# SURFING CONDITIONS AROUND JETTIES


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## EXECUTIVE SUMMARY

Jetties are built to stabilize inlet navigation channels by reducing the volume of sand trapped inside the harbor, estuary or lagoon. They also stabilize channel positions. Issues that are commonly discussed when building and modifying jetties are performance, local and downdraft beach erosion and accretion, and ecological effects. However, as people become more aware of the social and economic value of surfing, the effects of coastal projects on surfing breaks are increasingly being considered.

The economic benefit of having a surfing break at a beach is enormous. Money spent on food, beverages, surfing equipment, clothing, and accommodations sustains many small coastal communities. Recent attempts to quantify the economic value of beach recreation, including surfing, are impressive. It is critical that the preservation and enhancement of surfing breaks is considered in any project undertaken in the coastal environment.

Not all waves that break on a coastline can be surfed. This report begins with a review of the characteristics of waves that make them suitable for surfing. The four major surfing wave parameters that control whether a wave can be ridden are breaking wave height ($H_B$), wave peel angle ($\alpha$), wave breaking intensity ($B_I$), and wave section length ($S_L$). The character of any surfing wave can be described using these parameters alone. Other parameters exist but are functions of these main variables.

The bathymetric features of the seafloor that transform waves into quality surfing waves are described in this report. Previous studies have found that a surfing break is comprised of an arrangement of holistically linked components. These components are called ramps, platforms, wedges, focuses, ledges, ridges and pinnacles. Depending on their configuration, different types of surfing waves will be produced. Common configurations found in world-class surfing breaks are Ramp/Wedge, Ramp/Platform/Wedge, Ramp/Focus/Wedge and Ramp/Ledge/ Platform.

The primary objective of this study is to determine how surfable waves form around jetties. This study has identified the mechanisms that transform ordinary waves into surfing waves around jetties. Each mechanism has a varying degree of influence on wave transformation at different locations. Case studies of four types of surfing breaks are presented to show how these mechanisms can create good surfing waves. The classification types can be used to better understand the impact of jetty construction or modification on neighboring surfing breaks. Previously the specific physical processes that create surfing conditions around jetties had not been articulated in scientific literature. This report is written for coastal scientists and engineers who may or may not have knowledge about surfing and surfing terminology. Providing scientific information about surfing waves and breaks will allow these coastal scientists and engineers to incorporate the effects on surfing into their project's design. An improved understanding of surfing science will allow the concerns of surfing communities to be better satisfied.

Four types of surfing breaks around jetties have been identified (Figure 1). The two defining variables in type are the delta effect (preconditioning, wave breaking, or none) and the size of the jetty (longer/shorter than surfzone width).

A *Type One* jetty break occurs where waves break shoreward of the end of the jetty. The jetty length is longer than the surfzone width. Trapped sediment accumulates against the jetty, creating a fillet that acts as a wedge component. Energy from along the wave crest converges against the jetty, creating a peak in wave height and take-off zone. The wave then peels along the wedge feature.

A *Type Two* jetty break is created by the ebb tidal delta. Waves are preconditioned over the delta before breaking further inshore. The shoaling and refraction over the delta cause peaks in wave height to form and rotate waves suitable for surfing. Surfing waves are then formed by a combination of wave height peak, wave angle oblique to seabed contours, and complex rip/bar formations.

A *Type Three* jetty break is also created by an ebb tidal delta. The delta provides stable contours for waves to break over rather than acting as a preconditioning component. Some preconditioning will happen, but the dominant process that creates high quality surfing waves is the wave breaking function.

A *Type Four* jetty break is a jetty construction that does not change existing surfing conditions. The jetty is not long enough to trap sufficient sediment to change beach width significantly. The surfing conditions exist because of other natural features, such as reef that creates surfable waves.

## ACKNOWLEDGEMENTS

This report was completed during a short visit by Mr. Brad Scarfe to the San Diego area from New Zealand. Mr. Scarfe has worked with the staff of Coastal Environments, La Jolla, California. The authors would like to thank the surfers of San Diego who provided knowledge about local surfing breaks and the ways they function, in particular, Mike Jilka of Sal Rite surfboards, Witt Rowlett of the Carlsbad Pipeline surf shop and Steve Barilotti of Surfer Magazine for their initial guidance and accommodation. We also want to thank Paul Nester and Bob Friedman for generously accommodating Brad right by the water for most of his stay in San Diego. Margie Garrett, Ann Burges, Megan Hamilton, and David Hansen all have provided valuable editorial comments.

# 1.0 INTRODUCTION

Jetties are built to stabilize inlet navigation channels by reducing the volume of sand trapped within these channels. They also stabilize channel positions, possibly increasing tidal outflow velocity, flushing sediments, and reducing shoaling (Shaw, 1980; Mohr, 2001). They may also improve or worsen surfing conditions in the area (Figure 1-1). Issues that are commonly discussed when building and modifying jetties are performance, local and downdraft beach erosion and accretion, and ecological effects. However, as people become more aware of the social and economic value of surfing, the effect of proposed coastal projects on the local surfing breaks is becoming an additional consideration (Mead and Black, 2002).

The economic benefit of having a surfing break at a beach is enormous. The money spent on food, beverages, surfing equipment, clothing, and accommodations sustains many small coastal communities. Recent attempts to quantify the economic value of beach recreation, including surfing, are impressive. Surfing on the Cornwall coast of the United Kingdom, with its short summer and merely average surfing conditions, generates £21M (~$US33.1M) annually for the local economy (Ove Arup and Partners International, 2001). Examples of cost/benefit ratios for artificial surfing reef projects are also impressive. A ratio of 20:1 has been predicted for Bournemouth in the United Kingdom (Black et al., 2000), while a 60:1 return is expected for the Gold Coast of Australia (Raybould and Mules, 1998). Houston (2002) estimates the cost/benefit ratio for beach restoration in Miami, Florida to be 500:1.

The preservation, enhancement, and creation of surfing breaks are occurring throughout the world. For example, the Whangamata Bar surfing break in New Zealand has been listed on the National Geopreservation Index. The ebb tidal delta that creates the break is now recognized as a unique bathymetric landform that should be protected. Projects with the sole purpose of creating artificial surfing reefs have also been undertaken: two in Australia and one in California. Currently there are several artificial surfing reef projects around the world in various stages of planning, design, or construction (Mead and Black, 2002).

The study of the physical processes behind surfing waves and surfing breaks has come a long way since the initial investigations of Hawaiian surf breaks in the early 1970s (Walker and Palmer, 1971; Walker *et al.*, 1972; Walker, 1974a and 1974b). Significant advances began in the 1990s with the development of the Artificial Reefs Program at Waikato University in New Zealand (Andrews, 1997; Hutt, 1997; Mead, 2001; Moores, 2001; Sayce, 1997; Scarfe, 2002) and the Cable Stations Artificial Reef Project at the University of Western Australia (Pattiaratchi, 1997, 1999 and 2000; Pattiaratchi *et al.*, 1999; Bancroft, 1999). The First Artificial Surfing Reefs Symposium in Sydney, Australia (1997), and the Second in San Diego, California (1998) further spurred interest. They brought together surfing enthusiasts from a wide range of disciplines and localities. More recently, the Second Surfing Art, Science, and Issues Conference (SASIC2) in Ventura, California (2002), put on by the Groundswell Society, encouraged discussion.

A summary of the surfing science and artificial surfing reef construction knowledge was presented in the *Journal of Coastal Research,* Special Issue No. 29. Subsequently various areas of surfing research have defined themselves. They are as follows:

- The effects of submerged reefs on sediment transport and salient formation (Andrews, 1997; Black and Andrews, 2001a and 2001b; Black and Mead, 2001);
- The relationship of surfers to surfing waves (Dally, 1990, 2001a and 2001b; Hutt, 1997; Hutt *et al.*, 2001; Moores, 2001; Scarfe, 1999, 2002; Scarfe *et al.*, 2002);
- The bathymetric shape of surfing breaks (Achenbach, 1998; Mead, 2001; Mead and Black, 1999, 2001a and 2001b; Raichle, 1998; Scarfe, 1999 and 2002; Scarfe *et al.* 2002 and 2003; West *et al.*, 2002);
- The prediction of wave-driven currents (Symonds and Black, 2001);
- The prediction of breaker intensity of surfing waves (Sayce, 1997; Sayce *et al.*, 1999; Mead and Black, 2001c); and
- The prediction of beach surfability (Dally, 1989; Pattiaratchi *et al.*, 1999; Scarfe, 2002).

This report begins by explaining what types of waves are suitable for surfing. Next, the bathymetric features that create these types of waves are discussed. The specific tasks undertaken in this study are:

1. A review of the previous scientific literature on the characteristics of surfing waves;
2. A review of the previous scientific literature on the characteristics of surfing breaks;
3. A case study using Agua Hedionda Lagoon, Carlsbad, California to show how jetties can improve surfing conditions; and
4. A classification of the types of surfing breaks around jetties.

An example of a surfing break around a jetty is shown in Figure 1-1. This figure shows the jetties at Newport Beach and the location of one of the most famous jetty surfing breaks, “The Wedge.”

