THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

REPORT No. 59

Preliminary Study of Beach Erosion on Cronulla Beach

by

D. N. Foster, D. M. Stone and C. H. Munro

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The University of New South Wales
WATER RESEARCH LABORATORY

PRELIMINARY STUDY OF BEACH EROSION ON CRONULLA BEACH.

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Prepared for The Sutherland Shire Council

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D. N. Foster, D. M. Stone and C. H. Munro.

19th April 1963.

PREFACE

This investigation was undertaken for Unisearch Ltd. on behalf of the Sutherland Shire Council, New South Wales.

The work was carried out by Mr. D. N. Foster, Senior Lecturer in Civil Engineering, and Mrs. D. M. Stone, Project Officer, of the staff of the Water Research Laboratory of the University of New South Wales under the direction of Professor C. H. Munro.

H. R. Vallentine,
Assoc. Professor of Civil Engineering,
Officer-in-Charge of the Water
Research Laboratory.

SYNOPSIS.

This report first discusses basic phenomena associated with beach erosion and accretion, reviews typical U.K. and U.S.A. investigations of causes of and remedies for erosion, and considers the applicability of such measures to Cronulla Beach, N.S.W., Australia. A review of historical data relative to the past behaviour of the beach is given, together with some hindcasting of wave data from meteorological records. Some preliminary measurements of currents, analyses of wave refraction diagrams, estimates of littoral drift, and sand grading analyses are reported.

Preliminary conclusions are drawn regarding the effects of waves, tides, ocean currents, wind and the activities of man in the erosion and accretion of the beach. Various possible measures for mitigating erosion are discussed.

Recommendations are made for trials of stock piling and offshore dumping and for further data collection and analysis.

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1. INTRODUCTION.

During the past half century the citizens of Sydney have taken a natural interest in the many excellent surfing beaches on the adjacent Pacific Coast, and from time to time have been perturbed by evidence of beach erosion. However, no attempts have been made to inaugurate a systematic programme of data collection and an investigation of the causes of erosion and the conditions under which it occurs. In no case so far has it been considered necessary to institute measures to prevent erosion or to spend money on repair of damage caused by erosion. Some foreshore protection by sea walls has been carried out, sometimes with deleterious rather than beneficial results.

However, a few years ago the erosion of portion of Cronulla beach in the Shire of Sutherland was so bad that the Shire Council in February 1962 arranged with Unisearch Ltd. (an applied research organisation associated with The University of New South Wales) that the Water Research Laboratory of The School of Civil Engineering should make a preliminary investigation of the causes of and remedies for this erosion.

In the absence of any previous study of beach erosion in New South Wales, this preliminary investigation could only be based on studies of similar problems elsewhere and a consideration of the applicability to local conditions of methods of preventing and remedying erosion which have proved successful in other countries. This could be supplemented by a review of historical data relative to the behaviour of Cronulla Beach in the past, and also by attempting to build up indirectly a record of wave data by calculations based on meteorological data.

Therefore the programme of work approved by the Council was specified as follows:-

(i) Summary of basic principles of Beach Erosion phenomena and Remedial Measures, and a review of technical literature on methods of attack on similar problems overseas.

(ii) Collection of historical data relative to behaviour of Cronulla beach during period of human settlement, including interviewing local citizens and studies of government files; collection of data regarding mankind's interference with natural processes (such as mining for shell aggregate and sand, building of sea walls, building of roads and houses and other activities tending to stabilization of the sand dunes) ; search of past records of soundings and high water mark recordings; correlation of photographic record of previous beach behaviour with meteorological conditions existing over certain periods.

(iii) Preparation of report on what indication can be obtained from (i) and (ii) regarding the causes of the present beach denudation and possible remedies, such as artificial nurturing of the beach.

(iv) If the conclusions from (i) and (ii) cannot be stated with confidence, the preparation of a programme of data collection and/or experimentation aimed at obtaining a practical solution to the problem and including proposals for (a) consideration of the measurement of surface and sub-surface currents within the surf zone, (b) carrying out of littoral drift survey based on construction and analysis of wave refraction diagrams and estimates of littoral currents and the magnitude of littoral drift, (c) sand grading analyses and mineral analyses of sand along the beach and in Port Hacking, (d) carrying out of wave characteristic frequency studies, (e) conducting of hydraulic model experiments, and similar possible methods of investigation.

The results of this investigation are embodied in the following sections of this report. An endeavour has been made to phrase the report in such a manner as to be intelligible to laymen. Technical terms are usually defined when first introduced in the text, and a complete glossary of technical terms is included as Appendix "A'. References to relevant technical literature are given in the text and listed in detail in alphabetical order in Appendix B .

2. DESCRIPTION OF PROBLEM AREA.

Cronulla Beach is situated about 20 miles south of Sydney and is the main surfing beach for the southern suburbs of this metropolis of 2,000,000 people. The beach extends for a distance of about 2 miles between the Kurnell Peninsula south of Botany Bay and the Cronulla Peninsula which forms the northern entrance to Port Hacking. Figure 1 is a location map of the area. Plates 1-4 are relevant photographs.

The beach faces the Pacific Ocean with a south-easterly aspect, but is somewhat protected from the full force of the sea because of reefs which project into the sea at both ends of the beach, forming the semi-enclosed body of water known as Bate Bay. Although the maximum depth within this bay is 15 fathoms, there is a rise in the sea floor associated with the reefs which limits the depth across the entrance to the Bay to 7 fathoms. From Boat Harbour at its northern end, the main beach extends in an unbroken curve to within

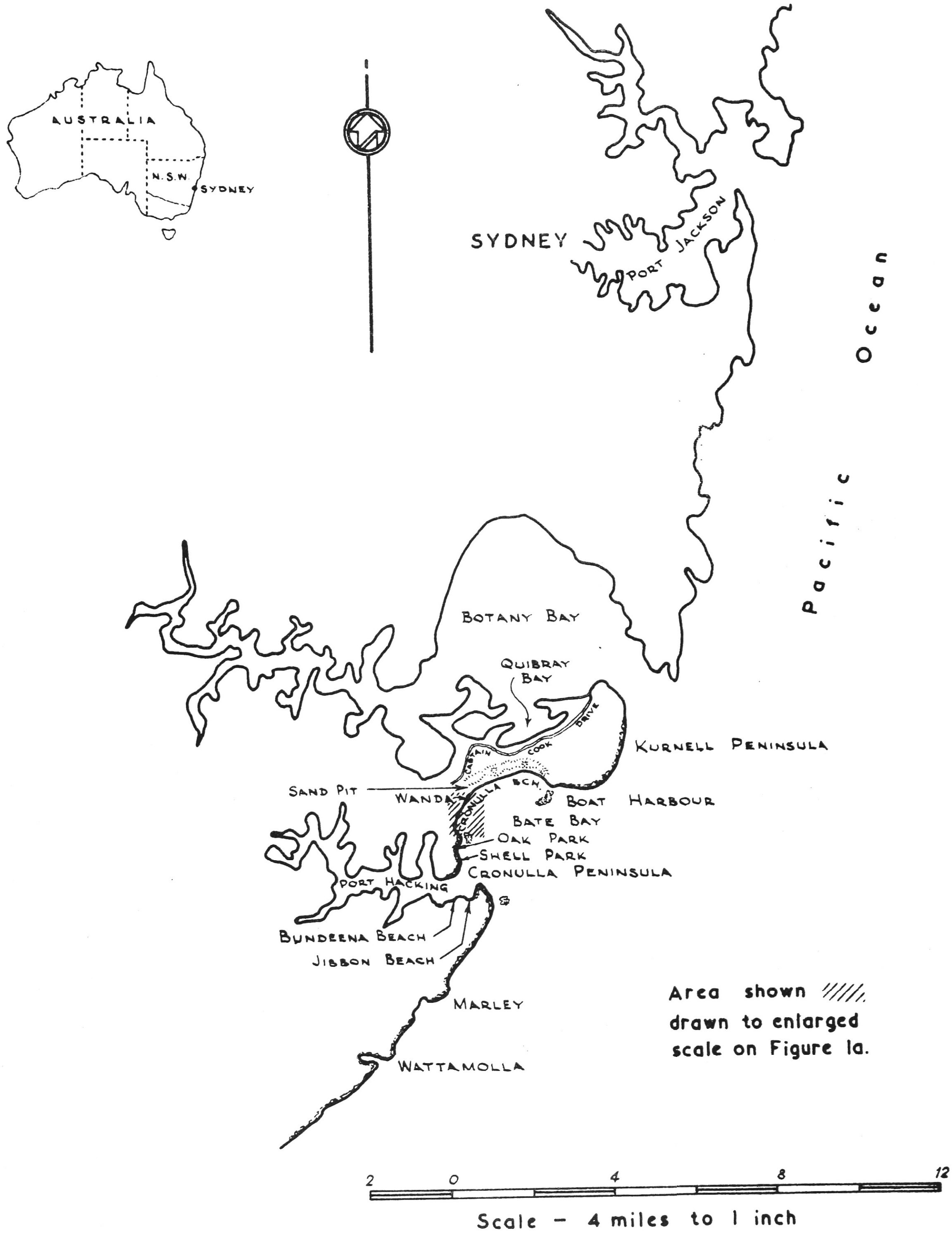


Figure 1: Location Plan

Plate 1: View of South Cronulla Beach from rocks between South and North Cronulla Beaches. Taken 25. 7. 62 at 1500 hrs. high tide and calm seas.

Plate 2 - View North from South Cronulla Beach showing sea baths and sandhills in the background. Taken 25. 7. 62 at 1500 hrs., high tide and calm seas.

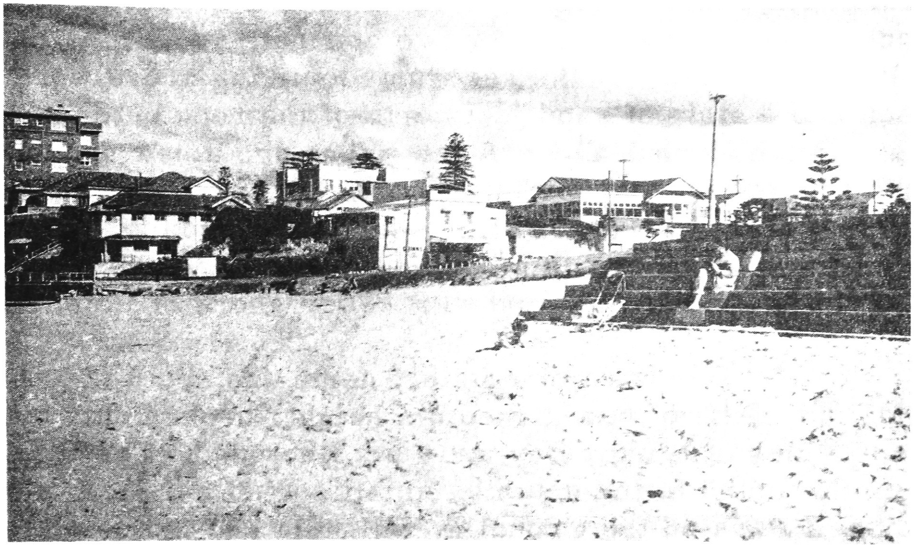


Plate 3: View South of North Cronulla Beach showing remains of stepped sea wall. Taken 25. 7. 62 at 1500 hrs., high tide and calm seas.

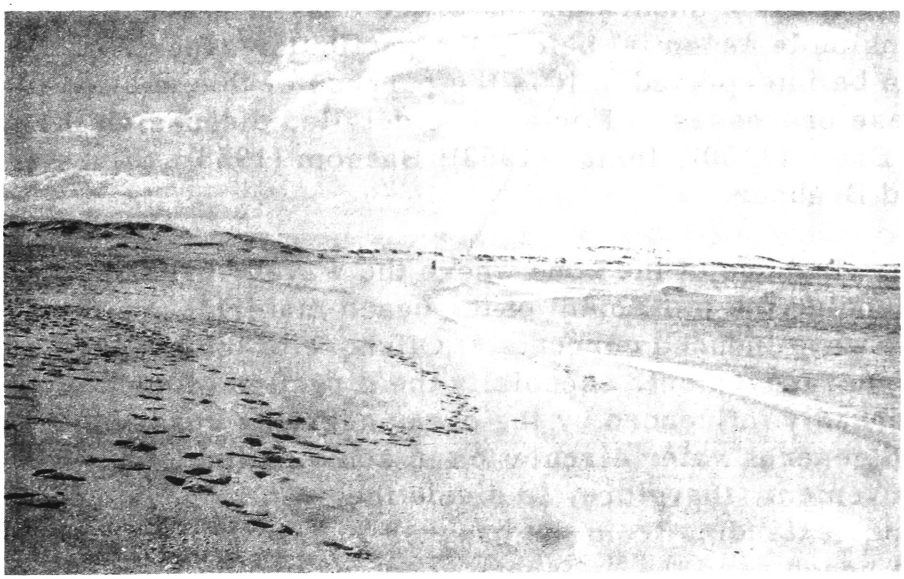


Plate 4: View North from Wanda Beach showing sandhills extending round towards Boat Harbour. Taken 25. 7. 62 at 1500 hrs., high tide and calm seas.

a quarter of a mile of its southern extremity. At this point a rock outcrop breaks the beach line and forms a natural division between the main beach and the relatively short "South Cronulla" or "Cronulla Park" beach. On the rock outcrop two concrete swimming baths have been built. Until recently the recognised surfing areas were South Cronulla beach and a strip of sand just north of the rock outcrop, usually referred to as "North Cronulla". A few years ago a new area some half a mile north was opened for surfing, and a club house built, and this section is now known as "Wanda" beach. North of Wanda both the beach and the area behind it are virtually uninhabited. Sandhills stretch from the beach in this area north and west to the shore of Botany Bay.

The foreshores immediately north and south of these beaches are sandstone cliffs of low to medium height, broken only by the major coastal entrances of Botany Bay and Port Hacking. These rocky foreshores are interrupted to the south by small pocket beaches such as Oak Park and Shell Park on the Cronulla Peninsula and Marley Beach some three miles south of the entrance to Port Hacking.

3.0 COASTAL PROCESSES AFFECTING BEACH EROSION

3.1 Introduction

A basic understanding of the coastal processes affecting beach erosion is essential before the particular aspects of the Cronulla problem can be interpreted. It is the purpose of this section to describe briefly these processes. For a more detailed discussion the reader is referred to Eaton (1950); Inman (1953); Bascom (1953); Silvester (1959); Mehaute and Brebner.

Inshore of the zone where the waves "break", the major factors influencing the movement of the beach material are the action of waves and wave induced currents. Offshore of the breaker zone, however, the net movement, especially the direction of such movement, may be markedly influenced by the ocean currents resulting from winds, tides, and general water circulation in combination with wave effects. It is convenient, therefore, to divide the area into two zones, the "inshore zone" extending from the breaker line to the limit of uprush of waves on the beach, and the "offshore zone" extending from breaker zone seaward. It should be emphasised, however, that the stability of a beach may be influenced by factors extending over some hundreds of miles of coastline and attention cannot be confined to an isolated area. For example, extensive sandstone cliffs are found to the south of Cronulla, unbroken except by several small beaches. As the predominant wave direction is

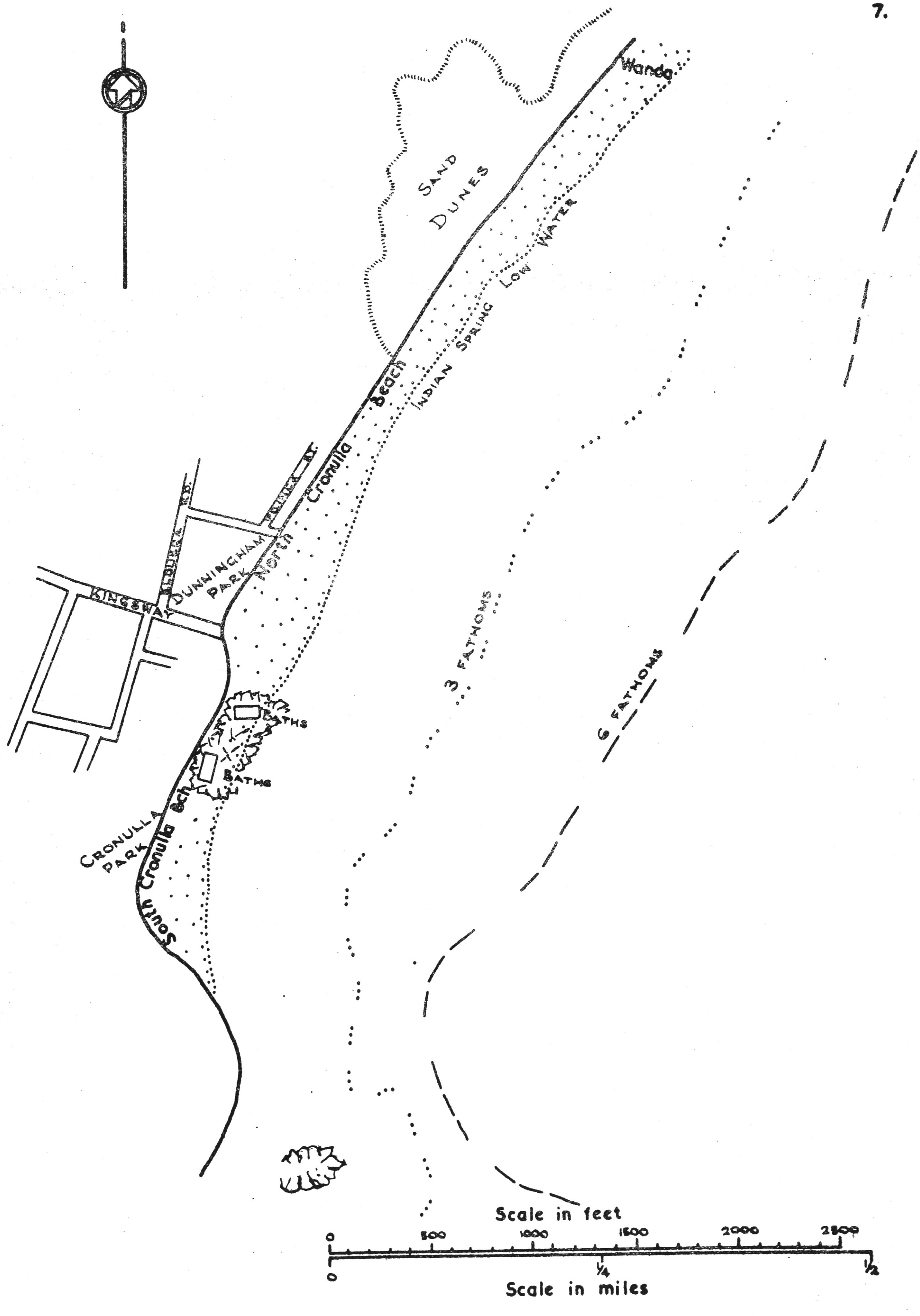


Figure 1a: Plan of North and South Cronulla Beaches

from the south, producing an inshore drift to the north, the rate of erosion of these cliffs might be a factor influencing the stability of the beaches in the Cronulla area

3. 2 Sand Movement in the Inshore Zone

3. 21 General

As previously stated, sand movement within the foreshore zone is caused mainly by waves and wave induced currents. The transport of large volumes of water shorewards by the broken waves produces long-shore or littoral currents which in turn feed rip currents flowing seawards. The water is highly turbulent and a large amount of material is stirred up by the waves and moved in suspension and as bed load with these induced currents. The main wave characteristics influencing the manner by which the sand is moved in the onshore zone are the type of wave and the direction from which it approaches the coast.

3. 22 Nature of Waves

Waves of the ocean in deep water are "oscillatory" waves, so called because the particles of water oscillate in appreciably closed circular orbits. As a result of the oscillations the wave form travels over the surface of the ocean. During the period necessary for a particle to complete one cycle, the wave form moves forward a distance equal to the wave length, denoted by the symbol L. The characteristics of wave motion in deep water are illustrated in Figure 2.

The time taken for one complete oscillation is termed the "period". It will be seen from this figure that this is equal to the time between the passage of successive crests past a stationary observer. "Frequency" is the reciprocal of the period, i.e. the number of oscillations or passage of crests per second. The speed of the wave with respect to the mean velocity of the water (strictly termed the celerity) is the frequency multiplied by the wave length, or the wave length divided by the period. The height of the wave is the distance from crest to trough.

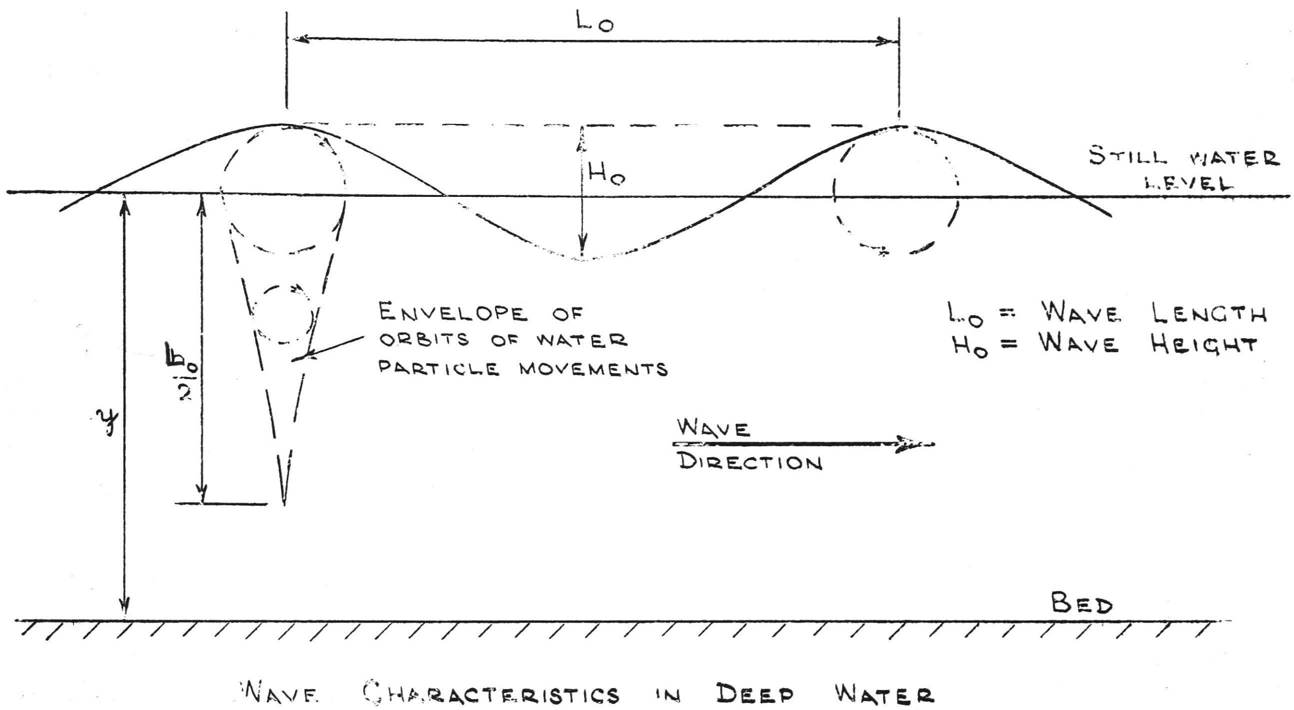


FIGURE 2.

