LAND & WATER CONSERVATION

QUEENSLAND GOVERNMENT
Department of Environment

Tweed River Entrance Sand Bypassing Project

Permanent Bypassing System

Technical Appendix III: Surf Impact Assessment

Hyder Consulting

Patterson Britton & Partners Pty Ltd

WBM OCEANICS AUSTRALIA

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FOR: New South Wales Department of Land and Water Conservation

and

Queensland Department of Environment

BY: Moffat & Nichol Engineers, USA on behalf of:
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1.0 INTRODUCTION

1.1 Purpose and Scope

This report documents the results of a study that characterizes surfing conditions on south Queensland and north New South Wales at the entrance to the Tweed River. The study included field observations and analyses of the potential impacts on surfing due to the Tweed River Entrance Sand Bypassing Project. Methods are suggested to restore and maintain recreational surfing amenities that pertain to the bypassing project. The scope of the study was to define the impacts of the sand bypassing project on surfing and to recommend methods to improve surfing conditions consistent with the objectives of the bypassing project.

The study was based on a review of available data, interviews with surfers, analytical studies, and basic coastal engineering judgment. Analytical studies relate the bathymetric conditions and oceanographic conditions to surf recreational parameters. Aerial photographs, bathymetric surveys, videos, interviews with local surfing experts, photographs, and analyses of wave transformations commonly found at surf sites were reviewed to classify the potential impacts and to propose measures to preserve surf quality. A basic parameterization of the surfing conditions was based on technical analyses, tempered by interviews with local surfers and field observations of surfing.

The quantity and quality of information for this task are sufficient for a general characterization and evaluation of impacts. The level of detail in the data and analyses are not sufficient for development of specific implementation measures intended to improve surf quality. The area of interest for this assessment is from Letitia Spit to North Kirra Beach.

1.2 Approach

This document discusses the basic principles of surf mechanics that relate breaking waves to bathymetric features, as described by Walker (1974). The oceanographic characteristics pertinent to surfing are identified and related to surfing characteristics. An assessment of environmental impacts and opportunities to preserve, maintain, or possibly enhance surfing is then made. Interviews with several surfers and judgment based on broad experience are key elements to define the surf sites.

A considerable amount of bathymetric and incident wave data exist at this site compared to many coastal areas in the world. Ideally, simultaneous measurement of the actual bottom conditions and the breaking wave properties are required to fully understand the wave transformations at a surf site. On a coral or rock reef, such measurements are possible because a reef remains relatively stable between a survey and a wave event. However, many of the surf sites in this study area break over beach bars that move in response to the waves, currents, tides, and sand supply. A review of the bathymetric data indicated a very wide range of bottom conditions. Hence, only a generalized characterization is indicated, and findings must be viewed with this limitation in mind.

Wave transformation studies carried out for the Tweed Bypassing EIS/IAS *(Technical Appendix II)* were used to help quantify the wave transformations and understand the influence of bottom conditions on surfing. The wave transformations of refraction and diffraction around Snapper Rocks and the added influence of currents on these parameters over the Tweed River entrance bar are important to actual surf conditions. The presence and transport of sand over the bottom on longshore beach bars are key parameters that define the quality of surf in the study area.

1.3 Data

Aerial photographs dating from 1947 to the present were reviewed. Table 1 lists 21 sets of photographs reviewed. These photographs represent a wide range of incident wave, surf, wind, tide, current, beach, and estuary conditions. The photographs indicate the wave patterns, peel angles, lengths and paths of probable rides, and beach and bar shapes. The photographs represent only a narrow range of data, so their interpretation must be expanded by application of coastal engineering knowledge of parameters that render a site valuable for surfing.

TABLE 1
AERIAL PHOTOGRAPHS REVIEWED

DATE	COMMENTS	DATE	COMMENTS
27-5-47	Letitia Spit- weak bar formation	21-4-56	Surf on Letitia Spit Bars
1961	Duranbah A-Frame waves	31-8-63	Surf from Duranbah to Kirra
1-6-65	Rainbow and Coolangatta	18-1-69	
13-2-74	Good surf quality	21-5-75	Kirra Groyne
18-4-78	Kirra Breaking	24-5-79	
17-11-80	NE waves	27-9-73	
19-12-94	Big Entrance bar Break	29-5-95	
15-7-95	Duranbah shore break	11-4-95	Rainbow good surf
15-7-95	Small day at Coolangatta	12-10-95	NE wind chop
25-11-95		11-4-96	
25-5-94			

The Gold Coast City Council has measured a great number of bottom profiles over the years to characterize the offshore bottom and slopes. Table 2 lists the dates of bathymetric profiles and contour bathymetric plots used for this study.

TABLE 2
PROFILE REVIEWED

Dec. 1960	Nov. 1962	June 1963	Oct. 1964	Sep. 1966
July 1967	May 1968	July 1969	May 1966	May 1971
June 1972	Mar. 1974	May 1988	May 1989	Aug. 1990
June 1992	June 1993	May 1994	May 1995	June 1996

Interviews were conducted on the site with several prominent surfers. Wayne "Rabbit" Bartholomew, Bruce Lee, Peter Turner, John Standing, Mike Perry, and others shared their knowledge of and passion for the world-famous surf breaks from Duranbah to Kirra Point.

2.0 SURF PARAMETERS

2.1 Surfing Mechanics

Surfing, the sport of wave riding, can be practiced using various form of equipment such as a board, canoe, kayak, or sailboard, or using no equipment other than perhaps fins. Board surfing is the most popular form of surfing and is the one referred to in this report. The basic principles may also apply to other types of surfing.

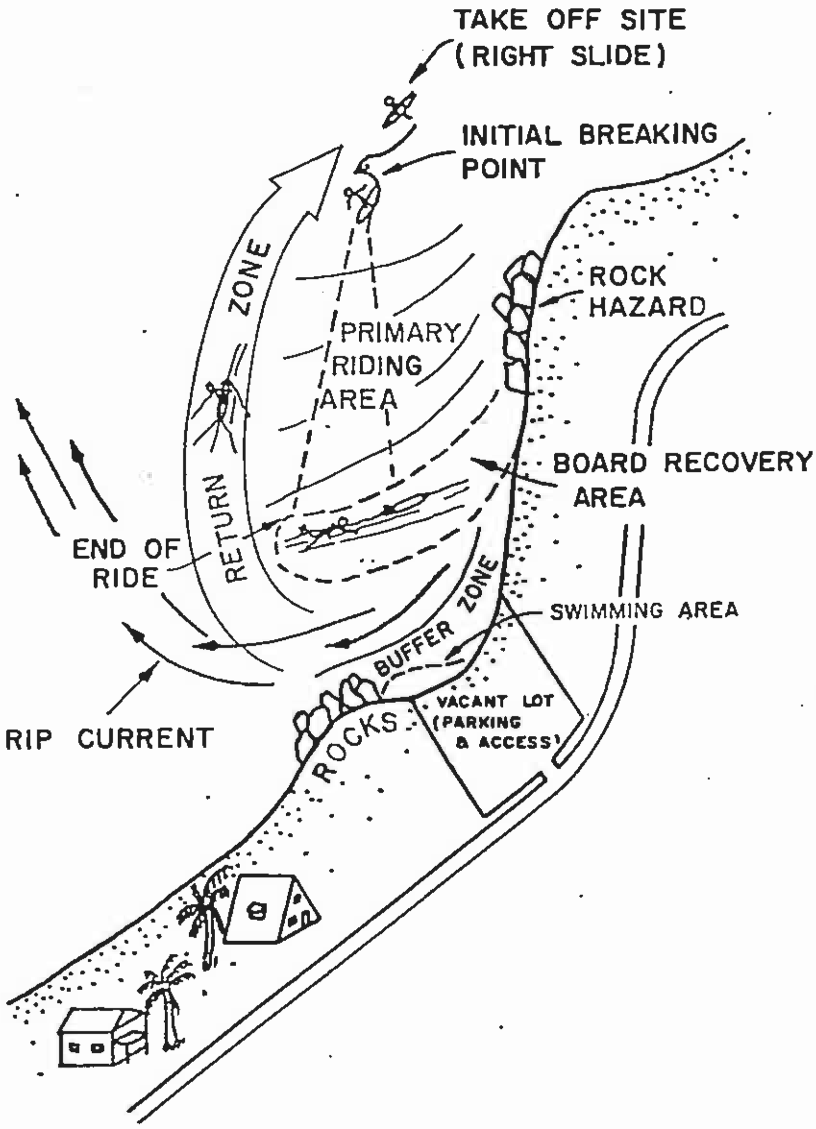
Surfing is generally performed at a specific location called a surf site. A surf site is an area in which waves break in a consistent and desirable form that is conducive to wave riding. Figure 1 shows the basic interrelation of a surf site and land access. The site has a take-off site, primary riding area, an end-of-ride area, a board-recovery area, and a return route to the take-off site. Board-recovery areas are not required today to the degree they were before the advent of leashes, however, a zone that separates surfing from swimming areas is desirable.

A sequence of a surfer catching a wave is shown schematically in Figure 2. The surfer attains a position just seaward of the breaking position and paddles in the direction with the advancing wave crest. The surfer utilizes the force due to gravity on the advancing wave crest along with paddling speed to match and slightly exceed the velocity of the advancing wave. At this point, the surfer can stand or crouch and balance the board on the slope of the wave. The surfer drops down part of the wave face or wall and can initiate a turn or maneuver on the face of the wave. The drop takes on the order of 1 to 5 seconds for 1- to 4-m high waves, respectively. Figure 3 shows the definitions of some of the key surfing wave terms.

2.2 Peel Angle

A good-quality surfing wave breaks laterally along the wave crest as it proceeds toward shore. The surfer can then maneuver near the intersection of the broken and unbroken regions, in the area called the peel or the curl. Generally, surfers avoid the turbulent white water region as it is difficult to negotiate. Figure 4 shows velocity vectors a wave and an ideal surfer riding the wave in the peel between two times. Velocity vectors give the speed and direction of the peel or surfer in the peel. The angle subtended by the peel at successive positions is defined by $\tan(\alpha)=V_p/V_w$, where V_p is the velocity of the peel and V_w is the velocity of the wave. The successful surfer maneuvers in the peel with a velocity V_s.

Peel angles can be measured directly from a sequence of aerial photographs or by analyses of surfer paths using survey techniques. Walker (1974) performed field surveys using survey equipment and time-sequential aerial photographs to define surfing characteristics at several well-known and some lesser-known Hawaiian sites. A semi-empirical relationship between peel angle, wave height, and surfer classifications was defined based on that study. Figure 5 shows the relation of peel angle to breaking wave height. The surfable range is from a straight-toward-shore breaker with a peel angle of 90 degrees, to a breaker with a 30-degree peel angle, which may be close to the limit of surfability. Peel angles more acute than 30 degrees are considered "close-out" waves for smaller waves; less-acute peel angles based on hypothesized maximum surfer velocity may define surfing limits on larger waves.



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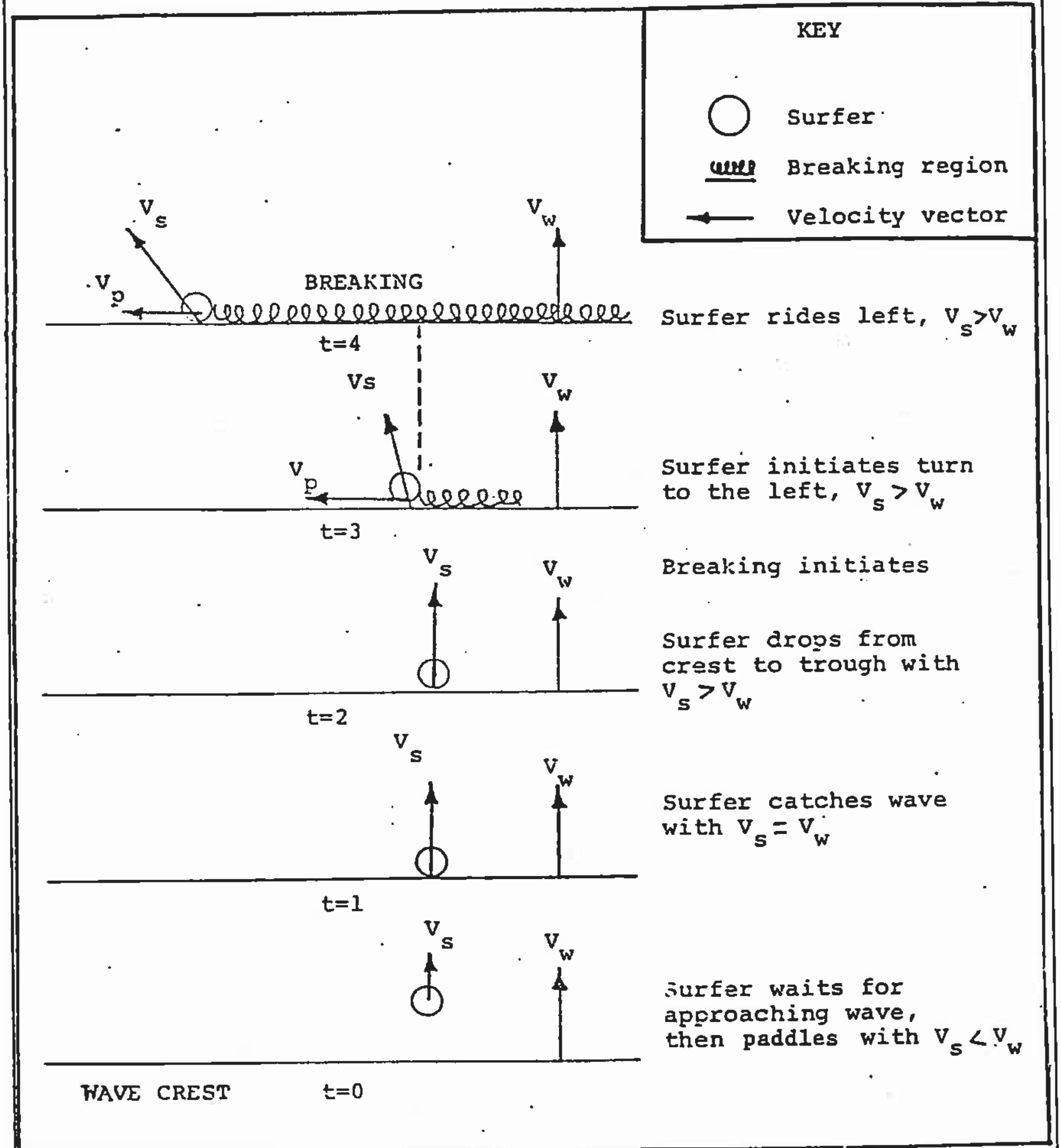
Tweed River Entrance Sand Bypass Project	Surf Site	Figure 1



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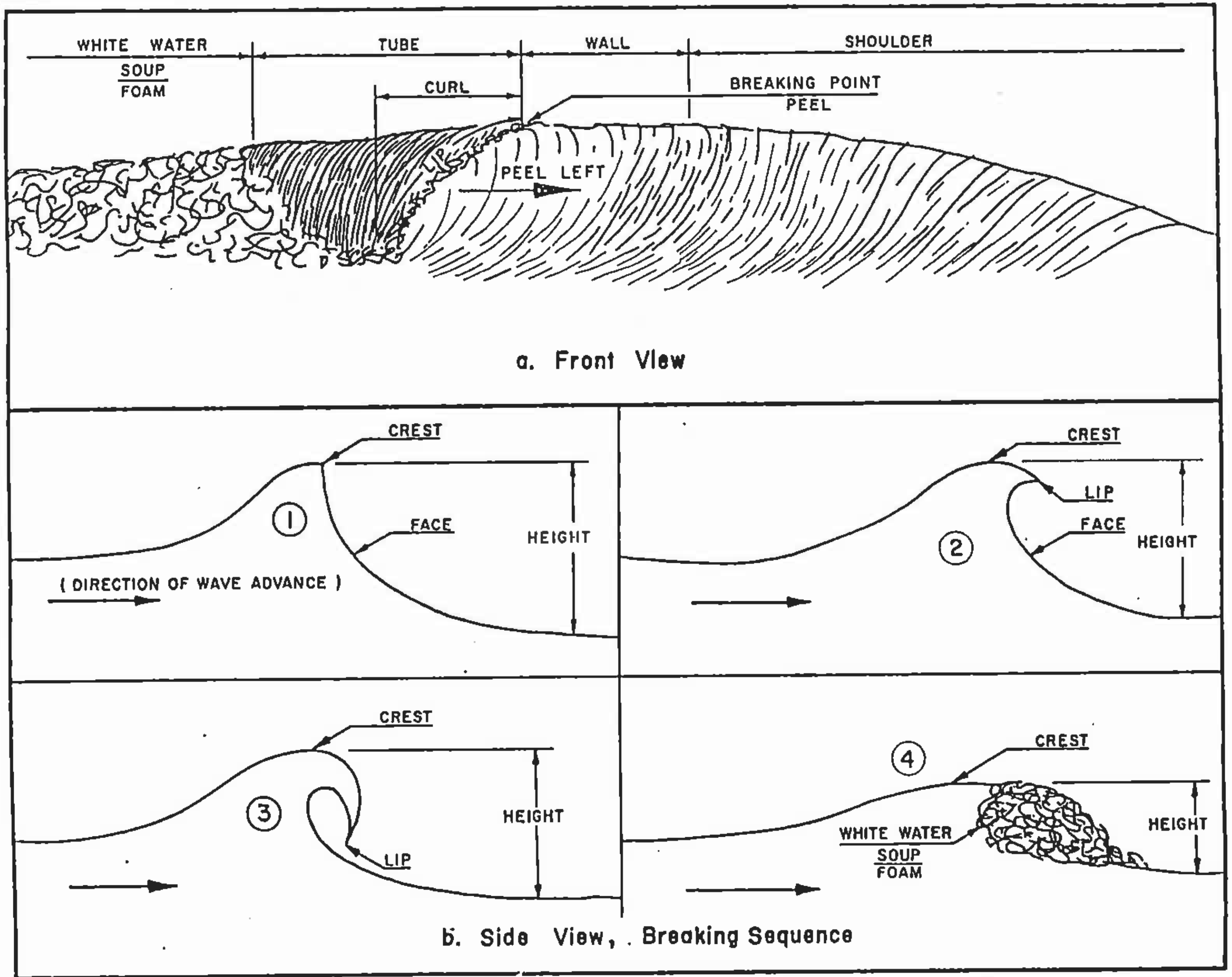
Tweed River Entrance Sand Bypass Project	Surfing Sequence Schematic	Figure 2



a. Front View

b. Side View, . Breaking Sequence

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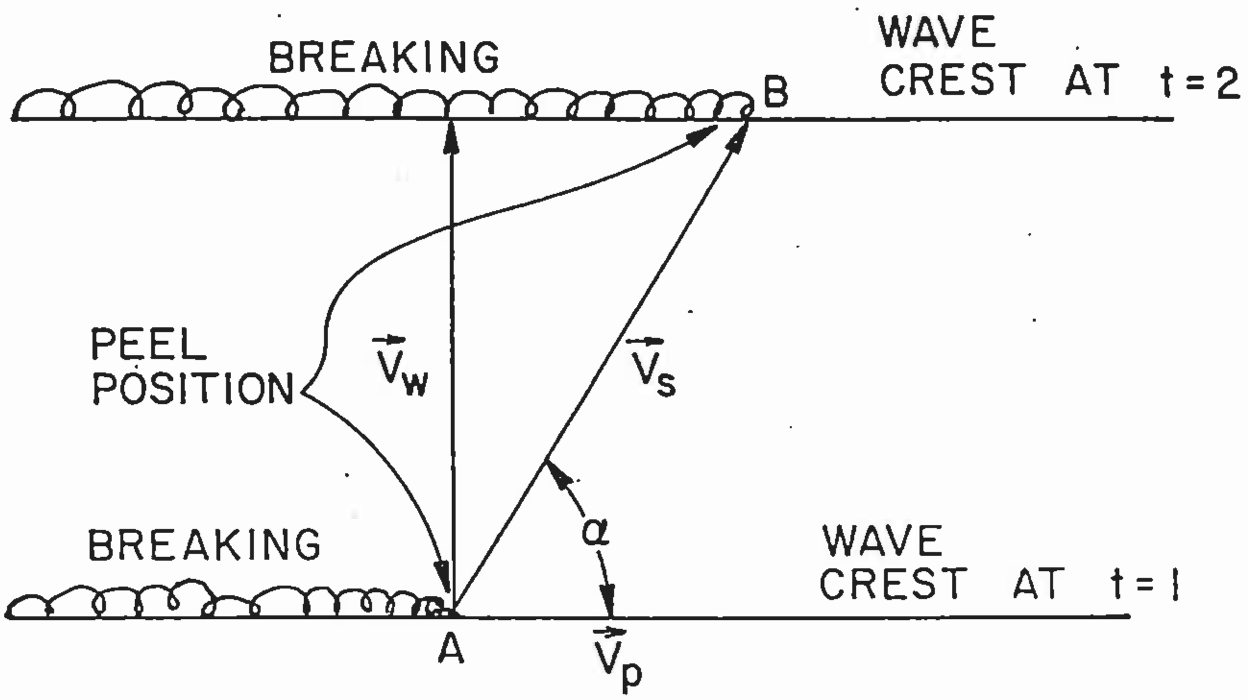
Surfing Wave Terms

Figure 3



$\vec{V}_w$ = VELOCITY OF WAVE
$\vec{V}_s$ = SURFER VELOCITY
$\vec{V}_p$ = PEEL VELOCITY
α = PEEL ANGLE

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Tweed River Entrance Sand Bypass Project	Peel Parameters	Figure 4

Figure 5 represents an objective method of describing surf site characteristics and provides a common basis for comparison of some of the key peel parameters. Of course, there are many other factors to take into account but the peel angle is a key parameter. Skill levels are divided into beginner, intermediate, and expert. These classifications are presented to indicate the level of expertise that may be required to negotiate a given wave condition. They are approximations to allow relative comparison or classification of sites.

