department of Harbours and Marine 'Sir Thomas Hiley' has undertaken dredging at the Port of Townsville on a contract basis for a few weeks each year, usually in two periods, during the winter months (Plate 6). Details of this dredging are given in Table 4 and will be examined further below. All this has been maintenance dredging except for some developmental dredging of the berths in 1988. In 1986, the split hopper barge 'Eric Netterfield' was completed for carrying dredge spoil from the harbour and dumping it at various disposal and reclamation sites. This design of barge allows unloading of spoil in shallower depths than is possible with a bottom door barge.

In 1981, the Environment Protection (Sea Dumping) Act was passed by the Federal Government. The Minister of State for the Arts, Sport, the Environment, Tourism and Territories is empowered under the Act to issue dredging and dumping permits. A copy of the General Permit, Appendix 1 and Annexes A and B, issued on 31 May 1988 for the Port of Townsville, forms Appendix 1 of this report. It:

1) grants a general permit to the Townsville Port Authority "... for a period of twelve months ... to load and to dump up to 350,000 tonnes of dredge spoil ... arising from the dredging of Townsville Harbour and approaches ..."

2) grants a general permit to the Townsville Port Authority "... for a period of thirty-six months ... to load and to dump up to 53,000 tonnes of dredge spoil per annum comprising uncontaminated siltation material and spillage arising from small scale maintenance dredging in Townsville Harbour and approaches".

The dump sites relating to each of these permits are clearly defined (Figure 1). The first permit refers to the deep draft dump site which has been in use since the early 1970's. The second permit which was subsequently modified with reference to the area, relates to a site close to and overlapping with the shallow draft dump site which has been used since the mid 1960's.

The co-ordinates for these sites are now as follows:
Permit 1 for large scale dredging operation

Corners of 4 sided figure -	NW	19° 08' 09"S	146° 56' 29"E
	NE	19° 08' 43"S	146° 57' 28"E
	SW	19° 10' 39"S	146° 54' 53"E
	SE	19° 11' 13"S	146° 55' 51"E

Permit 2 for small scale maintenance dredging operation

Corners of 4 sided figure -	NW	19° 12' 48"S	146° 52' 36"E
	NE	19° 13' 24"S	146° 53' 36"E
	SW	19° 14' 30"S	146° 51' 30"E
	SE	19° 15' 00"S	146° 52' 36"E

Dredged Depths at the Port of Townsville and Earlier Dredging Records

Recorded dredged depths at the port have been compiled into Table 1 covering the period 1884 to 1987. As indicated above, the records up to 1906 were taken at random intervals, but from 1906 onwards quarterly soundings were taken and the annual June data are shown in the Table. From 1925 onwards minimum depths only were declared for the safety of shipping. When considered overall, this table shows the steadily increased depths to which dredging was taken as the port developed and ships became larger, but it also reveals how quickly depths deteriorated when dredging was reduced or stopped.

Records of amounts of sediment dredged are scanty and intermittent up to 1965, but Table 2 has been drawn up from all available sources. The use of different units, the precise definition of some of which is unknown, results in comparisons being difficult within this table and between this and Tables 3 and 4, in which the data are given in tonnes. (At the end of Table 2, the dredging records are listed for the 'Sir Thomas Hiley' for the years 1973-4 to 1975-6 when she was contracted to Townsville for several months annually). The only reference to dump sites before 1965 were those referred to in 1883 and 1893 near Cockle Bay, Magnetic Island.

Detailed Dredging Records September 1965 to August 1988

As indicated in the above review of the history of dredging in Cleveland Bay detailed systematic records are available only for the last 23 years. Table 3 has been compiled from records of each load dredged by the S.D.'Townsville' for the period September 1965 to February 1983. The data are presented as monthly and annual totals dredged from the Platypus Channel, and the Outer Harbour swing basin and berths for the whole period, and in addition from the Ross River channel from 1979-80 to 1982-83. The 'dredging year' is defined as the 12 month period ending on 30 June of each calendar year.

After the S.D. 'Townsville' stopped dredging in the port in February 1983, the T.S.D. 'Sir Thomas Hiley' dredged under contract for the periods shown in calendar years in Table 4. The two periods each winter formed part of her assignment from her base in Brisbane to the port of Weipa, with the first period being during her northward voyage and the second during her return southward voyage. After the first period of dredging it is found necessary to allow suspended sediment to settle, before a survey can be carried out to determine the detailed localities and the amounts of further dredging which may be needed to reach required depths. Although records of each dredged load are kept it proved impossible to compile tables showing amounts dredged in different parts of the harbour, because an individual load was often taken from more than one part. Table 4 therefore shows only totals for each period of dredging, plus the total for each calendar year, together with notes as to where the dredging mainly took place.

The annual dredging records for the 'Townsville' and the 'Sir Thomas Hiley' in the Port of Townsville are plotted as graphs in Figure 4. The curve for the total amount dredged shows a steady rise up to 1971-72, followed by an enormous peak between then and 1975-76. During this period the 'Townsville' was assisted at times by the 'Sir Thomas Hiley' in the massive programme of developmental as well as routine maintenance dredging. The maximum was reached in 1973-74 when 2,112,879 tonnes was dredged, followed by 1,493,017 tonnes in 1974-75. In the late 1970's and up to 1980-81 the level was close to 600,000 tonnes annually but then fell sharply to about 350,000 tonnes during the 'Townsville's' final dredging year. Amounts dredged by the 'Sir Thomas Hiley' alone from 1983 onwards have varied between about 100,000 and 260,000 tonnes annually.

When the curves for dredging in the different parts of the port by the 'Townsville' are examined (Figure 4) it is clear that in most years by far the greatest amount was dredged from the Platypus Channel followed by a much smaller amount from the swing basin and even less from the berths. Only between 1975-76 and 1977-78 and in 1980-81 did the 'Townsville' dredge more from the swing basin than the Platypus Channel (and in 1975-76 the 'Sir Thomas Hiley' was also dredging in the port).

The monthly dredging records for the 'Townsville' from September 1965 to February 1983 are plotted in Figure 5. The gaps in the curve are periods when the dredge was being overhauled and repaired. Between 1965 and 1971 monthly dredged quantities were generally between about 10,500 and 30,500 tonnes. During the first half of 1972 the figure rose to over 60,000 tonnes following Cyclone 'Althea' in late December 1971. During the massive developmental and maintenance dredging operation between late 1972 and 1975-76 monthly figures varied widely, with the peak over 118,000 tonnes in October 1972. During the late 1970's and early 1980's when mainly maintenance dredging took place with some developmental dredging in Ross River channel, monthly dredging totals varied moderately mainly between 30,000 and 70,000 tonnes, with the only marked exception being about 96,000 tonnes in July 1980.

Although no written records could be found relating to the dumping of dredge spoil between 1965 and 1988, except when formal approval was granted on 15 January 1976 and permits were issued on 31 May 1988, it is understood from the Townsville Port Authority Engineer's Department that all the material dredged by the S.D.'Townsville' was dumped in the shallow draft site (Figure 1) which had been in use since the mid 1960's. However, Taylor (1980) states that the sediment dredged to cut the 'dog-leg' Sea Channel by the S.D. 'Townsville', beginning in late 1972 and later assisted by the T.S.D. 'Sir Thomas Hiley', was dumped in the deep draft dump site. The 'Sir Thomas Hiley' has continued to use this latter site subsequently.

The type of sediment dredged was visually inspected on the dredge and described on the record sheets, but was not regularly analysed to provide a more precise sedimentological description. From the general descriptions it appears that maintenance dredging from any part of the harbour and channel yields mainly 'silt' and 'mud'. Developmental dredging, especially within the harbour, yields harder 'sandstone' and 'stiff clay' in places, but the dog-leg extension to the Platypus Channel was cut in 'relatively soft material'.

Footnote

An inspection by the British Admiralty Hydrographic Department of editions back to 1886 of the Admiralty Hydrographic Chart No.1102 'Cleveland Bay' (which subsequently became Australian Naval Chart AUS 256) revealed no information about dump sites for dredged material. As far as they could ascertain the first edition of AUS 256 to show such a site was printed in July 1988, but this shows only the deep draft, large scale dump site (Figure 1).

CHAPTER 2

Coastal and Nearshore Zone Changes in the Cleveland Bay Area

Dredging, by removing sediment from one locality and dumping it in another, not only influences these two localities, but may also affect other areas of the seabed and neighbouring coasts to which the dumped sediment may be carried subsequently by wind, wave and tidal processes. A series of aerial photographs can provide a valuable record of coastal change and, under clear water conditions, of changes in the nearshore zone. These changes may be entirely natural or may be influenced by man to some degree where engineering structures are built and dredging takes place. Vertical aerial photographs of the Cleveland Bay area spanning the last 47 years, from 1941 to 1988 (Table 5) have been analysed to determine the type and amount of coastal and nearshore changes. These will be considered in detail in this chapter, plus an assessment of changes shown by a limited number of ground surveys. Subsequently the natural processes and man induced effects will be assessed in an attempt to determine the causes of the changes.

The aerial surveys listed in Table 5 were selected to span as long a period, and to give as regular a time interval between surveys, as possible. Because of the small number of aerial surveys undertaken in the 1940's, 1950's and 1960's the time interval was at its longest 17 years. Many more aerial surveys have been flown in the 1970's and 1980's, therefore the time interval has been reduced to 3-4 years generally for this period. The surveys selected were also those which gave an extensive cover of the Cleveland Bay area, at a small enough scale to show detailed coastal and nearshore features. Photographs at a scale of about 1:12,000 are particularly valuable and as six of the surveys were at this scale they could be compared directly. All the aerial surveys chosen from 1974 onwards used colour film and this provides a considerable advantage over black and white when detailed variations in sediment and vegetation are being studied. However after analysing colour aerial photographs it is relatively easy to analyse black and white photographs of the same area and similar range of phenomena.

The coasts of Cleveland Bay and the adjacent nearshore areas will be examined in an anticlockwise sequence from Shelly Beach - Cape Pallarenda to Cape Cleveland. A similar anticlockwise sequence around Magnetic Island will begin at West Point (Figure 1).

Shelly Beach - Cape Pallarenda

The best exposure of the intertidal and subtidal zones as well as the coastline itself is shown on the aerial surveys of 1-7 June 1959, 30 May 1974, 14 July 1981 and 15 June 1985 (Figure 6). The rock coast of Cape Pallarenda is cut in granite and volcanic agglomerates and two sand beaches have formed within an embayment and west of the rock outcrops. Shelly Beach is backed by a 3km long vegetated sand bar/spit which formed from east to west as indicated by the alignment of its lateral ridges. It may have originated as a nearshore bar which was driven landward by wave washover processes as it extended westwards, in a similar manner to the east Burdekin delta spits and bars (Pringle, 1983 and 1984). Streams from the higher ground inland flow into Shelly Creek which lies along the landward side of the bar/spit and has mouths at both its east and west ends. Throughout its length Shelly Creek is flanked by mangroves which reach the coast near its mouths. An extensive intertidal and subtidal foreland has developed northwards from the Shelly Beach - Cape Pallarenda coast and has been shaped by sediment supply and wave and tidal processes acting from both east and west.

The major change along the coast, revealed by these aerial photographs, is to the sand beach east of the east mouth of Shelly Creek. During the period 1959-1985 this beach was driven shorewards into the mangroves on its landward side. Some of these, now on the seaward side, have died as their roots are exposed by wave erosion.

Comparing the intertidal and subtidal foreland on the different surveys is complicated, firstly by the varying photographic cover of this area (this locality lies at the end of the Beach Protection Authority's St. Lawrence - Townsville coastal segment for aerial surveys) and secondly by the different tidal heights. Overall, the position and form of the major sand banks were similar on the four surveys. The main sediment source appears to lie in the west mouth of Shelly Creek and the mouths of the Bohle and possibly Black Rivers further west. This sediment is transported north-eastwards by wave and possibly tidal current action and is formed into major sand bars aligned south-west to north-east. A much smaller amount of sediment appears to be carried westwards around Cape Pallarenda to form curved sand banks close to the coast in the north-facing embayment and possibly feeding sand bars lying parallel to the coast further west. The eastward side of the foreland is not continuous as a deeper water area lies north of these smaller sandbanks. North of this, towards the apex of the foreland, the major sand bars swing round northward from their south-west to north-east alignment. This effect and the deeper water area are probably produced by strong tidal and wind-induced currents and possibly wave action within the narrow confines of West Channel between the mainland and the south-west coast of Magnetic Island.

Areas of seagrass were clearly visible in the central and coastward sections of the foreland on the 1959, 1981 and

1985 aerial photographs. However none showed on the 1974 photographs despite their high quality and the water clarity which enabled the sand banks to be mapped easily.

Cape Pallarenda to Ross Creek

This section is clearly shown on most of the aerial surveys (Figure 7). A narrow upper beach of relatively coarse sand adjoins the sand dunes in Rowes Bay and below this, exposed at L.W., are a series of irregular sand bars and troughs, generally arranged parallel to the coast. There are only two exceptions to this pattern. At the mouth of Three Mile Creek an intertidal to subtidal delta has formed which is symmetrical in plan view, but which has the best developed sand bars directly seaward and to the north of the mouth. In the inner part of Rowes Bay adjacent to the granite headland of Kissing Point the intertidal zone widens. Only a very narrow sand beach exists flanked by fine sand and mud seaward, in which mangroves are colonizing. Towards LWM a series of oblique sand bars have formed. Between Kissing Point and Ross Creek mouth the coast flanking The Strand in Townsville is artificially protected with large boulders. Only a narrow sand beach is present here and its volume becomes less towards Ross Creek. Before the Harbour was constructed this beach would have received sediment from Ross Creek and Ross River, but the Harbour now blocks that, in acting like a giant groyne.

Changes along this coast have been slight between 1942 and 1988, as shown on the aerial photographs. The delta at Three Mile Creek mouth has remained similar in size and form; the features characterising the inner part of Rowes Bay show little change except for a slight extension of the mangroves; and between Kissing Point and Ross Creek the major change has been man-made with the formation of the marina and reclamation for the hotel and casino adjacent to the Eastern Breakwater of the Harbour.

Ross River to Sandfly Creek

The aerial surveys which best show not only this section of coastline but also the intertidal zone are those of 1-7 June 1959, 14 June 1974, 14 July 1981 and 15 July 1985 (Figure 8). Ross River, its tributary Stuart Creek and Stuart Creek's distributaries, Sandfly Creek and the smaller creek westwards, have provided the main source of terrigenous sediment input to Cleveland Bay until the building of Ross River Dam in 1973. The coastline is composed of sand ridges with areas of mangroves commonly both seaward and landward. The intertidal zone clearly shows that Ross River carried the largest sediment load which was initially deposited in an intertidal and subtidal delta with its apex eastwards of the river mouth, reflecting the eastward curve of the main channel. Smaller sediment loads were deposited by Sandfly Creek and the western distributary and this extended the delta eastwards, in a series of sandbanks.

Changes to this coastline between 1941 and 1973 were examined in detail by comparing aerial photographs taken in 1941, 1952, 1959, 1961, 1965, 1971/72 and 1973 (McIntyre and Associates, 1974). Erosion was most pronounced near the mouths of Ross River and Sandfly Creek (Figure 9), especially during the inter-survey periods 1952-1959 and 1965-1971/2 and is attributed to cyclones in 1956 and 1971. Progradation of sand ridges in the Ross River mouth area and mangroves and sand ridges near the mouth of Sandfly Creek partially counterbalanced the erosion. Changes were less marked along the central section of this coast, where progradation by mangroves was dominant overall.

Whilst knowledge of this type and scale of coastal change is important in understanding the evolution of a particular coastline, it was felt that in the current project, where the possible effects of dredging are of major concern, a broader examination of both coastline and intertidal zone was more appropriate.

The map drawn from the 1959 aerial photographs (Figure 8) shows the Ross River mouth in a natural state except for the influence of the Harbour's Eastern Breakwater. The main channel curved eastwards from the mouth, but more minor channels were cut slightly to the west through sandbanks in which the river's load was initially deposited. The 1974 aerial photographs were taken at a higher state of the tide with the channels and banks therefore less exposed; a channel can be seen directly seaward of the mouth, but a major one eastwards is only hinted at. (The 1973 photographs show both channels more clearly). The major reclamation of land on the west shore of the mouth between 1968 and 1970 had involved the pumping ashore of 3,034,000 cu yards of sand from the adjacent intertidal sandbanks and this probably resulted in the development of a larger channel directly seaward of the mouth. By 1981 the main channel lay in this position, with the only evidence of the former eastward swinging one being in the position of the apex of the intertidal/subtidal delta. This change was strongly influenced by developmental dredging of the Ross River channel from 1977 into the early 1980's. Between 1981 and 1985 an angled harbour wall was constructed east of the Eastern Breakwater across part of the inter-tidal sandbanks on the west side of Ross River mouth. Changes will clearly result within the semi-enclosed area, but the main channel lying parallel to its eastern side has not changed position during this period. The minor channel leading westwards from it has diminished as sandbanks have grown west of the main channel. The apex of the delta in 1985 and in 1988 still shows the former dominance of the eastward curving main channel.

The intertidal zone beyond the mouth of Sandfly Creek and the western distributary has shown no major changes between 1959 and 1985. In each case the channel has curved westwards from the mouth and has contributed sand to the intertidal/subtidal delta and its eastward extension. The sandbanks between the two channels lie oblique to the coastline, being nearer to it at their western ends.

Along the coastline mangroves have become almost continuous, seaward of a vegetated sand ridge, during this period. Only immediately east of Ross River are they absent, with the sand ridge flanking the coast.

Sandfly Creek to Cocoa Creek

The aerial surveys of 11 August 1961, 9 October 1973, 30 May 1974, 28 November 1978, 14 July 1981 and 24 June/15 July 1985 provide the clearest views of this coast and the adjacent intertidal zone (Figure 10). This is a lower energy coast than that further west in Cleveland Bay, owing to the sheltering effect of Cape Cleveland. Three main creeks enter the bay along this coast, from west to east, Alligator, Crocodile and Cocoa Creeks. Elsewhere the coast is flanked almost continuously by mangroves and the adjacent intertidal zone is of mud or fine sand.

Changes along the coastline were examined by comparing aerial photographs taken in 1941, 1959 and 1973 (McIntyre and Associates, 1974)(Figure 11). The most pronounced erosion occurred between 1941 and 1959 along the mangrove coast between Sandfly and Alligator Creeks where a recession of 50m occurred, and along the west banks of the mouths of Alligator, Crocodile and Cocoa Creeks where about 30m was removed. Elsewhere between 1941 and 1973 mangrove colonization produced coastal progradation, of about 20m south of Sandfly Creek and east and west of Alligator Creek.

Examination of this coastline on the 1974, 1978, 1981 and 1985 aerial photographs revealed no change in the extent of the mangrove belt and little change in the channels and sandbanks in the intertidal zone seaward of the creek mouths. Elsewhere the intertidal zone of fine sediment was traversed by a network of very small drainage lines only. Between Sandfly Creek and the west side of Crocodile Creek no seagrass was visible on the 1974, 1978 and 1981 photographs. It was identified, however, on the 1985 survey near and seaward of LWM, between a point midway between Sandfly and Alligator Creeks and the west side of Crocodile Creek. Between Crocodile Creek and Cocoa Creek its extent varied on the different surveys:

1974 No seagrass was visible along this coast.

1978 Seagrass below LWM was visible immediately west of Crocodile Creek channel and north-eastwards from there parallel to the coast.

1981 Seagrass above and below LWM extended from immediately west of Crocodile Creek channel north-eastwards parallel to the coast.

1985 Seagrass below LWM extended parallel to the whole section of coast and appeared relatively dense east and west of the Cocoa Creek channel.

Cocoa Creek to Cape Cleveland

The aerial surveys of 11 August 1961, 9 October 1973, 30 May 1974, 28 November 1978, 15 July 1981 and 24 June 1985 provide the best cover of this coast for the present study. Along the west side of the granite promontory of Cape Cleveland, with volcanic rocks forming its tip, rocky coasts and small headlands are interspersed with small bayhead sand beaches with mangroves in places (Figure 10).

Comparison between 1959 and 1973 aerial surveys (McIntyre and Associates, 1974) showed these beaches to be relatively stable in comparison with other Cleveland Bay beaches. The changes which were noted had no clear pattern. The beach near the lighthouse receded about 4m whereas the next bay south, Red Rock Bay advanced by a similar amount. Long Beach was relatively stable except near the creek mouth where the shore prograded by 3m as also did the beach in White Rock Bay. The sandy part of Laun's Beach remained stable. The mangroves occurring at intervals along this section of coast, were also stable generally but with a small advance taking place where silt had accummulated at the southern end of each patch. A mangrove advance of 20m occurred on Long Beach, 25m on Laun's Beach and about 10m north of Cocoa Creek, south of the most southerly rock outcrop of Cape Cleveland.

In the present study, examination of the 1974, 1978, 1981 and 1985 aerial photographs showed no clear change to the sand beaches along this section of coast and only small changes along two parts of the mangrove fringed coast. At the north-east end of Laun's Beach, the mangroves extended a short distance along the coast towards the rock outcrop between 1974 and 1985; and mangrove colonisation began on the north-east side of White Rock Bay. The extent of the seagrass varied on the different surveys, as was the case further west between Sandfly and Cocoa Creeks:

1961 Seagrass was visible below LWM seaward of the north-east end of Laun's Beach and Long Beach.

1973 No seagrass was visible above or below LWM.

1974 Seagrass was visible only below LWM immediately east of Cocoa Creek channel. From Cape Cleveland south to Long Beach the water was very turbid with large southward pointing plumes of sediment in suspension.

1978 Seagrass was visible below LWM north-east of Cocoa Creek in two bands parallel to the coast, with a strip of sediment between. Along the rocky coast, seagrass was visible below LWM only intermittently due to highlights on the photographs where the sun was reflected from the sea surface.

1981 North-east of Cocoa Creek seagrass was visible above and below LWM in the troughs between oblique bars of sediment (the south end of the bars, lying closest to the coast). There was thicker, more continuous seagrass seaward. Along the rocky coast, a large area of seagrass was visible above and below LWM extending from the first rock headland south of Cape Cleveland to Long Beach.

1985 North-east of Cocoa Creek seagrass was visible again in troughs between oblique sediment ridges, and opposite the first rock headland north of Laun's Beach, in troughs between sediment ridges parallel to the coast. Northwards to the first rock headland south of Cape Cleveland seagrass was visible below LWM, in patches interspersed with sediment nearer the coast, but with denser growth seawards.

Magnetic Island, South-West Coast

The aerial surveys of 1-7 June 1959, 11 August 1961, 30 May 1974, 28 November 1978, 14 July 1981 and 15 June 1985 give a good overall view of this coast and the intertidal zone. The coasts of Magnetic Island have a distinct feature not found on the mainland coast of Cleveland Bay, namely fringing coral reefs. Because the south-west coast is the most sheltered, coral reef growth has been most extensive here, probably since Holocene time, and an extensive reef flat with overlying sediment extends seaward into West Channel from near Nobby Head to the south side of Bolger Bay, (Figures 12 and 13). Apart from rocky shores near Nobby Head and West Point, the remainder of this coast is depositional, with sand beaches south of West Point, between Young and Bolger Bays and in Cockle Bay, and with mangroves fringing the remainder.

The rocky shores and sand beaches show little change on this sequence of aerial surveys from 1959 to 1985, and the seaward margin of the mangroves is similar throughout. However whereas a dense continuous strip of mangroves is shown on the 1959 and 1961 photographs, extending landwards to salt flats or higher ground, marked destruction had occurred by 1974 in a broad strip landward of the seaward fringe. This destruction was most marked in the mangroves between Bolger and Cockle Bays, although it had occurred to a lesser extent in the Young Bay mangroves. The zone of dead mangroves continued to be a prominent feature in 1978, but by 1981 regrowth was turning the strip into patches and those patches had diminished further by the 1985 survey.

The coral reef flat is the most dominant feature of the intertidal zone along the southern half of this coast, with fine-sand and mud in this zone northwards off Bolger and Young Bays. In 1959 patches of seagrass and sediment were visible under water extending between these two bays. Further south areas of seagrass were growing in the channels near the landward side of the coral reef flat north-west of Cockle Bay and seaward, interspersed with sediment, on the reef flat off Bolger Bay. Patches of seagrass and sediment were visible also in a belt off Cockle Bay and extending along the shore to near Nobby Head. This seagrass distribution pattern was broadly similar in 1961, but in 1974 no seagrass appeared, despite clear under-water visibility on the aerial photographs. In 1978 a small area was visible in the channel landward of the reef flat south of Bolger Bay, more extensive areas were seen under-water off Young Bay and there were possibly small patches interspersed with sediment south-east of Cockle Bay. The 1981 aerial survey showed dense seagrass growing in the channel landward of the reef flat south of Bolger Bay and seagrass patches growing extensively in the sediment on the reef flat seawards. Dense seagrass was also seen growing under-water off the north end of the reef, seaward of Bolger Bay. The 1985 aerial photographs show dense seagrass patches in the channel landward of the reef, north-west of Cockle Bay and on the northern end of the reef flat. Seagrass interspersed with sediment is also extensive on the reef flat north-west of the water pipeline which was installed between 1981-1985 (a marked contrast existed between the two sides of the pipeline, with no seagrass identifiable to the south-east). Some seagrass was growing above LWM in the fine sediment seaward of Young and Bolger Bays.

Whilst much of the coral reef flat is dead with sediment on it, and seagrass in places, bare coral was visible in all the aerial surveys, off Cockle Bay, in the channel which separates the landward area of reef flat from the oval area seaward.

Magnetic Island, South-East Coast

The aerial surveys of 1-7 June 1959, 11 August 1961, 30 May 1974, 28 November 1978, 14 July 1981, 28 June 1985 and 30 June 1988 give good coverage of this coast and intertidal zone. The coast consists of a series of granite promontories separated by bays, which are only small along the northern half, but are much broader further south (Figure 12). In the major Picnic, Nelly and Geoffrey Bays large coral reefs have formed in the shelter of rock headlands to the north-east, with smaller reefs forming in similar positions in Alma, Arthur, Florence and Gowrie bays further north. In all except the last of these bays and in Rocky Bay sand bayhead beaches have formed.

From these aerial photographs at a scale of about 1:12,000 or more the sand beaches in the small bays show little change in width or bayhead position throughout the period 1959 to 1988. Similarly the coral reefs in the small Alma, Arther, Florence and Gowrie Bays, which are seen beneath the water on most of these surveys, show little detectable change in extent.

The three major bays have several characteristics in common and show a little variation between surveys. Picnic

Bay has a continuous upper beach of relatively coarse sand and is flanked by a lower beach of finer sand which reaches its broadest at the north-east corner of the bay. The fine sand covers the upper part of the coral reef flat. Seaward the reef flat with living coral is extensively exposed at LWST. The extent to which the reef flat was bare of sediment varied on different surveys. The lower beach was less extensive in 1974 than in 1959; it was more extensive west of the jetty in 1978 than in 1974; it was less extensive east of the jetty in 1981 than in 1978; but subsequently in 1985 and 1988 it showed little variation with 1981. A separate coral reef lies seaward and curves round Nobby Head.

Nelly Bay shows a similar distribution of upper and lower sand beaches to Picnic Bay, but towards the seaward side of the lower beach, sand bars are usually well developed, extending from the granite headland to the north-east towards the centre of the long upper beach. However the extent of sand bar formation showed some variation between surveys. There were less sand bars in 1974 than in 1959; they were better developed in 1978 than in 1974; they were less developed and smaller in 1981 than in 1978; there was little change in 1985, but in 1988 a very well developed large sand bar extended almost completely across the north-eastern end of the bay from close to the rock headland. Nelly Bay has an extensive coral reef seaward and south-west of the lower sand beach.

Geoffrey Bay has upper and lower beaches and a coral reef similarly distributed to those in Picnic and Nelly Bays. As in Nelly Bay sand bars develop along the seaward edge of the fine sand lower beach, from midway along the rock headland at the north-east end of the bay to about two-thirds of the distance south-westwards along the narrow upper beach. There were less variations on the lower beach in Geoffrey Bay than in Nelly Bay during the period of aerial surveys.

Little change occurred between the 1959 and 1981 surveys, then in 1985 the lower beach had extended towards the quay on the headland, but had moved away from it again by 1988.

Magnetic Island, North Coast

The aerial surveys of 1-7 June 1959, 11 August 1961, 30 May 1974, 28 November 1978, 14 July 1981 and 15 June 1985 provide the most complete cover of this coast. For most of its length this is a rocky coast mainly formed in granite, but with volcanic rocks outcropping near West Point (Figure 12). Bayhead beaches of relatively coarse sand have formed in the small bays: Radical, Balding, Maud, Norris, Wilson and Huntingfield Bays. Small coral reefs have developed seaward of the sand beaches in Maud and Wilson Bays which are well sheltered by rock headlands on their western sides. Horseshoe Bay is the only major bay along this coast. It has a long sand bayhead beach and coral reefs have formed in two sheltered embayments along the rock headland bounding its eastern side. A sand beach flanks the landward side of the northerly reef.

No pronounced changes could be detected in the small bays, either to the sand beaches or coral reefs, from the aerial surveys. In Horseshoe Bay, the sand beach varied little in width or length between 1959 and 1985. George Creek, which was diverted towards the eastern end of the beach in 1959 and 1961, had cut a more direct route seaward nearer the western end by 1974; then between 1981 and 1985 it became increasingly direct. The coral reefs and beach landward of the northern one changed little during the whole period, but there was a slight variation in the extent to which sand delivered by a small creek, covered the south end of the southern reef.

Ground Surveys

From the aerial surveys, changes in plan view have been mapped, described and discussed for the period 1941 to 1988. In comparison with the aerial surveys, coastal ground surveys have been much more limited in scope and frequency.

The most extensive ground surveys were carried out by the Beach Protection Authority in 1982 and 1983 along the west Cleveland Bay coast between Townsville Harbour and Cape Pallarenda, and on Magnetic Island between Picnic and Alma Bays on the south-east coast and between Radical and Horseshoe Bays on the north coast (Figure 14). 1/6 of the approximately 2,000m long cross profiles were surveyed only once, but the remaining 45 were surveyed in both years. Overall the vertical changes along these were slight and are summarized in Table 6. (As these survey results were obtained as plotted profiles amounts of change cannot be ascertained precisely).

Other coastal ground surveys were carried out by the Townsville Port Authority along 5 cross profile lines between Townsville Harbour and Cape Pallarenda (Figure 15). Replicate surveys were undertaken on 6 dates between 26 January 1978 and 28 March 1983 and a summary of the changes between successive surveys is given in Table 7. As with the Beach Protection Authority surveys, overall the vertical changes along the profiles were only slight (ie 0.1 - 0.2m accretion or erosion). The most consistent changes were in the sand bars and troughs along the landward 850m of the Run 4 profile in Rowes Bay. (Since this data was collected and analyzed a further survey was undertaken along 4 of the above cross profile lines on 7 December 1988).

CHAPTER 3

Processes Influencing Sediment Movement in Cleveland Bay

In order to assess any possible role which dredging has played in the coastal and nearshore zone changes revealed by the aerial surveys between 1941 and 1988 and the ground surveys of the late 1970's to early 1980's, it is necessary to review the processes influencing sediment movement in Cleveland Bay. Processes operating in the coastal catchments as well as marine processes are important.

A Coastal Catchment Processes

Cleveland Bay is influenced not only by the catchments of the small rivers flowing into it, of which the Ross River (catchment area 750 km^2) and Alligator Creek (69 km^2) are the largest, but also the vast 129,660 km^2 catchment of the Burdekin River, the delta of which lies south of Cleveland Bay(Figure 22). For both geological and climatic reasons ideal conditions exist for a high sediment yield.

1 Geology

Geologically, there are remnants of sedimentary basins containing Palaeozoic flysch sediments, inter-bedded with thick silica-rich volcanic flows and tuffs. Granitoid plutons were densely intruded probably during the Upper Carboniferous and basin outlines were changed later by igneous intrusions, faulting, folding, erosion and concealment by younger sediments. More recently during the Tertiary and Pleistocene large areas were covered by olivine basalts and surficial deposits of unconsolidated sands, gravels, clays and silts.

2 Climate

The seasonally wet and dry tropical climate, with rainfall occurring primarily during the hotter summer months between November and April, when tropical cyclones may occur and generate major river floods, produces rapid weathering and erosion. Rainfall records for Townsville Pilot Station (1871-1940) and Townsville Airport (1941-) have been amalgamated to produce Table 8, which is presented in hydrological years commencing in October. The mean annual rainfall is 1147mm and the monthly means show a clear concentration between December and March, but with moderate rainfall in November and April. Table 8 and Figure 16 reveal a further characteristic of the rainfall, its marked variability from year to year, ranging between a minimum yearly total of 236mm in 1901-2, to a maximum of 2661mm in 1889-90. The highest rainfall totals, as well as the highest intensity rainfall, are usually related to a tropical cyclone nearby.

3 River Regimes

The river regimes strongly reflect the rainfall pattern. Records of monthly volumes for Ross River at the Ross River Dam headwater (1974-1987) (Table 9a), Alligator Creek at Allendale (1974-1987) (Table 9b), and Black River at the Bruce Highway, slightly north of Cleveland Bay (1973-1987) (Table 9c) show maximum discharge between December and May. Low flows occur between June and November in Alligator Creek and Black River during the winter dry season, but on Ross River, dammed since 1973 no water passes over the spillway during most of this season. These are the only rivers flowing into Cleveland Bay or nearby for which Queensland Water Resources Commission (QWRC) records exist for more than 2 years. The high annual rainfall variability is clearly reflected in the variations in the annual volume figures for these three rivers: Ross River 302,672 - 0 Ml, Alligator Creek 66,932 - 6,327 Ml & Black River 399,051 - 55 Ml, and seasonal variations are shown in the monthly volume figures: for Ross River 191,089 - 0 Ml, for Alligator Creek 33,226 - 0 Ml, and for Black River 186,358 - 0 Ml.

For the much larger Burdekin River south of Cleveland Bay, longer discharge records exist, taken at Home Hill (1920-57) and at Clare (1949-). The Burdekin dominates coastal discharge over a wide area, including Cleveland Bay, with a mean annual discharge of 11,027,855 Ml and a range between 54,066,314 Ml and 305,185 Ml (QWRC data for Clare 1985). Analysis of Burdekin data for the period 1940 to 1980 has identified the major floods, and the close link between them and the passage nearby of a tropical cyclone is clearly shown in Table 10 (after Pringle, 1986). No further cyclones affected this coast between 1981 and 1987.

4 Sediment Supply to the Coast

The seasonality and high variability of rainfall from year to year is reflected through the river regimes in the rate of sediment supply to the coast. Whilst few measurements of sediment load have been taken along north-east Queensland rivers, some theoretical calculations have been made (Pringle, 1986). Belperio (1979) calculated the sediment and solute loads of the Burdekin River as follows in million tonnes:

	Washload	Bedload	Dissolved Load	Total
Average year	3.00	0.45	0.90	4.35
Flood year 1957-8	19.70	3.70	2.40	25.80
Drought year 1968-9	0.008	0.001	0.080	0.089
24h of peak discharge March 1946 (39,600cumecs)	6.40	1.70	0.30	8.40

For the Ross River (Belperio, 1983) has estimated the total mean annual load as 0.33 million tonnes but proportionate fluctuations will occur. The presence of the Ross River Dam since 1973 will have profoundly affected sediment delivery into Cleveland Bay, with the coarse fraction being trapped in the reservoir under most, if not all, conditions of flow.

5 Pollution

In addition to natural inputs of water and sediment from the rivers to the coast (even if these are distorted by engineering works upstream) man may be responsible for chemical and biological inputs through discharge of sewage and industrial effluent. Up to 1940 septic tanks were used in the Townsville area, but then after the installation of a mains sewage system, raw sewage began to be discharged into Cleveland Bay (G. Jones, Townsville & Thuringowa Water Board, personal communication 1988). Initially this was through a pipe at the Ross River mouth, directly into the inter-tidal zone (Figure 1). In 1986 this pipe was sealed and sewage was diverted to Sandfly Creek to double the existing level of effluent in that Creek. The Sandfly Creek sewage plant was commissioned in 1963, but not completed until 1976 therefore there was a gradual increase in effluent from 1963 to 1976. A secondary treatment plant was installed and became operational in 1989. Improvements are planned for the treatment of sludge from the plant. A further sewage treatment plant is in operation and discharges into lagoons near the Bohle River mouth. For the relatively isolated settlements on part of Magnetic Island and elsewhere in the Cleveland Bay area, package sewage treatment plants are installed and the effluent is used for irrigation water. The remainder of Magnetic Island is on septic systems.

Responsibility for monitoring and analysis of water quality lies with the Queensland Water Quality Council, recently renamed the Queensland Department of Environment and Conservation, Division of Environment. To determine the extent of influence of existing disharges to Cleveland Bay, water and sediment sampling exercises were undertaken between 1980 and 1982 and the results submitted in a report to the 98th Meeting of the Council (31 March 1982) and in a subsequent addendum (undated, c1983). Results of the sediment analyses are of relevance to the present project.

Sediment Pollution Study

Sediment sampling sites were located near the Ross River (eastern suburbs) and Sandfly Creek outfalls and seaward of these in an attempt to completely cover the zone of influence of the discharges (Figure 17a).

a) Sediment grain size

Sediment grain size analysis showed that >85% of most samples was <0.6mm (ie finer than coarse sand on the Wentworth scale). As settlement of particle-associated pollutants takes place mainly on sediment <0.063mm (finer than sand) the proportion of these fines in the samples was examined (Figure 17b). High levels were found in the mangrove fringe near HWM, lower levels in the higher energy mid to lower intertidal zone, then increasing levels seaward of LWM. Superimposed on this general pattern is an area of high levels seaward of the Ross River mouth, which may be part of the settling zone for fine particles discharged by the river and possibly also by Sandfly Creek.

b) Escherichia coli

The detection limit for E. coli was 10^2 colonies/gm of sediment and at most sites levels were lower (Figure 17c). However, positive results were obtained near the outfalls and in a zone northwards; and the shoreline and intertidal zones between the outfalls, together with Ross River were shown to be extensively contaminated.

c) Coprostanol

Coprostanol, found in the faeces of humans and other higher species is another useful indicator of sewage contamination, and persists longer than E. coli. Positive values were grouped round the outfalls, but also extended northwards from Ross River and Sandfly Creek mouths and linked seaward (Figure 17d). Two separate zones north-east of Sandfly Creek may reflect the movement of a plume in that direction under certain wave and tidal conditions.

d) Phosphorus

Total phosphorus shows a similar distribution pattern to that of sediment <0.063mm, as it is readily adsorbed onto fine particles (Figure 17e). As levels were low near the outfalls little enrichment occurred from the discharges.

e) Bicarbonate Extractable Phosphorus (BEP)

Only at sites close to the outfalls were levels raised (Figure 17f). B.E.P. is regarded as an acceptable relative measure of biologically available phosphorus and these results suggest there has been little increase in the eutrophication potential due to this factor.

f) Acid Extractable Phosphorus (AEP)

This has a completely different distribution pattern to those of the other phosphorus fractions (Figure 17g), but showed similarities with the *E. coli* and coprostanol patterns. Marked contamination occurred around each outfall and extended along the shoreline and intertidal zone between them. It also extended seawards north of Ross River mouth to the edge of the sampling grid (and therefore maybe beyond it) and northwards from Sandfly Creek.

g) Oil and Grease

Values were generally low over the sampling grid area, implying low contamination levels (Figure 17h). The higher values in Ross Creek mouth were believed to have a source other than sewage effluent.

h) E. coli, coprostanol and acid extractable phosphorus

Finally the distribution patterns of these three indicators of sewage contamination were combined (Figure 17i). Areas of greatest contamination lay around the two outfalls and the adjacent shoreline and inter-tidal zone, with a further area seaward of Ross River mouth. It is suggested that the latter is the zone where pollutant particles from both effluent plumes settle out in an area of predominantly fine sediment. A continuous area of lower pollution existed around the more highly polluted cores. Overall however it was concluded that the sewage effluent was making a relatively minor environmental impact because of the high degree of dilution and dispersion in Cleveland Bay. The only serious exception was in Sandfly Creek which was grossly polluted.

Since this report was completed about 1983, the closure of the eastern outfall in 1986 and diversion of its effluent through Sandfly Creek is likely to have changed the pollution pattern and levels considerably. However, the secondary treatment plant which recently became operational in 1989 should improve the situation rapidly.

B Marine Processes

1 Wind Influences

Within the Cleveland Bay area Bureau of Meteorology wind data is available from Townsville Airport and before 1987 was available from Cape Cleveland lighthouse, with observations at 0900h and 1500h local time. Comparison of the two data sets (Oliver, 1978) has revealed some marked differences especially at 1500h. The Cape Cleveland data more closely indicates the regional airflow, with less modification due to topography and urban development and therefore is of greater value in an assessment of wind influences on marine processes. Wind data is available also from the Townsville Port Control Building from 1979 onwards.

The percentage occurrence of wind speed versus direction for Cape Cleveland for the 30 year period from 1957-1986 has been calculated by the Australian Bureau of Meteorology (Table 11). The 0900h observations reveal the dominance of south-east winds throughout the year, with this being especially pronounced during the winter months. The most frequent wind speeds at 0900h between March and August are 21-30km/hr, and between September and February are 11-20km/hr. The 1500h observations reveal that east winds are dominant between January and October, but north-east winds dominate in November and December. The most frequent wind speeds at this time are 11-20km/h between August and

February and also in June, but they rise to 21-30km/h between March and May and in July. The regional air flow is most closely represented by the 0900h records, as the 1500h records are influenced also by the diurnal sea and land breeze cycle (Oliver, 1978). The sea breeze, which is more strongly developed than the land breeze, generally blows normal to the coast. It is the south-east winds therefore which exert a major control on wave development over the sea, and on wind-induced currents in shallow water.

Whilst the 30 year data gives a valuable summary of wind conditions generally in the Cleveland Bay area it does mask considerable variations within this period. In order to examine wind conditions preceding most of the aerial surveys, and at other times which might be significant in relation to particular dredging projects for which monthly data has been compiled, monthly summary wind data were obtained for the period January 1965 to November 1987 in a form similar to the 30 year data in Table 11.

2 Waves

Since July 1975 the Townsville Port Authority has owned, and the Queensland Beach Protection Authority (BPA) operated, a Datawell 'Waverider' buoy sited 6km north-east of Cape Cleveland. For most of this period four 20 minute records have been taken daily at 0300h, 0900h, 1500h and 2100h. The BPA has analysed those records by computer using routine and spectral techniques to obtain the following parameters:

i	Zero crossing period (Tz) in seconds	The average period of all waves in the record based on upward zero crossings.
ii	Crest period (Tc) in seconds	The average period of all the waves in the record based on successive crests.
iii	Root mean square wave height (Hrms) in metres	The root mean square of the heights from the record.

iv	Significant wave height (Hsig) in metres	The average of the highest one third of waves in the record.
v	Maximum recorded wave height (Hmax) in metres	The highest individual wave in the record.
vi	Significant period (Ts) in seconds	The average period of the highest one third of waves in the record.
vii	Peak energy period (Tp) in seconds	The wave period corresponding to the peak of the energy density spectrum.

This data has been obtained for the period 19 November 1975 to 29 December 1988. For each calendar month the average, standard deviation, maximum and minimum have been determined for each of the 7 parameters (Table 12). (NB There are a few gaps owing to wave recording failures). As with the monthly wind data, this enables conditions to be considered in relation to the monthly dredging records and in the periods preceding the later aerial surveys. To provide a more generalised view similar wave statistics have been determined for each calendar year and dredging year ending on 30 June (Table 13). In addition, each parameter was plotted on a computer-drawn annual graph to aid visual inspection of the data.

The Beach Protection Authority (1988) have summarised their analysis of this wave data for the period 16 July 1975 to 29 December 1987. Annual graphs for significant wave height (Hsig) and peak energy period (Tp) form Figure 18. Wave period has been tabulated against wave height occurrences for all the data (Table 14a) and this shows that waves of 0.21-0.40m height and 3.00-4.99s period occur most frequently. For the summer data only (Table 14b) and for the winter data only (Table 14c) the same is the case. This data (but from 19 November 1975 onwards) is plotted in a different form as histograms showing percentage of time occurrence of wave heights (Hsig) for all wave periods (Figure 19a) and of wave periods (Tp) for all wave heights (Figure 19b).

The predominance of south-east winds which has been demonstrated in the preceding section, suggests that these are responsible for producing a high proportion of the waves recorded near Cape Cleveland. Regretably this 'Waverider' buoy system measures only vertical water movements and not wave direction as well, so this cannot be examined in the records. The relatively small frequently occurring recorded waves will have been generated mainly in the limited 240km fetch to the south-east landward of the Great Barrier Reef, although some will probably have been generated from the east and north-east in shorter fetches of 112km and 72km respectively. When the waves enter shallow water (depth less than half the wave length) they will start to interact with the seabed and become refracted. Wave refraction diagrams have been constructed for 5 second period waves from south-east, east and north-east (McIntyre and Associates, 1974). The south-east waves (Figure 20a) are partially refracted before entering Cleveland Bay and wave energy levels east of about Sandfly Creek are very low. The orthogonals show that wave energy is mainly concentrated on the coast west of Townsville Harbour. With this wind direction waves can be generated also in the 18km fetch of Cleveland Bay itself and may reach heights of 0.5m before breaking on the south-east Magnetic Island coast. Easterly waves (Figure 20b) are also considerably refracted in the bay resulting in energy levels being very low east of about Alligator Creek, but considerably greater on the western coasts. North-east waves (Figure 20c) approach Cleveland Bay from its most open direction, therefore refraction and dissipation of energy are at their least, but the relatively short fetch limits potential wave size. Cape Cleveland provides some shelter from north-east waves and the orthogonals indicate relatively low energy levels eastwards from between Alligator and Crocodile Creeks. Most of this wave energy is concentrated on the coasts west of Alligator Creek.

Only on rare occasions, such as when a tropical cyclone passes near Cleveland Bay are moderate to large waves likely to be generated from any other direction. Then, normally sheltered, low energy coasts may experience high energy waves and suffer considerable erosion.

3 Tides and Tidal Currents

Tides in the Cleveland Bay area are mainly semi-diurnal in type with a range of up to 4.0m during spring tides and down to 0.0m at neap tides, during 1988 (British Admiralty Tide Tables for Townsville, 1988). Easton (1970) notes that the solar influence on tides along the Queensland coast increases north of Mackay and this results in an increase in neap to spring variations. At extreme neap tides they become almost diurnal in type at Townsville, whereas at spring tides successive semi-diurnal tides may differ by about 1m in height.

Tidal ebb and flood generates important tidal currents especially during the higher range spring tides. Drogue measurements made by the Townsville Port Authority on a number of different dates and tidal conditions (although avoiding neap tides) are amalgamated into Figure 21a and b (McIntyre and Associates, 1974). The flood tide (Figure 21a) is shown entering Cleveland Bay in three streams. The first originates from the east, swings round Cape Cleveland and moves across the bay south-westwards with speeds of up to 0.5ms^{-1}. The second stream enters the bay from the north and swings closer to Magnetic Island, reaching speeds of 0.2 and 0.3ms^{-1}. The third stream enters the bay through West Channel between Magnetic Island and Cape Pallarenda, and reaches speeds of 0.7ms^{-1}. The opposing flood currents meet off Cape Pallarenda. On the ebb tide the current continues to flow south-eastward through West Channel reaching speeds of 0.3ms^{-1} on spring tides. Water therefore leaves the bay either close to Magnetic Island in a northerly direction at speeds of up to 0.4ms^{-1}, or towards the north-east at the same speed on maximum spring tides.

Belperio (1978) from a series of spot measurements of tidal current confirmed this pattern, but took no ebb current measurements in West Channel. Furthermore he gives no indications of dates or tidal ranges when the measurements were made. Carter and Johnson (1987) used recording current meters at 3 sites in Cleveland Bay (Figure 1) to measure water depth, and current speed and direction during a full neap to spring tidal cycle. Their findings are not presented alone, but are amalgamated with earlier published observations. They indicate that the tide floods into Cleveland Bay in a "south to south-south-east (170^{0}-230^{0}) direction" (there is an obvious discrepency here) and rotates anticlockwise to ebb north-north-east to north-east (030^{0}-050^{0}). At the eastern end of West Channel the flood is more westerly and the ebb more easterly, and furthermore during neap tides a weak current floods and ebbs in a consistently north-east direction. The source of this information relating to West Channel is unclear as none of their current meters was placed here and a current flowing at right angles to West Channel is very difficult to explain. Overall this pattern described by Carter and Johnson is similar to that revealed by the Townsville Port Authority drogue measurements except that the latter indicate a south-eastward flow through West Channel. A close linear relationship is reported by Carter and Johnson between tidal magnitude and measured bottom currents. During neap tides (0.5-0.8m range) currents are irregular in direction and less than 0.05ms^{-1} velocity; during spring tides (2.3-3.6m range) currents vary between 0.2 and 0.3ms^{-1} with minor asymmetry between the slightly stronger flood and slightly weaker ebb, but with regular orientation.

C Sediment Movement in the Cleveland Bay Area

Except close to the Magnetic Island fringing coral reefs, coastal sediment and sediment on the neighbouring seabed is dominantly siliceous and has a terrigenous source. The main source of sediment in Cleveland Bay is the small rivers and creeks which flow into it, although the damming of Ross River is likely to have reduced the overall quantity significantly. It has been noted above also that the very large Burdekin River further south is capable of delivering huge quantities of sediment to the coast during times of major floods associated with tropical cyclones. Belperio (1978) has suggested that at such times a turbulent jet from the Burdekin is turned north to north-westwards from the mouth due to the prevailing south-east winds and waves and its influence may be felt as far as Townsville. (Geostrophic effects and coastal trapping, together with the effects of the wind, provide an alternative explanation of this north to north-westward movement.) As an example Belperio considers a long period of heavy rainfall between 15 January and 8 February 1974, which followed Cyclone Una in December 1973, during which the average flow of the Burdekin was 16,000 cumecs and the total discharge $33 \times 10^9 m^3$. Such rare but massive inputs of fresh water must have a considerable effect on the circulation pattern, sediment transport, salinity and biota. It is possible that fine sediment from the Burdekin was deposited in Cleveland Bay as a result of this event.

As the Cape Cleveland 0900h records show, 60% of winds blow from the east and south-east, and they are almost solely from these directions when the wind velocity is over $7.5 ms^{-1}$. As a result wind-induced surface water currents move predominantly towards the west and north-west carrying suspended sediment alongshore. Belperio (1978) reports observing such surface currents moving over tidal flood and ebb currents during spring tides, although the tidal currents were deflected to some degree towards the north-west. Measurements taken off Cape Cleveland and in West Channel indicate that a 7-10ms^{-1} east or south-east wind is sufficient to obliterate the southward moving flood tidal current and set up a unidirectional current around each headland so that inner shelf water is moving through Cleveland Bay and the adjacent bays in a north-westward direction. This current, combined with wind-induced currents in south Cleveland Bay induces a major current flowing southwards along the west leeward coast of Cape Cleveland, which is reinforced by the tidal flood current. Belperio found the best sorted sub-tidal sediments in this area, which is also one where, unusually, sub-tidal bed load movement occurs. Moderately sorted sand, from sub-aqueous erosion of deep weathered rock along Cape Cleveland, moves south by ripple migration and supplies sediment to the intertidal flats along the south coast of Cleveland Bay. Wave induced longshore drift is then claimed by Belperio to result in substantial suspended sediment movement westwards past Townsville and through West Channel into Halifax Bay. Wind induced surface currents were observed to have a velocity of 0.2-0.3ms^{-1} in open water areas, but reached 0.5ms^{-1} in the constricted West Channel.