Under actual conditions in the ocean the waves rarely proceed in the orderly formation of rows of marching troops, with the periods between successive crests always the same. For given conditions, the range of variation of the periods of successive waves is sometimes referred to as the "wave period spectrum", from the analogy of the spectrum of wave lengths from red to violet in the visible light rays from the sun.

This variation in height and period in individual waves results in waves of various sizes travelling in groups. This effect is familiar to keen surfers, who are aware that a batch of three or four high waves may be followed by a succession of smaller ones. The speed of the wave group is half the wave velocity.

As the wave approaches the beach, it "breaks" and the oscillatory motion changes to translatory movement, the water particles moving forward with the wave. Surf riders can ride only translatory waves.

3. 23 Wave Types in the Ocean

There are two basic types of ocean waves, termed "storm waves" and "swell", the main features of which are illustrated in Figure 3. Storm waves are used to describe waves within the generating area where energy is still being added to the wave by the wind. Waves of this type are generally irregular in shape, with a wide range or "spectrum" of wave periods and velocities. Propagation of the waves from the generating area takes place in a number of directions. These factors tend to lead to the confused sea with which everyone is familiar when a storm is in progress. The wave steepness is defined as the ratio between the height of the wave and the wave length. For storm waves the wave steepness in deep water is generally greater than 0. 03. For the reasons to be described later, these waves are responsible for the rapid erosion of the beach which occurs whenever a substantial storm area approaches close to the beach zone.

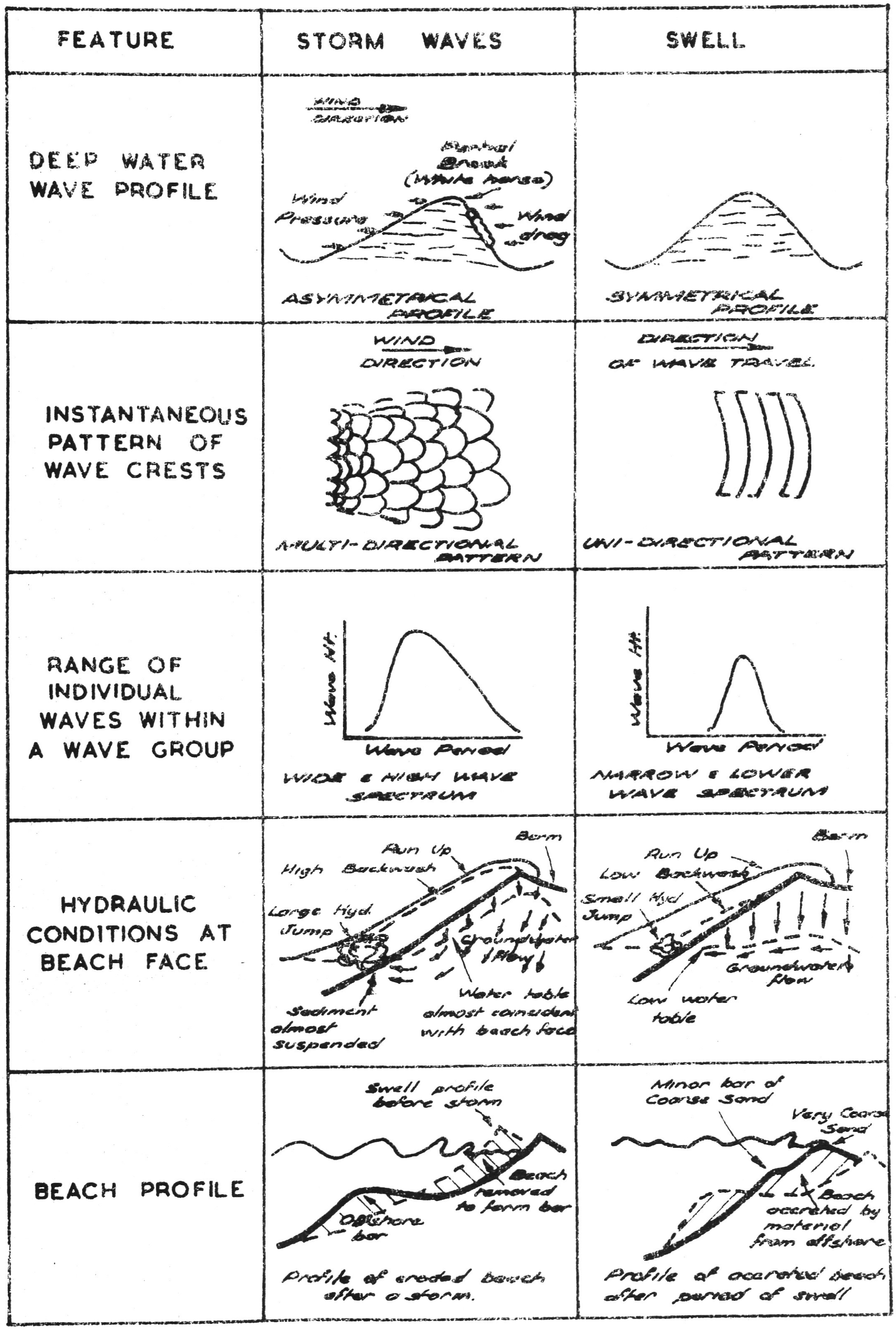
"Swell", on the other hand, is the term applied to waves arriving at a point a substantial distance from that part of the ocean where high winds are generating the waves. The higher velocity waves generated in the storm area soon outpace the slower waves and the small period disturbances previously existing are rapidly damped out. As a consequence these swell waves tend to have a much more regular profile and the variation in period between successive crests is much less than in the case of storm waves. Also the direction of approach towards the coast does not vary much. Swell waves may travel for thousands of miles, gradually increasing in period and diminishing in height with distance travelled, owing to the damping effect of the viscosity of the water. The steepness is generally less than 0. 03. The normal surfing conditions on Sydney beaches are predominantly due to swell waves. The effect on the beach is in direct contrast to that of storm waves. Instead of causing erosion, swell waves tend to promote the accretion or building up of the beach.

As a wave moves in shallow water of depth less than 1/ 20 of the deep water wave length, the height of the wave increases whilst the wave length is decreased. This causes an increase in the steepness of the wave and eventually a limiting value ($\frac{H}{L} = 0.14$) is reached at which the wave can no longer hold its form. After this point the water particles at the crest are travelling faster than in the body of the wave and breaking occurs. Broken waves approaching a shore at an angle carry a large amount of water forward and promote a littoral current flowing parallel to the shore.

FIGURE 3

COMPARISON BETWEEN STORM WAVES AND SWELL

(AFTER SILVESTER 1959)



In practice the strength of this current increases as the obliquity of approach of the wave to the shore increases.

If the longshore current moves against a barrier such as a downdrift headland or into a zone of reduced wave action, a rip current tends to be formed flowing away from the beach. This current tends to cause the waves in this area to steepen and break earlier than they otherwise would, helping to reduce wave action in the area and stabilize the rip.

The location and magnitude of these longshore and rip currents play a large part in determining the movement of material within the onshore zone.

3.24 Storm Profile.

The main features of a storm profile on a beach are shown in Fig. 3. Because of the wide period spectrum of storm waves, interference between the individual waves occurs frequently. The result is a confused break, with waves running up the beach at short intervals of time. Consequently the beach slope soon becomes saturated and percolation of the upwash is prevented. The volume of water running down the beach slope is almost equal to that running up. Because the water is running down the slope, the velocity of outflow is increased and the beach face is scoured. The large volume of water which is brought shoreward by the waves returns seawards by littoral and rip currents, transporting the eroded sand with it, until it reaches an area of less intense wave action and lower currents where it deposits its load as an offshore sandbar. As the sand is built up the point at which the waves break is moved offshore and the energy of the waves is dissipated before they reach the beach. Thus the best protection from beach erosion during a storm is an adequate beach capable of supplying enough material for the offshore bar. The presence of a sea wall too close to the water aggravates the erosion, as discussed in Section 5.31.

Material removed from the beach during a storm tends to be transported immediately offshore by rip currents Very little movement occurs alongshore, as the multiplicity of directions of travel of the waves generated within a storm centre is not conducive to the formation of strong littoral currents over long lengths of the beach.

3.25 Swell Profile.

The main features of a beach profile associated with swell are shown in Fig. 3. Unlike storm waves, swell tends to have a much narrower spectrum of wave periods, to be smaller in height and have a more undirectional approach to the beach. Because of the longer interval of time between breaking waves, the water table on the beach is much lower than is the case with storm waves, and portion of the uprush of water on the beach face seeps through the porous sand. As a result the volume of downwash is less than the uprush and velocities of down-wash are lower. Sand transported shorewards by the breaking waves is dropped on the beach face and accretion occurs. During this process the beach slope increases, and equilibrium between the wave forces moving material shoreward and the gravity forces tending to roll the material down the slope is reached.

Even under near-equilibrium conditions, however, material can be transported along the beach as a result of an action termed "beach drifting". (Fig. 4)

FIGURE 4.

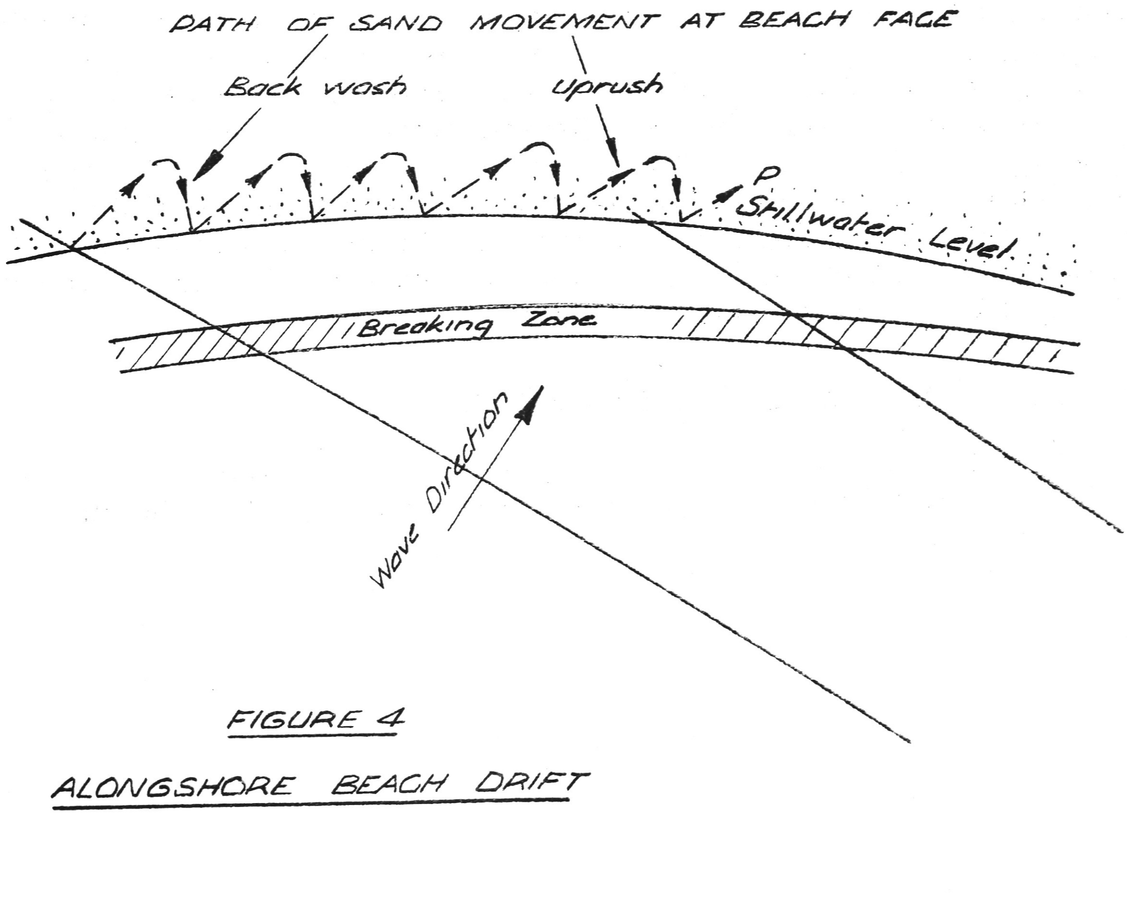


FIGURE 4

ALONGSHORE BEACH DRIFT

Waves breaking obliquely on the beach carry material in the upwash in the direction of the wave approach. The backwash, however, under the action of gravity tends to be along the line of steepest slope. Consequently, material transported by gravity in the backwash of the wave tends to move in a direction seawards at right angles to the line of beach. Sand is therefore seen to move along the beach in a zig-zag motion.

In addition to producing beach drift, the unidirectional wave approach of swell is conducive to the formation of a strong littoral current over long lengths of the beach. This current also helps to transport material brought onto the beach from offshore in the direction of the littoral drift.

3.26 Beach Cycles.

After a storm, material from the beach face is moved directly offshore in the form of a bar. Subsequent periods of swell return the material to the beach down drift of its original position. In Sydney the predominant swell arrives from the southern quarter and consequently the net movement of sand tends to be to the north. It is apparent that the sequences of storm and swell play a significant part in the movement of beach material alongshore. The greater the period of time between the storms the steeper the beach face tends to become, and erosion during the next storm is very severe. Subsequent storm waves tend to be dissipated on the offshore bar formed by the first storm, and further denudation is to a large degree prevented. It is again emphasized, therefore, that the most satisfactory defence against beach erosion is the provision of sufficient beach width to supply material for the formation of an offshore bar during the periods of storm.

3.3 Sand Movement in the Offshore Zone.

In deep water the motion of a water particle at any depth is circular, with orbital diameters decreasing exponentially from the surface (Figure 5.)

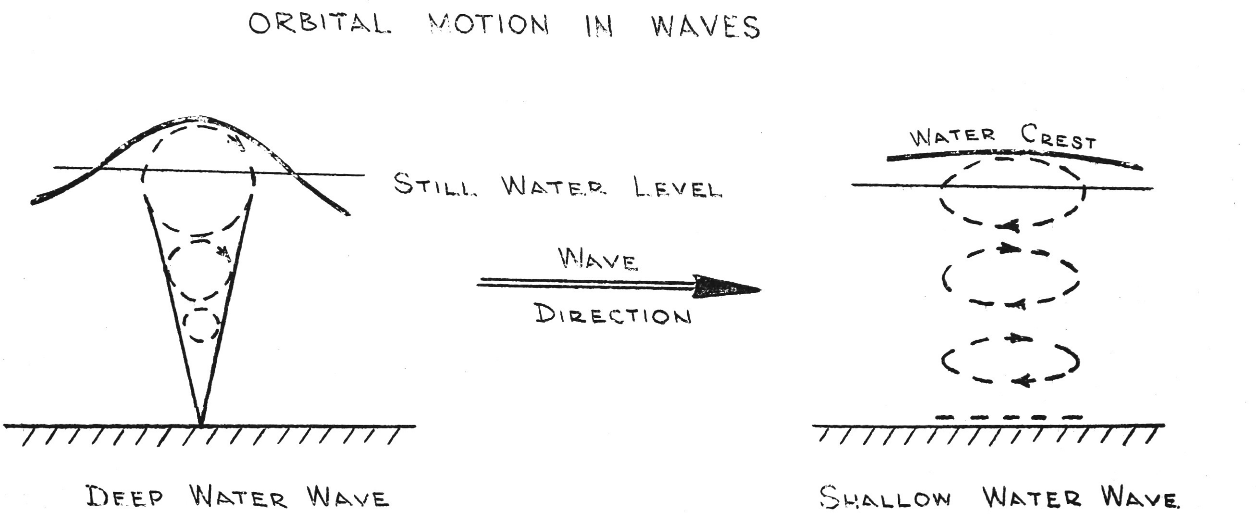
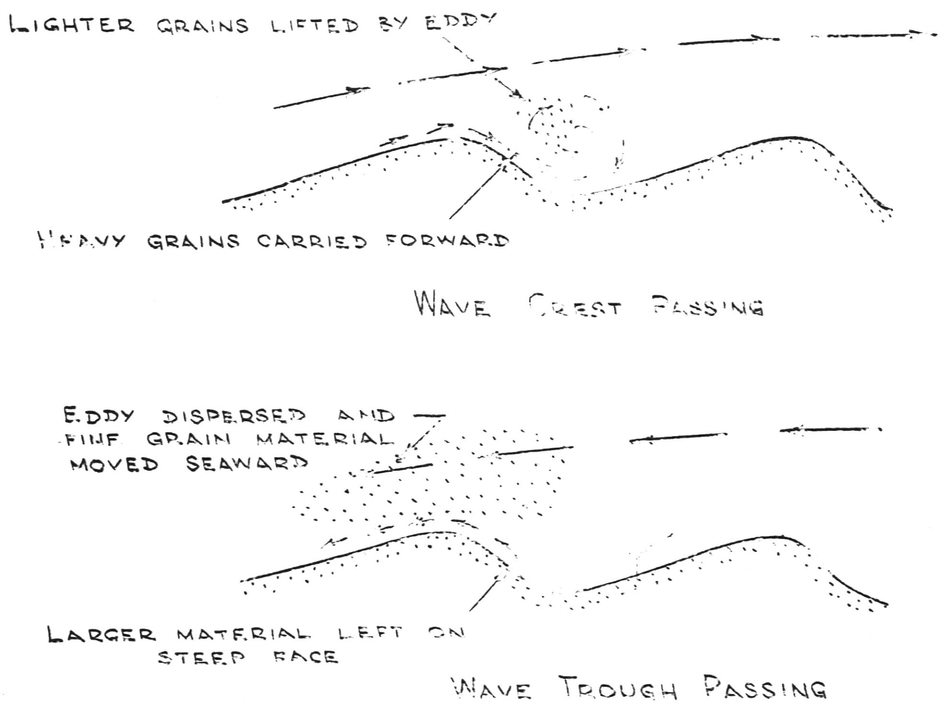


FIGURE 5.

As the wave proceeds into shallow water, bottom friction causes the water motion to change to an elliptical form (Figure 5) and an oscillatory velocity is induced at the bed. If this velocity is sufficiently high, the sand will be moved. The direction of this movement is governed to a large extent by two forces.

Firstly, as a wave moves into shallow water its crest length is shortened in relation to the length of its trough and consequently the water particles near the bed move forward under the wave crest at a higher velocity than in the backward movement under the trough. Thus coarse material tends to be transported shorewards by the higher velocity under the crest. When the bed slope becomes sufficiently steep, the tendency to forward movement of the sediment under wave action is counterbalanced by gravity down the slope and a state of equilibrium is reached. This results (Eagleson and Deen 1959) in a gradation of grain sizes in a direction at right angles to the shore, the size decreasing with distance offshore. If material is introduced of a size finer than that pertaining to a given depth, gravity effects will dominate and its movement will be offshore and vice versa for coarser material.

If the oscillatory velocity at the bed is somewhat greater than that which barely initiates motion of the sand on the bed, ripples commence to form on the bed (Figure 6).



MECHANISM OF SAND MOVEMENT OVER RIPPLES

FIGURE 6.

As the wave crest passes, the coarser sand fraction is transported as "bed load" and comes to rest on the lee side of the ripple travelling in the direction of the wave. The finer fraction, however, is taken into suspension by the vortex formed as a result of separation of the flow on the leeward side of the ripple. In this quazi-suspended state the material can be moved by any prevailing current occurring near the ocean bed and the direction of its net movement will depend upon the relative magnitudes and directions of these currents. Such currents may be the result of tides, wind stress, ocean circulation or wave induced.

3.4 Beach Stability

Considering the coast as a whole, beach stability depends on equilibrium being attained between material being brought into the area and that being transported away. The natural sources of beach material are supplied from streams and rivers, cliff and foreshore erosion and by wind action. This material is brought into the immediate beach segment by the processes described previously and will generally have a predominant direction of movement along the coast as a result of obliguity of wave approach to the area. Between any fixed boundaries, such as headlands, a beach tends to adjust its alignment in plan towards that necessary to maintain stability, and over a long period of time the average rate of sand drift into the area is balanced by that moving out. This overall stability pattern tends to be masked by the short term variations during which wave characteristics are continually changing. A seasonal variation is often particularly noticeable between the storm profile evident at the conclusion of winter storms and the swell profile at the conclusion of summer. Annual variations occur as a result of the variation of intensity of such storm and swell periods. For this reason, long periods of records are often required before a definite change in the stability pattern can be detected. Man made changes affecting the rates of supply or loss of material will result in a progressive change of the shoreline configuration until a new stability pattern is attained. As these changes may be masked by the short term variations, they may not be immediately obvious. It may take a long time to determine whether a structure is having a deleterious effect on a beach and by this time much damage may be done. For this reason, the probable effect of shore line structures should be thoroughly investigated before they are constructed.

4. COASTAL PROCESSES AFFECTING CRONULLA BEACH.

4. 0 Introduction

The main factors affecting coastal changes at Cronulla are:- (i) waves; (ii) tides; (iii) winds; (iv) ocean currents. Adequate data are not yet available to assess the magnitudes of the effects of tides, ocean circulation and winds, but the evidence so far collected indicates that waves and wave induced littoral currents play a major part.

In regard to tides, it is felt that the effect of tide induced currents is small, but tidal effects can be very significant when high tides and severe storms occur simultaneously, as severe erosion of the beach is likely under these conditions. At Cronulla large sand dunes are found shoreward of the beaches and wind drift occurs frequently, so that wind may have an appreciable effect on the overall beach changes. Ocean current effects are probably negligible. In the following sections the data at present available are assessed and the effect of each of these factors is discussed in greater detail.