The limit of what constitutes a surfable wave has been empirically estimated to be a wave for which surfer velocity approaches about 11 to 12 m per second on larger waves. There are insufficient data to make this an absolute number, but the closer the waves are to this limit, the more challenging the wave is to surfers. Pipeline and Maalaea in Hawaii were key surf sites where this limit was considered by Walker (1974).

Time-sequenced aerial photos or detailed ground surveys for a surf site are rarely available. Hence, the measurement of the peel angle can be approximated by looking at successive waves on a single aerial photograph. Refraction analyses over detailed bathymetry can also aid in defining surf parameters.

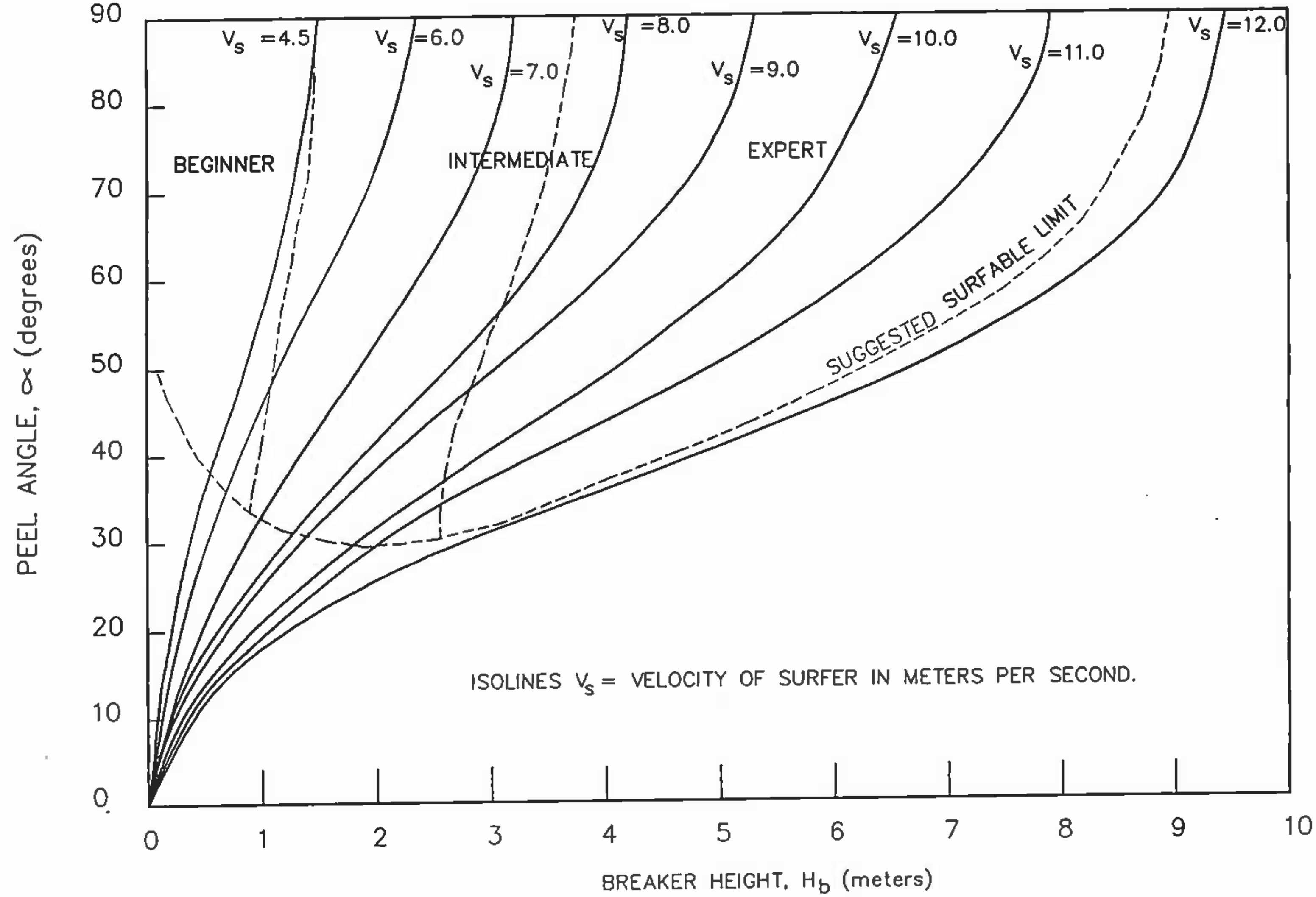
2.3 Wave Transformations

Surfing waves result from an interaction of the wave and the bottom configuration. Waves change direction by refraction as they travel into shallow water. Waves in shallow water increase in height as they propagate into lesser water depths by wave shoaling. Wave energy can be transmitted along the wave crest by diffraction. Most importantly, waves break as they enter water depths that are approximately equal to the wave height. Other phenomena that occur are reflection, dissipation, and other nonlinear transformations of energy to higher and lower wave periods. Many of these secondary effects can affect surfing conditions in significant ways.

Refraction causes convergence of waves over a submerged ridge and divergence of energy over a canyon or channel. Refraction changes the direction of wave propagation, tending to align the wave crests with the offshore bottom contours and the shoreline. To a first approximation, waves may break along a depth contour over a short reach. Classical standard methods of analyzing wave refraction by linear wave theory are not sufficient for a detailed analysis of a surf site: the velocity of wave propagation near the breaker zone can be significantly greater than linear theory suggests, the wave shoaling rate can be greater than linear theory suggests, and wave diffraction must be considered. Standard methods may be adequate for a general description but are inadequate for detailed analyses of waves breaking over a shoal or a reef. Detailed analyses may not be required except for the case of a detailed design or evaluation analysis.

2.4 Breaker Characteristics

Wave heights can amplify by two to three times the height of deep water incident waves depending on the bottom slope, wave period, and wave height relative to the water depth. This height amplification is termed "wave shoaling." Waves break when their height is approximately equal to the water depth on a sloping bottom. Waves also break when their steepness, H/L, exceeds 1/7. Figure 6 illustrates a nonlinear shoaling relationship developed by Walker (1974) specifically for surf site analysis. The shoaling relationship was observed



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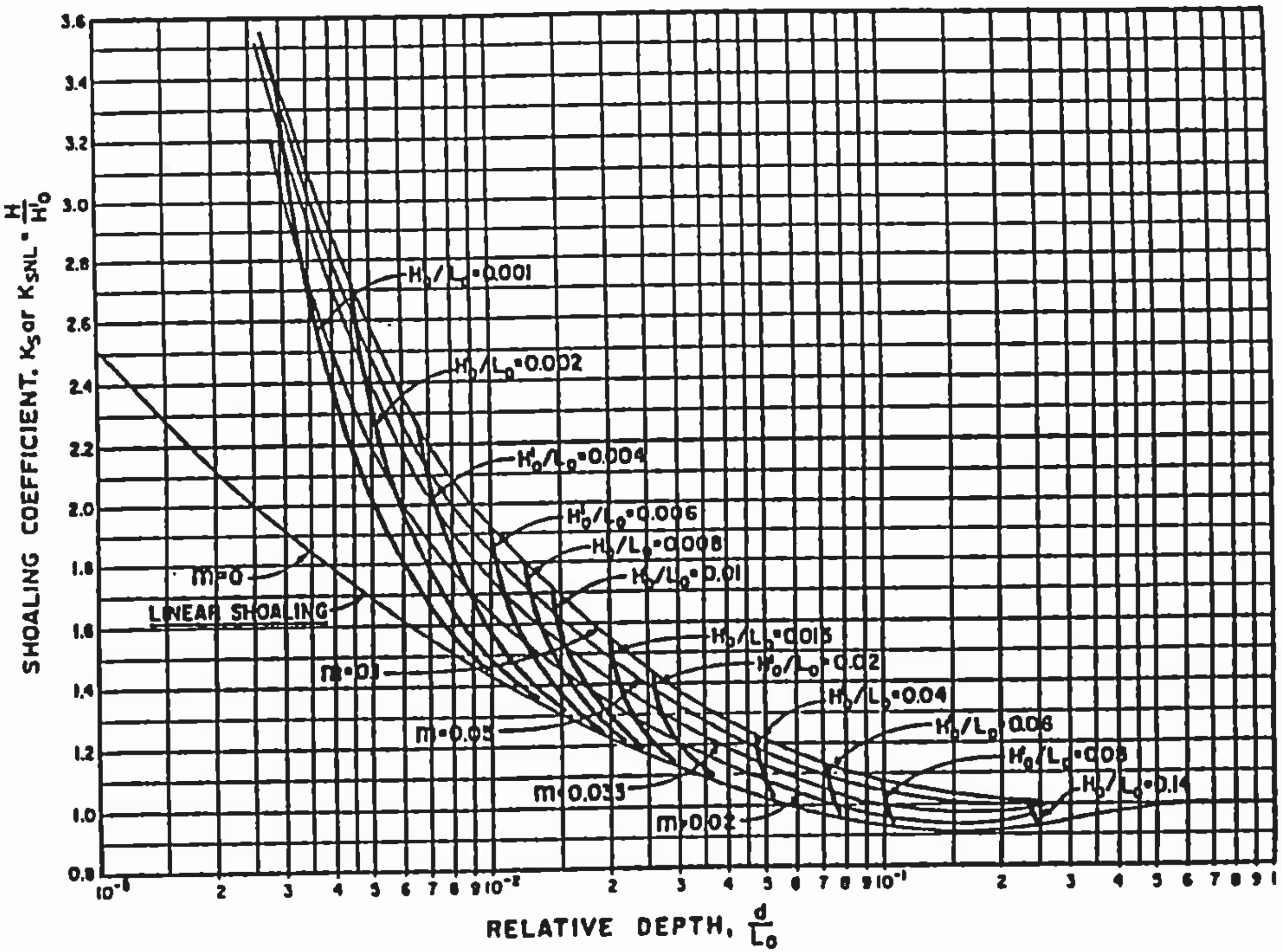
Peel Angle And Breaker Height

Figure
5



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Shoaling Coefficients, Linear And Nonlinear

Figure 6

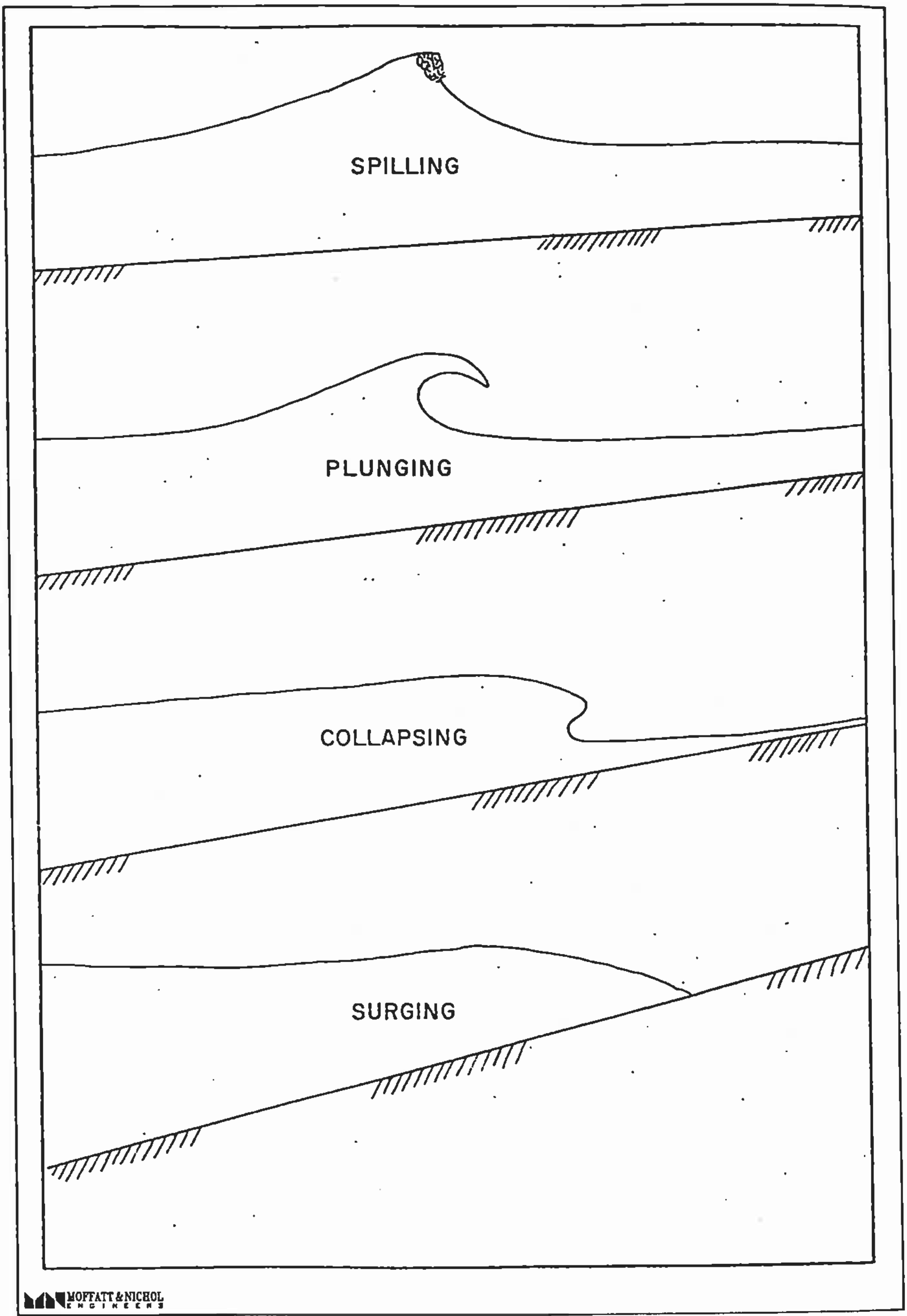
in the field and verified in a model study. The figure provides a transition from the empirical breaking relationship of LeMehaute (1968) for waves breaking on a slope and the linear wave theory shoaling coefficient. It indicates how wave height amplification H/H_o is a function of the ratio of depth, d, to deep water wave length, L_o, for various bottom slopes, m, and wave steepness, H_o/L_o, where H_o is the deep water wave height. The empirical relationship indicates that linear theory is acceptable where the wave is at a depth greater that twice the breaker depth. In water depths less than twice the breaking height, the wave height amplifies rapidly with a small change in water depth.

Figure 6 indicates the rapidity with which waves amplify over a sloping bottom and also indicates the breaker height. Short-period waves of low H_o/L_o and high d/L_o are reasonably well predicted by linear wave theory. However, waves with high H_o/L_o and small d/L_o amplify rapidly with a small change in depth near the breaker zone. Surf sites require only a small change in bottom depth to produce a controlled peel. Consequently, a beach bar with only minor changes in depth can have a major influence on the peel and other breaking properties.

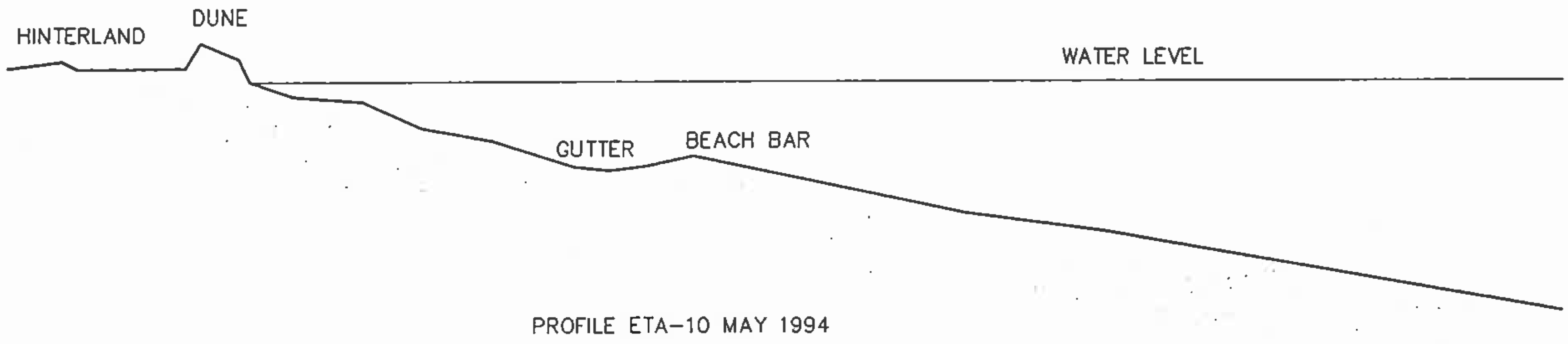
The most desirable surfing waves break in a form where the crest curls over the wall of the wave, creating a "tube" or "pipe." The form of the breaker depends on the degree to which the crest throws over the wave face. Figure 7 shows breakers classified as spilling, plunging, collapsing, and surging. Spilling and plunging waves are favored by surfers. Galvin (1968) presented a dimensionless parameters defining breaker type where $K = H_b m/gT^2$, where H_b is the breaker height, m is the slope (horizontal:vertical) seaward for breaking, g is the acceleration due to gravity, and T is the wave period. Waves surge and collapse when $K < 0.003$. Waves spill when $K > 0.068$ and plunge between surging and spilling waves. The stronger plunging waves are favored by expert surfers. Battjes (1976) presented a slightly different "surf similarity" parameters, ζ, using the same variables. This parameter could be used, but does not yield additional clarification for present purposes.

A wave does not necessarily break in response to instantaneous or very small bottom changes. Generally, the wave responds to a seaward slope on the order of ½ wave length. The shoreward slope is believed to influence the breaker type and quality as well. Breakers must travel a certain distance to produce desirable, high quality surfing waves. Abrupt depth changes can produce collapsing waves with no face to ride.

Waves and currents will alter the configuration of a beach profile. A beach bar is an important bathymetric feature that controls the quality of surfing waves in many coastal regions. Figure 8 shows a typical profile taken at Letitia Spit. The slopes and bar characteristics change as a function of wave and tide conditions. Hence, in this report, some of the area's general bar slopes have been taken as representative of the bar slopes and shapes that may occur during given surf conditions. Beach bars may form during a strong storm wave condition and take several days to respond to smaller waves. Waves may pass over the beach bar that was developed during a low tide and high surf. The beach bar surf site is an ever-changing one. However, sand must be present for the beach bar to form. Generally, the beach bar will have a steeper bottom slope than that of the underlying substrate. In the area of Greenmount, the underlying substrate appears to be a gently sloping, rocky bottom. The beach bar has a steeper bottom slope and tends to produce a stronger plunger-type wave than a rocky bottom.



Tweed River Entrance Sand Bypass Project	Breaker Classification	Figure 7



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Beach Profiles

Figure
8

2.5 Wind Effects

Wind is a primary factor in defining the quality of surfing conditions. A wind blowing from the shore into the direction of the approaching waves - called an offshore wind - is favorable. A wind with a component following the wave propagation - called an onshore wind - is unfavorable. Figure 9 schematically shows favorable and unfavorable wind conditions for surfing.

2.6 Bathymetric Features

Four basic bathymetric configurations that support surfing wave form are schematically shown in Figure 10. These configurations are a straight and parallel contoured beach, a promontory (or headland), a shoal (or reef), and a channel.

Waves arriving at an angle to the straight and parallel bathymetric contours generally produce a fast peel. Often, wave refraction aligns the wave crests close to the beach bar alignment, and a close-out wave exists. If the waves can arrive at a steep angle to the beach bar, a long, smooth peel may be formed, creating a classic ride. As will be discussed later in this report, the beach bar at Greenmount is subjected to southeast waves which create such a condition. Waves arriving at an acute angle over a beach bar have a high rate of littoral transport.

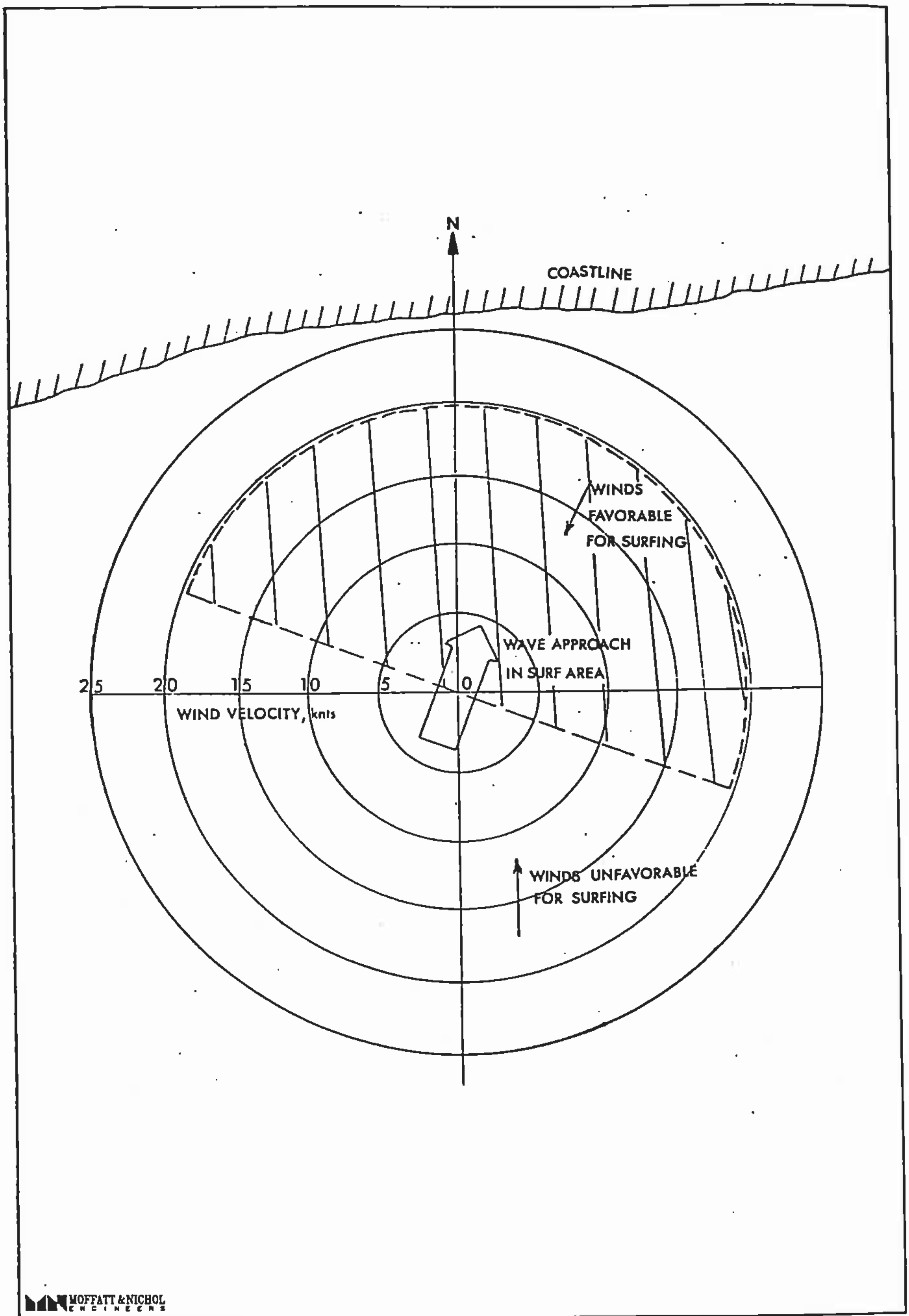
However, beach bars generally are not smooth, straight features. Rip currents and shore-normal channels or gutters (troughs) run through them, creating depth changes that are sufficient to induce a local peel. These features that induce undulations in the beach bar form are important for nearshore circulation and surfing, yet they are not readily identifiable features in bathymetric surveys because the surveys generally do not have a high enough density of soundings to adequately define these features.