To study the movement of wind-induced currents below the water surface Woodhead sea-bed drifters (Phillips, 1970) were released by Belperio at times of low tidal range but strong wind and wave activity. From the recovery pattern it was shown (Figure 22) that the drifters had moved alongshore north-westwards, and a particularly strong sea-bed water movement had been demonstrated around Cape Cleveland and southwards along its west, leeward side and also through West Channel into Halifax Bay. From these results Belperio concluded that the entire water column in Cleveland Bay and the adjacent bays is essentially wind driven when wind velocity exceeds 7-10ms^{-1}, and this will influence both suspended sediment and bed load movement. This conclusion that the entire water column moves in a downwind direction is contrary to findings from seabed drifter investigations in Morecambe Bay, north-west England (a temperate storm wave environment) where strong winds blowing from the prevailing westerly quarter set up counter currents near the seabed moving from east to west (Phillips, 1968 and 1969). Although Cleveland Bay and Morecambe Bay are of similar dimensions, it may be that West Channel acts as an escape route for such wind driven water in Cleveland Bay and prevents development of counter currents. Further current measurements are required to clarify this.

Wind waves and wind-induced currents, as well as tidal currents in restricted localities such as West Channel on spring tides, are strong enough to entrain fine sediment from the bed of Cleveland Bay and even fine to medium sand on occasions. Belperio (1978) has mapped suspended sediment concentrations under different sea states (Figure 23). For smooth to slight seas, less than 10ppm were measured except over the intertidal flats, where wave action would be dominant. During slight to moderate seas (wind velocity 5.0-7.0 ms^{-1} and wave height up to 0.8m) a narrow continuous 1-2km turbid coastal zone developed with over 10ppm. With moderate to rough seas (winds 7.5-9.5ms^{-1}, wave heights 1.0-1.8m) the coastal turbid zone widened to 2-7km. Under rough sea conditions (winds 10-12.5ms^{-1}, wave heights 1.9-2.5m) the entire bay became turbid, but effective transport off Cape Cleveland did not extend beyond 5km from the tip of the headland. In addition a marked plume of turbid water extended round Cape Cleveland and south-westwards into Cleveland Bay indicating, according to Belperio, advective transport of suspended sediment from Bowling Green Bay.

Transport of sand along the inter-tidal zone and in the surf zone is primarily the result of waves breaking obliquely to the coast. Belperio (1978) calculated a transport rate of 50 tonnes per day in the surf zone at Rowes Bay under moderate sea conditions. If these prevailed for 71 days in a year, north-westward transport of sand would be about 3,500 tones yr^{-1}, but would be supplemented by higher rates under rough sea conditions. The loss of sand from the Townsville beaches along The Strand and the southern end of Rowes Bay result from Townsville Harbour interrupting the natural north-westward sediment movement from south Cleveland Bay and especially Ross River and Ross Creek.

Recently the existence of a further water movement in Cleveland Bay has been suggested (E. Wolanski, personal communication 1988). This involves a narrow inshore strip of water moving very slowly eastwards along the south Cleveland Bay coast, then northwards along the west Cape Cleveland coast to finally escape as a jet past the tip of the headland. This is produced by the development of baroclinic and barotropic coastal boundary layers in wet and dry seasons respectively. In the dry season this inhibits mixing of estuarine and shelf waters and limits estuary flushing. Pollutants would then either be retained in an estuary, such as Sandfly Creek, or would escape only into this narrow coastal water body to be evacuated from there extremely slowly. The sediment in this zone would not be moved by this slow moving water but, especially the fine fraction, would be likely to become very polluted.

CHAPTER 4

An Assessment of the Influence of Dredging on Sediment Movement, and Growth of Mangroves, Corals and Seagrass in Cleveland Bay.

From sidescan seismic profiling and vibracore sampling, Carter and Johnson (1987) have produced an isopach map of dredge spoil distribution in Cleveland Bay and a map showing surficial sediment facies distribution beneath the spoil (Figure 24). A maximum thickness of 50cm of dredged material from Townsville Harbour and the Platypus Channel was found in the vicinity of the two present dump sites east of Magnetic Island and seaward of Ross River mouth. The 50cm isopach was closely surrounded by the 30cm isopach near the landward dump site, but from the main seaward dumping ground the 30cm isopach extended south-eastwards and broadened towards the south-east coast of the bay. The 10cm isopach surrounded the two centres of concentrations in a triangular shape with its apex near the north-east tip of Magnetic Island and its base broadly paralleling the south and south-east coasts of the bay between the 5m and 2m isobaths. A further concentration of dredge spoil with a maximum thickness of 30cm was identified west of Platypus Channel and south-east of Middle Reef and probably relates to the dump site used before about the mid-1960's.

The aim of the present project has been to assess the influence of dredging on the coastline and intertidal zone as revealed by aerial surveys between 1941 and 1988 and the two series of ground surveys which exist. The higher quality air photographs taken at times of clear under-water visibility, and some of the ground surveys, have enabled this assessment to include the adjacent part of the subtidal zone at certain dates. For the period prior to aerial surveys, it is possible to make only a general assessment of the likely effects, based on relatively scant dredging data and contemporary observations, but drawing on present knowledge of processes.

1 Influence of Dredging between 1883 and 1964

Taking into account availability not only of aerial surveys but also of detailed dredging records and process data, the influence of dredging will be assessed for two time periods, 1883-1964 and 1965-1988. For the former period, the history of dredging has been examined in Chapter 1, data on dredged depths has been compiled into Table 1 and the intermittent annual dredging records are listed in Table 2.

Whilst a fair record of dredging exists in relation to the development of Townsville Harbour and the maintenance of depths suitable for shipping, only two written records have been found concerning the dump sites used for disposal of the dredged material. In 1883 it was "deposited close to Magnetic Island, about 5 miles distant from where it is raised" (Annual Reports of the Engineer of Harbours & Rivers on Works, 1876-1928), that is off Cockle Bay or the south end of Nelly Bay. The report for 1891-92 notes that "The cost of carrying (dredge spoil)... will possibly be slightly greater in the coming year as all the dredgings will be carried to Cockle Bay, in Magnetic Island, it not being advisable to deposit any eastward of the Eastern Breakwater". (The comparison with earlier costs probably takes into account the fact that much early dredging provided infill for reclamations, and it is not a direct comparison with the dumping described in 1883). It seems probable that these two references are to the same site, but how long this was used is unknown. The next information about dump sites is that before the early to mid 1960's dumping was carried out south of Middle Reef, but for how long is again unknown (N. Butterworth, personal communication 1988).

When considering dredge spoil it is important to differentiate between that obtained during developmental and maintenance dredging. Developmental dredging was of major importance in the late 1800's and early 1900's when the harbour was being constructed initially and the Platypus Channel was being excavated. Many references were made in the early reports to the difficulties of removing the "tenacious clay", "stiff clay" and "sandstone" which were encountered as well as softer mud and clay. Excavations for the Casino complex, now built adjacent to the Western Breakwater, have revealed not only the rapid rate of sedimentation there since that breakwater was constructed in the 1880's, but that the weathered Pleistocene basement is almost at the 1880's surface with only a thin bay-sediment veneer over it in places (Carter and Johnson 1987). Elsewhere a sticky mangrove mud intervenes between the bay-sediment and the Pleistocene deposits. The top of the Pleistocene marks an abrupt increase in lithification and below it is a sequence, over 7m thick, of deeply weathered clays, quartz sand and a marine shellbed. Many of the beds contain carbonate or ferro-magnesian nodules resulting from deep sub-aerial weathering in the tropical climate. When this more lithified material forms dredge spoil it is probably relatively immobile after dumping and is likely to cause the raising of the seabed at the dump site. It will almost permanently bury the sediment, coral or seagrass previously on the surface of the seabed. This may have had a pronounced effect off Cockle Bay in the late 1800's and for as long as this dump site was in use and developmental dredging was being carried out. The sediment which is released from this more lithified state is likely to be more mobile and will be transported in suspension or as bedload and be more widely dispersed by waves and currents. More research is needed into tidal and wind-induced current flows and wave directions in West Channel to resolve the apparent contradictions in the results of different measurements made to date. Only then will it be possible with reasonable certainty to determine in which direction finer sediment would be carried from a dump site off Cockle Bay. Nevertheless it does seem likely that some fine sediment would settle in the shallow water on the extensive coral reef flat north-west of the bay and its presence there has been noted by Spenceley (1977), seaward of the mangrove fringe.

Maintenance dredging, to retain the depth excavated by developmental dredging, involves the removal of unconsolidated sand and mud deposited in the harbour and Platypus Channel by Ross Creek and as a result of general sediment movements in the bay controlled by wind, wave and tidal processes. Taylor (1980) claimed that 0.9-1.2m of sediment per year accumulated in the berths in "normal weather" and even greater thicknesses in Platypus Channel. Throughout the period of dredging from 1883 onwards it has been observed that deposition of sediment in the harbour and channel is especially rapid when a tropical cyclone occurs followed by major river flooding. The first such occurrence noted in the reports was in March 1890, followed by 24 January 1892, April 1894, January 1896 (Cyclone Sigma), March 1903, 1908, two in 1910, 18 February 1940, 7 April 1940, 28 March 1944, March 1946, 6 March 1956 (Cyclone Agnes), 24 December 1971 (Cyclone Althea) and February 1976. After such events a considerable amount of maintenance dredging was necessary to restore depths and therefore large quantities of fine sediments were carried out to the dump site(s). From the site off Cockle Bay it is likely that some of this sediment was transferred onto the neighbouring coral reef flats, although some was probably moved further away by tidal currents south-eastwards (Townsville Port Authority drogue measurements) or north-westwards by sea-bed currents induced by strong south-east winds (Belperio's sea-bed drifter investigations). A third influence, north-east tidal currents across West Channel reported by Carter and Johnson would have transferred most of the dredged sediment onto the south-west coast of Magnetic Island and its adjacent coral reef. As noted earlier however a tidal current flowing in this direction is very difficult to explain and appears improbable.

The dump site south of Middle Reef, which was used prior to the early to mid-1960's, would have been in a more central position on a cross-section of the eastern end of West Channel. It is important to note however that no written record or detailed description of its location has been found. Fine mobile sediment is likely to have affected Middle Reef itself but it probably had less effect on the nearby coasts, than that from the Cockle Bay dump site. This sediment was probably either carried into Cleveland Bay by tidal currents or moved north-westwards by currents induced by strong south-east winds. In the latter instance some of the fine sediment is likely to have been deposited on the Cape Pallarenda-Shelly Beach foreland.

2 Influence of Dredging between 1965 and 1988

From 1965 onwards much more detailed information exists about dredging and wind and wave conditions in Cleveland Bay. Monthly dredging records for the S.D. 'Townsville' 1965-1983 are presented in Table 3 and Figure 5. Records for the T.S.D. 'Sir Thomas Hiley' 1974-1976 are given in Table 2, and for 1983-1988 in Table 4. Annual dredging records amalgamating all these are plotted in Figure 4. All these records are examined in Chapter 1. Throughout this period it is understood that the present shallow draft dump site south-east of Magnetic Island (Figure 1) has been in use, although no written record has been found of when it was first used. Similarly it is not known when the deep draft dump site east of Magnetic Island began to be used, but it is believed to have been from the early 1970's onwards. As indicated in Chapter 3 monthly summary wind data has been obtained for Cape Cleveland from 1965 to 1987 and wave data from the nearby wave recorder from 1975 to 1987. The dredging data, wind and wave data and general information on tides and currents will be used in the following assessment of the influence of dredging on the changes identified from the aerial surveys and described in Chapter 2.

a) Coastline and Intertidal Changes

Along most of the coasts of Cleveland Bay and Magnetic Island these changes were slight between about 1941 and 1988. East of the east mouth of Shelly Creek the sand beach which was originally seaward of the mangroves was driven landward through them. Erosion near the mouths of the rivers and creeks between Ross River and Cocoa Creek between 1941 and 1973 were noted by McIntyre and Associates (1974). In all these cases the erosion is attributable to natural cyclone effects and is of a similar type to that observed along the east Burdekin delta coast during the same period (Pringle, 1983 and 1984). Erosion of the upper sand beach at the south-eastern end of The Strand in Townsville during the period was not a natural process but resulted from the Harbour interrupting the natural longshore sediment movement north-westwards from the south coast of Cleveland Bay.

Only near Ross River mouth have larger scale coastal changes taken place and these are directly linked to dredging. Reclamations along the west coast of Ross River mouth have been taking place for a long period as the Harbour and adjacent industrial area have expanded. Between 1968 and 1970, 2,319,660m^3 of sand were pumped ashore from the adjacent intertidal sandbanks for a major reclamation here. In 1979-80 about 400,000m^3 of sand was removed from the Ross River bed immediately upstream of Goondi Creek for an 8ha reclamation east of the Harbour's Eastern Breakwater. As relatively little sediment is being delivered to the coast by Ross River because of the presence of the Ross River dam completed in 1973, this sand is likely to be replaced only very slowly. In addition to this sediment removal, developmental dredging took place in the Ross River channel between 1977 and the early 1980's and this sediment was mainly pumped ashore although small quantities were taken to the shallow draft dump site south-east of Magnetic Island. Maintenance dredging has been undertaken here since and the sediment has been disposed of similarly. As was noted in Chapter 3, sediment in Ross River mouth and seaward of it, was found in the early 1980's to be heavily polluted by sewage effluent from the outfall on the east side of the mouth. This was likely to have been the case from at least the beginning of the period at present under consideration, namely 1965. Polluted sediment would therefore have been incorporated in the land reclamations and would also have been carried to the shallow draft dump site in Cleveland Bay. Further changes have been brought about by the construction between 1981 and 1985, of an angled harbour wall east of the Eastern Breakwater and extending across part of the intertidal sandbanks. The result of all this dredging and construction work in the Ross River mouth area has been to move the main channel westwards from its former position across the intertidal zone, so that it now lies almost due north of the mouth. The presence of the angled harbour wall has caused some sedimentation landward of it on the west side of the channel.

b) Changes to the Mangrove Coasts

Changes to the outline of the mangrove coasts were generally slight during this period. East of the east mouth of Shelly Creek mangroves have been killed due to exposure to wave action, after the sand beach which had protected them was driven landward through them. In the most sheltered part off Rowes Bay mangroves extended a little. Along the south and south-east Cleveland Bay coasts, McIntyre and Associates (1974) had earlier, between 1941 and 1959, observed about 50m of recession between Sandfly and Alligator Creeks and about 30m of recession along the west banks of the mouths of Alligator, Crocodile and Cocoa Creeks. This was attributed to cyclone effects. During the period now under consideration the extent of the coastal mangrove belt changed very little. There was a slight extension along the coast at the north-east end of Laun's Beach and mangrove colonization began on the north-east side of White Rock Bay. Such changes must be considered as natural.

The only more marked change to the mangrove coasts occurred along the south-west coast of Magnetic Island. The 1974 aerial survey showed considerable damage to what had been a dense and continuous belt of mangroves at the times of the 1959 and 1961 aerial surveys. By 1974 a broad strip of mangroves had been destroyed landward of, but parallel to, the seaward fringe. Further investigations have revealed that Cyclone Althea in December 1971 caused this destruction (Spenceley, 1977). It occurred primarily in the *Rhizophora* zone, where some wind throw took place immediately, but progressively, during the next 6 years, over 50% of the *Rhizophora* spp. were killed. The reason for this is unclear, but may be the result of an influx of fresh water, sediment overloading and blocking of pores, or fungal activity. Furthermore Gill and Tomlinson (1969) found that *Rhizophora* spp. lost their ability to regenerate by shoot development on reaching maturity. Only if sediment overloading was the cause, could dredging and more specifically the dumping of dredge spoil be in any way to blame. This cause was not proved, but if it was a contributory factor, the dumping of enormous quantities of dredge spoil in the early and mid 1970's may have played a significant part. (This will be examined in more detail below in relation to changes in seagrass cover). Later aerial surveys, especially those of

1981 and 1985 revealed the steady recovery of this damaged strip of mangroves.

c) Changes to the Coasts with Fringing Coral Reefs

As shown in Chapter 2, fringing coral reefs have developed in the Cleveland Bay area only along the coasts of Magnetic Island. The most extensive coral reef lies off the south-west coast. The likelihood of fine sediment being carried onto this reef flat from the earlier dump sites near Cockle Bay and south of Middle Reef has been considered above. During the period 1965-1988 it is believed that neither of these sites was in use. No marked change in sediment distribution was identified from the aerial surveys, although there were changes in seagrass growth in the sediment, which will be considered below. Movement of fine sediment to this locality from the present deep draft and shallow draft dump sites (Figure 1) is possible by tidal flood currents. It might be possible also by currents induced by strong north-east winds, but deflected north-westwards through West Channel.

The only changes on the coral reefs along the south-east coast of Magnetic Island, which could be identified from the aerial surveys at the scale of 1:12,000, were in the lower beach sand cover on the Picnic Bay, Nelly Bay and Geoffrey Bay reefs. The characteristics of this sediment which is partly terrigenous and derived from granite weathering primarily, and partly carbonate from the erosion of the reef are considered in detail by Smith (1974 and 1978). The smaller Picnic and Geoffrey Bays which are sheltered by headlands from wind, wave and tidal effects from the north-east and east, showed the smallest changes in the extent of lower beach cover over the inner reef flat. Conversely the larger and more exposed Nelly Bay showed greater lower beach change associated with sand bar development along its seaward edge. The changes seen in all three bays will have partly resulted from the effects of refracted waves generated by the prevailing south-east winds on the continental shelf landward of the Great Barrier Reef. However as noted in Chapter 3, the south-east wind is capable also of generating waves over the 18km fetch within Cleveland Bay and these unrefracted waves are probably responsible for the orientation of the beaches along the south-east coast of Magnetic Island, together with the changes which have been observed on them. No clear trend of expansion or contraction of these lower beaches was identifiable over the period 1965-1988 and it therefore appears unlikely that dumped dredge spoil is being redistributed onto those beaches. Collins (1987) notes that there have been many unsubstantiated claims locally that dredging is having a harmful effect on these coral reefs. Despite many years of detailed biological studies on them he has found no evidence of this, but notes that two natural events did temporarily damage the corals. The first was the freshwater dilution associated with the rainfall from Cyclones Althea and Bronwyn in December 1971 and January 1972 which caused the deaths of many shallow water colonies. The effects however were obliterated in about 10 years, after some regrowth and some new growth on the dead skeletons. The second event was a large scale 'bleaching' in 1982 which caused the depletion of certain species. Small scale 'bleaching' is common on Magnetic Island reefs and may be the result of such stress factors as high summer temperatures or rain dilution of sea water. The reefs had largely recovered from the 1982 event within 5 years. Thus searching for causes of change, it must be remembered that there are a range of natural events as well as human effects which can influence these.

d) Changes to the Seagrass Beds

Changes to the seagrass beds around Cleveland Bay and Magnetic Island, as identified from the aerial surveys, were the most marked coastal changes to be found. Although slightly outside the period under consideration at present, 1965-1988, the 1959 and 1961 aerial surveys will be referred to, as well as the later surveys.

The distribution of seagrass beds in the Great Barrier Reef lagoon have been mapped recently during a series of field studies by the Northern Fisheries Research Centre (Coles et al, 1987a & 1987b). Their field survey of the Cleveland Bay area was carried out in October 1987 and is currently being analysed, but their draft maps were made available for this project (Figure 25). The maps were drawn from data collected on a series of diving transects at right angles to the coast, as well as by inspection of the intertidal zone on the transect lines.

Determining seagrass distribution from aerial surveys can never be as accurate as from detailed ground and under-water surveys, because of the height from which the coastal area is being viewed. Aerial surveys do have the advantage however of providing a broad overview of the area and this may be especially important in more inaccessible places. There can be specific problems in identifying seagrass beds on aerial photographs (R.G. Coles personal communication, 1988), firstly because the common algae _Caulerpa_ may be difficult to separate from seagrass. (As little _Caulerpa_ is thought to be present in Cleveland Bay, this is not a serious problem here). Secondly water depth limits the area over which seagrass can be recognised and Coles believes it is not generally visible in water with a depth over 1m. In Cleveland Bay the densest seagrass growth is between +1.0m and -0.5m Chart Datum (CD), however it generally extends to about -2.0m CD, eg. seaward of The Strand, Townsville, and reaches -10m CD near Magnetic Island. From the aerial surveys used in this project it was certainly not possible to see the sea-bed in the deeper areas, where seagrass was located in the field surveys (Figure 25). Seagrass was not visible also along the south-west coasts of Cleveland Bay where greater turbidity occurs than along the more sheltered south and south-east coasts. Even in the intertidal zone it is not possible to locate low growing and thinly spread seagrass on the aerial photographs. Before seagrass distribution was mapped from these aerial photographs they were carefully inspected and discussed with R. G. Coles and W. J. Lee Long at the Northern Fisheries Research Centre, to ensure as high a level of accuracy as possible. When seagrass distribution is to be compared on a series of aerial surveys further difficulty may arise unless all the surveys are flown at the same time of year, because there can be marked changes in the pattern of growth between summer and winter. The aerial surveys referred to below were all flown in winter between late-May and mid-August, except for the 1973 survey which was flown in early October and the 1978 survey which was flown on 28 November (Table 5). Location of seagrass beds is surer on colour aerial photographs, which were available from the surveys between 1974 and 1985; however, using experience gained with these, seagrass could be identified with reasonable certainty on the black and white photographs from the earlier surveys.

The seagrass distribution pattern mapped from a series of aerial surveys for different sections of the coast of Cleveland Bay and Magnetic Island were described in detail in Chapter 2 and are shown in Figures 6,10 and 13. In the Shelly Beach - Cape Pallarenda section (Figure 6) areas of seagrass were clearly visible in the central and coastward parts of the foreland on the 1959, 1981 and 1985 aerial photographs, but none showed on the 1974 photographs despite their high quality and good under-water visibility. Between Sandfly and Cocoa Creeks (Figure 6) no seagrass could be located on the 1974 aerial photographs, however it was present north-eastwards from the mouth of Crocodile Creek in 1978 and 1981, and had extended along the whole section by the 1985 survey. Between Cocoa Creek and Cape Cleveland some seagrass was visible in 1961, none was observed on the 1973 survey and very little on the 1974 survey, but in the later case some might have been obscured by very turbid water conditions between Cape Cleveland and Long Beach. The subsequent aerial surveys in 1978, 1981 and 1985 revealed a steady increase in extent and density of seagrass beds. Along the south-west coast of Magnetic Island (Figure 13) seagrass was visible seaward of Bolger and Young Bays, on the landward side of the coral reef flat further south and along the shore between Cockle Bay and Nobby Head, on the 1959 and 1961 aerial photographs. In 1974 however none was visible, despite the high quality of the photographs and clear under-water visibility. By the 1978 survey, limited areas of seagrass were visible again, and these subsequently extended as shown on the 1981 and 1985 surveys.

The overall sequence of change in seagrass cover in the Cleveland Bay and Magnetic Island area was from a moderate cover in 1959 and 1961, to almost none in 1974, followed by a steady increase in cover again from 1978 to 1985. The relatively long gap between the 1961 and 1974 aerial surveys makes it impossible to determine the date of disappearance precisely. (The 1973 survey was useable only along some coasts owing to part of it being flown at HW). However there were some noteworthy natural events between December 1971 and February 1974 which may have played a part, and also in 1972 the largest dredging programme ever undertaken by the Port of

Townsville in a short period began. The importance of such ecological factors as substrate stability, water clarity and salinity in determining the distribution of different species of seagrass is poorly understood (Lanyon, 1986) and this increases the difficulty of determining the likely cause.

The major natural events were associated with Cyclone 'Althea' in December 1971, Cyclone 'Bronwyn' in January 1972 which affected the Townsville Area as a rain depression, Cyclone 'Una' in December 1973 and a long period of heavy rainfall which followed in January and February 1974. Major floods were produced in the Burdekin River in January 1972 and January 1974 (Table 10) and therefore there was a massive input of fresh water into the nearshore zone, carrying with it a large quantity of terrigenous sediment. As shown in Chapter 3 such a sediment plume curves north and north-westward from the mouth of the Burdekin and its influence may reach Cleveland Bay. In addition there would be a fresh water and sediment influx to the bay from the smaller rivers draining directly into it. In Chapter 1 it was noted that 458,733m^3 of sediment had been deposited in the Platypus Channel, reducing its depth by 1.4m, after Cyclone 'Althea'. This was subsequently removed by the S.D. 'Townsville' in 1972 and deposited at the shallow draft dump site east of Magnetic Island.

The enormous developmental dredging programme began in the latter part of 1972 and caused the total annual dredging figures to soar to a peak of 2,112,879 tonnes in 1973/4. It began with the dredging of a new 'dog-leg' channel to extend the Platypus Channel seaward, as shown in Chapter 1. It was cut in relatively soft material, probably the Holocene mud identified by Carter and Johnson (1987), and this dredge spoil was deposited at the deep draft dump site. Both this, and the sediment from the Ross River/Ross Creek floods following Cyclone 'Althea', is likely to have been fine so that it could have been readily redistributed in the bay from the two dump sites in response to tidal and wind-induced currents, especially during the subsequent high energy event of Cyclone 'Una'. Developmental dredging within the Harbour would have been in the more lithified Pleistocene deposits and probably this material would have been less liable to redistribution from the dump sites.

It seems likely therefore that a large quantity of fine sediment was spread widely over the bed and coastal zone of Cleveland Bay as a result partly of the natural cyclone events and the subsequent river floods and partly as a result of the huge dredging programme which reached its peak between 1972 and 1975. It is possible therefore that much of the seagrass was buried or was so adversely affected by the high turbidity and/or high levels of fresh water that much of it died. The seagrass was able to recover and showed early signs of this by 1978, and a more complete recovery by the early 1980's.

CHAPTER 5

Conclusions

In an environment such as that of the coast and near-shore zone of Cleveland Bay many variable processes interact to shape the physical and biological evolution. The geology and climate in the coastal catchments influence rock weathering, erosion, river regime and therefore fluvial sediment supply to the coast. Marine processes are controlled by wind, wave and tidal regimes. The wind produces waves not only within the bay but in the available fetch seaward and also may produce currents especially in shallow water. The alternate flooding and ebbing of the tides moves the zone of breaking waves back and forth across the intertidal zone and also induces tidal flood and ebb currents which reach maximum velocity on spring tides in restricted channels. In addition to these natural catchment and marine processes man may have a considerable effect, through such activities as constructing dams on rivers, which trap not only water but sediment; concentrating pollution at particular localities where sewage and industrial effluent flows out to the coast; and dredging sediment from one locality and dumping it in another. Where such a wide range of natural and man induced processes are interacting, isolating the effects of any one particular process is difficult and complicated. However, against such a background is set this assessment of the influence of dredging in Cleveland Bay.

For the first 81 years of dredging, from 1883 to 1964, records of amounts and localities of dredging in the Townsville Harbour area are intermittent. The fact that amounts of dredged material are recorded in several different units which cannot be related to each other lessens their usefulness further. The greatest problem concerning this earlier period however is shortage of information about dump sites; only for 1883 and 1893 do written records exist which indicate that dredge spoil was dumped near Cockle Bay, Magnetic Island. Verbal information only suggests that before the mid 1960's a dump site south of Middle Reef was used, but for what exact period is unknown. Because of these serious limitations in the records, it was possible to assess the effects of dredging only very generally in the light of present knowledge and understanding of processes. The more lithified dredge spoil from developmental dredging, especially in the harbour area, will not have been so liable to redistribution from the dump site as is the unconsolidated finer sediment from maintenance dredging. The latter is likely to have been moved from the dump site by tidal and wind-induced currents, but whether this was predominantly in an eastward or westward direction is uncertain from present knowledge of these currents, as the use of different methods to measure these has led to some contrasting results. It seems possible however that some of the fine sediment from the dump sites near Cockle Bay and Middle Reef was subsequently deposited on the large adjacent coral reef flat, which extends from the south-west coast of Magnetic Island.

From 1965 onwards detailed dredging records which show localities and amounts of dredging have been kept by the Townsville Port Authority. Throughout this period the main dredge spoil dump site has been the shallow draft site south-east of Magnetic Island with a deep draft dump site east of Magnetic Island being used in addition from the early 1970's onwards. A permit for continued dumping at these two sites was issued in 1988. Also, more wind, wave and tidal data has become available for all or part of this period, which greatly aids understanding of the processes influencing sediment movement in Cleveland Bay. Aerial surveys have been carried out in this area from 1941 onwards and although they were relatively infrequent and their cover was variable during the next 30 years, in the 1970's and 1980's comprehensive coastal surveys have been undertaken every 3 to 4 years. These aerial surveys have been used to investigate coastline and intertidal changes and, on occasions of clear under-water visibility, also changes in adjacent parts of the subtidal zone. An assessment has been made of the influence of dredging on these changes.

The most direct effect of dredging has been near the mouth of Ross River. Here 2,319,660m^3 of sand were removed from the intertidal sandbanks between 1968 and 1970 to be pumped ashore for adjacent land reclamation. A further 400,000m^3 of sand was removed in 1979-80 from the Ross River bed immediately upstream of Goondi Creek, for land reclamation on the east side of the Harbour's Eastern Breakwater. The presence of the Ross River Dam upstream, which traps sediment, is likely to result in only slow natural replenishment of this sand. The sand removal plus developmental dredging between 1977 and the early 1980's in the Ross River channel, followed by maintenance dredging, has had two effects. Firstly the channel has been moved westwards from its previous natural route across the intertidal zone, which has affected the pattern of sedimentation. Secondly the sediment, which has been proved to be highly polluted from the sewage outfall on the east side of the Ross River mouth, has been used for land reclamation mainly, but some has been carried to the shallow draft dumping ground south-east of Magnetic Island from which it is likely to have spread out subsequently in response to current movements.

The dumping of very large quantities of dredged sediment in the early and mid 1970's probably played a significant part in more widespread changes to the seagrass beds throughout the Cleveland Bay area. The moderate seagrass cover visible on the 1959 and 1961 aerial surveys was reduced to almost none by the time of the 1974 survey, but showed the beginnings of a recovery in 1978 and subsequently a steady expansion on the 1981 and 1985 aerial surveys. The long interval in the 1960's and early 1970's when no aerial survey suitable for assessing seagrass cover was flown is unfortunate and makes it difficult to pinpoint more precisely the time of seagrass cover destruction. However it seems highly likely that it occurred in the early 1970's when major natural events and dredging activities combined to deliver a huge amount of fine sediment for distribution in Cleveland Bay. Cyclone 'Althea' in December 1971, followed by the rain depression produced by Cyclone 'Bronwyn' in January 1972, and Cyclone 'Una' in December 1973, followed by a long period of heavy rainfall in January and February 1974 caused major Burdekin River floods. These entered the Coral Sea as freshwater plumes, carrying large quantities of terrigenous sediment, which were turned northwards and north-westwards by the prevailing south-east winds and waves to subsequently reach the Cleveland Bay area. There was also a more direct freshwater and sediment influx to the bay from the smaller rivers flowing into it; about 458,700m^3 of sediment had to be removed by maintenance dredging from the Platypus Channel following Cyclone 'Althea' and the subsequent river floods. Developmental dredging to cut the seaward dog-leg channel to the Platypus Channel and increase the swing basin depth in the Harbour during the early and mid 1970's produced enormous quantities of dredge spoil. The total annual dredging figures soared to a peak of over 2 million tonnes in 1973/74, which is equivalent to nearly two-thirds of the Burdekin River's average washload plus bedload of 3.45 million tonnes (Belperio, 1979). As much of this dredged sediment appears to have been Holocene mud it is likely to have been redistributed in the bay from the dump sites, in response to tidal and wind-induced currents.

It therefore seems highly probable that most of the seagrass was buried by the deposition of this huge quantity of sediment delivered to Cleveland Bay both by natural processes and from dredging. It may have contributed also to the extensive death of mangroves, which took place along the south-west coast of Magnetic Island, during the 6 years following Cyclone 'Althea'. However from the aerial survey evidence it was not possible to detect any changes to the coral reefs, except in the seagrass growing in the sediment on the extensive south-west Magnetic Island coral reef flat.

Future Assessment of the Effects of Dredging in Cleveland Bay

To assess the effects of dredging in the future, with greater precision than has been possible in this retrospective assessment, it is suggested that the following monitoring and research programme is required:

1 Detailed recording of localities of dredging, amounts and type of material dredged, and locality of dumping.

2 Observations of the movement of the dredge spoil plume under different wind, wave and tidal conditions.

3 More detailed instrumental measurements of tides and tidal currents throughout Cleveland Bay and West Channel to provide an understanding of the circulation pattern, and to resolve the apparent contradictions in the earlier measurements obtained by different methods.

4 Establishment of a wind recording station to replace that at Cape Cleveland, which closed in 1987. Continued measurement of regional wind flow at a similar station is important to link to wave records, and for determining wind-induced water currents.

5 The wave recorders should be adapted or changed to enable wave direction to be recorded, in addition to wave height and wave period, as at present. Records from both Townsville Port Authority wave recorders, sited off Cape Cleveland and in Cleveland Bay, should be analysed by the Beach Protection Authority, not only the former as at present.

6 Monitoring of the various types of change discussed in this report, should be undertaken at carefully selected sites. Linked aerial and ground surveys would be especially valuable. Analysis of these changes in the light of varying wind, wave and tidal conditions, and the dredging programme should enable its impact to be assessed effectively.

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Attachment A

'APPENDIX 1'

Townsville Port Authority, Townsville, Queensland

ENVIRONMENT PROTECTION (SEA DUMPING) ACT 1981

GENERAL PERMIT

I, Graham Frederick Richardson, Minister of State for the Arts, Sport, the Environment, Tourism and Territories, having had regard to the matters referred to in Section 19 of the Environment Protection (Sea Dumping) Act 1981 and pursuant to my powers under the Act,

> one, grant a general permit to the Townsville Port Authority, No 1 The Strand, Townsville, QLD, 4810 and any person contracted by them for the same purpose, for a period of twelve months commencing on the date of approval, to load and to dump up to 350,000 tonnes of dredge spoil of the kind specified in Clause 5 of Appendix 1 attached, arising from the dredging of Townsville Harbour and approaches, subject to the terms and conditions which are described and specified in Appendix 1,

> two, grant a general permit to the Townsville Port Authority, No 1 The Strand, Townsville, QLD, 4810 and any person contracted by them for the same purpose, for a period of thirty-six months commencing on the date of approval, to load and to dump up to 53,000 tonnes of dredge spoil per annum comprising uncontaminated siltation material and spillage arising from small-scale maintenance dredging in Townsville Harbour and approaches, subject to the terms and conditions which are described and specified in Appendix 1.

Dated ....31st.................... day of ....May........... 1988

Graham Richardson

GRAHAM RICHARDSON
Minister of State for the Arts,
Sport, the Environment, Tourism
and Territories

Appendix 1

Conditions for dumping at sea of spoil arising from the dredging of Townsville Harbour and Platypus Channel by the Townsville Port Authority (TPA)

1. It is a condition of this permit that any requirements lawfully imposed by State Departments and agencies in areas under their jurisdiction relative to the dredging, transport and handling of dredge spoil are met.

2. The period of the permit is for twelve months for the first part and thirty-six months for the second part, both commencing on the date of signature.

3. Matters relating to operation of vessels and handling of dredge spoil are to be to the satisfaction of both the Queensland Department of Harbours and Marine and the Commonwealth Department of Transport and Communications.

4. Vessels used in the loading, carrying and dumping of the dredge spoil are to comply with all relevant provisions of international conventions.

5. In the case of part one, the large-scale dredging operation; the dredge spoil to be loaded and dumped comprises mixtures of silt, fine sand and clay, and is to be in accordance with those materials described in the permit application of 3 July 1987 and in information subsequently provided by the applicant. If there is any departure from this description, the Department of the Arts, Sport, the Environment, Tourism and Territories (the Department) is to be consulted immediately regarding possible changes in requirements prior to the loading of such material. In the case of part two, the small-scale maintenance dredging operation; the material to be loaded and dumped comprises uncontaminated siltation material and spillage.

6. The material to be disposed of is to be derived from dredging operations at Townsville Harbour and Platypus Channel as indicated in the permit application. No other material additional to that referred to above is to be loaded or dumped.

7. The total quantity of dredge spoil to be dumped under part one of this permit is not to exceed 350,000 tonnes, arising from approximately 200,000 cubic metres of material. The total quantity of dredge spoil under part two of this permit is not to exceed 53,000 tonnes per annum, arising from approximately 30,000 cubic metres of uncontaminated siltation material.

8. Dumping of all dredge spoil and washing of vessels in part one of the permit is to take place within a four-sided figure whose corners are situated at:

19°10'39" S	146°54'53" E
19°08'09" S	146°56'29" E
19°08'43" S	146°57'28" E
19°11'13" S	146°55'51" E

9. Dumping of all dredge spoil and washing of vessels in part two of the permit is to take place within a four-sided figure whose corners are situated at:

19°13'48" S	146°52'00" E
19°14'51" S	146°54'00" E
19°15'54" S	146°53'18" E
19°14'45" S	146°51'22" E

10. No later than seven days prior to the commencement of loading and dumping of the dredged material, the following information concerning the carrier(s) of the material is to be provided to The Secretary, Department of the Arts, Sport, the Environment, Tourism and Territories, GPO Box 787, Canberra, ACT 2601 (the Secretary)

- name(s) of vessel(s);
- name(s) and address(es) of owner(s) of vessel(s);
- name(s) and address(es) of master(s) of vessel(s);
- port(s) of registration;
- type(s) of vessel(s);
- expected date of commencement of loading; and
- expected frequency of dumping and amounts (eg per day/week).

11. The Department is to be advised promptly of any variation of the information provided in Clause 10 above.

12. All costs incurred as a result of specified monitoring activity and analysis of samples are to be met by TPA.

13. Examination of the dredge and dumping vessel log book entries, and verification that dumping is taking place in the correct location, is to be the responsibility of TPA.

14. Continuous supervision of all activities associated with the operation is to be undertaken by TPA, which is to advise the Secretary immediately of any unscheduled and environmentally adverse event.

15. The monitoring programs in Annex A are to be undertaken for the large-scale sea dumping event of part one of the permit and those specified in Annex B undertaken for the small-scale sea dumping events of part two of the permit.

16. Certified copies of dumping vessels' log book entries covering all loading and dumping activities are to be submitted monthly to the Secretary. The details recorded should include:

- time and date;
- quantities dumped; and
- actual location at the commencement of each dumping operation (latitude and longtitude).

17. Discharge of material at the dumpsite is to be managed so that, as far as practicable, spoil is distributed evenly over, and not beyond, the area of the site.

18. If at any time a developing risk is identified from dredging and dumping operations, measures are to be taken immediately to mitigate such risk, including restrictions on time and location of operations. The Department is to be advised immediately of any such situation.

19. Any additional monitoring, investigation or inspection which may be required in connection with this operation by the Department, including air and/or surface surveillance and the provision of facilities mentioned in clauses 21 and 22 below shall be at the cost of TPA.

20. At the completion of the dredging operation the following information is to be provided to the Secretary:

- dates of commencement and completion;
- total quantity of dredge spoil handled, in metric tonnes; and
- the least depth of water over the dredge spoil dumping site determined by sounding and expressed with reference to chart datum.

21. If so required, up to two Commonwealth Government nominees are to be afforded access to witness, inspect or examine any part of the operations, including any monitoring activity or equipment, and are to be provided with any necessary assistance in carrying out their duties. The Permittee is to meet all costs for the attendance of Commonwealth Government nominees including their travel, accommodation and associated incidental expenses.

22. If the duties specified in clause 21 require the Commonwealth Government nominees referred to above to go to sea, the permittee is to provide them with food and accommodation of an acceptable standard incidental to the carrying out of the duties specified. Arrangements are to be made for nominees on completion of the operation to be returned to a convenient Australian port.

23. If measures are taken to mitigate any developing risks under clause 18, a report is to be made immediately to the Department detailing such situations, measures adopted and subsequent monitoring proposals.

24. "Uncontaminated" in this permit and appendix shall have the meaning of not more contaminated that the material described in clause 5 of Appendix I.

25. TPA is to ensure that all owners and persons in charge of vessels involved in the dredging, loading and dumping of dredge spoil are fully conversant with the requirements of this permit and of the Environment Protection (Sea Dumping) Act 1981.

MONITORING REQUIREMENTS FOR THE DUMPING OF DREDGE SPOIL FROM TOWNSVILLE HARBOUR AND PLATYPUS CHANNEL

Purpose

The TPA intends to dump a portion of the dredge spoil obtained from Townsville Harbour on land after July 1989. The general purpose of this monitoring program is to find a suitable dump site for that portion of dredge spoil which will continue to be dumped at sea.

Specifically this monitoring program is to:

- determine whether the dumping of dredge spoil interferes with marine ecosystems and, if so, whether the interference is unacceptable;
- obtain a better understanding of the circulation in Cleveland Bay and determine whether there is a suitable alternative dump site in Cleveland Bay which has less effect on Platypus Channel and Magnetic Island beaches and reefs; and
- determine a suitable dump site outside Cleveland Bay should there be no suitable dump site within Cleveland Bay for large-scale dredge spoil from Townsville Harbour dredging.

Requirements

At the commencement of the permitted operation, the time taken for the plumes of dumped spoil to settle or disperse at the dumpsite is to be recorded and the movement of plumes under the full range of the tidal and current conditions is to be observed by a nominee of the GBRMPA, who shall report on any actual or potential hazard to neighbouring reefs or areas of ecological importance.

The Townsville Port Authority shall, in consultation with the Great Barrier Reef Marine Park Authority, the James Cook University and the Australian Institute of Marine Science, develop and carry out a monitoring program acceptable to the Department of the Arts, Sport, the Environment, Tourism and Territories which includes the following components:

- hydrodynamic studies of the circulation in Cleveland Bay, to the extent necessary to verify the suitability of the dumpsite or of an alternative dumpsite. Such studies may include modelling;

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- water quality studies at the dumpsite and in areas of ecological significance to the extent necessary to verify the suitability of the dumping practices adopted; and

- investigation and recording of neighbouring sensitive areas, including the reefs fringing Magnetic Island and sea grass beds in Cleveland Bay.

Reports on the above are to be provided to DASETT at six monthly intervals.

ANNEX B

MONITORING REQUIREMENTS FOR THE DUMPING OF DREDGE SPOIL FROM SMALL-SCALE MAINTENANCE DREDGING OPERATIONS IN TOWNSVILLE HARBOUR

Part two of this permit refers to the occasional dumping of small quantities of uncontaminated siltation material or spillage derived from maintenance dredging in Townsville Harbour. It is understood that no contaminated material is to be handled in this way.

Discharge within the designated dumpside for this material is to be so arranged that, as nearly as practicable, the material is distributed evenly upon a substratum of similar nature and grading.

In collaboration with the GBRMPA, measures are to be taken to avoid interference with dugong habitats and activities in waters adjacent to the dumping area.

TABLES

TABLE 1

Dredged Depths at Port of Townsville 1884-1987(metres below LWOST)

Year ending 30/6	Outer Harbour			Inner Harbour - Ross Creek			Dredge
	Platypus Channel	Swing Basin	Berths	Channel	Swing Basin	Berths	
1884	3.7						Platypus
1885	3.7						"
1886				1.1			"
1887							"
1888							Octopus
1889	3.0						"
1890		4.6					"
1891							"
1892			5.5				"
1893			5.5				"
1894	3.5		4.0				"
1895	3.8	4.0	6.7	2.1			"
1896							"
1897	3.4	3.8	5.9	2.0			"
1898	4.6	3.4	5.5-5.8	1.8			"
1899	4.6	4.6	5.2-7.9				"
1900	4.6		6.7				"
1901	4.1		6.4-7.3				"
1902	4.4		6.4-7.3	1.8			Octopus & Crocodile
1903	4.8		6.4-7.3	1.8			"
1904	5.2	4.6	7.0-7.3			1.5-2.4	"
1905	4.8	4.3	7.0	2.4		1.8-3.0	"
1906	4.9	5.2	6.4-7.0			1.8-2.1	"
1907	4.7	5.3	7.5	2.3			"
1908	4.7	5.1	6.7-7.0	2.3			"
1909	5.2		7.0-7.3	4.6			"
1910	4.6		6.7-7.6	3.0		3.0-4.6	"
1911	5.2		7.3-7.6	3.7	2.6-4.3		"
1912	5.0	5.0	6.9-7.2	3.0		2.7-4.3	Cleveland Bay
1913	5.5	5.7	6.7-7.6	3.4	2.7	2.6-4.3	"
1914	5.5	5.3	6.7-7.6	2.7	2.6	2.4-4.0	Cleveland Bay & Crocodile
1915	6.4	6.1	7.9-8.5	2.7		2.7-4.0	"
1916	6.4	6.4-7.3	7.9	2.6		5.5	"
1917	6.7	6.7	7.6-7.9	3.0		5.2	"
1918	6.7	7.3	7.6-8.2	2.9	2.9	5.0	"
1919	5.8-6.7	6.7	7.6-8.5	2.9		4.9-5.5	"
1920	6.7		7.8-8.5	2.9		3.4-4.6	Cleveland Bay

TABLE 1 continued

Year ending 30/6	Outer Harbour			Inner Harbour - Ross Creek			Dredge
	Platypus Channel	Swing Basin	Berths	Channel	Swing Basin	Berths	
1921							
1922	6.7	7.0	7.6-7.9	2.4	2.4	4.3-5.2	
1923	6.1	7.0	7.6-7.9	2.4	2.4	4.3-5.2	
1924	6.1	7.3	8.2	2.3	2.4	4.3-4.6	
1925	6.7	7.3	7.0-8.2	2.0	2.0	2.7-3.7	
1926	6.7	7.3	6.7-8.2	1.8	1.8	2.7-3.7	
1927	6.7	7.0	6.7-8.2	1.8	1.8	2.7-5.5	Cleveland Bay
1928	6.4		6.1-7.9	2.1		0.9-4.6	
1929							
1930							
1931							
1932							
1933							
1934	7.0	7.3	7.9				Cleveland Bay
1935	6.7	7.0	8.2	1.7	1.8	0.6-4.3	"
1936	6.7	7.0	7.9	4.0		1.1-4.9	"
1937	6.7	7.6	7.9-8.5	4.0			"
1938	6.7	7.0	5.8-8.5	3.8	4.0	3.0	"
1939	6.7	7.0	7.5-8.5	4.0	4.0	1.4-4.1	"
1940	6.7	6.9	6.6-8.5	3.7	4.0	1.4-4.3	"
1941	6.7	6.7	6.1-8.5	3.7	4.0	4.6	Cleveland Bay & Trinity Bay
1942	7.2	6.1	6.1-9.8	2.7	4.0	4.6	Cleveland Bay Trinity Bay & Platypus II
1943	7.5	6.6	6.1-8.8	2.7	4.1	3.7-4.3	
1944	7.3	6.9	6.1-8.5	2.9	4.0	3.7-4.3	Morwong
1945	6.7	7.0	4.7-8.8	3.2	3.8	3.4-3.8	Cleveland Bay
1946	6.1	7.0	7.5-8.5	2.1	2.1	2.1	Cleveland Bay
1947	6.6	7.0	6.2-8.5	2.1	2.1	2.1	Morwong & Trinity Bay
1948	5.9	7.0	6.1-9.4	2.1	2.1	2.1	Cleveland Bay & Trinity Bay
1949	6.4	6.6	5.6-8.5	3.0	2.0	2.0-2.1	Cleveland Bay
1950	5.9	5.8	5.8-8.5	3.0	2.0	2.0-4.0	"
1951	6.1	6.1	7.0-7.8	3.0	1.8	1.5-4.0	"
1952	6.4	6.1	6.7-9.4	3.0	1.8	1.5-4.0	"
1953	7.0	7.0	6.7-8.7	3.0	1.8	1.5-4.0	Cleveland Bay & Townsville
1954	7.0	6.4	5.9-9.1				"
1955	7.0	7.0	6.1-8.8	2.4	2.4	1.8-3.4	"
1956	7.2	7.3	4.9-8.5	2.4	2.4	3.4	"
1957	7.2	7.3	8.5-8.8	2.4	2.4	2.4	"
1958	7.0	7.3	8.7-9.1	2.4	2.4	3.4	"
1959	7.2	7.5	8.5-9.1	2.4	2.4	3.4	Cleveland Bay & Platypus II
1960	7.3	7.3	7.9-9.1	2.4	2.4		Cleveland Bay & Townsville

TABLE 1 continued

Year ending 30/6	Outer Harbour			Inner Harbour - Ross Creek			Dredge
	Platypus Channel	Swing Basin	Berths	Channel	Swing Basin	Berths	
1961	7.6	7.2	8.8-9.3				Cleveland Bay & Townsville
1962	7.5	7.6	8.2-9.1				"
1963	7.6	7.9	8.7-9.4				"
1964	7.9	7.9	8.4-9.8				"
1965	7.8	7.9	7.5-10.0	3.4	3.4		Cleveland Bay Townsville & Mourilyan
1966	7.8	7.8	7.8-9.8	3.4	3.4		Townsville
1967	7.9	7.9	7.8-9.9	3.0	3.0		"
1968	8.5	8.5	9.1-10.2				"
1969	8.5	8.5	8.8-9.8				"
1970	8.5	8.5	7.5-10.0				"
1971	8.5	8.6	8.2-10.0				"
				Ross River Entrance Channel			
1972	8.8	8.5	8.4-10.6	3.7			"
1973	9.0	8.7	8.3-10.8				"
1974	9.0	8.6	8.0-11.7				Sir Thomas Hiley & Townsville
1975	9.9	8.7	7.5-11.7				"
1976	10.7	8.6	7.7-12.5				"
1977	10.6	9.0	7.2-12.3				Townsville
1978	10.7	9.0	7.0-12.3				"
1979	10.8	9.4	7.2-12.0				"
1980	10.7	9.4	7.2-12.3				"
1981	11.0	9.5	8.0-11.6				"
1982	11.0	9.5	8.1-11.6				"
1983	11.9	10.4	7.4-11.2	2.1			Townsville & Sir Thomas Hiley
1984	10.4	10.4	7.3-11.2	1.3			Sir Thomas Hiley
1985	10.9	10.5	7.2-11.0	2.2			"
1986	10.7	10.5	7.2-11.4	2.2			"
1987	10.7	10.5	7.2-11.4	2.5			"

Sources:

1 Annual reports of Engineer of Harbour & Rivers on Works (Queensland) 1876-1928 (with gaps - see References).
2 Annual Reports of the Marine Department (Queensland) 1894-1933 (except 1921).
3 Annual Reports of Queensland Department of Harbours & Marine 1934-1987.