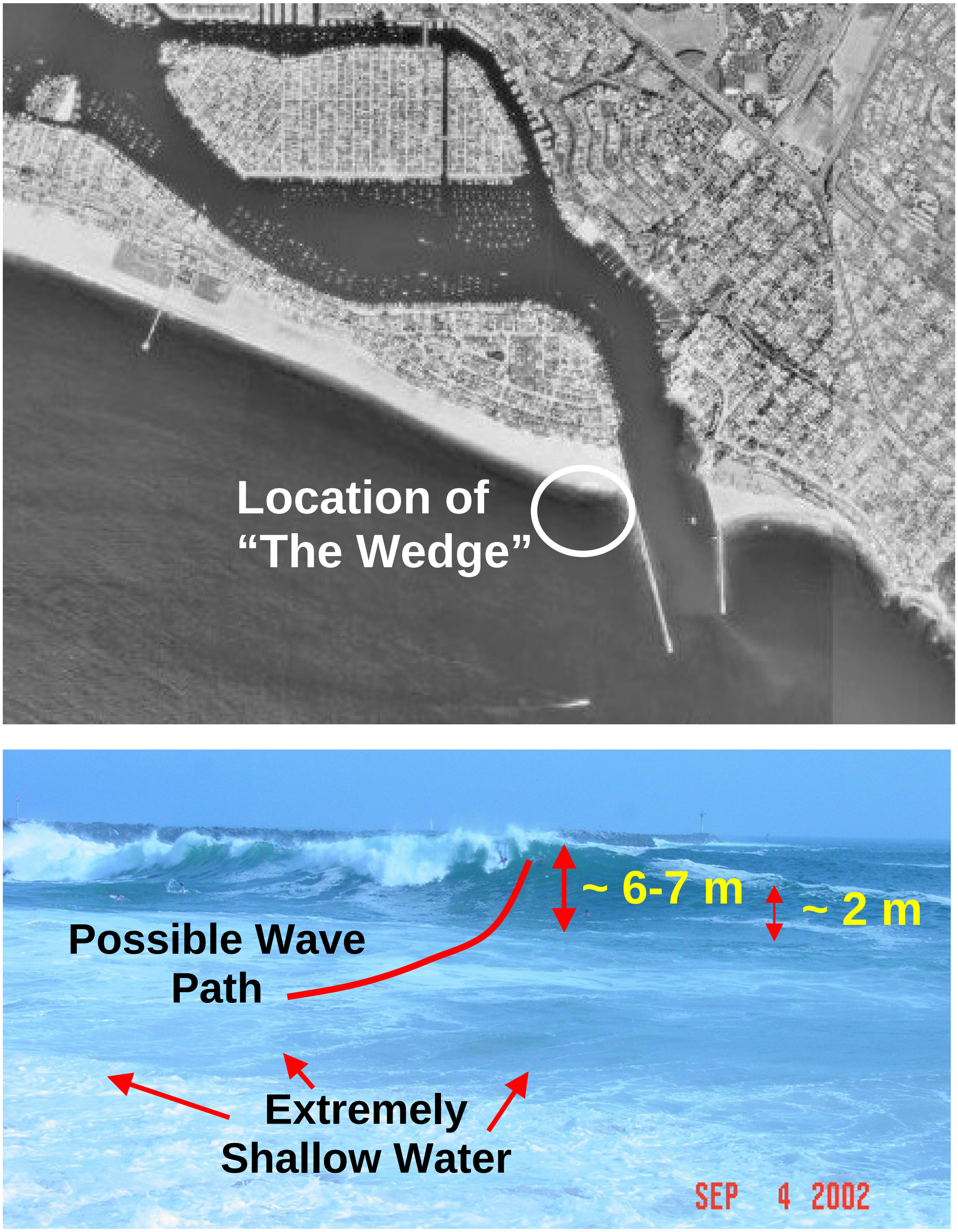



**Figure 1-1. Jetty presence at Newport Beach, California, has created a surfing break called “The Wedge” (photo courtesy of Chuck Mesa at USACE). Notice the amplification of the wave due to the jetty.**

## 2.0 CHARACTERISTICS OF SURFING WAVES

The break point of a wave "peels" along the wave crest when surfing condition are good. Surfers stay just ahead of the advancing wave crest in the "wave pocket" where most of the wave's power is located. Only beginning surfers enjoy riding waves that do not peel.

If the wave peels to the right from the surfer's perspective (to the left looking from the beach), it is said to be a "righthand" wave, or a "righthander." If it peels to the left from the surfer's perspective (to the right looking from the beach), it is said to be a "lefthand" wave, or a "lefthander."

The breaker type and the speed at which the wave peels determine the skill level required to surf the wave (Hutt, 1997; Hutt et al., 2001; Moores, 2001) and the types of maneuvers that can be performed (Scarfe, 2002; Scarfe et al., 2002). Not all waves are suitable for surfing, and among those that are, not all can be surfed by surfers of all skill levels. Surfing waves vary not only from location to location, but also from day to day because of changes in tidal level and swell. In fact, even successive waves can break with considerably different characters.

Different types of surfing are practiced: short boarding, long boarding, body boarding and body surfing (Figure 2-1). Surfboards for short boarding are generally between six and seven feet long, and the surfing style is aggressive. Surfers who ride short boards (called short boarders) perform fast and powerful maneuvers. The surfboards used for long boarding range from seven to eleven feet in length. Long boards are also called Malibu's (or Mal's) because they suit the slow and gentle waves found at places like Malibu, California (or Waikiki, Hawaii). Riding long boards, or long boarding, is a much slower and more relaxed type of surfing, because waves suitable for long boarding break more slowly and softly than those for short boarding. Shorter Mal's are called mini-Mal's, and these cross over between the two styles of stand-up surfing.

Body boarding, also called boogie boarding, uses a much smaller, foam board, about three feet long, and the surfer generally does not stand up on the board. When riding a body board lying down, the style is called "prone." There is a style of body boarding where the body boarder is almost standing, which is called "drop knee." Fins or flippers are used to catch waves rather than the paddling used in stand-up surfing, making it even more difficult to stand than it is due to small board size. When riding "drop knee," the surfer kneels on one knee and stands on the other. Body surfers do not use boards at all; they surf the waves using their bodies in the same ways that other surfers use boards. Fins are often used to help them catch waves.

A concise literature review is presented here to show how surfing waves can be described scientifically. Although there are four main types of surfing, most of the scientific surfing research has focused on short boarding. It has focused mainly on understanding surfing waves and surfing breaks in order to design artificial surfing breaks. Therefore, this review also focuses on short boarding waves. However, this information can be extrapolated to other surfing styles. For example, desirable long boarding waves have higher peel angles and lower breaking intensities than short boarding waves. Desirable body boarding waves have shorter rides and higher breaker intensities.

In this report, the variables used to describe surfing waves are discussed first. Then these variables are related to actual surfers by reviewing the research on surfer skill level and types of surfing maneuvers.

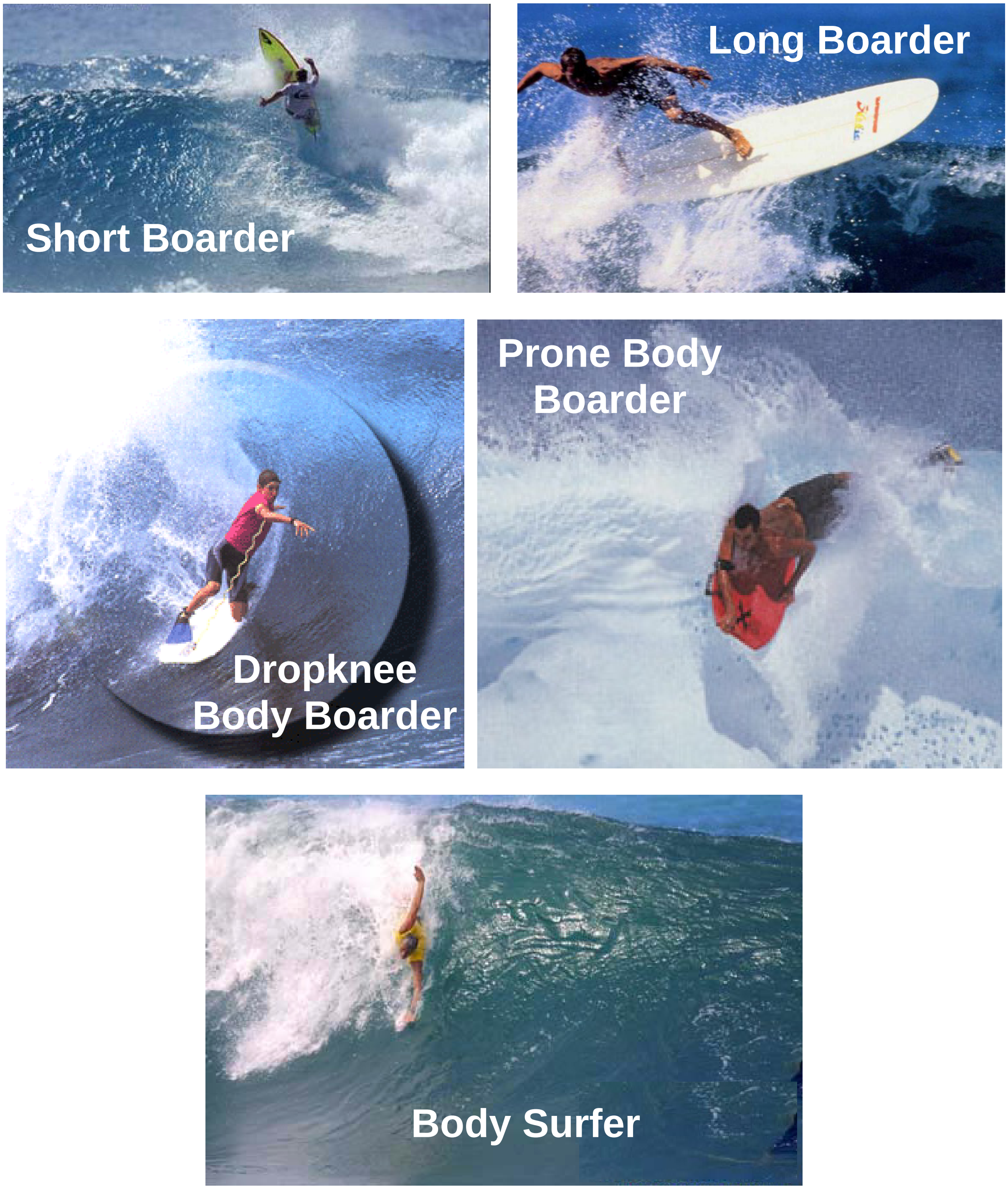



**Figure 2-1. Types of surfing, clockwise from top left: short board surfer, long board surfer, prone body boarder, body surfer, and drop knee body boarder. Information obtained from the following websites:**