The promontory is a distinct undulation in the shoreline. Usually a rock reef or coral reef outcropping protrudes into the surf zone creating depth contours at an angle relative to the incident waves. Training walls, breakwaters, and groynes may also produce promontory sites.

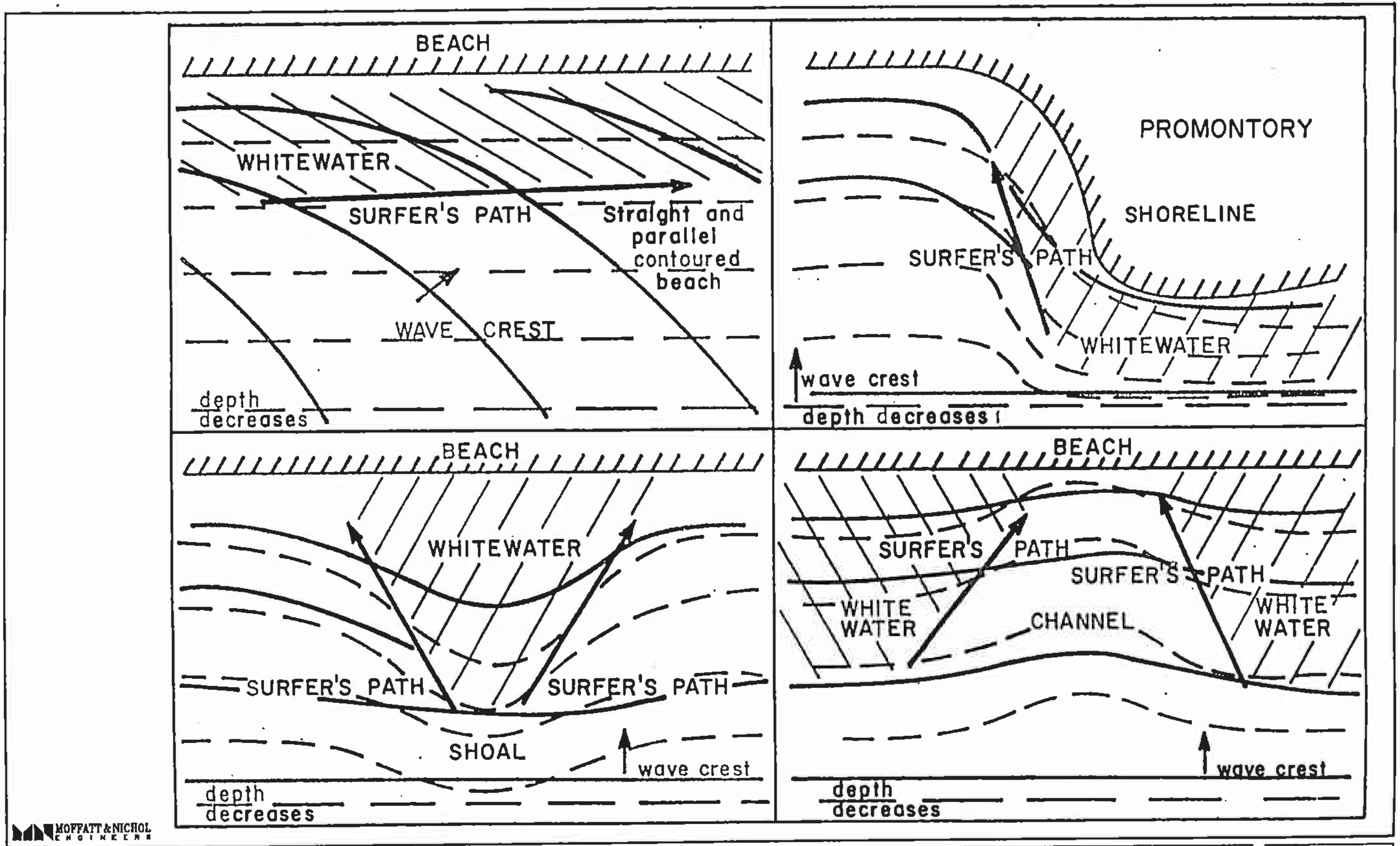
Stable bottom materials that hold shape as a mound in the surf zone may create a shoal (or reef) configuration. Surfers may ride to the right or left, depending on the configuration. Beach bar formations may also be considered to be a shoal-type site.

A channel site is formed by a depression oriented into the advancing wave crest. A promontory or shoal site might be associated with a channel. Channels are often manmade and their presence may contribute to good surf conditions.

Another important bathymetric feature that influences surf quality is a river delta or entrance channel tidal bar. This feature can be large and dynamic, in a form that can induce complex wave interactions that produce excellent surfing opportunities. Figure 11 shows wave refraction over the Tweed entrance bar prior to the dredging performed in early 1995 by the "Pearl River." Waves propagating from the east-southeast direction with 10 second periods arrive at the south side of the bar and bend toward Duranbah Beach. Waves arriving at the north side of the entrance bar also bend into the center of the entrance bar to arrive at Duranbah Beach. The Tweed entrance bar is a large enough feature that both sets of waves



Tweed River Entrance Sand Bypass Project	Wind Criteria For Favorable Conditions At A Surf Site	Figure 9



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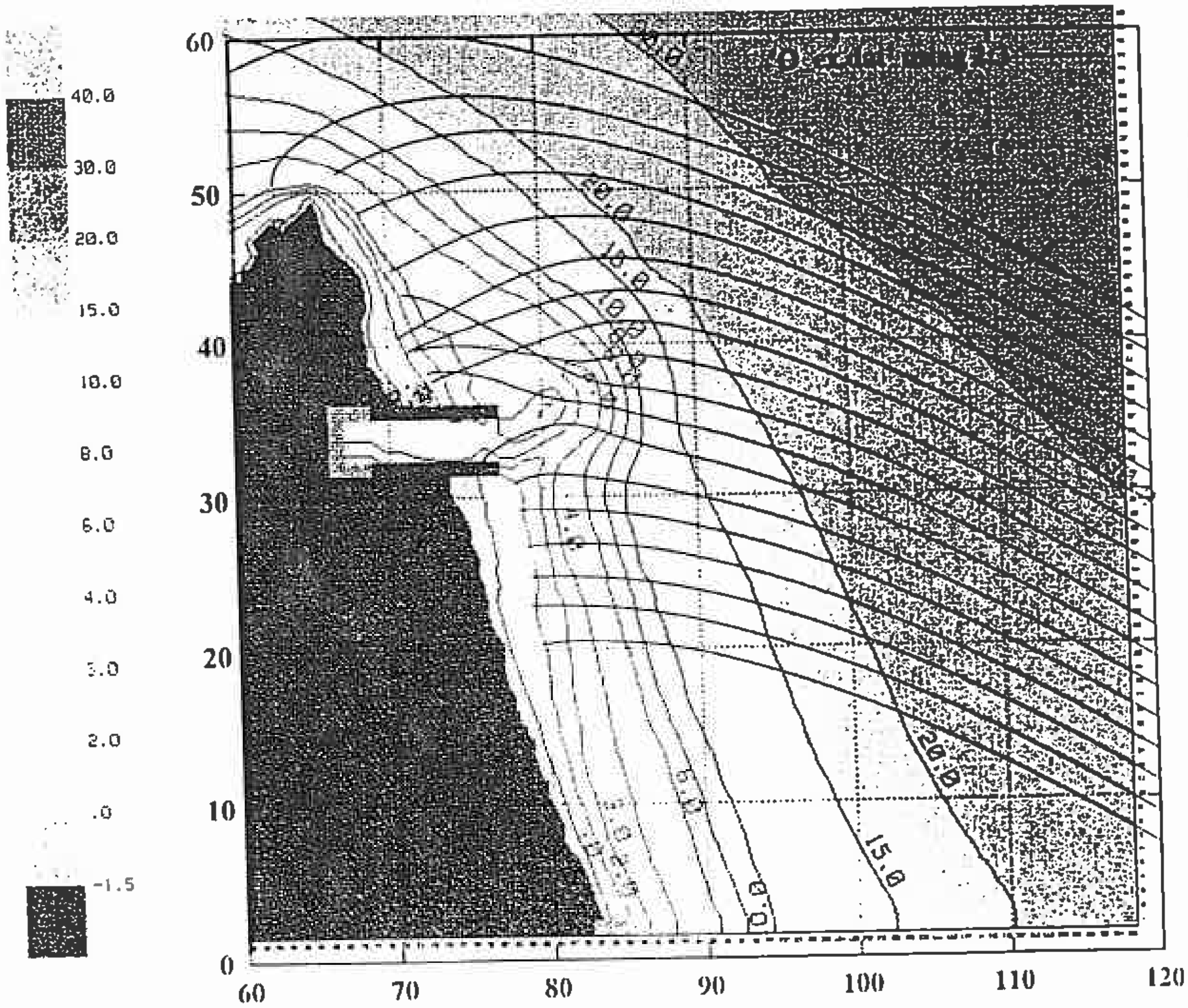
Basic Surf Site Bathymetric Configurations

Figure 10



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Tweed River Entrance Sand Bypass Project	Wave Refraction - Pre dredge Entrance Bar	Figure 11

approach shore simultaneously on the north side of the inlet. The wave amplitudes superpose; the combined wave amplitude is the instantaneous sum of the individual water surface elevations. The resultant wave height may be double the height of the individual waves and may break at its high point. This results in a wave form that resembles an "A-frame" from a shore vantage point. Waves arriving at a given point from multiple sources may also reinforce with similar results.

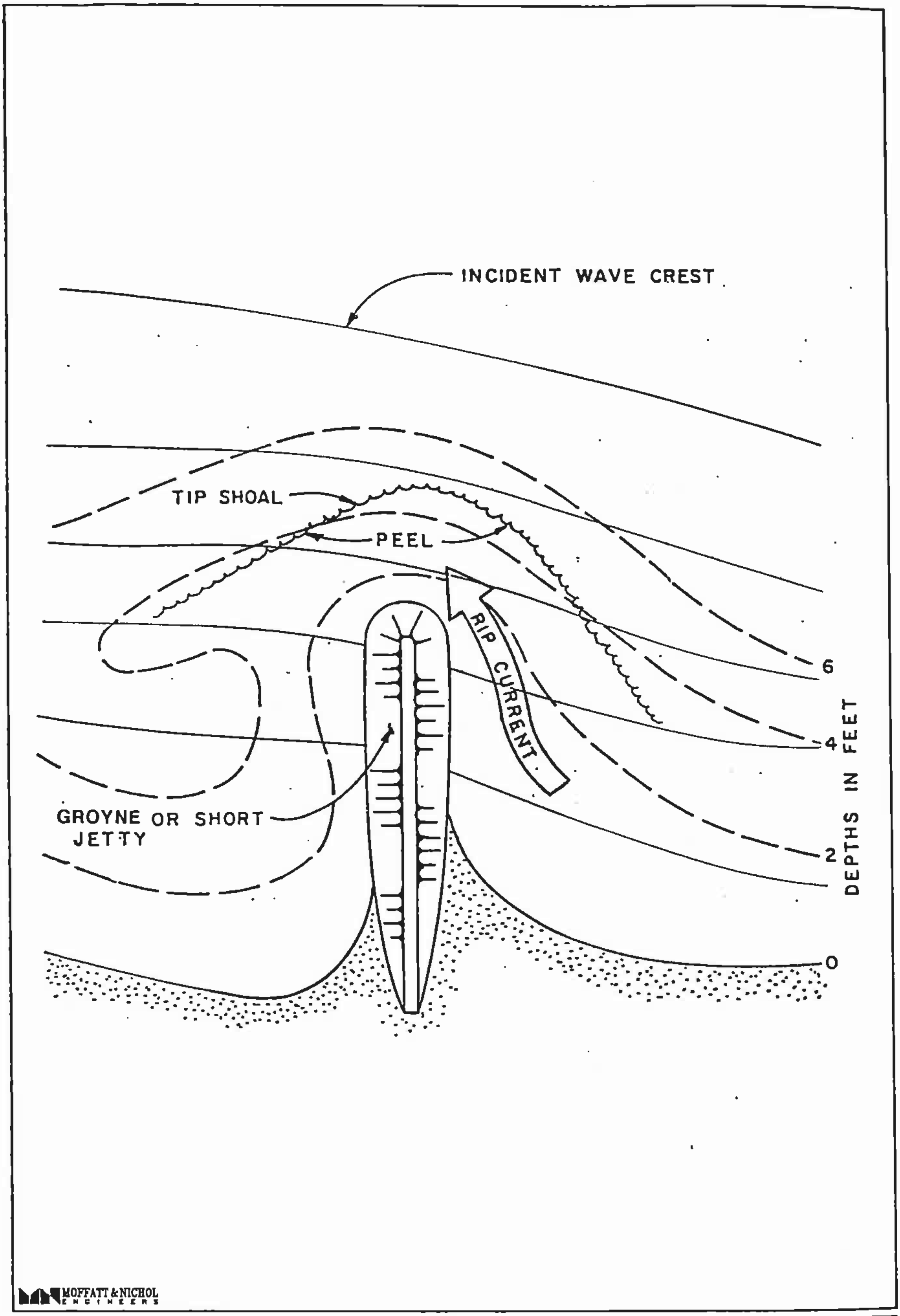
2.7 Manmade Features

Coastal structures - including training walls, breakwaters, and groynes - may enhance surf by inducing waves to arrive at an angle to the structure-induced bottom contour perturbation. Groynes can create or enhance a surf condition in two manners. Firstly, waves breaking at an angle to the beach or bar induce a longshore current that transports sand. A large part of the sand transport occurs over the bar formation. A groyne that protrudes into the bar may deflect the bar seaward and therefore create depth contours at an angle to the incident waves. This may be manifest in a rip at the groyne and a deflected bottom contour, as shown in Figure 12.

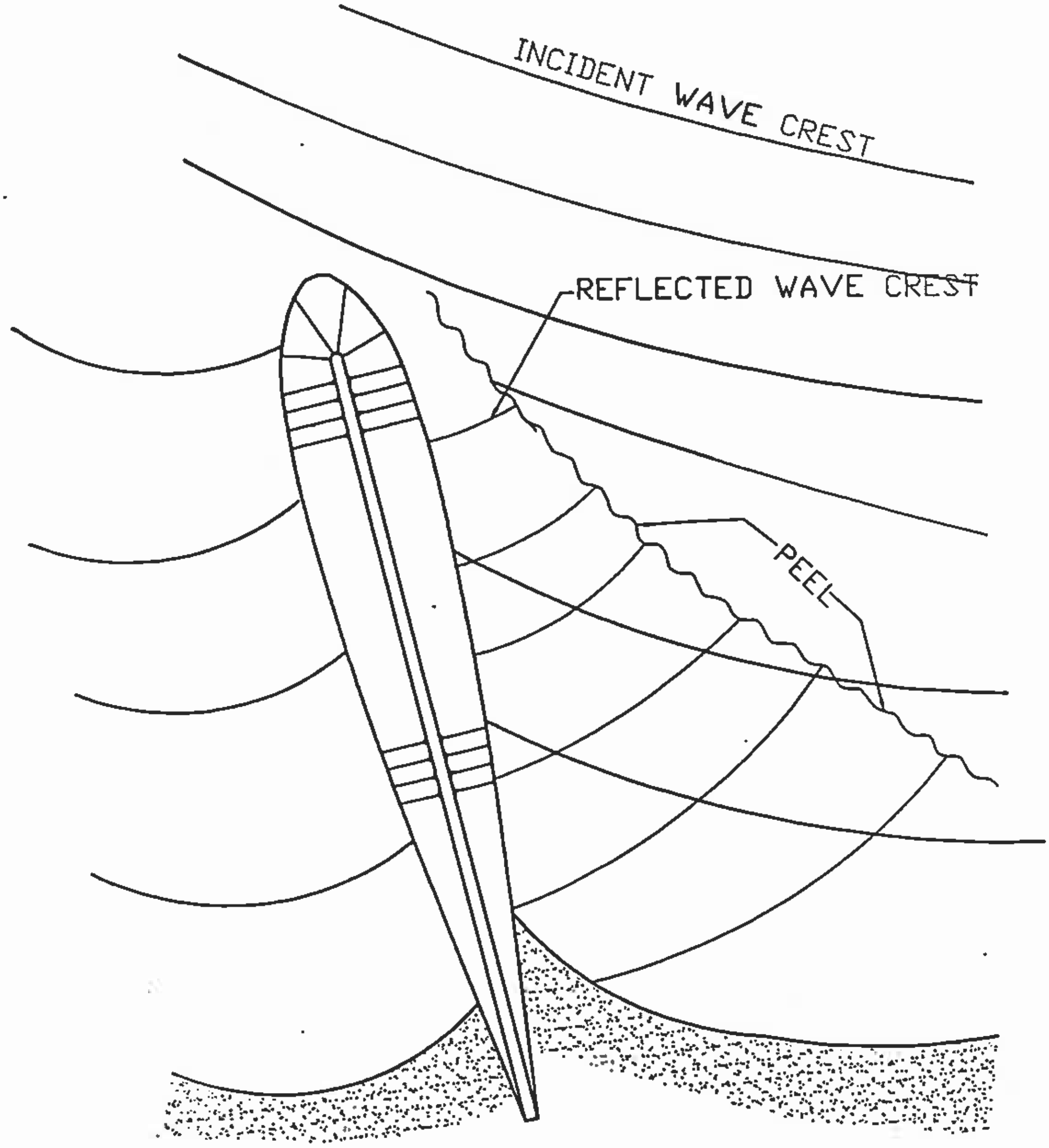
Secondly, long structures - such as a long groyne or training wall - can reflect waves. The reflected waves superpose with the incident waves, as shown in Figure 13. This superposed reflection scheme creates the famous Newport "Wedge" in California.

2.8 Access

Access to the waves is important. Surfing is most popular where the waves break in the most desirable form and access is readily available. Many excellent surf sites may seldom be surfed as a result of great distances or lack of a local access. Many sites may be heavily surfed as a result of ease of access to acceptable waves. Sites that are less popular now may eventually become crowded as the population shifts and as accessibility increases.



Tweed River Entrance Sand Bypass Project	Surf Site At A Groyne	Figure 12



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Tweed River Entrance Sand Bypass Project	Reflection At Breakwater Or Groyne	Figure 13

3.0 SITE CONDITIONS

3.1 Location

The study area extends from Letitia Spit, in New South Wales, northward through the Tweed River to Kirra Beach, in Queensland. Figure 14 shows the names and locations of important features and locations referred to in this report. The Tweed estuary was stabilized by small training walls in 1890, and these training walls were extended to their present position in 1964. Murray et al. (1996) discuss the Tweed River Sand Bypassing Project.

3.2 Oceanographic Conditions

The tide range is approximately 1.3 m (mean spring range) and tides are semidiurnal. Water depths are relative to Australian Height Datum (AHD).