4.1 Waves.

4.10 General.

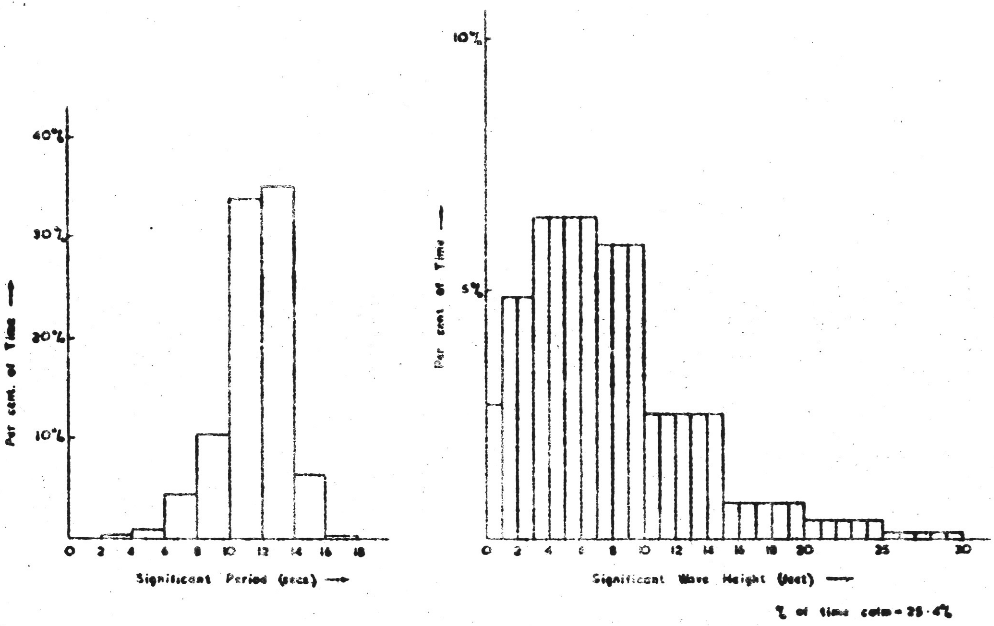
The Cronulla beaches are protected from storm waves and swell generated by large scale weather systems in the north east quarter. From these directions the main wave influence on the beach profile results from waves generated within Bate Bay during the summer months by the prevailing north-east "sea breeze". Because of the limited "fetch" (the area over which the wind blows) such waves do not often exceed 2 feet in height and 3 seconds in period. No information is available on the wind velocities and durations of sea breezes at Cronulla, so that their long term influence on the beach pattern is difficult to assess. Local information suggests, however, that during sustained periods of north-easterly weather, accretion occurs on the Cronulla beaches. This is probably due partially to a southerly littoral drift, since the steep, short period waves break at a sharp angle to the beach and induce a strong littoral current close inshore.

Storm waves or swell generated from the south-easterly quarter can approach directly into the problem area and it is these waves which produce the most obvious and sudden changes to the beach profile.

4.11 Frequency Analysis of Ocean Waves.

In order to estimate the effects of waves from the east, south-east and south, it is necessary to know their magnitude and the frequency of occurrence from different directions. No direct measurements of waves have been taken on the East Australian Coast and it is necessary to "hindcast" (estimate from past records) the wave characteristics from meteorological data. Several empirical methods for doing this have been suggested (Darbyshire, 1952; Bretschneider 1958, Pierson, Neumann and James, 1955), but none has been checked for Australian conditions. Using the S. M. B. method (Bretschneider, 1958), Foster and Stone (1962) have carried out a frequency analysis of deep water waves to be expected at Wybung Head some 50 miles to the north of Cronulla. It is considered that this analysis is reasonably representative of wave conditions to be expected in deep water off Cronulla and the results have been reproduced in this report.

To obtain data for the frequency analysis the weather patterns for the 5 year period 1951 to 1955 were studied with 6 hr. synoptic charts, and ocean waves off the N. S. W. coast associated with each distinct weather pattern were forecast. The waves so calculated were statistically analysed for heights and periods and yielded the data shown in Figs. 7 and 8.



(a) (b)

Figure 7: Histograms of Significant Wave Heights and Periods.

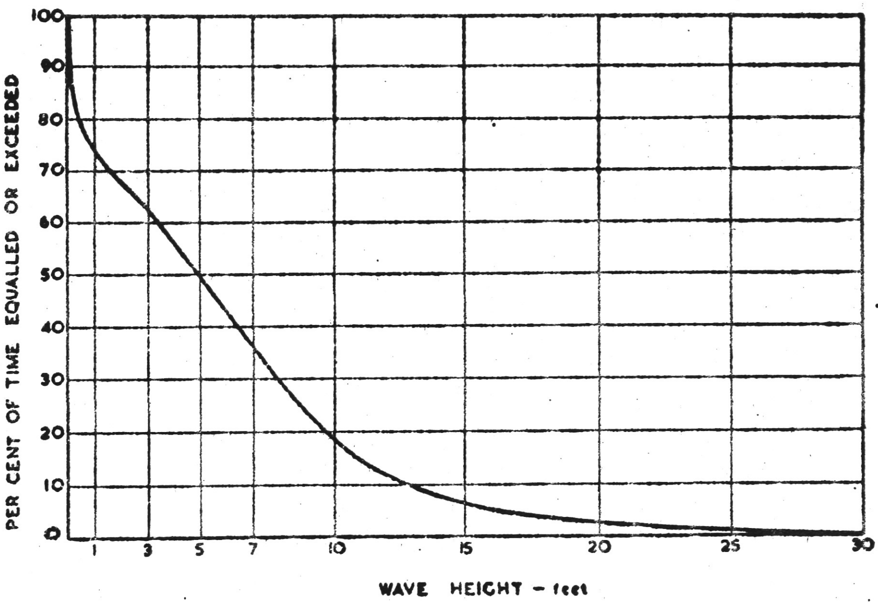


Figure 8: Cumulative Frequencies for Wave Heights.

The term "significant wave height" used in these forecast wave data indicates the mean height from trough to crest of the one-third highest waves, which is the height generally registered in the mind of an observer. The significant period is the period associated with the significant height and is very close to the mean period of all the waves in a train of waves. It can be seen that the waves normally lie in the range between 6 and 16 seconds in period and may reach up to 30 ft. in height. A period between 10 and 14 seconds is most common with about half the waves having periods shorter than 11 seconds and half longer. Most of the time the wave height lies between 1 ft. and 10 ft. with half the waves higher than 5 ft. and the other half lower.

A "rose" for wave height (see Fig. 9) has been drawn showing the percentage of time that waves of any height arrive from any direction. Some 25 pc. of the time calm was registered, meaning in this analysis an ocean wave of less than 1 ft. height. Of the remaining waves, half came from the south, the rest being divided mainly between east and south-east. Very little contribution came from the north-east. North-easterly waves from the ocean cannot reach Cronulla beaches in any case and may therefore be neglected.

It is emphasized that this analysis does not include the effect of the N.E. sea breezes prevailing in summer months, since not enough information is at present available to make quantitative predictions about their frequency and extent. Waves generated within Bate Bay by these breezes will usually have periods of about 2 or 3 seconds, corresponding to winds up to 30 m.p.h. The associated wave height is up to 2 feet.

4.12 Wave Refraction.

The above statistical analysis applies to ocean waves in deep water. However, ocean waves do not reach the beaches in their deep water form, for during shoaling the wave changes from an oscillatory wave to one of translation with alteration of many of its characteristics. One of the most important of these changes is that known as refraction. As a wave travels from deep into shallow water, the wave velocity is reduced as a result of the resistance of the bottom. Consequently, as a wave front approaches the coast at an angle, the wave velocity is reduced by varying amounts along the wave front causing the crest to bend or refract. From analysis of refraction it is possible to determine for an ocean wave with known period and height coming from any direction the characteristics of this wave when it reaches the shore. Knowing the characteristics of the waves as they approach the shoreline, an investigator can forecast the direction and magnitude of the littoral drift associated with the breaking waves.