Note: In early data, especially before 1925, some discrepancies occur between dredging figures in different reports for same year; also variation in description of locality within harbour between different reports & years.

TABLE 2

All Dredging Records for Port of Townsville 1889-1965 and for 'Sir Thomas Hiley' 1974-1976

Year ending 30/6	Quantity Dredged	Notes	Dredge
1889	93,620 cu yards		Octopus
1891	67,900 " "		Octopus
Total to 1891	547,423 " "		
1892	133,595 " "	Sandstone & tenacious clay & mud	Octopus & Plant for 12 months
1893	203,966 " "	Mud, clay & sandstone	Octopus
1894	112,830 " "	Mud, clay & sandstone	Octopus
1895	207,410 " "	Mud, clay (some stiff) & sandstone	Octopus
1896	149,725 " "	Mud, clay & sandstone	Octopus in 8 months
1897	145,990 " "	Mud, clay and standstone	Octopus in 5.5 "
1900	656,000 " "		Octopus and Crocodile
1941	533,626 cu yards		Cleveland Bay & Trinity Bay
1942	425,000 barge tons	Allied Works Council Scheme for Townsville Harbour improvement	Trinity Bay
	287,000 " "	"	Morwong
	395,600 " "	"	Fitzroy
	61,450 " "	"	Platypus II
	40,650 " "	"	Cleveland Bay
	6,800 " "	"	G.F.H.
	268,000 tons	Maintenance dredging in Platypus Channel	Trinity Bay
11-12/1943	135,000 barge yards	From Platypus Channel & Outer Harbour	Morwong
1945	155,318 " "	From Platypus Channel & Harbour	Cleveland Bay
8-11/1946	349,000 " "	From Platypus Channel & Harbour	Morwong (also Trinity Bay - no date)
1949	450,000 " "	From Platypus Channel & Berths	Cleveland Bay
1950	420,000 " "	From Platypus Channel, Swing Basin & Berths	Cleveland Bay
1954	177,760 " "	" " "	Cleveland Bay
	1,020,000 " "	" " "	Townsville
1958	222,605 yards	" " "	Cleveland Bay
	872,000 "	" " "	Townsville
1959	154,970 barge yards	No 2 Pier	Platypus II (also Cleveland Bay and Townsville-no data)
1960	199,915 barge yards	Mainly developmental dredging	Cleveland Bay
	830,000 " "	Maintenance dreding	Townsville
1962	205,434 " "	Developmental dredging	Cleveland Bay
	689,000 " "	Maintenance dredging	Townsville
1963	63,620 " "	Developmental dredging - Suter Pier	Cleveland Bay
	813,000 " "	Maintenance dredging	Townsville
1964	129,664 " "	Developmental dredging - mainly tanker berth	Cleveland Bay
	1,134,000 " "	Maintenance dredging	Townsville
	50,910 " "	Ross Creek boat harbour - developmental dredging	Mourilyan
1965	77,826 cu yards	Developmental dredging - tanker berth	Cleveland Bay
	1,074,000 hopper yards	Maintenance dredging	Townsville
	60,860 barge yards	Developmental dredging - Ross Creek boat basin and berths	Mourilyan

TABLE 2 continued

Year ending 30/6	Quantity Dredged	Notes	Dredge
1974	1,510,700 tonnes (dry)	Developmental dredging in Platypus Channel and Swing Basin	Sir Thomas Hiley
1975	1,086,890 tonnes (dry)	Dredging Platypus Channel From Beacon 7 to harbour entrance and dragline dredging of Ross Creek	Sir Thomas Hiley
1976	316,030 tonnes (dry)	Developmental dredging in Platypus Channel and several berths	Sir Thomas Hiley

Sources:

1 Annual Reports of Engineer of Harbours & Rivers on Works (Queensland) 1876-1928 (with gaps see References)
2 Annual Reports of the Marine Department (Queensland) 1894-1933 (except 1921)
3 Annual Report of Queensland Department of Harbours & Marine 1934-1987

TABLE 3

Townsville Port Authority Monthly Dredging Records (tonnes) for S.D.'Townsville'

Date	Platypus Channel	Swing Basin	Berths	Total	Notes
1965 July	no records	no records	no records	no records	
Aug	no records	no records	no records	no records	
Sept	3,271	2,538	-	5,809	
Oct	24,293	1,225	88	25,606	
Nov	1,574	-	-	1,574	
Dec	-	-	-	-	
1966 Jan	-	-	-	-	
Feb	5,741	299	464	6,504	
Mar	2,598	8,176	6,262	17,036	
Apr	-	10,426	-	10,426	
May	8,933	10,163	6,154	25,250	
June	23,515	1,985	1,887	27,387	
Total 1965/6	69,925	34,812	14,855	119,592	
1966 July	26,639	110	856	27,605	
Aug	18,375	4,545	697	23,617	
Sept	17,760	2,806	1,469	22,035	
Oct	19,234	1,749	1,413	22,396	
Nov	27,392	1,990	-	29,382	
Dec	9,448	105	-	9,553	
1967 Jan	13,038	1,173	285	14,496	
Feb	12,073	3,691	1,122	16,886	
Mar	20,019	4,515	929	25,463	
Apr	-	-	-	-	
May	-	-	-	-	
June	35,140	1,496	213	36,849	
Total 1966/67	199,118	22,180	6,984	228,282	
1967 July	14,125	2,765	1,566	18,456	
Aug	26,636	1,600	-	28,236	
Sept	28,190	2,056	3,065	33,311	
Oct	16,455	3,773	821	21,049	
Nov	18,730	1,520	1,723	21,973	
Dec	12,214	2,550	2,698	17,462	
1968 Jan	1,567	329	254	2,150	
Feb	12,413	3,302	2,938	18,653	
Mar	24,770	3,174	-	27,944	
Apr	6,407	9,784	1,882	18,073	
May	13,889	10,577	1,532	25,998	
June	6,996	11,946	1,109	20,051	
Total 1967/68	182,392	53,376	17,588	253,356	

TABLE 3 continued
Townsville Port Authority Monthly Dredging Records (tonnes) for S.D.'Townsville'

Date	Platypus Channel	Swing Basin	Berths	Total	Notes
1968 July	-	-	-	-	
Aug	16,851	347	890	18,088	
Sept	15,829	6,901	3,225	25,955	6,416 pumped into boat ramp reclamation
Oct	26,186	6,614	211	33,011	17,126 " "
Nov	20,570	6,443	-	27,013	17,968 " "
Dec	15,953	1,174	-	17,127	14,514 " "
1969 Jan	-	-	-	-	
Feb	17,247	5,767	1,784		24,798
Mar	27,757	3,670	-	31,427	
Apr	34,517	-	-	34,517	
May	28,952	1,876	-	30,828	
June	20,873	6,450	7,238	34,561	
Total 1968/69	224,735	39,242	13,348	277,325	56,920 " "
1969 July	10,755	21,592	843	33,190	
Aug	34,644	2,957	-	37,601	
Sept	13,799	297	931	15,027	
Oct	19,993	4,251	-	24,244	
Nov	38,261	2,042	-	40,303	
Dec	13,210	721	-	13,931	
1970 Jan	4,789	6,344	9,475	20,608	
Feb	20,489	6,490	6,085	33,064	
Mar	30,328	4,328	1,107	35,763	
Apr	21,003	10,036	2,776	33,815	
May	32,545	530	-	33,075	
June	19,564	-	-	19,564	
Total 1969/70	259,380	59,588	21,217	340,185	
1970 July	6,194	1,985	6,293	14,472	
Aug	20,980	1,983	10,640	33,603	
Sept	25,359	4,767	6,828	36,954	
Oct	13,036	18,788	3,853	35,677	
Nov	729	22,829	9,032	32,590	
Dec	9,374	17,072	1,770	28,216	
1971 Jan	9,224	15,904	7,997	33,125	
Feb	260	33,065	-	33,325	
Mar	7,939	15,911	5,330	29,180	
Apr	13,620	5,425	6,588	25,633	
May	23,282	5,052	3,858	32,192	
June	9,118	5,198	11,173	25,489	
Total 1970/71	139,115	147,979	73,362	360,456	

TABLE 3 continued

Townsville Port Authority Monthly Dredging Records (tonnes) for S.D. 'Townsville'

Date	Platypus Channel	Swing Basin	Berths	Total	Notes
1971 July	-	3,115	3,993	7,108	
Aug	-	-	-	-	
Sept	31,647	3,113	-	34,760	
Oct	15,207	22,045	492	37,744	
Nov	11,209	23,256	951	35,416	
Dec	15,106	17,936	-	33,042	
1972 Jan	20,249	9,531	1,993	31,773	
Feb	29,502	3,601	-	33,103	
Mar	38,730	1,002	421	40,153	
Apr	49,589	1,185	408	51,182	
May	57,677	3,942	-	61,619	
June	52,995	1,561	1,012	55,568	
Total 1971/72	321,911	90,287	9,270	421,468	
1972 July	66,022	583	-	66,605	
Aug	14,257	585	-	14,842	
Sept	36,430	-	-	36,430	
Oct	118,476	-	-	118,476	
Nov	57,813	19,131	-	76,944	
Dec	13,578	-	14,542	28,120	
1973 Jan	91,280	-	-	91,280	
Feb	88,553	-	325	88,878	
Mar	55,494	10,944	5,642	72,080	
Apr	-	19,381	-	19,381	
May	-	29,474	726	30,200	
June	-	-	-	-	
Total 1972/73	541,903	80,098	21,235	643,236	
1973 July	-	-	-	-	
Aug	32,180	-	-	32,180	
Sept	67,853	-	-	67,853	
Oct	79,656	-	-	79,656	
Nov	25,575	566	37,281	63,422	
Dec	16,292	-	23,359	39,651	
1974 Jan	32,822	-	6,984	39,806	
Feb	49,310	5,441	7,647	62,398	
Mar	25,402	7,814	-	33,216	
Apr	25,867	6,235	1,385	33,487	
May	43,688	14,668	12,986	71,342	
June	64,855	4,809	9,504	79,168	
Total 1973/74	463,500	39,533	99,146	602,179	

TABLE 3 continued

Townsville Port Authority Monthly Dredging Records (tonnes) S.D.' Townsville'

Date	Platypus Channel	Swing Basin	Berths	Total	Notes
1974 July	64,335	5,640	747	70,722	
Aug	69,533	557	-	70,090	
Sept	38,668	6,824	5,225	50,717	
Oct	34,363	1,694	1,977	38,034	
Nov	36,205	3,623	562	40,390	
Dec	1,924	-	18,198	20,122	
1975 Jan	-	-	-	-	
Feb	4,575	9,751	-	14,326	
Mar	17,986	2,778	4,175	24,939	
Apr	13,672	-	9,370	23,042	
May	25,104	-	2,039	27,143	
June	15,105	365	11,132	26,602	
Total 1974/75	321,470	31,232	53,425	406,127	
1975 July	20,743	2,687	4,628	28,058	
Aug	16,371	423	-	16,794	
Sept	-	-	-	-	
Oct	-	-	-	-	
Nov	-	3,841	818	4,659	
Dec	-	21,793	678	22,471	
1976 Jan	15,709	15,446	3,347	34,502	
Feb	9,083	21,848	2,420	33,351	
Mar	12,103	39,144	879	52,126	
Apr	954	24,416	6,966	32,336	
May	23,760	17,325	9,596	50,681	
June	646	20,117	19,723	40,486	
Total 1975/76	99,369	167,040	49,055	315,464	
1976 July	-	37,694	1,714	39,408	
Aug	8,214	38,608	4,833	51,655	
Sept	-	39,715	4,287	44,002	
Oct	1,231	27,769	-	29,000	
Nov	-	-	-	-	
Dec	10,562	26,002	-	36,564	
1977 Jan	12,587	25,226	-	37,813	
Feb	44,038	21,094	-	65,132	
Mar	45,766	27,719	3,326	76,811	
Apr	34,397	12,665	7,196	54,258	
May	42,861	20,987	5,735	69,583	
June	24,199	30,005	4,961	59,165	
Total 1976/77	223,855	307,484	32,052	563,391	

TABLE 3 continued

Townsville Port Authority Monthly Dredging Records (tonnes) S.D. 'Townsville'

Date	Platypus Channel	Swing Basin	Berths	Total
1977 July	10,893	27,313	2,176	40,382
Aug	-	-	-	-
Sept	-	-	-	-
Oct	4,016	21,873	2,397	28,286
Nov	1,839	52,974	-	54,813
Dec	16,407	33,421	3,242	53,070
1978 Jan	43,033	14,392	2,300	59,725
Feb	44,406	21,872	-	66,278
Mar	43,889	15,919	7,537	67,345
Apr	18,099	26,404	9,044	53,547
May	1,573	37,760	13,810	53,143
June	20,388	25,022	12,739	58,149
Total 1977/78	204,543	276,950	53,245	534,738
1978 July	-	-	-	-
Aug	-	-	-	-
Sept	15,851	27,321	9,059	52,231
Oct	9,403	34,545	11,023	54,971
Nov	26,977	35,034	5,937	67,948
Dec	11,531	18,763	9,451	39,745
1979 Jan	50,129	12,930	4,726	67,785
Feb	41,543	14,789	5,798	62,130
Mar	53,860	11,759	9,864	75,483
Apr	36,441	13,422	7,289	57,152
May	29,829	24,877	19,401	74,107
June	18,699	26,565	7,234	52,498
Total 1978/79	294,263	220,005	89,782	604,050

Date	Platypus Channel	Swing Basin	Berths	Ross River Channel	Total
1979 July	45,344	5,457	14,242	-	65,043
Aug	64,525	-	-	2,121	66,646
Sept	-	-	-	-	-
Oct	26,915	668	8,565	-	36,148
Nov	38,139	-	2,563	10,875	51,577
Dec	23,705	-	3,193	10,422	37,320
1980 Jan	36,967	3,242	1,287	11,497	52,993
Feb	11,966	11,719	8,638	14,081	46,404
Mar	26,548	11,878	2,687	4,921	46,034
Apr	41,757	6,545	-	-	48,302
May	36,580	3,360	6,390	-	46,330
June	84,784	-	-	-	84,784
Total 1979/80	437,230	42,869	47,565	53,917	581,581

TABLE 3 continued

Townsville Port Authority Dredging Records (tonnes) for S.D.'Townsville'

Date	Platypus Channel	Swing Basin	Berths	Ross River Channel	Total
1980 July	95,935	-	-	-	95,935
Aug	8,935	58,326	-	992	68,253
Sept	38,636	18,518	2,188	4,630	63,972
Oct	-	-	-	-	-
Nov	19,942	8,324	-	5,648	33,914
Dec	35,831	9,493	-	5,242	50,566
1981 Jan	20,382	16,327	1,528	10,867	49,104
Feb	27,972	11,230	623	12,094	51,919
Mar	35,073	12,326	595	11,831	59,825
Apr	21,815	10,323	6,968	7,353	46,459
May	13,317	20,129	11,162	1,081	45,689
June	18,959	22,152	4,826	-	45,937
Total 1980/81	336,797	187,148	27,890	59,738	611,573
1981 July	9,650	14,025	10,354	-	34,029
Aug	-	-	-	-	-
Sept	-	-	-	-	-
Oct	-	-	-	-	-
Nov	7,324	45,020	-	5,750	58,094
Dec	8,533	27,803	-	7,550	43,886
1982 Jan	10,493	21,154	-	13,948	45,595
Feb	3,161	24,402	710	10,527	38,800
Mar	18,016	17,305	6,345	13,769	55,435
Apr	12,451	13,945	3,925	11,340	41,661
May	13,115	15,801	552	7,108	36,576
June	21,102	7,214	-	2,563	30,879
Total 1981/82	103,845	186,669	21,886	72,555	384,955
1982 July	-	-	-	-	-
Aug	31,832	8,983	966	-	41,781
Sept	35,219	12,645	8,073	4,399	60,336
Oct	47,468	9,468	-	8,357	65,293
Nov	35,735	5,535	559	12,038	53,867
Dec	31,080	4,559	2,670	4,061	42,370
1983 Jan	33,124	4,697	1,378	-	39,199
Feb	8,580	17,526	4,553	13,754	44,413
Mar	End of dredging by 'S.D. Townsville'				
Apr					
May					
June					
Total 1982/83	223,038	63,413	18,199	42,609	347,259

Notes: 1 From July 1983 dredging for a few weeks each year by Trailer Suction Dredge 'Sir Thomas Hiley'.

2 Although no written records have been found, it is believed that the dredged material in this table was dumped in the shallow draft dump site (Figure 1), except for that obtained during the dredging of the Sea Channel in the early to mid 1970's, which was dumped in the deep draft dump site.

TABLE 4

Townsville Port Authority Dredging Records 1983-88 for T.S.D. 'Sir Thomas Hiley'

		Dry solids (tonnes)	
1983	12 - 16 July	45,920	
	14 - 18 August	63,340	
		109,260	
1984	7 - 22 August	224,190	
	11 - 13 September	35,200	
		259,390	
1985	12 - 17 June	87,050	
1986	8 - 23 July	221,060	
	16 - 18 August	41,000	
		262,060	
1987	18 - 20 April	36,240	
	18 July - 1 August	216,110	
		252,350	
1988	17 June - 2 July	164,600	(including 62,780 tonnes developmental dredging spoil)
	27 July - 2 August	81,810	
		246,410	

NOTES

1983	Dredging in Swing Basin, Harbour & seaward along Platypus Channel mainly to Beacons 11-12.
1984	Dredging in Swing Basin, Harbour & seaward along Platypus Channel mainly to Beacons 13-14.
1985	Dredging in Platypus Channel, Harbour entrance to 11 and 12
1986	Dredging in Harbour & seaward along Platypus Channel mainly to Beacons 11-12, with a little to 7-8.
1987	Dredging in Swing Basin & seaward along Platypus Channel mainly to Beacons 11-12.
1988	Dredging in Swing Basin, Berths & Channel (locations not specified in earlier period, but seaward to Beacons 7 & 8 in later period); small amount of dredging in Sea Channel (dog-leg to main Platypus Channel seaward of 7 & 8) in earlier period.
1983-88	Dredge spoil deposited in deep draft dump site (Figure 1).

TABLE 5

Air Photographs used in this Report

Date	Area Covered	Type	Scale	Aerial Surveyor	Source
1941	E of Ross R mouth - Crocodile Ck	B & W	1:36,945	RAAF	D. Hopley, James Cook University
c1942	S Rowes Bay - E of Ross R mouth	B & W	enlargements	RAAF	Townsville City Council
1-7.6.59	Magnetic Is,Shelly Beach-Alligator Ck	B & W	1:11,520	Adastra	Townsville City Council
11-18.6.61	Magnetic Is, Shelly Beach-Cocoa Ck	B & W	1:86,502	CAB	Geograpy Department James Cook University
18.6.61	Magnetic Is, Shelly Beach - Cape Cleveland	B & W	1:86,502	CAB	AIMS
11.8.61	Magnetic Is, Shelly Beach, T'ville Harbour - E Cleveland Bay	B & W	1:24,049	Adastra	Geography Department James Cook University
7&8.71	Magnetic Is, Shelly Beach - E Cleveland Bay	B & W	1:31,680	Mapmakers	Townsville City Council
5-11.10.73	Magnetic Is, Cape Pallarenda-Cape Cleveland	B & W	1:12,066	AAM	Townsville Port Authority
30.5.74 & 14.6.74	Magnetic Is, Cape Pallarenda-Cape Cleveland	Colour	1:12,000	Beach Protection Authority	Geography Department James Cook University
28.11.78	Magnetic Is, Cape Pallarenda-Cape Cleveland	Colour	1:12,000	BPA	Sunmap
14-15.7.81	Magnetic Is, Cape Pallarenda-Cape Cleveland	Colour	1:12,000	BPA	Sunmap
15&24.6.85 28.6.85 & 15.7.85	Magnetic Is, Cape Pallarenda-Cape Cleveland	Colour	1:12,000	BPA	Sunmap
11.7.85	Magnetic Is - Cleveland Bay area	Colour	1:50,000	BPA	Sunmap
28.5.88	S Magnetic Is, Cape Pallarenda-Sandfly Ck (mosaic)	Colour	1:10,000	AAM	Townsville City Council
30.6.88	Magnetic Is, Pallarenda-E Cleveland Bay	Colour	1:28,575	D Hopley	Sir G Fisher Centre James Cook University

TABLE 6

Beach Protection Authority Cross Profiles - Summary of Changes

Townsville Harbour to W of Shelly Beach

Profile No Town	No of Surveys	Dates	Cross Profile Changes (distances in m from landward end)
19	1	Feb 1982	
20	1	"	
20.4	1	Jan 1983	
20.5	1	"	
20.6	1	"	
20.7	1	"	
20.8	1	"	
20.9	1	"	
21	2	2/1982 & 1/1983	Small change to upper beach swash bars - almost no change to 2,000 seaward of coast.
22	2	" "	Swash bar on upper beach slightly seaward in 1983. Slight erosi to 2,000.
23	2	" "	Slight change throughout 2,000.
24	2	" "	Small accretion throughout most of 2,000.
25	2	" "	Slight accretion to c 270, slight erosion in places to 1650.
26	2	" "	Small accretion at top of upper beach, small accretion at intervals to 1950.
27	2	2/1982 & 2/1983	Small accretion at top of upper beach. Slight accretion & erosi to large sand bars 200-750. Slight accretion seaward of 1300.
28	2	" "	Small accretion throughout, sand bars more developed especially landward of 1000.
29	2	" "	Slight accretion throughout most of profile, sand bars more developed landward of 750.
30	2	" "	Slight accretion landward of 750. Very slight erosion at intervals between 750 & 2000.
31	2	" "	Slight accretion & erosion landward of 500 as bars became more pronounced. Slight overall accretion 500 to 2000.
		" "	Bars well developed landward of 750.
32	2	" "	Small scale erosion & accretion as small bars moved slightly landward of 1250. Slight erosion seaward to 2000.
33	2	" "	Slight erosion & accretion as bars moved slightly along whole profile 0-2000.
34	2	" "	Slight erosion & accretion throughout with bar movement.
25	2	" "	Slight erosion & accretion throughout with subdued bar movement.
36	2	" "	Slight accretion along almost whole profile.
37	2	" "	Slight accretion & erosion along profile including Virago shoal. Erosion of seaward dune slope.
38	2	" "	Slight erosion with bar development 0-350. Slight accretion in places 850-1600.
39	2	" "	Slight accretion throughout, with little erosion in places.
40	2	" "	Slight accretion 0-250, slight erosion 250-2000.
41	2	" "	Slight erosion throughout, erosion of dune face.
42	2	" "	Slight erosion throughout, except small accretion on upper beach
43	2	" "	Slight accretion throughout to 2250.
44	2	" "	Slight accretion throughout to 2000.
46	2	" "	Slight erosion in places, especially 100-500, slight accretion landward of 100.
48	2	" "	Very slight erosion & accretion at intervals.
50	2	" "	Very slight erosion at intervals.

TABLE 6 continued

Profile No Town	No of Surveys	Dates		Cross Profile Changes (distances in m from landward end)
52	2	"	"	Very slight erosion & accretion with sand bar development.
55	2	"	"	Very slight erosion & accretion with landward sand bar movement seaward of 500.
57	2	"	"	Very slight erosion & accretion with sand bar development.
Magnetic Island from Picnic Bay to Horseshoe Bay				
102	2	3/1982 & 1/1983		Slight erosion & accretion throughout. Accretion of sand bars 450-750.
103	2	"	"	Slight erosion in places dominant.
104	2	3/1982 & 1/1983		Slight erosion & accretion in places.
105	1	3/1982		
106	2	"	"	Very slight erosion & accretion in places.
108	2	"	"	Erosion & accretion related to sand bar development 0-600. Slight accretion dominant 600-2000.
109	2	2/1982 & 1/1983		Slight erosion & accretion alternating along 0-2000 profile.
110	2	"	"	Erosion 0-400, v slight alternating accretion & erosion 400-1900.
111	1	3/1982		
112	2	2/1982 & 1/1983		Alternating accretion & erosion 0-500, slight accretion dominant 500-1950.
113	2	"	"	Slight accretion & erosion in places 0-1500.
114	2	"	"	Slight erosion 0-350, accretion 350-600, & v slight accretion in places 600-1950.
115	1	3/1982		
116	1	"		
117	2	2/1982 & 2/1983		Slight accretion dominant 0-1000, v slight erosion 1000-1950.
130	1	3/1982		
132	1	"		
134	1	"		
135	2	3/1982 & 1/1983		Very slight erosion & accretion in places 0-1950.
137	2	"	"	Very slight erosion & accretion in places 0-1950.
139	2	"	"	Very slight erosion & accretion in places 0-1950.
141	2	"	"	Slight erosion dominant 0-1950, most marked 25-600.
143	1	3/1982		

Notes: 1 Localities of profiles shown in Figure 14

2 The small scale vertical erosional and accretional changes described in this Table are of the order of 0.1m to 0.2m.

TABLE 7

Townsville Port Authority Cross Profiles - Summary of Changes

Townsville Harbour to Cape Pallarenda

		Cross Profile Changes (distances in m from landward end)
26.1.78-3.11.78	Run 1	Little change
	Run 2	Little change
	Run 3	Little change
	Run 4	Slight variations (= erosion & accretion) in sand bars & troughs 0-850
	Run 5	Slight variations in upper part of profile 0-200
3.11.78-11.6.79	Run 1	Little change
	Run 2	Slight upper beach erosion, no change otherwise
	Run 3	Little change
	Run 4	Slight variations in sand bars & troughs 0-850
	Run 5	Slight variations in upper beach & low sand ridges to 1000
11.6.79-27.3.80	Run 1	Little change
	Run 2	Slight upper beach accretion, slight accretion in places seaward
	Run 3	Slight upper beach variations, slight accretion in places seaward
	Run 4	Slight variation (mainly erosion) in sand ridges to c.850
	Run 5	Slight variation in upper beach, mainly to 200
27.3.80-9.3.82		(Landward part of profiles not surveyed, 0-47 to 0-87 on different runs, on 9.3.82)
	Run 1	Slight erosion to 850, almost no change seaward
	Run 2	Slight erosion in places
	Run 3	Slight erosion & accretion places
	Run 4	Slight variations in sand bars & troughs 47-850
	Run 5	Slight variations in low sand ridges throughout profile
9.3.82-28.3.83		(Landward part of profiles 0-87 not surveyed on 28.3.83)
	Run 1	Little change
	Run 2	Little change, slight accretion 87-450
	Run 3	Little change

Notes: 1 Locality of profiles shown in Figure 15

2 The small scale vertical erosional and accretional changes described in this Table are of the order of 0.1m to 0.2m.

TABLE 8

Townsville Rainfall Records (mm)

Bureau of Meteorology data for Townsville Pilot Station 1871-1940 and Townsville Airport 1941 - , presented in hydrological years beginning 1 October.

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1871/72	82	12	122	565	214	69	28	21	11	4	1	1	1130
1872/73	24	170	368	309	309	183	55	9	171	0	12	0	1610
1873/74	6	33	271	479	376	192	111	45	55	99	2	0	1669
1874/75	54	0	275	236	600	31	467	123	11	0	0	0	1797
1875/76	0	25	38	86	216	162	17	206	48	0	0	0	798
1876/77	0	15	96	341	871	313	103	4	18	21	0	34	1816
1877/78	7	6	69	77	200	347	3	51	51	14	35	6	866
1878/79	96	41	57	138	164	483	309	46	28	9	83	2	1456
1879/80	76	15	0	318	364	34	83	0	0	11	7	0	908
1880/81	37	34	153	33	426	422	214	22	11	0	0	45	1397
1881/82	1	52	36	38	493	492	104	6	55	12	0	3	1292
1882/83	136	29	52	41	673	8	46	72	0	0	0	0	1057
1883/84	0	125	49	15	516	371	5	29	12	28	0	31	1181
1884/85	0	21	215	375	36	99	50	1	22	0	10	0	829
1885/86	0	3	311	70	225	122	261	23	110	80	15	8	1228
1886/87	48	34	191	300	162	601	142	12	18	2	11	12	1533
1887/88	5	28	153	53	437	35	9	1	0	4	1	16	742
1888/89	0	8	51	57	115	82	196	25	69	39	6	94	742
1889/90	20	174	333	608	574	571	18	123	7	54	1	178	2661
1890/91	11	6	11	420	626	328	224	64	181	1	11	6	1889
1891/92	45	20	6	831	14	98	4	172	13	3	3	18	1227
1892/93	141	10	31	51	219	287	8	2	11	2	113	0	875
1893/94	60	89	32	718	474	191	592	16	160	3	2	24	2361
1894/95	39	170	95	215	821	7	119	8	14	7	11	22	1528
1895/96	16	3	193	751	561	279	36	3	8	12	7	1	1870
1896/97	1	28	10	559	190	154	4	23	26	5	5	5	1010
1897/98	73	44	188	357	515	55	22	0	19	6	4	39	1322
1898/99	5	1	52	259	272	278	96	15	0	20	23	0	1021
1899/00	9	4	14	536	2	43	27	59	10	15	3	6	728
1900/01	23	1	19	379	329	118	75	25	9	6	41	5	1030
1901/02	32	3	20	39	75	51	10	2	3	0	1	0	236
1902/03	7	1	157	99	190	587	52	39	27	1	4	11	1175
1903/04	62	152	483	139	132	102	26	6	1	0	0	1	1104
1904/05	93	30	145	348	50	51	163	13	9	17	2	97	1018
1905/06	14	18	0	255	357	109	10	46	8	0	12	83	912
1906/07	37	197	356	317	197	187	26	79	61	0	2	4	1463
1907/08	1	72	616	313	196	229	10	57	0	43	7	7	1551
1908/09	40	8	2	176	43	178	33	27	38	21	15	3	584
1909/10	53	33	292	587	276	440	58	7	28	9	0	85	1868
1910/11	3	64	172	648	486	121	83	2	3	0	0	0	1582
1911/12	10	8	83	41	192	179	115	16	114	17	4	0	779
1912/13	16	68	37	297	337	198	197	57	14	0	0	0	1221
1913/14	8	0	171	379	121	364	124	16	116	2	1	0	1302
1914/15	10	3	108	230	51	1	19	9	1	4	14	2	452
1915/16	4	8	82	251	192	182	1	15	7	86	16	1	845
1916/17	65	95	457	533	510	243	83	61	2	0	53	6	2108
1917/18	9	335	280	705	181	65	67	0	1	0	32	5	1680
1918/19	0	63	20	168	212	50	71	7	9	1	1	3	605
1919/20	0	4	17	298	102	47	469	136	26	7	41	48	1195
1920/21	31	19	31	146	35	75	9	52	15	88	4	45	550
1921/22	147	0	141	133	339	34	7	6	5	38	0	6	856
1922/23	48	5	173	29	7	17	30	18	62	2	43	1	435
1923/24	0	9	52	39	242	324	133	4	23	0	68	31	925
1924/25	79	148	212	278	304	187	1	0	44	3	50	34	1340
1925/26	2	21	128	95	353	45	1	0	27	5	1	117	795
1926/27	2	15	189	473	511	77	11	1	106	137	0	27	1549

TABLE 8 continued

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1927/28	11	2	216	201	245	182	4	0	12	1	0	0	874
1928/29	16	91	96	405	133	252	64	0	52	2	0	4	1115
1929/30	3	9	56	447	195	26	0	114	35	8	1	0	894
1930/31	274	3	23	36	89	117	76	12	3	2	3	8	646
1931/32	94	139	211	225	56	179	32	57	4	0	0	0	997
1932/33	3	50	219	152	255	8	143	12	99	32	47	23	1043
1933/34	31	149	290	352	360	22	43	6	61	21	7	5	1347
1934/35	10	78	20	70	15	71	12	60	10	15	0	1	362
1935/36	5	9	13	195	729	240	55	14	125	7	0	5	1397
1936/37	0	63	179	140	119	247	4	3	19	16	0	0	790
1937/38	2	49	2	386	390	42	2	10	24	94	0	0	1001
1938/39	19	68	4	79	244	176	41	11	55	2	14	0	713
1939/40	5	20	17	209	538	159	62	3	10	0	59	2	1084
1940/41	3	17	6	1015	150	402	174	61	4	2	1	1	1836
1941/42	0	101	53	86	299	11	58	18	76	86	5	29	822
1942/43	26	4	419	135	595	22	23	1	25	0	3	45	1298
1943/44	2	42	19	93	454	382	38	9	12	32	15	1	1099
1944/45	12	6	74	77	307	430	15	41	75	11	0	2	1050
1945/46	22	24	26	398	47	426	1	5	0	0	0	0	949
1946/47	2	4	31	9	735	29	0	27	4	0	83	67	991
1947/48	3	150	34	222	104	118	5	36	3	27	1	2	705
1948/49	2	25	88	300	296	560	62	8	0	1	0	5	1347
1949/50	50	11	18	417	304	612	181	42	37	173	2	6	1853
1950/51	39	280	103	849	34	81	6	25	10	2	7	1	1437
1951/52	19	6	4	465	91	64	131	11	36	3	2	6	838
1952/53	26	27	62	1142	497	37	4	8	0	1	36	0	1840
1953/54	18	11	47	131	674	159	285	2	15	29	8	4	1383
1954/55	93	18	85	79	688	426	90	150	20	10	0	1	1660
1955/56	29	10	59	339	422	379	122	134	81	45	39	20	1679
1956/57	13	117	318	237	90	251	8	13	10	17	2	0	1076
1957/58	49	46	15	131	431	326	307	5	98	0	2	6	1416
1958/59	3	25	89	377	70	155	115	57	5	2	0	0	898
1959/60	0	52	408	138	560	366	9	45	7	1	1	4	1591
1960/61	11	135	90	34	221	118	9	8	0	3	9	0	638
1961/62	4	130	61	198	399	91	32	4	16	14	7	11	967
1962/63	1	27	79	411	144	361	61	5	3	0	32	0	1124
1963/64	2	12	39	172	514	138	38	38	54	26	3	0	1036
1964/65	51	48	177	276	36	306	97	25	8	1	1	0	1026
1965/66	8	5	270	240	100	31	22	31	10	2	16	0	735
1966/67	10	52	18	108	186	189	3	6	107	1	7	0	687
1967/68	18	10	132	349	904	46	32	72	0	12	0	6	1581
1968/69	14	4	44	174	63	52	1	9	37	0	0	0	398
1969/70	27	38	63	44	91	275	20	0	4	0	53	3	618
1970/71	5	76	149	103	195	253	36	29	42	10	43	0	941
1971/72	20	27	347	600	171	210	1	23	11	1	0	6	1417
1972/73	0	31	37	219	465	199	30	10	5	2	0	55	1053
1973/74	58	116	351	878	442	143	43	48	3	0	54	5	2141
1974/75	4	37	52	239	67	270	17	2	4	3	36	81	812
1975/76	253	19	458	283	495	222	15	2	1	3	1	3	1755
1976/77	23	71	318	98	478	272	85	181	0	0	22	21	1569
1977/78	2	33	128	437	210	76	115	37	3	22	29	18	1110
1978/79	13	49	61	184	217	310	53	5	34	9	0	11	946
1979/80	16	0	185	257	95	154	21	82	4	10	2	0	826
1980/81	18	2	76	745	321	18	97	118	18	16	28	1	1458
1981/82	5	333	61	164	182	113	109	26	9	2	5	27	1036
1982/83	0	7	46	147	4	178	152	152	71	0	5	2	764

TABLE 8 continued

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1983/84	16	44	12	344	299	98	26	0	2	59	6	21	927
1984/85	20	39	48	33	98	86	26	28	22	28	4	1	433
1985/86	100	158	47	255	114	30	28	52	1	2	26	38	851
1986/87	26	26	25	216	86	47	7	15	13	10	7	2	480
1987/88	19	57	290	15	208	10	66	13					
MEAN =	29	50	126	284	289	188	74	34	23	16	13	15	1147

TABLE 9a

ROSS RIVER AT ROSS RIVER DAM HEADWATER (catchment area 750km^2)

MONTHLY AND ANNUAL VOLUMES IN MEGALITRES AND ANNUAL RUNOFF IN MILLIMETRES

Climatic Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Climatic Year Total	Runoff
1974-75	0	0	0	2	1	9,007	13,715	2	0	0	0	0	22,727	30
1975-76	0	0	2,995	12,682	191,089	48,184	1,470	0	0	0	0	0	256,420	342
1976-77	0	0	39,990	3,605	104,412	90,866	466	43,730	909	0	0	0	283,978	379
1977-78	0	0	0	19,438	109,544	0	0	0	0	0	0	0	128,982	172
1978-79	0	0	0	0	31,588	12,249	25	2	0	0	0	0	43,864	58
1979-80	0	0	0	52,784	5,225	0	0	0	0	0	0	0	58,009	77
1980-81	0	0	0	138,660	164,012	0	0	0	1	0	0	0	302,672	404
1981-87	No flow over spillway													
13yrMEANS	0	0	3,307	17,475	46,605	12,331	1,206	3,364	70	0	0	0	84,358	209*

* 7 yr MEAN

TABLE 9b

ALLIGATOR CREEK AT ALLENDALE (catchment area 69km^2)

MONTHLY AND ANNUAL VOLUMES IN MEGALITRES AND ANNUAL RUNOFF IN MILLIMETRES

Climatic Year	October	November	December	January	February	March	April	May	June	July	August	September	Climatic Year Total	Runoff Millimetres
1973-74	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1974-75	29	0	0	4,697	3,288	8,440	5,265	1,365	555	152	402	702	24,896	361
1975-76	1,582	39	9,875	6,098	33,226	10,247	2,580	1,125	598	735	368	130	66,601	965
1976-77	29	25	9,656	1,911	19,777	20,999	2,245	10,115	1,153	743	185	96	66,932	970
1977-78	97	26	373	21,522	5,526	2,777	2,208	1,131	741	444	130	147	35,121	509
1978-79	8	38	252	3,879	12,253	26,307	2,062	1,010	521	165	57	0	46,550	675
1979-80	0	0	160	8,398	3,540	6,649	1,358	1,299	819	483	126	18	22,849	331
1980-81	0	0	0	32,446	21,134	2,129	1,836	2,029	1,179	1,075	654	121	62,602	907
1981-82	0	556	611	168	443	1,617	2,023	722	183	5	0	0	6,327	92
1982-83	0	0	0	423	88	841	1,956	4,429	1,431	571	57	0	9,797	142
1983-84	0	0	0	2,831	7,367	2,251	1,286	771	593	544	570	18	16,230	235
1984-85	0	0	0	0	2,026	4,942	1,651	1,000	985	468	21	0	11,093	161
1985-86	1,420	1,165	634	5,241	10,911	1,761	1,444	2,783	1,214	849	763	690	28,875	418
1986-87	2,112	366	567	1,001	3,857	1,238	1,003	1,905	1,142	843	914	-	-	-
MEANS	406	170	1,702	6,816	9,495	6,938	2,071	2,283	855	544	327	160	33,156	481

NOTE: "-" INDICATES INCOMPLETE RECORD

TABLE 9c

BLACK RIVER AT BRUCE HIGHWAY (Catchment area 260km^2)

MONTHLY AND ANNUAL VOLUMES IN MEGALITRES AND ANNUAL RUNOFF IN MILLIMETRES

Climatic Year	October	November	December	January	February	March	April	May	June	July	August	September	Climatic Year Total	Runnoff Milli-metres
1972-73	-	-	-	-	-	-	7,717	3,966	733	366	494	253	-	-
1973-74	200	233	15,540	186,358	136,137	51,095	4,953	2,150	1,211	561	401	213	399,051	1,535
1974-75	24	2	0	7,506	1,116	28,179	6,860	1,174	238	104	35	17	45,254	174
1975-76	1,465	420	40,685	6,387	38,756	-	-	-	107	147	17	0	-	-
1976-77	0	199	24,363	566	36,393	35,526	8,958	-	-	-	-	41	-	-
1977-78	7	0	1,587	23,913	6,922	5,414	7,286	1,858	499	15	1	0	47,501	183
1978-79	0	0	163	6,327	22,527	41,168	1,501	444	155	40	12	3	72,341	278
1979-80	0	0	269	31,514	8,278	8,373	1,015	1,363	1,043	155	7	0	52,015	200
1980-81	0	0	0	88,861	72,923	14,497	3,614	8,437	1,622	1,011	467	58	191,491	737
1981-82	13	1,377	163	94	1,886	1,855	620	55	0	0	0	0	6,061	23
1982-83	0	0	0	518	0	1,766	4,376	19,632	1,175	175	5	0	27,648	106
1983-84	0	0	0	7,612	29,292	6,510	718	26	0	23	0	0	44,181	170
1984-85	0	0	0	0	7	42	3	3	1	0	0	0	55	0
1985-86	0	86	1	1,806	18,992	8	0	175	0	0	0	0	21,069	81
1986-87	308	1	0	1	39	0	0	0	0	0	0	-	-	-
MEANS	144	165	5,912	25,819	26,662	14,956	3,401	3,022	485	185	103	56	82,424	317

NOTE: "-" INDICATES IMCOMPLETE RECORD

TABLE 10

Tropical Cyclones affecting the Burdekin Delta Area and Major Burdekin River Floods 1940-1980

Tropical Cyclone		Major Flood		
Date	Pressure (mb)	Date	Instant-aneous max(cumecs)	Daily Volume (Ml)
		20.02.40	24,989	1,987,633
07.04.40		09.04.40	38,290	2,756,685
28.03.44				
		05.03.46	40,392	3,040,461
05.02.47				
08.03.50		09.03.50	30,398	2,272,238
07.02.54	990	08.02.54	20,305	1,528,884
06.03.56	961			
20.02.58		24.02.58	26,240	2,171,783
01.04.58	968	03.04.58	36,000	2,456,134
16.02.59	948	17.02.59	19,120	1,304,553
		17.02.68	25,964	2,068,939
24.12.71	952			
		11.01.72	26,140	1,956,386
19.12.73	988			
		25.01.74	26,618	2,202,180

Flood data after Queensland Water Resources Commission
Cyclone data after R.S. Lourensz, 1977, with additional information from P.M. Fleming.

Notes

Major floods defined as over 19,000 cumecs instantaneous flow.
1940-50 flood data from Home Hill gauging station.
1951-80 flood data from Clare gauging station.

TABLE 11

Cape Cleveland Percentage Occurrence of Wind Speed Versus Direction.
Based on 30 years of Bureau of Meteorology records.

BUREAU OF METEOROLOGY - SURFACE WIND ANALYSIS

PERCENTAGE OCCURRENCE OF SPEED VERSUS DIRECTION BASED ON 30 YEARS OF RECORDS

FIRST YEAR : 1957 LAST YEAR : 1986 NUMBER OF MISSING OBSERVATIONS (AS PERCENTAGE OF MAXIMUM POSSIBLE) : 2.21 %

STATION : 032005 CAPE CLEVELAND LIGHTHOUSE 19 11 S, 147 01 E 58.0 m ELEV

JANUARY 0900 HOURS LST

SPEED (KM/HR)

CALM 4 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	4	2	*			9
NE	1	3	6	2	1	*	*	13
E	1	3	5	3	2	1	*	16
SE	1	4	14	15	6	2	*	41
S	1	1	1	1	1	*		4
SW	1	2	1	1	*			6
W	*	1	1	*				2
NW	*	2	3	1	*			6
ALL	6	18	34	25	9	4	*	

NO. OF OBS. 925

FEBRUARY 0900 HOURS LST

SPEED (KM/HR)

CALM 5 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	1	1	1				4
NE	*	2	3	1	*	*		8
E	1	4	4	2	1	1	*	13
SE	1	6	18	18	7	2	*	53
S	*	1	1	2	1	*	*	5
SW	1	2	1	1	*		*	5
W	*	*	*	*	*			1
NW	1	2	2	1	*		*	6
ALL	5	19	31	26	9	3	1	

NO. OF OBS. 847

MARCH 0900 HOURS LST

SPEED (KM/HR)

CALM 4 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	1	1	1			*	4
NE	*	2	3	1	*			6
E	1	2	3	2	1	*	*	8
SE	2	6	16	26	10	2	*	63
S	1	1	2	3	1	*		7
SW	2	2	2	1		*		5
W	*	*	*	*		*		1
NW	*	1	1	*				2
ALL	6	15	26	33	12	3	*	

NO. OF OBS. 927

APRIL 0900 HOURS LST

SPEED (KM/HR)

CALM 3 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	1	1	*				2
NE	*	1	1	*		*		2
E	*	2	2	1	*	*	*	5
SE	2	5	17	29	17	5	*	74
S	1	1	1	3	2	*	*	9
SW	1	2	1	*	*	*		4
W	*							*
NW	*	*	*	*				1
ALL	4	12	22	32	20	5	*	

NO. OF OBS. 899

JANUARY 1500 HOURS LST

SPEED (KM/HR)

CALM 1 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	9	4	*	*		18
NE	1	5	16	8	*	*		32
E	*	2	8	14	8	2	1	35
SE	*	1	1	4	3	2	1	12
S		*	*	*		*		*
SW		*	*					1
W		*	*					*
NW		*	1	1	*	*		2
ALL	2	12	35	32	12	5	1	

NO. OF OBS. 930

FEBRUARY 1500 HOURS LST

SPEED (KM/HR)

CALM 1 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	6	2	*	*		13
NE	1	4	13	4	*	*		22
E	1	2	12	16	7	4	*	42
SE	*	1	4	6	4	2	*	17
S	*	*	*	*	*			1
SW	*	*	*	*	*		*	1
W					*			*
NW	*	*	1	1	*			3
ALL	3	12	36	29	12	6	1	

NO. OF OBS. 846

MARCH 1500 HOURS LST

SPEED (KM/HR)

CALM * DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	4	1	*			9
NE	1	6	9	4	*			20
E	1	3	11	17	9	4	*	45
SE	*	1	4	9	6	2	*	22
S		*	*	*	*			1
SW	*	*	*	*				1
W		*						*
NW	*	*	1	*	*			2
ALL	3	13	30	31	16	6	1	

NO. OF OBS. 928

APRIL 1500 HOURS LST

SPEED (KM/HR)

CALM 1 DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	2	2	*				5
NE	1	6	6	2	*	*		15
E	*	4	11	19	12	4	*	50
SE		1	3	10	10	3	*	27
S		*	*	*	*			1
SW		*	*	*	*			1
W	*	*						*
NW	*	1	*					1
ALL	2	13	24	31	22	7	1	

NO. OF OBS. 897

* OCCURRED BUT LESS THAN 0.5 PERCENT

PRODUCED BY M.I.S.S. 29/ 7/86

TABLE 11 continued

BUREAU OF METEOROLOGY - SURFACE WIND ANALYSIS

PERCENTAGE OCCURRENCE OF SPEED VERSUS DIRECTION BASED ON 30 YEARS OF RECORDS

FIRST YEAR : 1957 LAST YEAR : 1986 NUMBER OF MISSING OBSERVATIONS (AS PERCENTAGE OF MAXIMUM POSSIBLE) : 2.21 %

STATION : 032005 CAPE CLEVELAND LIGHTHOUSE 19 11 S, 147 01 E 58.0 M ELEV

MAY 0900 HOURS LST

SPEED (KM/HR) — CALM 4

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N		*	*	*				1
NE	*	*	1	*		*		1
E	*	2	1	*	*		*	4
SE	2	5	17	26	17	5	1	72
S	1	2	3	2	1	1		10
SW	2	3	3	1	*			8
W	*	*	*					*
NW	*		*					*
ALL	5	11	25	30	18	6	1	

NO. OF OBS. 926

JUNE 0900 HOURS LST

SPEED (KM/HR) — CALM 6

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*		*	*				*
NE	*	*	*					*
E	*	1	1	*	*	*		3
SE	2	5	14	23	14	6	*	65
S	2	3	3	3	1	1	*	13
SW	2	4	4	2	*	*		12
W		*	*					1
NW			*	*				*
ALL	6	14	23	28	15	7	1	

NO. OF OBS. 869

JULY 0900 HOURS LST

SPEED (KM/HR) — CALM 5

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	*	*					*
NE	*	*						*
E	*	1	1	*				3
SE	1	5	14	26	15	6	*	67
S	2	3	3	3	1	*	*	11
SW	3	5	2	2	1	*		13
W	*	*	*					1
NW	*		*	*				*
ALL	6	15	20	31	16	6	*	

NO. OF OBS. 895

AUGUST 0900 HOURS LST

SPEED (KM/HR) — CALM 5

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	1	1	*				2
NE	1	1	1	*				3
E	1	3	2	1	*			7
SE	1	6	16	24	11	5	1	63
S	2	2	1	2	1	*	*	8
SW	2	5	2	1	*	*		11
W	*	*	*		*			1
NW	*	*	1	*				1
ALL	7	17	24	28	12	5	1	

NO. OF OBS. 895

MAY 1500 HOURS LST

SPEED (KM/HR) — CALM 1

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	2	1	*				4
NE	1	5	5	2	*			13
E	1	4	13	18	7	3	*	46
SE	*	1	6	12	8	3	*	31
S	*	*	1	*				1
SW	*	*	1	1				2
W	*	*	*					1
NW	*	*	*	*				1
ALL	4	13	27	32	16	6	1	

NO. OF OBS. 927

JUNE 1500 HOURS LST

SPEED (KM/HR) — CALM 1

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	1	*				6
NE	2	7	6	*				15
E	1	7	14	12	6	2	*	41
SE	*	1	7	10	6	3	*	28
S	1	1	1	1	*	*		3
SW	*	*	1	1				3
W	*	*	*					1
NW	*	1	1	*				2
ALL	6	20	30	25	12	5	*	

NO. OF OBS. 869

JULY 1500 HOURS LST

SPEED (KM/HR) — CALM 2

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	3	1	*				6
NE	2	7	6	3	*	*		18
E	1	5	13	15	7	1	1	42
SE	*	2	5	10	7	2	*	26
S	*	*	1	*		*		1
SW	*	1	1	1	*	*		3
W	*	*	*					*
NW	*	*	*					1
ALL	5	20	26	29	14	3	1	

NO. OF OBS. 897

AUGUST 1500 HOURS LST

SPEED (KM/HR) — CALM 1

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	4	4	1				9
NE	2	6	11	5	1	*		24
E	1	3	14	14	8	3	1	43
SE		1	4	7	4	2	1	18
S	*	*	*		*			*
SW		*	1	*	*			1
W	*	*		*				*
NW	*	1	1	*				2
ALL	4	15	35	27	12	5	2	

NO. OF OBS. 895

* OCCURRED BUT LESS THAN 0.5 PERCENT

PRODUCED BY M.I.S.S. 29/ 7/86

TABLE 11 continued

BUREAU OF METEOROLOGY - SURFACE WIND ANALYSIS

PERCENTAGE OCCURRENCE OF SPEED VERSUS DIRECTION BASED ON 30 YEARS OF RECORDS

FIRST YEAR : 1957　　LAST YEAR : 1986　　NUMBER OF MISSING OBSERVATIONS (AS PERCENTAGE OF MAXIMUM POSSIBLE) : 2.21 %

STATION : 032005　　CAPE CLEVELAND LIGHTHOUSE　　19 11 S, 147 01 E　　58.0 M ELEV

SEPTEMBER　　0900 HOURS LST

CALM 5

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	2	3	*				6
NE	1	3	5	2	*			11
E	1	4	5	2	1	*	*	13
SE	1	5	14	16	11	3	*	50
S	1	1	1	1	1	*		4
SW	1	3	1	1	*	*	*	7
W	*	1	*	*				2
NW	1	1	1	*				2
ALL	7	19	30	23	13	4	*	

NO. OF OBS. 867

OCTOBER　　0900 HOURS LST

CALM 3

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	4	5	3	*			13
NE	1	5	7	4	1			18
E	1	4	6	6	3	1	*	20
SE	*	4	11	14	5	1	*	35
S	*	*	1	*	*			1
SW	1	1	1	*	*	*		3
W	*	1	*					1
NW	*	2	2	2	*			6
ALL	4	20	33	29	8	2	*	

NO. OF OBS. 899

NOVEMBER　　0900 HOURS LST

CALM 3

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	4	10	4	*			19
NE	1	5	11	3	*	*		21
E	*	3	8	5	2	1		18
SE	*	2	8	10	4	1		26
S	*		*	1				1
SW	1	1	1					2
W		1	*					1
NW	*	1	5	2	1			9
ALL	4	17	44	24	7	2		

NO. OF OBS. 868

DECEMBER　　0900 HOURS LST

CALM 3

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	1	4	8	5	*			18
NE	1	6	9	3	*	*		18
E	1	4	7	5	2	1	*	19
SE	*	4	9	10	3	1	*	28
S	*	1	*	1		*		2
SW	*	2	1	*	*			3
W	*	1	*	*				1
NW	*	2	4	2	1			9
ALL	4	23	38	25	6	2	*	

NO. OF OBS. 893

SEPTEMBER　　1500 HOURS LST

CALM 1

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N		4	10	2				17
NE	1	6	17	6	*	*		31
E		1	9	15	9	5	1	39
SE		*	2	4	3	1	1	10
S	*			*				*
SW			*	*				*
W	*	*						*
NW		1	*	*				1
ALL	1	13	39	28	12	6	1	

NO. OF OBS. 870

OCTOBER　　1500 HOURS LST

CALM *

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	3	12	7	*			22
NE	1	5	16	9	2	*		33
E	*	1	8	17	8	3	1	38
SE	*	*	*	2	2	1		5
S		*	*					*
SW		*	*	*				*
W								
NW		*	1	*				1
ALL	1	10	37	35	13	4	1	

NO. OF OBS. 897

NOVEMBER　　1500 HOURS LST

CALM *

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	4	15	9	1	*		29
NE	*	5	19	11	2	*		38
E		1	7	10	6	3	1	28
SE		*	*	1	1	1	*	[illegible]
S								
SW								
W		*						*
NW		*	*	1	*			1
ALL	1	10	42	32	10	4	1	

NO. OF OBS. 870

DECEMBER　　1500 HOURS LST

CALM *

DIRN	1 TO 5	6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 & UP	ALL
N	*	3	13	10	1			27
NE	1	5	18	11	1	*		36
E	*	1	8	11	5	3	*	27
SE		*	1	2	3	1	*	6
S		*		*		*		*
SW		*	*	*				1
W								
NW		*	*	1				1
ALL	1	9	42	34	10	4	*	

NO. OF OBS. 893

* OCCURRED BUT LESS THAN 0.5 PERCENT

PRODUCED BY M.I.S.S. 29/ 7/86

TABLE 12

Monthly Wave Statistics for Wave Buoy near Cape Cleveland.