- **www.aspworldtour.com**
- **www.kahunavideo.com**
- **www.bodyboarderweb.com**
- **www.worldbodysurfing.com**
- **www.bodyboarderweb.com.**

## 2.1 SURFING WAVE PARAMETERS

The four most important parameters for surfing wave analysis are breaking wave height ($H_B$), wave peel angle ($\alpha$), wave breaking intensity ($B_I$), and wave section length ($S_L$) (Scarfe et al., 2002, 2003). Other parameters exist (see Dally, 1990, 2001a; Mead, 2001; Moores, 2001; Sayce, 1997; Sayce et al., 1999; Scarfe, 2002; and Walker, 1974), but they are derivatives of, or controlled by, these four main variables. Scarfe et al. (2002 and 2003) recommend using only these four to maintain consistency in the scientific surfing literature.

### 2.1.1 Wave Height (Hb)

Surfing wave height is often considered the most important variable at a surfing break (Raichle, 1998). Oceanographers measure wave height from the crest to the trough of the wave. Groups of surfers develop their own definitions of wave heights, which can be slightly larger or smaller than crest-to-trough distances. In the scientific study of surfing waves, the oceanographic method is used.

Waves come in sets, and surfers ride the largest waves in these sets. Hutt (1997) recommends using the average of the top 10% of waves ($H_{1/10}$) when measuring wave statistics for surfing rather than significant wave height ($H_{1/3}$).

### 2.1.2 Peel Angle ($\alpha$)

Peel angle is defined as the angle between the trail of the broken whitewater and the crest of the unbroken wave as it propagates shoreward (Figure 2-2; Walker, 1974; Hutt, 1997; Hutt, et al., 2001; Mead, 2001b; Scarfe, 2002). Peel angles range between 0° and 90°, with low angles creating fast surfing waves and high angles creating slow waves. An angle of 0° is described as a “closeout” (Mead and Black, 2001b).

The wave peel rate is measured in meters per second and describes how fast the wave breakpoint advances laterally along the wave crest. Surfers must surf at least as fast as the wave peel rate in order to stay in front of the wave break point. Peel angle is closely related to wave peel rate because they both relate to the speed at which a wave is breaking. Although theoretical models designed to relate peel angle to peel rate have been developed (Dally, 1990, 2001a), Scarfe (2002) and Scarfe et al. (2002) recommend the use of peel angle, because it can be more accurately numerically modeled than peel rate and is more sensitive to maneuver type.

### 2.1.3 Breaking Intensity ($B_I$)

Waves will break either as spilling, plunging, surging, or collapsing breakers, depending on the orthogonal seabed gradient. Waves break on a continuum consisting of between these main breaker types (Komar, 1998). Surfers generally prefer waves with steep or plunging faces (Mead and Black, 2001c). These waves provide greater power to propel surfers and the opportunity for more advanced surfers to experience barrel rides. Spilling breakers are characterized by foam and turbulence at the wave crest (Komar, 1998), as depicted in Figure 2-3. They have the lowest breaker intensity of all wave types.

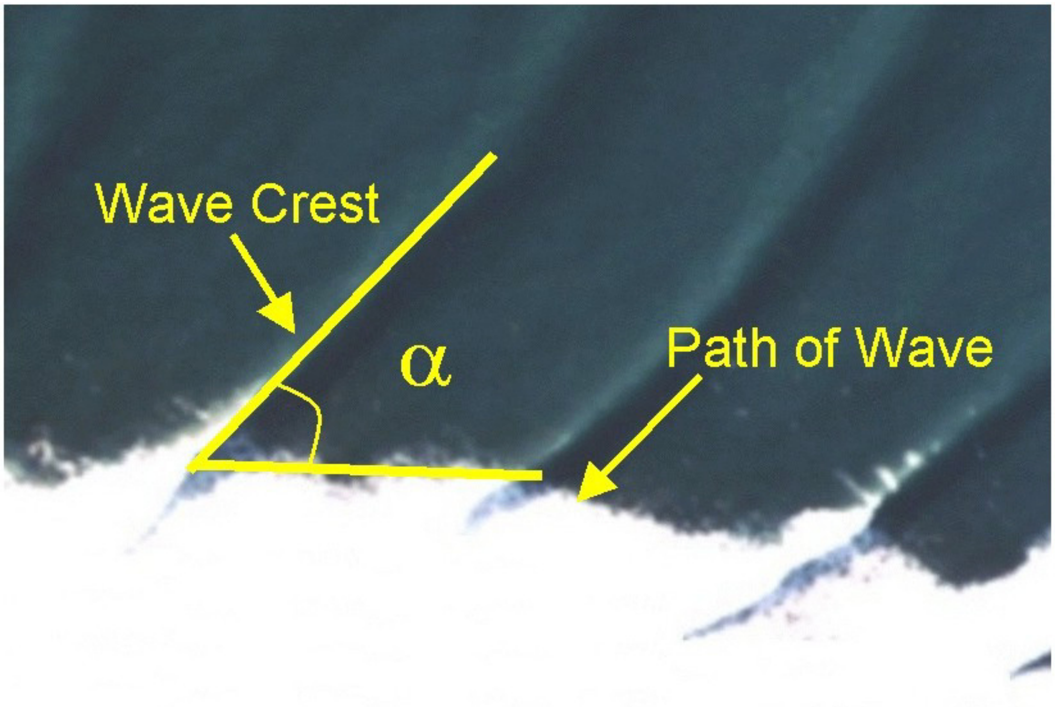



**Figure 2-2. The peel angle, α, is defined as the angle between the trail of the broken white water and the crest of the unbroken part of the wave as it propagates shoreward (from Mead, 2001).**

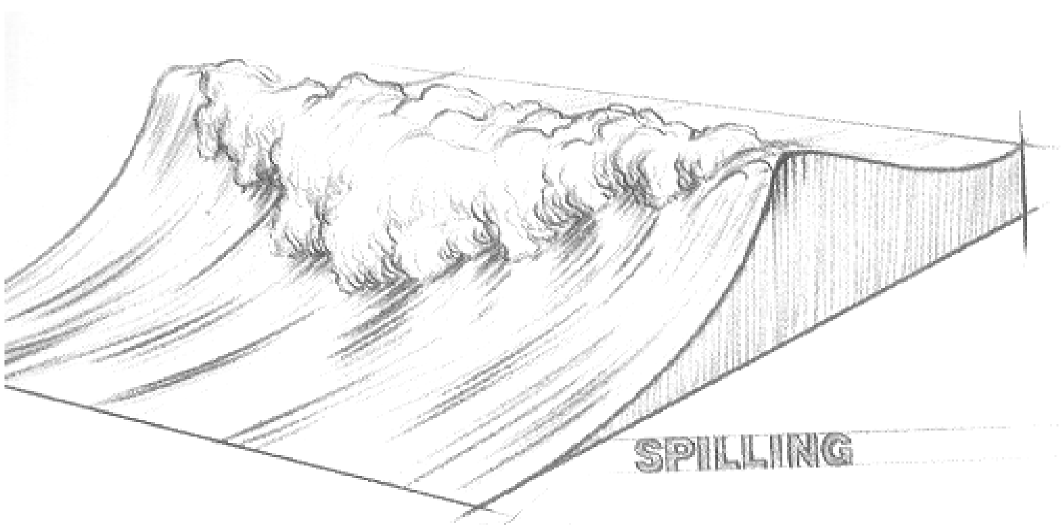



**Figure 2-3. Spilling breaker (from Kampion, 1989).**

Figure 2-4 shows an example of a plunging breaker. When waves plunge, the shoreward wave face becomes vertical, curls over, and plunges forward and downward as an intact mass of water (Komar, 1998).

Figure 2-5 shows an example of a surging breaker. These breakers are found where waves from relatively deep water approach steep beach profiles (Kampion, 1989). The wave peaks up as if to plunge, but then its base surges forward and the whole wave collapses (Komar, 1998). These waves are not suitable for surfing. These types of waves break with the highest intensity.

A fourth type of wave identified by Galvin (1968) is a collapsing breaker. This wave type is located on the continuum between plunging and surging and is also not suitable for surfing.