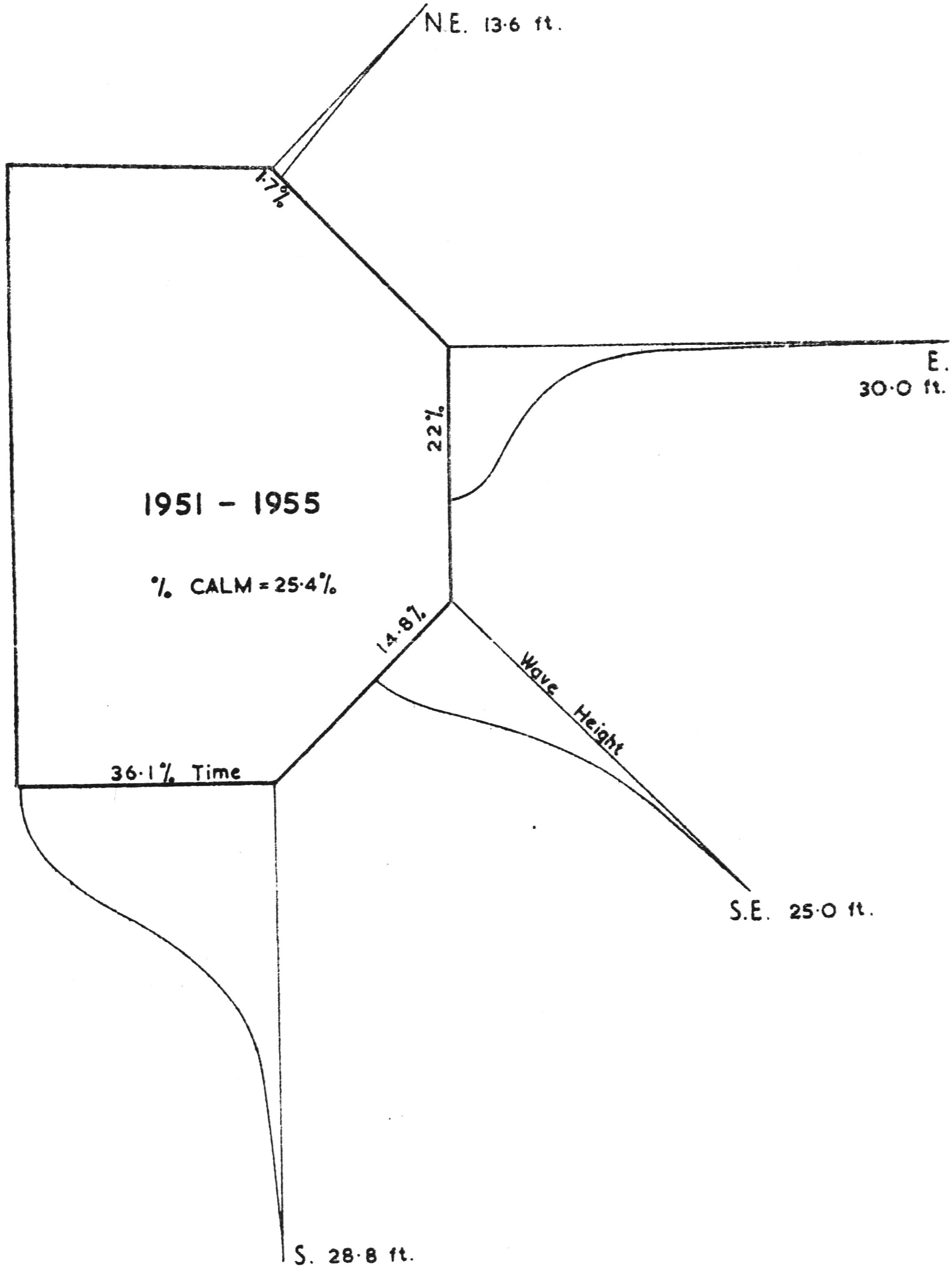


Figure 9: Annual Wave Rose

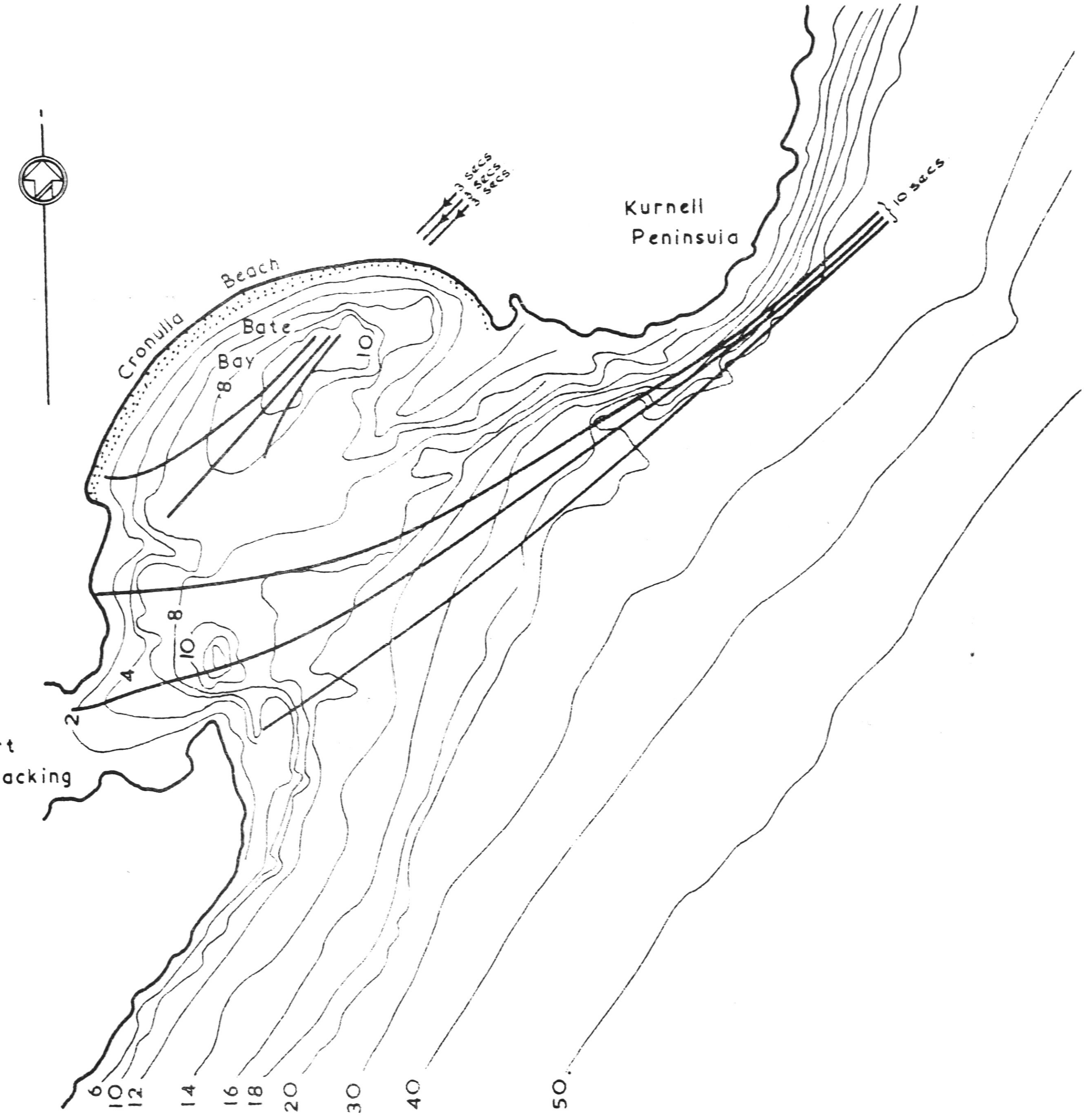


Figure 10: Refraction Diagram for Waves from North East

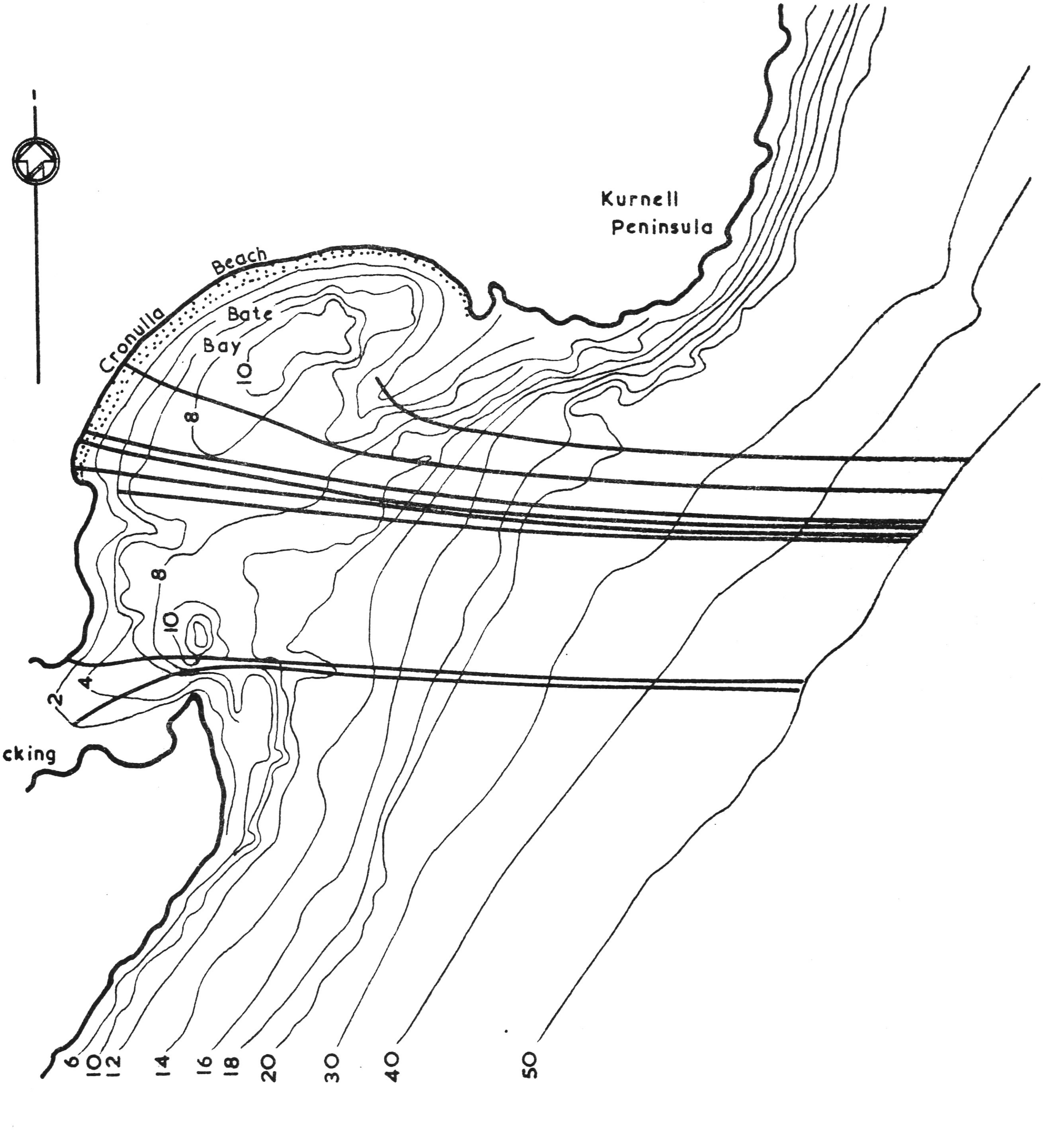


Figure 11: Refraction Diagram for 10 second Period Waves from East

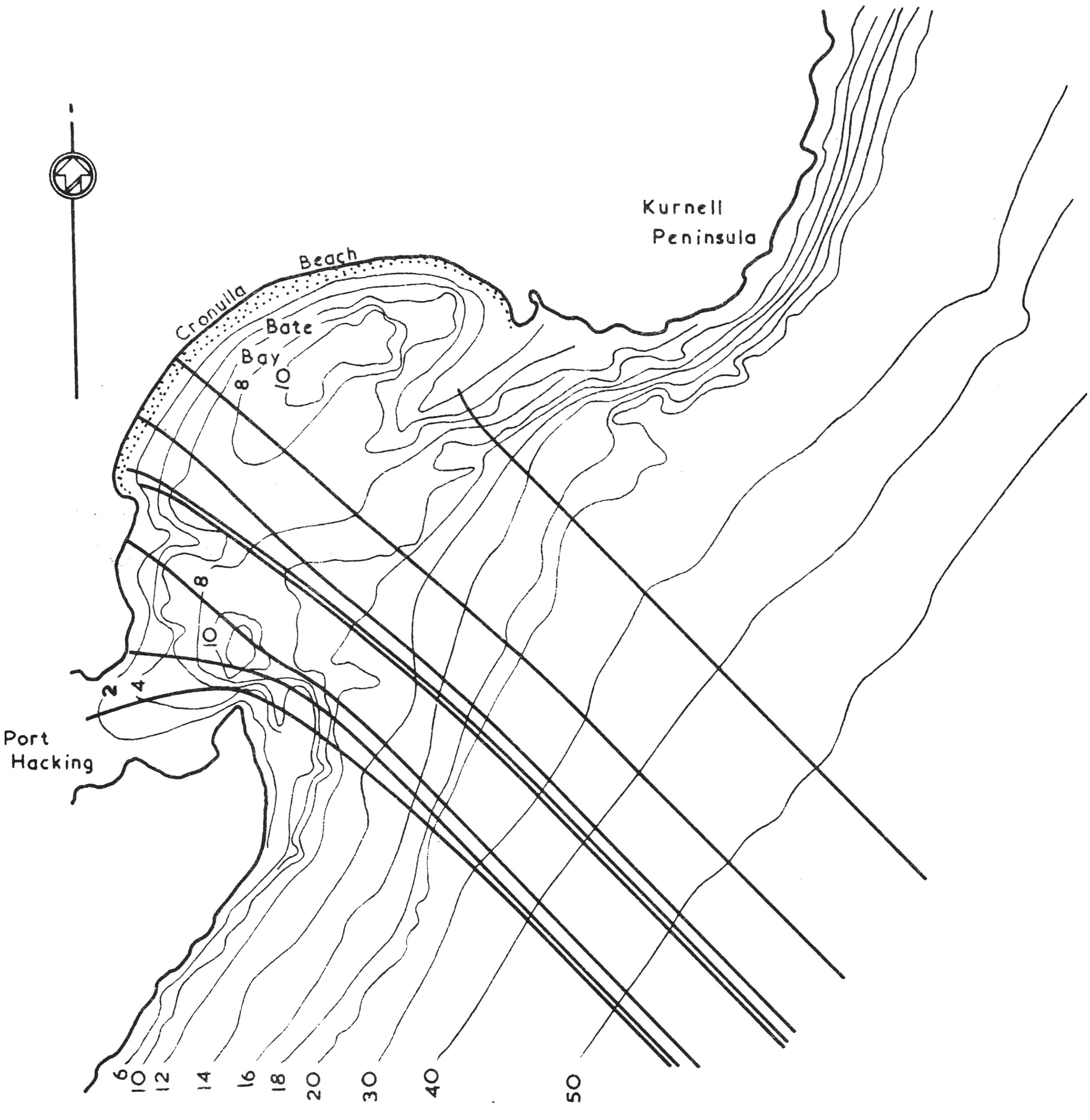


Figure 12: Refraction Diagram for 10 second Period Waves from South East

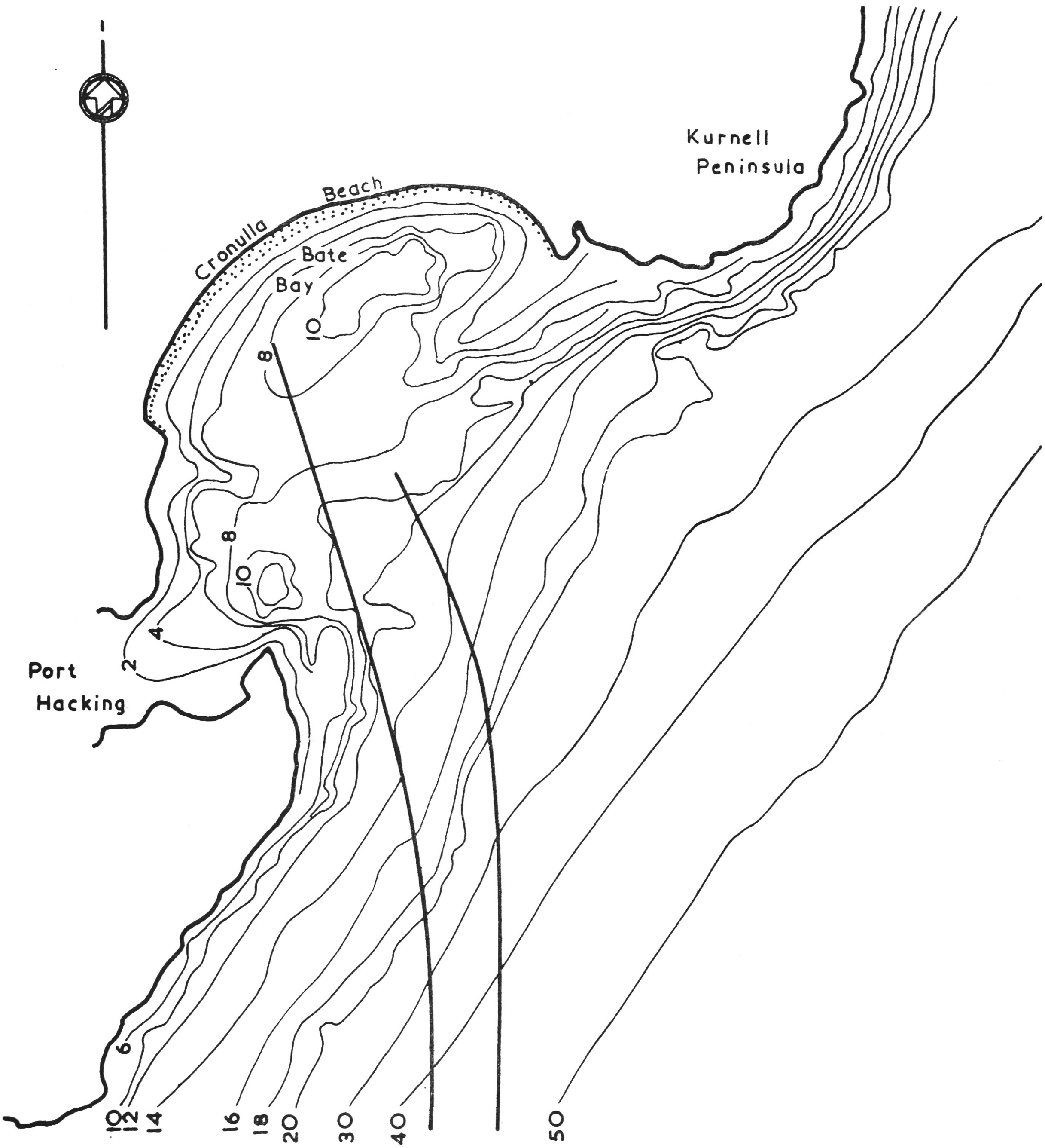


Figure 13: Refraction Diagram for 10 second Period Waves from South

Standard techniques (Arthur, Munk and Isaacs, 1952) have been developed for predicting the degree by which a wave from any direction will refract as it approaches the shore. These have been applied to waves approaching Cronulla Beach and the refraction patterns at low water ordinary spring tides obtained for waves from north-east through east to south are shown in Figures 10, 11, 12 and 13. For directions east to south, the diagrams have been drawn for a period of 10 seconds, this being a fairly representative ocean wave period. Refraction diagrams for waves in Bate Bay from north-east winds have been drawn for a wave period of 3 seconds, since this is the maximum period they can reach. With such short periods refraction is slight. Refraction diagrams can be used to compute the changes in wave height as the wave travels through shoaling water, the law being that the wave height is inversely proportional to the square root of the distance between any two given rays. A ray is the locus of the normals to the wave crest as the wave travels through shoaling water. To compute the magnitude of wave effects at the beach, the height of the refracted wave is required.

4.13 Wave Shoaling and Breaking

The changes in wave characteristics as a wave moves into shallow water of depth less than $\frac{1}{2}$ wave length are shown in Figure 14. As the wave moves into water of depth less than 1/ 20 of its deepwater wave length, the period remains the same but the height is increased and wave length decreased as a result of resistance from the bed. Eventually the waves become too steep to hold their form and breaking occurs. The shoaling of ocean waves has been investigated by Sverdrup and Munk (1946) and the conditions at breaking were obtained as

$$y_b = 1.28H_b$$

and

$$C_b = \left[g(y_b + H_b)\right]^{\frac{1}{2}}$$

where

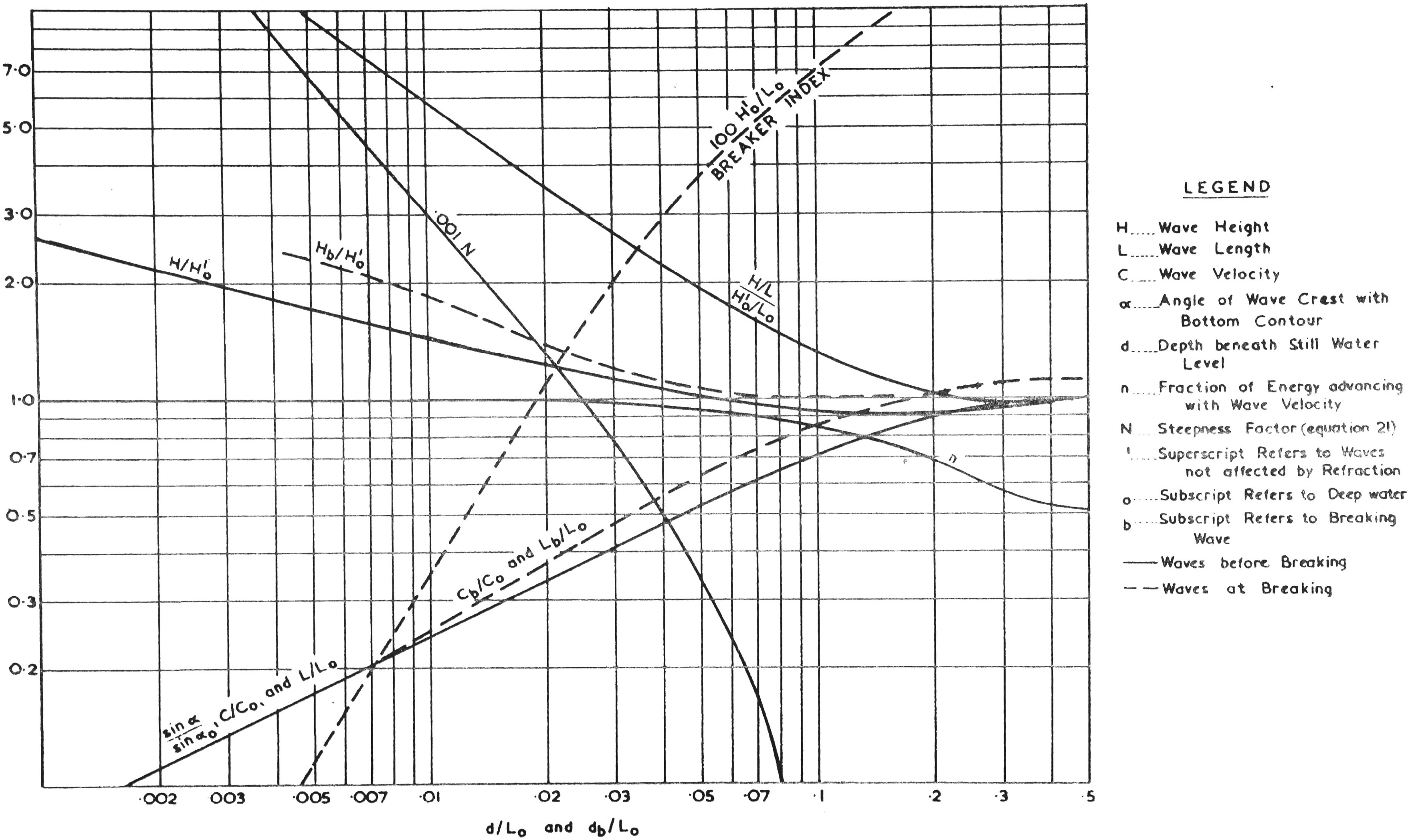
y_b = depth below still water level at point of breaking

H_b = height of breaking wave

C_b = wave celerity of breaking wave

g = gravitational acceleration.

Thus a 10 foot high wave would break in a water depth of 12.8 ft. and would travel shoreward with a velocity of 18.5 m.p.h.



CHANGE IN HEIGHT AND LENGTH FROM DEEP WATER TO POINT OF BREAKING

Figure 14: Shoaling Effects on Waves.

4.14 Littoral Drift

Broken waves approaching a shore at an angle carry a large amount of water forward producing longshore or littoral currents. Laboratory and field studies (Putnam, Munk and Traylor, 1949) have indicated that the strength of these currents can be approximately related to the wave characteristics by the formula

$$U_L = \frac{R}{2} \left(\sqrt{1 + 4 \frac{C}{R} \sin a_b} - 1 \right)$$

where U_L = velocity of the longshore current

a_b = angle between the shore and the breaker line

C = wave celerity

and $R = \dfrac{8A_b \cos a_b}{1 \text{ ft.}}$

where A_b = cross sectional area of the wave at the breaker line

$\doteq 2.31\, y_b^{3/2} H_b^{\frac{1}{2}}$ where y_b = depth at breaking

H_b = breaker height

l = distance from shore to the breaker line

f = friction factor ($\doteq 0.06$ for sand)

T = wave period

An analysis has been made of the intensity and direction of the littoral drift associated with computations for waves of 10 ft. height and 10 seconds period approaching Cronulla from directions east to south. The results are shown in Table I.

TABLE I.

Computed Wave Induced Littoral Drifts at Cronulla Beaches.

Beach / Wave Direction	South Cronulla	North Cronulla	Wanda
Waves from south	Protected	North	North - strong
Waves from south-east	North-1 ft/ sec.	North-1 ft. / sec.	Nil
Waves from east	North $1\frac{1}{2}$ ft/ sec.	South 2.5 ft/ sec.	South 2.5 ft/ sec.
Waves from north-east	South	South	South

To the accuracy obtainable in these calculations, littoral currents for waves of other heights and periods can be approximated by assuming that the current is independent of wave period and directly proportional to the wave height.

Some measurements of littoral currents have been taken at Cronulla and these are given in Appendix 1. In general these confirm qualitatively those given by the above computations but are too few to be conclusive. In addition it should be remembered that littoral currents can be affected by other factors such as the state of the tide and in particular the variations of wave height along the beach. Whenever a variation in wave height occurs, a current tends to be generated towards the protected area and may be in the opposite direction to the longshore component of the direction of wave approach. This could affect currents along South Cronulla Beach with waves from the south and S. S. E. as the beach is partially protected from weather from these directions.

Figure 9 indicates that excluding the effect of sea breezes 2/ 3 of all ocean waves approach from E. S. E. to S. and 1/ 3 from directions E. S. E. to N. N. E. From Table I it would appear then that the preponderance of littoral drift at the Cronulla beaches is to the north.

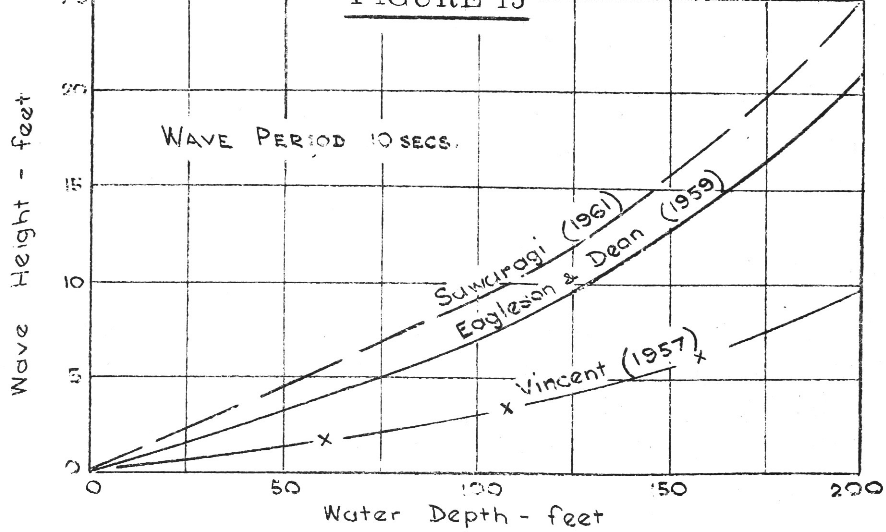
This conclusion is supported by the narrow width of the beach at the southern end as compared with the wide stable beach area to the north.

Savage (1959) has shown that the quantity of littoral drift can be estimated from wave conditions at breaking. From the frequency distribution of ocean waves, it would be possible therefore to estimate the net northerly drift from waves produced by the major weather systems. However, unless the frequency distribution of waves produced by sea breezes can be calculated, computations of this type would have little meaning. Although waves produced by sea breezes are relatively small and steep, they suffer little refraction and because they approach the beach at a sharp angle are capable of generating strong littoral currents. The fact that both North and South Cronulla beaches accrete after periods of sustained N.E. weather indicates that the littoral drift produced by these currents is appreciable. However, it is most unlikely that it outweighs the more frequent drift produced by the major weather systems.

4.15 Movement of Material in the Offshore Zone.

Typical size gradings of sands along the Cronulla beaches are given in Appendix C. These indicate a median grain size of approximately 0.4 mm. The wave conditions required to initiate movement of material of this size in the offshore region have been investigated by Eagleson and Dean (1959), Vincent (1957) and Sawaragi (1962). Application of the results of these investigations to Cronulla sands yields the curve shown in Figure 15, which shows the height of wave required to just initiate movement in various depths of water.

FIGURE 15



Depths at which sand 0.4 mm. dia will be moved by waves.

In these calculations a wave period of 10 seconds has been assumed and the effects of bed slope and wave reflection from the beach have been neglected. The curves do not coincide, which is probably due to a difference in definition of the point of initial grain movement used by the various authors. The maximum water depth within Bate Bay is 15 fathoms (90 ft.)and a 5 foot wave is equalled or exceeded for 50 per cent of the time, so that significant movement of bed material within Bate Bay by wave action can be expected. However, comparison of the hydrographic survey map of 1873 and 1961 shows little variation in the depth contours. This would indicate that no substantial net movement of the bed material has occurred over this period.

4.16 Movement of Material in the Inshore Zone

As discussed in Section 3, the beach profile is subject to rapid short term variations as a result of erosion during periods of storm, and accretion during periods of swell. For example, at Stockton Beach in N.S.W., the only beach for which measurements have been made, the beach has moved horizontally as much as 400 ft. During the heavy weather between 1940 and 1947 it was badly eroded, but has since built up to its previous level. According to Mehaute the change between erosion and accretion at the beach berm occurs quite suddenly at a wave steepness $(\frac{H_o}{L_o})$ of 0.03.

In order to study these changes at Cronulla, some measurements have been taken of the beach profile for various conditions of tide and weather. The Sutherland Council engineers assisted in this work by taking beach surveys at approximately weekly intervals and the records available from this survey have done a lot to clarify the historical picture of beach changes to be discussed in the next section, and show clearly the conditions when erosion and accretion occurs. However, further measurements would be required over a considerable period of time in order to determine the net rate of erosion of sand from the beaches. It is important, therefore, that this work should continue if possible.

Movements of the beach profiles are available for the period March to November 1962. (Sutherland Shire Council Plan No. 1043). The beach changes over this period have been correlated with tide and weather as shown in Table 2. Wind data used are that recorded at Sydney at 9 a.m. and 3 p.m. These winds are, of course, not responsible for the waves which cause the erosion at Cronulla. However, it would need a much more protracted study to investigate all the weather patterns responsible for the beach changes at Cronulla. Usually winds at Sydney bear a fairly good correlation with the winds causing the seas responsible for the erosion at

TABLE 2

Correlation Between Beach Profiles and Weather Conditions

PERIOD	PREDOMINANT WINDS SYDNEY		BEACH CHANGES		TIDAL DATA		
	DIRECTION	SPEED M.P.H.	SOUTH CRONULLA	NORTH CRONULLA	DATE	MOON	TIDAL RANGE
5·3·62 to 12·3·62	S.E.	6	Accretion ½ ft. to 1 ft.	Accretion ½ ft.	6·3·62	New	6 ft. 1 in.
12·3·62 to 19·3·62	S.W. to S.E.	10	Steepening	Accretion 1 ft. and steepening			
19·3·62 to 26·3·62	W. through S. to E.	10	Steep then flat berm	Steepening	21·3·62	Full	4 ft. 3 ins.
26·3·62 to 2·4·62	Var. and S.E	12	Accretion ½ ft; flat berm removed	Accretion and berm			
2·4·62 to 9·4·62	S.E.	15	Erosion ½ ft.	Erosion 2 ft. and flattening	5·4·62	New	5 ft. 8 ins.
9·4·62 to 16·4·62	Var. and S	12	Erosion ½ ft.	Erosion 3 ft.			
16·4·62 to 30·4·62	Var.	5	Accretion ½ ft.	Accretion 3 ft.	20·4·62	Full	3 ft. 11 ins.
30·4·62 to 7·5·62	W.	10	Steepening	Accretion 1 ft.	4·5·62	New	5 ft. 5 ins.
7·5·62 to 21·5·62	S. to W	14	Slight flattening	Slight steepening	20·5·62	Full	4 ft. 0 ins.
21·5·62 to 28·5·62	N.W.	10	Steepening	Slight steepening			
28·5·62 to 4·6·62	W.	10	Accretion ½ ft.	Accretion 1 ft. flattening	2·6·62	New	5 ft. 6 ins.
4·6·62 to 11·6·62	W.	12	Erosion ½ ft. and slight steepening	Steepening			
11·6·62 to 18·6·62	W.	5	Very slight flattening	Erosion ½ ft.	18·6·62	Full	5 ft. 3 ins.
18·6·62 to 2·7·62	W.	9	Accretion up to 3 ft. with flattening	Accretion ½ ft. flattening	2·7·62	New	5 ft. 3 ins.
2·7·62 to 27·8·62	W.	10	No change	Erosion 1 ft.			
27·8·62 to 4·10·62	W.	10	Accretion 2 ft.	Accretion 1 ft.			
4·10·62 to 22·10·62	W.	15	Erosion 1 ft.	No change	13·10·62	Full	5 ft. 8 ins.
22·10·62 to 5·11·62	N.W.	18	Erosion 2 ft.	Erosion 1 ft.	28·10·62	New	4 ft. 2 ins.

Cronulla, though they may be out of phase by a day or two. At the commencement of movements, the beach was somewhat lower than normal following on a heavy storm period combined with the high tide towards the end of February which produced considerable erosion over a period of several days. From Table 2 the following comments can be made:

(i) Since the records commenced, the rate of accretion has exceeded the rate of erosion. North Cronulla Beach has accreted in height a total of 2 ft and South Cronulla 1 foot.

(ii) The maximum accretion that has occurred at North Cronulla before a period of erosion is 4 ft. from 16. 4. 62 to 7. 5. 62. Winds during this period were light and variable. Over the same period South Cronulla accreted only ½ foot beaches.

(iii) The maximum depths of erosion that have occurred, before a period of accretion, are 5 ft. at North Cronulla and 1 foot at South Cronulla from 2. 4. 62 to 16. 4. 62. The winds at Sydney during this period were moderate and from the South to South East. The maximum weekly rate of erosion recorded was 3 ft. at North Cronulla and ½ ft. at South Cronulla.

(iv) Offshore winds promote accretion at both beaches; strong southerly seas tend to produce erosion. Accretion or erosion tends to occur simultaneously at both beaches although the rate of change differs. It can be seen that whereas North Cronulla is eroded badly by southerly conditions, southerly seas have much less chance of causing bad erosion at South Cronulla. Seas from the south east, however, have been observed to produce considerable erosion at both beaches (see Appendix 3 - inspection of Cronulla Beaches 18. 2. 62).

(v) North Cronulla, because of its greater exposure, has a much greater variation in beach profile between cycles of accretion and erosion than South Cronulla.

4.2 Tides.

4.21 Tidal Currents.

In the open ocean there are small rotary tidal currents. The magnitude and direction change continuously. For the Pacific Ocean with semi diurnal tides one complete rotation of current directions occurs about every twelve hours. Current speeds of about 0.05 knots have been measured off the west coast of the United States. Similar currents could be expected to exist in the ocean off Cronulla. It does not seem likely that these currents will have major effect on water movements near the beach.

Because Bate Bay is a semi-enclosed body of water, a tidal current is created in the bay. Classical tidal mechanics could possibly be applied to estimate the strength of this current. This would be a major study, impossible within the terms of reference of this preliminary investigation. For a more detailed investigation it may conceivably be warranted, but this is doubtful and would have to be assessed on the basis of the importance of such a current on the problem in hand and the applicability of the results of classical tidal mechanics to the area.

The main currents associated with tides generally occur in narrow bodies of water connecting larger water masses. A lake discharging to the ocean for example may induce a current of some 3 or 4 knots in the interconnecting channel. Tidal currents into and out of Botany Bay to the north of Cronulla and Port Hacking to the south could be expected to reach values of the order of one knot. It has been suggested that the tidal currents in and out of Botany Bay cause a change in the circulation of water off the east coast of the Kurnell Peninsula and therefore cause a change in the circulation within Bate Bay. This aspect has not been investigated quantitatively but it is thought by the present investigators to be minor compared with other forces influencing the local currents. A more serious effect could be caused by the tidal flows into and out of Port Hacking. In this connection it should be noted that in the ocean just outside an estuary the ebb and flood currents are not reversed vectors but differ in distribution because the ebb current issues as a jet with a very small spread, whereas the flood is drawn in from a much wider area. Water would come from near the Cronulla beaches to feed the flood current at Port Hacking, for example, but on the ebb the water would jet straight out to sea and might even form a back eddy near the beaches.