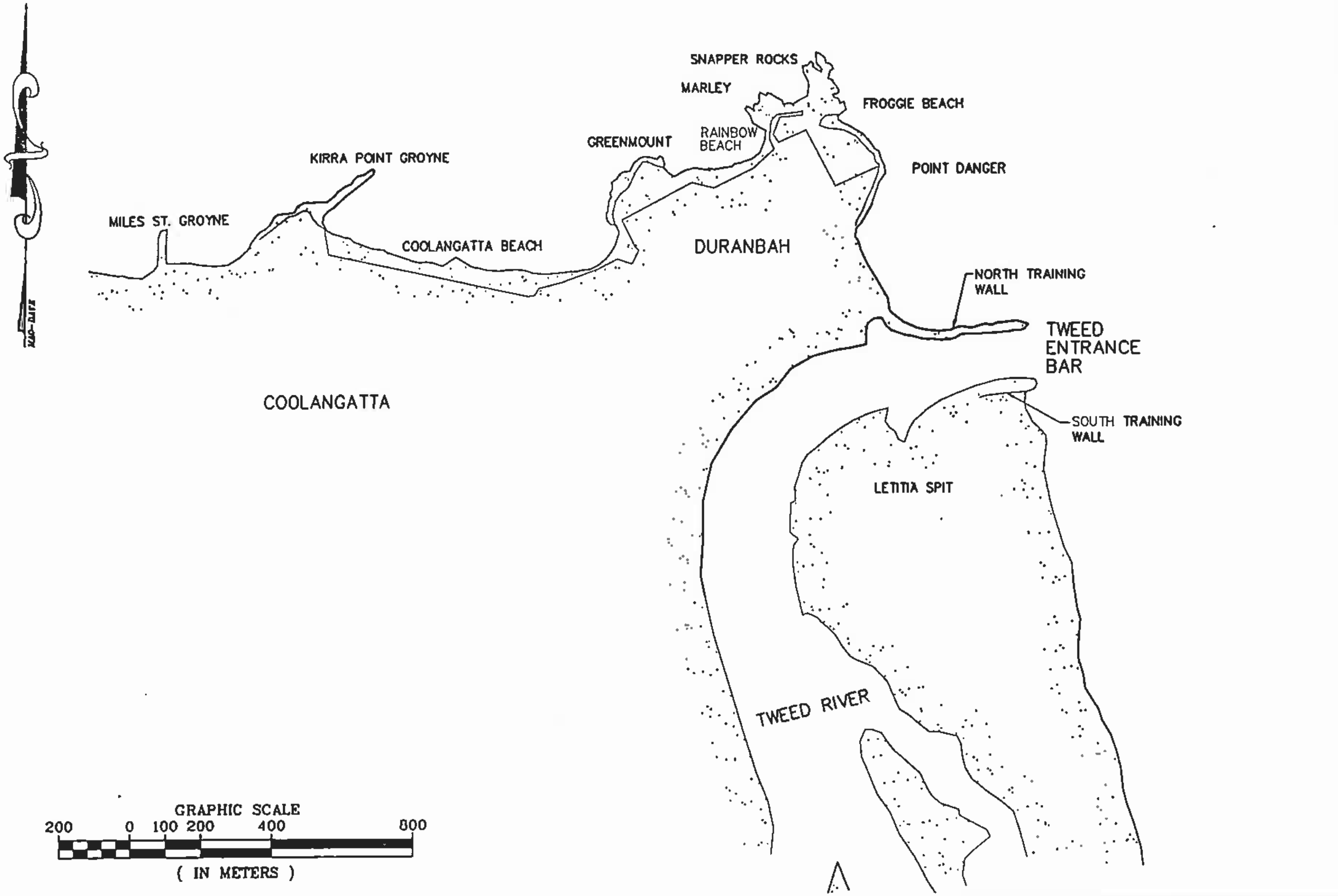
The predominant waves are east to southeast sea and swell generated by easterly tradewinds driven by a belt of high-pressure system south of the study area. The high-pressure anticyclones can shift northward to generate waves from the northeast on occasion. The anticyclones can be interspersed with extratropical cyclones that generate southeast swell.

The meteorological weather pattern changes in the winter. These winds are predominantly from the southwest to the northwest. Consequently, offshore winds do not produce waves at the site. On occasion, a strong winter storm in the Tasman Sea and farther to the east can generate south and southeast swell that reach the study area.

Afternoon sea breezes can occur during warmer days. The sea breezes generate a short-period chop that may spoil the wave surface. Figure 15 shows the wind frequency diagram for Southport for morning and afternoon time periods.

Tropical cyclones forming to the north of the study area can generate east and northeast swell arriving at the Queensland Beaches. As the tropical cyclones move southward, the winds and waves intensify and shift to the east and southeast. On the average, three tropical cyclones occur per year in Queensland waters. The effects of each cyclone last for three to five days. Few of the tropical cyclones make direct landfall at the study area. However, when they do, the effects can be major on coastal features, including beaches, bars, and rivers.

Deep water waves have been measured by Waverider Buoys offshore of Kirra Beach in 16 m of water, off Brisbane in 80 m of water, and off the Tweed Heads in 25 m of water. Conservation Data Reports W09.2 and W51 in August of 1994 summarize the basic wave data from 1988 to 1994 and from 1976 to 1994 respectively. Tables 3 and 4 summarize the wave data.



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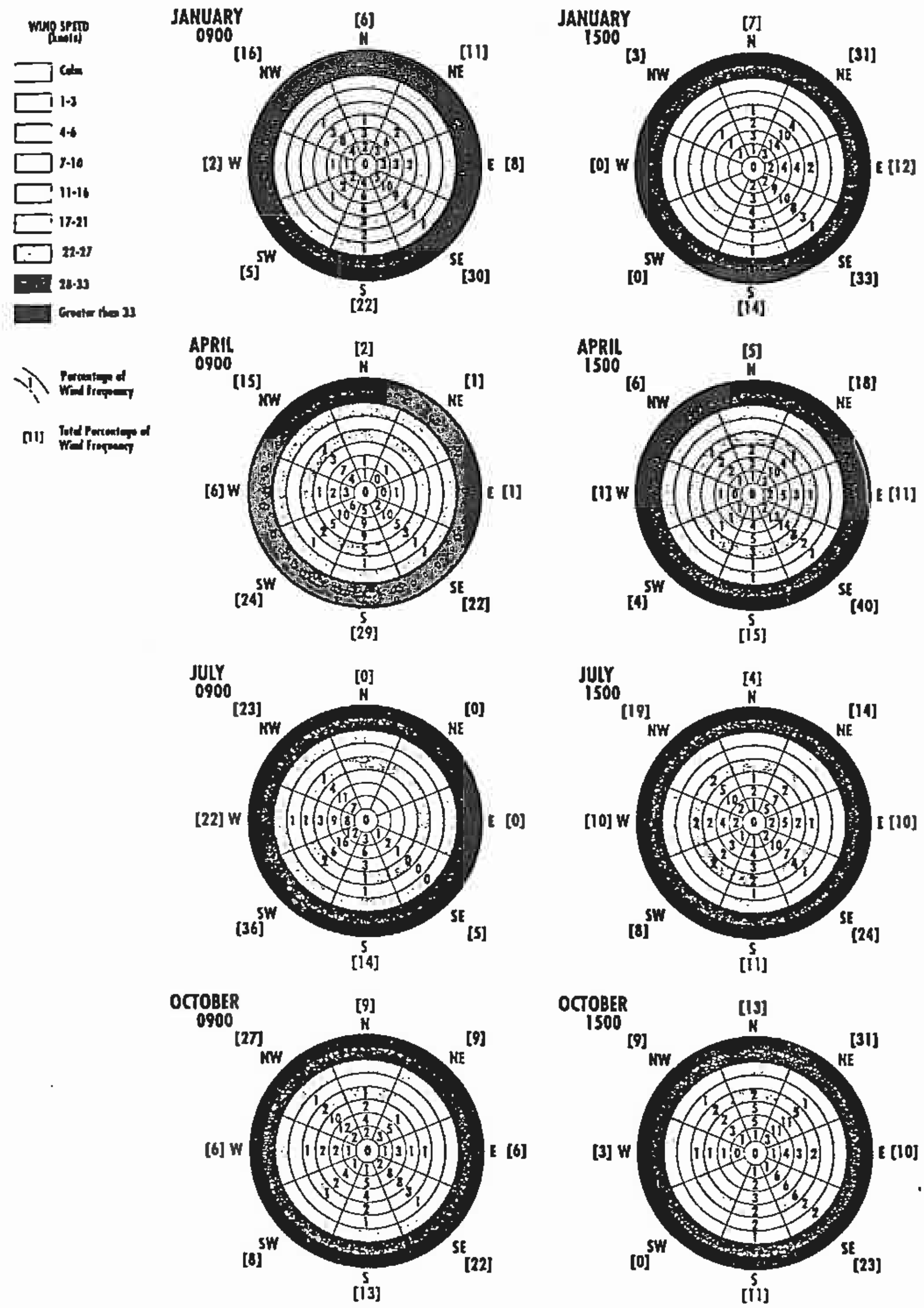
Location Map

Figure 14

WIND FREQUENCY DIAGRAM – SOUTHPORT



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Tweed River Entrance Sand Bypass Project	Wind Frequency Diagram - Southport	Figure 15

TABLE 3
KIRRA WAVE DATA IN DEPTH = 16 m

	Percent Probability of Exceedance			
Wave Height (m)	1	2	3	max. Height, H_s
summer	30	3	0.4	4.5
winter	18	1	0.03	3

TABLE 4
BRISBANE WAVE DATA IN DEPTH = 80 m

	Percent Probability of Exceedance			
Wave Height (m)	1	2	3	max. Height, H_s
summer	90	20	3	7
winter	90	16	2	5

The predominant wave period ranges from 8 to 12 seconds, but 14-second waves do occur. Wave direction is not given by the buoy data during the period of record cited in the Delft Hydraulics Laboratory (1970) characterization of waves. Waves are from the southeast from April to August about 60 percent of the time. Waves from the southeast arrive about 40 percent of the time the remainder of the year. Waves from the northeast occur most frequently from September to December at about 15 to 25 percent of the year and about 10 to 15 percent of the remainder of the year. Waves from the east occur most frequently at about 30 percent of the time between December and April and occur 20 percent the remainder of the year.

Along the Letitia Spit beaches and bars, the net average northerly littoral transport rate is about 500,000 m^3/year , but may range from 275,000 to 900,000 m^3/year (Patterson Britton, 1994).

The grain size of the quartz sand is about 0.25 mm and originates from the beaches to the south. The beaches are characterized by a mild slope of about 1:100 (vertical:horizontal) in the nearshore zone. A shore-parallel bar may be 100 to 500 m offshore. The Tweed entrance has a major impact on littoral transport. The tidal and river currents transport sediments into and out of the river and some of the sand is stored on the bars. Some of this storage is long-term and is released only during major rain storm events. The released sand is then naturally bypassed to Duranbah Beach and Snapper Rocks, where it is free to be transported along the beaches to the north. The sand transported around Snapper Rocks nourishes the beaches, bars, and offshore areas, where the best surfing conditions are found.

Sand is delivered north of Snapper Rocks by southeast and east waves. The height of the southeast waves is greatly diminished as waves refract around Snapper Rocks; the sand transport rate decreases below the rate at which sand is supplied to the offshore. Hence a deposition occurs and is slowly moved by these waves. The east and northeast waves more directly affect the coastline at Greenmount, Rainbow, and Coolangatta. Transport may be most rapid during these wave events to remove sand and transport it to Kirra and the beaches to the north.

The mismatch between delivery at Greenmount and the transport from Greenmount makes this reach of beach and bar highly variable. Sand accumulates and is depleted in discrete lumps. Two situations that can take place will produce very different results due to this variability. One of these situations consists of a series of small northeast storms and normal southeast waves. This situation is ideal for maintaining surfing conditions. The other situation is a weak southeast swell season and a strong northeast and east season; this situation depletes the beaches and bar and degrades surfing.

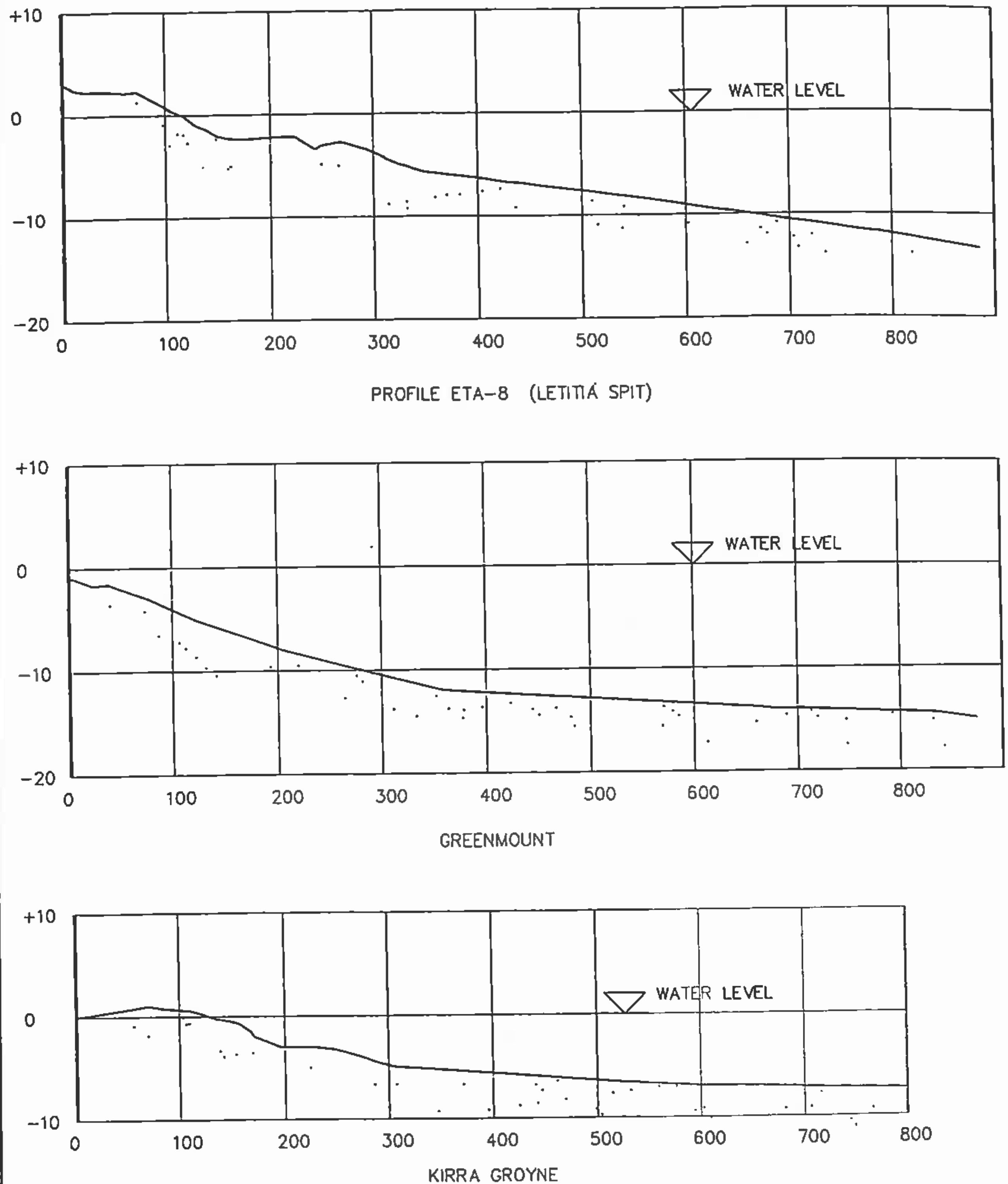
3.3 Estuary

The Tweed River has a watershed catchment area of 1,000 km^2. The river flow is on the order of 3,000 m^3/second during major floods. The tidal prism is about 10 million m^3. The tidal flow during spring conditions is 900 m^3 /second. In 1994, the entrance had a sizable entrance bar that extended 1,000 m offshore. According to Patterson Britton (1994), the bar had been accumulating sand at a rate of about 100,000 m^3 /year and naturally bypassing sand at a rate of about 400,000 m^3 /year. In 1994, the bar had a volume of about 7,500,000 m^3 of sand. The natural channel depth on the bar below AHD was about 3 to 3.5 m and the training walls are 180 m apart, centre to centre. The training walls extend 100 m offshore of Letitia Spit. The south training wall is considered saturated in that it can no longer accumulate additional sand. The north training wall at Duranbah extends seaward of Duranbah Beach and prevents much of the sand from entering the channel by littoral transport in the swash zone.

Recent dredging in 1996 by hopper dredges has removed about 2,300,000 m^3 from the entrance bar. This represents about one-third of the total volume in the bar that existed prior to the dredging that commenced in March 1995.

3.4 Beaches and Bars

The beaches are very dynamic features that respond to wave and current forces. The bathymetric profiles indicate a gentle beach slope in the swash zone, gutters about 1 to 2 m deep, and a bar located about 200 to 300 m from the beach with a crest elevation ranging from 1 to 3 m deep. Bars are important feature governing many of the surfing conditions along this coast. The seaward slope of the bars and beach profiles, from a depth of about 1 to 4 m, is about 1:30 (V:H). Surfers report poor breaking conditions from Greenmount to Kirra if the beach bar is not present. Figure 16 shows a range of bottom profiles at Letitia Spit and Kirra Point.



NOTES:

1. ALL MEASUREMENTS IN METERS
2. VERTICAL DATUM AHD

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Tweed River Entrance Sand Bypass Project	Beach And Offshore Profiles	Figure 16

4.0 SURF SITE ANALYSIS

4.1 General

The following discussion describes the surf conditions at each of the major sites in the study area and addresses issues pertinent to the impacts that may result from sand management practices. The description starts at Letitia Spit and proceeds northward along the direction of the net littoral transport. Because the conditions at each of the sites depends to a great extent on the condition of the beach bars, the characteristics of the sites will change with different bottom conditions. Classification of the peel angles and breaker types is made to formulate a basis for identification of potential impacts of sand management practices and to help identify the value of modifying or defining the sand management practices to enhance surf quality where feasible. Table 5 summarizes the surf sites estimated from the aerial photographs and from bathymetric contours. The wave heights were estimated from the photographs. Breaker types were estimated based on an assumed wave period of 12 seconds.

4.2 Letitia Spit

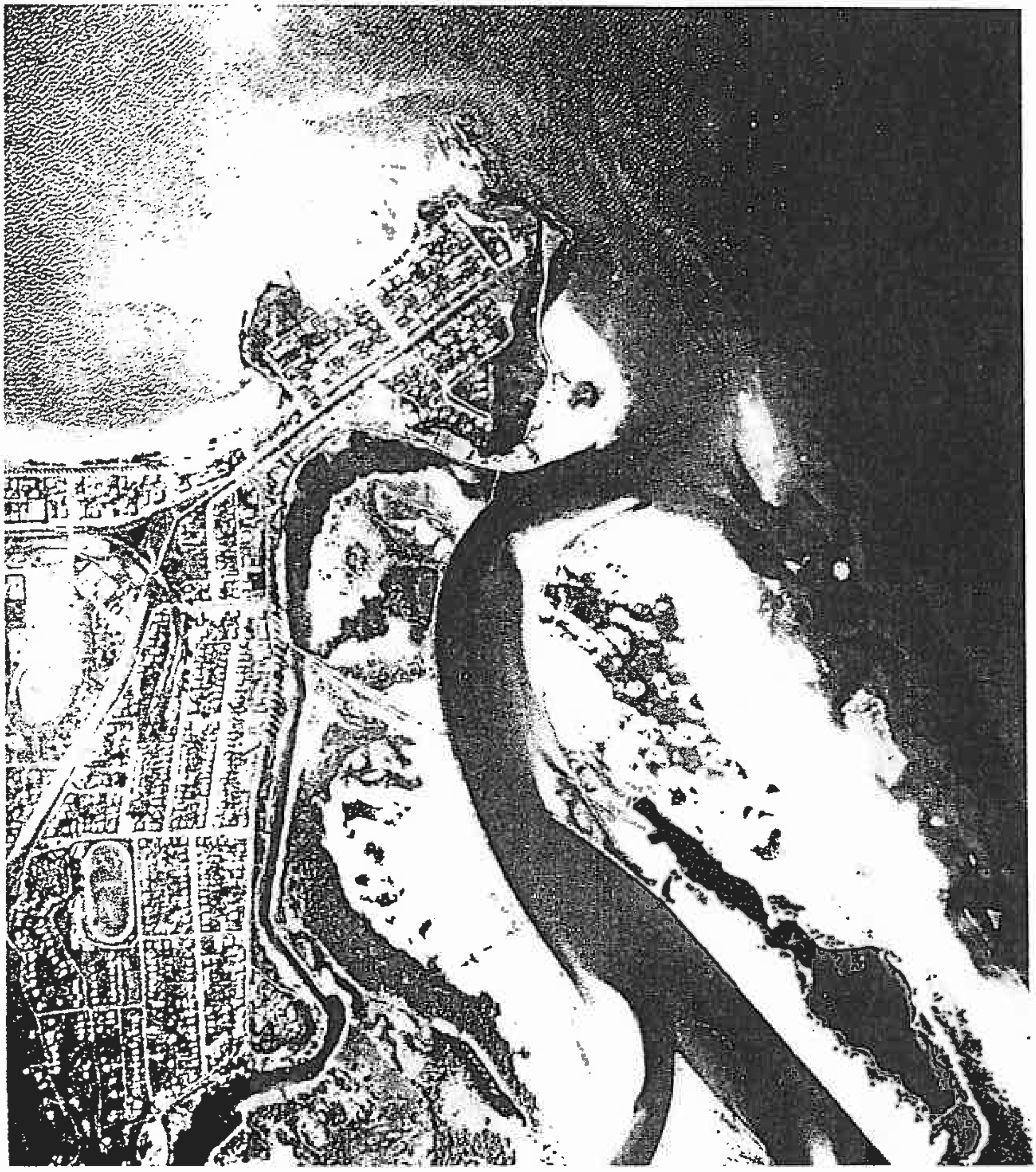
Letitia Spit is a long, curving beach that is located between Captain Cook Island and the Tweed entrance bar. The Tweed entrance bar has a major influence on this beach. The beach at Letitia Spit has a fine sand on a 1:40 (V:H) slope in the swash zone. Slopes will be referred to herein as vertical to horizontal (V:H), as measured normal to the shore, whenever possible. A well-developed sand dune exists in the backshore. A bar and gutter system dominates the offshore. The beach bar is the primary feature that influences surfing waves in this area.

The beach bar at Letitia Spit is a highly dynamic feature that varies as a function of tide, currents, wave characteristics, and sand supply. It is 200 m offshore, has a depth of 1 to 3 m, and has a seaward slope of 1:30. Seaward of the beach bar, where wave heights may exceed 3 to 4 m, the slope is 1:100. The surf is probably characterized most of the time as a spilling breaker type with an onshore wind. Figure 16 shows a typical beach and bar profile. The bar is generally a continuous feature for the length of beach. Waves refract into the bar and break with a very acute peel angle of about 20 degrees for waves from the southeast. These conditions are not conducive to good surfing. However, bars are not a completely uniform, continuous feature. Small, shore-normal gutters through the bars allow water to circulate seaward in rip currents. Under mild wave conditions, the beach bar formation may migrate shoreward and meld onto the beach. Photograph 1 shows the complex beach formation. Under many conditions, less-defined sites may offer surfing opportunities on this beach. Rides of less than 100 m would be likely with wave heights of about 1 to 3 m.