Traditional methods of describing wave breaking parameters, such as the Irribarren number the surf scaling parameter, or the surf similarity parameter have been found to be inappropriate for surfing rides (Mead and Black, 2001c; Sayce, 1997; Sayce et al., 1999). These methods are used to describe all forms of wave breaking, from spilling to collapsing, and therefore are too general for surfing waves (Mead and Black, 2001c).

Mead and Black (2001c) investigated the shapes of plunging waves at 28 world-class surfing breaks. A cubic curve was fitted to the barrel shape (also termed the wave vortex). The ratio between the height and width of the vortex is called the vortex ratio and is a good indicator of breaker intensity (Mead and Black, 2001c). A linear relationship was seen when the vortex ratio was plotted against the orthogonal seabed gradient for each surfing site (Figure 2-6). Regression analysis by Mead and Black (2001c) showed that Equation 2.1 can be used to quantify wave breaker intensity ($R^2 = 0.71$) where $X$ is the orthogonal seabed gradient and $Y$ is the breaker intensity. This formula can be used with a simply measured orthogonal seabed gradient to estimate breaker intensity.

$$\boldsymbol{Y = 0.065\,X + 0.821} \qquad \textbf{(2.1)}$$

Mead and Black (2001c) note that Equation (2.1) was the first attempt at quantifying the breaker intensity of plunging surfing waves and is simplistic. They suggest that the method could be improved by incorporating wave height and period into the equation. In reality, orthogonal seabed profiles are made up of varying gradients with the deeper water gradient generally lower than the shallow water gradient. The shallower water gradient has more effect than the deepwater gradient. The effect of steps in the profile (or multiple gradient profiles) on breaker intensity is still relatively unknown. However, Mead and Black's (2001c) simple relationship can still be used to quantify the design characteristics of artificial surfing reefs and to differentiate between breaker intensity at surfing breaks. Table 2.1 shows how Mead and Black classify the breaker intensity of surfing waves.

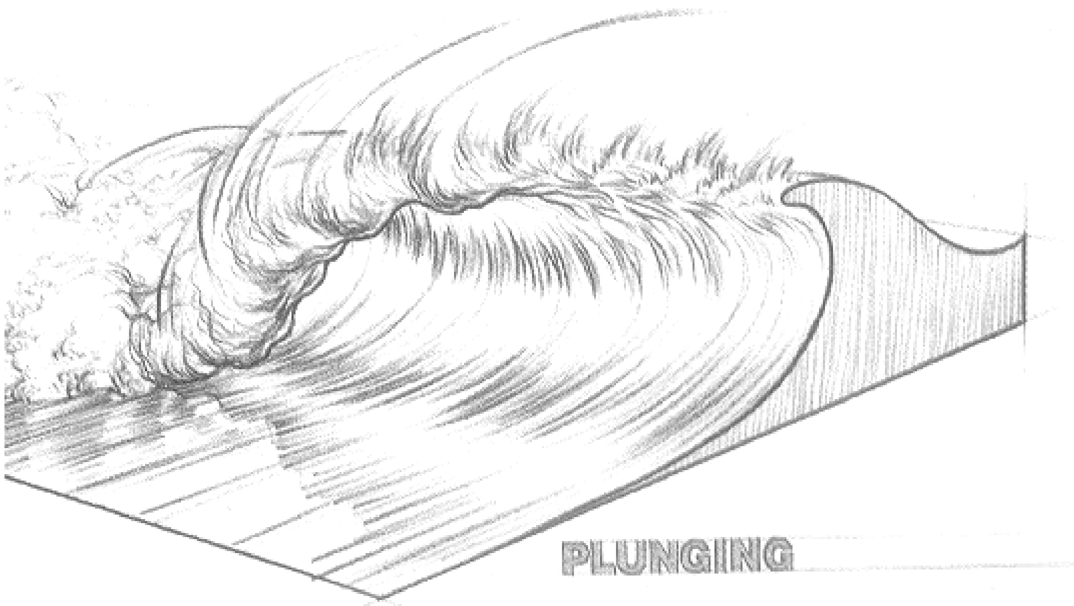



**Figure 2-4. Plunging breaker (from Kampion, 1989).**

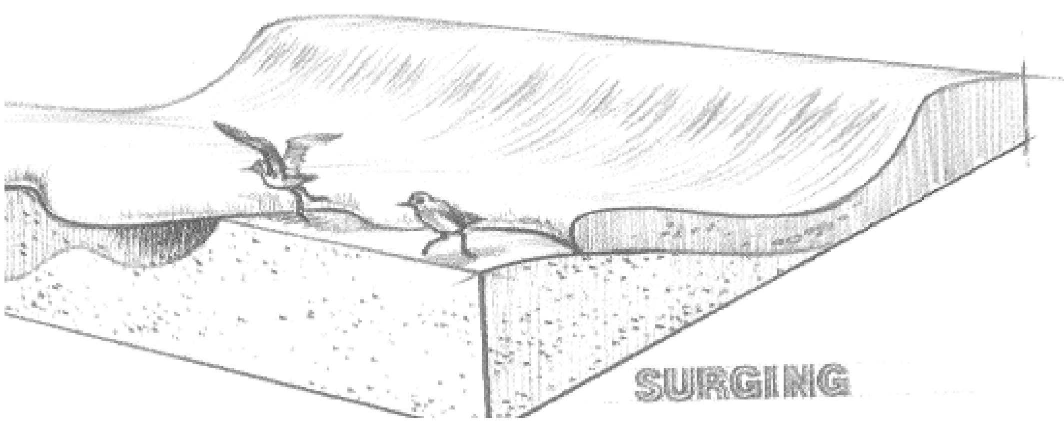



**Figure 2-5. Surging breaker (from Kampion, 1989).**

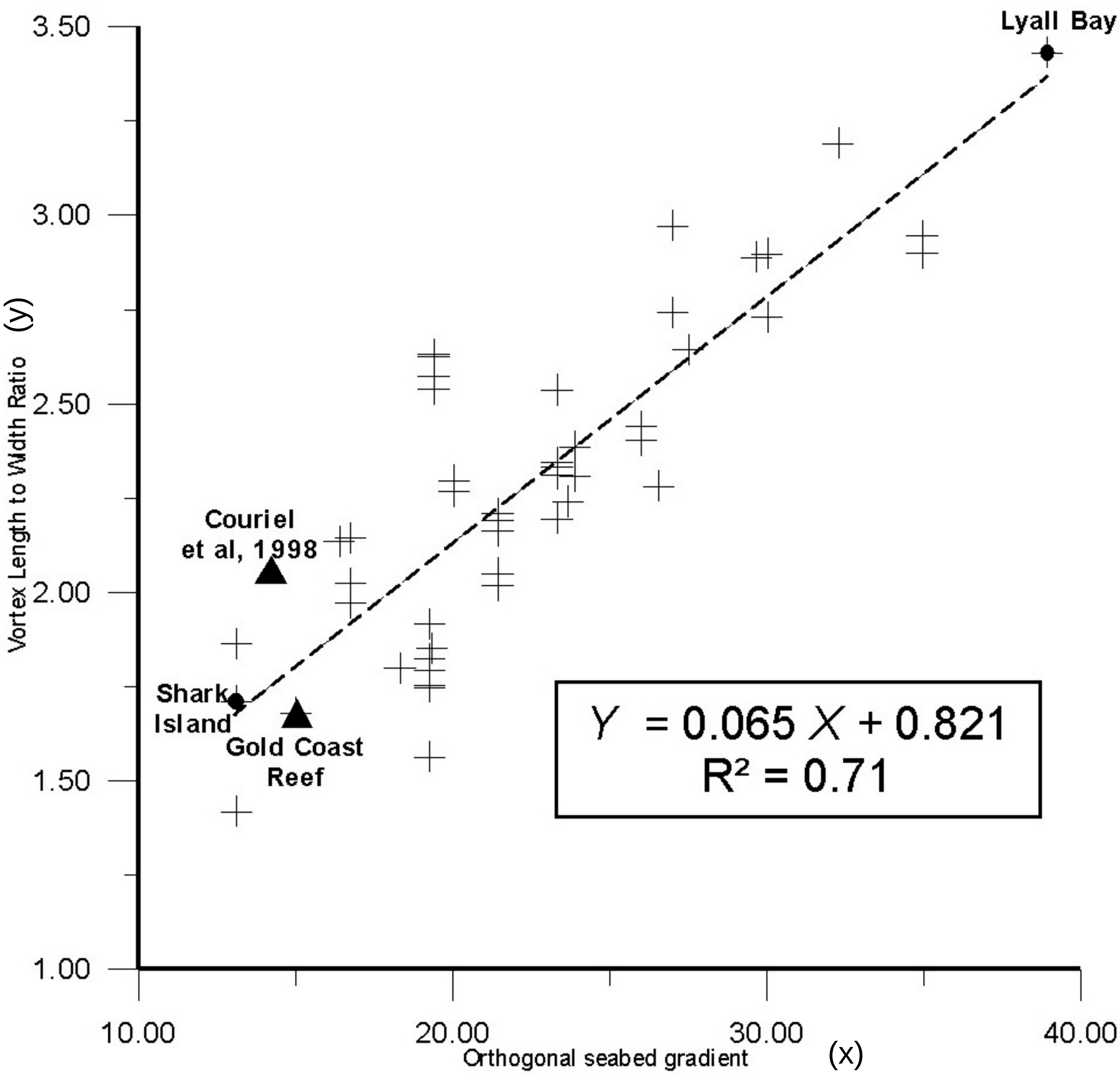
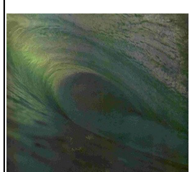
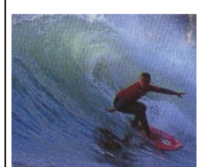