Thus the current near the beaches may be south both on the ebb and the flood. Whether these currents have sufficient strength to move material, or whether there are rips strong enough to feed material in suspension into these currents has not yet been ascertained. It is felt that such currents may have some significance, particularly near South Cronulla, though transient littoral drift currents may be substantially higher. As one moves further away from Port Hacking, of course, the tides have a much increased volume of water to draw from and the currents are reduced accordingly.

Another effect of tidal currents that requires further consideration is the shortening and steepening of the waves by currents running in the opposite direction to the waves, and the elongation and flattening of the waves by currents running in the same direction. Because of these effects, the location of the breaking zone is shifted, and the efficacy of the waves in moving material varies between the ebb and the flood. The differential effect in such an estuary as Port Hacking is fairly well established. On the flood the long waves can stir up material so that it can be drawn into the estuary. On the ebb the short waves may not have the power to reach material on the bottom or may break before reaching the inlet thus reducing their capacity to entrain material at depth. Thus, although ebb currents in the ocean are stronger than flood currents, the net material movement may be into the estuary. This would appear to be so at Port Hacking where dredging is frequently required to remove sand from the estuary.

4.22 Association of High Tide with Heavy Seas.

It has been observed that most of the severe erosion that has occurred at Cronulla has happened when storms have been associated with very high tides. This has been particularly so since man-made structures have existed in the area. A high tide associated with heavy weather must induce erosion of a degree greater than normal, since the destructive force of the waves is moved further up the beach. Added to this, when a barrier such as a seawall is located with insufficient beach area in front of it, the destructive forces of the waves are increased and erosion of the beach in front of the barrier is accelerated. The waves reflected from the wall produce a partial clapotis (standing wave) seaward of the wall. The bed velocities and turbulence are increased and a large quantity of sand is taken into suspension, thus expediting longshore movement by the prevailing littoral currents.

4.3 Currents.

In addition to the currents resulting from waves and tides, ocean currents due to other causes occur in the Cronulla area. These currents are rarely strong enough to initiate movement of the material themselves, but are capable of influencing the direction of drift of sediment taken into suspension by turbulence generated at the sea bed by wave action.

The most important of these currents are those associated with wind effects and the large scale oceanic circulation off the east coast of N.S.W. Wind blowing over the surface of the sea creates a drag at the surface producing a current which is transmitted by shear through the layers of water, often to considerable depth. As a result of the movement of water mass associated with these currents, secondary effects such as upwelling and sinking at the coast considerably complicate the overall pattern of movement. These factors are discussed in some detail by Foster and Stone (1962). The large scale ocean circulation off the east coast of N.S.W. has been described by Hamon (1961). An East Australian current normally flows to the south off Cronulla at speeds as high as 4 knots some 30 miles from the coast and might be expected to have a substantial influence on current magnitudes and directions within Bate Bay. With the general southerly set, a back eddy would tend to be formed within the bay, the strength of which would depend on the magnitude and inshore penetration of the southerly current.

Except for some measurements of littoral currents within the immediate beach zone, no nearshore measurements of current patterns and magnitudes have been taken. Because of the numerous causes of currents within Bate Bay, an extensive programme of measurements under various conditions of wind, sea and tide would be required and the data would have to be statistically analysed before definite conclusions could be postulated. This is beyond the scope of this investigation.

4. 4 Winds

Winds are responsible for large scale sand movements of the dunes forming the Kurnell Peninsula. Sand blowing from the ocean beach side across Captain Cook Drive has frequently made the road impassable, and much sand has been finding its way into Quibray Bay. The sanding up of Quibray Bay over the known period of Cronulla's history indicates a net sand movement to the west. This is confirmed by statements on old plans on which the sand dunes are described as "Range of sandhills constantly varying (slightly) in form and moving westward" (See Section 5). Several houses located on the dunes have been completely covered by sand and an underground sewer line which runs along the dunes has frequently been exposed. The predominant westward movement of sand would indicate that wind is a major factor influencing loss of material from the beach face and affecting the overall stability of the Cronulla beaches.

It has been suggested that the north-east weather conditions would cause similar large scale movement of sand from the sandhills north of Wanda towards the direction of North Cronulla Beach. This sand may form a source of supply to the beaches and could partially account for the accretion that occurs at North and South Cronulla under these conditions. During the summer of 1959-60 observers state that under continued strong north-east weather both baths between South and North Cronulla beaches filled with sand. This may have been caused by wind-blown sand assisted by littoral transport of material in the surf zone of the type described in Section 4. 14.

5. HISTORICAL REVIEW

5.1 Introduction

The cyclical processes of erosion and accretion of the beaches described in Section 4 have been going on for many hundreds of years. Whether the long term trend is accretion or denudation, or whether in the long run there is no change, can only be ascertained by reviewing the nature of the changes which have occurred over a fairly long period. This would be true even if the natural coastal processes described in Section 4 were the only agencies at work moulding the beaches. With the building of structures and alteration of topography imposed since the white man's advent, it becomes even more important, if causes are to be distinguished, to study closely the history of the area. Historical record at Cronulla is sadly lacking. Had Captain Phillip chosen Botany Bay as the first settlement in 1788, as suggested by Cook, we might now have 175 years of reasonable record. However, once Phillip had transferred his fleet to Port Jackson, the land to the south was neglected for nearly a century, except by a few who saw its commercial possibilities, and it was not until about 1900 that any sort of record of the Cronulla Beaches started to build up. No aboriginal legends have so far been found, to give any pre-history of the area. With beach cycles running into decades, some 60 years is not a long record, especially since there were only 20 years before the building of waterfront structures altered the naturally existing balance. From this time until 1940 there were man made alterations every few years. It seems that the beach did not have sufficient time between these changes to reach a state of equilibrium with its new surroundings. However, recently with no changes made for nearly 20 years, it seems that a new set of equilibrium conditions is becoming manifest and in spite of the shortness of the record, some inferences can be drawn regarding the causes of erosion.

The beach area at Cronulla was missed by the earliest explorers in Australia. Captain Cook's expedition produced some information about the Kurnell Peninsula and Botany Bay, including a drawing of trees at Kurnell. However, neither men from Cook's expedition nor the earliest settlers under Captain Phillip travelled as far across the Peninsula as Cronulla Beach. To the south, Port Hacking was named by Bass and Flinders in 1795; but although Bass and Flinders used Port Hacking and Botany Bay on more than one of their expeditions, they missed the area known as Bate Bay and no information is forthcoming from their journals. It was not until 1827 that Mr. Surveyor Dickson officially named Cronulla, the origin of the name being in some dispute. Whether it is an aboriginal word meaning a shellfish or an aboriginal version of the name Connell is not known. Connell was one of the earliest inhabitants of the area south of Botany Bay and records show that he was engaged in the shell gritting industry in Port Hacking about 1850. Connell never attempted any exploitation of the land to any extent. This was left to Holt, a settler who arrived in the district about 1840 to 1850 with the intention of developing the land. He is reputed to have cut much timber in the area to the north of Bate Bay though it is improbable that his activities extended to the area now used as a surfing beach.

Although white men were interested in the area for its commercial possibilities from a time quite soon after the settlement of Australia, nobody was sufficiently interested in the beaches to either write about them or survey them, and very little can be gleaned about the state of these beaches before the end of the 19th century. We therefore have less than 100 years of even vague historical information on which to base any idea of what has actually happened at Cronulla. Of this information, the only part that contains any degree of authenticity is that on the hydrographic charts or parish and other maps. Photographs can sometimes help elucidate problems of this nature but those available of Cronulla from about 1900 onwards, though numerous, are so badly documented as to exact time of day and state of tide, and even sometimes to the date itself, that many of them are misleading. Land sale documents are useful where they are available but do not cover any appreciable part of the area under study. In all historical surveys of this nature, verbal information depends on the memory of people who have known the area many years since, and is frequently grossly incorrect. Investigators seeking flood levels only 20 years after a flood, have received reports which would place the flood height as far apart as 20 feet from different residents of the same district. Remembered "facts" about beach levels seem to be just as divergent. A classic example found during the investigation of the erosion of Cronulla Beach referred to the rocks between South Cronulla Beach and the northern beaches. According to many respected and longtime residents of the Cronulla area, these rocks "used to be always covered with sand", but both hydrographic and land maps prior to 1900 and photographs since, would indicate that at most times a similar amount of rock was visible above the beach in this area as has generally been the case during the last few years.

The only reliable way to trace the changes which have occurred on a beach, and to identify the causes, is to make periodical surveys and measurements over a reasonably long period, with the surveys tied into an existing survey network. Such surveys are not available for Cronulla, nor probably for any beach in Australia. Authorities concerned about the future of a beach should put such systematic surveys in hand at once. Some recent beach surveys have been made at Cronulla, and are described and discussed later in this report.

In spite of the shortness of available historical records, some inferences can be drawn regarding the causes of erosion at Cronulla. In the following sections a chronological account of the known beach history is given and some factors, which seem to have had an effect on the beach, are discussed. Table No. III summarises the chronological history.

5. 2 Maps, Plans and Charts

5. 21 Hydrographic Plans

The British Admiralty hydrographic chart of 1873 is the earliest available information regarding the state of the sea bottom beyond the beaches. This chart has been compared with the Australian Navigation Chart of 1961 and no appreciable difference has been found in the area that has been sounded. It should be noted that the soundings are in fathoms generally, and sometimes in fathoms and feet, and are not so detailed that minor changes would be revealed. A small change in depth over such an area as Bate Bay could represent a considerable depth of sand when placed on the narrow beach surrounding the Bay. These hydrographic charts also show soundings in Port Hacking up to Burrameer Point. Immediatelysouth of Burrameer Point some changes in the shape of sand areas are noticeable, but beyond about one fathom very little change seems to have occurred. Unfortunately, the soundings of 1873 do not cover the immediate problem area near South and North Cronulla beaches. The reason why this area is undocumented is not known, but it can fairly be assumed that beyond some small depth no major change would have occurred on the sea bed in this area.

Hydrographic charts also indicate the sanding of Quibray Bay, an arm of Botany Bay. This is presumed to have been caused by the sandhills moving westward from the ocean side of the peninsula.

5. 22 Land Maps

Though some plans exist of the years 1815-1840, these reveal very little about the state of Cronulla Beach. In 1884 the area was carefully surveyed and the map of this date shows many interesting features. Substantial rock outcropping is shown between South and North Cronulla Beaches.

TABLE III.

CRONULLA HISTORICAL REFERENCES

SOME DATES.

1827	Surveyor Dixon named Cronulla Beach
1840	Wells map of New South Wales shows "Kurranulla" Beach
1856	Connell recorded as gathering shell in Port Hacking.
1873	Admiralty Chart 2179 showing soundings.
1884	Map showing sand dunes and other features P256 old roll C76-2063.
1905	Earliest photographs
1914	Land sale documents with photographs.
1919	Rickard reclaimed swamp with sand from dunes to the east to make Dunningham Park.
1924	Stepped seawall built at South Cronulla. Aerial and other photographs in "Watch Cronulla Grow".
1930	Photographs of beaches.
1931	Northern baths built; also southern part of North Cronulla sea-wall.
1935	South Cronulla Surf Life Saving Club completed.
1935	Tourist map showing Green Hills.
1937	Resumption of land seaward of Prince Street because of cliff erosion.
1939	North Cronulla sea-wall completed.
1941	Southern baths built.
1942	Storm damage at North Cronulla.
1946	Major storm damage at North Cronulla - Surf Life Saving Club moved.
1949	Earliest Lands Office aerial photographs.
1950	Storm damage South Cronulla sea-wall.
1959-1960	Baths filled with sand during summer.

and the following informative notes have been written on the map by the surveyors who compiled it:

(a) "The position of the high water mark at Cronulla Beach is ever varying. After storms the change is considerable, amounting in many places to 100 and even 150 links". Thus the effect of storms on the beach was manifest before the building of structures began.

(b) A note covering the area north of North Cronulla Beach: "Range of sandhills constantly varying (slightly) in form and moving westward. The change after a southeast gale is very noticeable".

(c) Note behind sandhills north of North Cronulla Beach: "Large timber dead". This reinforces the idea that some substantial trees had been cut in the area prior to 1884.

(d) Note located behind the present position of Wanda Surf Club. "Line pegged and marked by stakes. No trees, being loose sandhills".

(e) General Note: "Some sandhills fixed by vegetation. Others loose sand and subjected to extraordinary changes from south-east gales."

Subsequent parish maps are not sufficiently detailed in the beach area to indicate the amount of erosion. Maps around the turn of the century show mining leases for shell grit both north of Boat Harbour and in Port Hacking from the ocean to past Burraneer Bay.

5.23 Photographs and Documents.

At a beach with a 6 ft. spring tide and a slope of about 1 in 50, as is usual on the east coast of Australia, two photographs taken only 6 hrs. apart could reveal a difference in beach widths of 300 ft. Therefore photographs for which the state of the tide is not known can be very misleading for assessing beach changes. Furthermore, if the photograph has been taken after a period of unusual erosion or accretion, which, at Cronulla may quite frequently make a difference of 4 ft. from normal beach levels, it is seen that the width of the beach could be increased or reduced by about the same amount again. If it could be assumed that erosion was normal in winter and accretion in summer and the beach was not subject to sudden storm changes, this factor could be approximately allowed for. As far as Cronulla is concerned, sudden storm changes have an overwhelming influence on the erosion of the beach. Furthermore, as has been evidenced in 1962, accretion may quite easily be the winter phenomenon and erosion occur in the summer. With the correlation that has been established between weather conditions and beach erosion and accretion at Cronulla, an investigation of the weather conditions during several months prior to the date of any photograph could yield an indication of the relationship of the beach levels to the normal beach levels prevailing during that era. Such detail could not be undertaken for a general preliminary study such as this.

Photographs taken on the land are subject to distortion in distances depending on the angle at which the photographs are taken, and it is almost impossible with the manmade changes that have occurred at Cronulla to relate many of the old photographs to present positions precisely enough to take measurements from these photographs. Since photographs give the only reliable record (apart from a few documents) over the greater part of Cronulla's history, it is on these, in spite of their limitations, that we must largely base our estimate of what has occurred in the past. The first available photographs were taken in 1905 and these show low dunes covered with grass, behind South Cronulla Beach, and grassed high dunes behind North Cronulla. Landward of Wanda Beach area, the dunes are not grassed - (See Plate 5). It is interesting to note that from one of these photographs, more rocks are visible between North Cronulla and South Cronulla Beaches than there are to-day. Behind these rocks there is no sand as there is to-day - only cliffs with trees.

The next 20 years were a boom period for Cronulla. This was the era during which the steam trains ran to Cronulla beginning in 1911, making it a readily available beach for the new sport of surfing that had become popular since 1900. Photographs taken about 1914 show bathing boxes on the beach at South Cronulla. About 1924, towards the end of this rapid expansion period in Cronulla, land sale posters show lots on the ocean side of Prince Street with a depth of about 140 ft. Seaward of these lots there is a public reserve. No measurements are on the land sale poster but the reserve seems to be about 100 ft. wide, which would be normal, as this is the foreshore reserve on many Australian coast beaches. Beyond this reserve there is a beach shown diagrammatically as about 100 ft. wide, although this dimension could be misleading.

About the same time, the growing prosperity of the Cronulla area warranted the publication of a pamphlet entitled "Watch Cronulla Grow" which contained a photograph taken from an aeroplane. Aerial photographs are much better for comparing features than photographs taken from a point on the ground even when the aerial photographs are not

South Cronulla Beach 1905.

(By courtesy N. S. W. Govt. Printer)

verticals. The aerial photograph of the Cronulla Peninsula included in this pamphlet shows an expanse of rock between South and North Cronulla Beaches with some sand behind it in front of the cliffs. There is also in this pamphlet a photograph of the new sea wall which had been built at South Cronulla. The number of steps showing above the sand level in this photograph may be compared with the number of steps showing on photographs taken in recent years.

There is also available a photograph taken about 1921 abstracted from an old railway timetable showing a wide stretch of sand between South and North Cronulla and there are no rocks visible. It would seem that some time between 1905 and 1921 there was accretion on the beach either from wave action or from windblown sands under heavy northeast weather conditions which covered the rocks entirely at the time when the photograph was taken, but by 1924 when the first known aerial photographs of Cronulla were flown these rocks were completely exposed once again. At this time a history of the Sutherland Shire was written by Cridland (1924). The fast growing period of the Cronulla Beach area ended about this time as the most desirable land close to transport had been taken up.

The next photographs are of the years 1930 and 1937. The photographs of 1930 show a beach similar to that of the earlier photographs, but by 1937 it would appear that the width of the South Cronulla Beach had decreased. This photographic estimate, of course, is liable to error on the grounds mentioned previously, such as different states of the tide. During this period a concrete swimming bath had been built between North Cronulla and South Cronulla. This occurred in 1931. The southern 70 ft. of the North Cronulla sea wall had also been built in 1922. At South Cronulla, the surf life saving club was completed in 1935. By 1936 440 ft. of stepped wall had been added to the 70 ft. of wall built at North Cronulla.

By 1937 many of the lots seaward of Prince Street had been reduced in depth from their original 140 ft. (as shown in 1924), as the cliffs had eroded, and this land was resumed by the Council on account of the fact that it could no longer be used for building. Seaward of Prince Street there is now not enough land remaining for even a reasonable foreshore reserve where once there were blocks some 140 ft. deep as well as the foreshore reserve. It would seem that a good percentage of the cliff erosion responsible for this state of affairs occurred between the years 1924 and 1937, and if this erosion was occurring about the same time as that of the beaches it could be that the period 1930 to 1937 accounted for most of the erosion. More documentation would be needed to confirm this.

During 1938 the main wall, 1000 ft. long, north of the 500 ft. of stepped wall at North Cronulla, was commenced by relief work. By 1941 the baths that had been built in 1930 were considered dangerous and another set of baths was built further south.

From 1942 onwards large storm waves were alreach reaching the sea walls both at North Cronulla and South Cronulla; and this fact, (combined with military activities in the area, in which some parts of the construction were removed so that gunsights could be built), caused these walls to become unstable with water penetrating behind them. In 1942, substantial storm damage to the North Cronulla wall was noted, and in 1946 a combination of a very high tide and strong seas caused major disaster at both North and South Cronulla, as well as many other parts of the East Coast of Australia. This was following a few years in which there had been a noticeable absence of north-easterly weather such as tends to build the beach. The combination of a very high tide with heavy seas is a chance occurrence for which there is a rather low probability, and the combination of these circumstances with a state of affairs whereby the beach has already been much reduced in level could not be expected to occur frequently.

Photographs have been taken at regular intervals by the Department of Public Works between 1946 and 1950. Another combination of high tide and heavy seas caused damage to the South Cronulla sea wall in 1950. From 1949 onwards there are available, at some years intervals, aerial photographs of Cronulla Beaches. Between 1949 and 1962 the erosion of Cronulla beaches has not been noticeable, nor has the beach accreted to the level which probably existed before the bad erosion period between 1930 and 1950.

Although the interpretation of these photographs is subjective, an indication of the behaviour of the beaches can be obtained, which is, in the absence of sufficient plans, maps and surveys, the best that can be done. A more intense investigation of these photographs, including measurements where possible and research into old files to attempt to associate with each photograph the time of day, state of tide and even in some instances, time of year the photographs were taken, would yield a more reliable and significant picture.

5.3 Factors Affecting Beach Changes at Cronulla.

5.31 Sea Walls.

Sea walls were built at South Cronulla in 1924 and at North Cronulla between the years 1932 and 1939, as described in detail in Section 5.23 above. These walls protected the land behind the beaches from the onslaught of the sea. However, such walls have a deleterious effect on the beaches themselves when they are so located that it is possible for the waves to reach the walls, as, for example, when a heavy sea is running at a time of high tide. When this occurs, waves will be reflected from the walls, creating "standing waves" seaward of the walls. Water particle movements are accelerated and a greater quantity of sand is taken into suspension from the bed and removed from the immediate location at relatively rapid rates by the littoral currents. This increases the loss of sand from the area, causing erosion of the beach and possibly under-mining the sea-walls themselves. This danger was apparently not appreciated by the authorities who constructed the sea walls at Cronulla, because, in 1942 and 1946 heavy seas combined with high tides caused the destruction of the wall at North Cronulla and portions of that at South Cronulla. In 1950 further storm destruction was caused at South Cronulla. This may not have been due entirely to an incorrect location of the walls, as the operations of the Armed Services during World War II involved the building of certain structures which may have affected the stability of the walls.

Another effect of sea wall construction is to reduce the sand storage available for natural supply of sand to the off-shore bars during storm action, because the sand behind the sea wall is not available for supply

5.32 Swimming Baths.

In 1932 a concrete enclosure was built on the rocky outcrop between North Cronulla and South Cronulla beach, the walls being of relatively low height. At both low and high tides the larger storm waves break seaward of these baths and their energy is dissipated before reaching them. For this reason the effect of the baths on wave action is likely to be small. It is possible that the baths might act as a groyne influencing, to some extent, the normal littoral drift along the beach. The baths might also have aggravated the effect of the natural rip on the northern side of the rocky outcrop. To ascertain whether these effects are of importance in the behaviour of the beach would require more detailed investigation.

In 1941 new baths were built on the rocky outcrop midway between the old baths and South Cronulla beach. These new baths consisted of concrete walls enclosing a swimming enclosure, and the tops of these walls are considerably higher than those of the old baths. At low tide the larger storm waves break seaward of the wall of the baths, but at high tide no breaking occurs and the waves are practically totally reflected from the wall and standing waves are produced seaward of the baths. For the reasons discussed in Section 5.31 above, this leads to the taking up into suspension of considerable volumes of sand and consequently accelerated erosion. Members of Cronulla Surf Club have stated that there has been a considerable deepening of the bed in this area since the construction of these baths. However, measurements would be required to confirm this.

When man-made structures such as these baths are introduced to a beach which is in a state of equilibrium, it may take several years for the beach to adjust itself to a new state of balance. Local information establishes clearly that whatever erosion has occurred at Cronulla was occurring at its fastest rate between the years 1930 and 1950. It might be argued that this relatively rapid erosion was caused by the construction of the baths. On the other hand, however, it is known that between the years 1940 and 1946 weather conditions all along the eastern seaboard of Australia were abnormally severe. In this period many seaboard roads were washed away between Gladstone in Queensland, and Eden in the south of New South Wales. Had the weather during these years been normal, one might conclude that the building of the baths at Cronulla was responsible for any damage that occurred to the beaches. However, in this case we have a combination of interference with nature, and increased natural erosion during this period, and it is impossible to state how much of the change is due to the natural phenomenon of abnormal weather conditions and how much was due to man's interference with nature.