YEAR	MONTH		TZ	TC	HRMS	HSIG	HMAX	TS	TP
75	11	AV	3.01	2.21	0.47	0.66	1.30	3.66	4.63
		SD	0.68	0.35	0.29	0.41	0.61	0.94	1.40
		MAX	4.49	2.88	1.17	1.65	3.10	5.67	7.02
		MIN	2.09	1.64	0.16	0.21	0.35	2.42	2.15
75	12	AV	3.14	2.32	0.50	0.70	1.22	3.99	4.50
		SD	0.54	0.31	0.23	0.33	0.58	0.73	1.09
		MAX	4.64	3.31	1.27	1.80	3.58	5.80	7.40
		MIN	2.15	1.66	0.13	0.18	0.30	2.64	2.61
76	1	AV	2.87	2.03	0.34	0.48	0.86	3.85	4.95
		SD	0.63	0.27	0.17	0.25	0.46	1.02	2.02
		MAX	4.83	2.75	0.86	1.22	2.17	7.78	9.90
		MIN	1.78	1.48	0.08	0.11	0.19	2.15	1.38
76	2	AV	3.15	2.21	0.47	0.67	1.18	4.18	4.99
		SD	0.51	0.30	0.23	0.33	0.58	0.77	1.60
		MAX	4.39	2.91	0.99	1.41	2.47	6.07	9.16
		MIN	2.23	1.58	0.13	0.18	0.32	2.70	0.34
76	3	AV	2.93	2.09	0.36	0.50	0.90	3.90	4.72
		SD	0.48	0.26	0.18	0.25	0.43	0.87	1.70
		MAX	4.05	2.89	0.85	1.21	2.08	6.31	9.59
		MIN	2.09	1.64	0.14	0.19	0.34	2.47	1.19
76	4	AV	3.49	2.45	0.62	0.88	1.52	4.53	5.42
		SD	0.47	0.28	0.23	0.32	0.55	0.64	1.00
		MAX	4.45	3.01	1.23	1.74	3.16	5.65	8.20
		MIN	2.17	1.76	0.17	0.24	0.36	2.73	2.24
76	5	AV	3.42	2.40	0.54	0.76	1.29	4.40	5.23
		SD	0.41	0.26	0.19	0.27	0.50	0.54	0.90
		MAX	4.07	2.78	0.92	1.31	2.62	5.30	8.31
		MIN	2.26	1.58	0.11	0.15	0.25	2.74	2.71
76	6	AV	3.29	2.31	0.44	0.63	1.09	4.27	5.12
		SD	0.47	0.30	0.22	0.31	0.57	0.64	1.08
		MAX	4.31	2.84	1.06	1.48	2.81	5.42	8.44
		MIN	2.15	1.67	0.11	0.15	0.27	2.61	2.61
76	7	AV	3.45	2.38	0.50	0.71	1.24	4.53	5.43
		SD	0.39	0.27	0.22	0.31	0.51	0.61	1.22
		MAX	4.44	2.82	0.92	1.30	2.19	6.79	8.50
		MIN	2.50	1.74	0.15	0.22	0.41	3.10	3.13
76	8	AV	3.06	2.23	0.38	0.53	0.91	3.92	4.58
		SD	0.56	0.31	0.20	0.28	0.51	0.83	1.39
		MAX	3.96	2.90	0.89	1.27	2.22	5.52	7.33
		MIN	2.02	1.66	0.11	0.16	0.25	2.21	2.02
76	9	AV	3.03	2.19	0.35	0.49	0.86	3.86	4.84
		SD	0.51	0.31	0.22	0.31	0.55	0.68	1.65
		MAX	4.26	2.92	1.05	1.48	2.88	5.28	8.29
		MIN	2.02	1.59	0.13	0.19	0.33	2.20	2.07
76	10	AV	2.87	2.16	0.35	0.50	0.88	3.57	4.26
		SD	0.44	0.23	0.14	0.20	0.37	0.68	1.44
		MAX	3.77	2.61	0.77	1.09	2.05	4.90	7.81
		MIN	1.85	1.63	0.16	0.23	0.39	1.91	1.85
76	11	AV	2.97	2.11	0.33	0.45	0.79	3.69	4.14
		SD	0.34	0.22	0.13	0.19	0.35	0.53	1.29
		MAX	3.80	2.70	0.84	1.19	2.00	5.15	7.19
		MIN	2.35	1.73	0.14	0.20	0.34	2.80	2.10
76	12	AV	2.96	2.16	0.37	0.51	0.89	3.70	4.08
		SD	0.51	0.33	0.22	0.32	0.55	0.71	1.24
		MAX	4.60	3.30	1.22	1.71	3.01	5.73	7.55
		MIN	2.07	1.63	0.13	0.17	0.32	2.48	2.00
77	1	AV	3.21	2.31	0.49	0.68	1.18	4.07	4.69
		SD	0.49	0.32	0.25	0.36	0.61	0.66	1.11
		MAX	4.22	2.97	1.15	1.62	2.80	5.70	7.34
		MIN	2.29	1.66	0.18	0.25	0.39	2.84	2.18
77	2	AV	3.27	2.32	0.57	0.80	1.36	4.18	4.78
		SD	0.71	0.41	0.34	0.48	0.82	0.97	1.25
		MAX	4.60	3.09	1.32	1.89	3.30	6.15	7.06
		MIN	2.01	1.55	0.11	0.14	0.26	2.35	1.85
77	3	AV	3.17	2.18	0.43	0.61	1.07	4.03	4.38
		SD	0.86	0.34	0.32	0.45	0.75	1.24	1.69
		MAX	6.14	3.29	1.31	1.86	3.08	7.36	9.46
		MIN	2.03	1.61	0.09	0.12	0.21	2.15	1.19
77	4	AV	3.49	2.47	0.66	0.93	1.62	4.46	5.15
		SD	0.40	0.23	0.19	0.27	0.48	0.51	0.87
		MAX	4.12	2.90	1.04	1.44	2.72	5.31	8.11
		MIN	2.38	1.87	0.23	0.32	0.51	2.84	3.02
77	5	AV	3.07	2.23	0.40	0.56	0.98	3.89	4.80
		SD	0.56	0.33	0.23	0.33	0.59	0.83	1.59
		MAX	4.26	2.99	1.10	1.55	3.03	5.68	9.03
		MIN	1.93	1.52	0.09	0.12	0.25	2.14	1.43
77	6	AV	3.31	2.33	0.42	0.59	1.02	4.31	5.03
		SD	0.47	0.25	0.17	0.24	0.42	0.75	1.27
		MAX	4.76	2.76	0.76	1.07	1.89	7.00	8.33
		MIN	2.25	1.56	0.11	0.15	0.25	2.79	2.26
77	7	AV	3.42	2.45	0.55	0.77	1.34	4.41	5.06
		SD	0.43	0.23	0.19	0.27	0.46	0.63	0.90
		MAX	4.41	2.87	0.95	1.36	2.43	6.04	6.67
		MIN	2.37	1.77	0.13	0.18	0.29	2.65	2.84
77	8	AV	3.54	2.51	0.53	0.76	1.29	4.54	5.04
		SD	0.42	0.24	0.20	0.28	0.50	0.55	0.84
		MAX	5.18	3.13	0.96	1.35	2.43	6.79	7.93
		MIN	2.70	1.91	0.17	0.25	0.41	3.14	3.17
77	9	AV	3.26	2.27	0.44	0.62	1.06	4.25	5.32
		SD	0.53	0.31	0.26	0.37	0.63	0.77	1.42
		MAX	4.17	2.83	1.04	1.48	2.41	5.56	8.02
		MIN	2.16	1.66	0.12	0.17	0.26	2.46	1.79
77	10	AV	3.36	2.37	0.54	0.76	1.34	4.34	5.11
		SD	0.41	0.26	0.22	0.31	0.54	0.57	1.13
		MAX	4.29	2.83	0.91	1.29	2.74	5.46	7.65
		MIN	2.22	1.64	0.12	0.17	0.28	2.60	2.66
77	11	AV	3.22	2.31	0.45	0.63	1.10	4.13	4.87
		SD	0.48	0.27	0.23	0.34	0.57	0.71	1.41
		MAX	4.32	2.98	1.18	1.73	2.83	6.40	8.12
		MIN	2.46	1.85	0.18	0.25	0.42	2.99	2.80
77	12	AV	3.22	2.35	0.52	0.73	1.27	4.10	4.73
		SD	0.52	0.27	0.26	0.37	0.64	0.81	1.33
		MAX	4.38	2.94	1.20	1.73	3.03	5.63	7.13
		MIN	2.31	1.65	0.18	0.25	0.45	2.65	2.45
78	2	AV	3.08	2.24	0.44	0.62	1.14	3.86	4.61
		SD	0.75	0.46	0.36	0.51	0.91	1.08	1.98
		MAX	4.01	2.89	0.97	1.38	2.49	5.03	6.76
		MIN	2.41	1.82	0.13	0.19	0.32	2.83	2.09
78	4	AV	3.12	2.24	0.37	0.52	0.91	3.98	4.57
		SD	0.57	0.32	0.20	0.28	0.51	0.82	1.14
		MAX	4.93	3.26	0.99	1.42	2.69	6.03	6.85
		MIN	2.05	1.75	0.14	0.19	0.32	2.31	2.42
78	5	AV	3.62	2.56	0.68	0.96	1.66	4.66	5.24
		SD	0.32	0.17	0.18	0.25	0.45	0.51	0.77
		MAX	4.34	3.02	1.11	1.59	2.70	5.66	6.55
		MIN	2.92	2.16	0.33	0.46	0.81	3.35	3.26
78	6	AV	2.94	2.13	0.28	0.38	0.66	3.67	4.06
		SD	0.58	0.26	0.13	0.18	0.33	0.88	1.42
		MAX	4.80	2.86	0.59	0.84	1.54	5.99	7.40
		MIN	2.18	1.56	0.10	0.14	0.23	2.38	1.95
78	7	AV	3.44	2.29	0.43	0.61	1.04	4.51	4.91
		SD	0.59	0.23	0.19	0.27	0.48	1.10	1.25
		MAX	5.74	2.65	0.77	1.09	2.19	9.00	7.03
		MIN	2.47	1.54	0.10	0.15	0.27	2.83	2.09
78	8	AV	3.33	2.34	0.51	0.71	1.24	4.29	4.83
		SD	0.38	0.23	0.22	0.31	0.52	0.54	1.07
		MAX	4.32	2.93	1.21	1.70	2.70	5.28	7.37
		MIN	2.47	1.89	0.15	0.21	0.34	2.95	2.43
78	9	AV	3.21	2.23	0.36	0.51	0.91	4.30	5.36
		SD	0.49	0.26	0.16	0.22	0.39	0.80	1.48
		MAX	4.84	2.69	0.73	1.05	1.85	7.05	8.09
		MIN	2.39	1.61	0.14	0.20	0.38	3.16	3.23
78	10	AV	3.44	2.42	0.67	0.94	1.63	4.41	5.21
		SD	0.53	0.32	0.29	0.41	0.68	0.67	1.01
		MAX	4.59	3.04	1.26	1.78	2.80	5.76	7.16
		MIN	2.17	1.68	0.17	0.24	0.48	2.51	2.03

TABLE 12 continued

78	11	AV	3.24	2.33	0.50	0.70	1.21	4.12	4.71
		SD	0.51	0.28	0.25	0.35	0.61	0.71	1.23
		MAX	4.18	2.86	1.07	1.50	2.47	5.52	7.61
		MIN	2.28	1.84	0.21	0.29	0.45	2.55	2.44
78	12	AV	2.73	2.09	0.31	0.43	0.75	3.29	3.85
		SD	0.42	0.23	0.12	0.16	0.28	0.63	1.43
		MAX	3.51	2.45	0.60	0.84	1.38	4.60	7.28
		MIN	1.97	1.63	0.16	0.21	0.35	2.22	1.73
79	1	AV	3.52	2.48	0.70	0.99	1.70	4.48	5.10
		SD	0.73	0.40	0.44	0.63	1.11	0.97	1.36
		MAX	5.00	3.41	1.66	2.36	4.70	6.29	8.50
		MIN	2.38	1.90	0.19	0.27	0.43	2.75	2.64
79	2	AV	3.17	2.16	0.48	0.68	1.17	4.23	5.02
		SD	0.61	0.27	0.18	0.26	0.45	1.02	1.42
		MAX	5.25	2.74	0.89	1.28	2.10	8.78	8.52
		MIN	2.19	1.66	0.22	0.31	0.50	2.73	1.87
79	3	AV	3.09	2.18	0.49	0.70	1.18	4.08	5.02
		SD	0.62	0.33	0.32	0.45	0.74	0.90	1.23
		MAX	5.46	3.32	1.94	2.76	4.58	7.12	7.77
		MIN	2.17	1.66	0.10	0.13	0.28	2.70	2.11
79	4	AV	3.16	2.28	0.50	0.70	1.20	4.03	4.48
		SD	0.45	0.25	0.23	0.32	0.56	0.66	1.54
		MAX	4.19	2.93	1.11	1.56	2.81	5.21	9.73
		MIN	2.42	1.83	0.10	0.13	0.22	2.93	0.36
79	5	AV	3.31	2.36	0.49	0.69	1.19	4.22	4.98
		SD	0.47	0.27	0.25	0.35	0.61	0.70	1.15
		MAX	4.31	2.82	0.93	1.32	2.20	6.31	7.03
		MIN	2.14	1.75	0.12	0.18	0.32	2.58	1.76
79	6	AV	3.47	2.43	0.56	0.78	1.31	4.46	5.16
		SD	0.39	0.25	0.22	0.31	0.51	0.57	1.04
		MAX	4.48	3.06	1.19	1.70	2.77	5.68	8.23
		MIN	2.65	1.85	0.18	0.25	0.35	3.15	2.81
79	7	AV	3.50	2.42	0.49	0.70	1.16	4.53	5.21
		SD	0.36	0.22	0.20	0.28	0.48	0.55	1.21
		MAX	4.35	3.02	1.05	1.50	2.52	5.58	8.58
		MIN	2.77	1.67	0.16	0.23	0.37	3.04	3.13
79	8	AV	3.36	2.29	0.32	0.45	0.79	4.37	5.21
		SD	0.59	0.29	0.21	0.29	0.51	0.98	1.82
		MAX	4.85	2.96	0.90	1.27	2.33	6.73	9.02
		MIN	2.41	1.66	0.08	0.11	0.22	2.74	2.03
79	9	AV	3.43	2.42	0.47	0.66	1.15	4.39	5.11
		SD	0.41	0.27	0.22	0.31	0.55	0.57	1.25
		MAX	4.87	2.93	0.95	1.35	2.27	6.71	7.87
		MIN	2.54	1.78	0.15	0.21	0.36	3.15	2.49
79	10	AV	3.18	2.30	0.40	0.56	0.94	3.96	4.48
		SD	0.38	0.24	0.17	0.24	0.40	0.59	1.24
		MAX	4.21	2.96	1.01	1.42	2.30	5.74	7.15
		MIN	2.29	1.82	0.16	0.22	0.34	2.66	2.02
79	11	AV	3.22	2.26	0.43	0.59	1.01	4.05	4.55
		SD	0.39	0.24	0.19	0.27	0.47	0.53	1.18
		MAX	4.16	2.76	0.95	1.32	2.11	5.37	7.04
		MIN	2.38	1.80	0.18	0.26	0.46	2.75	2.53
79	12	AV	3.26	2.33	0.43	0.60	1.03	4.11	4.75
		SD	0.38	0.27	0.23	0.32	0.54	0.55	1.29
		MAX	4.22	2.93	1.05	1.45	2.41	5.24	8.17
		MIN	2.47	1.67	0.12	0.16	0.32	2.99	2.90
80	1	AV	3.01	2.20	0.35	0.49	0.86	3.74	4.22
		SD	0.48	0.33	0.19	0.27	0.50	0.71	1.31
		MAX	4.87	3.36	1.25	1.72	2.95	6.13	7.43
		MIN	2.13	1.65	0.15	0.20	0.31	2.45	2.61
80	2	AV	3.55	2.25	0.49	0.69	1.11	4.56	4.92
		SD	0.58	0.25	0.34	0.49	0.70	0.79	1.21
		MAX	5.90	2.67	1.91	2.65	3.05	6.54	7.91
		MIN	2.48	1.70	0.13	0.18	0.30	2.93	2.92
80	6	AV	3.26	2.30	0.43	0.61	1.06	4.28	4.98
		SD	0.46	0.22	0.20	0.29	0.50	0.78	1.31
		MAX	4.22	2.62	0.85	1.21	2.16	6.11	7.56
		MIN	2.19	1.74	0.13	0.19	0.33	2.53	2.21
80	7	AV	2.74	2.04	0.22	0.31	0.54	3.43	3.68
		SD	0.51	0.27	0.12	0.17	0.30	0.84	1.35
		MAX	3.80	2.47	0.54	0.76	1.27	5.05	5.76
		MIN	1.94	1.47	0.12	0.16	0.25	2.34	1.38
80	9	AV	3.06	2.21	0.41	0.58	1.01	3.88	4.57
		SD	0.49	0.31	0.20	0.29	0.51	0.61	1.36
		MAX	4.07	2.68	0.88	1.24	2.23	5.05	7.19
		MIN	2.26	1.76	0.17	0.23	0.47	2.76	2.31
80	10	AV	3.20	2.17	0.38	0.52	0.95	4.01	4.30
		SD	0.60	0.20	0.13	0.19	0.36	0.80	1.40
		MAX	6.04	2.57	0.70	0.98	1.65	6.96	7.00
		MIN	2.13	1.76	0.18	0.24	0.39	2.44	2.35
80	11	AV	3.16	2.29	0.44	0.62	1.06	3.97	4.24
		SD	0.45	0.23	0.19	0.27	0.51	0.68	1.22
		MAX	4.47	2.92	1.10	1.50	3.19	5.43	7.25
		MIN	2.31	1.86	0.24	0.33	0.56	2.62	2.41
80	12	AV	3.39	2.24	0.41	0.57	1.03	4.03	4.15
		SD	0.69	0.26	0.26	0.37	0.58	0.70	1.03
		MAX	5.72	2.84	1.04	1.48	2.43	5.47	6.89
		MIN	2.48	1.68	0.08	0.11	0.19	3.01	2.22
81	1	AV	3.85	2.24	0.23	0.32	0.60	4.30	4.57
		SD	1.21	0.27	0.08	0.12	0.20	1.05	0.93
		MAX	6.69	2.91	0.46	0.66	1.11	5.81	6.13
		MIN	2.04	1.68	0.09	0.13	0.22	2.48	1.68
81	2	AV	2.99	2.14	0.42	0.59	1.03	3.96	4.85
		SD	0.44	0.29	0.26	0.37	0.61	0.64	1.48
		MAX	4.08	2.73	1.08	1.52	2.56	5.60	8.14
		MIN	2.34	1.56	0.15	0.21	0.40	2.93	2.41
81	3	AV	3.00	2.20	0.43	0.61	1.08	3.89	4.79
		SD	0.50	0.26	0.22	0.31	0.56	0.82	1.52
		MAX	4.17	2.67	0.98	1.41	2.68	6.06	9.51
		MIN	2.07	1.69	0.14	0.20	0.31	2.29	2.28
81	4	AV	2.78	2.13	0.39	0.55	0.98	3.50	3.87
		SD	0.51	0.27	0.23	0.33	0.56	0.75	1.27
		MAX	3.97	2.66	0.90	1.25	2.23	4.97	5.72
		MIN	2.13	1.57	0.10	0.14	0.24	2.35	0.06
81	5	AV	3.07	2.24	0.47	0.66	1.17	3.95	4.94
		SD	0.42	0.28	0.25	0.35	0.64	0.55	1.39
		MAX	3.99	2.72	1.00	1.41	2.52	5.12	9.18
		MIN	2.30	1.54	0.10	0.15	0.29	2.74	2.43
81	6	AV	2.56	1.94	0.21	0.29	0.55	3.27	4.18
		SD	0.31	0.21	0.10	0.14	0.25	0.58	1.52
		MAX	3.48	2.31	0.45	0.63	1.22	4.76	9.67
		MIN	1.94	1.48	0.07	0.09	0.16	2.19	1.36
81	7	AV	3.43	2.35	0.48	0.67	1.15	4.56	5.92
		SD	0.42	0.21	0.19	0.28	0.47	0.64	1.49
		MAX	4.36	2.90	1.01	1.43	2.42	6.08	8.43
		MIN	2.38	1.82	0.20	0.27	0.47	3.15	3.13
81	8	AV	2.79	2.07	0.29	0.41	0.73	3.56	4.68
		SD	0.48	0.29	0.17	0.24	0.44	0.80	1.73
		MAX	3.89	2.76	0.85	1.20	2.15	5.22	7.39
		MIN	1.93	1.50	0.08	0.12	0.23	2.06	1.82
81	9	AV	3.46	2.46	0.62	0.88	1.49	4.45	5.14
		SD	0.54	0.29	0.29	0.41	0.68	0.77	1.01
		MAX	4.63	2.98	1.22	1.74	3.15	5.72	6.88
		MIN	2.17	1.74	0.15	0.21	0.38	2.39	2.38
81	10	AV	3.24	2.37	0.57	0.80	1.39	4.16	4.90
		SD	0.36	0.21	0.18	0.25	0.49	0.52	0.82
		MAX	4.07	2.78	0.97	1.37	3.21	5.21	7.68
		MIN	2.27	1.64	0.19	0.27	0.47	2.98	3.02
81	11	AV	2.91	2.17	0.38	0.53	0.92	3.71	4.70
		SD	0.46	0.27	0.21	0.29	0.53	0.70	1.73
		MAX	4.08	2.96	1.07	1.51	2.77	5.33	8.30
		MIN	2.00	1.67	0.16	0.22	0.37	2.32	1.89
81	12	AV	2.70	2.10	0.31	0.44	0.79	3.38	3.74
		SD	0.31	0.20	0.11	0.15	0.27	0.54	1.14
		MAX	3.35	2.51	0.58	0.83	1.57	4.90	8.79
		MIN	2.03	1.63	0.15	0.21	0.33	2.34	1.70

TABLE 12 continued

82	1	AV	2.94	2.04	0.19	0.27	0.45	4.05	5.90
		SD	0.38	0.24	0.03	0.03	0.06	0.36	0.38
		MAX	3.36	2.31	0.22	0.30	0.49	4.43	6.25
		MIN	2.62	1.85	0.17	0.24	0.38	3.72	5.50
82	2	AV	2.96	2.22	0.42	0.59	1.02	3.69	4.32
		SD	0.44	0.26	0.21	0.29	0.52	0.60	1.21
		MAX	4.01	2.89	1.00	1.42	2.56	4.98	8.17
		MIN	2.06	1.70	0.15	0.21	0.31	2.36	2.06
82	3	AV	3.23	2.33	0.54	0.76	1.31	4.06	4.70
		SD	0.54	0.30	0.26	0.37	0.65	0.75	1.13
		MAX	4.21	2.93	1.13	1.60	3.40	5.41	7.89
		MIN	2.01	1.70	0.10	0.13	0.23	2.13	2.04
82	4	AV	3.59	2.50	0.68	0.96	1.61	4.58	5.23
		SD	0.45	0.26	0.25	0.35	0.59	0.59	0.85
		MAX	4.51	3.08	1.25	1.77	3.45	5.61	6.79
		MIN	2.18	1.61	0.15	0.21	0.37	2.85	2.69
82	5	AV	3.32	2.39	0.52	0.73	1.27	4.21	4.84
		SD	0.41	0.23	0.22	0.31	0.58	0.56	0.91
		MAX	4.37	3.05	1.28	1.82	3.73	5.67	7.23
		MIN	2.21	1.69	0.16	0.23	0.38	2.77	2.55
82	6	AV	3.02	2.20	0.37	0.53	0.92	3.82	4.55
		SD	0.51	0.31	0.23	0.32	0.54	0.80	1.55
		MAX	4.21	3.09	1.11	1.60	2.69	5.23	9.86
		MIN	1.91	1.57	0.07	0.09	0.18	1.93	1.42
82	7	AV	3.05	2.27	0.45	0.64	1.12	4.01	4.72
		SD	0.47	0.26	0.17	0.24	0.42	0.65	0.99
		MAX	3.91	2.73	0.77	1.09	1.94	5.22	6.33
		MIN	2.06	1.68	0.18	0.25	0.42	2.62	2.70
82	8	AV	3.78	2.67	0.81	1.15	1.95	4.90	5.61
		SD	0.38	0.22	0.20	0.29	0.51	0.46	0.67
		MAX	4.77	3.26	1.21	1.70	2.88	6.32	7.12
		MIN	2.86	2.12	0.30	0.43	0.79	3.84	3.34
82	9	AV	3.17	2.33	0.48	0.68	1.15	4.07	4.91
		SD	0.52	0.32	0.24	0.34	0.57	0.69	1.41
		MAX	4.36	3.12	1.09	1.55	2.53	5.37	8.05
		MIN	2.01	1.71	0.18	0.24	0.40	2.31	1.90
82	10	AV	2.95	2.20	0.40	0.56	0.98	3.81	4.31
		SD	0.44	0.20	0.17	0.24	0.43	0.70	1.33
		MAX	3.79	2.64	0.85	1.18	2.14	5.46	7.80
		MIN	2.21	1.76	0.18	0.26	0.46	2.62	2.18
82	11	AV	3.13	2.31	0.50	0.71	1.21	4.07	4.71
		SD	0.53	0.31	0.28	0.39	0.65	0.68	1.26
		MAX	4.31	2.92	1.13	1.60	2.62	5.48	7.44
		MIN	2.24	1.79	0.19	0.27	0.45	2.79	0.66
82	12	AV	3.14	2.53	0.40	0.56	0.98	3.77	4.16
		SD	0.55	0.46	0.20	0.28	0.48	0.63	0.88
		MAX	4.48	3.49	1.11	1.56	2.71	5.34	6.63
		MIN	2.20	1.82	0.15	0.20	0.29	2.65	2.38
83	1	AV	3.69	2.93	0.50	0.69	1.19	4.37	4.83
		SD	0.48	0.31	0.22	0.31	0.53	0.66	1.15
		MAX	4.77	3.75	1.05	1.49	2.61	5.64	6.21
		MIN	2.50	2.26	0.14	0.19	0.29	2.63	0.20
83	2	AV	3.71	2.92	0.55	0.77	1.35	4.45	5.04
		SD	0.42	0.24	0.23	0.33	0.58	0.60	1.17
		MAX	4.70	3.51	1.17	1.65	2.92	5.61	8.23
		MIN	2.85	2.42	0.17	0.24	0.39	3.17	2.63
83	3	AV	3.36	2.72	0.42	0.58	1.02	3.96	4.35
		SD	0.56	0.33	0.24	0.34	0.59	0.86	1.43
		MAX	4.48	3.33	0.99	1.38	2.43	6.09	8.17
		MIN	2.31	2.06	0.08	0.11	0.19	2.47	2.15
83	4	AV	3.46	2.79	0.45	0.62	1.07	4.08	4.52
		SD	0.44	0.26	0.21	0.29	0.50	0.63	0.98
		MAX	4.44	3.28	0.92	1.30	2.53	5.69	6.90
		MIN	2.46	1.87	0.11	0.15	0.24	2.77	2.46
83	5	AV	3.57	2.77	0.48	0.67	1.15	4.36	4.96
		SD	0.48	0.23	0.19	0.27	0.43	0.78	1.41
		MAX	4.86	3.27	1.00	1.39	2.63	6.17	8.25
		MIN	2.55	2.24	0.14	0.20	0.35	2.69	2.37
83	6	AV	3.57	2.74	0.44	0.62	1.08	4.38	5.11
		SD	0.55	0.35	0.26	0.36	0.66	0.83	1.66
		MAX	4.81	3.49	1.23	1.73	3.26	6.59	9.63
		MIN	2.15	1.75	0.05	0.07	0.12	2.24	1.72
83	7	AV	3.58	2.82	0.46	0.65	1.10	4.32	4.88
		SD	0.41	0.26	0.20	0.29	0.49	0.65	1.06
		MAX	4.40	3.38	0.91	1.28	2.14	6.16	7.94
		MIN	2.37	1.89	0.07	0.10	0.17	2.46	2.41
83	8	AV	3.76	2.90	0.52	0.72	1.24	4.56	5.29
		SD	0.53	0.32	0.28	0.40	0.68	0.79	1.34
		MAX	4.95	3.49	1.14	1.61	2.92	6.79	8.90
		MIN	2.55	2.20	0.11	0.15	0.21	2.69	2.09
83	9	AV	3.59	2.76	0.42	0.58	1.01	4.37	4.99
		SD	0.48	0.31	0.26	0.36	0.62	0.65	1.43
		MAX	4.77	3.57	1.22	1.71	3.06	5.80	7.90
		MIN	2.72	2.08	0.12	0.16	0.26	3.18	2.55
83	10	AV	3.34	2.70	0.40	0.56	0.98	3.94	4.42
		SD	0.38	0.26	0.16	0.23	0.40	0.54	1.19
		MAX	4.33	3.34	0.91	1.26	2.35	5.55	8.01
		MIN	2.54	2.00	0.13	0.19	0.35	2.99	2.34
83	11	AV	3.27	2.67	0.41	0.58	1.02	3.80	4.16
		SD	0.41	0.27	0.18	0.26	0.43	0.59	1.22
		MAX	4.34	3.28	1.00	1.41	2.42	5.38	8.02
		MIN	2.57	2.09	0.15	0.22	0.45	2.81	2.15
83	12	AV	3.73	2.95	0.59	0.82	1.42	4.42	4.84
		SD	0.50	0.29	0.28	0.39	0.68	0.73	1.00
		MAX	4.86	3.68	1.32	1.84	4.03	5.93	7.08
		MIN	2.73	2.32	0.19	0.27	0.46	2.93	2.95
84	1	AV	3.28	2.65	0.34	0.48	0.86	3.82	4.10
		SD	0.40	0.25	0.14	0.19	0.33	0.67	1.27
		MAX	4.32	3.23	0.72	1.00	1.73	6.03	8.26
		MIN	2.36	2.05	0.10	0.14	0.23	2.38	2.17
84	2	AV	3.64	2.86	0.55	0.77	1.33	4.37	4.92
		SD	0.43	0.26	0.23	0.32	0.56	0.61	1.10
		MAX	4.66	3.45	1.17	1.65	3.14	6.07	8.76
		MIN	2.86	2.39	0.13	0.18	0.36	3.07	2.81
84	3	AV	3.48	2.78	0.48	0.67	1.17	4.13	4.64
		SD	0.57	0.37	0.30	0.42	0.72	0.77	1.24
		MAX	4.65	3.61	1.20	1.68	2.99	5.77	7.95
		MIN	2.50	2.01	0.12	0.17	0.33	2.73	2.14
84	4	AV	3.63	2.87	0.55	0.77	1.48	4.36	4.91
		SD	0.54	0.35	0.28	0.39	0.94	0.76	1.26
		MAX	4.83	3.58	1.22	1.69	7.00	6.04	8.96
		MIN	2.29	1.88	0.08	0.10	0.29	2.40	2.01
84	5	AV	3.70	2.92	0.59	0.83	1.44	4.44	5.01
		SD	0.36	0.23	0.21	0.30	0.54	0.49	0.66
		MAX	4.46	3.45	1.16	1.63	3.15	5.48	6.38
		MIN	2.92	2.45	0.17	0.24	0.42	3.29	2.96
84	6	AV	3.71	2.89	0.54	0.76	1.31	4.47	5.08
		SD	0.48	0.28	0.24	0.34	0.54	0.68	1.14
		MAX	4.55	3.49	1.03	1.44	2.37	5.68	8.66
		MIN	2.55	2.14	0.14	0.20	0.47	2.96	2.33
84	7	AV	3.46	2.73	0.40	0.56	1.00	4.15	4.44
		SD	0.64	0.29	0.19	0.27	0.48	0.89	1.06
		MAX	7.88	3.92	0.91	1.27	2.29	9.72	6.89
		MIN	2.32	2.09	0.12	0.16	0.29	2.44	1.99
84	8	AV	3.42	2.73	0.33	0.46	0.83	4.02	4.40
		SD	0.42	0.29	0.18	0.25	0.45	0.61	1.33
		MAX	4.43	3.51	0.83	1.17	2.20	5.41	8.36
		MIN	2.46	2.13	0.10	0.14	0.29	2.51	1.26
84	9	AV	3.16	2.56	0.29	0.40	0.76	3.64	4.16
		SD	0.39	0.28	0.17	0.24	0.44	0.54	1.40
		MAX	4.62	3.42	1.11	1.55	2.42	5.46	8.33
		MIN	2.54	2.08	0.11	0.16	0.30	2.60	2.02
84	10	AV	3.50	2.80	0.46	0.64	1.15	4.07	4.46
		SD	0.58	0.40	0.29	0.41	0.71	0.72	1.18
		MAX	4.98	3.93	1.32	1.84	3.47	5.80	7.98
		MIN	2.65	2.07	0.16	0.22	0.38	2.86	2.20

TABLE 12 continued

84	11	AV	3.54	2.86	0.52	0.72	1.35	4.10	4.56
		SD	0.67	0.46	0.36	0.51	0.92	0.86	1.26
		MAX	5.38	4.02	1.58	2.23	3.67	6.39	8.31
		MIN	2.51	2.15	0.15	0.21	0.40	2.73	2.51
84	12	AV	3.27	2.61	0.38	0.53	1.00	3.86	4.31
		SD	0.48	0.28	0.23	0.32	0.62	0.76	1.39
		MAX	4.45	3.37	1.17	1.65	3.11	5.82	8.42
		MIN	2.22	1.84	0.14	0.20	0.40	2.48	1.91
85	1	AV	3.46	2.74	0.50	0.70	1.22	4.12	4.67
		SD	0.52	0.32	0.27	0.39	0.63	0.72	1.35
		MAX	5.00	3.68	1.45	2.05	3.56	6.01	8.94
		MIN	2.47	2.07	0.15	0.21	0.39	2.64	1.94
85	2	AV	3.57	2.82	0.59	0.82	1.47	4.27	4.68
		SD	0.43	0.29	0.23	0.33	0.57	0.57	0.99
		MAX	4.39	3.47	1.08	1.53	2.81	5.41	6.20
		MIN	2.68	2.06	0.11	0.15	0.34	2.85	2.34
85	3	AV	3.49	2.74	0.54	0.75	1.33	4.18	4.65
		SD	0.45	0.27	0.24	0.34	0.59	0.65	1.18
		MAX	4.55	3.42	1.04	1.47	2.79	5.88	7.00
		MIN	2.71	2.23	0.16	0.23	0.39	3.09	2.45
85	4	AV	3.47	2.68	0.51	0.72	1.25	4.17	4.52
		SD	0.59	0.36	0.27	0.38	0.63	0.85	1.36
		MAX	5.86	3.48	1.23	1.76	2.89	7.67	7.09
		MIN	2.40	1.90	0.13	0.18	0.32	2.60	0.67
85	5	AV	3.81	2.90	0.65	0.91	1.56	4.69	5.38
		SD	0.38	0.22	0.20	0.28	0.47	0.56	0.98
		MAX	4.53	3.35	1.12	1.56	2.81	5.83	8.40
		MIN	2.94	2.44	0.21	0.31	0.63	3.42	3.27
85	6	AV	3.62	2.80	0.58	0.81	1.40	4.38	5.04
		SD	0.48	0.29	0.23	0.32	0.57	0.69	1.09
		MAX	4.49	3.34	1.01	1.40	2.83	5.55	7.05
		MIN	2.76	2.20	0.16	0.23	0.44	3.04	2.65
85	7	AV	3.52	2.72	0.51	0.72	1.27	4.25	4.75
		SD	0.61	0.35	0.25	0.35	0.60	0.91	1.36
		MAX	4.52	3.48	1.05	1.48	2.54	5.72	8.63
		MIN	2.29	1.99	0.13	0.17	0.40	2.40	2.37
85	9	AV	2.80	2.09	0.36	0.51	0.94	3.45	4.00
		SD	0.55	0.33	0.26	0.38	0.68	0.75	1.64
		MAX	4.36	3.06	1.24	1.76	3.36	5.42	8.10
		MIN	2.12	1.62	0.16	0.21	0.43	2.38	0.99
85	10	AV	3.47	2.53	0.67	0.94	1.61	4.32	4.88
		SD	0.73	0.44	0.35	0.49	0.81	0.96	1.39
		MAX	5.10	3.62	1.46	2.02	3.40	5.93	9.28
		MIN	2.27	1.79	0.21	0.29	0.55	2.69	2.37
85	11	AV	2.95	2.19	0.43	0.60	1.07	3.66	4.22
		SD	0.48	0.27	0.20	0.29	0.50	0.71	1.29
		MAX	4.01	2.90	1.04	1.46	2.99	5.50	8.20
		MIN	1.87	1.59	0.15	0.21	0.40	2.01	1.43
85	12	AV	2.63	2.06	0.35	0.49	0.86	3.23	3.60
		SD	0.26	0.19	0.10	0.13	0.23	0.35	0.68
		MAX	3.27	2.48	0.66	0.93	1.76	4.08	5.88
		MIN	2.07	1.66	0.16	0.23	0.47	2.35	2.19
86	1	AV	3.29	2.43	0.60	0.85	1.48	4.10	4.61
		SD	0.64	0.36	0.28	0.40	0.68	0.89	1.18
		MAX	4.62	3.13	1.26	1.76	3.16	6.16	6.95
		MIN	1.99	1.62	0.15	0.22	0.46	2.24	2.26
86	2	AV	3.01	2.31	0.44	0.61	1.07	3.69	4.15
		SD	0.64	0.36	0.33	0.46	0.83	0.84	1.23
		MAX	5.20	3.51	1.74	2.50	4.95	6.86	7.36
		MIN	2.05	1.64	0.11	0.16	0.30	2.29	2.17
86	3	AV	3.62	2.63	0.70	0.99	1.71	4.55	5.14
		SD	0.47	0.26	0.22	0.32	0.58	0.65	0.96
		MAX	4.55	3.13	1.27	1.80	3.13	5.79	7.23
		MIN	2.36	1.88	0.17	0.25	0.41	2.64	2.28
86	4	AV	3.58	2.59	0.63	0.89	1.52	4.57	5.21
		SD	0.37	0.21	0.19	0.27	0.48	0.53	0.83
		MAX	4.49	3.07	1.15	1.63	2.84	6.22	8.76
		MIN	2.64	2.00	0.23	0.33	0.56	3.32	2.68
86	5	AV	3.24	2.41	0.47	0.65	1.12	4.07	4.81
		SD	0.44	0.27	0.23	0.33	0.57	0.60	1.37
		MAX	4.32	3.06	1.09	1.54	3.22	5.52	9.57
		MIN	2.35	1.79	0.16	0.22	0.38	2.69	0.39
86	6	AV	3.26	2.41	0.46	0.65	1.10	4.14	5.00
		SD	0.53	0.31	0.27	0.38	0.65	0.78	1.48
		MAX	4.41	3.12	1.15	1.63	3.00	5.61	9.87
		MIN	2.00	1.61	0.08	0.12	0.16	2.30	1.76
86	7	AV	3.41	2.51	0.48	0.68	1.16	4.32	5.13
		SD	0.33	0.22	0.19	0.28	0.49	0.50	1.15
		MAX	4.21	2.97	0.93	1.33	2.48	5.59	7.94
		MIN	2.60	1.82	0.17	0.24	0.40	3.20	2.46
86	8	AV	3.26	2.44	0.41	0.57	0.96	4.08	4.75
		SD	0.60	0.36	0.20	0.29	0.47	0.86	1.43
		MAX	5.29	3.39	1.16	1.64	2.71	6.45	7.45
		MIN	1.70	1.47	0.09	0.13	0.20	1.83	1.35
86	9	AV	3.04	2.28	0.41	0.57	0.99	3.81	4.53
		SD	0.66	0.36	0.25	0.35	0.59	0.98	1.70
		MAX	4.37	3.06	1.04	1.49	2.53	5.93	9.56
		MIN	2.00	1.68	0.09	0.12	0.22	2.10	1.50
86	10	AV	2.65	2.06	0.26	0.36	0.63	3.31	4.32
		SD	0.37	0.20	0.09	0.13	0.22	0.64	1.76
		MAX	4.35	3.01	0.49	0.68	1.09	4.98	8.73
		MIN	1.75	1.54	0.08	0.11	0.21	1.85	1.56
86	11	AV	2.70	2.05	0.27	0.37	0.66	3.44	4.71
		SD	0.45	0.20	0.09	0.13	0.24	0.86	2.19
		MAX	4.83	2.89	0.56	0.80	1.41	7.25	9.26
		MIN	1.61	1.37	0.06	0.09	0.16	1.61	1.35
86	12	AV	2.68	2.08	0.29	0.40	0.70	3.36	4.49
		SD	0.31	0.16	0.09	0.13	0.23	0.59	2.02
		MAX	3.59	2.47	0.68	0.97	1.85	4.88	9.98
		MIN	2.09	1.74	0.13	0.18	0.31	2.30	2.15
87	1	AV	2.46	2.04	0.24	0.33	0.58	2.89	3.12
		SD	0.24	0.15	0.06	0.09	0.15	0.37	0.65
		MAX	3.52	2.54	0.45	0.64	1.00	4.29	5.34
		MIN	2.00	1.73	0.13	0.18	0.30	2.19	1.56
87	2	AV	2.88	2.18	0.34	0.48	0.84	3.66	4.47
		SD	0.42	0.21	0.15	0.21	0.36	0.73	2.10
		MAX	4.08	2.94	0.90	1.29	2.15	5.55	9.76
		MIN	2.16	1.69	0.11	0.16	0.28	2.31	0.32
87	3	AV	2.75	2.11	0.27	0.38	0.65	3.49	4.44
		SD	0.40	0.17	0.09	0.12	0.21	0.76	1.86
		MAX	4.09	2.68	0.60	0.84	1.43	5.65	8.02
		MIN	2.10	1.69	0.12	0.17	0.28	2.24	1.56
87	4	AV	3.19	2.28	0.42	0.59	1.01	4.21	5.59
		SD	0.52	0.28	0.21	0.30	0.52	0.83	2.17
		MAX	4.84	3.14	1.03	1.44	2.82	6.31	9.80
		MIN	2.03	1.70	0.01	0.02	0.03	2.15	0.05
87	5	AV	3.40	2.47	0.51	0.72	1.24	4.34	5.15
		SD	0.43	0.27	0.21	0.30	0.54	0.60	1.11
		MAX	4.55	3.10	1.03	1.46	3.07	5.91	9.09
		MIN	2.15	1.60	0.11	0.16	0.31	2.68	2.61
87	6	AV	3.46	2.51	0.54	0.76	1.31	4.39	5.22
		SD	0.46	0.23	0.23	0.32	0.58	0.70	1.16
		MAX	4.46	3.14	1.20	1.70	3.70	6.20	7.83
		MIN	2.38	1.79	0.13	0.19	0.31	2.79	2.15
87	7	AV	3.31	2.38	0.42	0.59	1.02	4.27	5.14
		SD	0.48	0.28	0.24	0.34	0.63	0.71	1.28
		MAX	4.55	3.12	1.19	1.69	4.02	6.15	8.22
		MIN	2.15	1.68	0.09	0.13	0.20	2.45	1.95
87	8	AV	3.16	2.35	0.39	0.54	0.93	3.98	4.62
		SD	0.50	0.31	0.21	0.30	0.50	0.75	1.50
		MAX	4.49	3.35	1.08	1.47	2.70	5.49	8.36
		MIN	1.91	1.62	0.12	0.17	0.29	2.09	1.66
87	9	AV	3.47	2.51	0.51	0.72	1.25	4.40	5.12
		SD	0.51	0.28	0.26	0.36	0.65	0.71	1.25
		MAX	4.81	3.24	1.21	1.72	2.95	5.71	7.87
		MIN	2.19	1.78	0.11	0.16	0.26	2.52	2.17

TABLE 12 continued

87	10	AV	3.03	2.33	0.41	0.57	1.01	3.76	4.32
		SD	0.44	0.26	0.20	0.28	0.51	0.60	1.25
		MAX	4.52	3.15	1.26	1.77	3.09	5.71	7.27
		MIN	2.28	1.80	0.17	0.24	0.41	2.59	2.17
87	11	AV	2.99	2.32	0.42	0.59	1.05	3.68	4.13
		SD	0.44	0.25	0.21	0.29	0.55	0.62	1.09
		MAX	4.51	3.09	1.32	1.87	3.87	5.64	7.43
		MIN	2.10	1.78	0.15	0.22	0.38	2.36	2.16
87	12	AV	3.19	2.41	0.45	0.63	1.14	3.98	4.48
		SD	0.36	0.24	0.17	0.24	0.52	0.52	1.11
		MAX	3.87	2.85	0.87	1.25	3.70	5.17	7.88
		MIN	2.30	1.78	0.15	0.21	0.35	2.72	2.20

Tz - zero crossing period (sec)
Tc - crest period (sec)
Hrms - root mean square wave height (m)
Hsig - significant wave height (m)
Hmax - maximum recorded wave height (m)
Ts - significant period (sec)
Tp - peak energy period (sec)

TABLE 13

Annual Wave Statistics for Wave Buoy near Cape Cleveland.