**Figure 2-6. Orthogonal seabed gradients relative to wave vortex ratios for 28 world-class surfing breaks (from Mead and Black, 2001c). The linear relationship can be used to predict the breaking intensity of surfing waves from the orthogonal seabed gradient.**

**Table 2-1. Classification schedule of surfing wave breaking intensity (from Mead and Black, 2001c).**

| Intensity | Extreme | Very High | High | Medium/ High | Medium |
|---|---|---|---|---|---|
| Vortex Ratio | 1.6-1.9 | 1.91-2.2 | 2.21-2.5 | 2.51-2.8 | 2.81-3.1 |
| Descriptive Terms | Square, spitting | Very hollow | Pitching, hollow | Some tube sections | Steep faced, but rarely tubing |
| Example of Break | Pipeline, Shark Island | Backdoor, Padang Padang | Kirra Point, Off-The-Wall | Bells Beach, Bingin | Manu Bay, Whangamata |
| Example of Breaking Wave Profile |  |  |  |  |  |

### 2.1.4 Section Length ($S_L$)

It is rare to find surfing waves peeling regularly and consistently. Peaks in wave crests from unorganized swells and wave focusing as well as from undulating bathymetry cause waves to break in sections. Waves breaking in sections create interesting and challenging surfing rides because surfers can perform different maneuvers on the various sections. However, the section must not be so long or fast that the surfer is trapped behind the wave pocket. A new section begins when there is a change in wave height ($H_B$), peel angle ($\alpha$), or breaking intensity ($B_I$), and is said to have a section length of $S_L$. Wave sections have been investigated by Moores (2001), Scarfe (2002), and Scarfe et al. (2002).

## 2.2 RELATING SURFING WAVES TO SURFERS

### 2.2.1 Surfer Skill Level

Different kinds of surfing waves suit different kinds of surfers, and surfers prefer to ride waves that match or challenge their abilities. The range of wave heights, peel angles, breaking intensities, and section lengths that a surfer can successfully negotiate depends on skill level. Walker (1974) developed a classification scheme to describe the surfable limits of beginner, intermediate, and expert surfers based on peel angles and wave heights (Figure 2-7). Subsequently, the scheme was revalidated by Hutt et al. (2001) for modern surfing standards (Figure 2-8), who delineated surfer skill level categories using the more quantitative ranking system of a scale ranging from 1 to 10 (Table 2-2). Also, it is known that the higher the skill level, the greater the ability to negotiate difficult sections and link sections together for long surfing rides. Although surfers of higher skill levels can ride waves of higher breaker intensity, the relationship between the two has not yet been quantified.

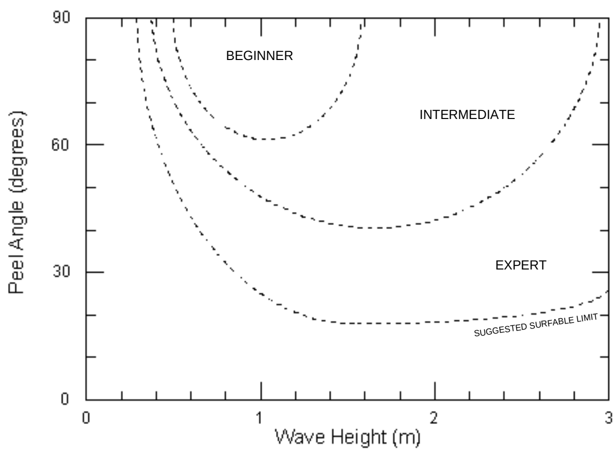



Figure 2-7. Surfer skill level classification scheme (from Walker, 1974).

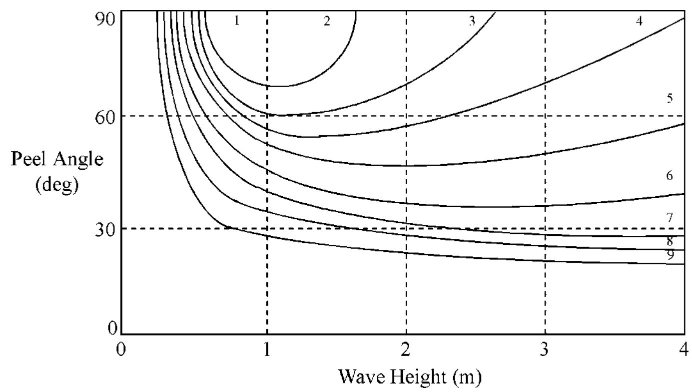



Figure 2-8. Surfer skill level classification scheme (from Hutt et al., 2001).

**Table 2-2. Definitions of surfer skill levels (from Hutt et al., 2001).**

| Rating | Description of Rating | Peel Angle Limit (deg) | Min/Max Wave Height (m) |
|---|---|---|---|
| 1 | Beginning surfers not yet able to ride the face of a wave; simply move forward as the wave advances. | 90 | 0.70 / 1.00 |
| 2 | Learner surfers able to successfully ride laterally along the crest of a wave. | 70 | 0.65 / 1.50 |
| 3 | Surfers who have developed the skill to generate speed by “pumping” on the face of the wave. | 60 | 0.60 / 2.50 |
| 4 | Surfers beginning to initiate and execute standard surfing maneuvers on occasion. | 55 | 0.55 / 4.00 |
| 5 | Surfers able to execute standard maneuvers consecutively on a single wave. | 50 | 0.50 / >4.00 |
| 6 | Surfers able to execute standard maneuvers consecutively; execute advanced maneuvers on occasion. | 40 | 0.45 / >4.00 |
| 7 | Top amateur surfers able to consecutively execute advanced maneuvers. | 29 | 0.40 / >4.00 |
| 8 | Professional surfers able to consecutively execute advanced maneuvers. | 27 | 0.35 / >4.00 |
| 9 | Top 44 professional surfers able to consecutively execute advanced maneuvers. | Not Available | 0.30 />4.00 |
| 10 | Surfers in the future | Not Available | 0.3 / >4.00 |

### 2.2.2 Surfing Maneuvers

Surfing is a recreational activity, and performing maneuvers is the goal of most surfers. The types of maneuvers a surfer performs are dependent on his or her ability, the style of surfing, and type of wave. The first investigations into types of surfing maneuvers were undertaken by Scarfe (2002) and Scarfe et al. (2002). The terms used to describe these maneuvers were noted to change among different groups of surfers but serve as a guide for studies into maneuvers. The definitions of the maneuvers are:

- Surfing the Wave Crest – This is the most basic of all maneuvers, apart from surfing in a straight line toward the shore. It involves pointing the surfboard in the direction of the advancing wave break point and riding the wave face ahead of the break point. The speed of the surfer is determined by the peel rate of the wave. As the peel rate increases and decreases, so will the speed of the surfer. The surfer has no ability to generate speed.
- Bottom Turn (Figure 2-9) – After dropping down the face of a wave, a surfer needs to turn at the bottom of the wave set-up for the next maneuver. Bottom turns can be made after take-off or on any section of the wave. A surfer can obtain speed and power by pushing off of the bottom of the wave and into its powerful face (the “power pocket”).
- Top Turn (Figure 2-10) – This maneuver allows the surfer to drop back into a wave, either vertically for a slowly peeling wave or laterally for a quickly peeling wave. The radius of the turn is not tight. The maneuver is smooth so that speed is generated rather than lost.
- Speed Weaving (Figure 2-11) – A surfer can actively generate speed by weaving up and down, effectively dropping into the wave over and over again. This allows surfers to make it through fast sections or generate enough speed to perform advanced maneuvers. Speed weaving is simply the linking of top and bottom turns, or “pumping” the surfboard to generate speed via the board’s design (e.g., through fin arrays, channels, etc.).
- Reo, Vertical Re-entry, Vert Smack, Snap (Figure 2-12) – A reo is similar to a top turn but executed more aggressive. The radius of the turn is very tight, and the surfer travels vertically up the wave face before the turn. Speed is lost during the maneuver. Reo’s are best performed on waves with steep faces, so that the surfer is pushed out of the move with speed, ready for the next maneuver.
- Cutback (Figure 2-13) – Cutbacks allow surfers to stay in the power pocket of a wave. They are often performed at the end of a fast wave section when peel angle increases. The move involves the surfer outrunning the wave, and then performing a large radius turn back toward the advancing wave face.
- Round House (Figure 2-14) – A round house is a maneuver with two parts. First, the surfer performs a cutback, so that he or she surfer is now traveling toward the advancing wave. In this maneuver, the surfer rides a lefthand wave like a righthand wave, and the opposite is true for a righthand wave. The second part involves performing a reo on the advancing wave face. The surfer is then pushed along by the breaking wave, ready to perform another maneuver.
- Floater (Figure 2-15) – Often the most enjoyable and efficient maneuver that can be used to negotiate a fast section is a floater. It involves traveling (floating) over the top of a wave to make it to the front of the wave face. High speeds are required to perform floaters, because once the surfer is on the top of the whitewater, speed is quickly lost. Floaters are also frequently performed at the end of a surfing ride when the wave closes out.