5.33 Shell Grit Mining.

In Parish maps around 1900, shell grit mining is indicated north of Boat Harbour, and on Port Hacking. Whether the beaches themselves were being denuded of shell grit as early as this cannot be definitely determined. However, many maps and photographs of subsequent dates indicate removal of the shell grit fraction along the entire beach. From observations of photographs and discussion with residents of the district, it would seem that during the period 1900-1950 the rate of removal of shell grit might well have been of the order of 10 cubic yards per day. This would indicate a decrease in beach height of about 1 yard, and assuming a 2 per cent slope on the beach this would mean that the width of the beach would be decreased by 50 yards. Removal of the shell grit fraction could, moreover, change the grading of the beach material and therefore alter such factors as the beach slope and curvature.

Though it would seem improbable at first sight that enough material could be removed from the beach by this method to decrease to any extent the available sand, the above estimates show that when carried on for a sufficient period of time, this type of removal of material could be responsible for a substantial amount of loss on the beach. There is also a theory that people leaving the surf may be carrying away on their legs and bodies sufficient sand to substantially affect the available supply. No estimate of the quantity of removal by this means has been made, but perhaps it could be a factor to be considered and investigated. Some sand would be carried away by stormwater drains. It would depend upon the location of the outfall whether this material were in fact being made available again for the beach.

5.34 Dune Stabilisation and Denudation.

The dunes behind the beaches, especially the frontal dune, are the natural source of sand for the building up of off-shore bars during periods of storm, and thus providing natural protection to the beach. If these dunes are built upon or in some other way stabilised, this supply of sand is not available. This state of affairs exists only at the southern end of the Cronulla beaches.

The major portion of the sand dunes behind Cronulla beach have not yet been built upon. The effect of onshore winds will be to remove sand from the bed and on to or across the dunes. However, this effect is partially counter-balanced by offshore winds bringing the sand back to the beach. Possibly changes in the vegetation and general lowering of the sand dunes and abstraction of sand from sand pits may have affected this balance. The net effect of these factors cannot be estimated.

5.35 Sand Pits.

Much of the sand used for commercial purposes in Sydney and environs is obtained from the sand hills of the Kurnell peninsula. A major source of supply is from a pit located immediately north of Wanda beach as shown on Figure I. It is understood that this excavation is continually supplied with fresh sand by wind drift along the beach. Under natural conditions this wind drift may possibly have served to replenish sand on the South Cronulla beaches during periods of north easterly weather.

5.36 Sea Level Rise

Throughout the world the sea level is rising at a rate which taken over thousands of years is quite small. This rise is, however, irregular in space and time. During the last half century measurements in many areas of North America (Brunn 1962) have shown a very fast rate of rise as compared with the average. Between the years 1930 and 1950, a rise of 0.5 feet was recorded at several stations along the Florida coast, and this has been suggested as a cause of beach erosion over this period. Such a rise would cause a decrease in beach width of 25 feet for a beach slope of 2 per cent. This, however, would not be the only effect of sea level rise. An even more important effect would be the shifting of the active wave zone with respect to the rocky shoreline in cases where the rate of cliff erosion was not compatible with the rate of rise of sea level. Because of this shift of the active zone, the current pattern could be substantially altered. Whether such a natural phenomenon has occurred at Cronulla is unknown.

5.4 Historical Indications of Erosion.

The study of the history of the Cronulla area has yielded the following indications of beach erosion.

5.41 Short Term Erosion.

Sudden and violent changes during storms have been shown to be a feature of the Cronulla erosion picture. Accretion usually follows such erosion and short term fluctuations in beach width and level occur frequently.

5.42 Long Term Erosion.

Since 1905 there has been some movement of sand back and forth on North and South Cronulla beaches. From the evidence available this would appear to be no greater than what could be caused by the natural semi-cyclic beach changes. It can not therefore be stated categorically that man's interference has aided erosion, although many of the things that have been done certainly would not have helped. Sea walls have been constructed at South and North Cronulla beaches; baths built on the rocky outcrop between the two beaches, shell grit mined from the beach face, frontal dunes denuded of their vegetation and the sand drift to the south under north-easterly weather interfered with. All these factors would tend to affect the overall beach stability to some extent. If these factors have increased erosion, the rate can not at the moment be ascertained.

Some reported local changes such as the removal of sand from immediately seaward of the southern baths, and the steepening of the beach slope at the southern extremity of North Cronulla beach may be explained by observed effects of man made structures on wave and wind conditions at these localities. However, more exact evidence would be required to confirm that such changes have in actual fact occurred and are not a part of the natural semi-cyclic beach changes

The lack of exact survey data has limited the conclusions that can be obtained from a historical study. Recent measurements of beach profiles by the Sutherland Shire Council are the only exact data available, but these cover too short a period to indicate any long term changes. For these reasons it would be most desirable to continue such surveys in the future at periodic intervals.

6. POSSIBLE METHODS FOR WIDENING THE BEACH AT CRONULLA.

6.0 Introduction.

The methods in use for preventing erosion or restoring eroded beaches or widening beaches may be grouped into two categories - structural and beach nourishing. This division, though made on the basis of the means used for achieving the required result, is not entirely unrelated to the type of problem to be solved. In general, structural methods are most useful for beaches where there is a strong drift, structures generally being used to retain the sand and/ or to direct the flow of material along the beach. Beach nourishing, on the other hand, can best be carried out where there is not a very powerful drift; because if the drift is very strong the only type of nourishment that will achieve a wide enough beach for any length of time is a continuous supply, which is not often available at a reasonable cost.

Some methods by which beaches can be widened cannot be applied to the problem at Cronulla. Such methods include offshore breakwaters such as have been used at Waikiki. (Horton, 1948). There the offshore breakwater protects the beach without interfering with surfboard riding farther out to sea. Such a structure if used at Cronulla would, however, interfere with the present and anticipated future uses of the area for body surfing and close shore board riding and would therefore hardly be an acceptable solution.

Some systems of groynes would also be non-applicable to the Cronulla problem, but there are some types of groyne such as groynes at the end of the beach, generally known as "end groynes", which could possibly be used if the littoral drift proved to be such that a groyne of this nature was the most economic solution. Indications at South Cronulla so far are that the littoral drift is slight and that the method known as beach nourishment may be the most economic solution to the problem. In the following paragraphs some possibilities of groynes and beach nourishment are discussed.

6.1 Groynes and Groyne Fields.

Many of the groynes that have been used in the past for the purpose of building up beaches have played an active and major part in the erosion of the beaches which they were supposed to protect. Because of this there is a general reaction at the present time against such structures on beaches. However, a more systematic study has been made of the use of groynes during the last few years and much research has been done on the best angle at which groynes should be placed and the best location for them. (Kemp, 1962; Nagai and Kubo, 1958). With proper care a groyne field could be designed (for any suitable location) that will not cause erosion and will have a good chance of achieving its object of increasing the amount of material on the beach.

Use of a small scale model for the design of the groynes would ensure a greater chance of success. Such a model study is expensive and whether or not it would be a worthwhile investment for studying the erosion problem at Cronulla cannot be stated until a systematic programme of data collecting has been undertaken. This programme should give sufficient information to decide whether some form of groyne field would succeed.

A combination of groyne field and beach nourishing programme has been used in the U.S. with success. In certain places in England, a system of permeable groynes has recently been found to arrest the required amount of littoral drift without denuding down-drift areas.

6.2 Beach Nourishment.

Beach nourishment is a relatively recent practice which consists of feeding a beach with sand obtained from some other area. There are four main ways of doing this (Hall, 1952): (i) by dumping sand offshore from the beach; (ii) by stockpiling material at some point on the beach and letting the natural agencies cause a movement from the stockpile; (iii) by continuous supply, usually achieved by pipeline; and (iv) by placing material where it is required all over the beach.

To choose which of these methods is most likely to succeed at any locality, the deficiency in material supply with respect to time must be known as well as the predominant direction of littoral drift. The predominant direction of littoral drift for beaches northwards from North Cronulla is fairly obviously north. For South Cronulla beach it is difficult of determination and the littoral drift may indeed be negligible. The total deficiency in material supply can be calculated for any period of time over which accurate surveys are available. There are no such surveys at Cronulla earlier than 1962, and an approximate estimate must be made from maps and photographs. From the maps and photographs so far collected, it is quite difficult to determine the deficiency of material supply and much more study is required. It is felt that there may be available more maps, photographs and documents which could help to provide a firm estimate and which have not yet come to the notice of the authors.

After the deficiency has been determined it remains to select what type of material is required for the beach in question. Briefly, the fill material should be similar to the material already on the beach and nearby environments such as dunes and the seabed out to the limit of appreciable wave movement. Exact specifications for fill are not available but variations from the existing material should tend towards coarser material and better sorting (Krumbein, 1957). All finer material will be carried to sea by the same process which has already sorted the beach material into its present state. Material substantially coarser would be associated with a much steeper beach slope and this is probably not desirable. The sand to be used may be found in the area offshore of Cronulla Beach or may be available in some of the Kurnell sandhills. A sampling programme has been begun and the results so far are recorded in Appendix C1. It seems that there is not much variation between the sands of Cronulla beaches, the offshore sands and the sands on the beaches on the southern side of Port Hacking. It can therefore be hoped that suitable beach nourishing material may be available at a reasonably low cost.

The new beach may or may not resemble the state of the beach at any previous time in its history. Since a relationship exists between the size of the sand on a beach and the slope which this beach material will attain under a given set of weather conditions, or under changing sets of weather conditions in the long term, the beach slope has already been chosen when the fill material has been selected. The remaining parameter to be chosen is that of the width of the beach. In determining the fill required for any chosen beach width, it should be remembered that the desired profiles should be continued to such a depth that the material from the beach will not be carried away by the waves to stabilise the profile to this depth.

When all of the relevant factors have been assessed, the cost of the various methods of nourishing the beach can be compared. Some brief details of some of these methods are given in the following sections.

6.21 Offshore Deposition.

Dumping of material offshore from the beaches in the hope that it will be carried by natural processes onto the beaches has been tried more than once on American beaches. (Harris , 1954). The material used has not usually been the ideal sort of material that would be prescribed for the beach in question but has frequently been similar. The material has been dumped in depths greater than that which would be prescribed from theoretical calculations, because of the limiting draft of the barges used to dump this material. In all cases, dredging has been in progress nearby, and the use of the dredged material for beach nourishment has been included in the operation as a secondary benefit, even though the dredged material was not of the theoretically correct size grading, and the depth at which dumping was carried out was greater than that for best efficiency of beach nourishment. Disposing of dredged material in this way is attractive by reason of its cheapness, so that often it has been considered worthwhile to try out the method. So far material has been dumped in depths between 25 and 40 ft. where average wave heights of about 2 ft. prevail, and as far as can be ascertained the material has not succeeded in reaching the beaches. Despite this experience overseas, it is possible that material dumped in a depth compatible with the draft of barges used for dredging Port Hacking will be carried ashore on the Cronulla beaches. The difference between conditions here and overseas where dumping has been tried is in the average wave height. For Cronulla Beach this is of the order of 5 ft. as against figures of about 2 feet in previous trials overseas. Since wave energy is proportional to the square of the height it may be hoped that this method would be successful here, even though failure has so far been the result of similar operations overseas.

6.22 Stock Piling of Sand

The stock piling of sand that could be contemplated for Cronulla has a somewhat different basis from stock piling that has been used overseas. At Cronulla the immediately suggested possibility is that of pushing a large quantity of sand from the dunes towards North Cronulla beach at the beginning of summer in the hopes that the north-east winds will blow this stock pile in the direction of the Cronulla beaches. As has been stated before, a deep sand pit at North Wanda near the beaches is a possible stoppage to a natural process of this type. The littoral drift under the north east conditions such as occur in summer being southerly, stockpiles dumped north of the beaches would be moved south to the required area by the agency of water as well as by the wind. Several examples of stock piling of sand for water transport on American beaches have proved that the method is generally successful, the sand being placed in such an area that the forces of the sea will distribute it over the beach as required.

6.23 Continuous Supply

Continuous nourishment is a method that is usually more expensive than either of the methods previously discussed (Watts, 1959), except where its use is ancillary to the shifting of sand which requires to be removed from some nearby area for some other purpose. This method could be considered, for example, in the transport by pipeline to the Cronulla beaches of the sand that is now filling Quibray Bay if it were desired to remove such sand. It would seem, however, that if it were desired to prevent sand from blowing westward across the peninsula it would be more economical to stabilise the area with vegetation. There is little possibility of pumped sand being available economically.

6.24 Direct Placement on the Beach.

Where a beach is not subject to any degree of littoral transport, and where, for example, some unusual storm occurrence has caused erosion of the beach, it may be possible to put the beach back to where it was before the storm without waiting for nature to restore the beach. This has been a sound and economical solution at some areas in the U. S., where the protective value of the beach to the behind beach area was great. (Vesper, 1961; Watts, 1958). If the storm conditions that have eroded the beach are such that they would occur once in 50 years, for example, and the placing of sand would provide a beach of the desired width for such a long period of time, the protection to property may warrant direct placement. This could possibly be the best way of nourishing a pocket beach such as South Cronulla; depending, of course, on the results of the investigation into the movement of sand as littoral drift in the area.

6.25 Cost of Nourishment.

A rough estimate of the cost of direct placing of sand so as to increase the beach width at South Cronulla by something of the order of 50 yds. can be given on the basis of an assumed slope of 1 in 50 as requiring some 250 cu. yds. of material per yd. of beach to carry the beach slope out to a depth of 30 ft. This would cost £ 40. per yd. of beach for sand at 3/6d. per cubic yard, that is a total of £17,000 for 1/4 of a mile. Further research would be needed to define the depth to which beach profiles must be carried. The figure of 30 ft. used above could be in error by a factor of 2 in either direction and such an error would have a proportional effect on costs.

The cost of deposition of material at sea when dredgings from Port Hacking are available could be quite small, and it would seem that when such material is available every effort should be made to dump the material off Cronulla Beach in water as shallow as can be tolerated by the barges, taking a chance that a small expenditure will perhaps help to solve the problem. At the same time investigations to trace the movement of the sand should be undertaken to provide data for further work.

Methods involving littoral drift such as stock-piling or wind action require some measurements of the forces that would be responsible for shifting the material to the desired location before estimates can be made. Simple experiments could yield a figure of the quantity of sand blown under north-east winds of various force, and the direction of travel and final destination reached by particles of sand placed in any initial location. Fluorescent sand tests could yield more accurate quantitative data regarding littoral drift at sea. With such data, the feasibility of stock-piling either for the wind or for the forces of the sea could be assessed.

It is considered improbable at this stage that a continuous supply would be an economic solution for Cronulla and its economics have not therefore been investigated. Future developments might make a source of material available for continuous supply, in which case the economics would need to be looked into further.

6.3 Dune Stabilisation.

Associated with the programme of beach widening at Cronulla, an investigation should be made into the ways of ensuring that the source material for the beach is not blown across the dunes into Botany Bay or lost in any other fashion. The planting of various grasses and building of brush fences to retain the sand temporarily while a more permanent cover of timber is established behind the frontal dune may be necessary in certain places at this or at some future date (Davis 1957). The method for doing this would have to be spelled out. Not being experts in this field the present investigators will refrain from further comment on methods. As to advisability, more data is needed before this can be ascertained, and this report can do no more than reiterate that proper treatment of the frontal dunes is an essential part of the total solution to the problem. If it is not properly considered in association with the problem, much of the money spent on beach remedial measures might be wasted.

7. CONCLUSIONS

The following conclusions are reached from this preliminary investigation:-

7.1 Nature of Wave Effects

7.11 Direction

Neglecting the effect of sea breezes, approximately two-thirds of all ocean waves approach from East-South-East to South and one third from East-South-East to North-North-East.

7.12 Period

The wave periods normally lie in the range between 6 to 16 seconds, with the median (most common value) about 11 seconds.

7.13 Height

Waves can reach a height of 30 ft., but the usual range is 1 ft. to 10 ft., with a medium value of 5 ft.

7.2 Littoral Drift

7.20 General Comment

The littoral drift along the beach varies with wave height and direction of wave approach (see Section 4.14). Neglecting the effect of tides and longitudinal variation of wave height, which may in some circumstances modify the direction of movement, the following conclusions can be drawn.

7.21 North Cronulla and Wanda Beaches

The computed direction of drift is to the North for waves from the South and South-East and North for waves from the East and North-East. The net direction of drift appears to be towards the North.

7.22 South Cronulla Beach

This beach is protected from waves from the South, and has a drift to the North, for waves from the East and South-East, and to the South for waves from the North-East.

The net direction of drift, if any, cannot be computed from the data available.

7.3 General Movement of Sand in Bate Bay

Significant movement of sand by average wave conditions can be expected at all depths experienced in Bate Bay. The net movement must, however, be small, as no depth difference can be discerned between the soundings on the hydrographic charts of 1873 and 1961.

7.4 Effect of Tides

Insufficient data are available to assess the magnitude of tidal currents or their effect on sand movement at the Cronulla Beaches. There is some indication, however, that the movement, if any, which does occur from this cause will be towards Port Hacking. It is unlikely, however, that tidal currents outweigh the direct influence of waves.

Tides have a secondary influence on the rate of erosion whenever storms occur at periods of exceptionally high tides. The breaking point of the wave is moved closer inshore and the destructive force of the wave is moved further up the beach. As a result, erosion is accelerated. This is particularly the case if wave reflection occurs from a sea wall or similar obstructions as is the case at Cronulla.

7.5 Effect of Ocean Currents

Sand movement in the offshore zone will be influenced by the magnitude and direction of currents associated with wind and ocean circulation. These currents, although generally insufficient to initiate movement of the bed, will affect its direction of movement after being disturbed by waves. No nearshore measurements of currents are available on which to estimate the magnitude of these effects.

7.6 Effect of Winds on Sand Movement

Winds produce large scale movement of the sand dunes of Kurnell Peninsula especially during south-easterly gales. The net direction of movement is to the West, indicating an overall loss of material from the beach face. With north-easterly weather, movement of sand to the South may form a source of supply to North and South Cronulla beaches, partially offsetting this loss.

7.7 Effect of Activities of Man

Construction of sea walls and baths, mining of shell grit, denudation of vegetation from the frontal sand dunes, and interference with sand drift to the South by N.E. winds has affected to some extent the overall beach stability. It cannot be stated categorically that these factors have accelerated erosion, although in most cases they would tend to denude the beach of sand. Whether the overall effect is appreciable cannot be ascertained with the available data.

7.8 Cycles of Beach Erosion and Accretion

Since 1905 there has been movement of sand back and forth from the Cronulla Beaches.

Beach profiles are subject to rapid short term variations. Storm waves produce erosion and swell accretion. Because of its greater exposure, North Cronulla has a much larger variation in beach profile between cycles of accretion and erosion than does South Cronulla. The maximum change in elevation recorded over the period March to November 1962 was 5 ft. at North Cronulla and 1 foot at South Cronulla. A land map of 1884 also notes changes in the position of high water of up to 150 links (99 ft.). These short term cyclic changes mask the long term erosion or accretion pattern. After sustained north-easterly weather beach accretion occurs at South and North Cronulla. This may be the result of the combined effect of sand drift along the beach by wind and a southerly littoral current with the north-east sea breeze.

The most severe period of erosion occurred between 1930 and 1950. Between 1940 and 1946 weather conditions were unusually severe and damage was experienced over the entire east coast of N.S.W. Between 1924 and 1937 the cliffs seaward of Prince Street were severely eroded. Since 1950 accretion has occurred but the beach level has probably not as yet reached the level which existed prior to 1930.

A rock outcrop separates North and South Cronulla Beaches. Hydrographic plans, land maps and photographs show that since 1870 the amount of rock exposed has not changed materially for most of the time, although there have been some relatively short periods where the rock outcrop has been practically covered by sand.

Summing up, the variations in the character of the beaches since 1905 may well have been no greater than is to be expected from natural semi-cyclic beach changes, and there is insufficient evidence to decide whether the natural long term trend is denudation, accretion, or whether a state of equilibrium has existed.

7.9 Remedial Measures to Combat Erosion

No firm conclusion can be reached as to the most economic method of widening North and South Cronulla Beaches until further data are collected. However, it is possible that one or a combination of some of the following methods may be found to be practical and economic:-

(i) Use of groynes.

(ii) Beach nourishment by stockpiling of sand north of Wanda at the start of summer.

(iii) Beach nourishment by offshore dumping from barges.

(iv) Beach nourishment by direct placement.

(v) Stabilization of the frontal sand dunes.

A comprehensive analysis and plan for remedial action involves some further expenditure on data collection and analysis. Nevertheless, some inexpensive trial solutions could be tested at the present stage.

South Cronulla is partially protected from storm waves and existing evidence indicates the rate of littoral drift out of the area may be small. If this is so, the direct placement of sand to increase the beach width could be an economic solution. The cost of such works is estimated at from £17,000 to £35,000 for an increase in beach width of 50 yards.

8.0 RECOMMENDATIONS

8.1 Trial Test of Stockpiling Techniques

Sand should be bulldozed directly into the surf zone from the nearby sandhills (see Section 6.22), preferably at the beginning of summer. The manner in which waves and wind mould this sand naturally into the beach profile should be observed, and during the test period measurements of littoral drift and study of sand movement by fluorescent tracer should be made from time to time to determine the efficacy of the method and whether it should be repeated on a larger scale.

8.2 Trial of Offshore Dumping

When sand is dredged from Port Hacking in future, arrangements should be made to dump it offshore of Cronulla Beach instead of at sea, and sand movement traced by fluorescent tracer to observe whether appreciable shoreward movement occurs.

8.3 Collection of Survey Data

In the preliminary investigation the lack of exact survey data has limited the conclusions that can be reached on erosion at the Cronulla beaches. In the interest of further studies it is most desirable therefore that the measurement of beach profiles commenced by Sutherland Shire Council in March 1962 be continued in the future. To be of maximum benefit these should be carried out at weekly intervals for a continuous period of one year to enable the short term variations to be adequately correlated with wave and meteorological conditions. Subsequent surveys would be necessary only annually or bi-annually to enable the long term variation to be established.

8.4 Further Investigations

In order to assess completely the efficacy of the various methods discussed in Section 7.9, and to ensure that the future development of the beach area is wisely planned and money is not wasted, further studies should be made of:-

(i) The magnitude and direction of littoral currents under various weather conditions.

(ii) The location, stability and magnitude of rip current systems.

(iii) The magnitude and direction of nearshore currents.

(iv) The quantity and direction of sand drift by wind action, in particular that from the north-east sea breeze.

(v) The net rate of erosion from the beaches.

(vi) Locations of suitable material for beach nourishment.

The cost of an adequate programme of data collection is estimated at between £10,000 and £15,000.

Use of a small scale model to supplement the field studies could reduce the volume of field work required but would be unlikely to reduce the cost substantially. However, it would have the added advantage of being able to test the performance of any proposed solution. Use of such a model would be particularly desirable if groynes are considered, since incorrect location of these structures can lead to deleterious results.

8. 5 Criteria Governing Council's Consideration of Above Recommendations.