YEAR	MONTH		TZ	TC	HRMS	HSIG	HMAX	TS	TP
75	12	AV	3.10	2.29	0.49	0.69	1.24	3.96	4.53
75	12	SD	0.58	0.33	0.25	0.35	0.64	0.79	1.17
75	12	MAX	4.64	3.31	1.27	1.80	3.58	5.80	7.40
75	12	MIN	2.09	1.64	0.13	0.18	0.30	2.42	2.15
76	6	AV	3.17	2.25	0.47	0.66	1.15	4.14	4.97
76	6	SD	0.56	0.32	0.23	0.33	0.58	0.80	1.42
76	6	MAX	4.83	3.31	1.27	1.80	3.58	7.78	9.90
76	6	MIN	1.78	1.48	0.08	0.11	0.19	2.15	0.34
76	12	AV	3.12	2.22	0.42	0.59	1.03	4.03	4.81
76	12	SD	0.53	0.31	0.22	0.31	0.54	0.79	1.47
76	12	MAX	4.83	3.30	1.23	1.74	3.16	7.78	9.90
76	12	MIN	1.78	1.48	0.08	0.11	0.19	1.91	0.34
77	6	AV	3.15	2.26	0.44	0.61	1.06	4.02	4.68
77	6	SD	0.57	0.32	0.24	0.35	0.60	0.82	1.40
77	6	MAX	6.14	3.30	1.32	1.89	3.30	7.36	9.46
77	6	MIN	1.85	1.52	0.09	0.12	0.21	1.91	1.19
77	12	AV	3.30	2.34	0.50	0.70	1.22	4.23	4.92
77	12	SD	0.55	0.31	0.25	0.36	0.62	0.79	1.27
77	12	MAX	6.14	3.29	1.32	1.89	3.30	7.36	9.46
77	12	MIN	1.93	1.52	0.09	0.12	0.21	2.14	1.19
78	6	AV	3.30	2.35	0.48	0.68	1.18	4.24	4.91
78	6	SD	0.51	0.29	0.24	0.34	0.58	0.75	1.23
78	6	MAX	5.18	3.26	1.20	1.73	3.03	6.79	8.12
78	6	MIN	2.05	1.56	0.10	0.14	0.23	2.31	1.79
78	12	AV	3.25	2.30	0.46	0.65	1.13	4.16	4.78
78	12	SD	0.55	0.29	0.24	0.34	0.60	0.84	1.30
78	12	MAX	5.74	3.26	1.26	1.78	2.80	9.00	8.09
78	12	MIN	1.97	1.54	0.10	0.14	0.23	2.22	1.73
79	6	AV	3.28	2.31	0.51	0.71	1.23	4.23	4.91
79	6	SD	0.55	0.30	0.27	0.38	0.66	0.82	1.30
79	6	MAX	5.74	3.41	1.94	2.76	4.70	9.00	9.73
79	6	MIN	1.97	1.54	0.10	0.13	0.22	2.22	0.36
79	12	AV	3.30	2.33	0.48	0.67	1.15	4.24	4.92
79	12	SD	0.51	0.29	0.26	0.37	0.63	0.75	1.35
79	12	MAX	5.46	3.41	1.94	2.76	4.70	8.78	9.73
79	12	MIN	2.14	1.66	0.08	0.11	0.22	2.58	0.36
80	6	AV	3.30	2.31	0.42	0.59	1.01	4.21	4.82
80	6	SD	0.48	0.27	0.23	0.32	0.53	0.73	1.36
80	6	MAX	5.90	3.36	1.91	2.65	3.05	6.73	9.02
80	6	MIN	2.13	1.65	0.08	0.11	0.22	2.45	2.02
80	12	AV	3.21	2.23	0.40	0.57	0.98	4.03	4.42
80	12	SD	0.58	0.26	0.23	0.33	0.53	0.79	1.30
80	12	MAX	6.04	3.36	1.91	2.65	3.19	6.96	7.91
80	12	MIN	1.94	1.47	0.08	0.11	0.19	2.34	1.38
81	6	AV	3.10	2.18	0.37	0.52	0.93	3.85	4.42
81	6	SD	0.69	0.27	0.22	0.31	0.53	0.73	1.36
81	6	MAX	6.69	2.92	1.10	1.52	3.19	6.96	9.67
81	6	MIN	1.94	1.47	0.07	0.09	0.16	2.19	0.06
81	12	AV	3.06	2.20	0.40	0.56	0.99	3.88	4.70
81	12	SD	0.64	0.29	0.23	0.33	0.57	0.80	1.46
81	12	MAX	6.69	2.98	1.22	1.74	3.21	6.08	9.67
81	12	MIN	1.93	1.48	0.07	0.09	0.16	2.06	0.06
82	6	AV	3.18	2.30	0.48	0.68	1.17	4.04	4.80
82	6	SD	0.53	0.30	0.25	0.36	0.61	0.77	1.33
82	6	MAX	4.63	3.09	1.28	1.82	3.73	6.08	9.86
82	6	MIN	1.91	1.50	0.07	0.09	0.18	1.93	1.42
82	12	AV	3.25	2.37	0.52	0.73	1.26	4.12	4.78
82	12	SD	0.54	0.32	0.26	0.37	0.63	0.74	1.19
82	12	MAX	4.77	3.49	1.28	1.82	3.73	6.32	9.86
82	12	MIN	1.91	1.57	0.07	0.09	0.18	1.93	0.66
83	6	AV	3.43	2.64	0.49	0.69	1.19	4.22	4.81
83	6	SD	0.55	0.37	0.25	0.35	0.59	0.75	1.30
83	6	MAX	4.86	3.75	1.23	1.73	3.26	6.59	9.63
83	6	MIN	2.01	1.68	0.05	0.07	0.12	2.24	0.20
83	12	AV	3.50	2.81	0.50	0.70	1.22	4.12	4.51
83	12	SD	0.51	0.31	0.25	0.35	0.60	0.73	1.16
83	12	MAX	4.86	3.68	1.32	1.84	4.03	5.93	8.02
83	12	MIN	2.57	2.09	0.15	0.22	0.45	2.81	2.15
84	6	AV	3.57	2.83	0.51	0.72	1.27	4.24	4.73
84	6	SD	0.50	0.31	0.25	0.35	0.65	0.71	1.17
84	6	MAX	4.86	3.68	1.32	1.84	7.00	6.07	8.96
84	6	MIN	2.29	1.88	0.08	0.10	0.23	2.38	2.01
84	12	AV	3.50	2.78	0.46	0.64	1.16	4.14	4.61
84	12	SD	0.53	0.34	0.26	0.37	0.68	0.74	1.24
84	12	MAX	7.88	4.02	1.58	2.23	7.00	9.72	8.96
84	12	MIN	2.22	1.84	0.08	0.10	0.23	2.38	1.26
85	6	AV	3.48	2.75	0.47	0.66	1.19	4.13	4.59
85	6	SD	0.54	0.34	0.27	0.38	0.65	0.75	1.27
85	6	MAX	7.88	4.02	1.58	2.23	3.67	9.72	8.94
85	6	MIN	2.22	1.84	0.10	0.14	0.29	2.44	0.67
85	12	AV	3.35	2.57	0.52	0.73	1.27	4.07	4.58
85	12	SD	0.62	0.42	0.26	0.37	0.62	0.82	1.30
85	12	MAX	5.86	3.68	1.46	2.05	3.56	7.67	9.28
85	12	MIN	1.87	1.59	0.11	0.15	0.32	2.01	0.67
86	6	AV	3.24	2.41	0.52	0.73	1.27	4.04	4.62
86	6	SD	0.60	0.36	0.27	0.39	0.67	0.83	1.31
86	6	MAX	5.20	3.62	1.74	2.50	4.95	6.86	9.87
86	6	MIN	1.87	1.59	0.08	0.12	0.16	2.01	0.39
86	12	AV	3.14	2.35	0.45	0.63	1.08	3.95	4.74
86	12	SD	0.59	0.34	0.25	0.36	0.62	0.85	1.53
86	12	MAX	5.29	3.51	1.74	2.50	4.95	7.25	9.98
86	12	MIN	1.61	1.37	0.06	0.09	0.16	1.61	0.39
87	6	AV	2.99	2.25	0.37	0.52	0.89	3.77	4.65
87	6	SD	0.56	0.30	0.20	0.28	0.48	0.86	1.77
87	6	MAX	5.29	3.39	1.20	1.70	3.70	7.25	9.98
87	6	MIN	1.61	1.37	0.01	0.02	0.03	1.61	0.05
87	12	AV	3.11	2.32	0.41	0.57	1.00	3.92	4.65
87	12	SD	0.53	0.29	0.21	0.30	0.54	0.80	1.57
87	12	MAX	4.84	3.35	1.32	1.87	4.02	6.31	9.80
87	12	MIN	1.91	1.60	0.01	0.02	0.03	2.09	0.05

Tz - zero crossing period (sec)
Tc - crest period (sec)
Hrms - root mean square wave height (m)
Hsig - significant wave height (m)
Hmax - maximum recorded wave height (m)
Ts - significant period (sec)
Tp - peak energy period (sec)

Note: Data is presented both for calendar years ending 31 December and for dredging years ending 30 June.

TABLE 14

WAVE STATISTICS

WAVE PERIOD/WAVE HEIGHT OCCURRENCES

a) ALL DATA, ALL DIRECTIONS

Significant Wave Height (metres)	Peak Energy Wave Periods (Seconds)								Totals
	0 - 2.99	3 - 4.99	5 - 6.99	7 - 8.99	9 - 10.99	11 - 12.99	13 - 14.99	> 14.99	
.00 - .20	40.87	35.50	39.00	19.37	6.25	3.25	*	*	144.24
.21 - .40	275.95	370.57	242.43	119.80	6.49	2.75	0.75	*	1018.74
.41 - .60	61.70	643.74	128.16	46.41	4.01	1.25	0.50	*	885.77
.61 - .80	1.00	423.09	184.27	11.50	1.00	*	*	*	620.86
.81 - 1.00	*	189.19	283.10	4.75	*	1.00	*	*	478.04
1.01 - 1.20	*	73.20	262.49	0.49	0.50	0.50	*	*	337.18
1.21 - 1.40	*	11.51	146.83	0.50	*	*	*	*	158.84
1.41 - 1.60	*	2.50	66.95	0.75	*	*	*	*	70.20
1.61 - 1.80	*	0.50	29.47	0.50	*	*	*	*	30.47
1.81 - 2.00	*	*	6.75	*	*	*	*	*	6.75
2.01 - 2.20	*	*	2.25	*	*	*	*	*	2.25
2.21 - 2.40	*	*	1.50	0.50	*	*	*	*	2.00
2.41 - 2.60	*	*	*	0.25	*	*	*	*	0.25
2.61 - 2.80	*	0.50	*	0.50	*	*	*	*	1.00
TOTALS	379.52	1750.30	1393.20	205.32	18.25	8.75	1.25	0.0	3756.59

Values in the above table are durations in days and have been rounded to the second decimal place.

TABLE 14 continued

WAVE STATISTICS

WAVE PERIOD/WAVE HEIGHT OCCURRENCES

b) SUMMER DATA, ALL DIRECTIONS

Significant Wave Height (metres)	Peak Energy Wave Period (Seconds)								Totals
	0 - 2.99	3 - 4.99	5 - 6.99	7 - 8.99	9 - 10.99	11 - 12.99	13 - 14.99	> 14.99	
.00 - .20	15.25	18.75	12.50	4.25	3.25	*	*	*	54.00
.21 - .40	158.15	216.40	112.04	50.65	5.00	2.00	0.25	*	544.49
.41 - .60	42.54	329.76	58.83	22.26	3.26	1.00	0.50	*	458.15
.61 - .80	0.50	201.17	67.04	5.75	1.00	*	*	*	275.46
.81 - 1.00	*	99.38	105.12	3.75	*	1.00	*	*	209.24
1.01 - 1.20	*	43.84	113.61	0.25	0.50	0.50	*	*	158.70
1.21 - 1.40	*	7.26	64.71	0.50	*	*	*	*	72.47
1.41 - 1.60	*	1.25	39.11	0.50	*	*	*	*	40.86
1.61 - 1.80	*	0.50	18.24	0.25	*	*	*	*	18.99
1.31 - 2.00	*	*	5.25	*	*	*	*	*	5.25
2.01 - 2.20	*	*	2.00	*	*	*	*	*	2.00
2.21 - 2.40	*	*	1.50	0.50	*	*	*	*	2.00
2.41 - 2.60	*	*	*	0.25	*	*	*	*	0.25
2.61 - 2.80	*	0.50	*	0.50	*	*	*	*	1.00
TOTALS	216.44	918.81	599.95	89.40	13.01	4.50	0.75	0.0	1842.86

Values in the above tables are durations in days and have been rounded to the second decimal place.

TABLE 14 continued

WAVE STATISTICS

WAVE PERIOD/WAVE HEIGHT OCCURRENCES

c) WINTER DATA, ALL DIRECTIONS

Significant Wave Height (metres)	Peak Energy Wave Period (Seconds)								Totals
	0 - 2.99	3 - 4.99	5 - 6.99	7 - 8.99	9 - 10.99	11 - 12.99	13 - 14.99	> 14.99	
.00 - .20	25.62	16.75	26.50	15.13	2.99	3.25	*	*	90.24
.21 - .40	117.79	154.16	130.39	69.15	1.50	0.75	0.50	*	474.24
.41 - .60	19.17	313.98	69.33	24.14	0.75	0.25	*	*	427.62
.61 - .80	0.50	221.92	117.23	5.75	*	*	*	*	345.40
.81 - 1.00	*	89.82	177.98	1.00	*	*	*	*	268.80
1.01 - 1.20	*	29.36	148.88	0.25	*	*	*	*	178.49
1.21 - 1.40	*	4.25	82.12	*	*	*	*	*	86.37
1.41 - 1.60	*	1.25	27.84	0.25	*	*	*	*	29.34
1.61 - 1.80	*	*	11.23	0.25	*	*	*	*	11.48
1.81 - 2.00	*	*	1.50	*	*	*	*	*	1.50
2.01 - 2.20	*	*	0.25	*	*	*	*	*	0.25
TOTALS	163.08	831.49	793.27	115.92	5.24	4.25	0.50	0.00	1913.73

Values in the above table are durations in days and have been rounded to the second decimal place.

FIGURES

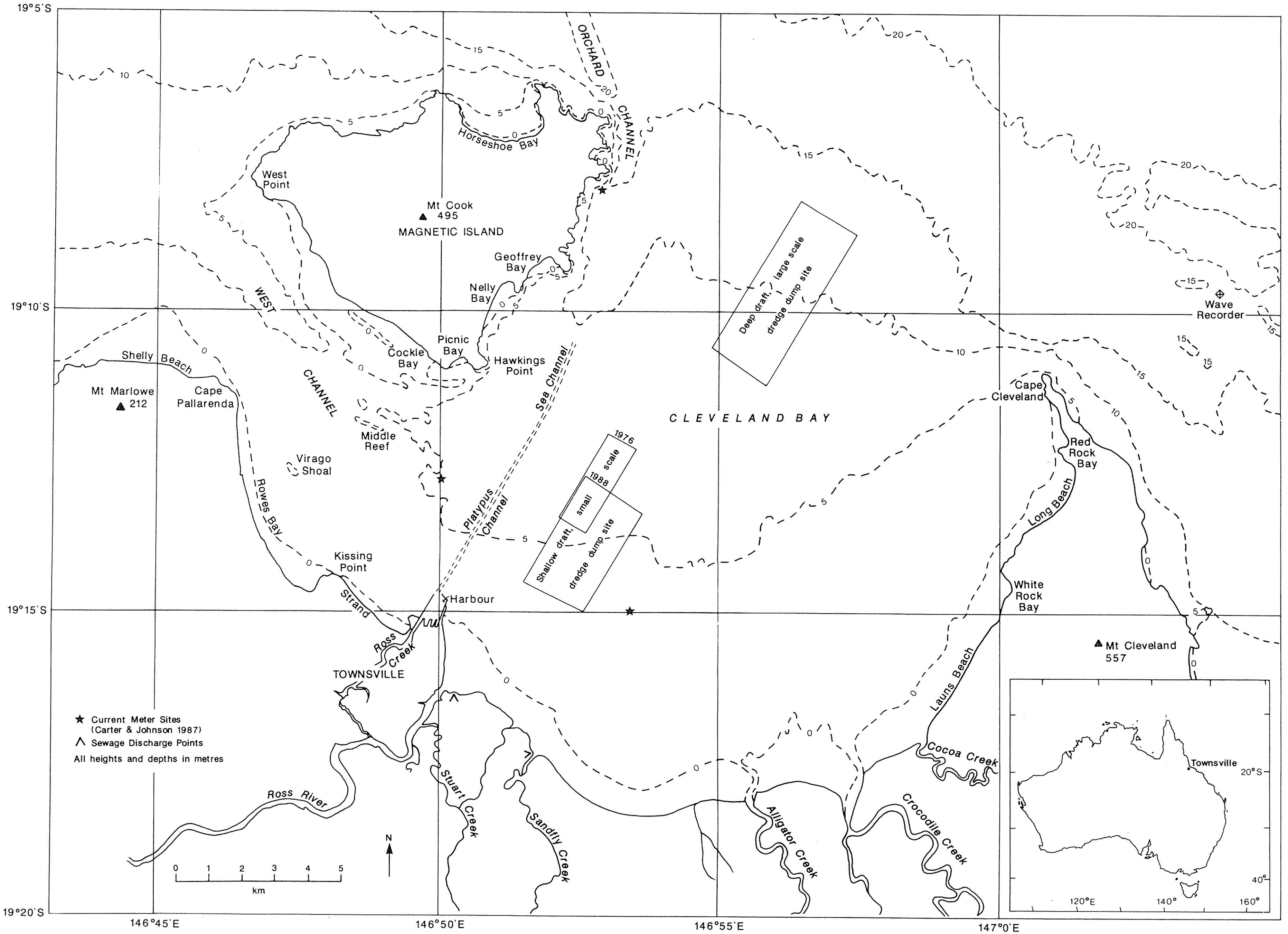
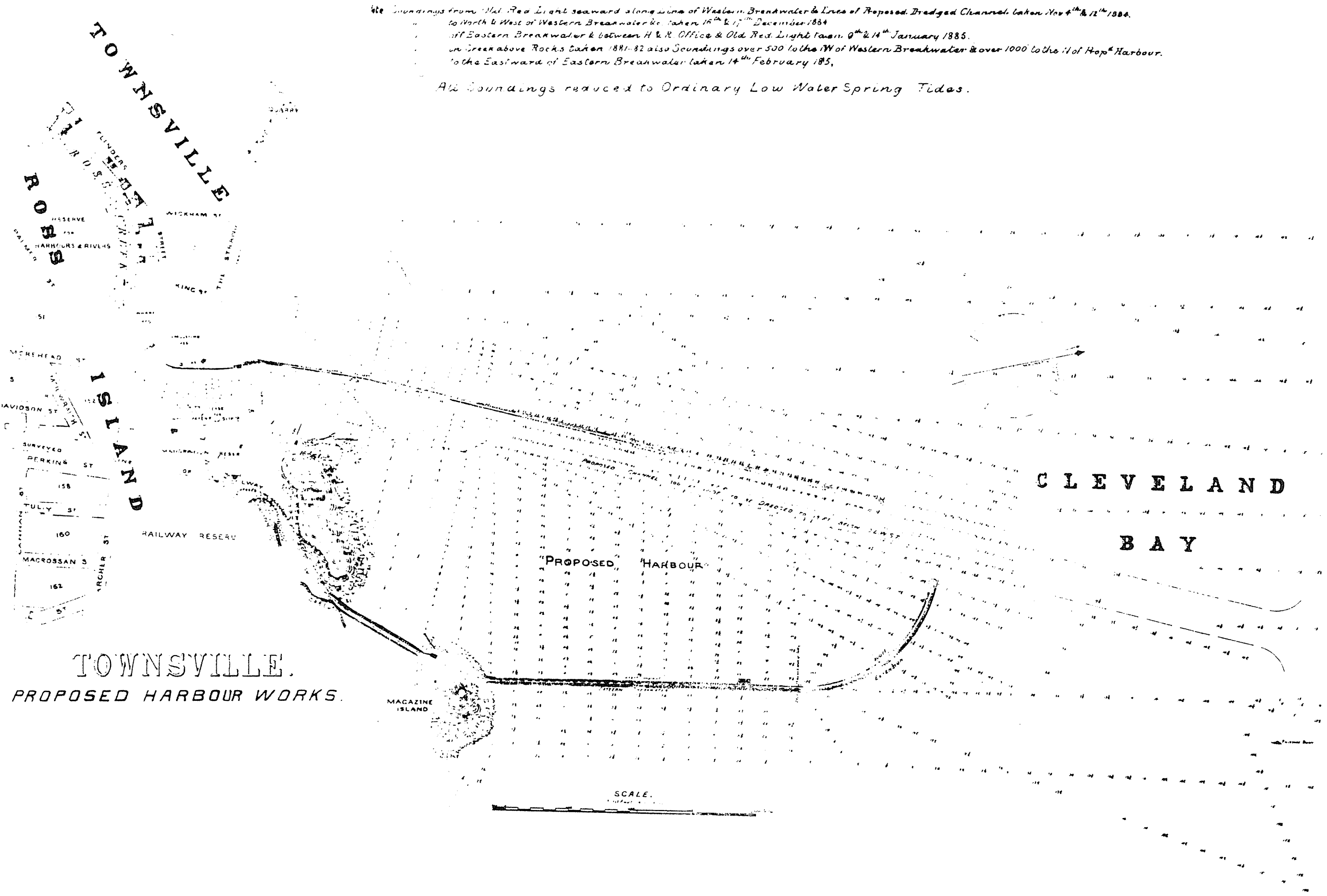


FIGURE 1 Location map of Townsville and Cleveland Bay area.



Note. Soundings from Old Red Light seaward along Line of Western Breakwater & Lines of Proposed Dredged Channel taken Nov 4th & 12th 1884.
" to North & West of Western Breakwater &c. taken 16th & 17th December 1884
" off Eastern Breakwater & between H & R. Office & Old Red Light taken 9th & 14th January 1885.
" in Creek above Rocks taken 1881-82 also Soundings over 500 to the W of Western Breakwater & over 1000 to the N of Propd Harbour.
" to the Eastward of Eastern Breakwater taken 14th February 1885.

All Soundings reduced to Ordinary Low Water Spring Tides.

FIGURE 2 Nisbet's plan showing progress of harbour works, 1885.

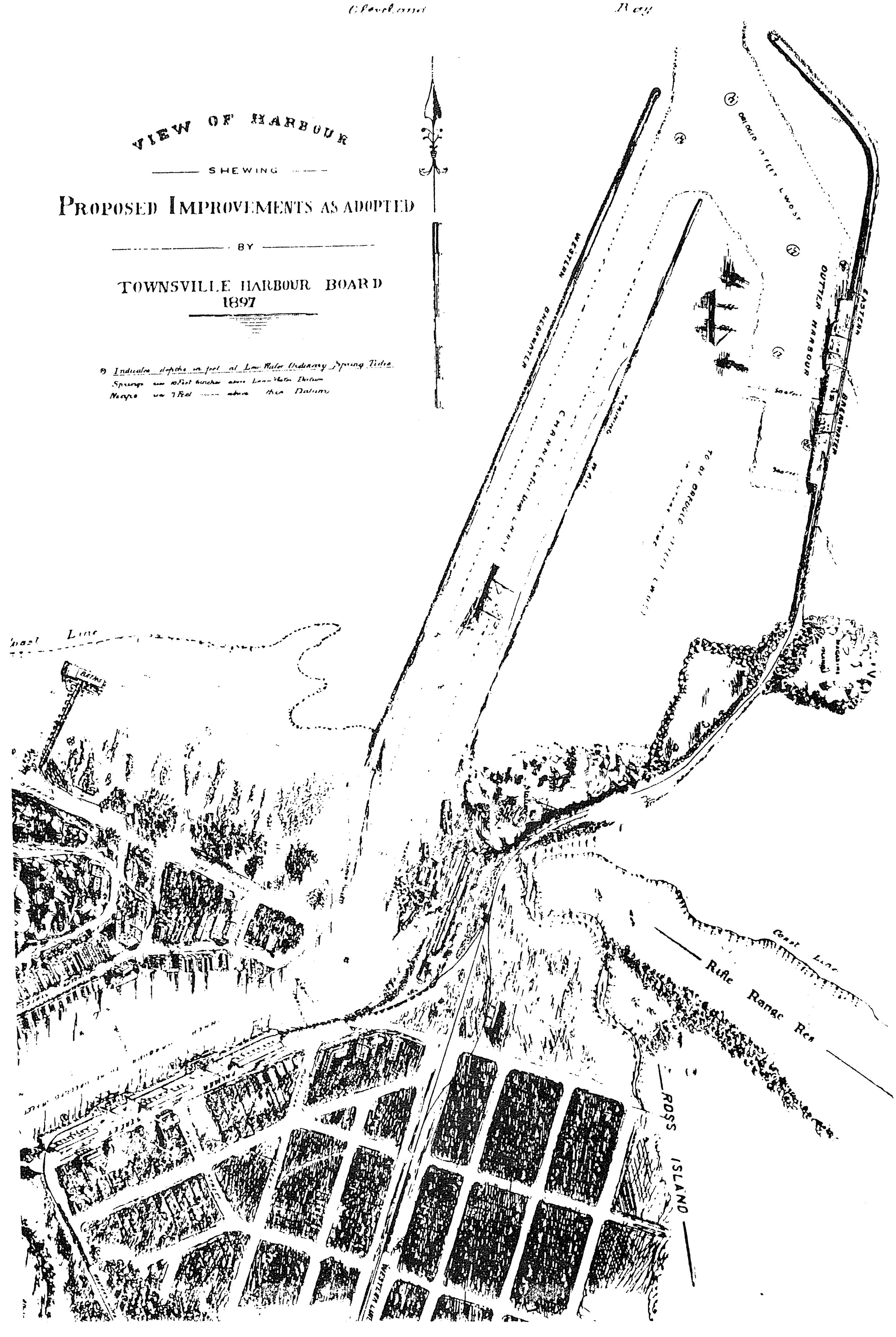


FIGURE 3 View of Harbour showing proposed improvements as adopted by Townsville Harbour Board, 1897.

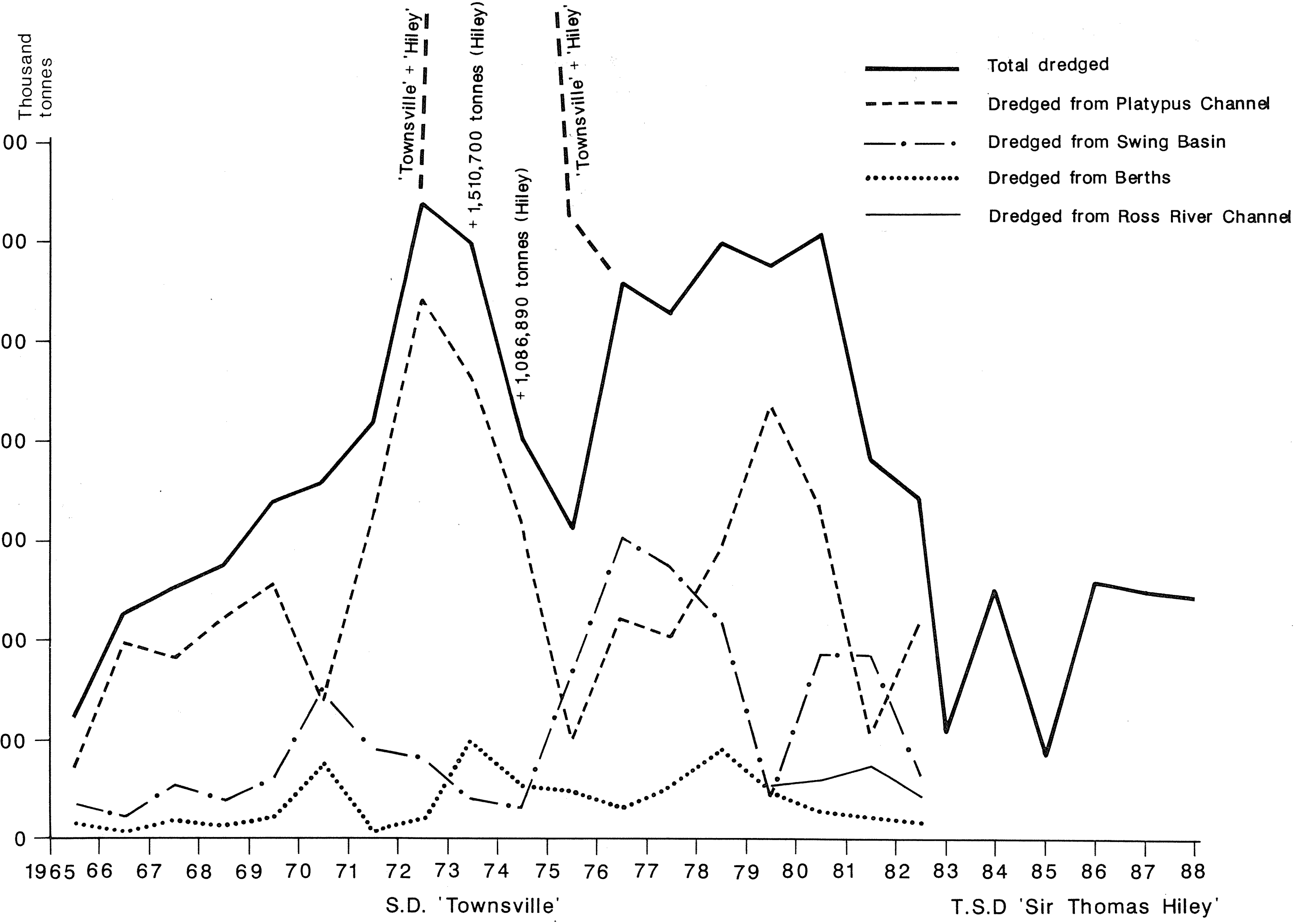


FIGURE 4 Townsville Port Authority annual dredging records September 1965 to February 1983 for S.D. 'Townsville' and July 1983 to August 1988 for T.S.D. 'Sir Thomas Hiley'. Note that additional dredging was carried out by 'Sir Thomas Hiley' between 1973 and 1975.

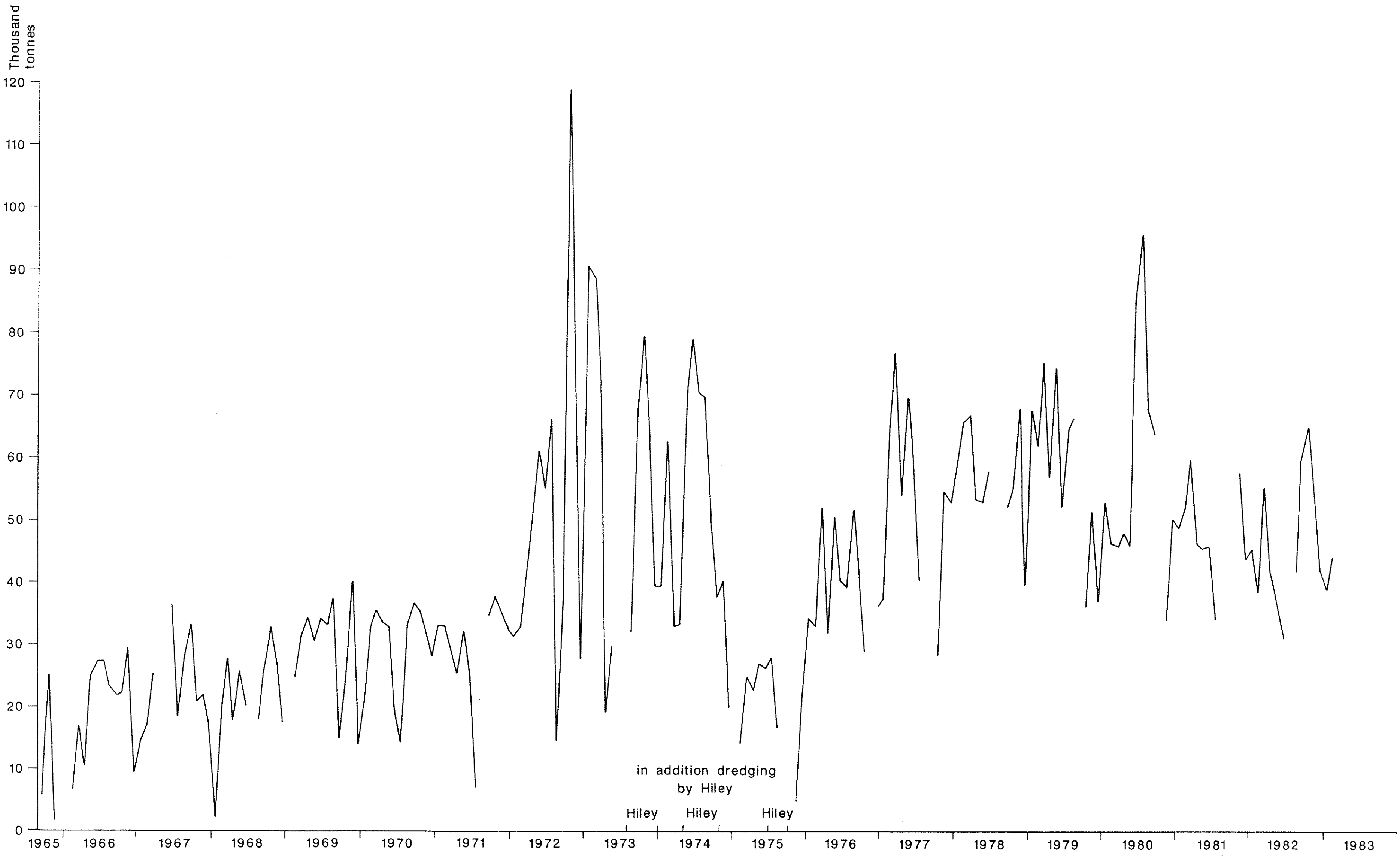


FIGURE 5 Townsville Port Authority monthly dredging records September 1965 to February 1983 for S.D. 'Townsville'. Gaps occur when the dredge was being overhauled and repaired.

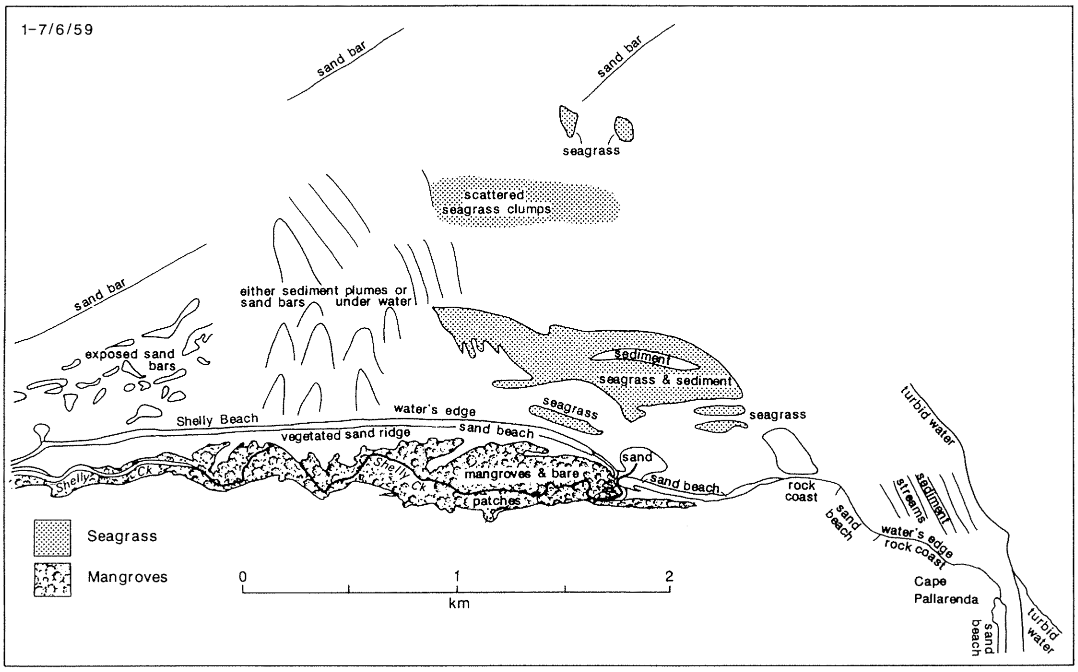


FIGURE 6 Maps of coastal area between Shelly Beach and Cape Pallarenda drawn from aerial photographs taken in 1959, 1974, 1981 and 1985.

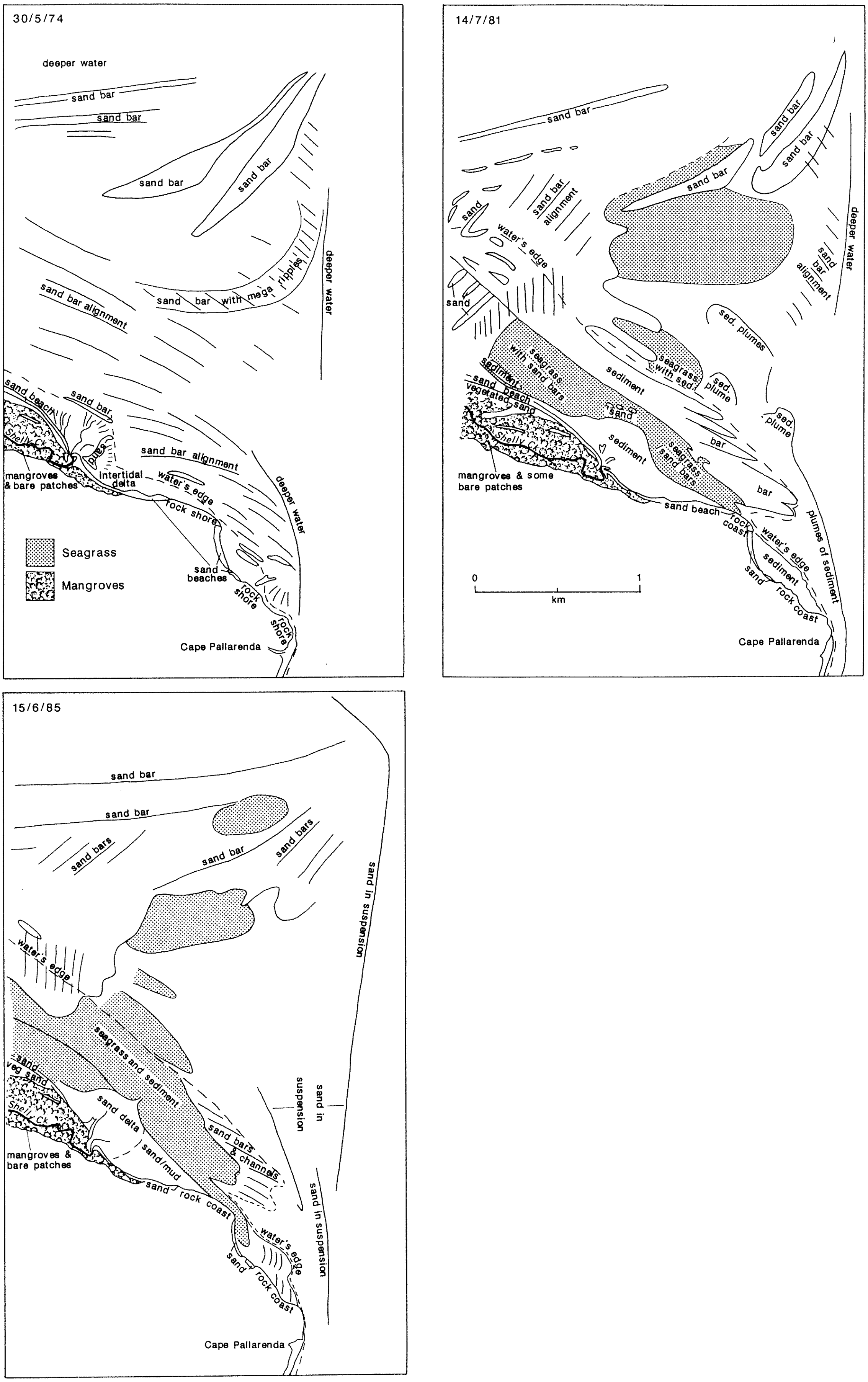


FIGURE 6 continued

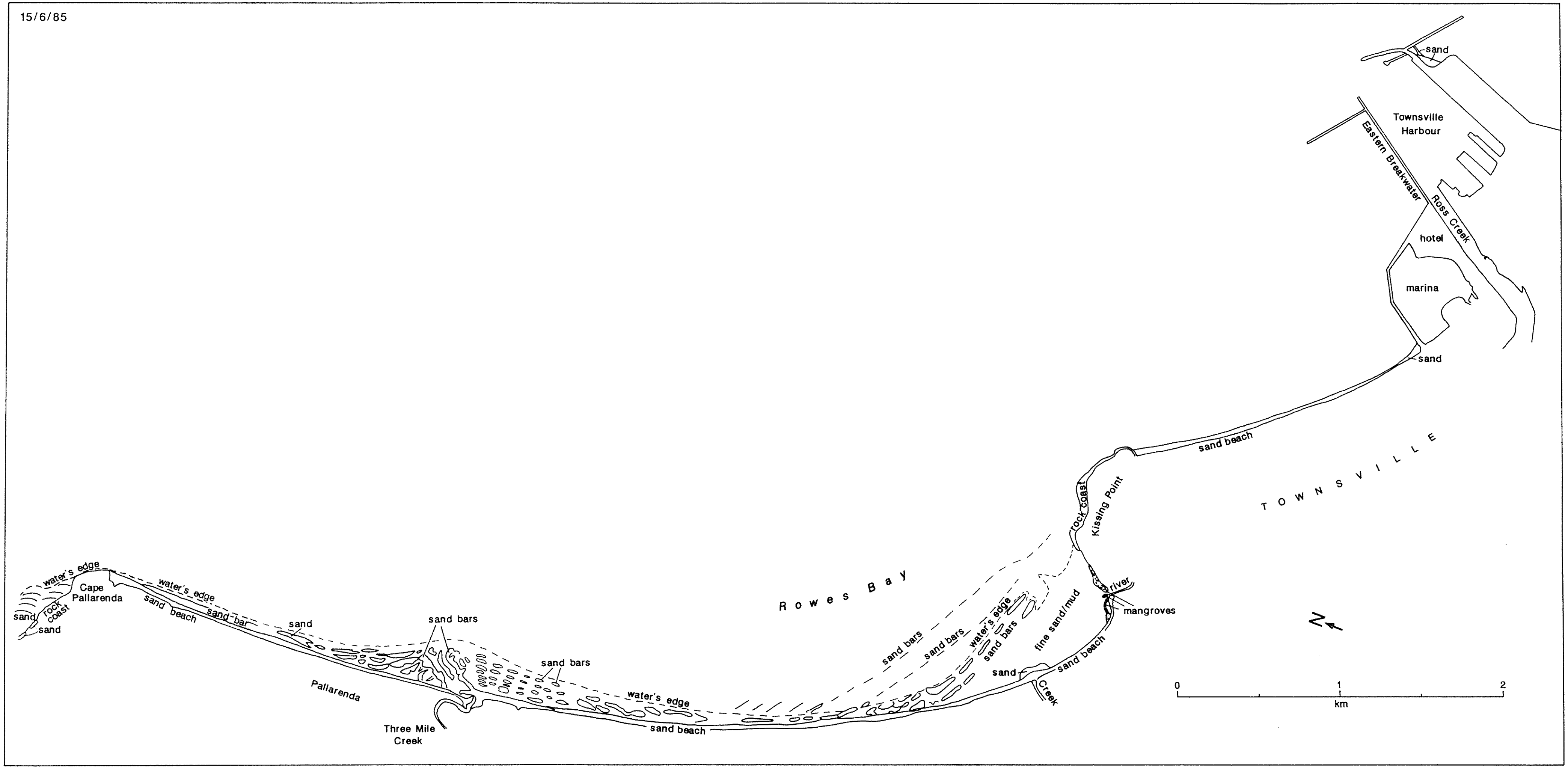


FIGURE 7 Map of coast between Cape Pallarenda and Ross Creek drawn from aerial photographs taken in 1985

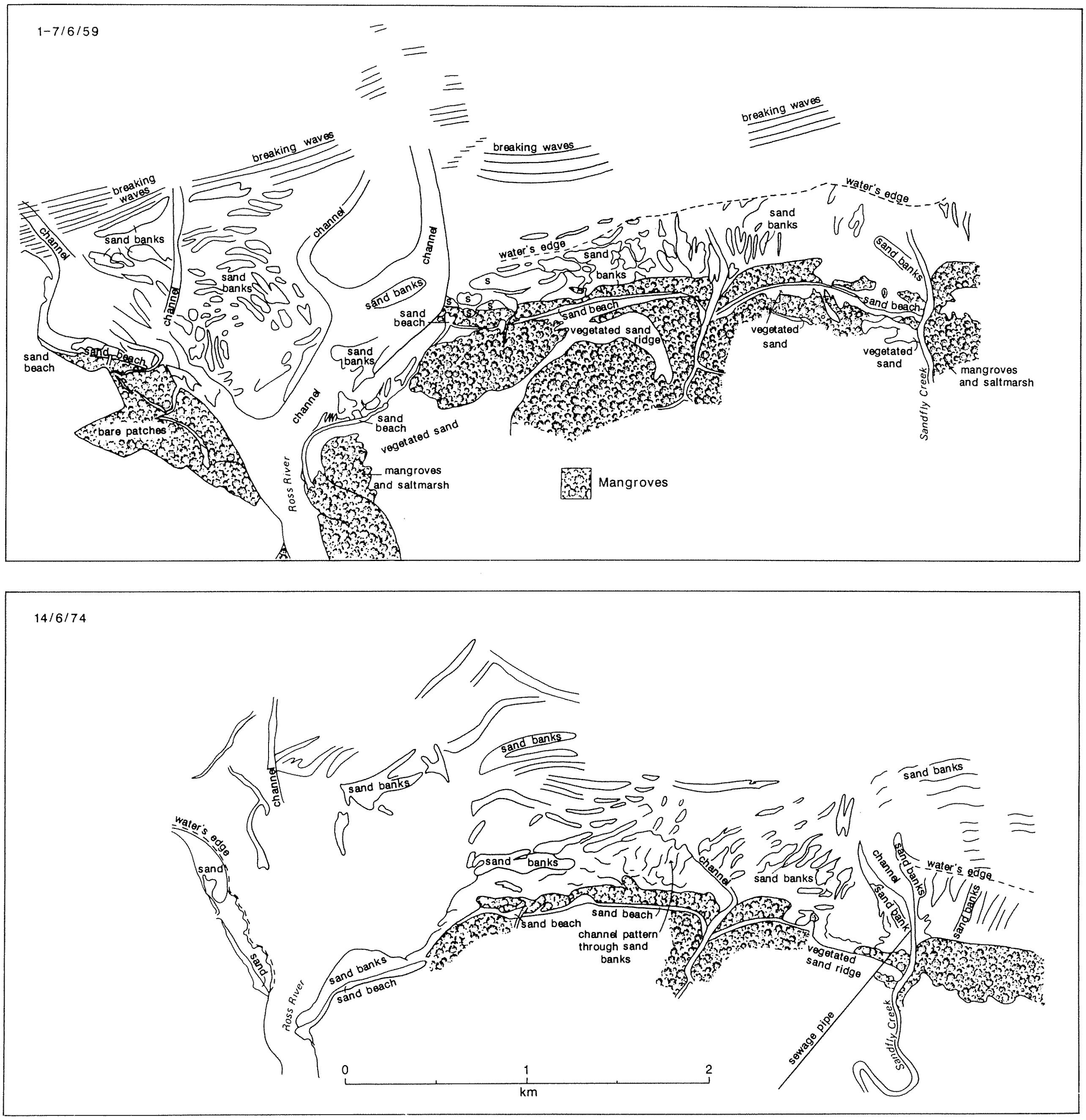


FIGURE 8 Maps of coast between Ross River and Sandfly Creek drawn from aerial photographs taken in 1959, 1974, 1981 and 1985.

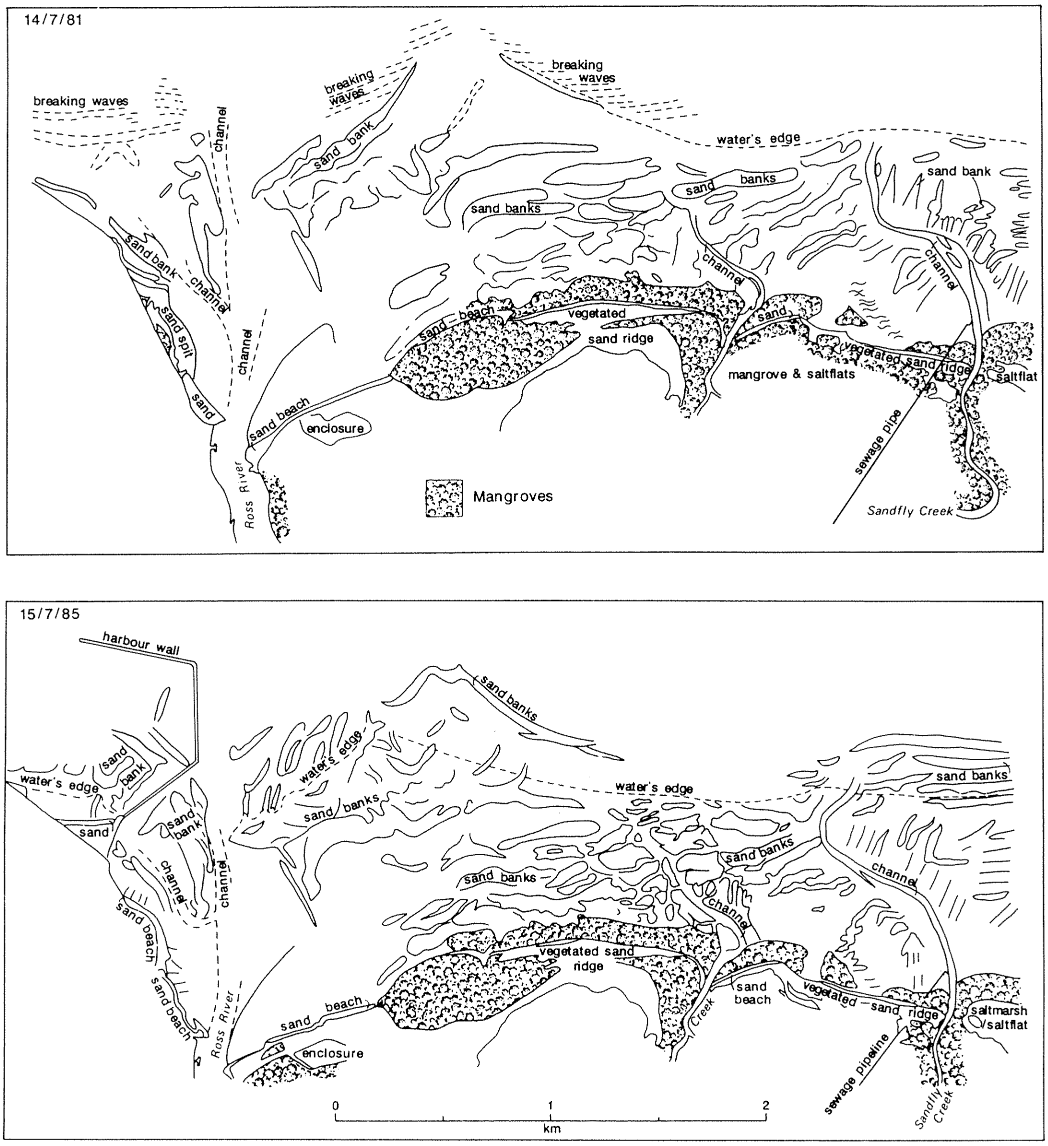


FIGURE 8 continued

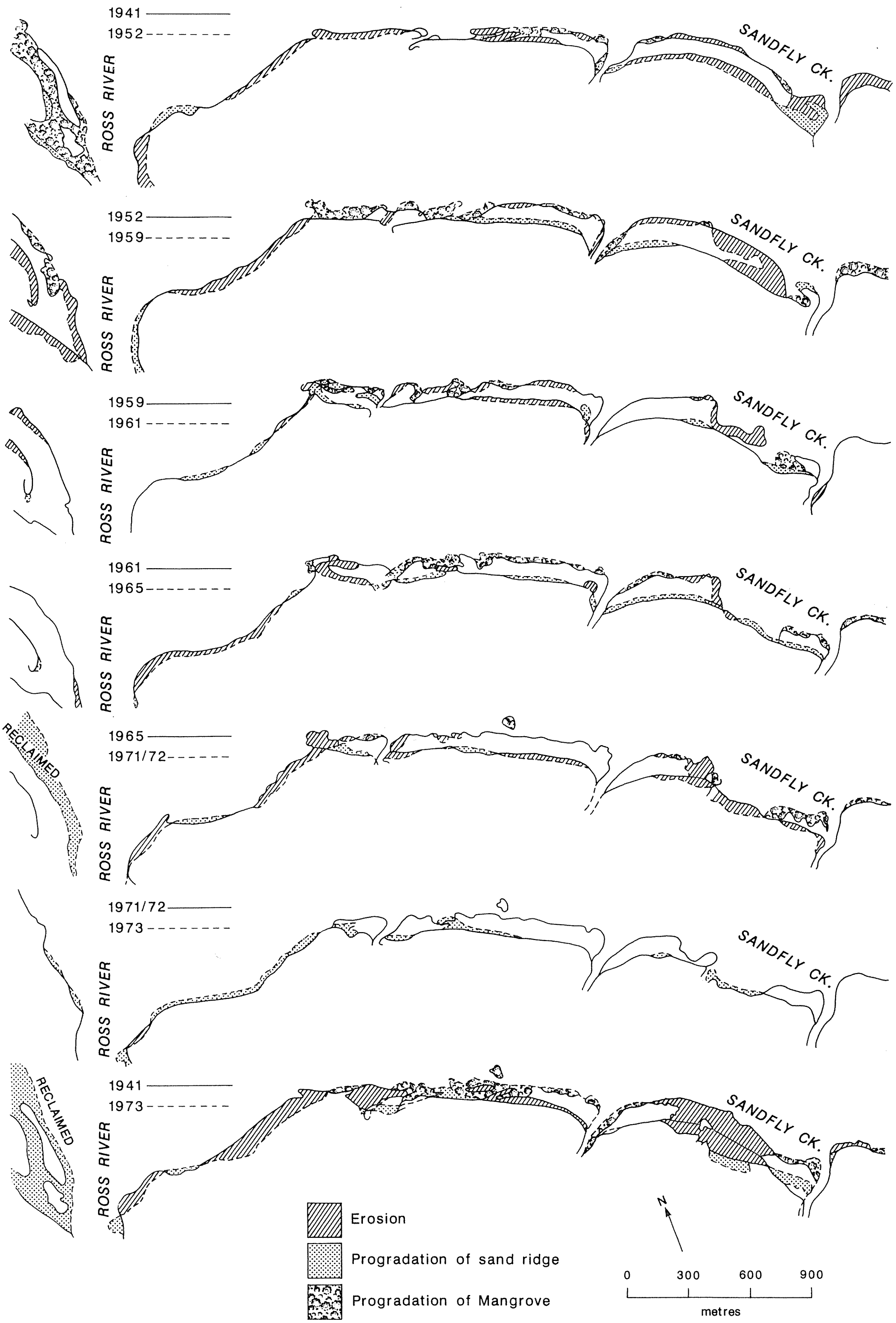


FIGURE 9 Shoreline changes in the Ross River to Sandfly Creek area 1941–1973. After McIntyre and Associates, 1974.