Letitia Spit is not well known as a surf site, perhaps because of the availability of much better sites with easier access and the onshore winds that accompany the better wave conditions. Letitia Spit is away from major population centers and is served by an unpaved road. Letitia Spit may one day become a popular site under certain conditions as other sites become more crowded and if access is improved in the future.

TABLE 5: Peel Angles

Date of Photo	Site	Peel Angle (deg)	Length of Ride (meters)	Breaking Depth (meters)	Bottom Slope (h:v)	H_s (meters)	T (seconds)	K	Ride Type	Breaker Type
1973	Duranbah	30	200	2	67	1	12	0.0144		plunge
	Duranbah	50	200	2	67	1	12	0.0144		plunge
1976	Duranbah	70	250	3	67	2	12	0.0289	left	plunge
1976	Duranbah	60	250	3	67	2	12	0.0289		plunge
1961	Duranbah	65	400	3	100	3	12	0.0647	right	plunge
1974	Duranbah	43	100	1	100	1	12	0.0216	left	plunge
1974	Duranbah	65	100	1	100	1	12	0.0216	right	plunge
5/11/95	Duranbah	60	200	3	200	3	12	0.1294		spill
1961	Duranbah	40	200	2	200	2	12	0.0863	right	spill
1978	Duranbah	40	300	3	200	3	12	0.1294	bar right	spill
1979	Duranbah	30	150	2	200	2	12	0.0863	a-frame left	spill
1979	Duranbah	60	150	2	200	2	12	0.0863	a-frame righ	spill
5/11/95	Tweed	44	200	4	50	4	12	0.0431	left	plunge
1961	Tweed	35	150	2	200	2	12	0.0863	n jetty right	spill
	Tweed	40	200	4	100	4	12	0.0863	bar right	spill
1973	Greenmount	52	600	2	50	2	12	0.0216	bar right	plunge
11/4/96	Greenmount	43	300	2	100	1	12	0.0216	right	plunge
1973	Greenmount	52	400	3	100	2	12	0.0431	right	plunge
1974	Greenmount	68	400	1	200	1	12	0.0431	right	plunge
1965	Greenmount	65	60	0.5	200	0.5	12	0.0216	right	plunge
1969	Snapper	50	600	3	60	2	12	0.0259	right	plunge
10/12/95	Snapper	50	200	1	100	1	12	0.0216	right	plunge
5/29/95	Snapper	45	150	0.5	200	0.5	12	0.0216	right	plunge
1965	Marley	44	50	0.5	200	0.5	12	0.0216	right	plunge
5/29/95	Marley	70	100	0.5	200	0.5	12	0.0216	right	plunge
10/12/95	Marley	45	200	1	100	1	12	0.0216	right	plunge
7/15/95	Kirra Point	30	300	1	100	1	12	0.0216	right	plunge
5/29/95	Kirra Point	45	100	0.5	50	0.5	12	0.0054	right	plunge
11-May	Kirra Point	34	150	1	50	1	12	0.0108	right	plunge
10/12/95	Kirra Point	40	200	2	100	2	12	0.0431	right	plunge
5/25/94	Kirra Point	40	100	1	50	1	12	0.0108	right	plunge



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Tweed River Entrance Sand Bypass Project	**Letitia Split (with bar migrating onshore)**	**Photograph 1**

4.3 Tweed Entrance Bar

The Tweed entrance bar is a major geomorphological feature characteristic of many tidal estuaries around the world. Natural and man-made entrances to embayments and rivers are confluences of strong tidal currents and wave-induced forces. Sediments carried by the tidal currents scour and deposit in a manner that creates bars in the ocean and bars up the estuary channel. Sediment is transported between the river and the ocean as well as along the coast, past the entrance bar. Natural, unstabilized inlets are often free to migrate along the coast, but have the same general characteristics as inlets with training walls. River training walls may stabilize the location of an entrance and consequently the location of the entrance bar. Training walls also influence the location of the beaches by acting as groynes. The entrance bar stores sand and acts as a reservoir and transport path for sediment to nourish the beaches on the opposite side of the channel. The reservoir may release or transport sand primarily during storm-wave or high-wave events; consequently beach nourishment may be sporadic.

An entrance bar creates a very complex set of wave transformations that result in varied surf conditions. The Tweed entrance bar is a major feature that held about 7 .5 million m^3 of sand before the recent bar-dredging program. Patterson Britton (1994) calculated that the bar was accumulating about 100,000 m^3/year of sand through 1995. The bar extended about 1 km offshore, was 1 km wide and had a depth of 2 to 3 m over the outer edge. The slopes on the bar were 1:5 to 1:30 (V:H). A narrow ebb channel ran through the bar with a depth of about 3 to 3.5 m AHD. The entrance bar had several surf sites that were surfed under special wave conditions. The dredging that occurred removed a large portion of the bar; future maintenance and bypass dredging will continue to modify the shape of the entrance bar, thereby significantly influencing the quality of surf opportunities on the entrance bar and adjacent beaches. The following discussion starts with the bar in its pre-dredge condition and progresses toward one possible future condition in which the entrance bar is maintained as a sand trap.

The fully developed entrance bar provides many surfing opportunities by refracting waves thus concentrating energy in various locations over the entrance bar and decreasing waves at other locations. The entrance bar has a convex shape that produces a wide range of wave peel angles. Tidal currents further modify the propagation and behavior of waves. These currents may refract the waves and cause premature breaking during an ebb tide to reduce wave energy arriving at shore or they may delay breaking during a flood tide to increase the wave energy arriving on the shore. Wave refraction over the bar is so intense that waves from a single direction in deep water may be broken into distinct sets of waves near the beach, as is shown schematically in the refraction diagram in Figure 11. Photograph 2 shows this very clearly with a southeast wave condition. Note that the principal wave transforms over the southeast side of the outer bar toward Duranbah, while deeper water waves refracting around the northeast side of the bar reach the same place. This produces a complex wave field over the bar and on adjacent beaches, where the resulting wave is a superposition of several waves that originated from a single direction.

Photograph 2 shows wave refraction over the entrance bar. Southeast waves break on the southeast face, creating a left peel with a 40-degree angle. The breaker height is presumed to be greater than 2 m. These conditions would be classified as excellent intermediate surf condition. The data point for these presumed conditions is plotted in Figure 17. Photograph 3 shows the bar with northeast waves. The break has moved to the north side of the channel, with peel properties being less conducive to surfing as a result of the heavy onshore winds that accompany these waves.

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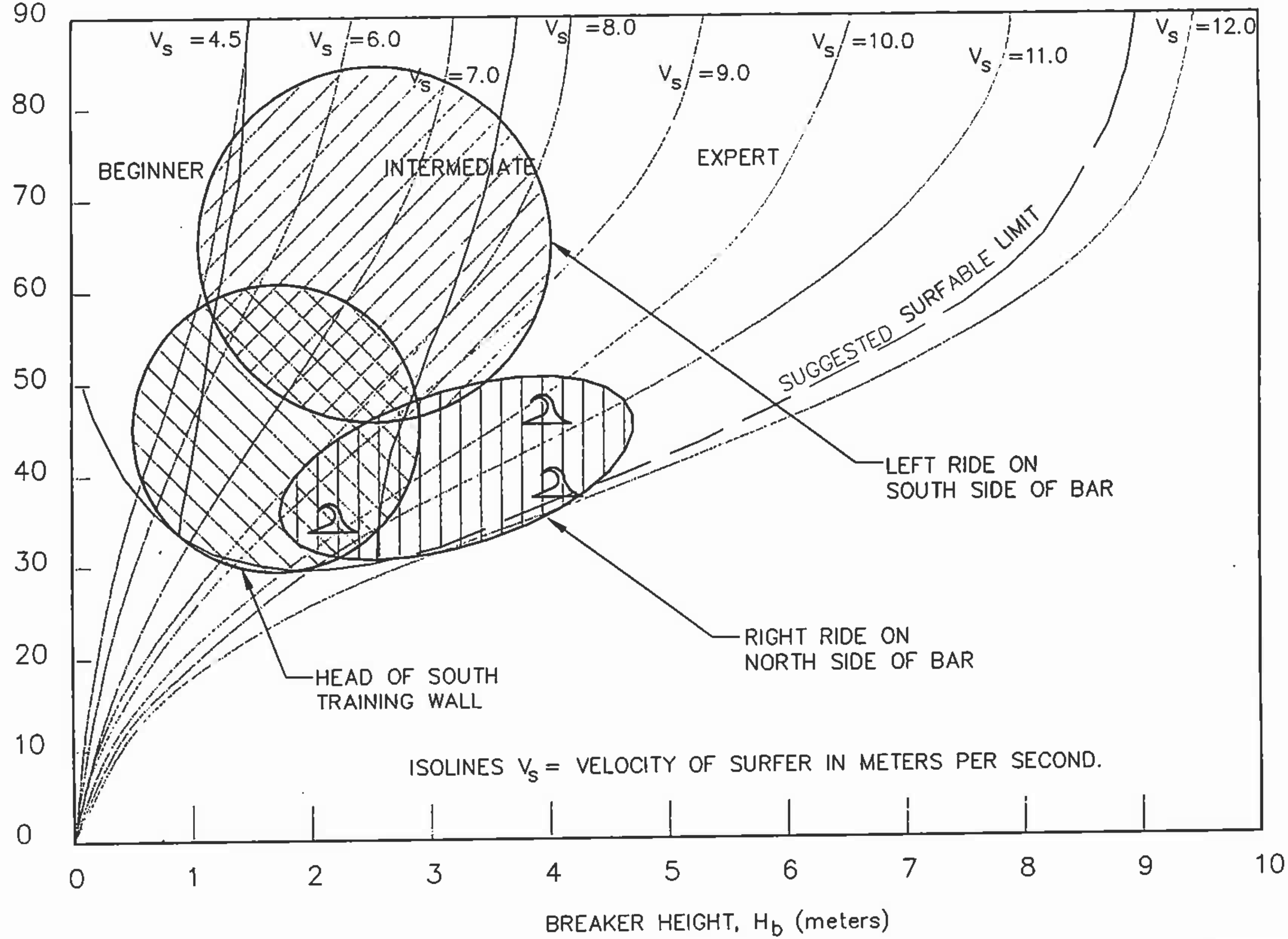
Tweed River Entrance Sand Bypass Project	Wave Refraction over Tweed Entrance Bar	Photograph 2



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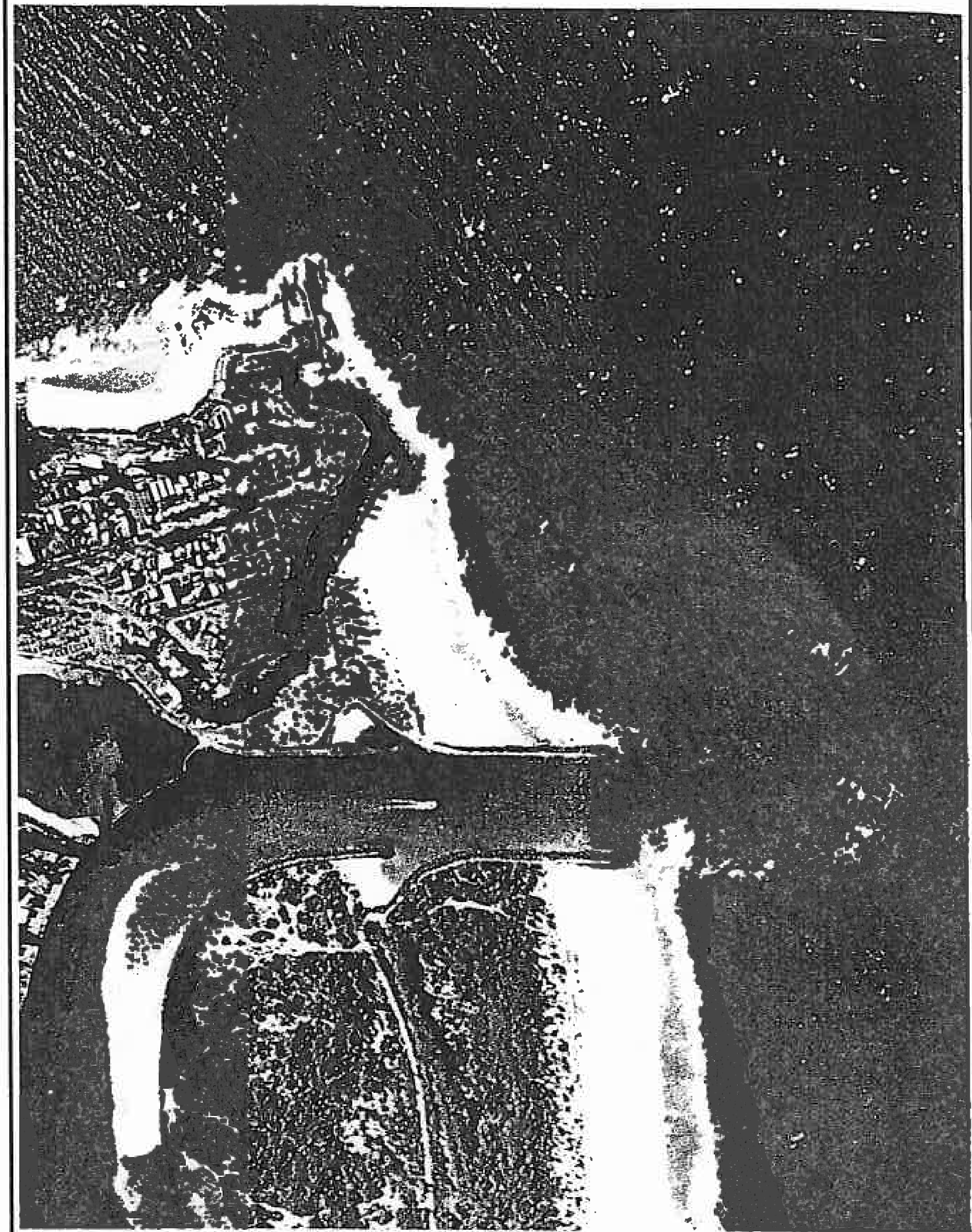
Tweed River Entrance Sand Bypass Project	Tweed Entrance Bar Surf Parameters	Figure 17



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Tweed River Entrance Sand Bypass Project	**Tweed Entrance Bar under NE waves**	**Photograph 3**

The Tweed entrance bar provides many opportunities for surfing which are summarized schematically in Figure 18. Since 1890, the Tweed entrance bar has been in a stable location and had grown to accumulate 7,500,000 m^3 of sand. In 1995-1996, approximately 2,300,000 m^3 of sand have been removed from the bar. This removal has decreased the size and altered the shape of the bar in a very significant manner. The dredging is ongoing at the time of preparation of this report, so the ultimate impact or present condition cannot be assessed at this time. Because this is a man-made dredge cut, time will be required before a new equilibrium is established. The new equilibrium will shape a new bar as a function of future sand management practices. The surf sites on the seaward, or easterly, side of the entrance bar will be significantly modified. Surfing opportunities may exist in the future, but not with the same qualities as those of the former sites. Specific dredge management practices will influence the quality and features of the sites.

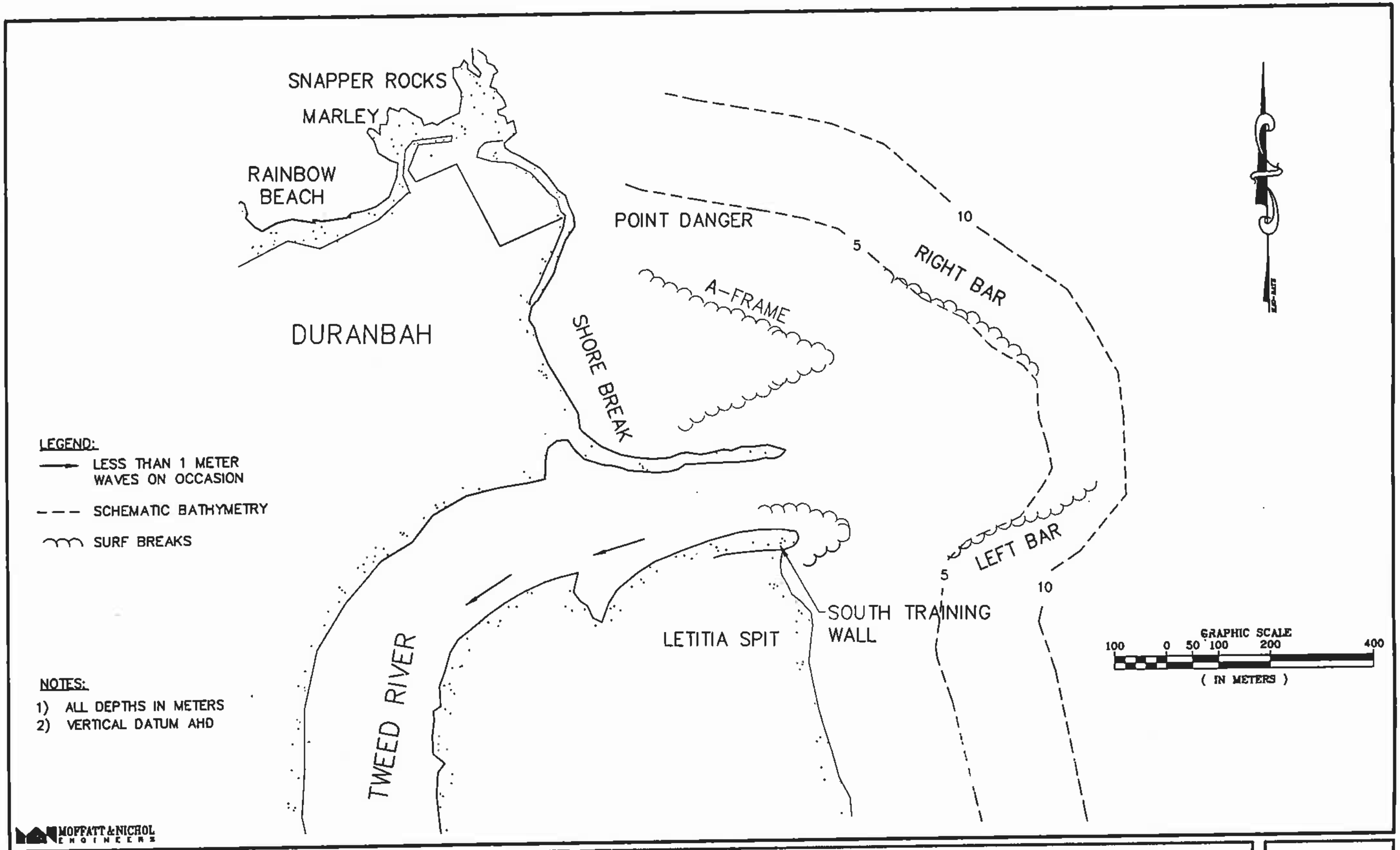
During the August 1996 field trip, surfers were using the area at the end of the south training wall in the entrance channel as shown in Figure 18. On occasion, surfing has been practiced inside the entrance channel, at the head of the old training walls on the south side of the channel, and even farther upstream on the interior bars.

4.3 Duranbah to Snapper Rocks

Duranbah is a world-famous surfing site characterized by a strong shore break and a feature known as "A-frames." Duranbah is heavily used by local and regional surfers. The A-frames form, especially valued by the expert surfer, is a direct result of wave transformations over the fully developed complex entrance bar. Waves refract and split into two distinct wave sets that superimpose locally offshore of the center of the beach, creating a high, peaky wave. The peaky wave forms an initial take-off position that can be as much as twice the height of the incident waves. Rides can be to the right or left, with a wide variety of peel angles. Measured peel angles taken from the photographs indicate that they are on the order of 40 degrees. Photograph 4 is a ground level view of an A-frame with a surfer on it. The wave can have a plunging to spilling type, depending on tidal elevation and wave characteristics.

Duranbah is also is also characterized by a shore break with acute peel angles and a strong plunging breaker type. The bottom slope is estimated to be 1:30 (V:H) for 1- to 3-m waves. The characteristics of the Duranbah shore break and the A-frame breaks under pre-dredge conditions are plotted in Figure 19. Figure 11 shows wave refraction over a typical bathymetry taken in 1994, prior to the entrance bar dredging. Figure 20 is a refraction analysis carried out for the Tweed Bypassing EIS/IAS *(Technical Appendix II)*. It shows the wave height contours over the bar under the pre-dredged condition. The wave heights are amplified to be over twice the height of the adjacent beaches at Snapper Rocks and at Letitia Spit as a result of the complex refraction over the entrance bar. The entrance bar has steep outer-bank slopes, and a shallow channel runs through the bar.

The entrance channel and a gutter were located about 600 m offshore and were shore-parallel. This gutter has a seaward slope of 1:40. The wave breaker form may "see" a flatter slope if it arrives at an angle to the slope feature. The gutter is 3 to 4 m deep. Waves proceed onto a bench that is 2 to 3 m deep. Depending on tide, wave, and bottom conditions, the surf may break in a plunge or a gentle spill. The dynamics of sand transport over the bar produce a wide variety of bottom conditions and water depths, which are difficult to generalize with the available data. The complex wave transformations, the hard plunge, and fast peel give A-frames surf qualities that are an extremely highly regarded surfing resource.