In considering what action should be taken to control beach erosion and accretion phenomena, it is obvious that the first objective is to prevent progressive denudation of the beach. However, there is a second objective, viz; the possibility of improving the beach and surfing conditions. Even if we could be satisfied that in the long term erosion is not occurring at Cronulla and the beaches are reasonably stable, it would probably be desirable to widen portions of the existing beaches and so improve the present surfing facilities.

In regard to the matter of data collection, it is respectfully submitted that sea-board Councils have some responsibility to posterity and to the general public of Australia to carry out an adequate programme of data collection so that in future years reliable investigations can be made and recommendations for preserving and improving beaches can be set down with confidence. The surfing facilities in Australia are an important national asset just as worthy of adequate data collection as water and soil conservation schemes.

ACKNOWLEDGMENTS.

The authors would not have been able to carry out this study without valuable contributions from many sources. The Shire Council has made available many documents, including plans of the beach surveys which Mr. Wood, the Shire Engineer, instituted in 1962. The Lands Office, The Mitchell Library and the Government Printer have been sources of many old documents and plans.

Don Lucas Dip. Eng. has kept the investigators informed of unusual changes at the beach during the last year and the Surf Life Saving Club has supplied and manned surf boats used in the collection of data. Radio Station 2SM has made a place in their beach patrol plane available so that beach changes could be observed directly from the air.

Long time residents of the district, too numerous to mention by name, have co-operated in supplying information and photographs and the thanks of the authors are due to each of them.

D. N. Foster, D. M. Stone and C. H. Munro.

APPENDIX A

GLOSSARY OF TERMS

ACCRETION - May be either NATURAL or ARTIFICIAL. Natural accretion is the gradual build-up of land over a long period of time solely by the action of the forces of nature, on a BEACH by deposition of water- or air-borne material. Artificial accretion is a similar build-up of land by reason of an act of man, such as the accretion formed by a groyne, breakwater, or beach fill deposited by mechanical means.

AMPLITUDE, WAVE - (1) in hydrodynamics one-half the wave height; (2) in engineering usage, loosely, the wave height from crest to trough.

BACKRUSH - The seaward return of the water following the uprush of the waves. For any given tide stage the point of farthest return seaward of the backrush is known as the LIMIT of BACKRUSH or LIMIT of BACKWASH.

BAR - An offshore ridge or mound of sand, gravel, or other unconsolidated material submerged at least at high tide, especially at the mouth of a river or estuary, or lying a short distance from and usually parallel to, the beach.

BEACH(1) - The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form. . . or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of the beach - unless otherwise specified - is the mean low water line. A beach includes FORESHORE and BACKSHORE; (2) Sometimes, the material which is in more or less active transport, alongshore or on-and-off shore, rather than the zone.

BEACH BERM - A nearly horizontal portion of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several.

BEACH EROSION - The carrying away of beach materials by wave action, tidal currents, or littoral currents, or by wind.

BEACH FACE -The section of the beach normally exposed to the action of the wave uprush. The FORESHORE zone of a BEACH. (Not synonymous with SHOREFACE).

CLAPOTIS - (1) The French equivalent for a type of STANDING WAVE; (2) In American usage it is usually associated with the standing wave phenomenon caused by the reflection of a wave train from a breakwater, bulkhead, or steep beach.

CREST OF WAVE - (1) The highest part of a wave; (2) That part of the wave above still water level.

CURRENT, LITTORAL - The nearshore currents primarily due to wave action, e.g. Longshore currents and Rip currents.

CURRENT, RIP - A narrow current of water flowing seaward through the breaker zone. A rip current consists of three parts: (1) The "feeder currents flowing parallel to the shore inside the breakers; (2) the "neck" - where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and (3) The "head" - where the current widens and slackens outside the breaker line

DATUM - The plane or level to which soundings on a chart are referred, usually taken to correspond to a low water stage of the tide. Also REFERENCE PLANE. The plane is called TIDAL DATUM when defined by a certain phase of the tide. MEAN LOW WATER SPRINGS and LOW WATER INDIAN SPRINGS are used for datums of hydrographic plans referred to in this report.

DECAY OF WAVES - The change that waves undergo after they leave a generating area (fetch) and pass through a calm, or region of lighter winds. In the process of decay, the significant wave height decreases and the significant wave length increases.

DEEP WATER - Water of depth such that surface waves are little affected by conditions on the ocean bottom. It is customary to consider water deeper than one-half the surface wave length as deep water.

DUNES - Ridges or mounds of loose, wind-blown material, usually sand.

FATHOM - A unit of measurement used for soundings. It is equal to 6 feet (1.83 meters).

FETCH - (1) In wave forecasting, the continuous area of water over which the wind blows in essentially a constant direction. Sometimes used synonymously with FETCH LENGTH. Also GENERATING AREA; (2) In wind setup phenomena, for enclosed bodies of water, the distance between the points of maximum and minimum water surface elevations. This would usually coincide with the longest axis in the general wind direction.

GENERATING AREA - In wave forecasting, the continuous area of water surface over which the wind blows in essentially a constant direction. Sometimes used synonymously with FETCH LENGTH. Also FETCH.

GROUP VELOCITY - The velocity at which a wave group travels. In deep water, it is equal to one-half the velocity of the individual waves within the group.

GROYNE - A shore protective structure (built usually perpendicular to the shore line) to trap littoral drift or retard erosion of the shore. It is narrow in width (measured parallel to the shore line), and its length may vary from less than one hundred to several hundred feet (extending from a point landward of the shore line out into the water). Groynes may be classified as permeable or impermeable; impermeable groynes having a solid or nearly solid structure, permeable groynes having openings through them of sufficient size to permit passage of appreciable quantities of littoral drift.

HEIGHT OF WAVE - The vertical distance between a crest and the preceding trough. See also SIGNIFICANT WAVE HEIGHT.

HINDCASTING, WAVE - The calculation from historic synoptic wind charts of the wave characteristics that probably occurred at some past time.

HYDROGRAPHY - (1) A configuration of an underwater surface including its relief, bottom materials, coastal structures, etc. and (2) The description and study of sea, lakes, rivers, and other waters.

INSHORE (ZONE) - In beach terminology, the zone of variable width extending from the shore face through the breaker zone.

KNOT - (Abbreviation kt. or kts.) The unit of speed used in navigation. It is equal to 1 nautical mile (6,080. 20 feet) per hour

LENGTH OF WAVE - The horizontal distance between similar points on two successive waves measured perpendicularly to the crest.

LITTORAL - Of or pertaining to a shore, especially of the sea. A coastal region.

LITTORAL DRIFT - The material moved in the littoral zone under the influence of waves and currents.

MASS TRANSPORT - The net transfer of water by wave action in the direction of wave travel.

MEDIAN - The diameter which marks the division of a given sample into two equal parts by weight, one part containing all grains larger than that diameter and the other part containing all grains smaller.

NOURISHMENT - The process of replenishing a beach. It may be brought about by natural means, e.g. littoral drift, or by artificial means, e.g. by the deposition of dredged materials.

ORTHOGONAL - On a refraction diagram, a line drawn perpendicular to the wave crests.

OSCILLATORY WAVE - A wave in which each individual particle oscillates about a point with little or no permanent change in position. The term is commonly applied to progressive oscillatory waves in which only the form advances, the individual particles moving in closed orbits. Distinguished from a WAVE of TRANSLATION.

PLUNGE POINT - (1) For a plunging wave, the point at which the wave curls over and falls; (2) The final breaking point of the waves just before they rush up on the beach.

PROFILE, BEACH - The intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement.

REFLECTED WAVE - The wave that is returned seaward when a wave impinges upon a very steep beach, barrier, or other reflecting surfaces.

REFRACTION OF WATER WAVES - (1) The process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours. (2) The bending of wave crests by currents.

REFRACTION DIAGRAM -A drawing showing positions of wave crests and/ or orthogonals in a given area for a specific deep water wave period and direction.

RIP CURRENTS - A strong surface current of short duration flowing seaward from the shore. It usually appears as a visible band of agitated water and is the return movement of water piled up on the shore by incoming waves and wind. With the seaward movement concentrated in a limited band its velocity is somewhat accentuated. A rip consists of three parts: the FEEDER CURRENT flowing parallel to the shore inside the breakers; the NECK, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the HEAD, where the current widens and slackens outside the breaker line. A rip current is often miscalled a RIP TIDE. Also RIP SURF.

RIPPLE MARKS - Small, fairly regular ridges in the bed of a waterway or on a land surface caused by water currents or wind. As their form is approximately normal to the direction of current or wind, they indicate both the presence and the direction of currents or winds.

RUN-UP - The rush of water up a structure on the breaking of a wave. Also UPRUSH. The amount of run-up is the vertical height above still water level that the rush of water reaches.

SALTATION - That method of sand movement in a fluid in which individual particles leave the bed by bounding nearly vertically and, because the motion of the fluid is not strong or turbulent enough to retain them in suspension, return to the bed at some distance downstream. The travel path of the particles is a series of hops and bounds.

SEA BREEZE - (1) A breeze blowing from the sea toward the land; (2) A light wind blowing toward the land caused by unequal heating of land and water masses.

SEAWALL - A structure separating land and water areas primarily designed to prevent erosion and other damage due to wave action.

SHALLOW WATER - (1) Commonly; water of such a depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than half the surface wave length as shallow water. (2) More strictly; in hydrodynamics with regard to progressive gravity waves, water in which the depth is less than 1/25th the wave length. Also called VERY SHALLOW WATER.

SIGNIFICANT WAVE - A statistical term denoting waves with the average height and period of the one-third highest waves of a given wave group. The composition of the higher waves depends upon the extent to which the lower waves are considered. Experience so far indicates that a careful observer who attempts to establish the character of the higher waves will record values which approximately fit the definition. A wave of significant wave period and significant wave height.

SIGNIFICANT WAVE HEIGHT - The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered. In wave record analysis, the average height of the highest 1/3 of a selected number of waves, this number being determined by dividing the time of record by the significant period.

SIGNIFICANT WAVE PERIOD - An arbitrary period generally taken as the period of the 1/3 highest waves within a given group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered. In wave record analysis, this is determined as the average period of the most frequently recurring of the larger well-defined waves in the record under study.

SOLITARY WAVE - A wave consisting of a single elevation (above the water surface) of height not necessarily small compared to the depth, and neither followed nor preceded by another elevation or depression of the water surfaces.

SOUNDING - A measured depth of water. On hydrographic charts the soundings are adjusted to a specific plane of reference.

STANDING WAVE - A type of wave in which the surface of the water oscillates vertically between fixed points, called nodes, without progression. The points of maximum vertical rise and fall are called antinodes or loops. At the nodes, the underlying water particles exhibit no vertical motion but maximum horizontal motion. At the antinodes the underlying water particles have no horizontal motion and maximum vertical motion. They may be the result of two equal progressive wave trains travelling through each other in opposite directions. Sometimes called STATIONARY WAVE.

SWELL - Wind-generated waves that have advanced into regions of weaker winds or calm.

TIDE EBB - That period of tide between a high water and the succeeding low water; falling tide.

TIDE, FLOOD - That period of tide between low water and the succeeding high water; a rising tide.

TIDE, NEAP - A tide occurring near the time of quadrature of the moon. The neap tidal range is usually 10 to 30 percent less than the mean tidal range.

TIDE, SPRING - A tide that occurs at or near the time of new and full moon and which rises highest and falls lowest from the mean level.

VELOCITY OF WAVES - The speed with which an individual wave advances.

WAVE CREST - The highest part of a wave. Also that part of the wave above still water level.

WAVE DECAY - The change which waves undergo after they leave a generating area (fetch) and pass through a clam, or region of lighter or opposing winds. In the process of decay, the significant wave height decreases and the significant wave length increases.

WAVE DIRECTION - The direction from which a wave approaches.

WAVE GROUP - A series of waves in which the wave direction, wave length, and wave height vary only slightly.

WAVE HEIGHT - The vertical distance between a crest and the preceding trough.

WAVE LENGTH - The horizontal distance between similar points on two successive waves measured perpendicularly to the crest.

WAVE, OSCILLATORY - A Wave in which each individual particle oscillates about a point with little or no permanent change in position. The term is commonly applied to progressive oscillatory waves in which only the form advances, the individual particles moving in closed or nearly closed orbits.

WAVE PERIOD - The time for a wave crest to traverse a distance equal to one wave length. The time for two successive wave crests to pass a fixed point. See also SIGNIFICANT WAVE PERIOD.

WAVE STEEPNESS - The ratio of a wave's height to its length.

WAVE TRAIN - A series of waves from the same direction.

APPENDIX B

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APPENDIX C.

FIELD NOTES ON CRONULLA BEACH INSPECTIONS 1962.

The field notes made during visits to Cronulla Beach in 1962 follow. Though they have not yielded sufficient information to warrant detailed analysis, they may be an adjunct to data collected in the future and for this reason their preservation in this form has been deemed wise.

Sand samples collected during some of the field trips have been sieved in the laboratory and the gradings are included on attached diagrams.

Sands from the ocean beaches, the sea bed and two protected beaches south of Port Hacking are remarkably similar in size. A tendency for the sand to be coarser and better sorted in March than in July is also apparent. However, it should not be inferred that this will always be so, because the winter of 1962 was unusually free from storm weather.

INSPECTION OF CRONULLA BEACHES 18. 2. 62

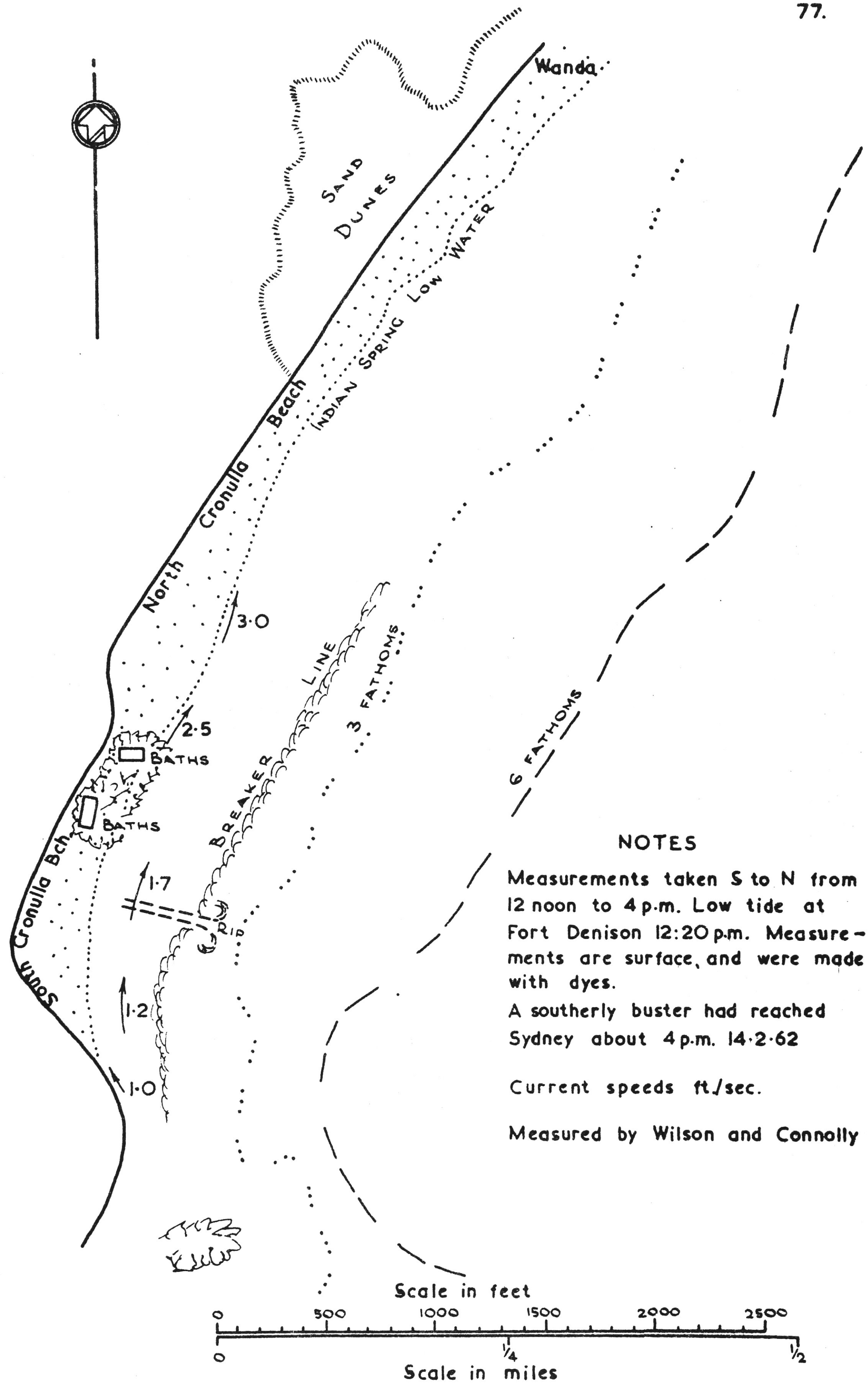
1. South Cronulla Beach. (D. M. Stone).

Beach observed 12 noon to 4 p. m. Low tide at Fort Denison 2. 18 p. m.

The high seas of the preceding 2 days had washed up over the road near Cronulla Surf Club at high tide. Considerable erosion of the beach had taken place, and the grassed bank was undermined. According to local residents the beach had been steadily accreting since the last inspection of 13. 12. 61 until about 11. 2. 62.

On 18. 2. 62 the beach was some feet lower than at 13. 12. 61 and local estimates of erosion during the preceding week ranged from 3' to 5'. A deep transverse gully was observed just south of the baths giving the beach an unusual convexity in two directions. Wind and seas on 18. 2. 62 appeared to be S. E. tending S. S. E.

Both poles installed for measuring beach level changes had been washed out in the heavy weather. One was found on North Cronulla



NOTES

Measurements taken S to N from 12 noon to 4 p.m. Low tide at Fort Denison 12:20 p.m. Measurements are surface, and were made with dyes.

A southerly buster had reached Sydney about 4 p.m. 14·2·62

Current speeds ft./sec.

Measured by Wilson and Connolly

Figure 16: Current Measurements 15·2·62

Beach and the other had escaped to sea.

2. North Cronulla Beach

Mr. Harry Brown of North Cronulla Surf Club stated that the beach in front of the stepped wall had eroded about 2 feet, but just south in the washaway area he estimated a greater depth of erosion.

3. Wanda Beach

No exact figures were given for the erosion. Washed away gravel from the nearby road was making a mess of the beach over several hundreds of square yards in front of the Wanda Surf Club building.

4. Port Hacking

The Port Hacking area was viewed from several sites on the northern shore. Long breakers rolling in from the sea continued for about a mile up the Port. The orientation of these under such S. E. weather was rather amazing to the casual observer, but agrees with refraction diagrams.

Tides

Sat. 17.2.62	0.35 a.m.	1'-5"
	7.07	5'-2"
	1.44 p.m.	1'-0"
	7.39	4'-0"
Sun. 18.2.62	1.20 a.m.	1'-4"
	7.45 a.m.	5'-4"
	2.18 p.m.	0'-10"
	8.12 p.m.	4'-2"

Notes of Meeting with Mr. Don Lucas at Cronulla, Sunday 18. 2. 62.

Mr. Lucas, member Cronulla Surf Club, drew attention to the following points:-

(1) Wave reflection from baths between Cronulla and North Cronulla beaches.

(2) Travel of water up the sides of the southern baths and subsequently towards Cronulla Beach from both sides especially at high tides.

(3) Strong current out to sea along the rocks at the south end of Cronulla Beach.

(4) Rip current south of southern baths.

(5) Rip current centre North Cronulla Beach.

Mr. Lucas has resided in Cronulla since the 1930s and is a keen beach watcher.

Mr. Hilton Smith, who has resided in Cronulla since 1913, confirmed that shell gritting on the beaches was a major industry uhtil about 1940 when it became uneconomic. A great deal, if not all, was carried out illegally so it would be hard to obtain figures to estimate total removal (Cf. P. W. D. photo re dates.)

Both Mr. Lucas and Mr. Smith said that S. E. weather caused much worse beach erosion than S. weather and that N. E. weather brought the sand back. In 1959-60 when there was a predominance of N. E. weather the baths were filled with sand and the beach was at a very high level everywhere.

CRONULLA BEACH INSPECTION 17.3.62 - 9 a.m. - 5 p.m.

(Stone and Wilson).

Tide Conditions				
High	5.55 a.m.	4'11"	)	at Fort Denison
Low	12.30 p.m.	1'4"	)	
High	6.33 p.m.	4'1"	)	

Weather Conditions.

During the morning a very light westerly breeze was blowing. The sea was extremely calm with waves of the order of 1 foot high. After noon, a slight north easterly breeze sprang up, creating waves about $1\frac{1}{2}$ to 2 feet high.

Date	Time	Direction	Wind at Sydney average of 1 hour. Speed.
17.3.62	3.00	W.N.W.	3
	6.00	W.N.W.	2
	9.00	W.N.W.	6
	12.00	E	6
	15.00	E.N.E.	10

Dye measurements at sea.

Dyes were dropped from a surf boat into the ocean at the times and places indicated on the sketch. Very little movement of the dye occurred.

Dye measurements shoreward of the breaking zone.

At low tide, and again half way up the rising tide, dye was introduced into the channel landward of the sand bar at a point just south of the southern baths. This dye moved rapidly southward along Cronulla Beach to the southern extremity indicating a current of about 2 ft/sec. Half way up the rising tide dye was introduced off the rocks at the southern end of Cronulla Beach. This dye travelled at a similar velocity in an E.N.E. direction to sea.