- Foam Bounce (Figure 2-16) – This maneuver is a cross between a floater and a top turn. The surfer generates speed, and then approaches a wave section in a way resembling a floater. However, rather than surfing right on top of the wave as when performing a floater, the surfer turns back down the wave face as when performing a top turn, and the breaking wave accelerates the surfer.
- Aerial (Figure 2-17) – This is an advanced maneuver. To perform an aerial, a surfer requires a great deal of speed. This maneuver is best performed on a steep wave sections with a light onshore wind to hold the board against the surfer's feet.
- Barrel (Figure 2-18) – In this maneuver, a surfer rides inside a plunging wave section. This is the most desired maneuver by surfers. It is an advanced maneuver that requires the surfer to precisely control the speed and position vertically on the wave face.
- Tail Slide (Figure 2-19) – A tail slide can be performed at the end of an aggressively executed reo or gouge. Extra force is put into the turn, so that the tail slides freely. In order to do this, the surfboard fins must release themselves from the water.
- Reverse (Figure 2-20) – In a reverse, the surfer rides the surfboard backward. This maneuver requires that the surfer be very balanced, because the surfboard naturally tends to face forward because of the fins. To turn the surfboard around, surfers either do a tail slide or a 180° Ollie. An Ollie is an advanced move taken from skateboarding where the board is popped into the air by the surfer.
- Stall – A stall is done when a surfer releases the weight of the front foot to slow the surfboard down. It is performed for a very short time to allow the wave to catch up to the surfer. A common use of a stall is to slow the surfer down enough to get a barrel ride without outrunning the wave, after a top or bottom turn.
- Gouge or Hard Stall – This maneuver is very similar to a stall, but it is executed more quickly and aggressively. The tail is buried or gouged into the wave face by putting the surfer's entire weight on the tail and performing a small turn.

The analysis of peel angles during certain maneuvers by Scarfe (2002), which was presented in Scarfe et al. (2002), yielded design criteria that could be used to incorporate maneuver types into wave sections of artificial surfing reefs (Figure 2-21).

### 2.2.3 Configuration of Wave Sections

Variation in any of the four surfing wave parameters creates a new section. Depending on the configuration of wave sections, different maneuvers can be performed. Maneuver type is not dependent only on the section's wave parameters, but also on those of the preceding section (Scarfe et al., 2002). Figure 2-22 illustrates how section length, peel angle, and breaker intensity of the wave section can affect maneuver types. Surfers are likely to perform the maneuvers shown in Figure 2-22 for the different wave sections. Maneuver type is highly dependent on the way that a wave section breaks (Scarfe, 2002; Scarfe et al., 2002). Interesting wave section configurations in surfing rides challenge surfers and keep rides exciting.