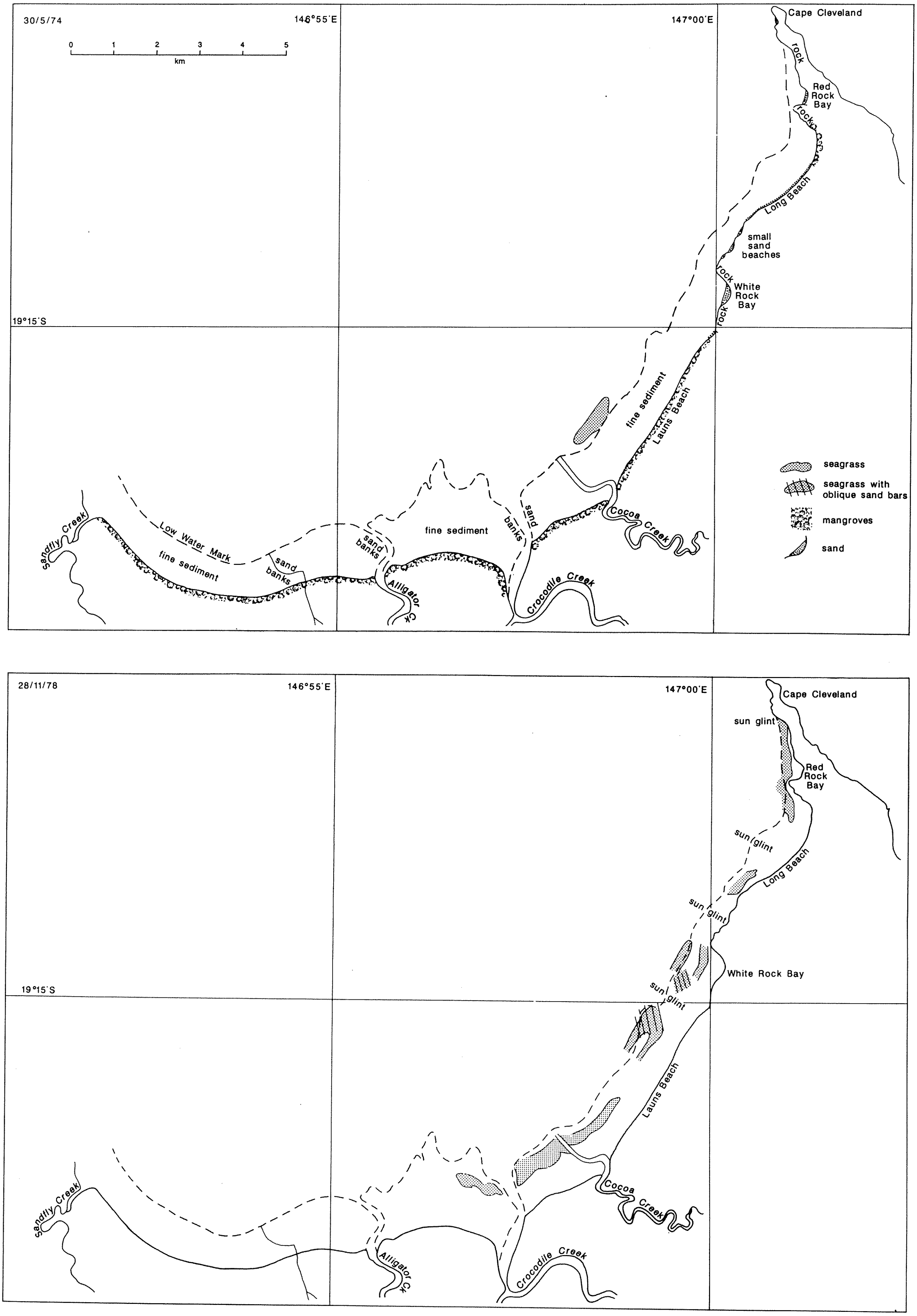


FIGURE 10 Maps of coast between Sandfly Creek and Cape Cleveland drawn from aerial photographs taken in 1974, 1978, 1981 and 1985. Note especially the changing distribution pattern of seagrass.

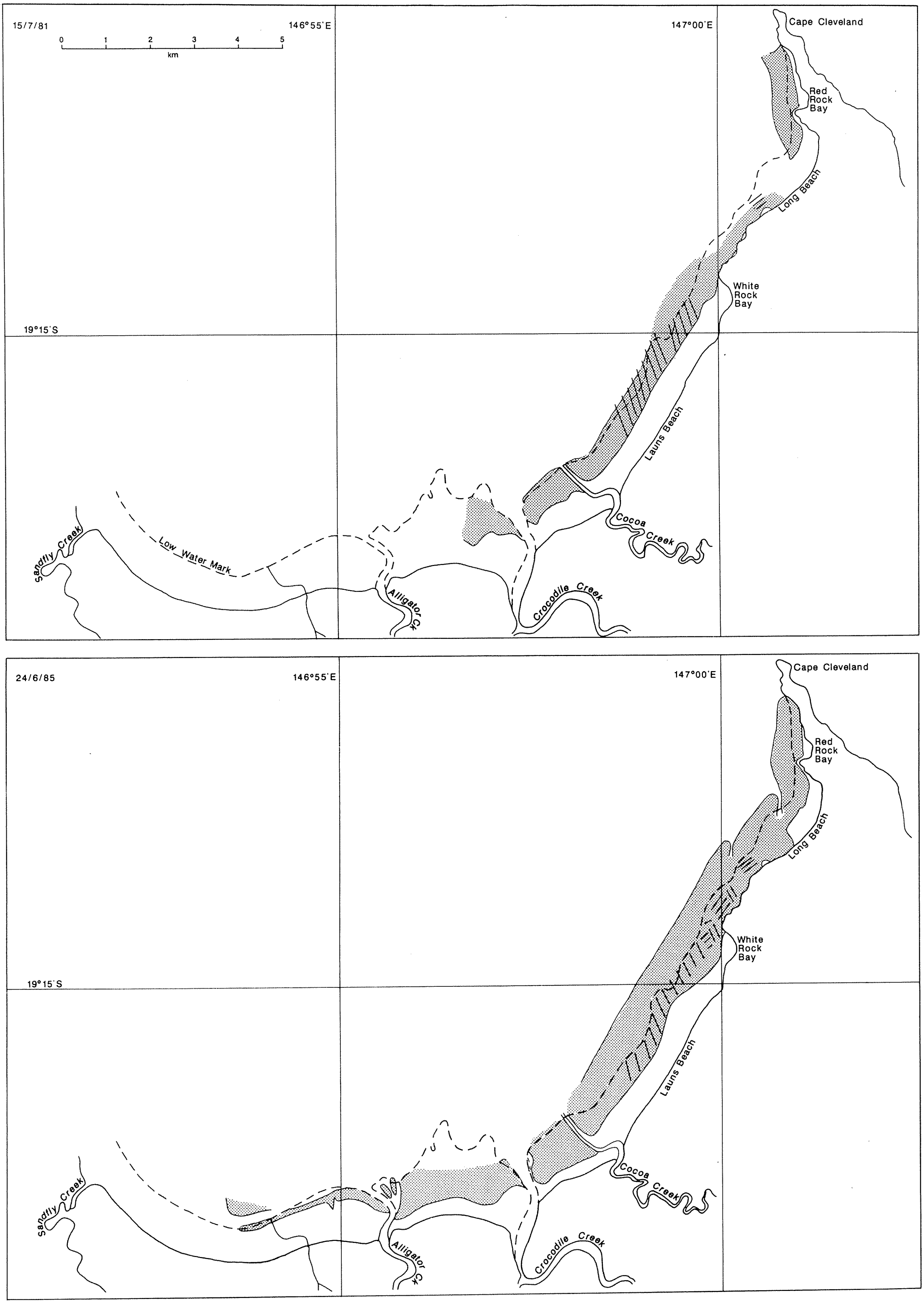


FIGURE 10 · continued

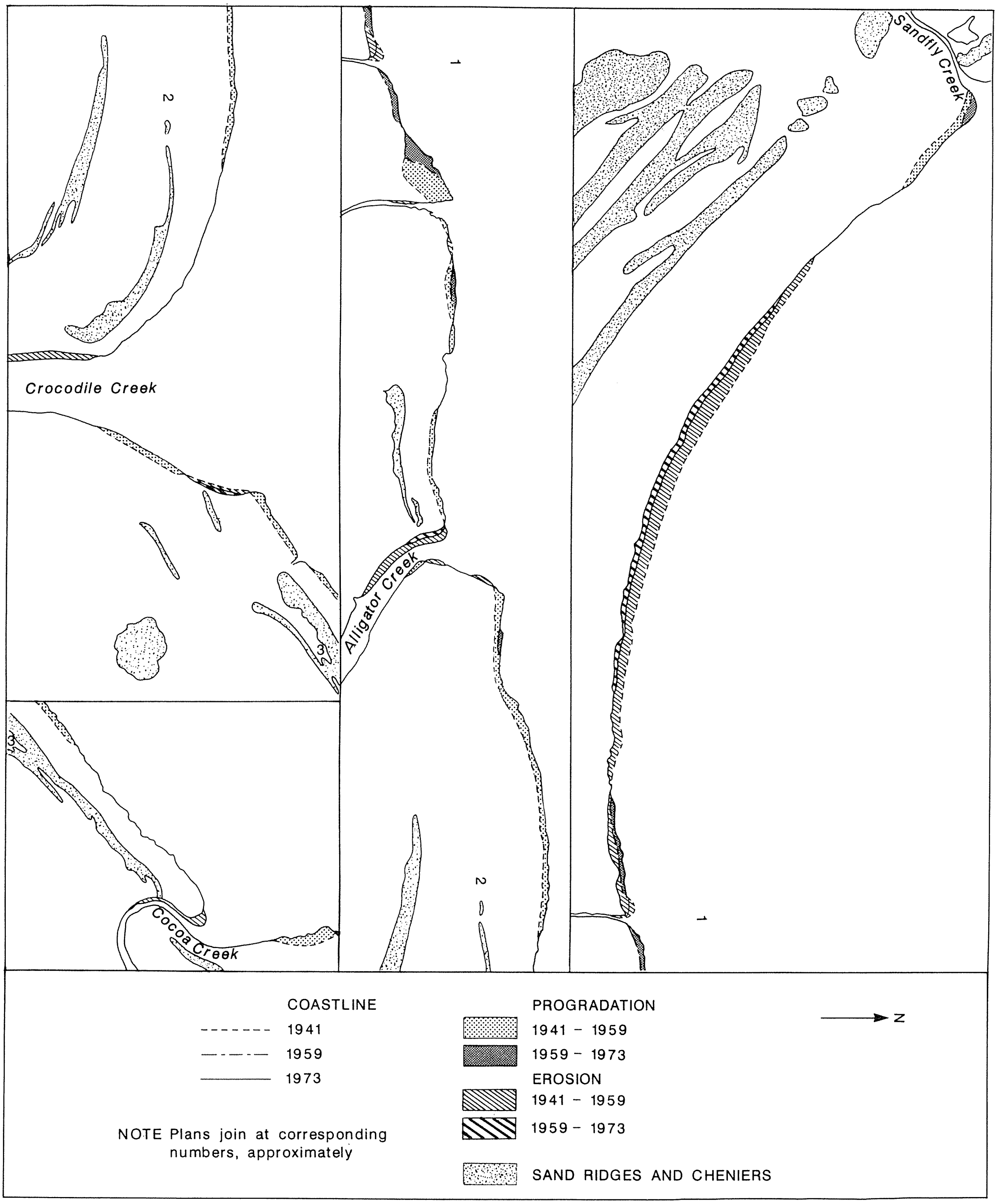


FIGURE 11 Shoreline changes in south Cleveland Bay, between Sandfly Creek and Cocoa Creek 1941-1973. After McIntyre and Associates, 1974.

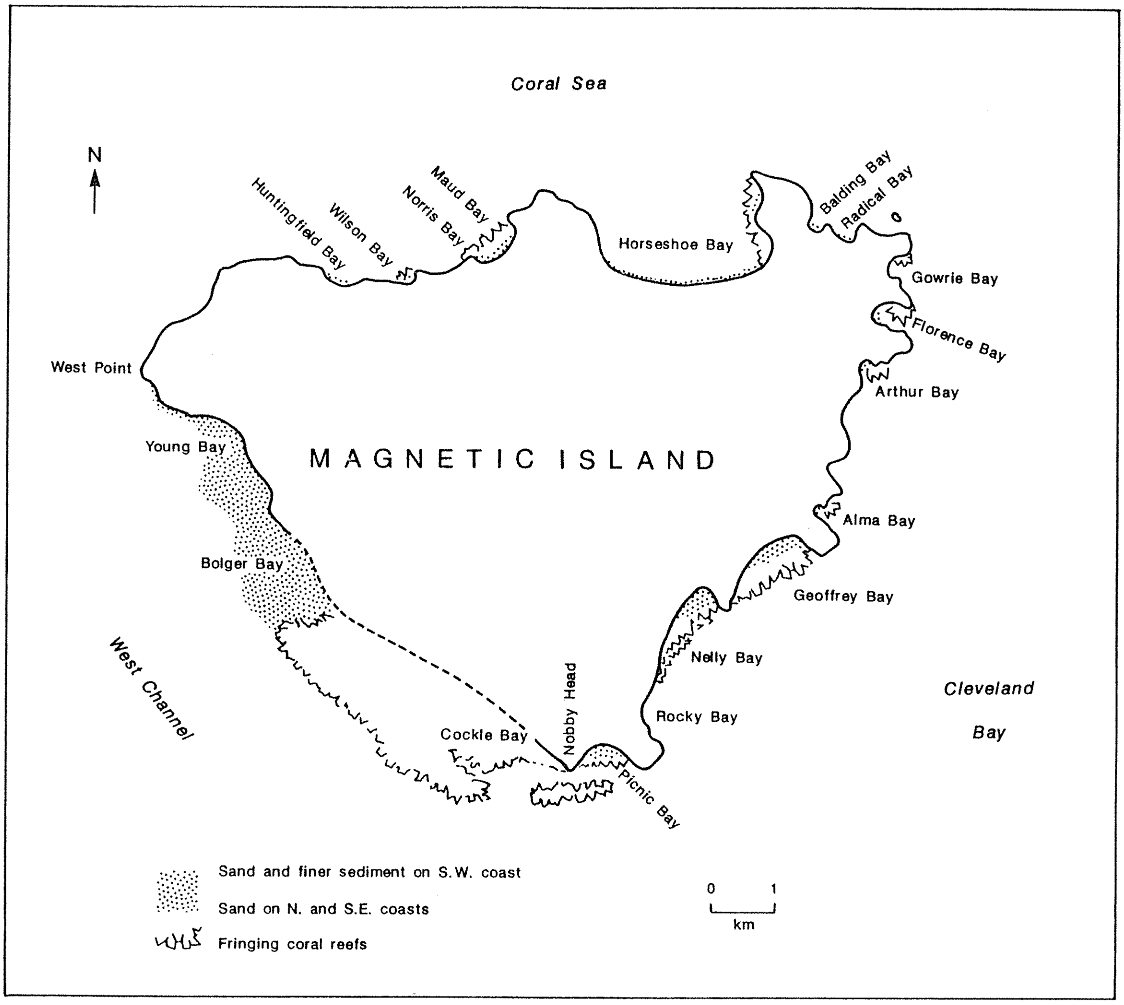


FIGURE 12 Coastal features of Magnetic Island.

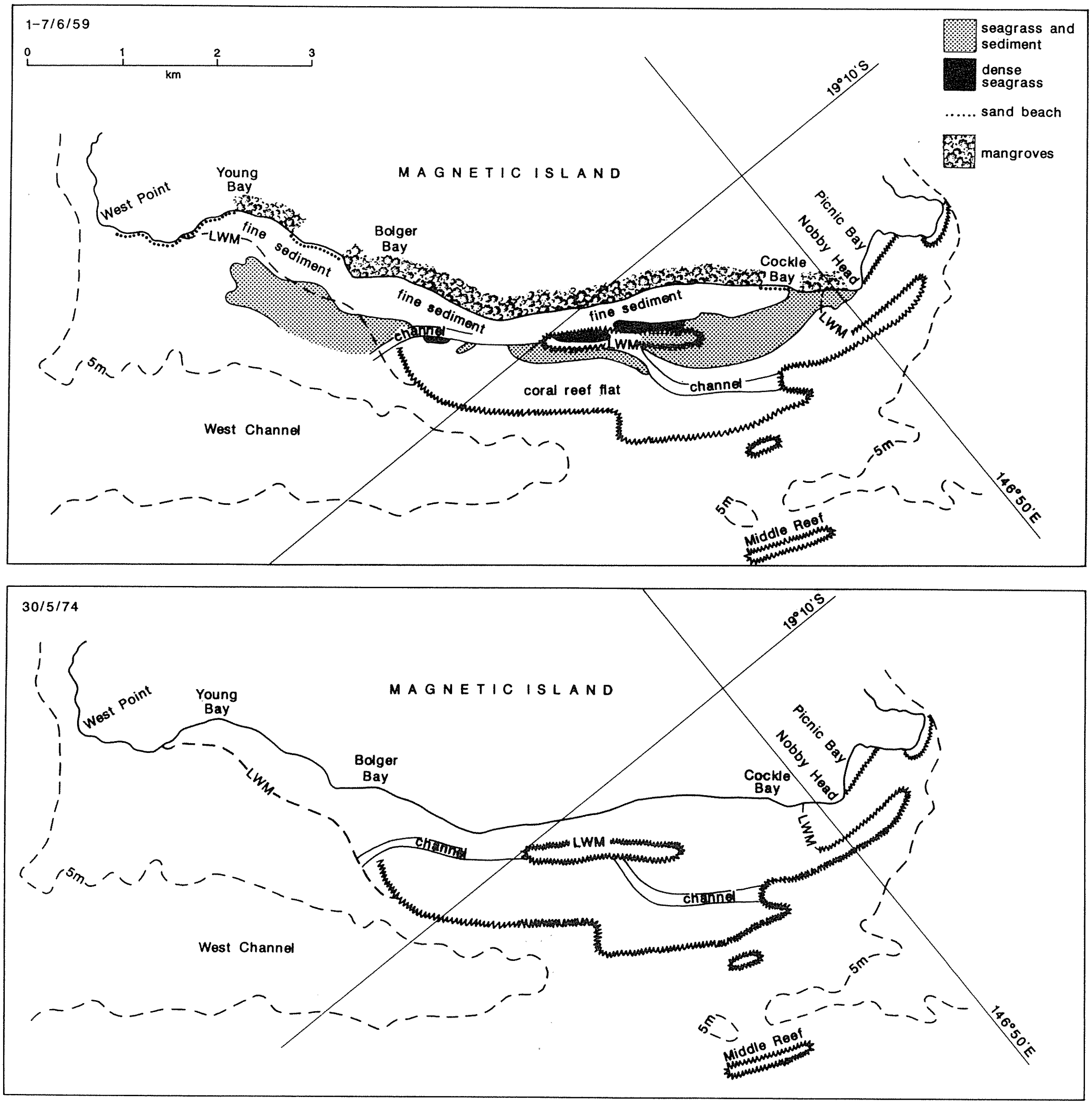


FIGURE 13 Maps of south-west coast of Magnetic Island drawn from aerial photographs taken in 1959, 1974, 1978, 1981 and 1985. Note especially the changing distribution pattern of seagrass.

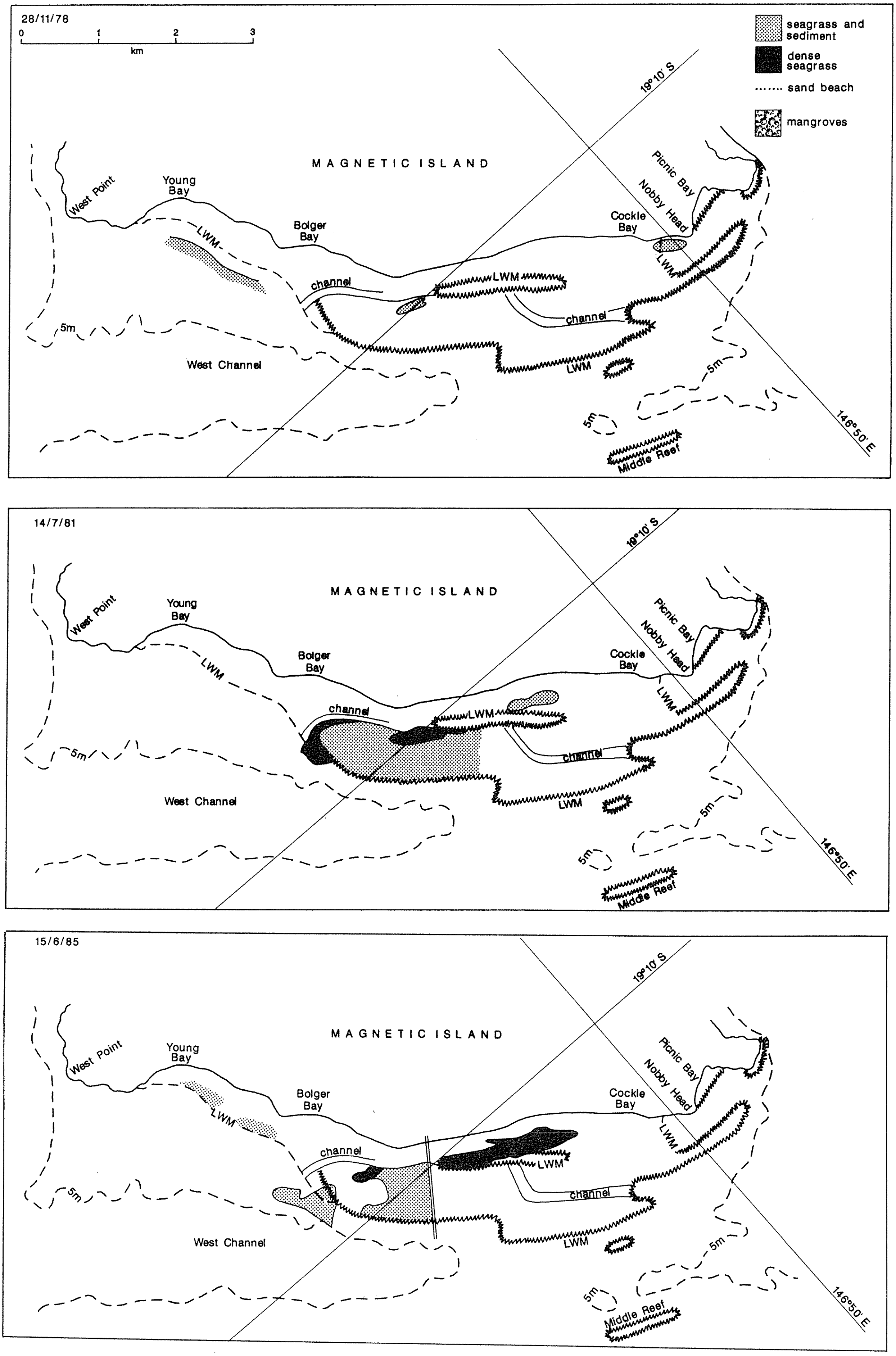


FIGURE 13 continued

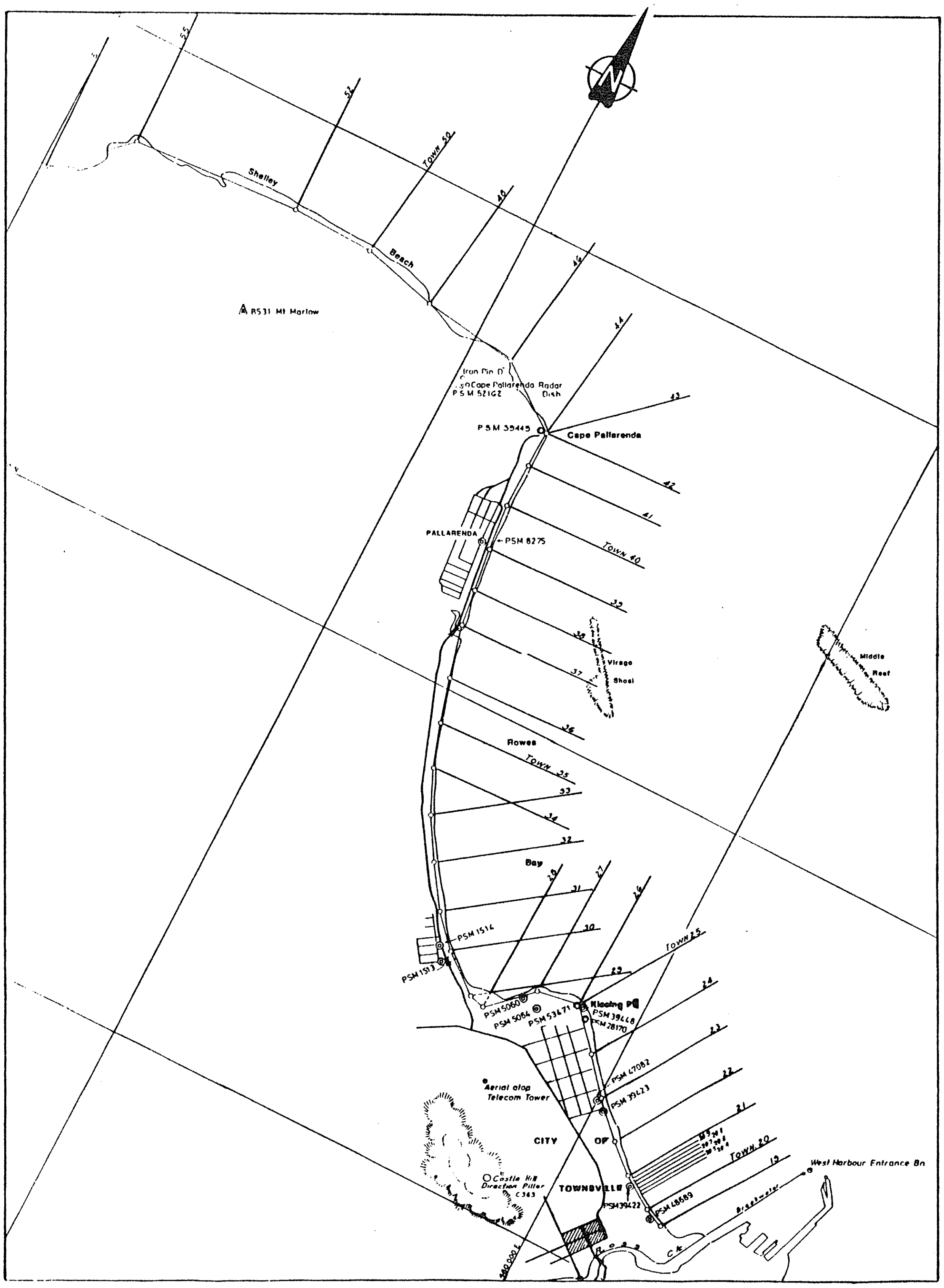


FIGURE 14 Maps showing location of Beach Protection Authority cross profile lines between Townsville Harbour and Shelly Beach and on Magnetic Island.

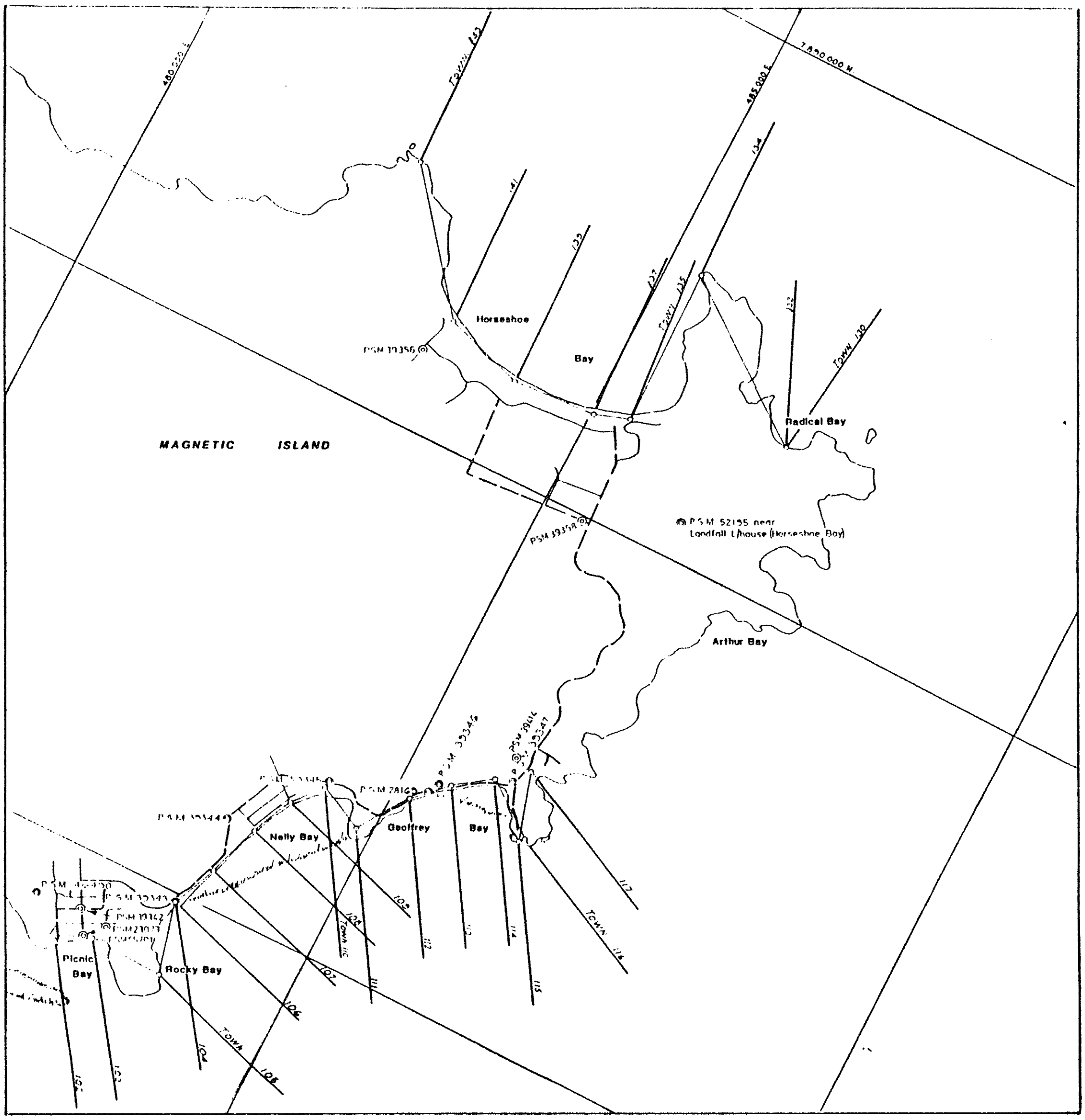


FIGURE 14 continued

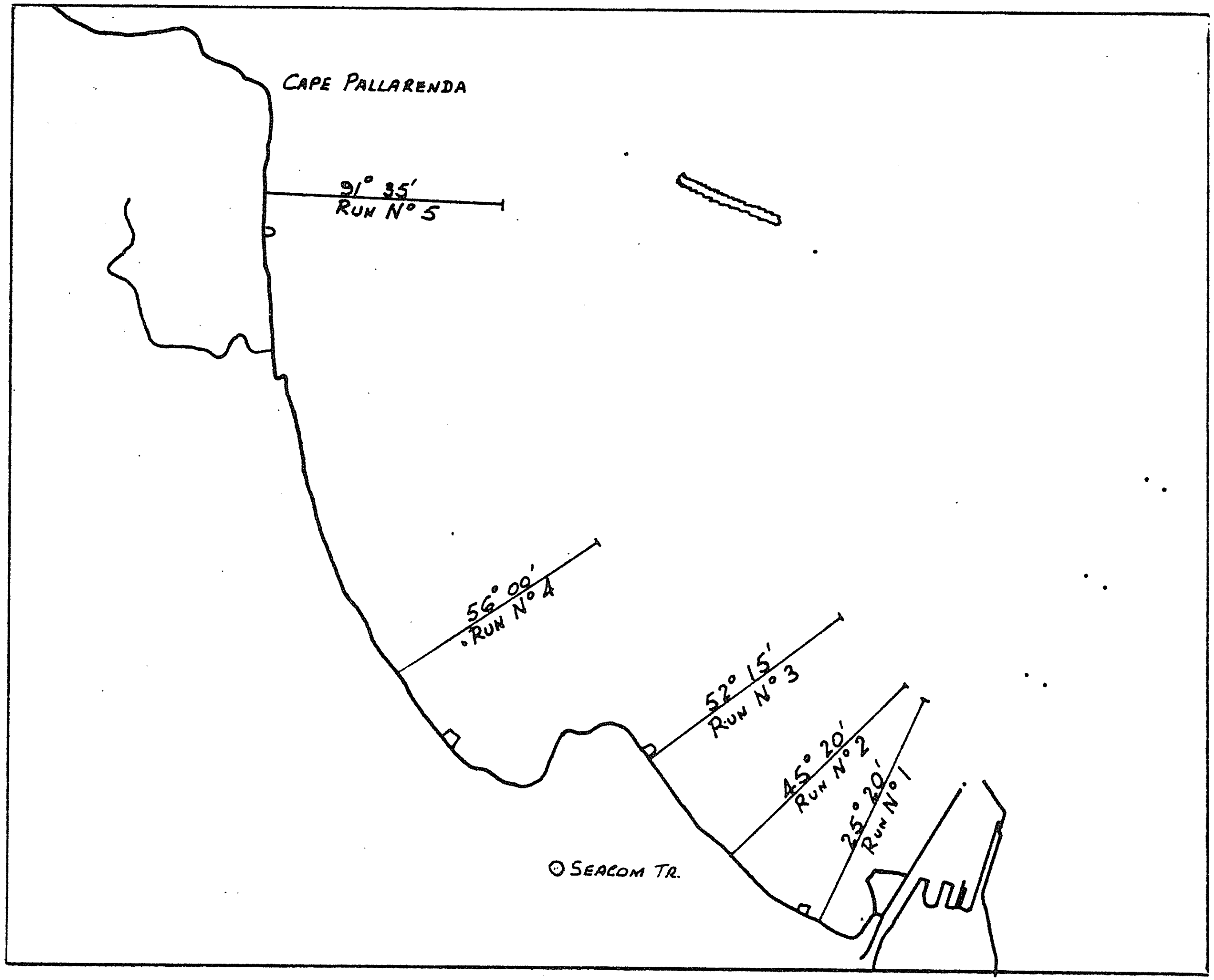


FIGURE 15 Map showing location of Townsville Port Authority cross profile lines between Townville Harbour and Cape Pallarenda.

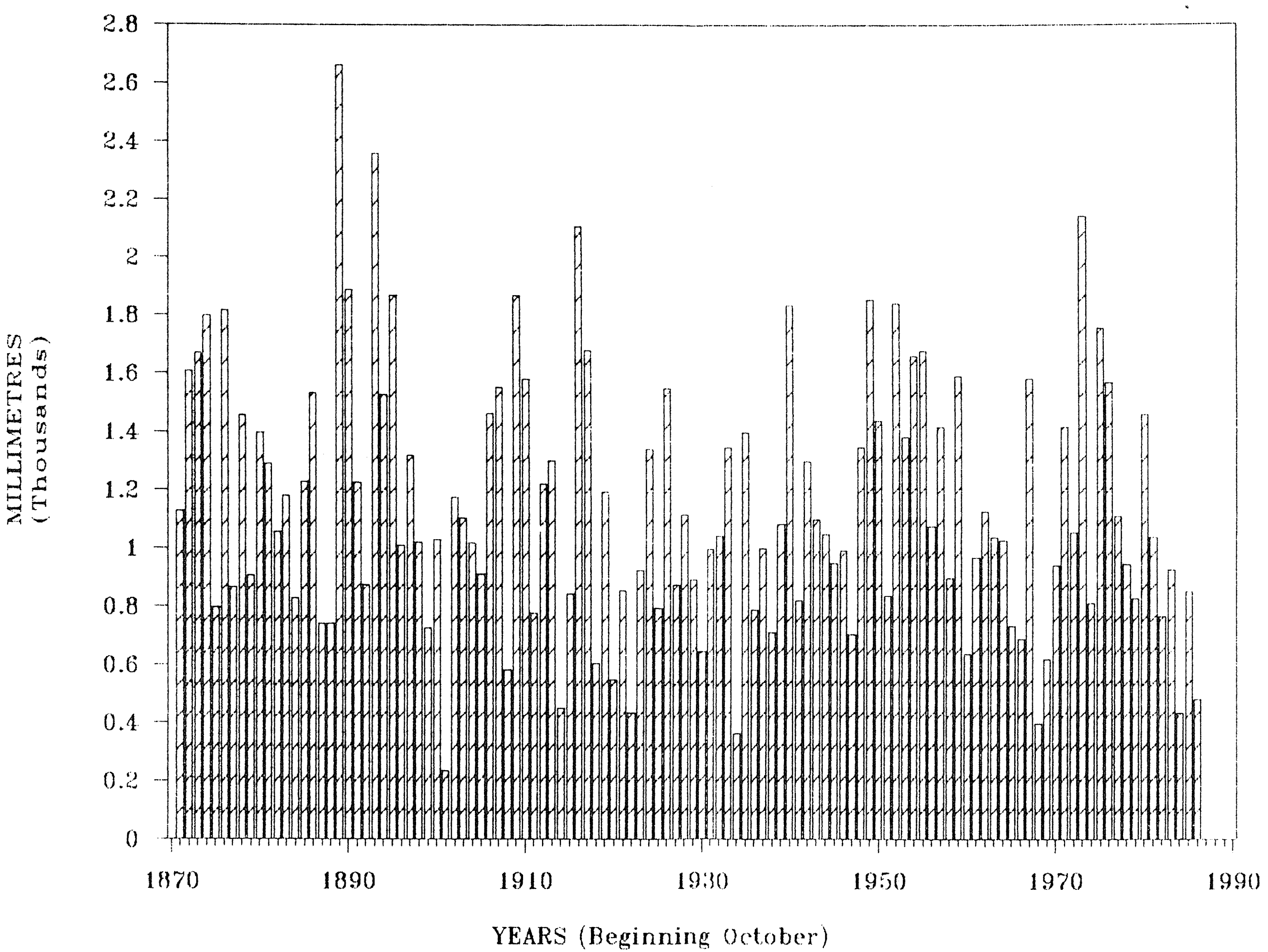


FIGURE 16 Townsville annual rainfall 1870-1987, shown for hydrological years beginning 1 October.

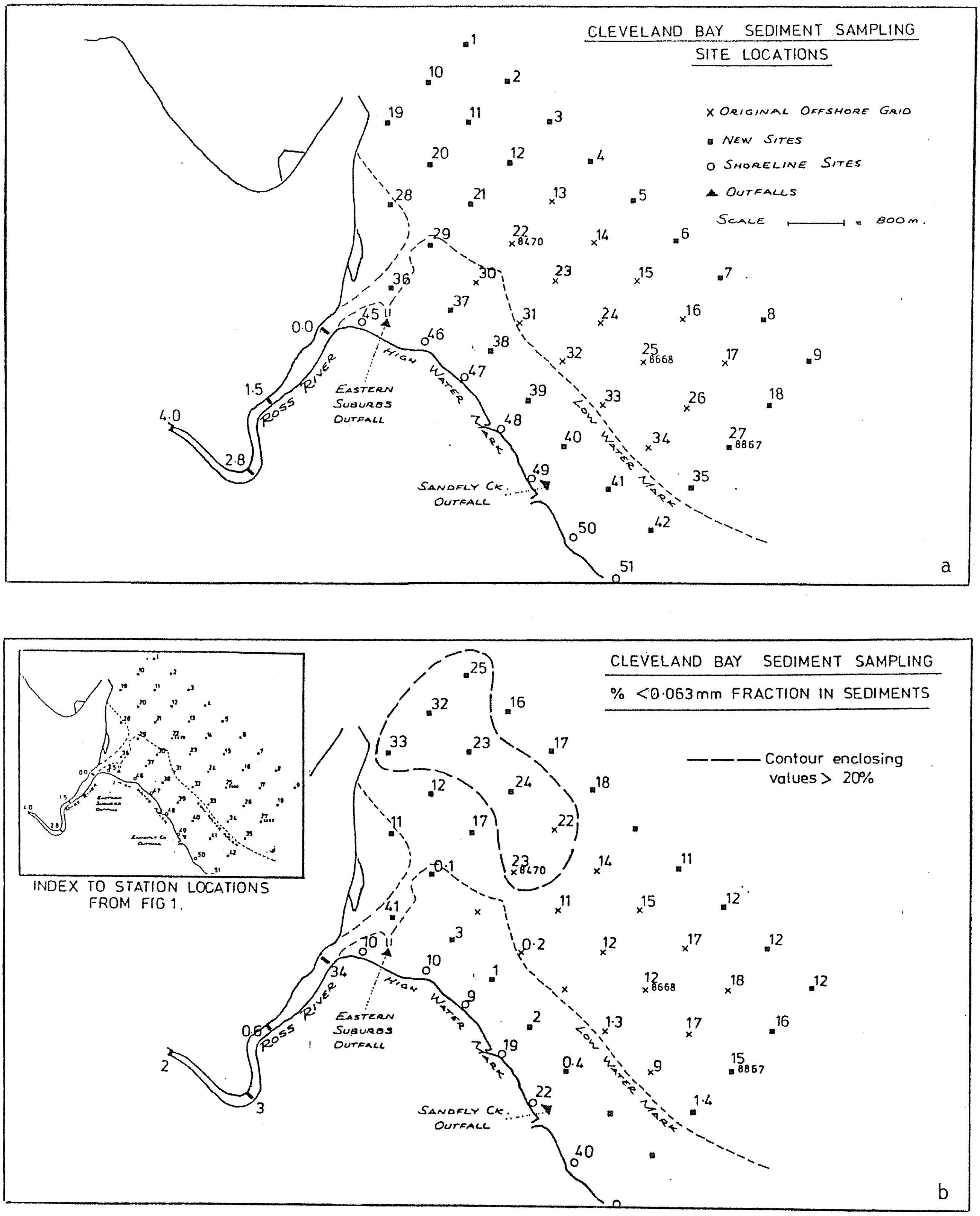


FIGURE 17 Queensland Water Quality Council's Cleveland Bay sediment pollution study.