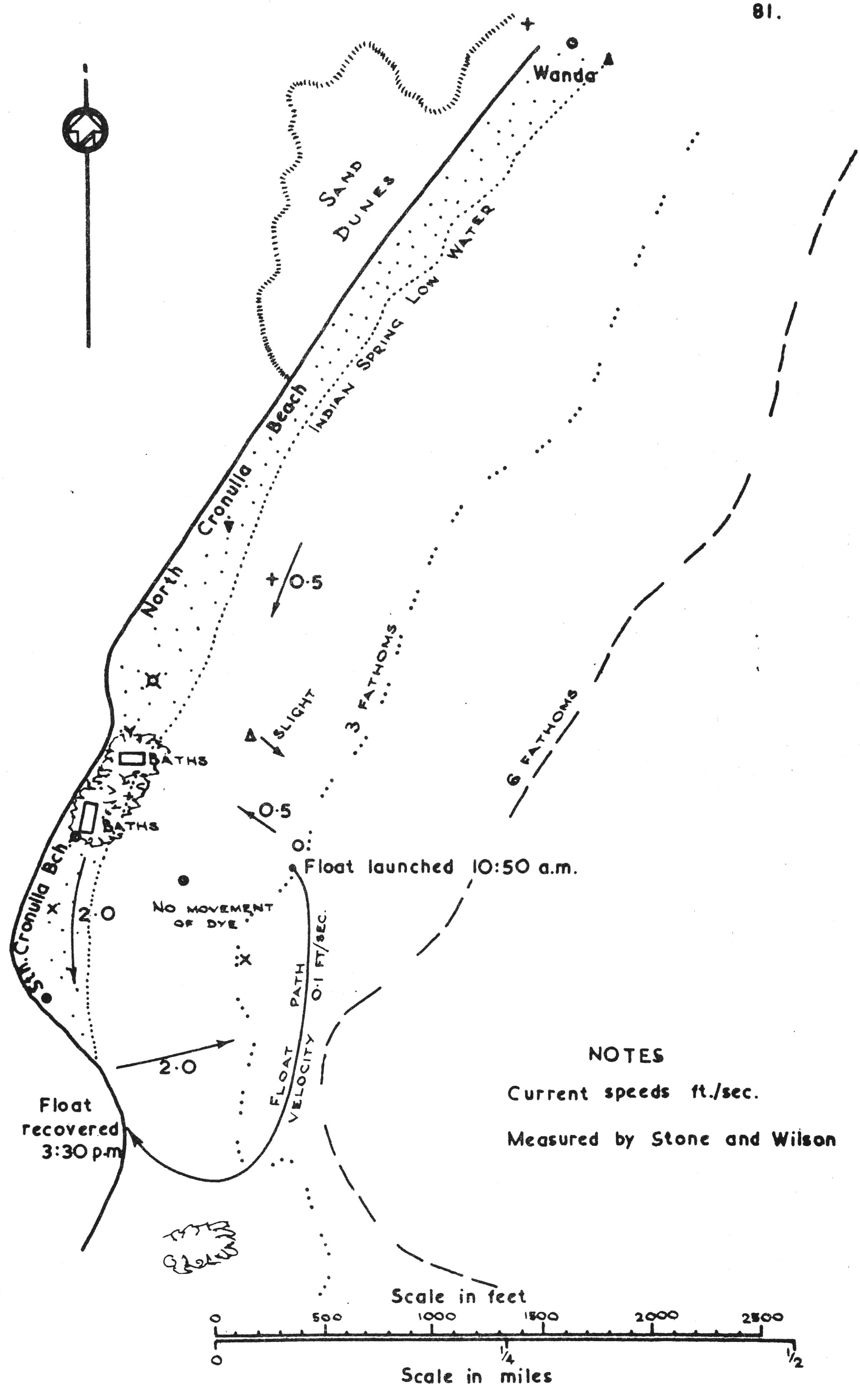


Figure 17: Current Measurements and Sand Samples 17·3·62

Float Measurements

One pole type (6' x 4" x 4") surface float was dropped in the sea at 10. 50 a. m. at the point indicated on the map. This float was observed off Cronulla Beach further south and seaward at 11. 30 a. m. The float was not tracked after this, and was not found until caught on the rocks south of Cronulla Beach at 3. 30 p. m. A casual observer said he had noticed it some hours before this farther around towards Port Hacking. Its probable path and velocities shown on the sketch have been determined from these indications.

Sand Samples

Sand samples were taken at sea and on the beach at the times and places indicated. These will be size-graded and mineralogically analysed. Later they will be compared with samples from other areas nearby.

CRONULLA BEACH INSPECTION 7. 4. 62 9 a. m. - 5 p. m.

(Foster, Stone, Wilson).

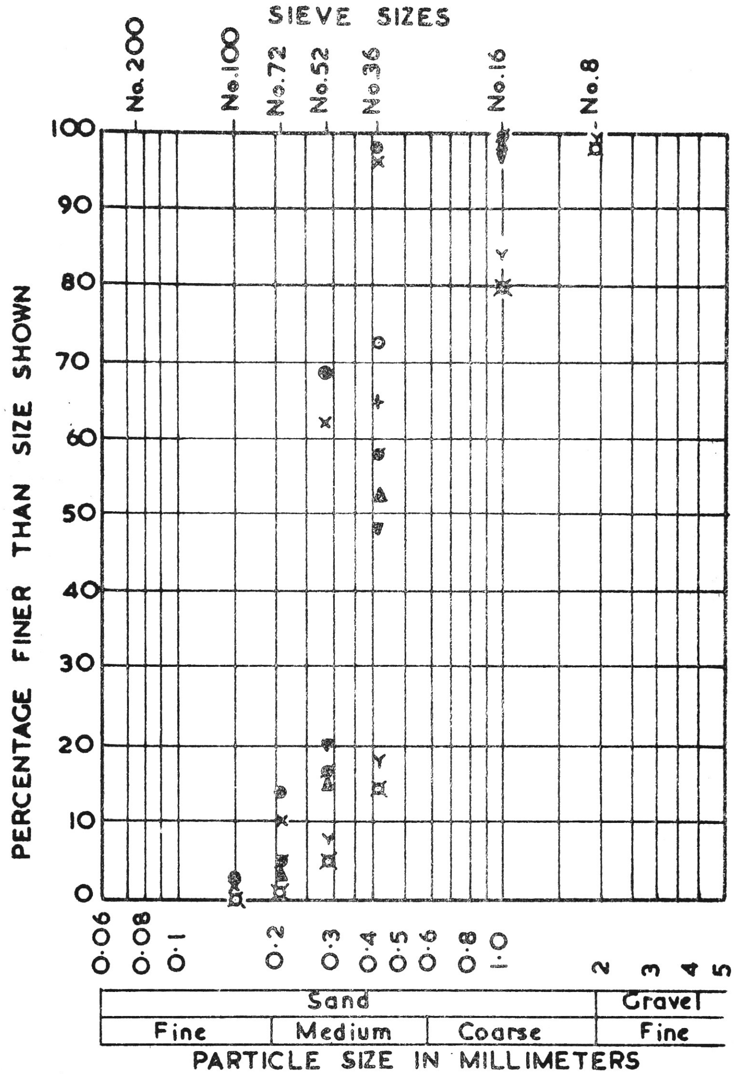
Tide Conditions

Low 4. 05 a. m. 0'-4"
High 10. 12 a. m. 5'-1"
Low 4. 14 p. m. 0'-7"

Weather Conditions

Date	Time	Speed	Wind at Sydney Direction
4. 4. 62	3 p. m.	16	S
5. 4. 62	9 a. m.	10	S
	3 p. m.	13	S. E.
6. 4. 62	9 a. m.	12	S. E.
	3 p. m.	16	S. S. E.
7. 4. 62	9 a. m.	18	S. E.

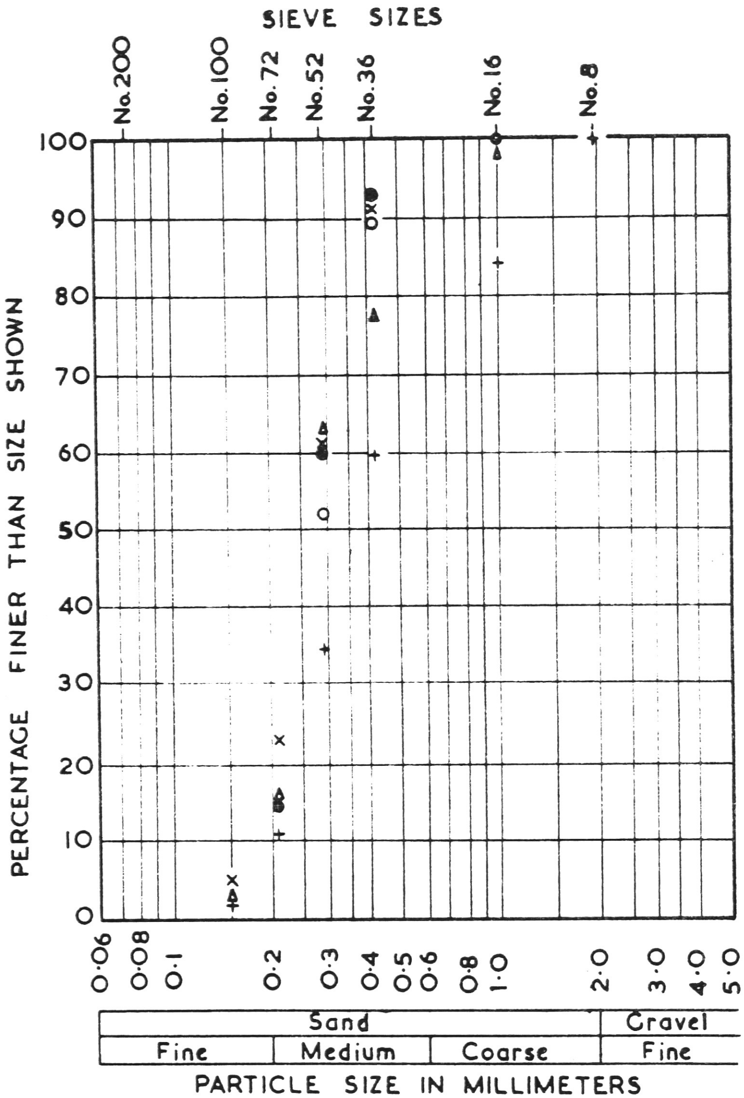
Heavy seas.



Note: All samples taken from halfway between high tide and low tide

Symbol	Location
●	South End South Cronulla Beach
×	Middle South Cronulla Beach
o	Wanda - Half tide
+	" -Sandhills
Δ	" -Low tide
ø	North End South Cronulla Beach
∇	North Cronulla Beach. Nth. End PWD wall
Y	" " " Sth. End Stepped wall
¤	" " " opp. End of Kingsway

Figure 18: Gradings of Sand Samples Taken from Cronulla Beaches - 17·3·62



Symbol	Location
●	At Sea off Southern Baths
×	" " " South Cronulla Beach
⊙	" " " Northern Baths
+	" " opp. Northern End P.W.D Wall
▲	" " " Kingsway

Figure 19: Gradings of Ocean Bed Samples off Cronulla - 17·3·62

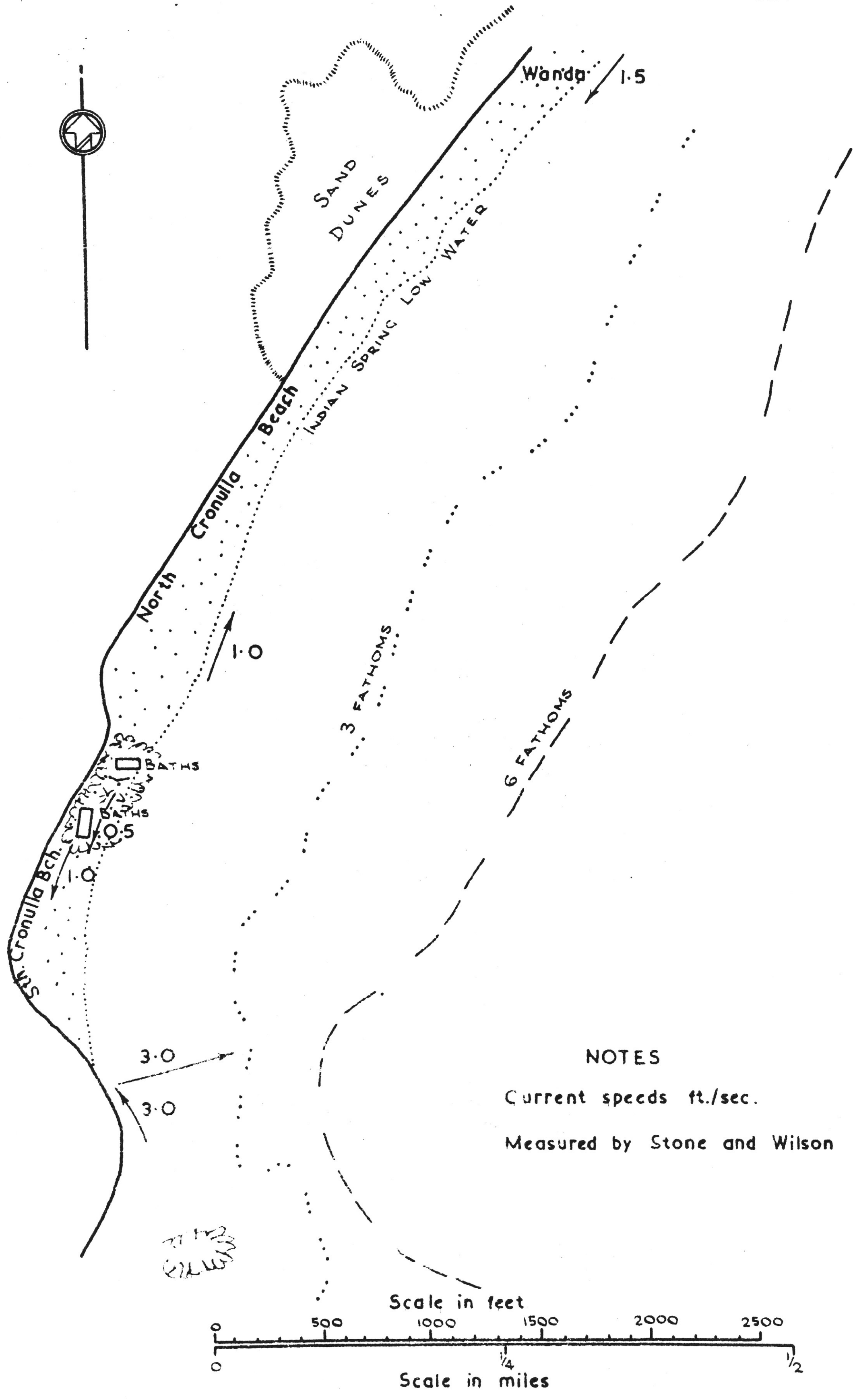


Figure 20: Current Measurements 7·4·62

Observations from South Cronulla S. L. S. C. Tower

For the first time the area was observed at high tide. Reflection of waves from the southern baths was intense, and subsequent interference between incident and reflected waves seaward of the baths created a spray of the order of 20 feet high. No deleterious effects from the northern baths were obvious at the time.

Dye Measurements Shoreward of the Breaking Zone

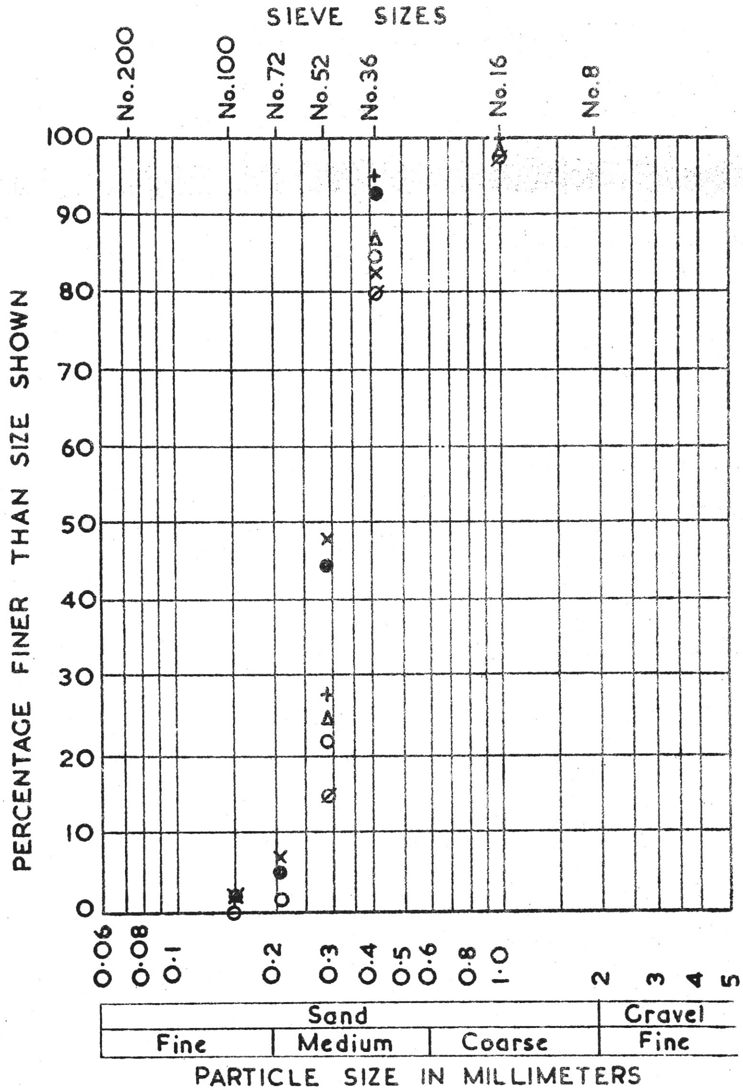
The heavy seas made it difficult to reach the seaward line of breakers with the dye. Most measurements were therefore somewhat shoreward. Dye introduced off the rocks south of South Cronulla beach travelled in to shore along the coast and then eastward to sea very fast, at about 3 ft/ sec. Dye introduced just south of the Kingsway travelled north along North Cronulla Beach at 1 ft/ sec. At Wanda S. L. S. C. dye travelled south at $1\frac{1}{2}$ ft/ sec.

Sand Samples

Sand samples were collected from Jibbon and Bundeena Beaches. The sands on these beaches show a much higher degree of sorting than those on the ocean beaches and have d median = 0. 3 mm.

Historical Information

Several local residents and people who had lived at Cronulla some time ago were interviewed by tape recorded conference. Present at the conference were Messrs. Perryman, Dallimore, Wright, Switzer, Lucas and the President of the South Cronulla Surf Club, Foster and Stone representing the University.



Note: All samples taken from halfway between high tide and low tide

Symbol	Location
●	Middle of Bundeena Beach
×	100' from East End of Bundeena Beach
o	40' " West " " " "
+	250' " East " " Jibbon Beach
Δ	Mid-point of Jibbon Beach
Ø	50' from West End of Jibbon Beach

Figure 21: Gradings of Sand Samples Taken from Beaches on Southern Shore of Port Hacking – 7·4·62

CRONULLA BEACH INSPECTION 25.7.62 11 a.m. - 4 p.m.

(Stone, Wilson).

Tide Conditions.

Low	8.47 a.m.	1'1"
High	3.19 p.m.	4'11"
Low	9.44 p.m.	1"6"

Weather Conditions.

At Sydney	9 a.m.	Wind N.W. at 4 knots.
	3 p.m.	Wind W at 15 knots.

Beach Levels.

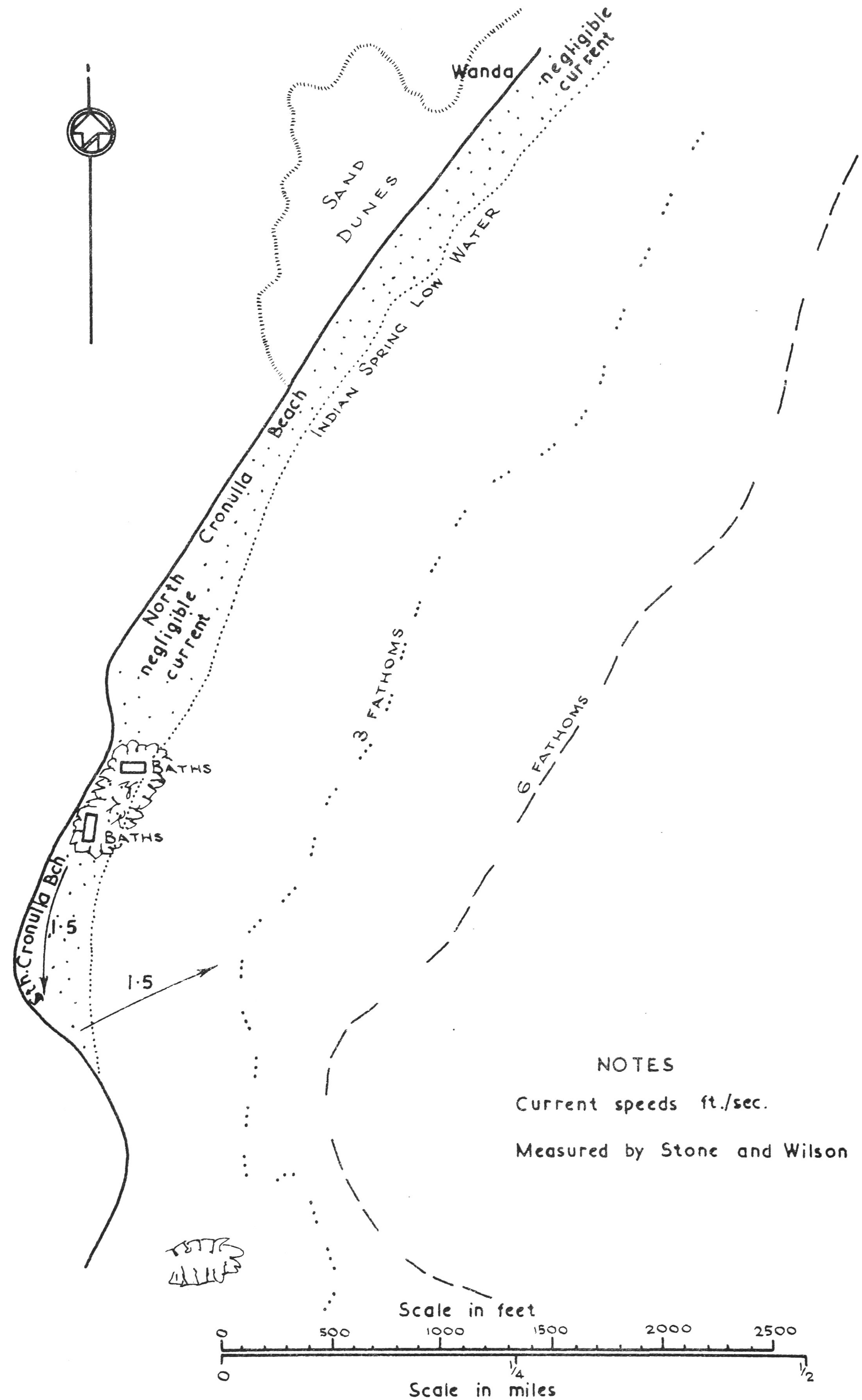
Very high for this time of year. Absence of usual winter weather from south and south-east during 1962 probable cause.

Current Measurements.

Rockets with dye fired into surf. South flowing current at South Cronulla Beach turning E.N.E. to sea at rocks at 11 a.m. and again at 4 p.m. Negligible currents at North Cronulla and Wanda Beaches. Wanda Beach showing cusps with currents depending on distance from cusp.

Sand Samples.

Samples taken along beach at mid tide level north end, middle and south end of South Cronulla, North Cronulla and Wanda. These samples were sieved and showed gradings similar to those found in April except that the July samples contained an average of 5 per cent above 1 mm. in size while the April samples contained only about 1 per cent.



NOTES

Current speeds ft./sec.

Measured by Stone and Wilson

Figure 22: Current Measurements 25·7·62