**Figure 2-9. Short board surfer performing a bottom turn (photo source– New Zealand Surfing Magazine).**

**Figure 2-10. Short board surfer performing a top turn (photo source– New Zealand Surfing Magazine).**


**Figure 2-11. Short board surfer performing speed weaving (from Scarfe, 2002).**

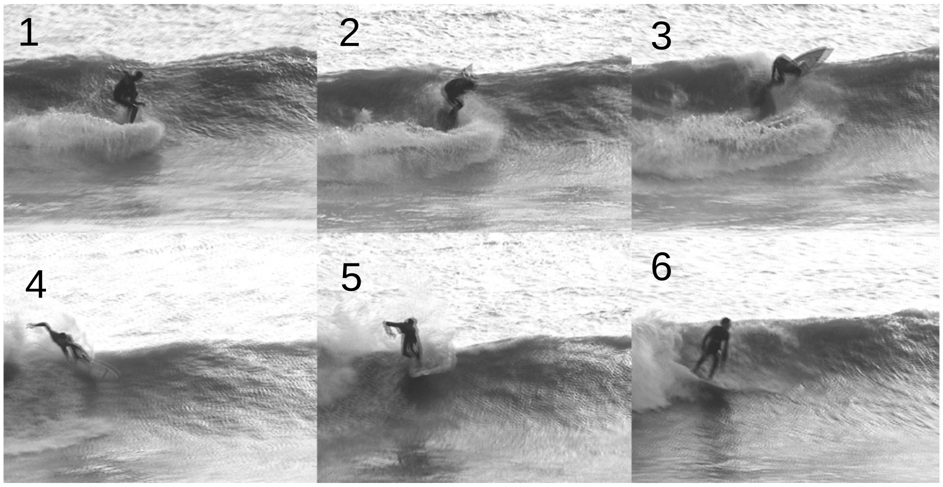



**Figure 2-12. Short board surfer performing a reo (from Scarfe, 2002).**


**Figure 2-13. Short board surfer performing a cutback (from Scarfe, 2002).**

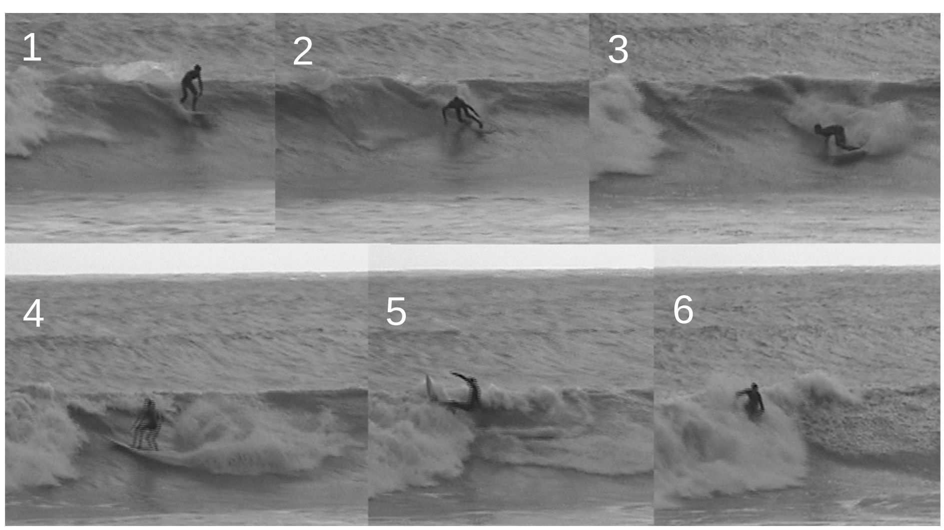



**Figure 2-14. Short board surfer performing a roundhouse (from Scarfe, 2002).**


**Figure 2-15. Short board surfer performing a floater (from Scarfe, 2002).**


**Figure 2-16. Short board surfer performing a foam bounce (from Scarfe, 2002).**

**Figure 2-17. Short board surfer performing an aerial (photo source – New Zealand Surfing Magazine).**

**Figure 2-18. Short board surfer riding inside a barrelling wave (photo source - www.aspworldtour.com).**


**Figure 2-19. Short board surfer performing a tail slide (from Scarfe, 2002).**


**Figure 2-20. Short board surfer performing a reverse (from Scarfe, 2002).**

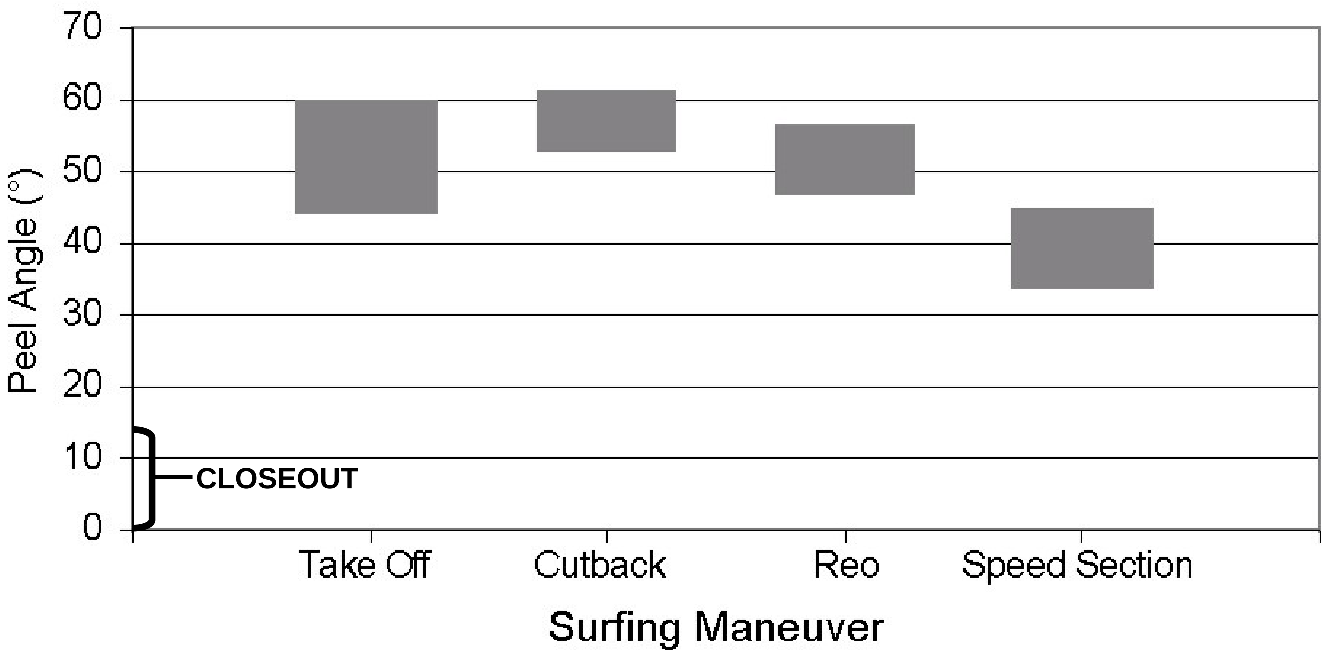



**Figure 2-21 Range of peel angles suitable for different surfing maneuvers (from Scarfe, 2002; Scarfe et al., 2002).**

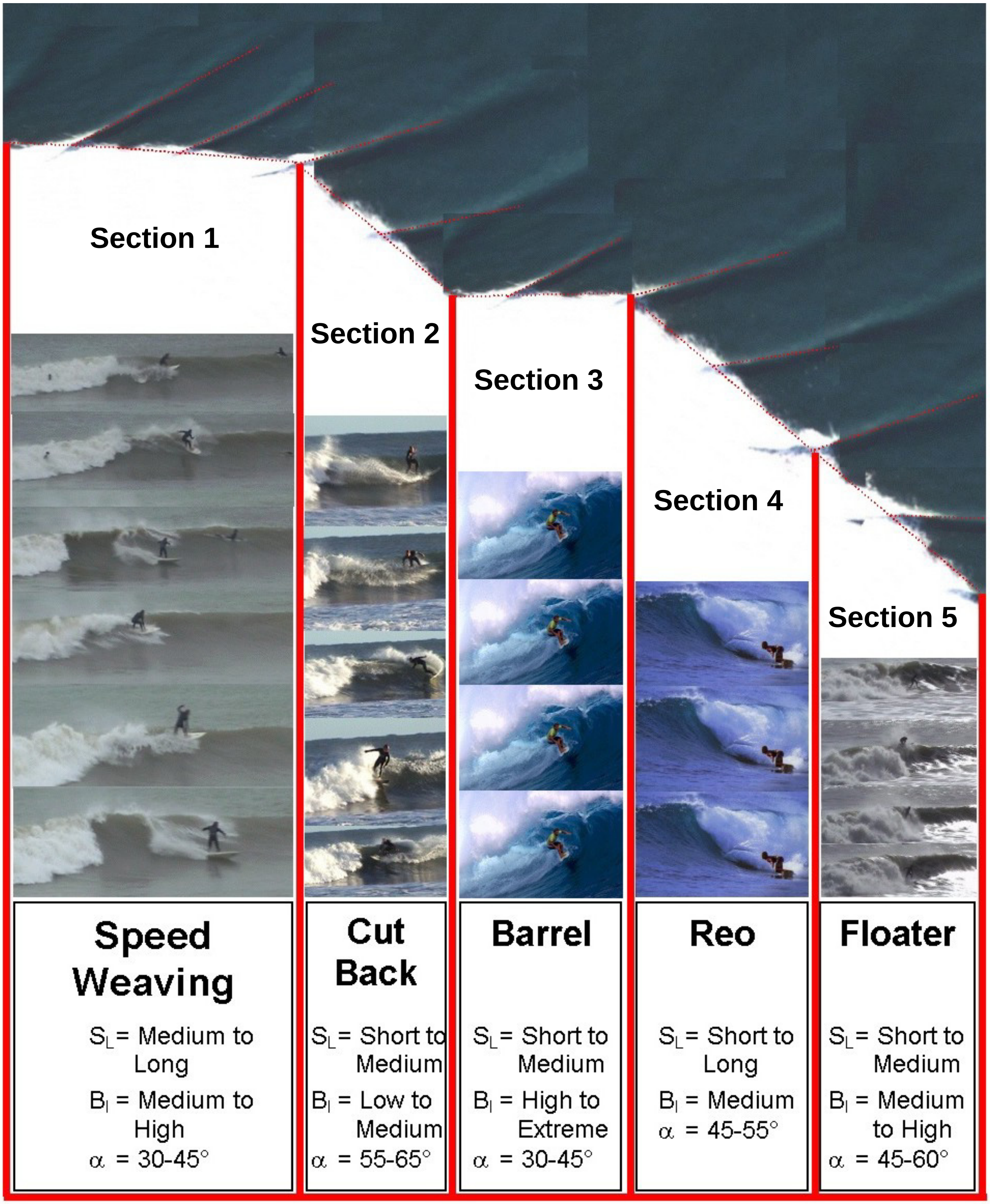



**Figure 2-22. Configuration of wave sections suitable for different types of maneuvers. Adapted from concept shown in Scarfe et al. (2002).**

# 3.0 CHARACTERISTICS OF SURFING BREAKS

Planar beaches with parallel contours do not produce good surfing breaks. Waves simply "closeout" as the wave crest breaks all at once rather than peeling. The peel angle is too low for surfing. Certain kinds of bathymetric features are needed to cause waves to break along the wave crest rather than all at once. All good surfing breaks have preconditioning components and/or shallow water features that cause waves to peel. This is why most surfing spots are near distinctive morphological features, such as river mouths with ebb deltas, coral/rock reefs, points, rock ledges, piers, jetties, or places where large-scale bar/rip features are created by edge waves.

The majority of waves that break on shorelines are not suitable for surfing. In order for waves to break well for surfing, wave height, peel angle and breaking intensity must be within the surfable range (Hutt et al., 2001; Moores, 2001; Scarfe 2001; Scarfe et al., 2002). Top surfers can ride waves ranging from a very low breaking intensity to an extremely high, dangerous breaker intensity within a range of wave heights from 1 to 50 feet. In fact, it is becoming apparent that top surfers now are able to surf waves of almost any size and any breaking intensity. The major surfing wave parameter that is often not within a surfable range is the peel angle. Therefore, the role of a surfing break is to increase the peel angle to within surfable limits. Although peel angles can be too high to challenge surfers of high abilities, high peel angles do not prevent surfers from riding waves whereas, low peel angles do.

## 3.1 SURFING REEF COMPONENTS

Mead and Black (2001a) identified the major bathymetric features that cause surfing breaks to form good surfing waves. Surfing reef or surfing break components were classified based on surveys and numerical modeling of world-class surfing breaks in New Zealand, Australia, Indonesia, Hawaii, California and Brazil. Each component was distinguished based on its shape and function. Mead and Black (2001a) refer to these features as surfing reef components, but this term also includes features that are made of material other than reef. These components are:

- Ramps
- Platforms
- Wedges
- Focuses
- Ledges
- Ridges
- Pinnacles

Depending on the configuration, orientation and size of these components, Mead and Black (1999 and 2001b) found that different wave types are produced. Any alteration of these components by natural processes or human actions will change the surfing wave parameters at the surfing break.

The "favored orthogonal direction" is the wave alignment that produces the best quality surfing waves over a reef component (Mead and Black, 2001a). Any deviation from the optimum alignment will cause an increase or decrease in ideal peel angle. This leads to waves breaking more quickly or slowly than is desirable for high-performance surfing. Examples from surf break surveys and schematic diagrams of each component are shown in Figure 3-1.