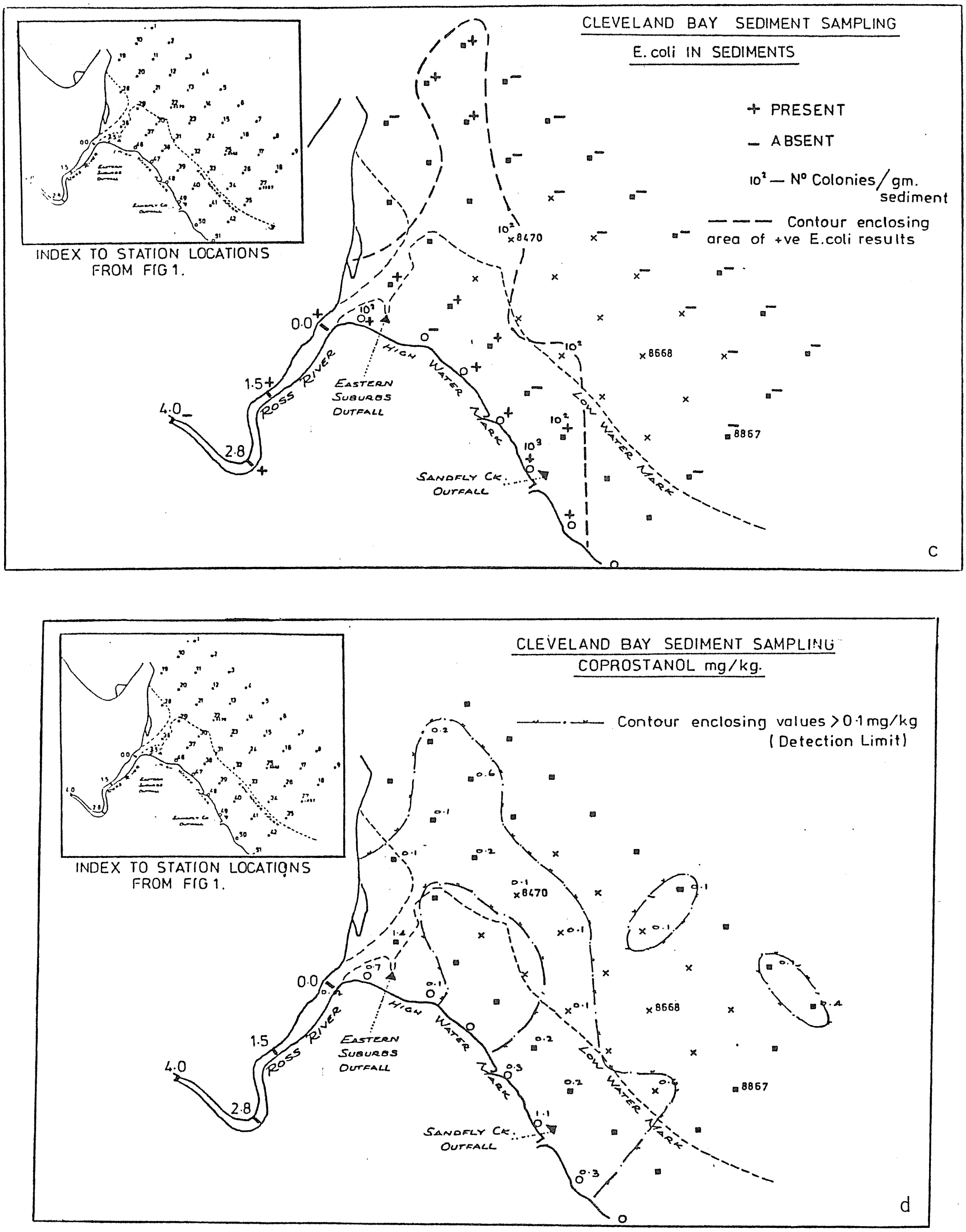


FIGURE 17 continued

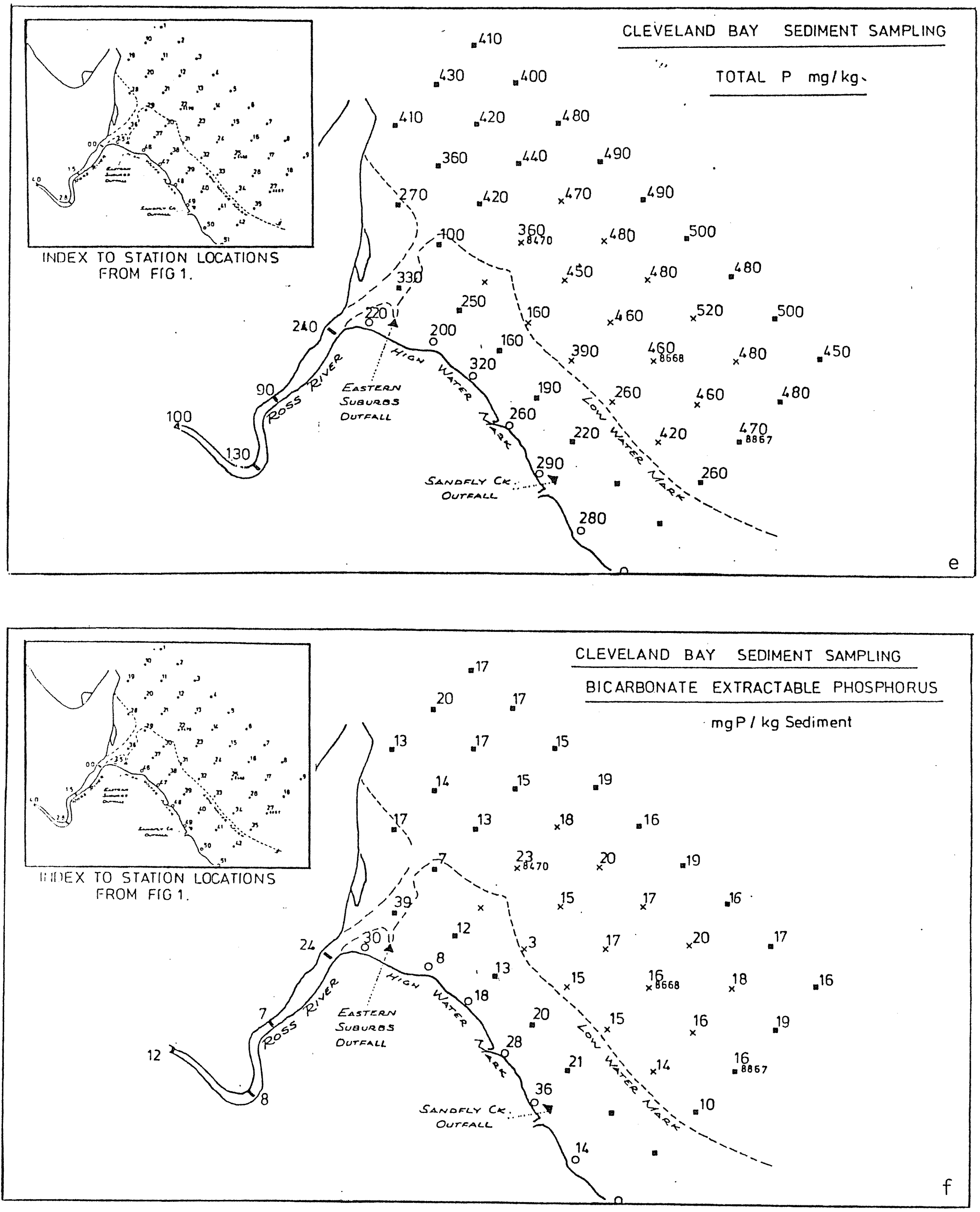
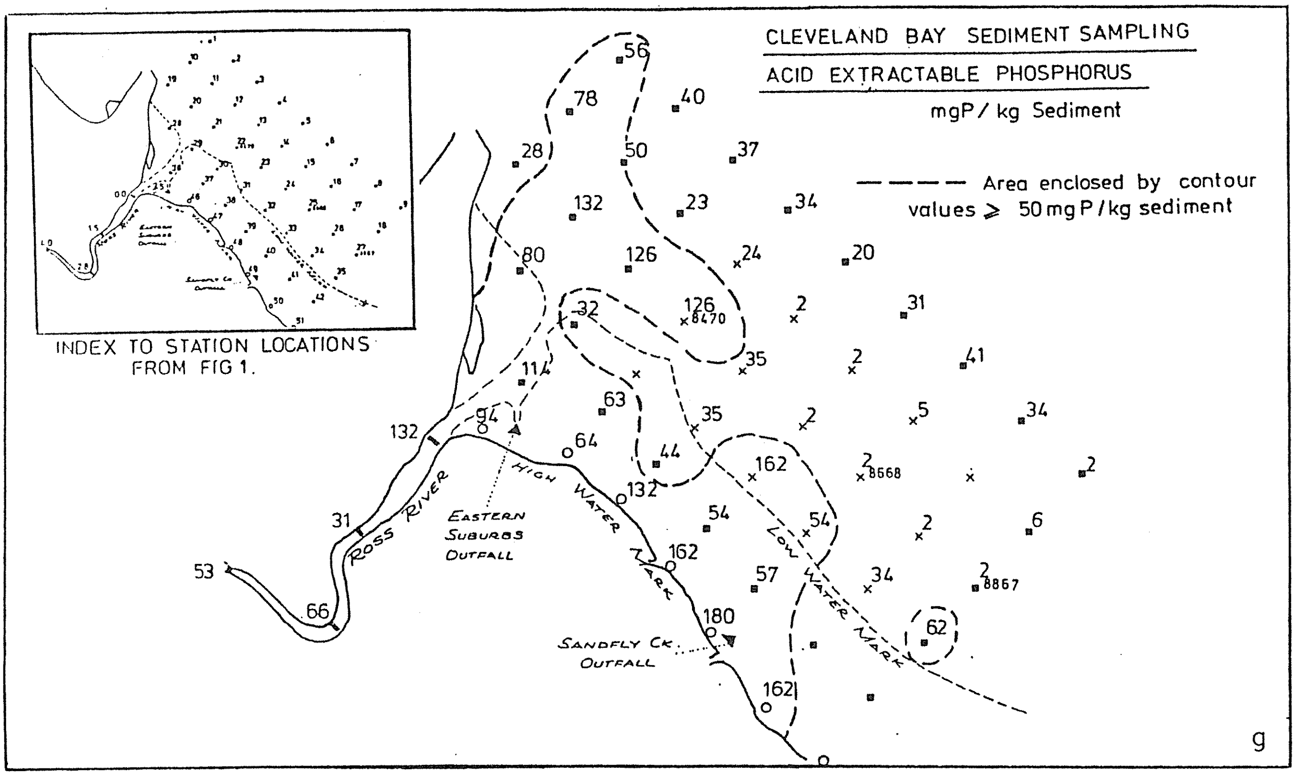


FIGURE 17 continued



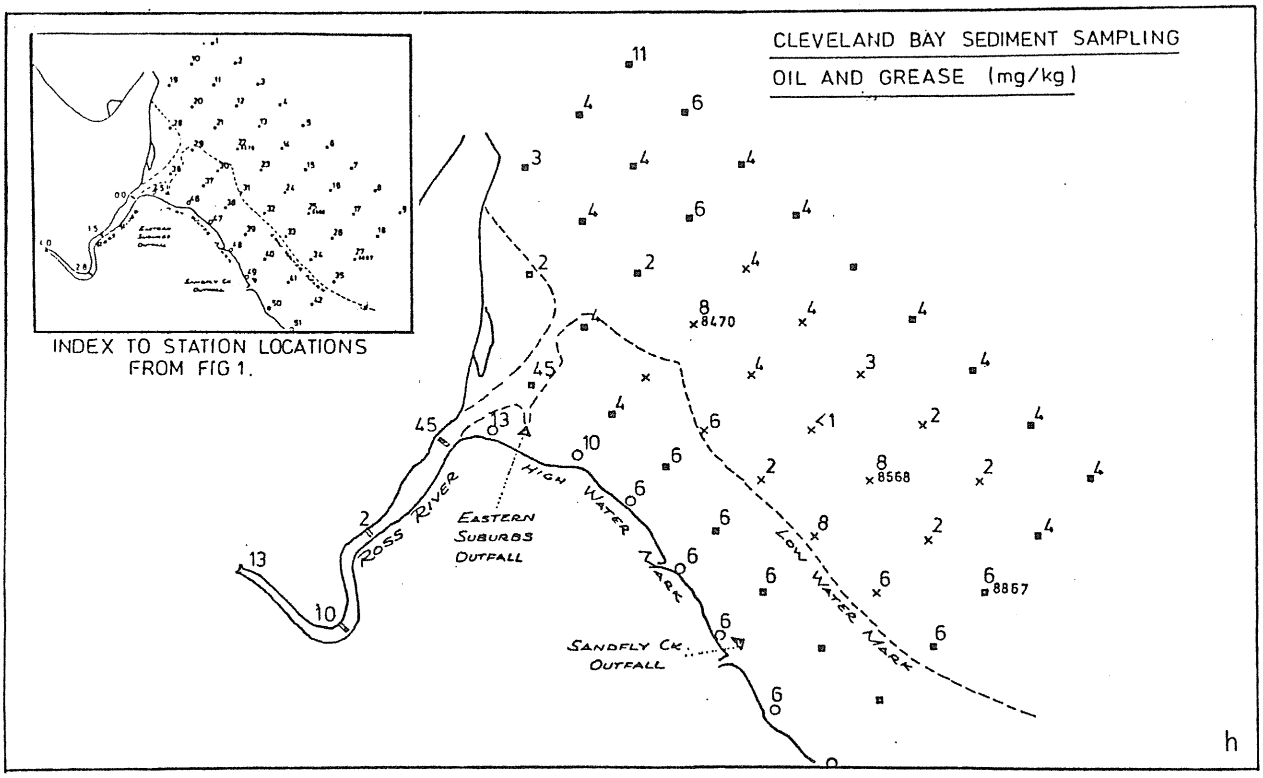


FIGURE 17 continued

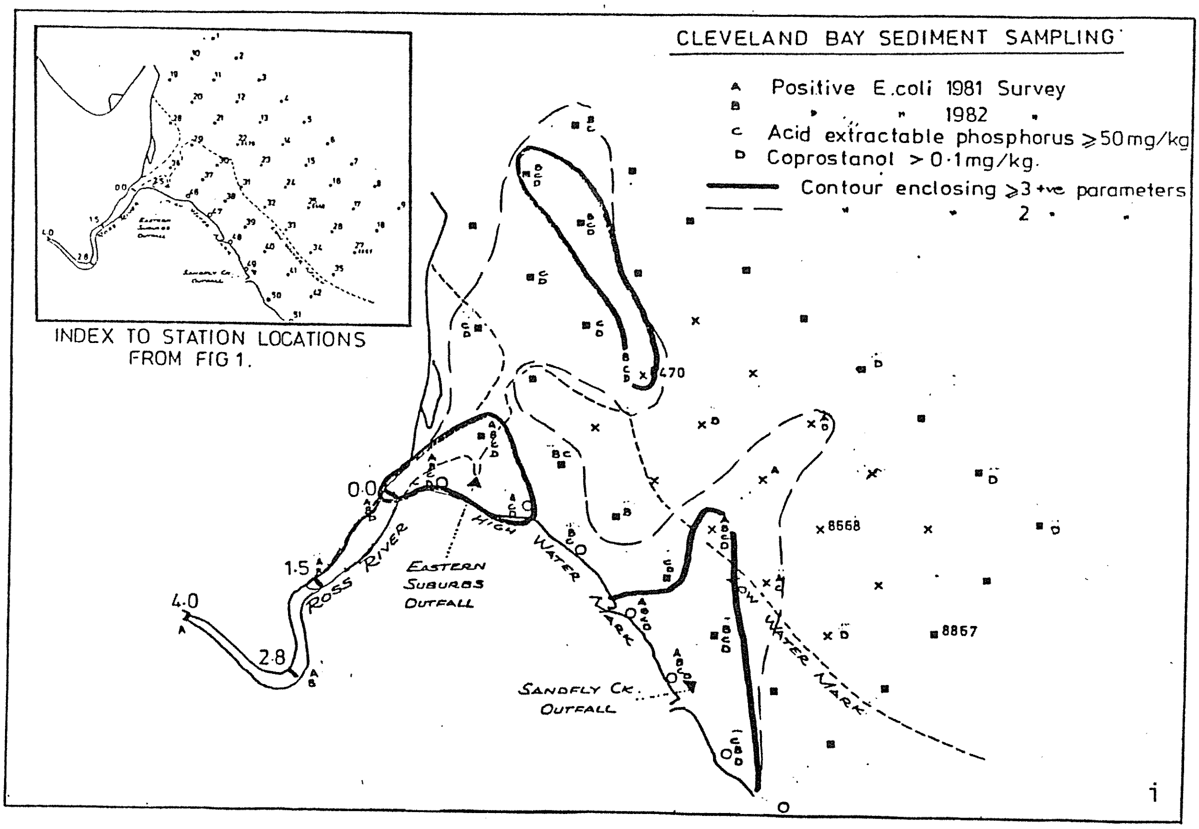


FIGURE 17 continued

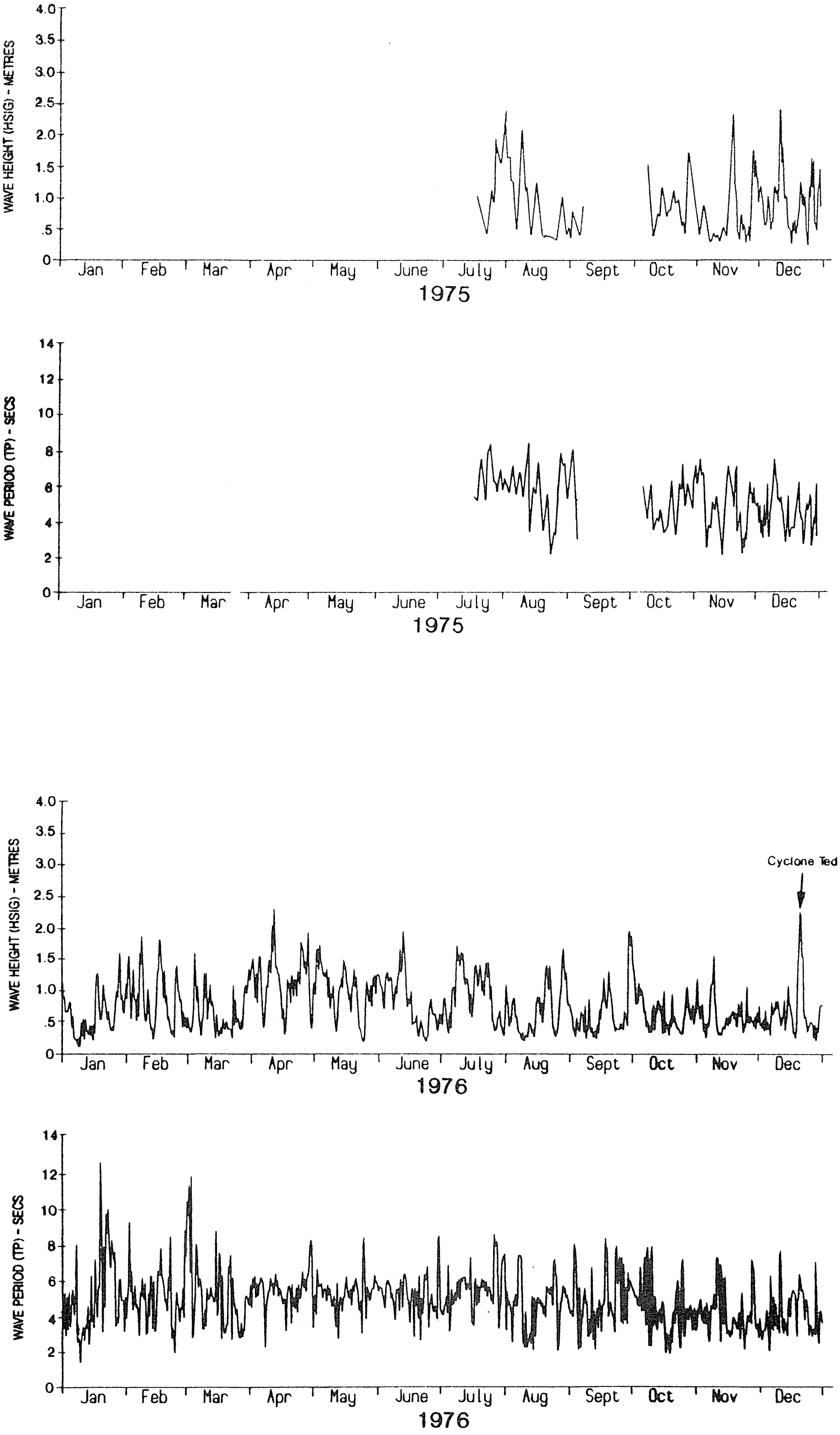


FIGURE 18 Annual records of wave height (Hsig) and wave period (Tp) at wave buoy near Cape Cleveland 1975-1987. After Beach Protection Authority, 1988.

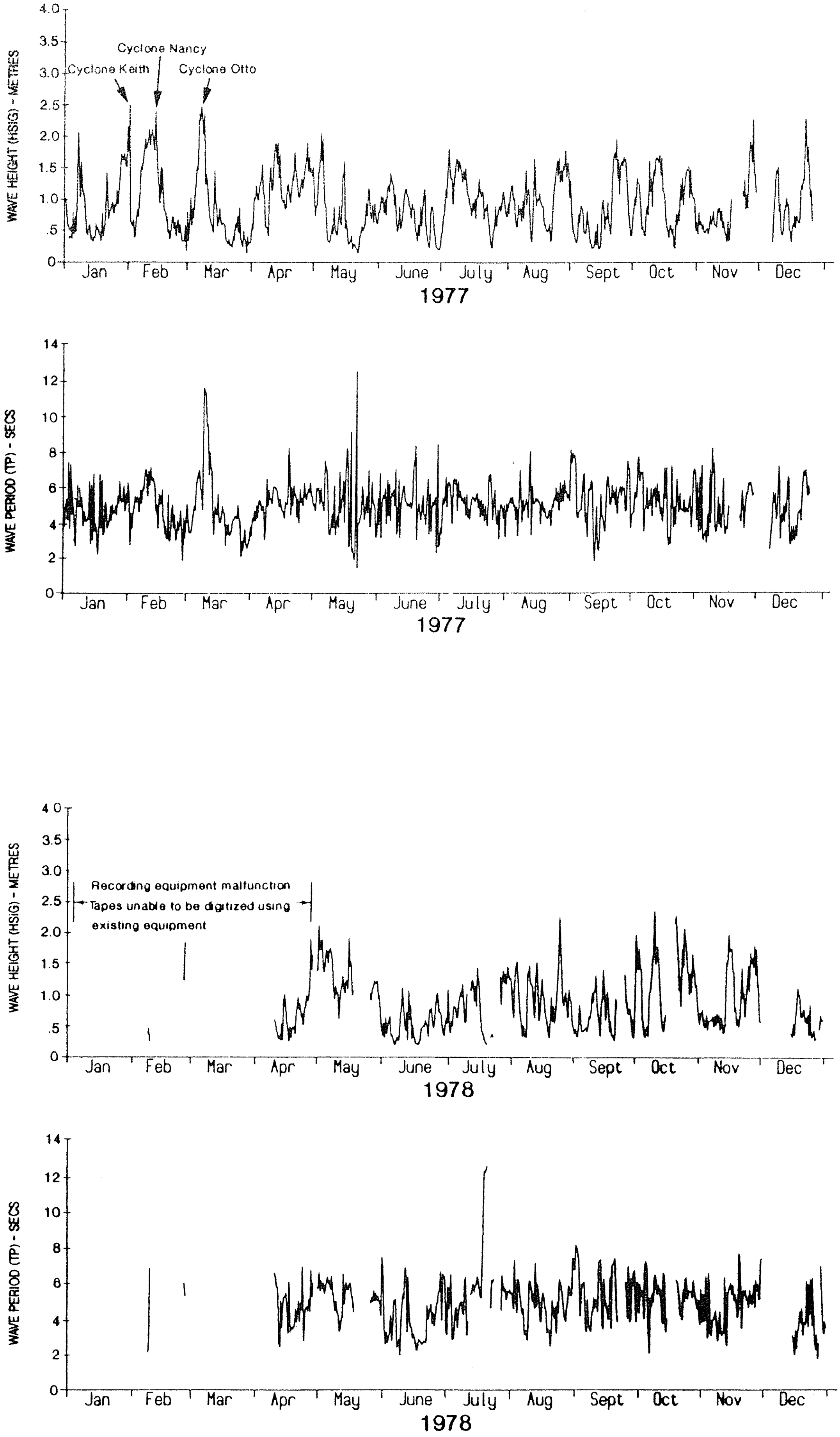


FIGURE 18 continued

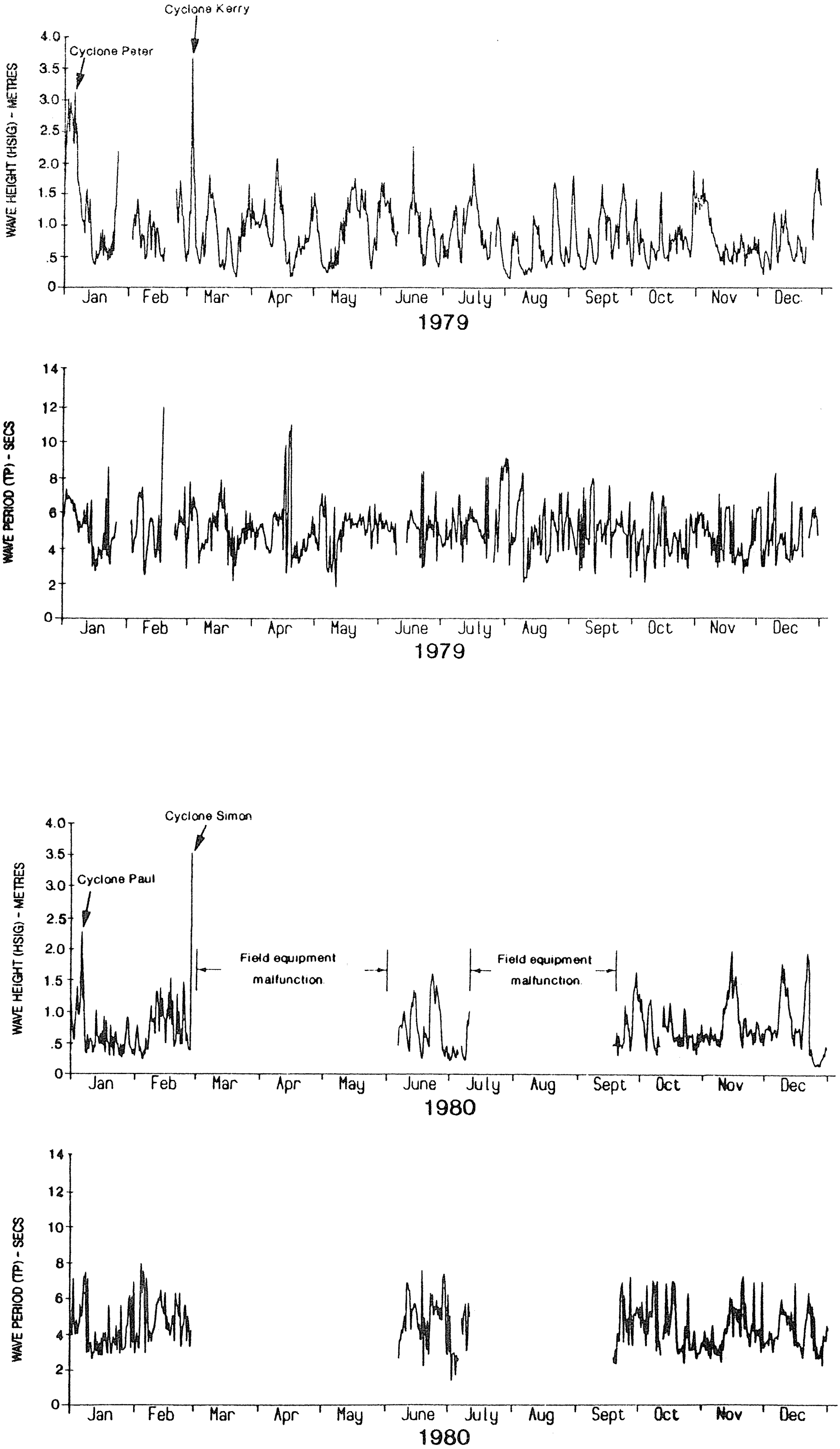


FIGURE 18 continued

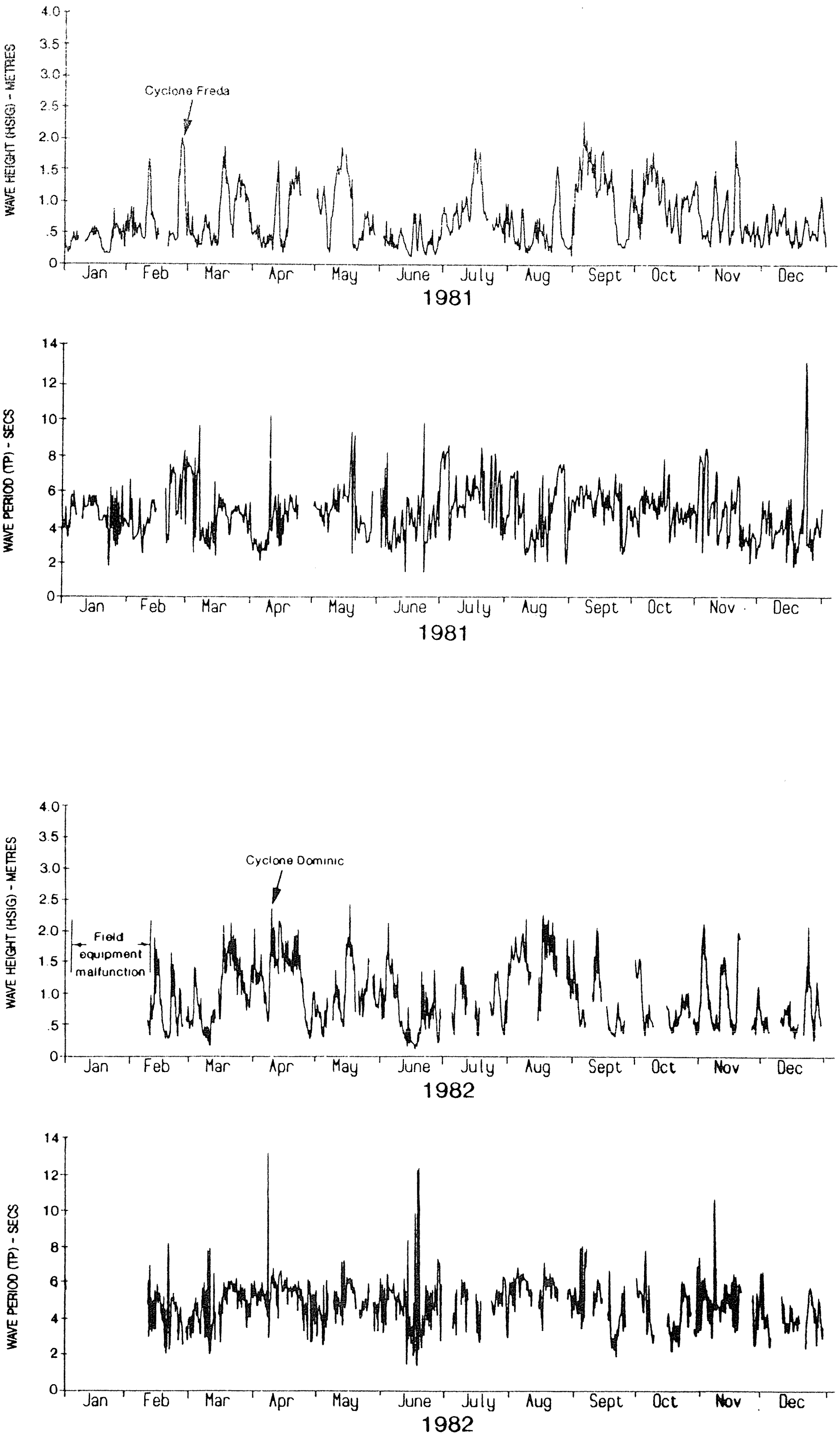


FIGURE 18 continued

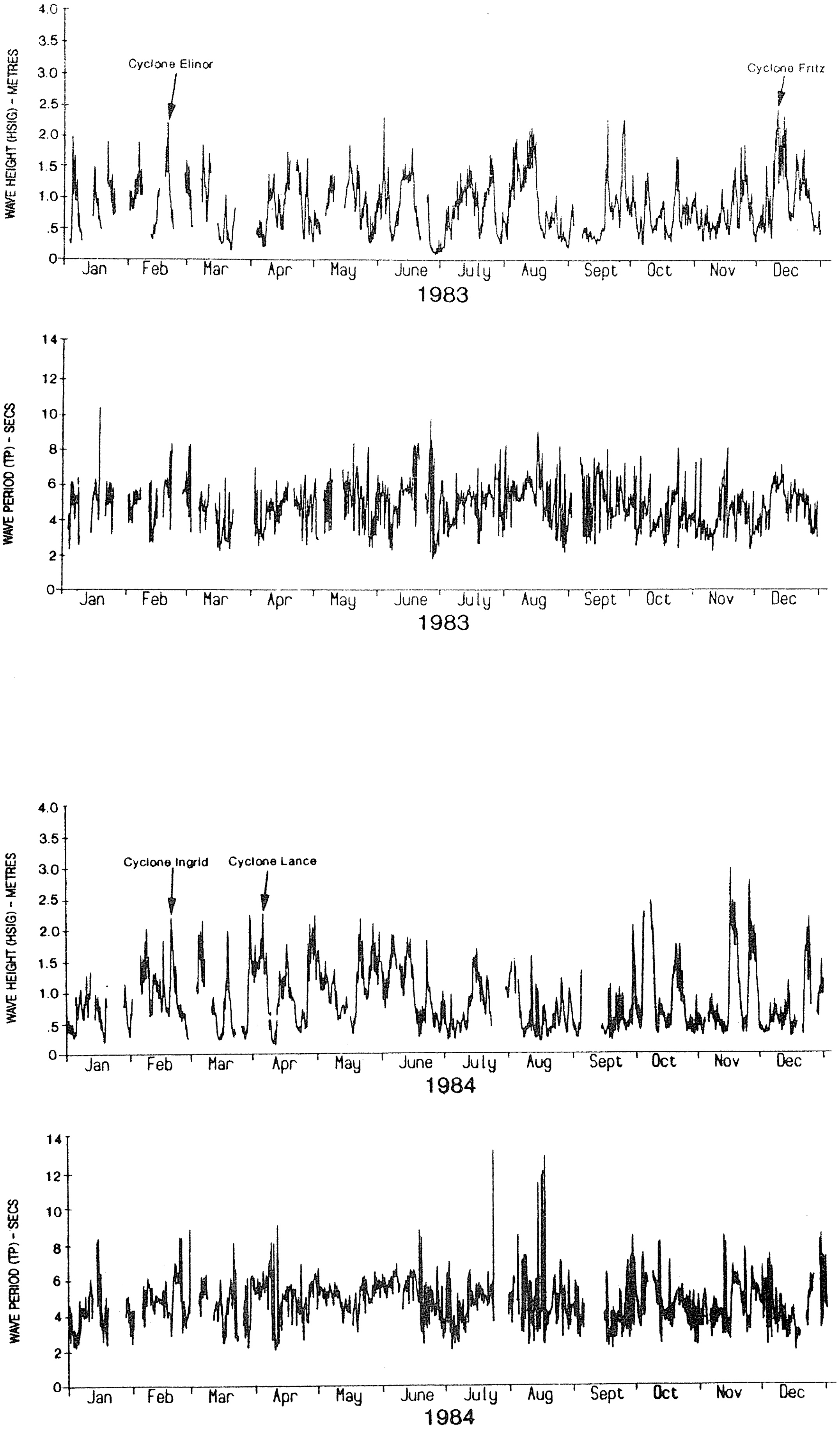
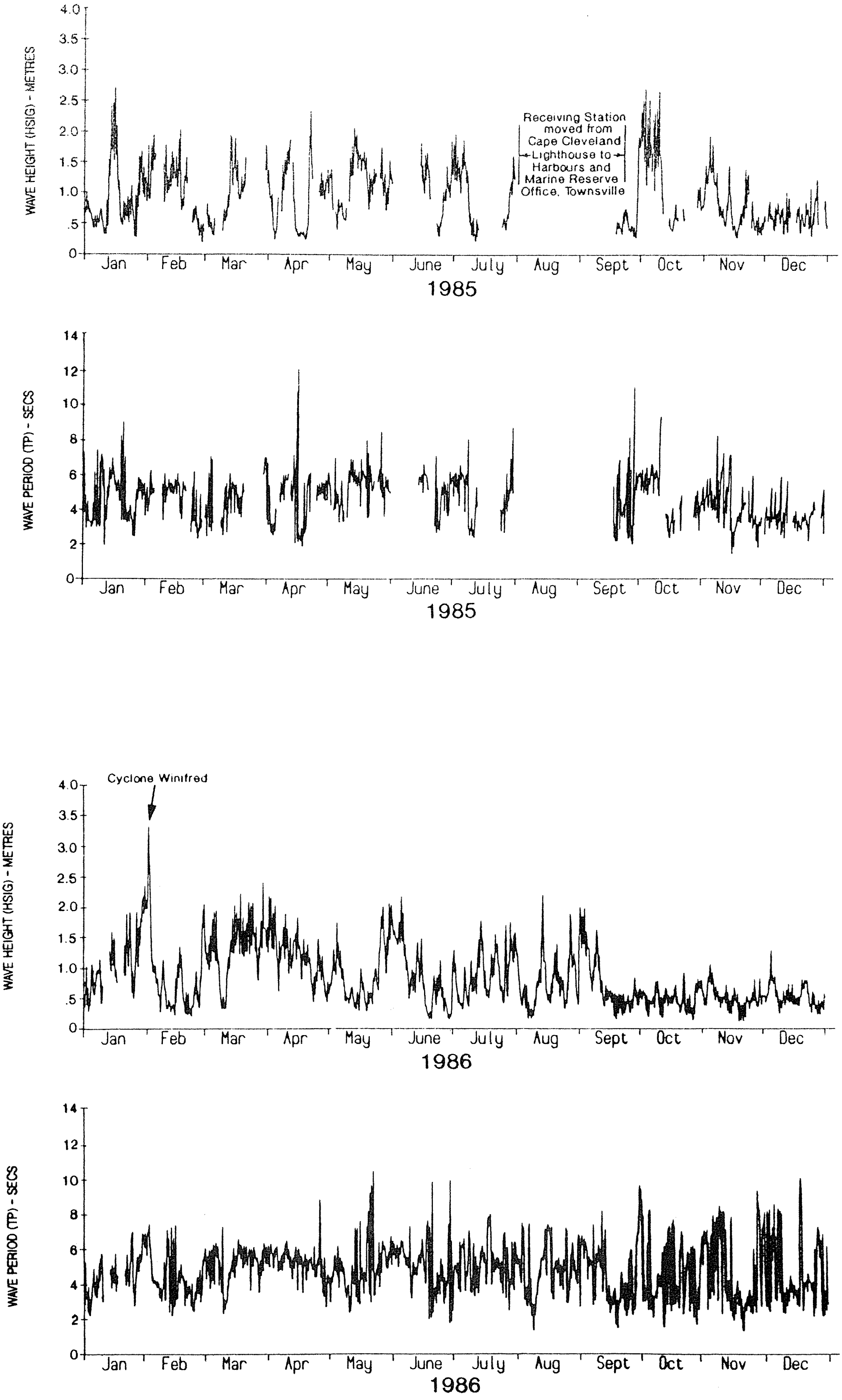


FIGURE 18 continued



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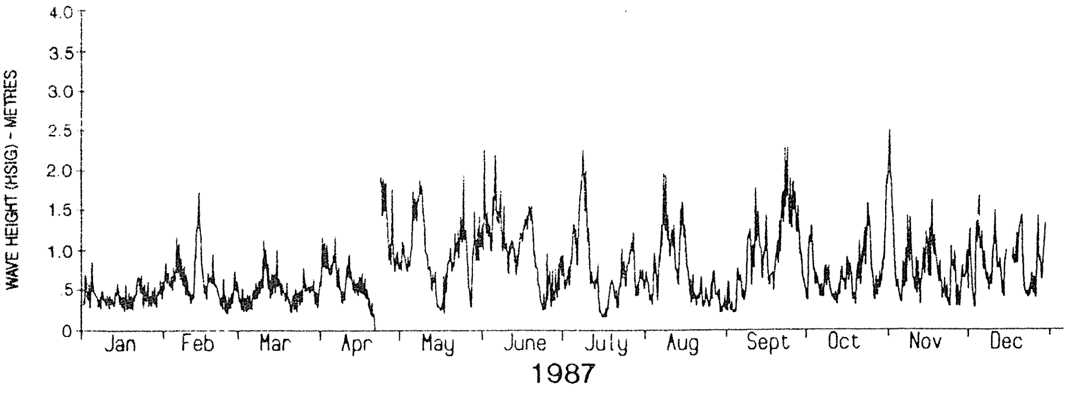

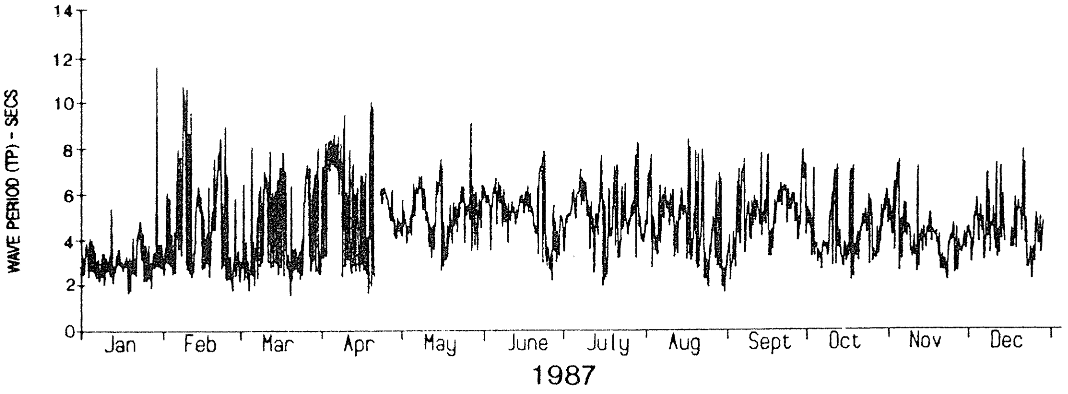

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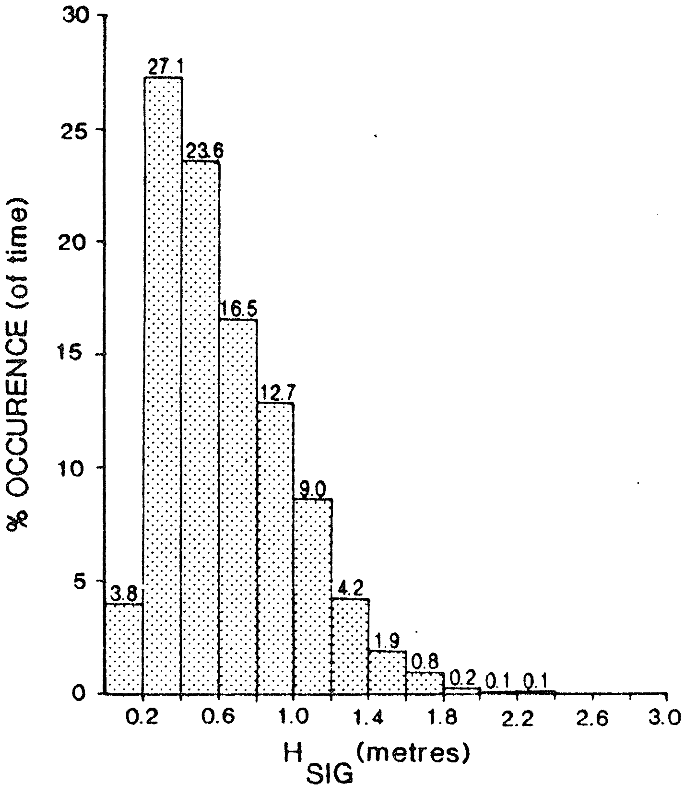
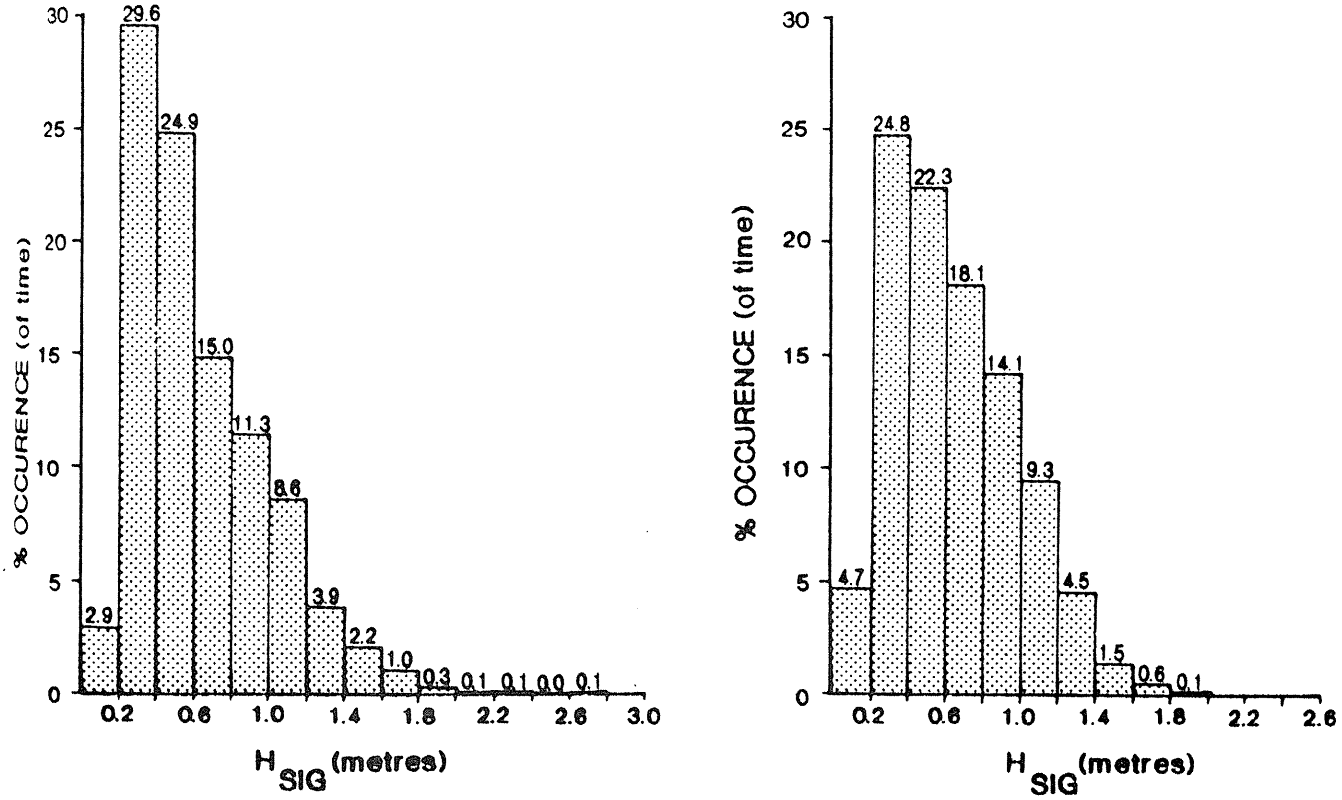


ALL DATA



SUMMER DATA

WINTER DATA

FIGURE 19 Wave records from wave buoy near Cape Cleveland 1975-1987. After Beach Protection Authority, 1988.

a) Histograms showing percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

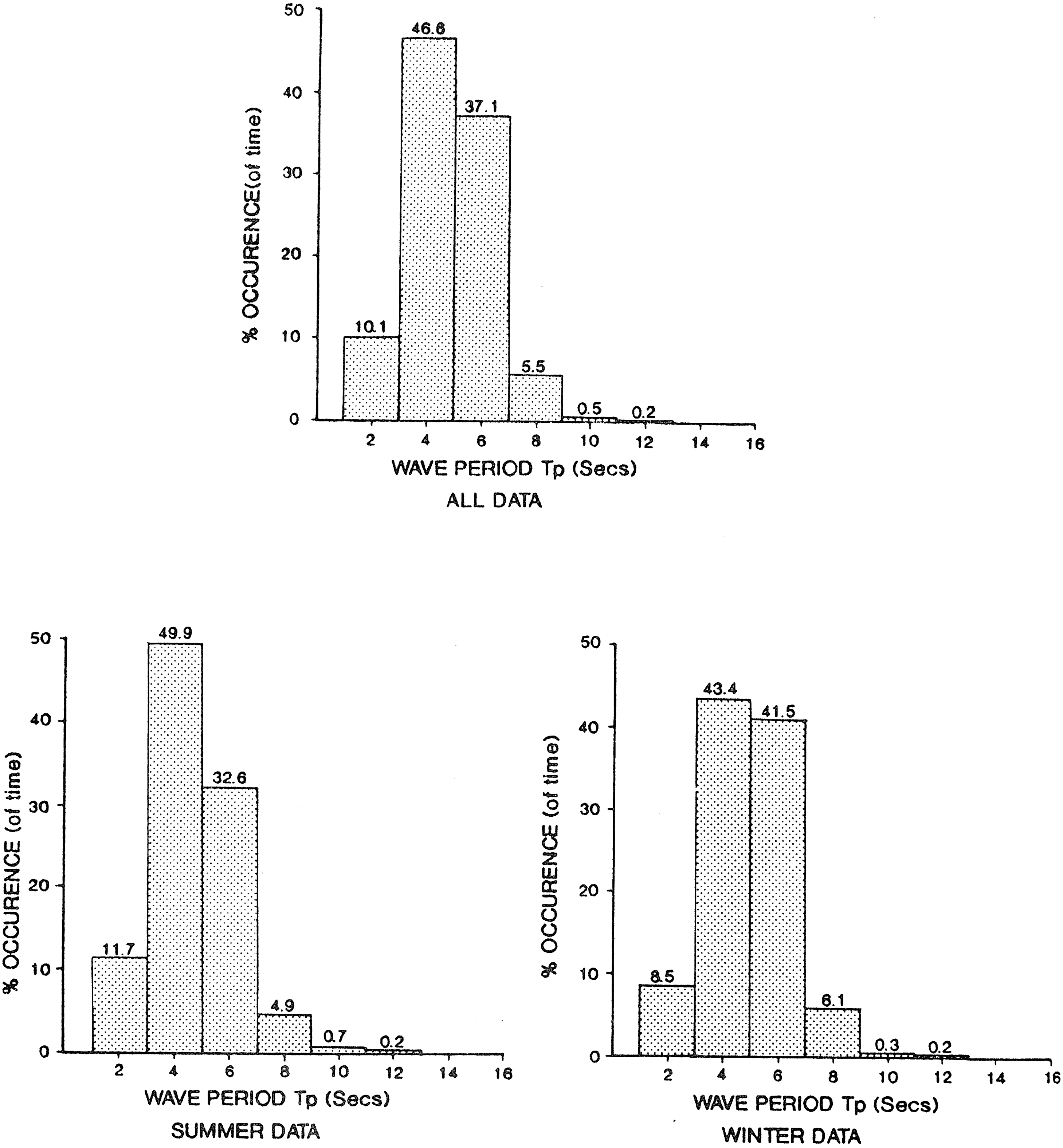


FIGURE 19 continued

b) Histograms showing percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig).

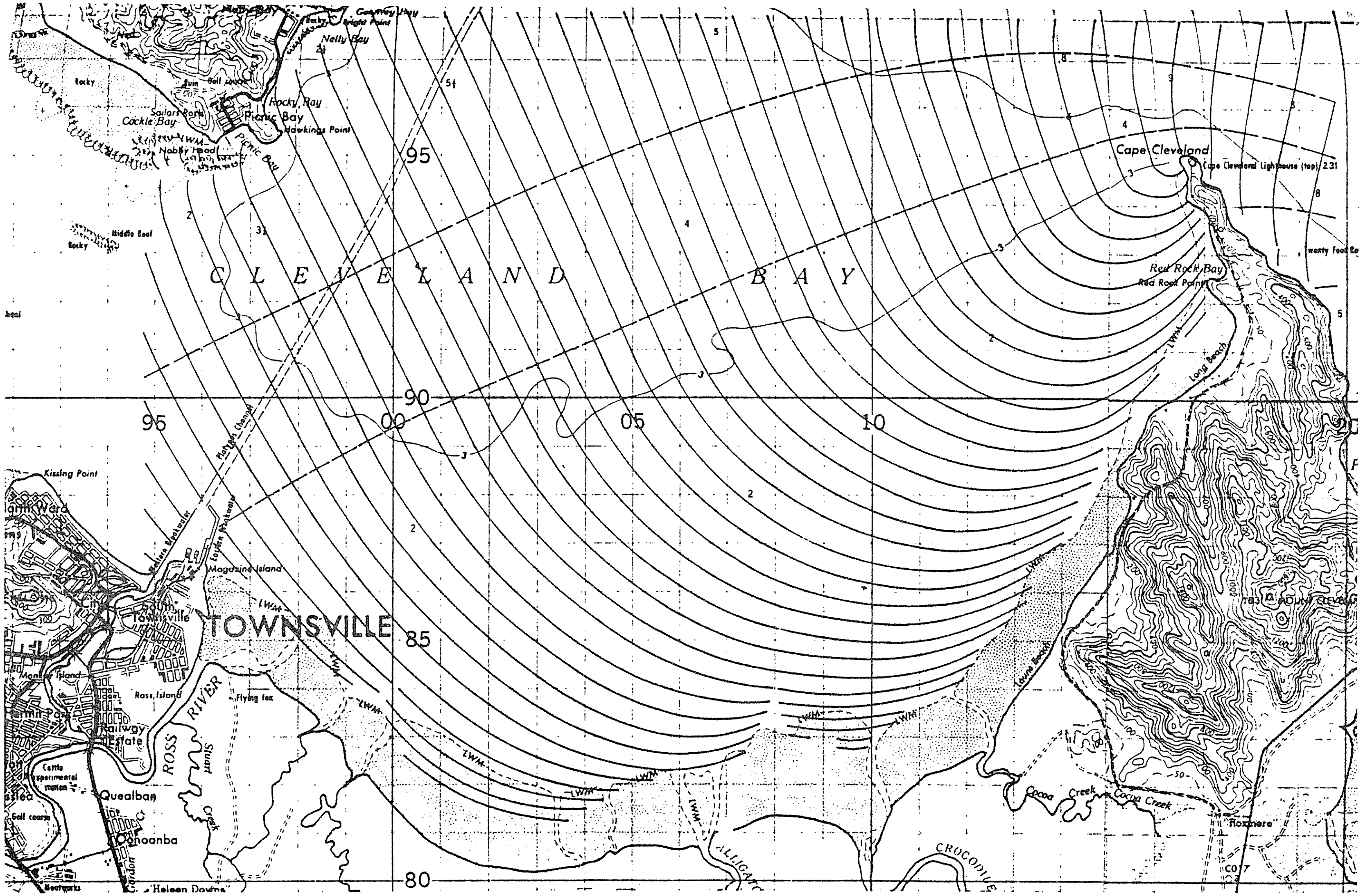


FIGURE 20 Cleveland Bay wave refraction diagrams. After McIntyre and Associates, 1974.

(a) For south-east waves with 5 second period.