Tweed River Entrance Sand Bypass Project	Tweed Entrance Bar Surf Sites	Figure 18

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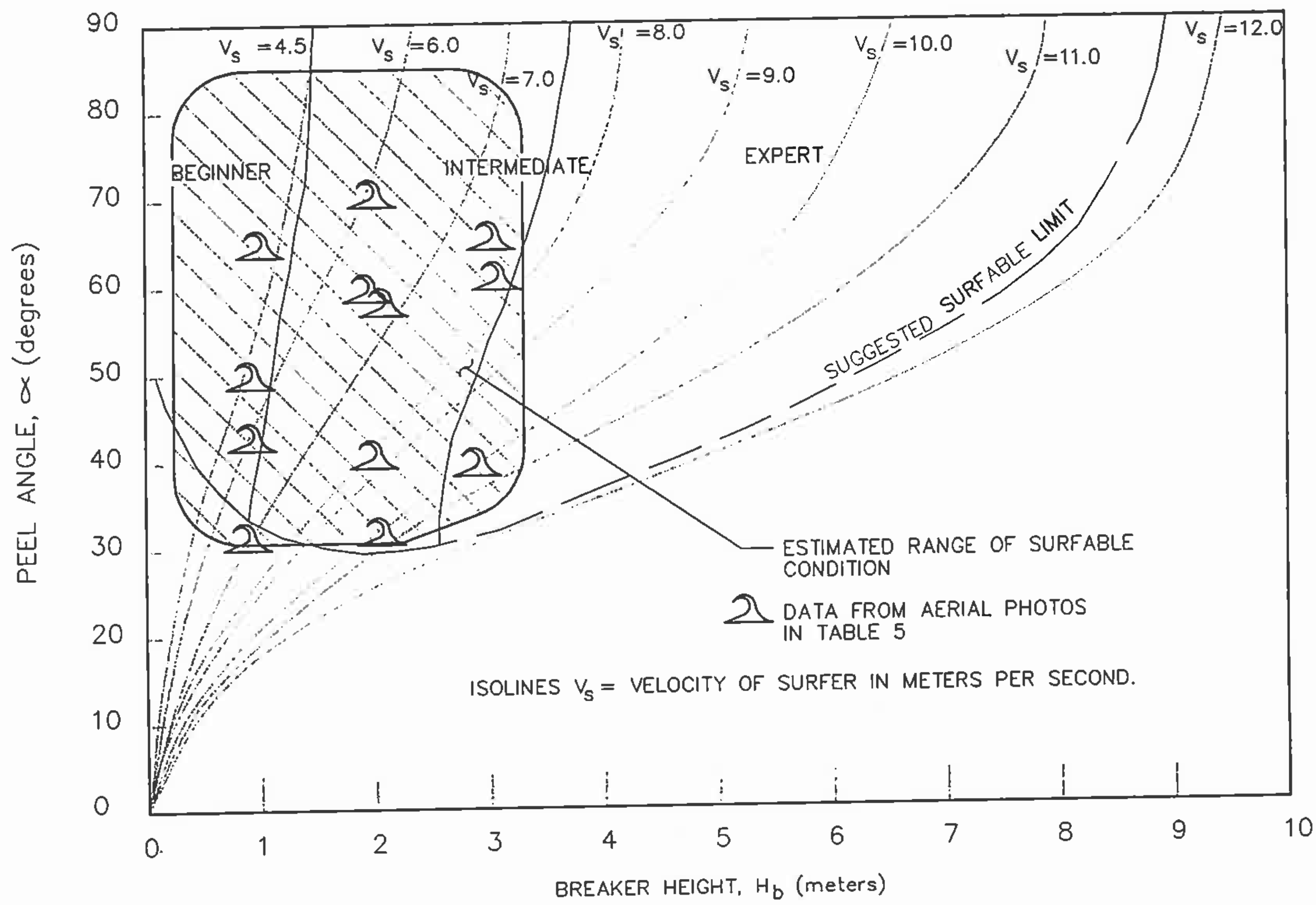
PHOTO BY JOLI

Tweed River Entrance Sand Bypass Project	Duranbah "A-Frames" (From Ground Level)	Photograph 4



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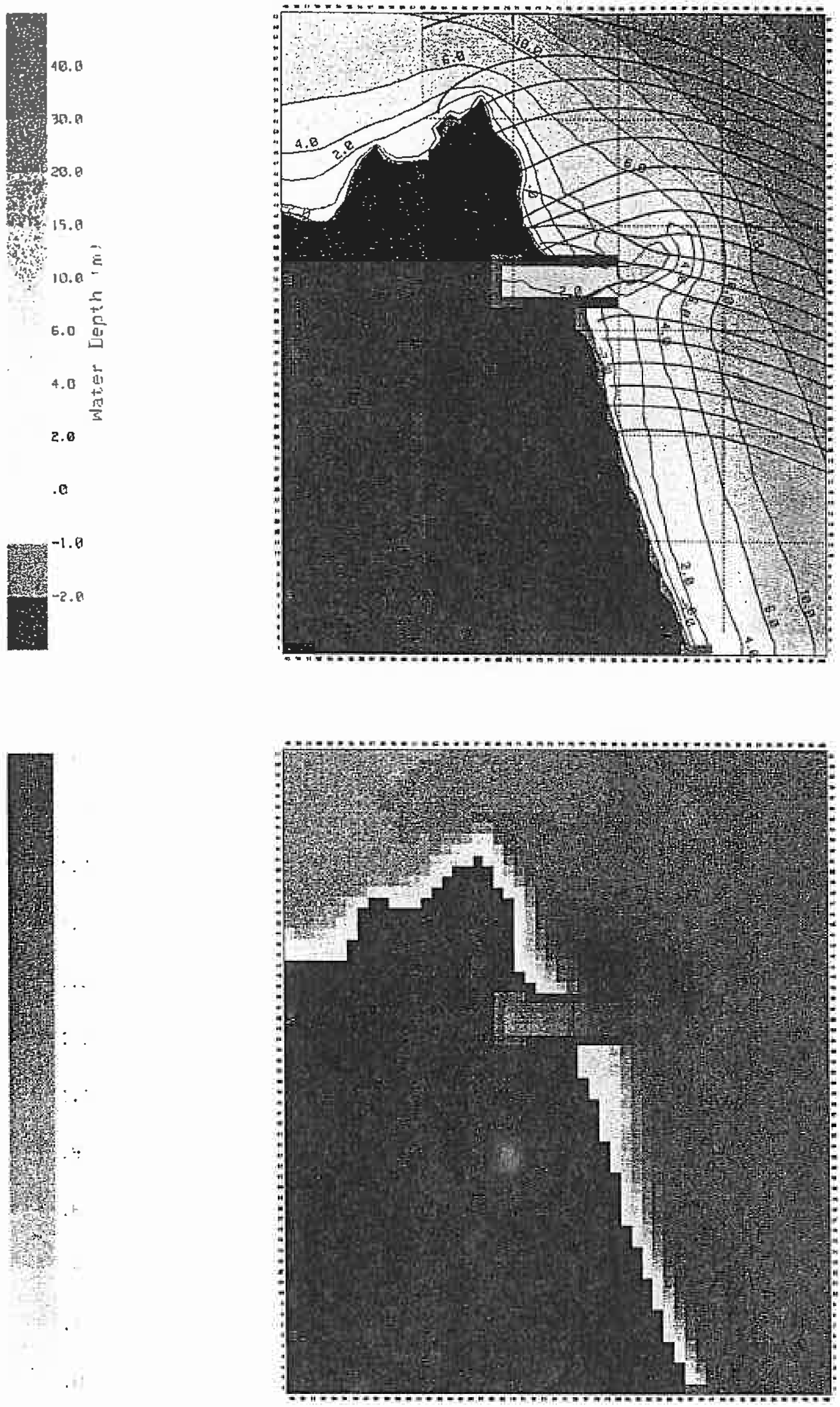
Tweed River Entrance Sand Bypass Project	Duranbah Surf Parameters	Figure 19



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Tweed River Entrance Sand Bypass Project	Wave Refraction - Pre dredge Bar Bathymetry	Figure 20

The entrance bar dredging by the "Pearl River" and the "Krankeloon," which started in May 1995, has taken about one-third of the total volume of the Tweed entrance bar and has placed the sand into the Queensland beach system. Sand had been trimmed from the seaward edge steepening the offshore slope to 1:5 (V:H) and straightening the convex entrance bar form. The Stage 1 dredge plan was revised during the course of dredging to preserve as much of the entrance bar off Duranbah to preserve surfing. The August 1996 bathymetry and wave refraction for the same southeast wave conditions as those shown in Figure 20 are shown in Figure 21.

The dredging project has influenced the surf quality at Duranbah. For two months after the dredge had finished the project, the surf quality was reported to be mushy and of less than optimal quality. In late October 1996, three months after dredging had removed the sand from the bar, Bruce Lee reported that Duranbah had some of the best surfing in many years. A considerable amount of sand remained on the entrance bar to influence refraction and shoaling. Wave and tidal inlet-induced currents reshaped the entrance bar, redistributed material, and adjusted the slopes of the entrance bar.

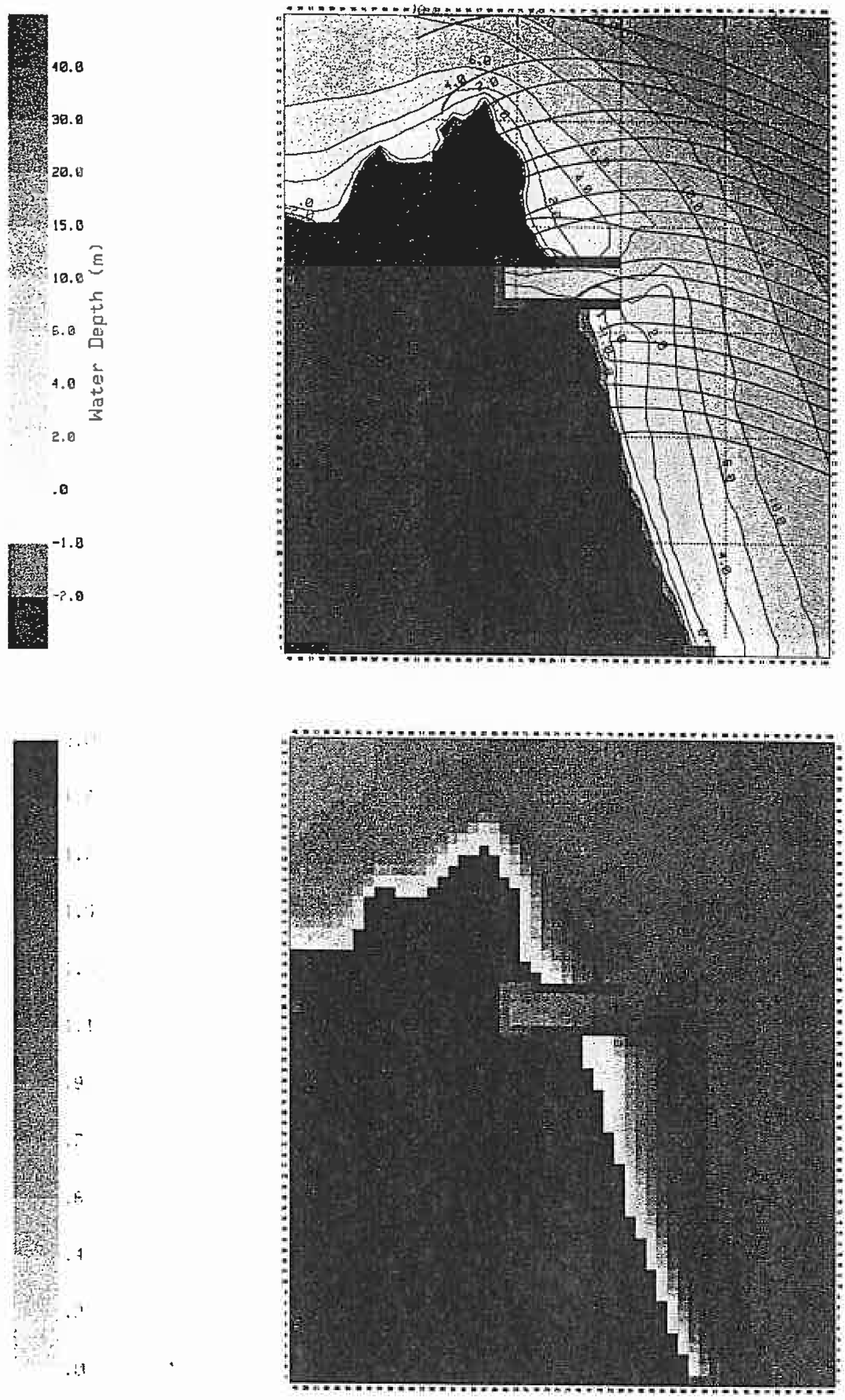
Refraction diagrams indicate that the crossing wave patterns and height amplifications induced by the pre-dredged entrance bar have been reduced. Comparison of the refraction diagram in Figures 20 and 21 shows some subtle changes in wave and wave height amplification.

Removal of part of the entrance bar allowed waves to more directly approach Duranbah beach, with less loss of wave energy over the bottom. The convex entrance bar shape and size have been reduced to an extent that surfing characteristics were altered at Duranbah for east and southeast waves.

In the future, the long-term surf quality will depend to a large degree on how the Tweed entrance bar is managed. The optimal entrance bar shape and configuration may not be the biggest entrance bar.

Entrance bar dredging and possible interception of sand south of the bar, as part of a permanent bypass system, will alter the refraction and breaking characteristics over the entrance bar. In order to manage the surfing assets, an analysis of a possible future dredged conditions are instructive to help define criteria to preserve attributes of the surf site.

Figure 22 shows a hypothetical bathymetry and associated wave refraction that could occur if the entrance bar were to be maintained with a large sediment trap in the long term (EIS Technical Appendix II). It can be seen that a permanent bypass system (not considering the impacts of sand nourishment) would cause Duranbah surfing conditions to emulate those at Letitia Spit surf sites. However, it is significant that the proposed sand bypass strategy in the Deed of Agreement allows for enhancement of the surf conditions. The Deed of Agreement allows for up to a maximum of ten percent of the amount mechanically bypassed to Queensland beaches. The average annual nourishment amount of 50,000 m^3 of sand is the average annual nourishment at Duranbah Beach. The management of the surf resources is expanded upon in the Findings section of this report.



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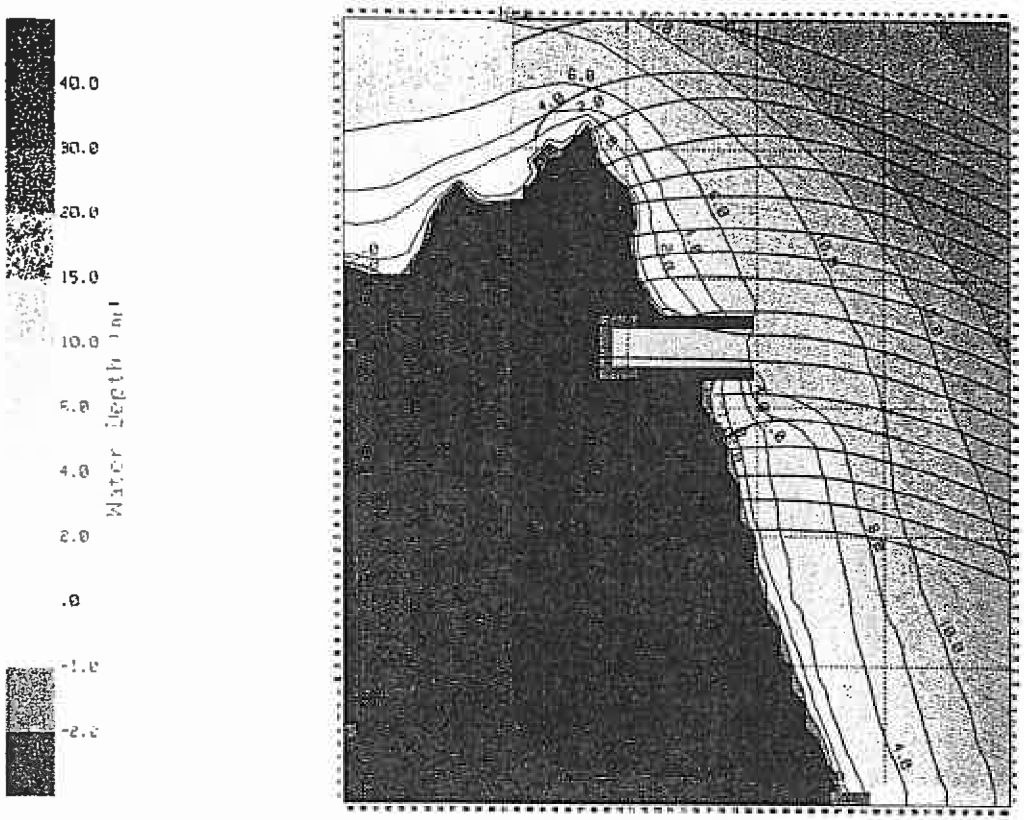
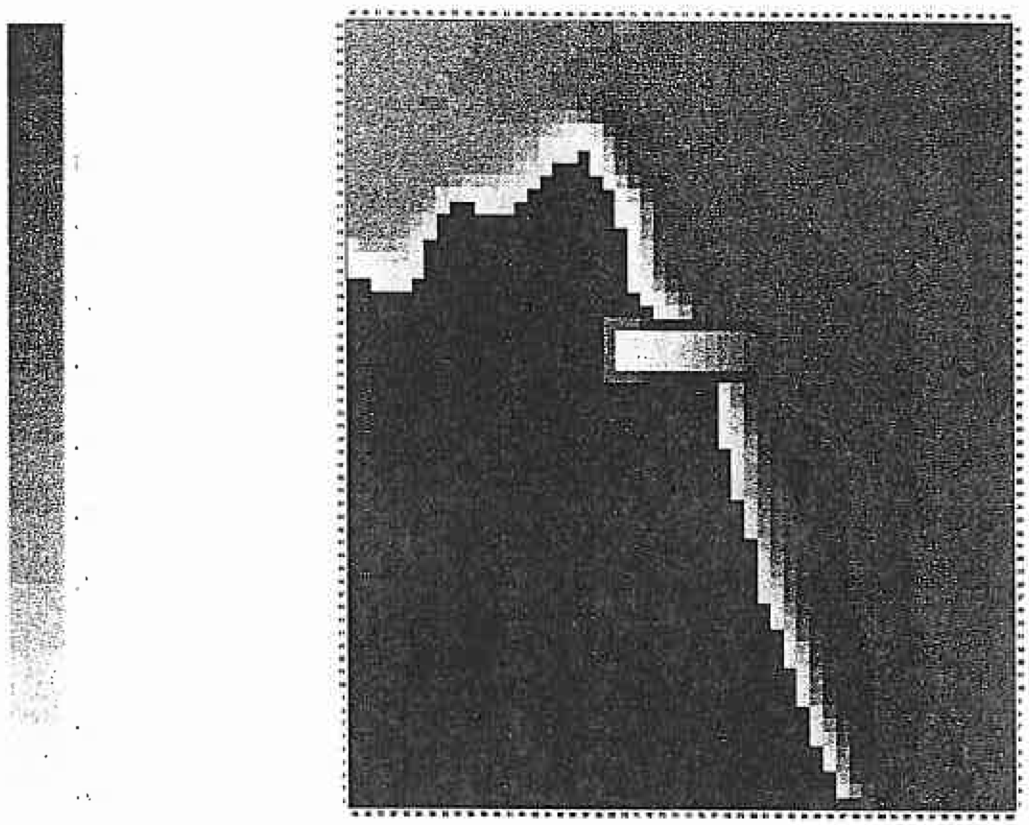
Tweed River Entrance Sand Bypass Project	Wave Refraction Post-dredge Bar Bathymetry	Figure 21





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Tweed River Entrance Sand Bypass Project	**Wave Refraction - Removed Entrance Bar**	**Figure 22**

4.4 Snapper Rocks to Coolangatta

Several surf locations exist along this 1-km reach of beach: Snapper Rocks, Marley, Greenmount, and Coolangatta. Southeast and east waves refract around Snapper Rocks and bend into the beaches at these locations often with favorable offshore winds while the sites at Duranbah and Letitia are "blownout." Surf quality is best when a longshore beach bar exists along the offshore region in depths of about 2 to 3 m and reaching from Snapper Rocks to Coolangatta. However, surf is most frequently practiced on 1-m waves in the point breaks off the rocky headlands. Photograph 5 shows classic refraction and surf conditions along this reach. The bathymetry in the region is shown in Figure 23. The slope of the beach bar measures 1:30, but waves approaching the bar at an angle effectively "feel" a milder slope as a result of the oblique angle of wave incidence. The bottom slope that influences the breaking for smaller point-break waves is 1:60. This produces a milder plunging breaker type than the harder-plunging, larger waves that break on the steeper-sloped bar. When there is little sand present and the rock bottom is exposed, the rocky shore-normal bottom slope flattens to about 1:100 producing a spilling breaker type closer to shore with a less-acute peel angle.

Figure 24 shows the general surf parameters in this reach. The presence of a beach bar in this area is a very important and essential feature upon which the high quality of surf along this reach is dependent. At the rare times when the beach bar extends from Snapper Rocks to Coolangatta, the ride is one of the world's longest surf rides extending over a km.

The rides terminate at Greenmount Beach which is oriented in such that the peel angles of the point breaks become steeper than 20 degrees. This produces a wave that breaks too fast for normal peel riding and is a "close out." The Coolangatta and Greenmount Beach sites also have several less well-defined sites used by board surfers, body surfers and boogie boarders. The bar formation offshore and arrival of multiple short crested waves create short, local peels. The sites are protected from the high southeast winds to produce offshore winds that are favorable for surfing. A large number of beginner and intermediate surfers use the area; this is a valuable surfing resource.

The 1995 Stage 1 dredge program placed 2,300,000 m^3 off of the Greenmount beaches within a year. Part of the sand was placed offshore in depths of 6 to 9 m. The other portion was deposited in water depths of 3 to 6 m and subaerial placement on the beaches. The material was placed directly west of Snapper Rocks in an inner deposition zone to create a shoal. However, waves could not move and shape as a bar in a short time period to produce waves suitable for surfing. The sand slug overwhelmed the system and caused many of the quality surfing waves to close out on the widened beach.