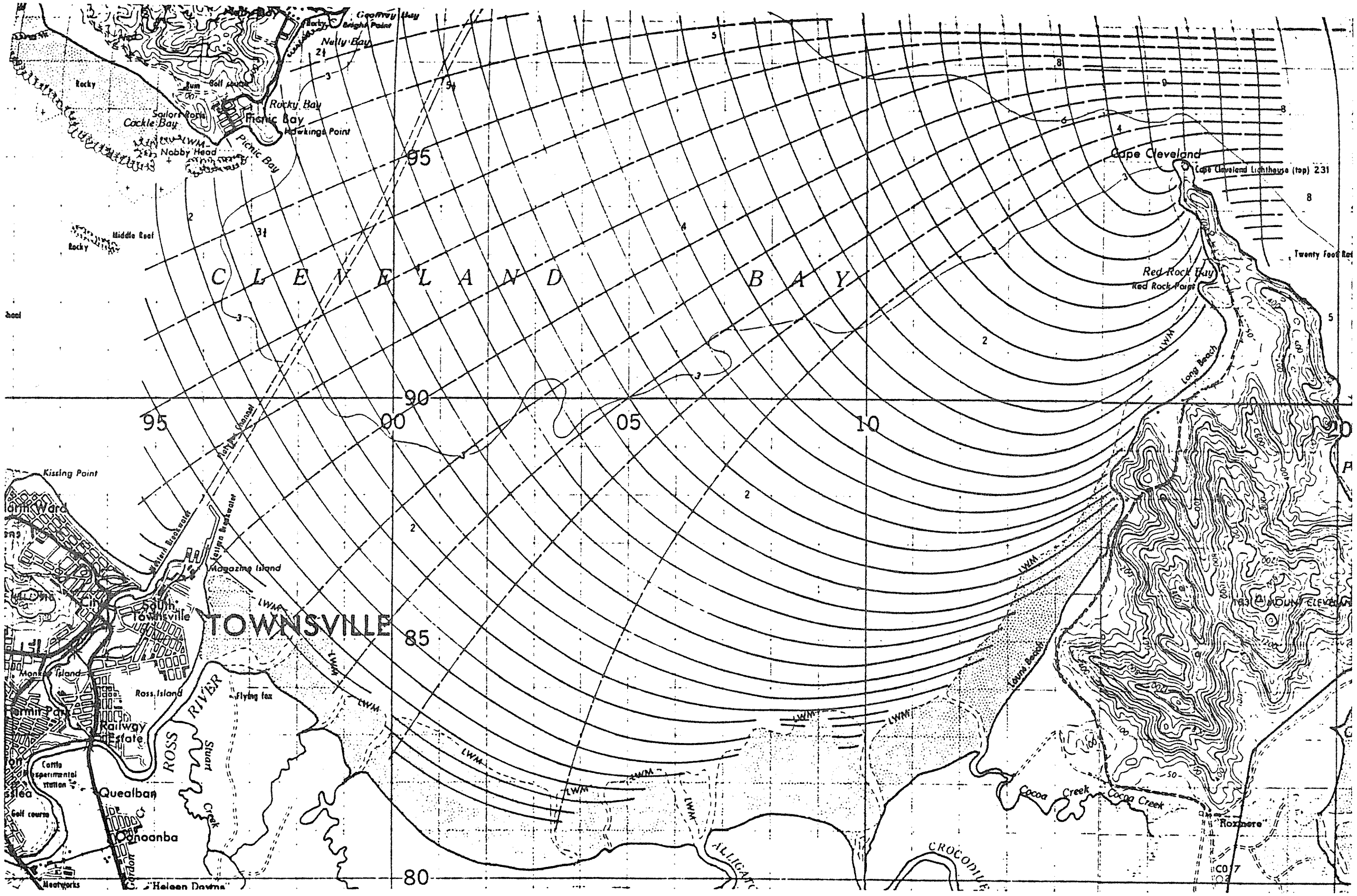


FIGURE 20 continued

(b) Wave refraction diagram for easterly waves with 5 second period.

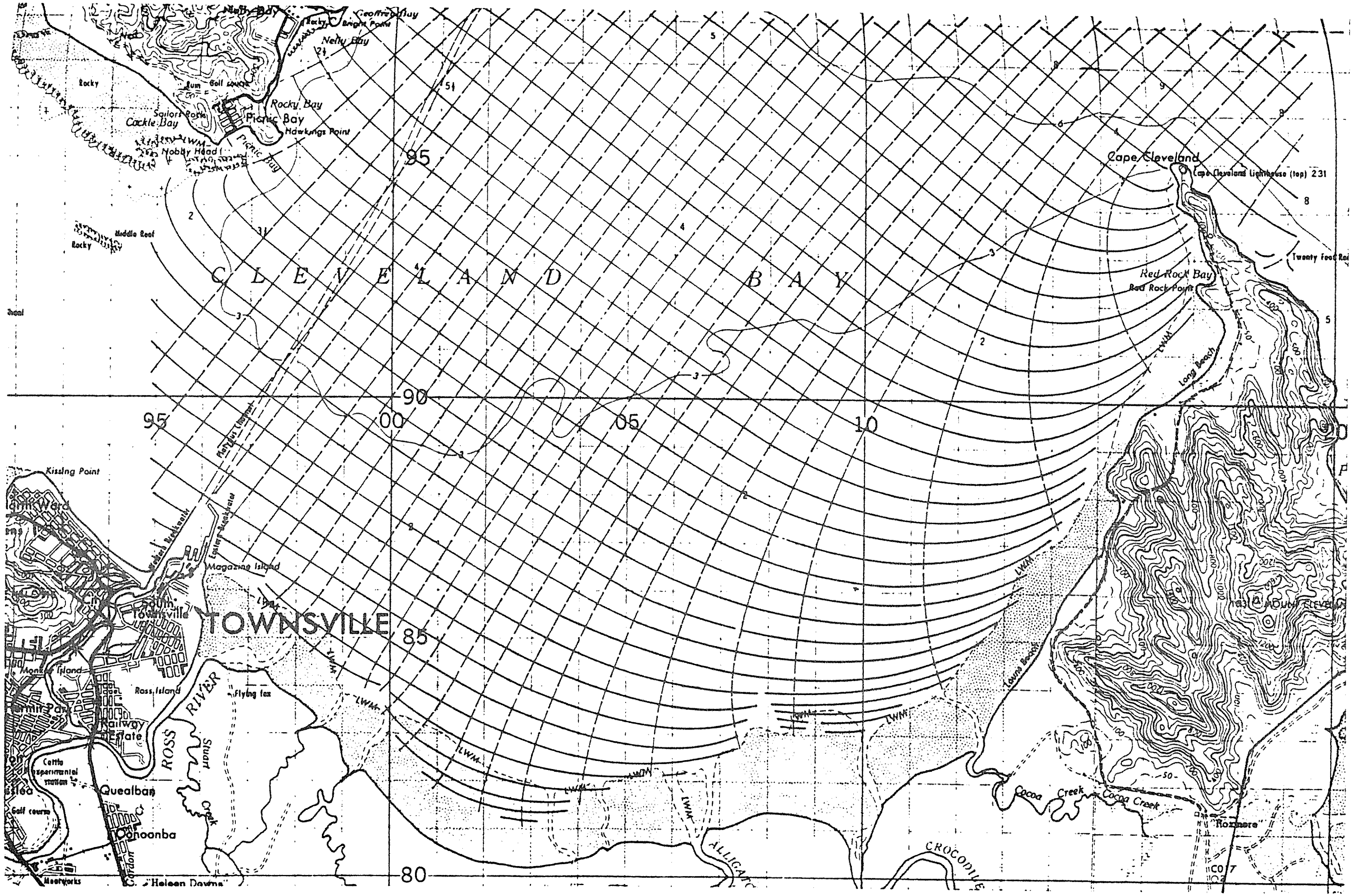


FIGURE 20 continued

(c) Wave refraction diagram for north-east waves with 5 second period.

Figures give speeds in knots.

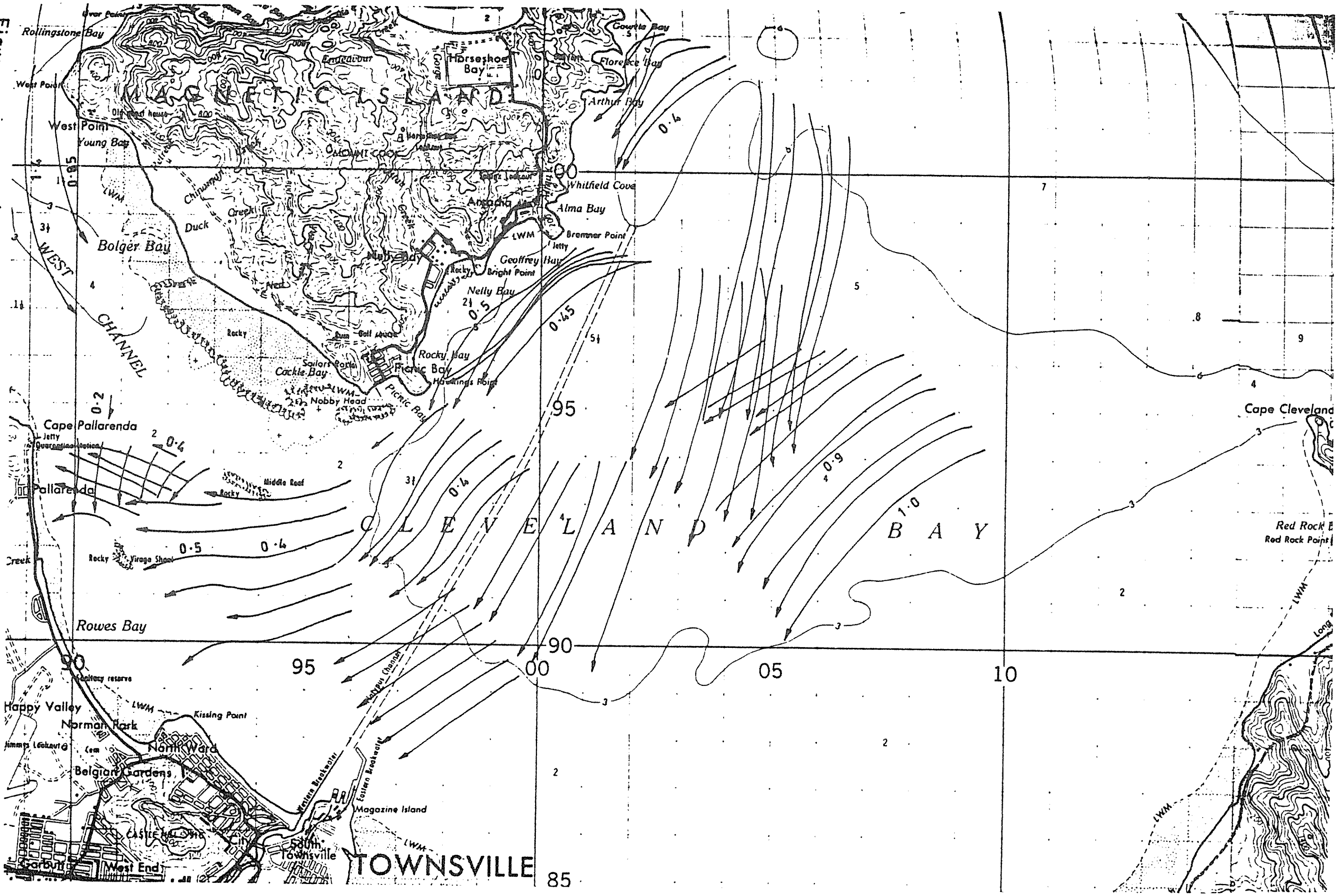
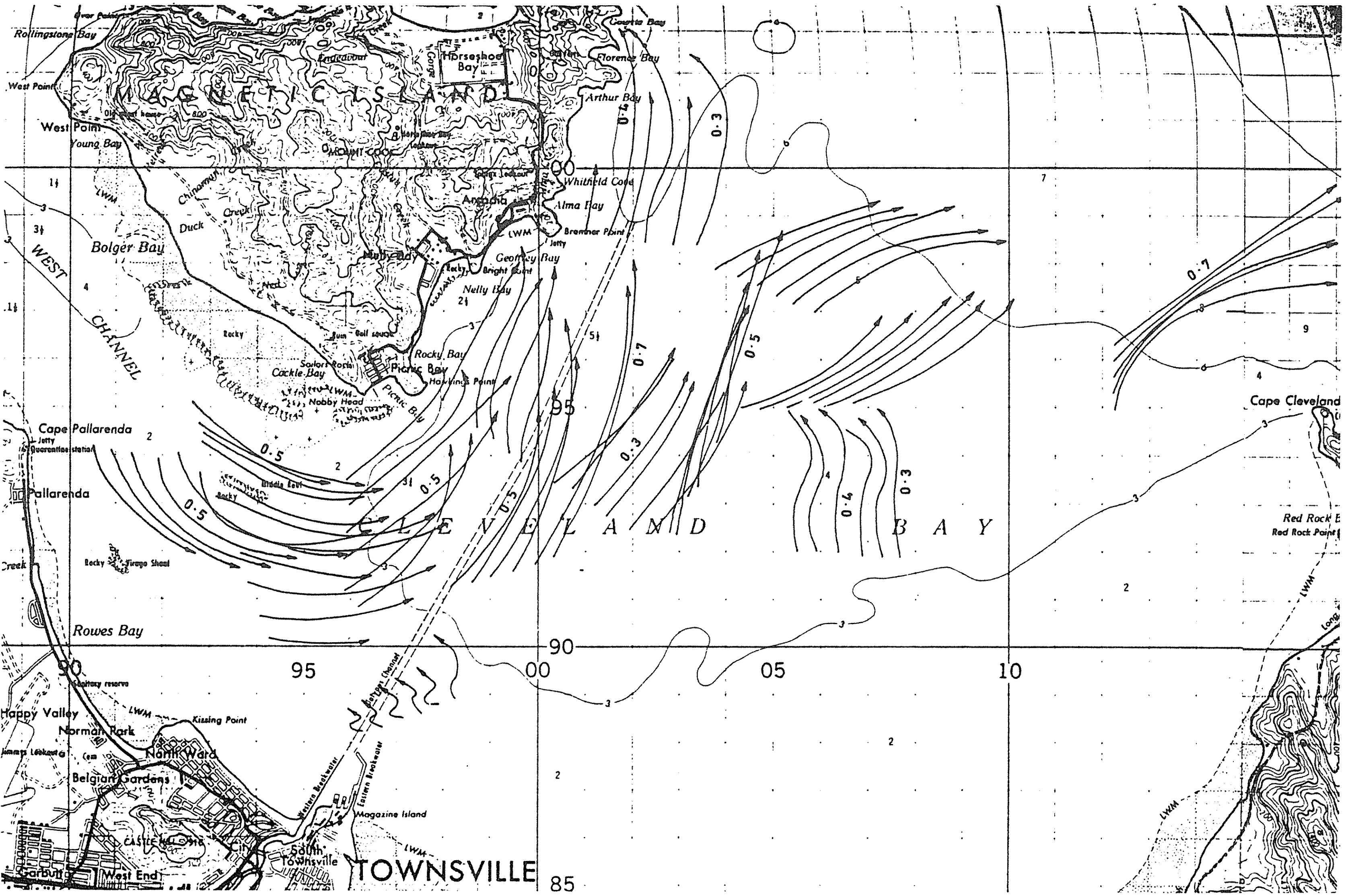


FIGURE 21 Drogue measurements by Townsville Port Authority

(a) Flood tidal currents.



Figures give speeds in knots.

FIGURE 21 continued

(b) Ebb tidal currents.

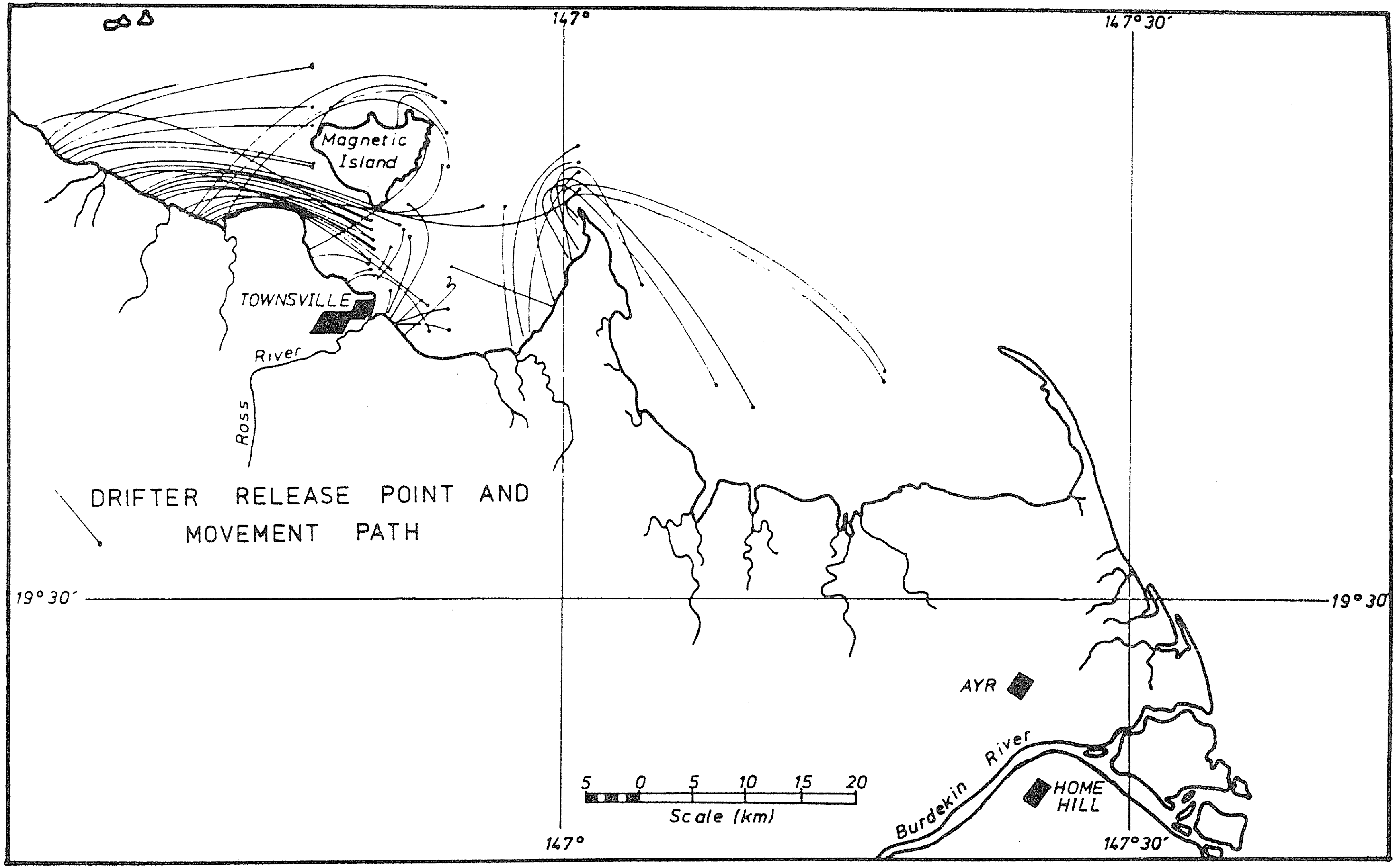


FIGURE 22 Release and retrieval points for Woodhead sea-bed drifters and schematic transport paths. Drifters released in November 1976 and March and April 1977 during moderate and rough sea conditions. After Belperio, 1978.

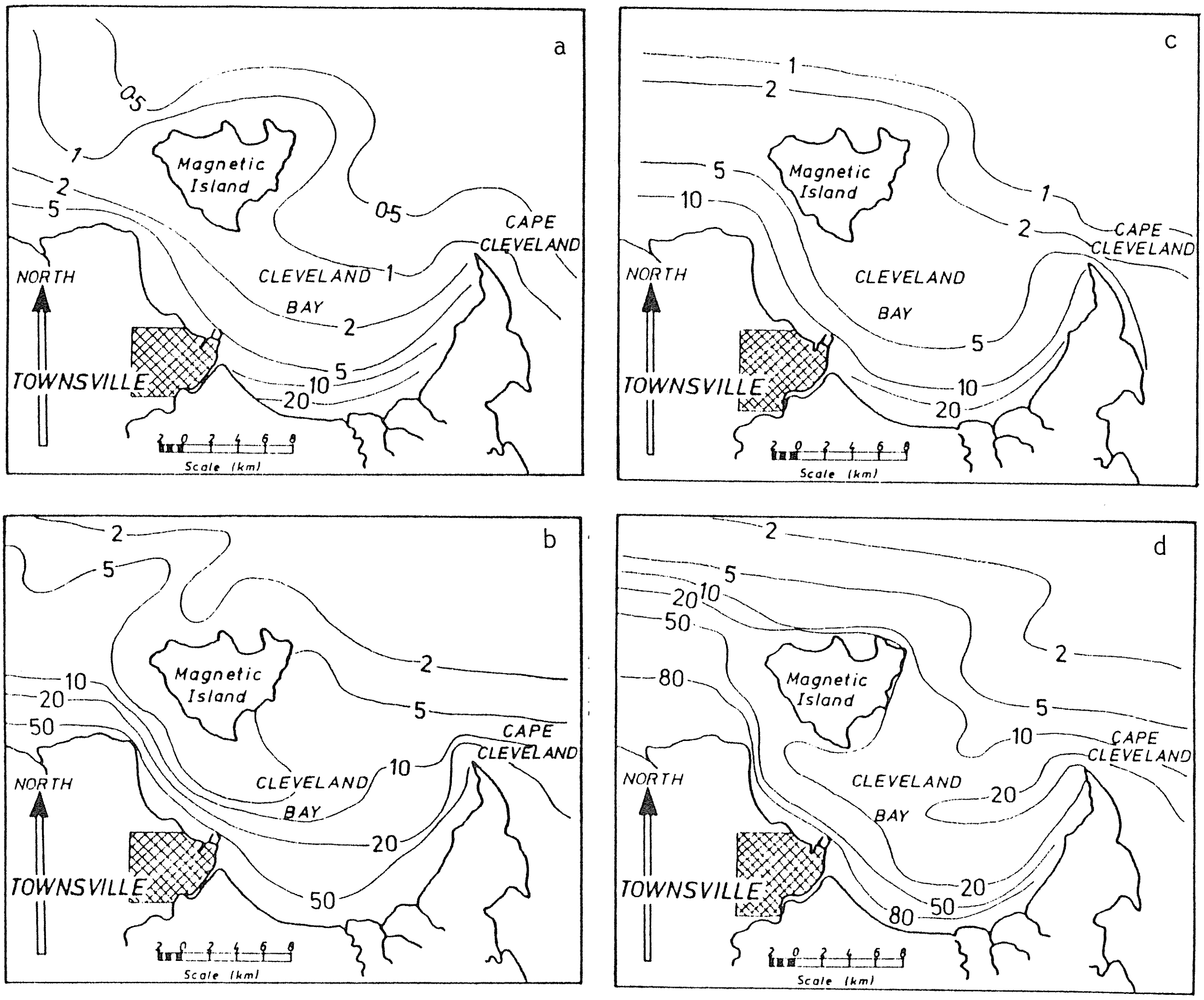


FIGURE 23 Distribution of surface suspended sediment in Cleveland Bay. Contours in parts per million total particulate matter. After Belperio, 1978.

a) For sea conditions smooth and smooth-slight.
b) For sea conditions slight and slight-moderate.
c) For sea conditions moderate and moderate-rough.
d) For rough sea conditions.

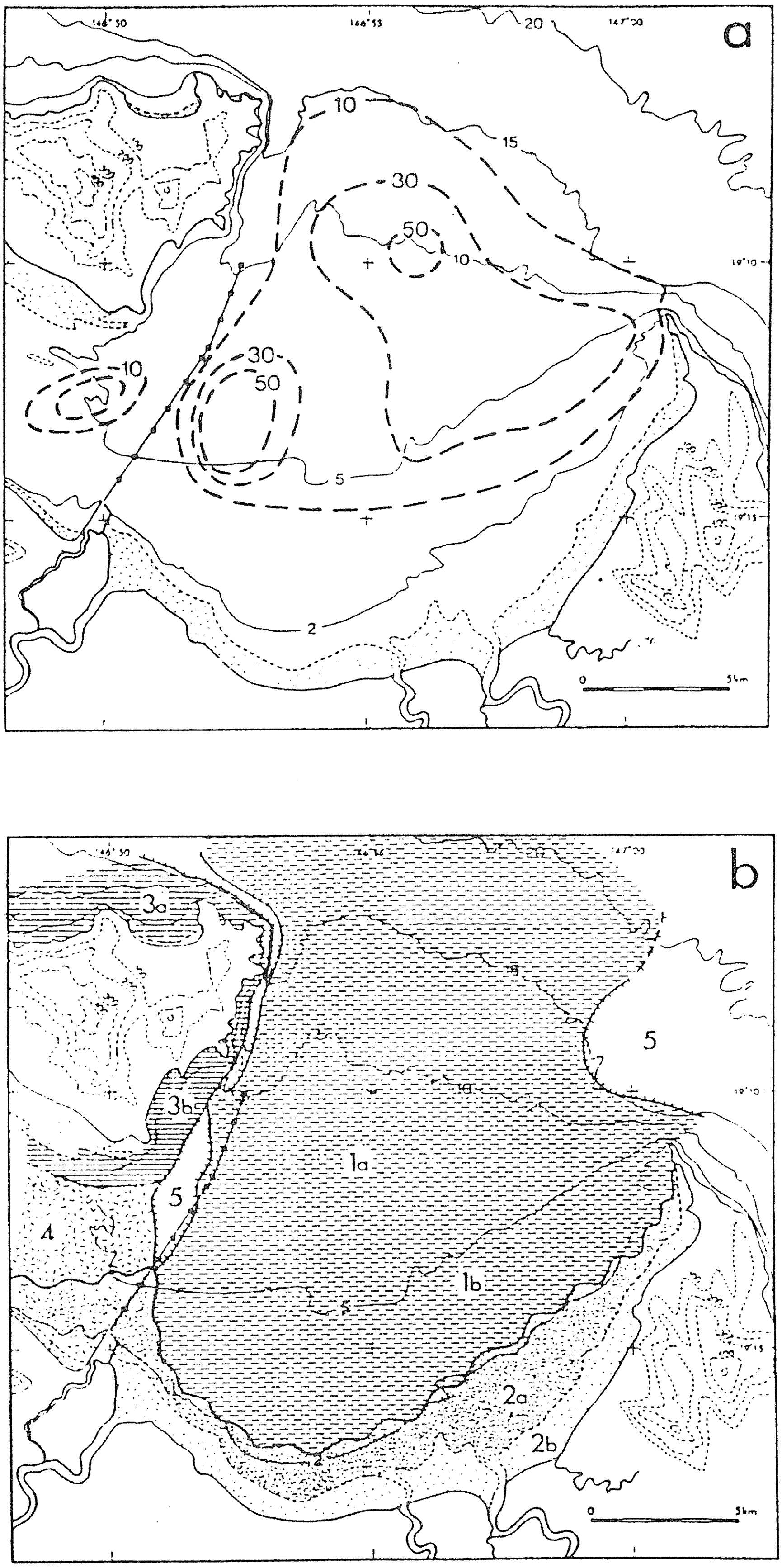


FIGURE 24 a) Isopachs of dredge spoil distribution within Cleveland Bay as inferred from vibracores.

b) Surficial sediment facies distribution within Cleveland Bay beneath dredge spoil. 1a - terrigenous bay mud; 1b - bay mud seagrass subfacies; 2a - silty fine sand foreshore facies; 2b - tidal flat sands; 3a - island-connected terriginous mud; 3b - island-connected facies containing carbonate component; 4-field of longitudinal sand bedforms; 5-Pleistocene at shelf surface, often with surficial armour of cohesive shelly mud.

After Carter and Johnson, 1987.

MAP LEGEND

Seagrass Cover	
< 10% cover	░
between 10% and 50% cover	▤
> 50% cover	▦
Dugong sightings	Ⓓ
Dugong feeding trials sighted	DF
Turtle sighting	▽ T

SEAGRASS SPECIES CODES

CS	1	Cymodocea serrulata
EA	2	Enhalus acoroides
HS	3	Halophila spinulosa
HO	4	Halophila ovalis
HUW	5	Halodule uninervis (wide)
CR	6	Cymodocea rotundata
HUT	7	Halodule uninervis (thin)
SI	8	Syringodium isoetifolium
TH	9	Thalassia hemprechii
HD	10	Halophila decipiens
HP	11	Halophila pinifolia
HT	12	Halophila ovata
WS	13	Halophila tricostata
ZC	14	Zostera capricorni

FIGURE 25 Seagrass distribution in the Cleveland Bay area. Draft maps (1988) from Northern Fisheries Research Centre, Queensland Department of Primary Industries.

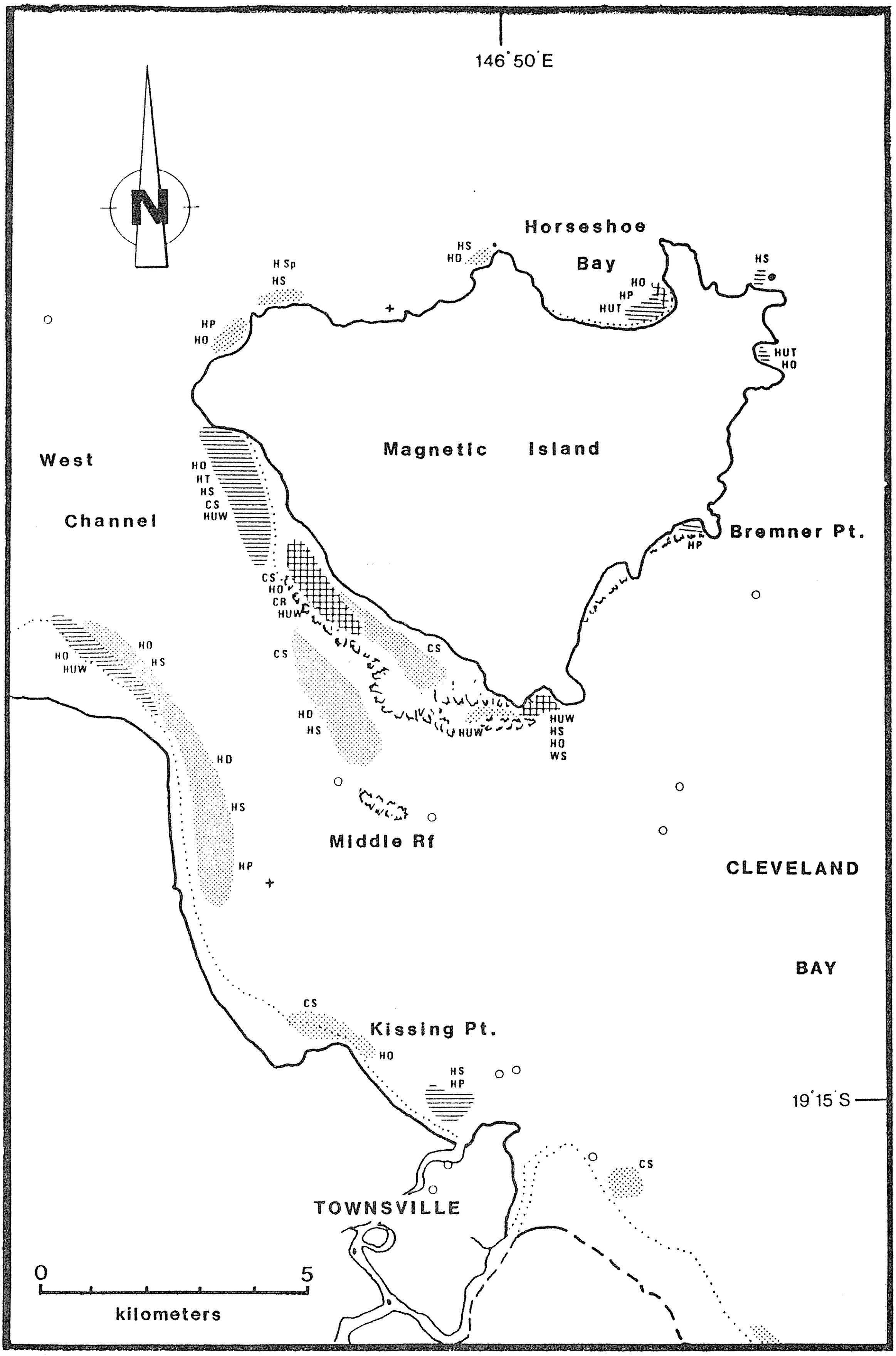


FIGURE 25 continued

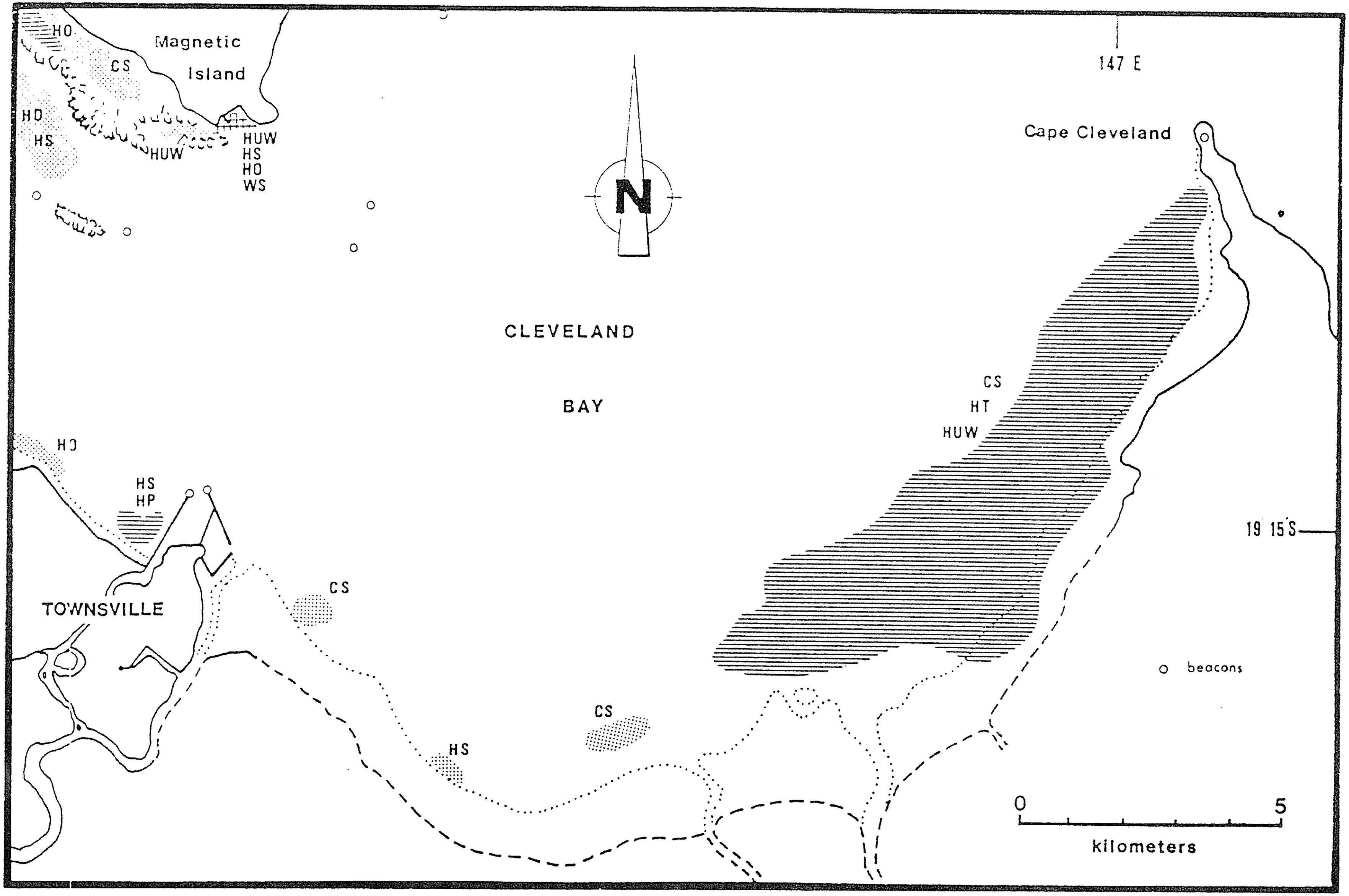


FIGURE 25 continued

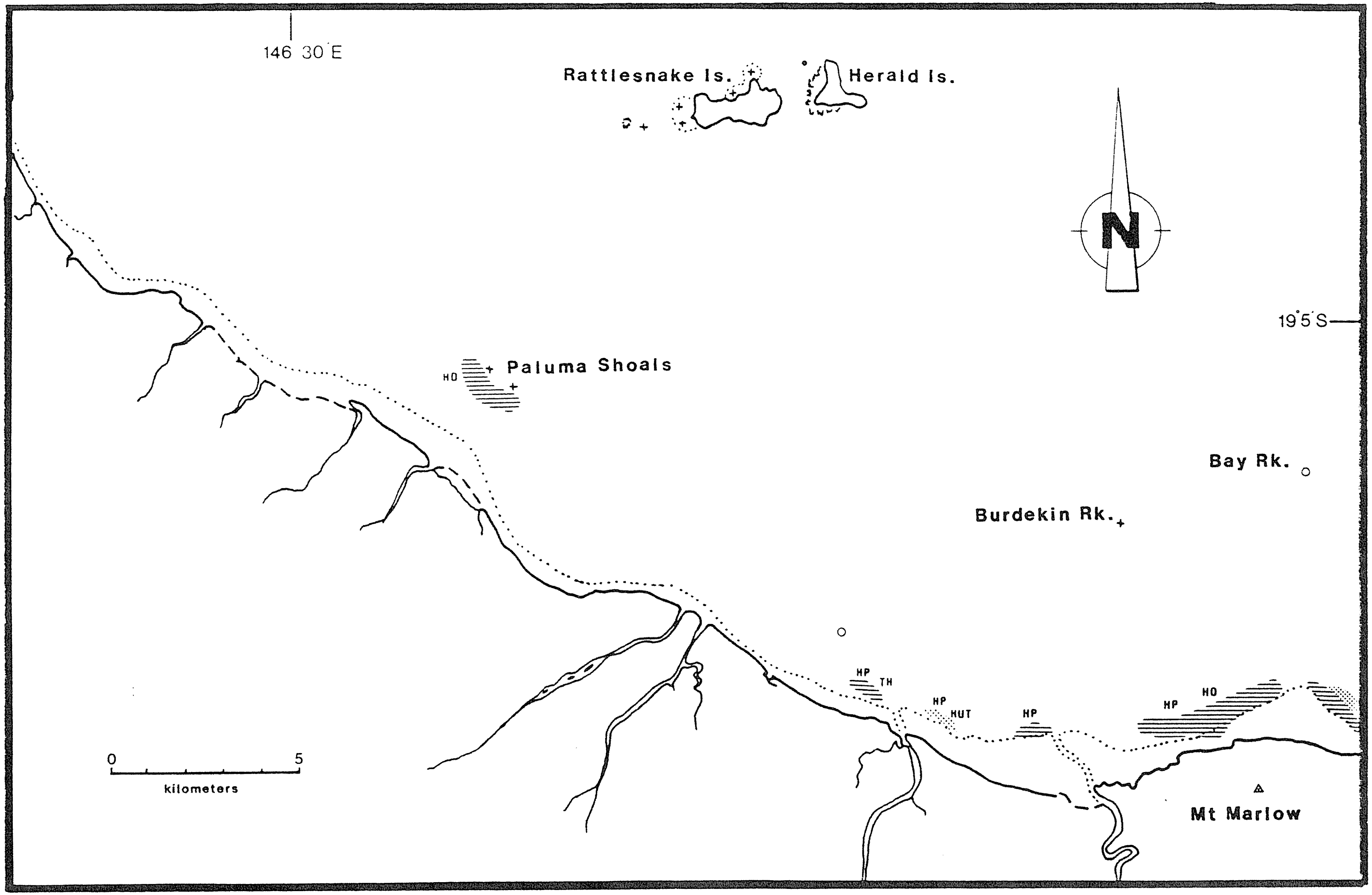
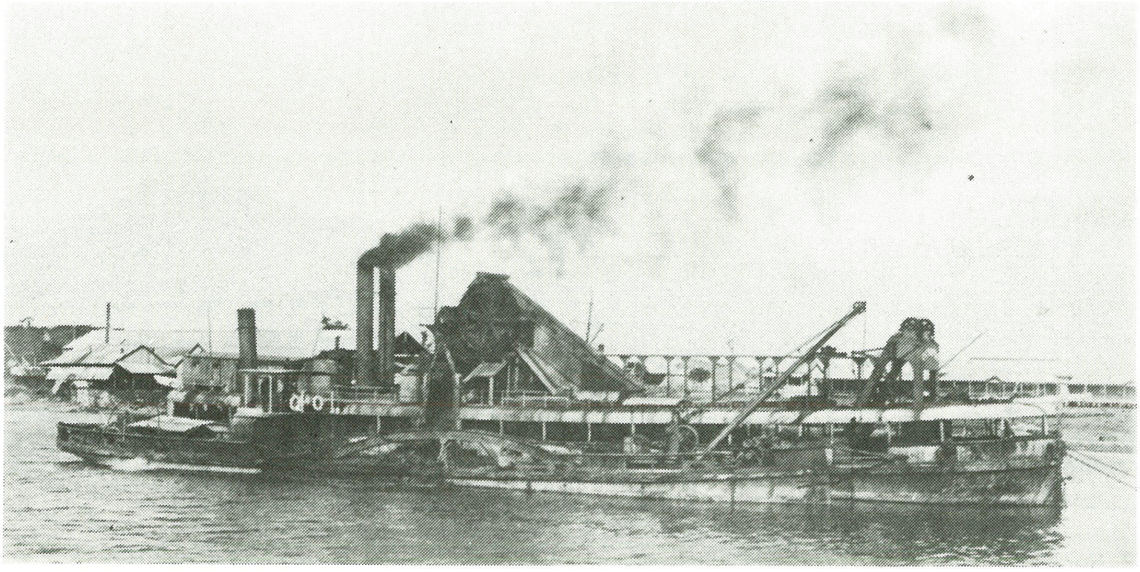
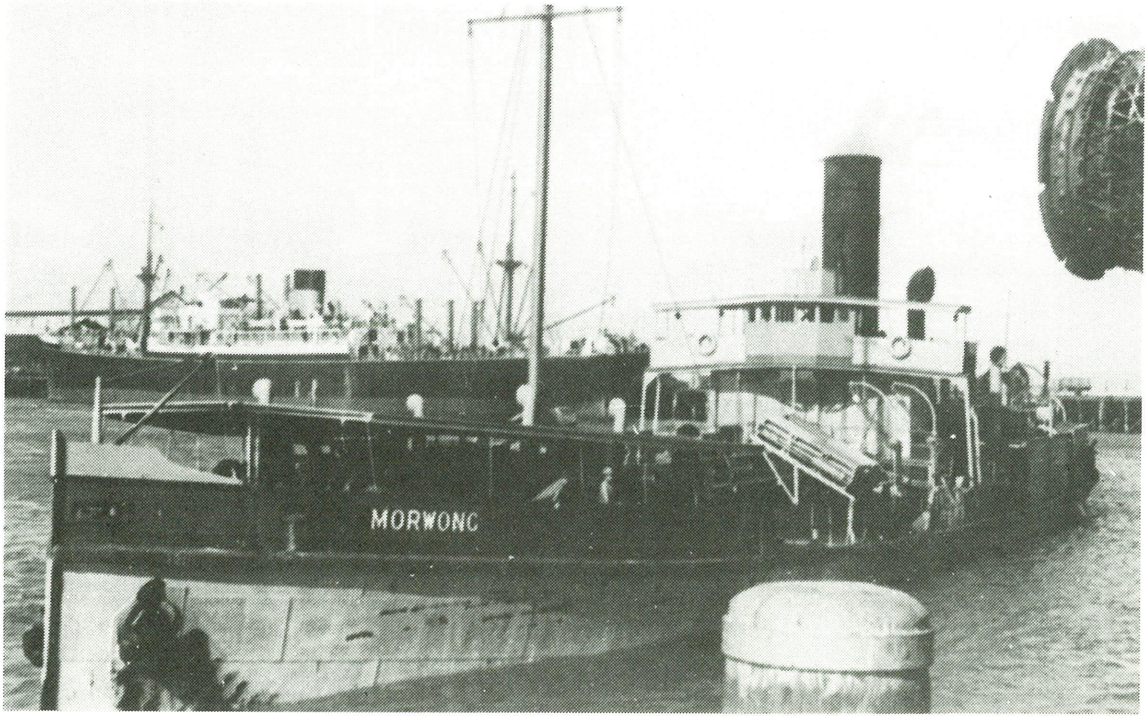


FIGURE 25 continued

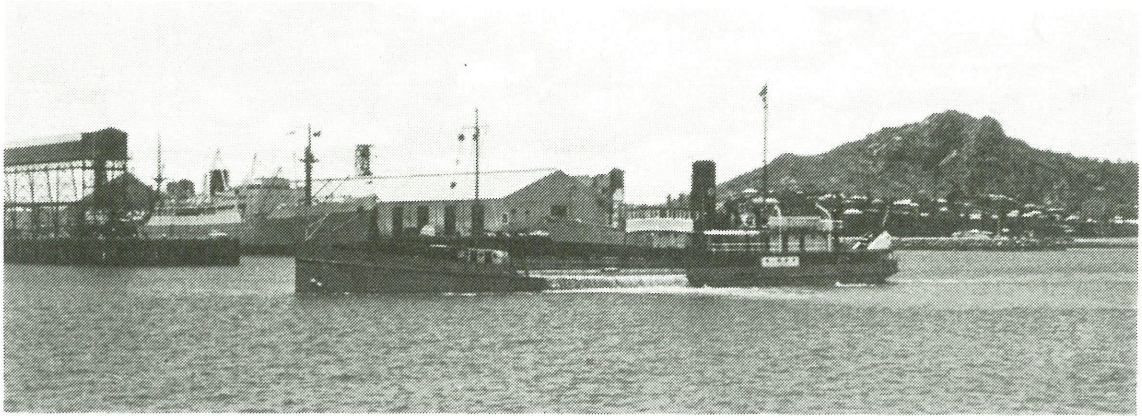
PLATES



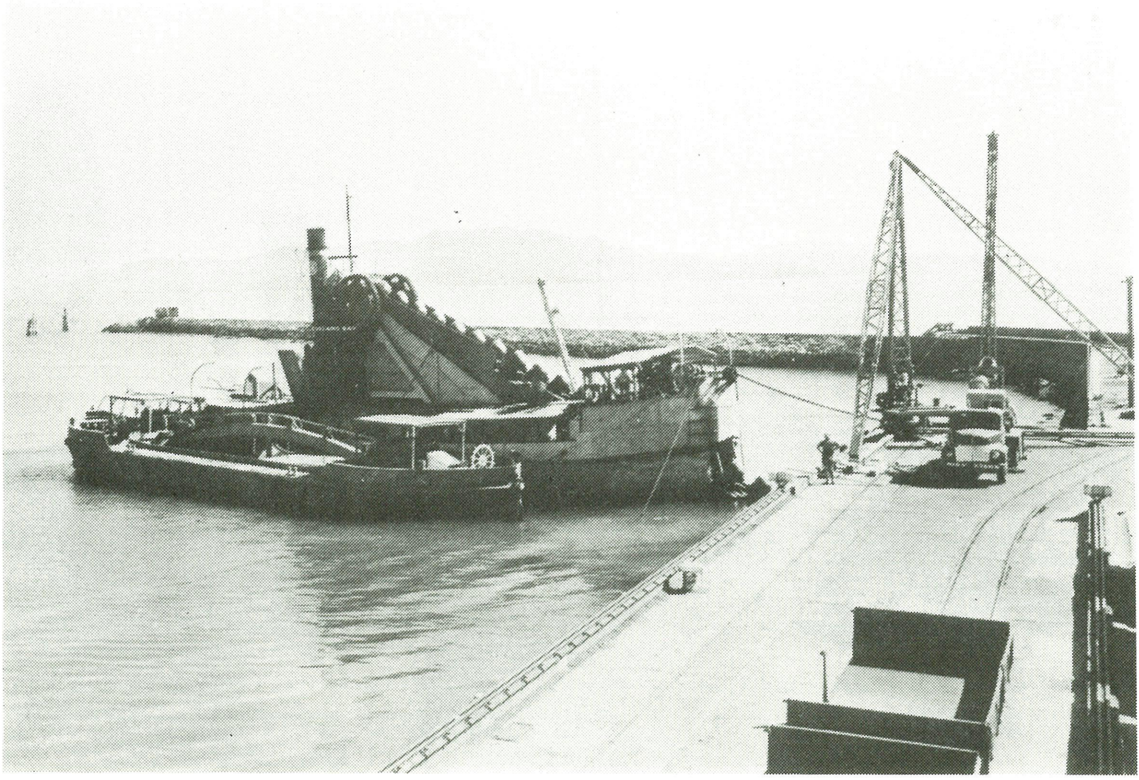
1 Bucket Dredge 'Octopus' dredging Ross Creek in 1901.



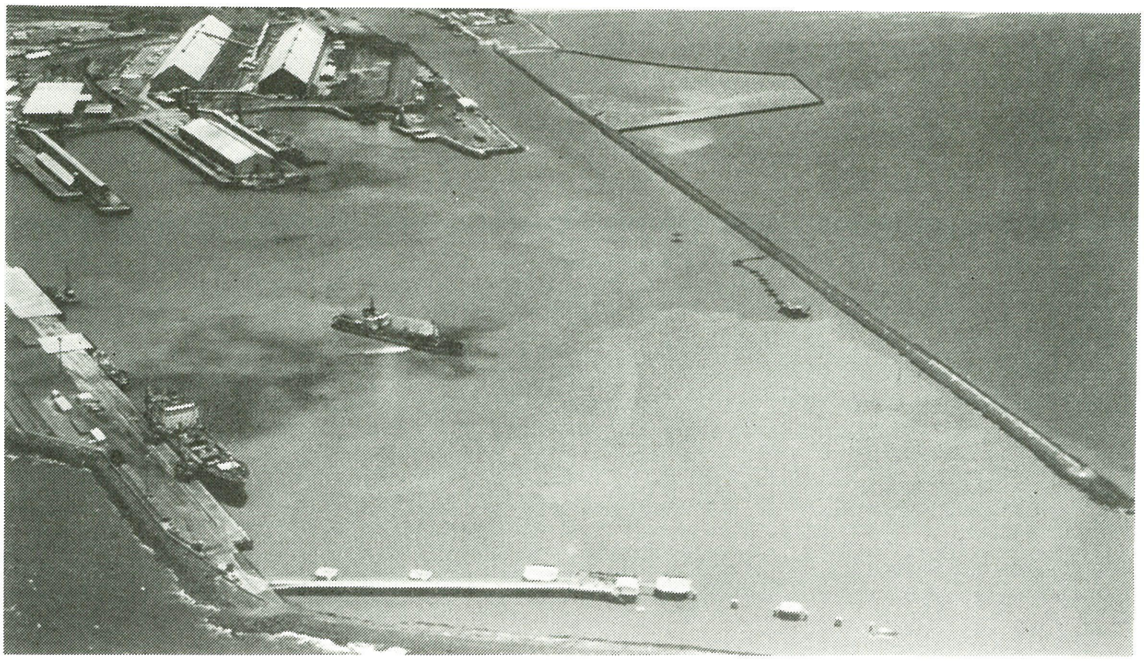
2 Suction Dredge 'Morwong' in October 1946.



3 Suction Dredge 'Townsville' maintaining depths in the Swing Basin.



4 Bucket Dredge 'Cleveland Bay' in 1964 on her final assignment, dredging the new oil and tanker berth.



5 Trailer Suction Dredge 'Sir Thomas Hiley' carrying out developmental dredging in the Swing Basin in 1973.

6 Trailer Suction Dredge 'Sir Thomas Hiley' carrying out maintenance dredging in the Swing Basin in June 1988.