Photograph 6 shows the post-beach-deposition, May 1996 condition when a natural deposition of a large sand slug deposited off of Marley. The shoal blocked some of the wave energy to reach Marley and Greenmount and tended to closeout in a form less desirable for surfing. Both natural and man-made nourishment can produce undesirable surf conditions. A more steady supply of sand by a well-managed sand bypassing program could enhance the surf quality in the area.

Future dredge disposal plans should more evenly distribute sand in both subaerial and time frames to more closely duplicate natural sand transport rates. Some sand placed in the beach bar transport zone of 2- to 3-m depths is desirable, but large quantities placed in depths of less than about 3 m would induce waves to break over an over-nourished beach bar. These waves might have too acute a peel angle to be rideable.

4.5 Kirra Point

Kirra Point is a natural rocky headland that extends about 100 m into the sea. A sand layer often covers part of the rocky reef substrate. A beach bar forms during high wave energy; over which 2- to 4-m waves break over this bar with a peel angle near the limits of surfability. Before 1974, the takeoff area was located in the area shown in Figure 25. The ride, a right peel with an angle of about 35 degrees and waves from 1 to 3 m, was comparable to rides at Maalaea on Maui and at Pipeline on the north shore of Oahu. It is one of the world's renowned surf sites. The ride is about 200 to 500 m long and lasts up to 60 seconds. Photograph 7 shows a ground-level view of the Kirra Point break on a classic day. Peel parameters taken from several photographs and with consideration to the bathymetric charts and wave approach angles from refraction analyses are summarized in Figure 26.

In 1974, a beach fill project was undertaken and a groyne was extended 400 m at the head of Kirra Point. The groyne, designed and functioned to stabilize Coolangatta Beach, had major impacts on surfing. The stabilization of the beach oriented the beach to align with the direction of the incident wave crests. The ride at Greenmount was shortened by a negligible amount. The stabilized beach trapped sand and reduced the flow of sand to Kirra Point. This was a temporary impact until the groyne filled with sand within a year. The groyne deflected the beach bar seaward by about 100 m, which extended the takeoff point seaward. This was a positive influence on surfing because the ride was lengthened.

Kirra owes much of its excellent surf quality to waves breaking over the beach bar. Photograph 8 shows how the groyne deflects the beach bar to influence its shape and position. The bar provides a smooth bottom and well-formed peel compared with conditions the occur over the rock substrate that underlies the bar. The bar has a steeper slope and hence shoals the wave break at a greater height and produces a hard-plunging breaker type. The beach bar is a very important element of the surf at this important site. The bar has a steep 1:30 slope for wave heights of 2 to 3 m and a 1:60 slope for wave heights less than 1 m.

In June 1996, a length of about 30 m of the seaward end of the groyne was removed. No data nor reports have been available since the groyne end was removed, so assessment of the actual impacts on surf quality has not been documented. However, the ride may have been shortened because the takeoff area would be moved shoreward by 30 m. Also the peel angle may become more acute at the take off and the beach bar may become oriented slightly to produce a more acute peel angle for the length of ride as illustrated in Figure 25. Determining the exact effects of these changes would require time to observe the break under a variety of conditions.

Several other surfing opportunities are found north of the Kirra Point Groyne. These sites are beach-bar breaks similar to the Coolangatta sites. The Miles Street groyne does not have a site similar to the Kirra Point groyne because the beach bar is deflected laterally along the coast to remain parallel to the general trend of the shoreline. The surfing opportunities in this area are beach-bar breaks.

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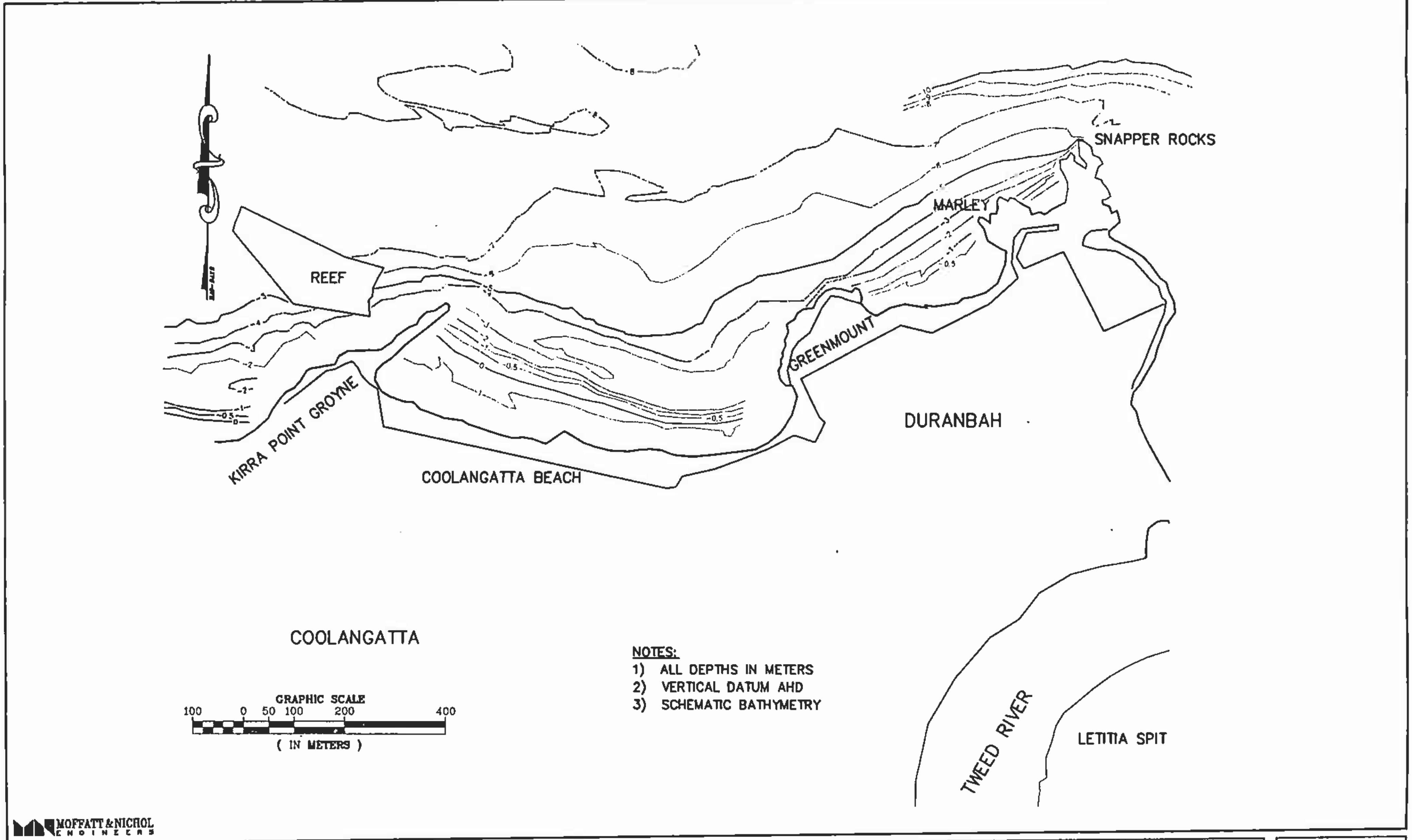
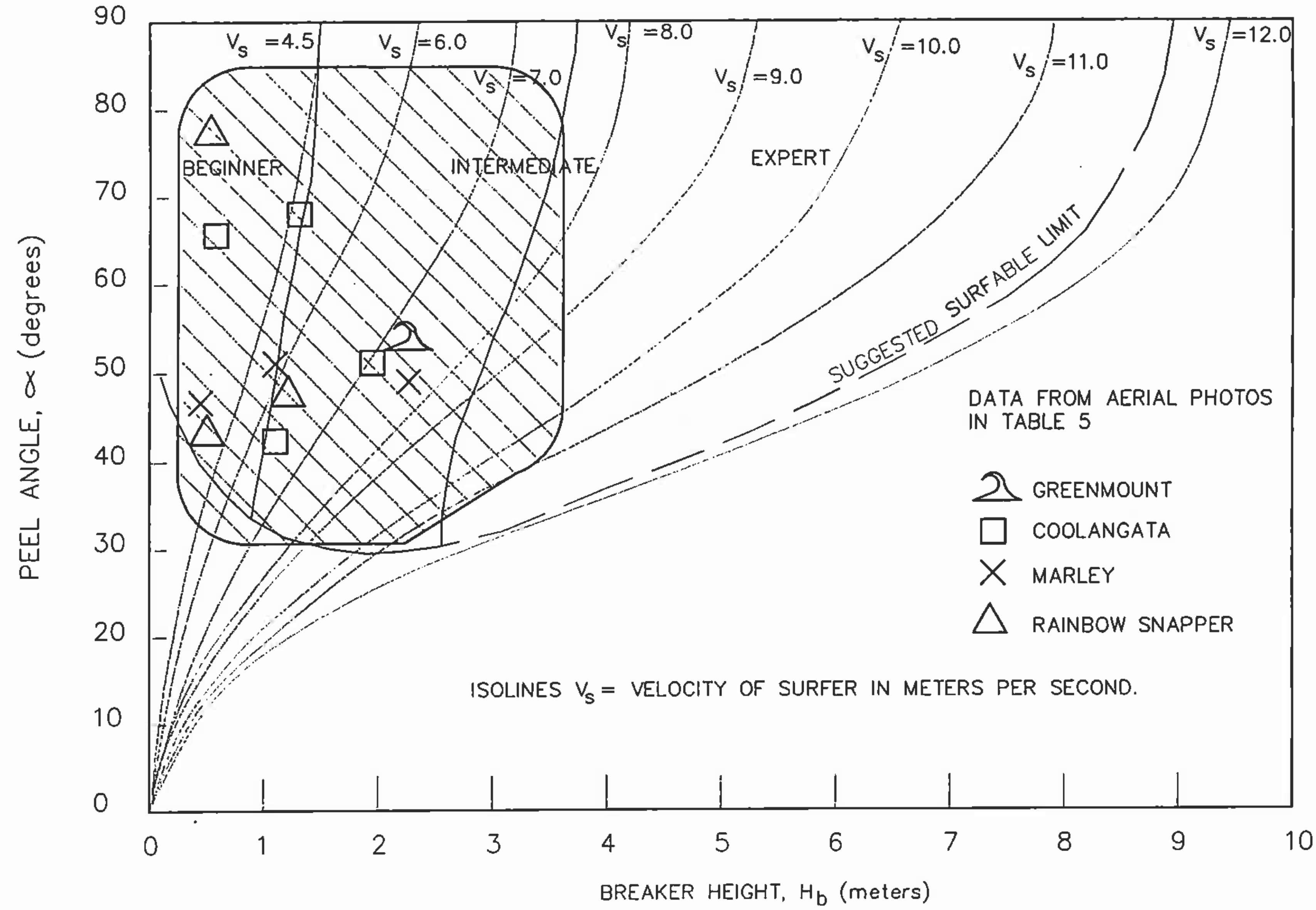
Tweed River Entrance Sand Bypass Project	Snapper Rocks to Coolangatta Aerial	Photograph 5



Tweed River Entrance
Sand Bypass Project

Greenmount Bathymetry

Figure 23



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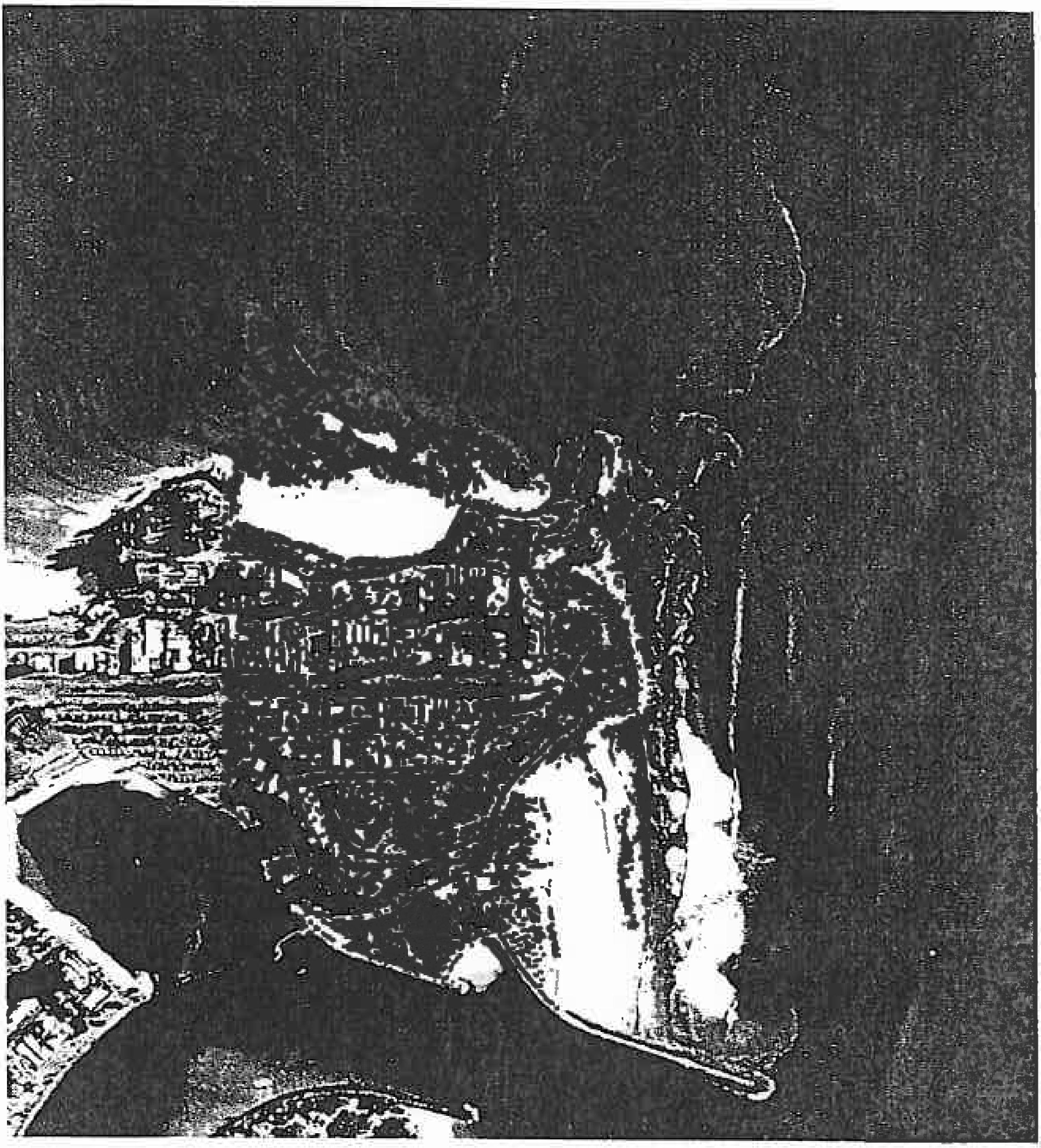
Tweed River Entrance Sand Bypass Project	Greenmount Surf Parameters	Figure 24



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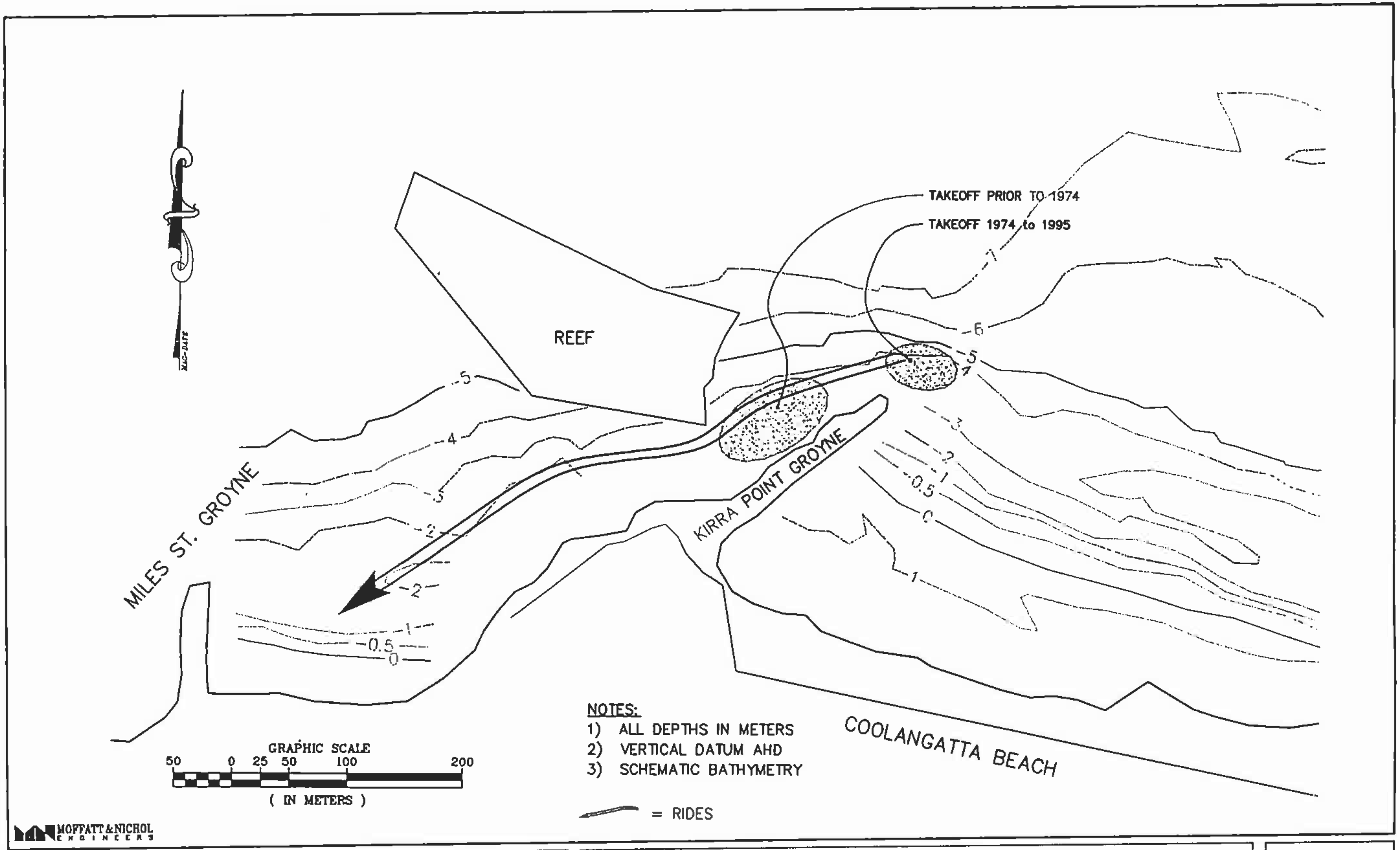
Tweed River Entrance Sand Bypass Project	Marley Sand Slug	Photograph 6



Tweed River Entrance
Sand Bypass Project

Kirra Point Groyne Bathymetry

Figure 25

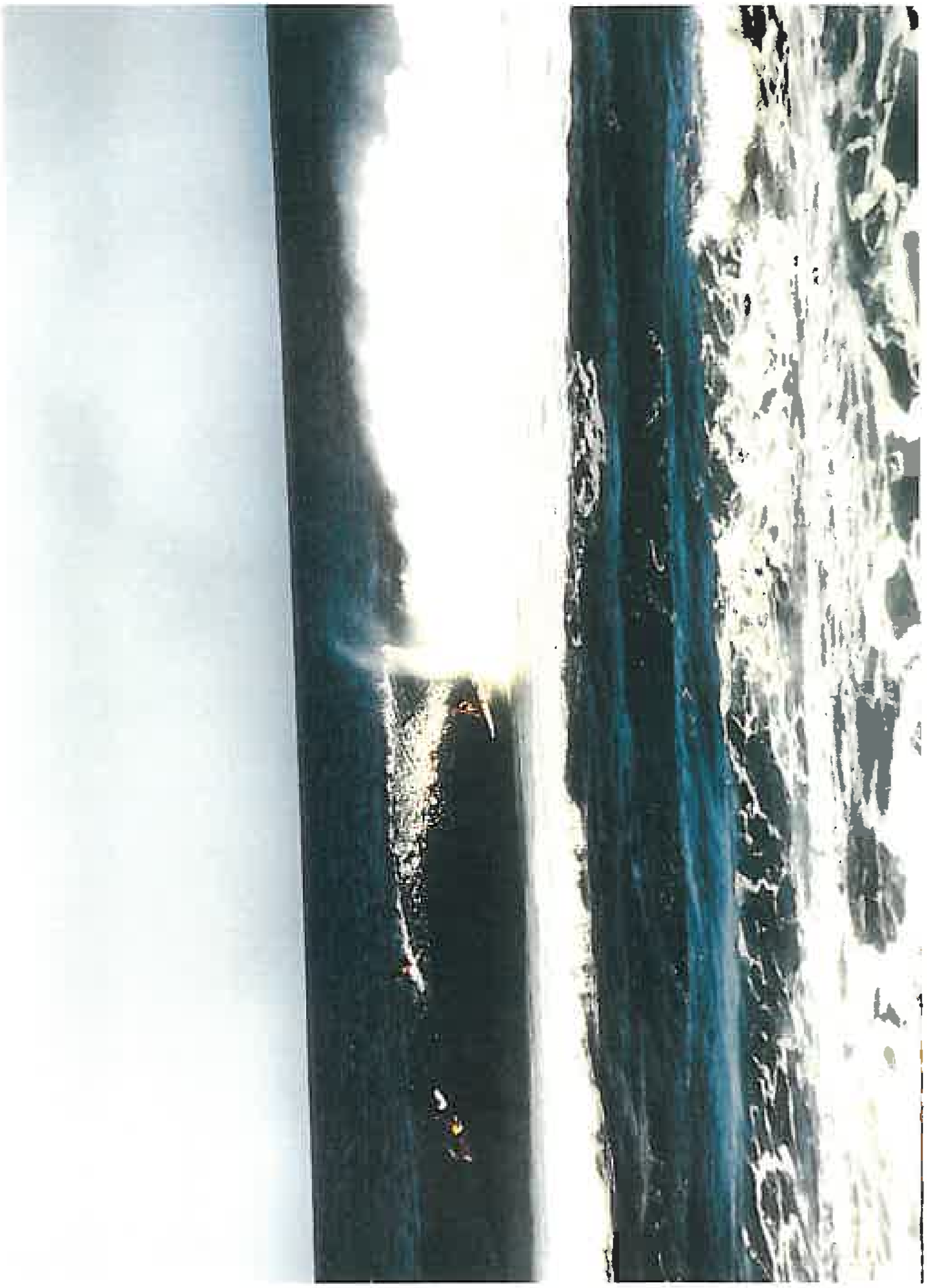


PHOTO BY JOLI

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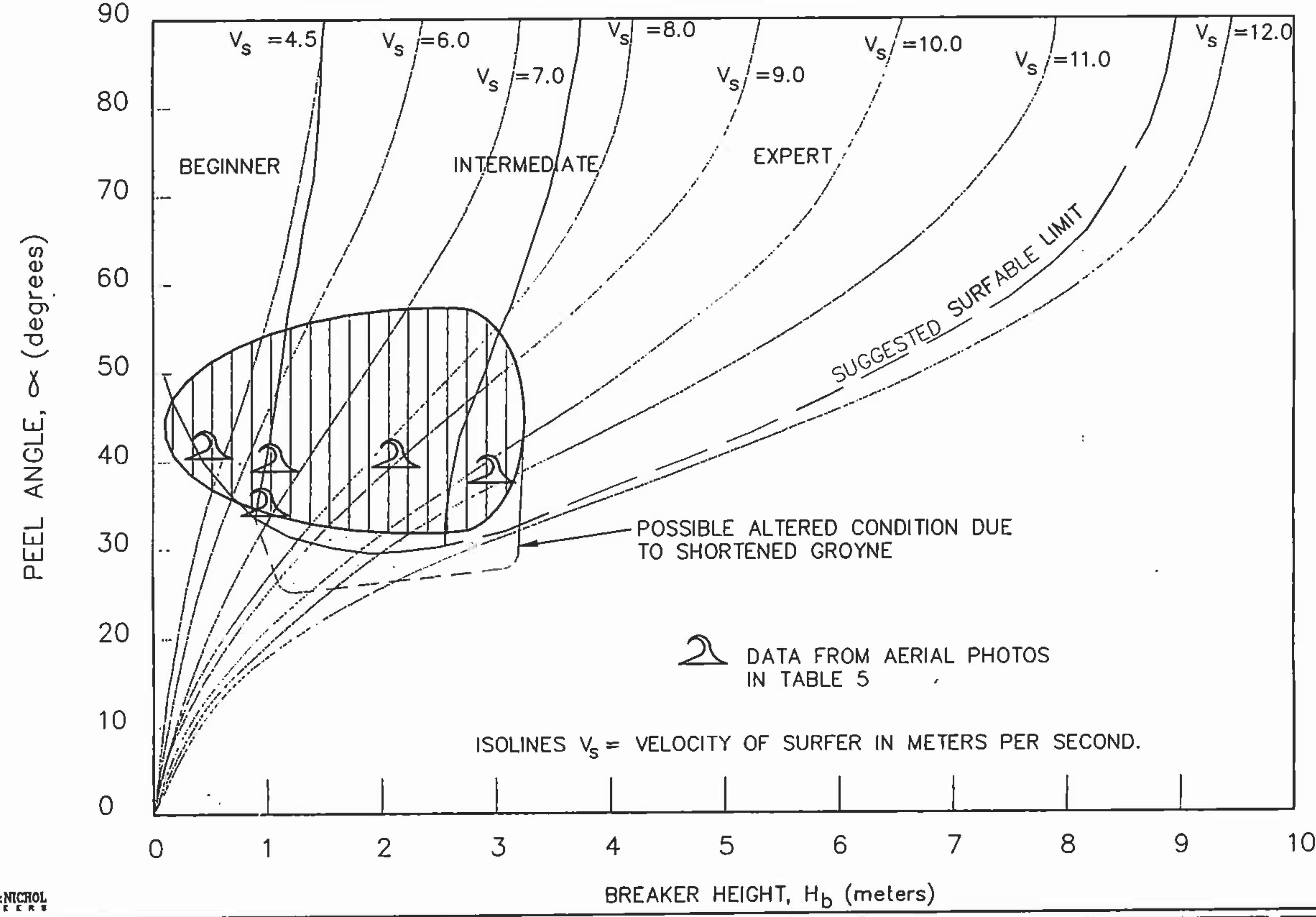
Tweed River Entrance Sand Bypass Project	Kirra Point (Ground Level Of Classic Wave And Surfer)	Photograph 7



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Tweed River Entrance Sand Bypass Project	**Kirra Point Surf Parameters**	Figure **26**

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Tweed River Entrance Sand Bypass Project	Beach Bar Pattern off Kirra Groyne	Photograph 8

5.0 FINDINGS

Some of the best surfing sites in the world are located in this study region. These sites are valuable assets to the region because a great number of local residents surf and because spectators and surfers from around the globe are attracted to this region. Several hundred surfers of all ages and positions in the community use these sites at a given time.

Fifty percent of the year, the wave climate has high-quality waves with heights exceeding 1 to 1.7 m at the Greenmount and Duranbah sites, respectively. The favorable offshore winds occur concurrently with many of these waves at the Snapper Rocks to Kirra Point sites. The presence of the beach bar is critical to surf quality. The beach bar has a seaward slope that influences the wave breaker type and provides a faster peel rate than produced by the underlying rocky substrate. The beach bar also provides a safer bottom than an irregular rocky bottom. The beach bar was found to vary in location and characteristics as a function of sand supply and wave climate.

Naturally occurring wave and tidal current forces tend to store some sand in the Tweed entrance bar; the remainder either ventures in and out of the entrance channel or naturally bypasses across the entrance bar. The bypassing from Letitia Spit to the sites west of Snapper Rocks may take more than one wave event to move the bulk of material. This is because sand bypasses the entrance bar and may be stored in or at least transits over more than a km of shoreline before it is transported around Snapper Rocks. Natural storm and wave events have bypassed large slugs of sand to the beaches west of Snapper Rocks. The deposition of large slugs has at times created a temporary sand storage area at Marley. This storage area has, on occasion, adversely affected the surf for a time period until the bulk of material can be transported farther westward and northward by natural forces. A dredge plan that more consistently bypasses sand throughout the year may decrease both the natural and man-made large sand slugs that adversely influence the surf at Marley. The more consistent deposition plan would also beneficially nourish the beach bar and beaches at a more continuous rate to promote good surfing opportunities. The 1995-1996 Stage 1 bypassing project did beneficially influence surfing due to the sand that reestablished the beach bar.

Beach bars naturally occur given waves and a sand source. The sand supply to the beaches north of Snapper Rocks is ephemeral because the transport of sand around Snapper Rocks depends on the southeast waves while the transport along beaches to the north to Coolangatta may be more influenced by the east and northeast seas. The forces that supply sand to Snapper Rocks for transport along the beaches from the south are not in phase with those that transport sand along the Snapper Rocks to Greenmount shores. This produces a naturally variable sand supply rate that renders the quality of surfing dependent upon the waves as well as the sand supply. For the most part, the sand supply by natural forces has been very irregular. The sand supply for the 1995 to 1996 dredge program was an extreme anomaly.

After the 1996 dredge program, a considerable amount of sand remains on the Tweed entrance bar. Wave and tidal forces will shape the entrance bar in convex form that may be conducive to good quality surf. November 1, 1996 had some of the best surf quality at Duranbah in recent memory according to Bruce Lee. This in part is due to the refraction effects induced by the northern lobe of the Tweed entrance bar.

A hypothetical refraction analysis presented in the preceding section of this report demonstrates the importance of the entrance bar. The surf quality may be severely degraded if the bar is over dredged. Surfing conditions can be preserved and optimized in the future by careful management of the Tweed entrance bar.

The Memorandum of Agreement allows up to 50,000 m^3/year to be placed on Duranbah Beach. The bypassing project will affect the amount of sand available to Duranbah and consequently the beach may erode. The Memorandum of Agreement took this into consideration and provided sand nourishment to Duranbah Beach. This sand could be placed by undefined measures or with purpose to enhance the surf conditions. The objective of a disposal program would be to maintain a beach and enhance surf conditions. Development of the specific program would take some study and the results should be monitored each year to measure the effectiveness of prior program to devise better disposal plans that best maintain the surf.

Surfing, sand bypassing, and navigation conditions could be refined by monitoring the effectiveness of each issue as a function of sand removal and disposal practice over the years. The surfing conditions and the bathymetric features over the beach and bar must be monitored. The monitoring program would correlate the bathymetric features with surf conditions as well as with the depths and widths of the navigation channel. The objective would be to shape the entrance bar by dredging practice to maintain a navigation channel and to dispose of sand on the downdrift beaches for nourishment to have more consistent beaches and surfing opportunities. Shaping the entrance channel and sand trap will most likely be the most influential long-term impact on surf quality. Disposal of sand in a shoal over the nearshore region of Duranbah Beach will have the most dramatic short-term impact on surfing.

The disposal plan to nourish Duranbah Beach with up to 50,000 m^3 of sand each year can be modified with each episode, depending on the experience with prior episodes. The objective would be to place a mound of sufficient size and shape that waves would shoal into breaking with an appropriate peel angle, without posing an unusual risk to surfers, and without a significant part of the materials returning to the Tweed entrance channel. A roughly triangular mound about 2 m thick, extending about 250 m along the shore and 200 m offshore placed in 3 to 5 m of water would yield a large shoal that would refract waves toward its center to amplify smaller waves and induce breaking to create a left and right peels. Figure 27 shows a possible planform of the shoal that accommodates 50,000 m^3 of sand.

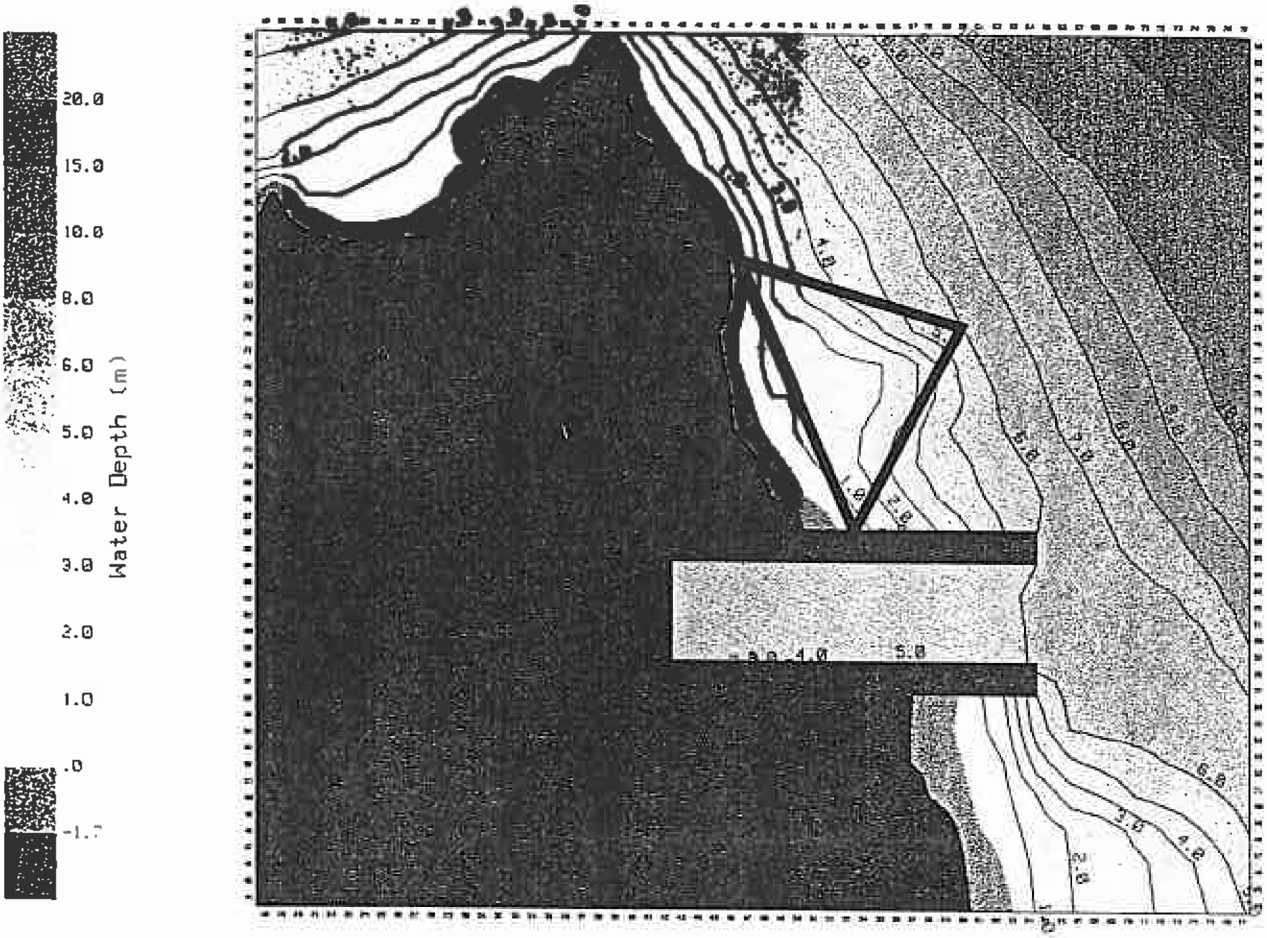
Such a shoal would be subject to littoral transport. Its longevity and usefulness must be carefully evaluated. Installing it in January, after the northeast storm waves, would decrease the probability of littoral transport rapidly returning the sand to the entrance channel. The shoal would be ready to transform southeast wave events into surfing waves. The timing of shoal creation could be consistent with a surf contest or high probability of good surf. The longevity and effective use of the shoal are difficult to predict, but basic calculations indicate that 1.5- to 2-m waves would erode the shoal by about 1,000 to 2,000 m^3 day. Hence, it is anticipated that the shoal could favorably influence surf conditions for two months after placement. A storm could rapidly redistribute the material.

Another possible location of the shoal would be adjacent to the north entrance training wall. A triangular wedge placed against the wall, approximately 200-m long, 2-m thick and with a base of about 200 m, would produce a right peel with about a 40- to 45-degree peel angle, depending on how quickly the littoral transport moves and reshapes the material. Figure 28 shows the possible shoal planform. The wave activity in the region against the training wall is more complex than that for off the center of Duranbah Beach. Littoral transport rate will be greater than the shoal in the center of Duranbah (WBM, 1996). Such a shoal would have about 40,000 m^3 of sand that would remain effective for about a month, depending on the wave climate.

A program to monitor the surf conditions, the channel, and the bar configurations would be beneficial toward optimizing the placement of sand in order to meet the objectives of the project. A detailed numerical model of the bar to predict wave transformations and sediment transport would be a useful tool toward optimizing the placement of sand and understanding how sand is transported over the shoal to create surfing opportunities. The model needs to predict both sediment transport and surf conditions to help devise an optimum program for dredging as well as beach and surf enhancement. Basic wave transformation models can be used to generally predict the waves approaching the site and to make relative assessments of wave transformations over the shoal. A model that incorporates wave breaking, nonlinear wave shoaling and finite-height effects on wave velocity near the surf zone is required to reasonably predict wave breaking over a surf site.

The managed entrance channel through the bar will also create an opportunity for a peel on either side of the channel. The sand traps could be managed in a manner that would induce waves to refract into Duranbah favorably and create peels on the sides of the traps.

Care must be exercised when considering construction or removal of groynes. Groynes not only modify the beach shape, but they also may divert or influence the position and behavior of the beach bar over which surfing takes place. A groyne can have a favorable influence on surfing, but it would possibly adversely influence the adjacent downcoast beaches. The effect of the recent removal of part of the Kirra groyne should be monitored carefully to determine what effect the removal may have on the quality of the surf. The prime concern is whether peel rates are too fast with a shortened groyne.



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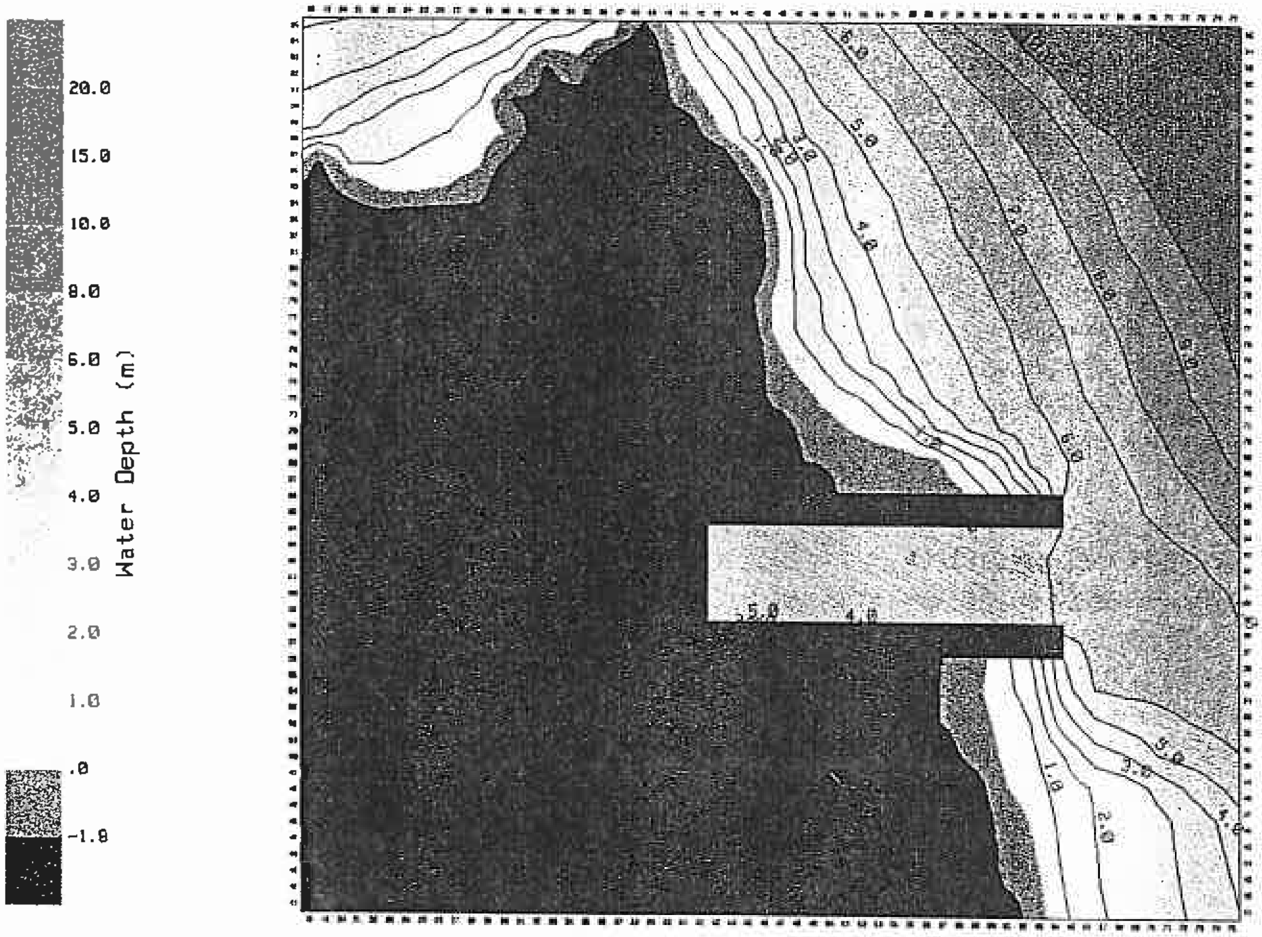
Tweed River Entrance Sand Bypass Project	Duranbah Surf Shoal	Figure 27



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Tweed River Entrance Sand Bypass Project	Duranbah Training Wall Shoal	Figure 28

6.0 RECOMMENDATIONS

Surfing is an asset to the region for recreational value as well as economic value. The sites in this area are among the most recognized in the world. Efforts need to be put forth to preserve and enhance the sites. A management plan for the sand bypassing and entrance channel maintenance project should consider recreational surf quality as a feature of the plan.

Duranbah will be the most directly influenced by the Tweed entrance bar maintenance program. Experience with recent 1996 entrance bar dredge program illustrates that the surfing sites can be preserved and perhaps enhanced with careful bar management. Duranbah needs to have beach and shoal nourishment strategies for dredging and placement of sand in a manner that optimizes preservation of the beach and maintains surfing opportunities. The program requires monitoring the quality of the surf, monitoring the bathymetry and waves, and studying the influence that sand deposition and dredging practice has on surfing conditions.

Management of the Tweed entrance bar, including any sand traps that may be created as part of a sand bypass program should, to the most practicable extent, be designed to create conditions favorable for surfing.

The steady placement of sand in the nearshore zone south of Snapper Rocks in water depths 2-to 4-m deep on a reasonably continuous basis, as opposed to large instantaneous depositions, would be the most beneficial practice for maintaining a longshore beach bar from Snapper Rocks to Kirra Point. This would make the area's surf sites and beaches have higher quality surfing conditions more of the time.

A great deal of care needs to be exercised in placing and removing groynes at Kirra. Small changes to the bathymetric features may ultimately render the waves less rideable; conversely, they may become even more challenging.

Placement of sand on the south side of Snapper Rocks would emulate a more natural flow of sand to be distributed over a wide section of the surf zone. This action would reduce the chance of overfilling surf areas along the Snapper Rocks to Coolangatta region.

Numerical modeling of the entrance bar features may help manage this valuable resource. A full understanding of how the Duranbah site functions would help devise better options to utilize the sand that will be available to nourish this beach. This model should be based on detailed bathymetric features, include nonlinear wave refraction and shoaling , diffraction, breaking, decay, setup, and the influence of currents and tide elevations over various shoal alternatives.

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