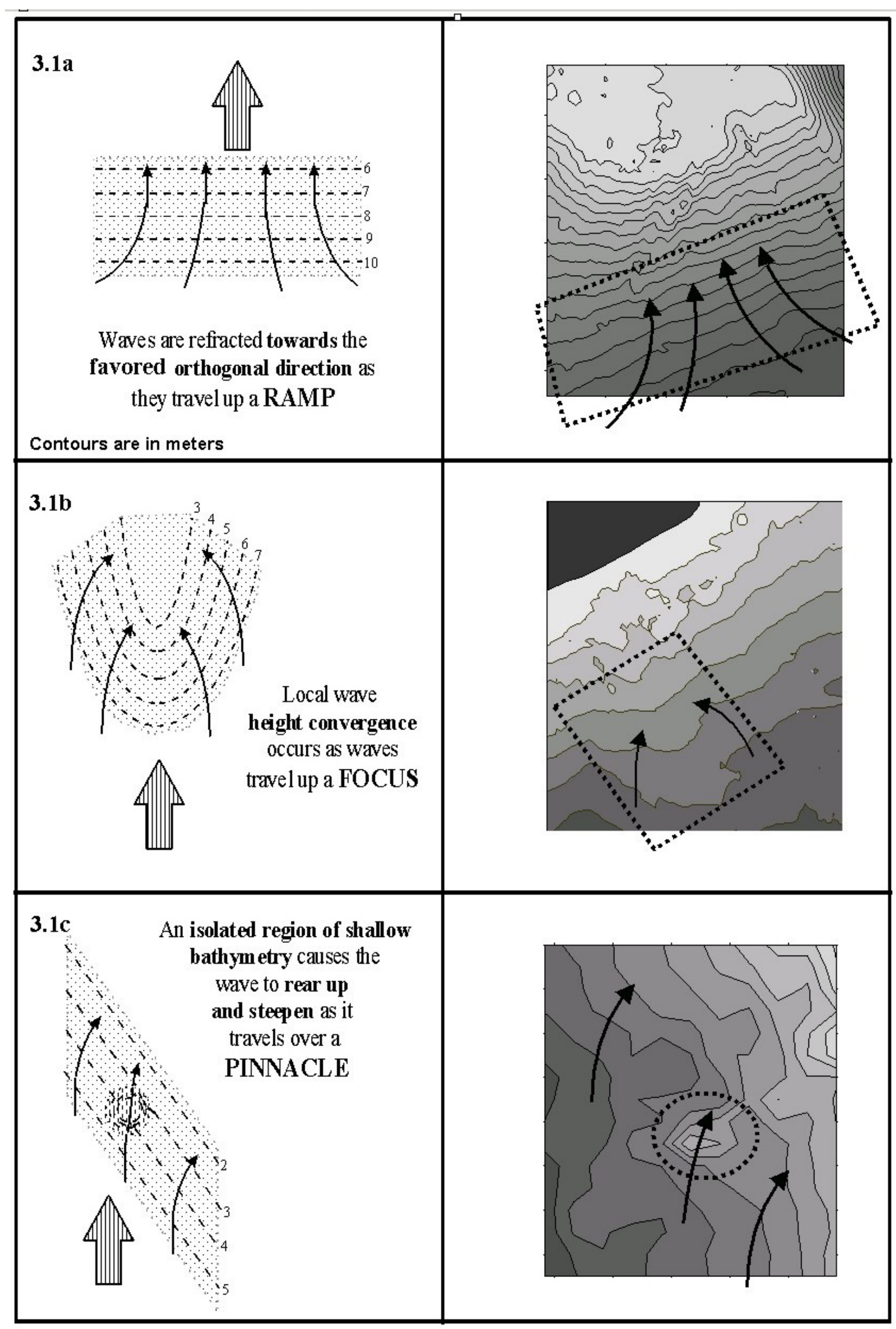



**Figure 3-1. Reef components that make up the bathymetry of world-class surfing breaks (from Mead and Black, 2001a). The large arrows represent the "favored orthogonal direction," and the small arrows represent transformations of the wave orthogonals. Schematic diagrams are accompanied by an example of a reef component from a measured bathymetry. Note that the platform has not been included here because it is essentially a flat component that does not refract waves that pass over it. (Figure is on this page and next.)**

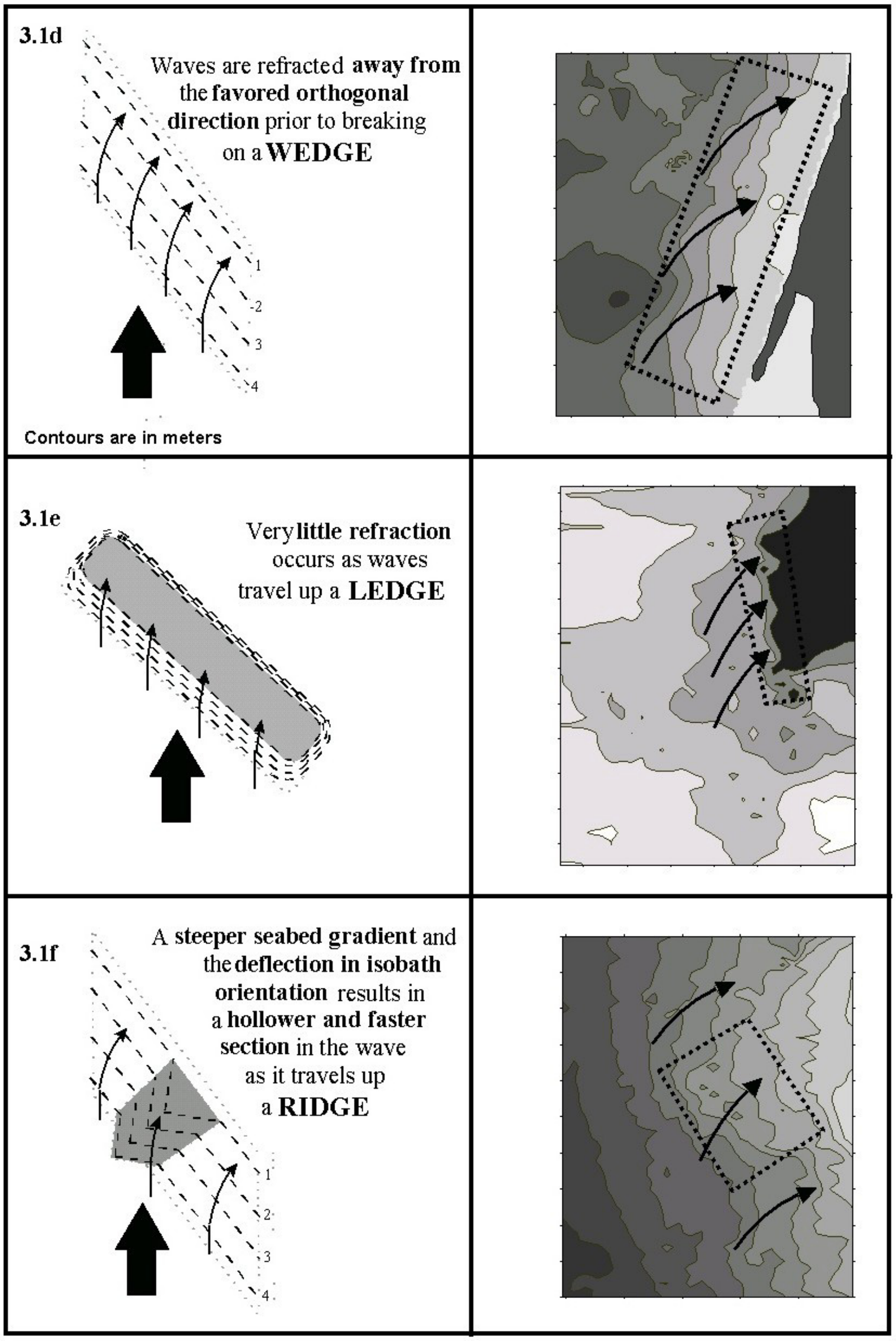



**Figure 3-1. Continued (caption on previous page.)**

### 3.1.1 Definition of Components

Mead and Black's (2001a) definitions of functional reef components are as follows:

#### *Ramp*

A ramp causes waves to refract and organize themselves. The directional spread of offshore waves is aligned orthogonally to ramp contours prior to breaking on another morphological component. Good quality surfing waves do not break on a ramp.

#### *Focus*

A focus is a seabed ridge that causes a peak in wave height and lowers the effective seabed gradient, making it easier for a surfer to take off. Focuses can also occur at any section of a surfing ride. Depending on the water depth relative to the swell and the extent of focusing, peaks will cause wave breaking or increase the wave height of an advancing wave prior to breaking over another reef component.

#### *Platform*

A platform is a flat, horizontal plane and therefore has little effect on advancing waves. Platforms join different components without altering wave orientation or causing excessive shoaling. Their two main functions are to maintain wave orthogonals established by a ramp or focus and to allow sufficient depth of water for waves to break above a ledge. In this first situation, an optimal platform is just deeper than the depth where waves will break at a particular site.

#### *Wedge*

A wedge is a planar component tilted downward in the offshore that is direction similar to a ramp. It differs because it is at an angle to the favored orthogonal direction and in shallow enough water to cause wave breaking. This is the main wave-breaking component of most surf breaks. The orientation of the wedge determines the amount of refraction and therefore the wave peel angle.

#### *Ledge*

A ledge is a very steep wedge with a platform extending shoreward from its top edge. Little or no refraction can occur, and therefore the orientation of the ledge is critical. A ledge must have a gradient of >1:4, or waves are likely to surge and collapse. Plunging waves are common on ledges.

#### *Ridge*

A ridge is similar in shape to a focus but is oriented so that it does not cause wave convergence. The ridge provides a section of steeper seabed gradient, causing a decrease in peel angle and increase in breaker intensity. Ridges do not refract waves significantly compared with wedges. A focus can become a ridge when the wave angle changes significantly and the water depth is low enough to cause wave breaking.

#### *Pinnacle*

A pinnacle increases breaker intensity in the same way as a ridge, except it does so more abruptly and affects a smaller area. Pinnacles often define the take-off zone and help surfers to catch waves, as do focuses.

### 3.1.2 Component Function

Mead and Black (2001a) subcategorized components by function. Ramps, focuses, and platforms precondition the wave prior to breaking by aligning and shoaling. Wedges, ledges, ridges and pinnacles cause the wave to break. The breaking components are often small-scale features that are nestled on larger, preconditioning components. Figure 3-2 shows the approximate size and function of each component.

## 3.2 CONFIGURATION OF REEF COMPONENTS

Different types of waves can be produced depending on the configuration of the reef components. The components combine holistically to produce high quality surfing waves and different types of waves, depending on size, orientation, and configuration (Mead and Black, 1999). Analysis of reef component configurations by Mead and Black (2001b) showed four common set-ups of surfing breaks. They are:

- Ramp/Wedge
- Ramp/Platform/Wedge
- Ramp/Focus/Wedge
- Ramp/Ledge/Platform

In a case study of Bingin Reef in Bali, Indonesia, by Mead and Black (1999), the role of different reef components was investigated with numerical modeling. Bingin was found to produce consistent and surfable peel angles over a range of wave heights because of the configuration of five main components (Figure 3-3). Bingin is a Ramp/Focus/Platform/Wedge configuration with a ridge superimposed on the wedge.

Waves approaching from offshore are first affected by the ramp. The ramp aligns the waves to the favored orthogonal directions, reducing the directional spread of waves. The ramp also begins the shoaling process. The aligned waves then converge and break on the focus, creating a take-off point for surfers. The wave crest then refracts and breaks on the wedge. The function of the platform is to maintain the wave direction so that a consistent peel angle results from breaking on the wedge. The ridge component creates a section with a localized increase in breaker intensity and lower peel angle. Surfers are often able to get deep barrel rides while surfing over the ridge.

The actual Bingin bathymetry was manipulated so that the importance of each component could be seen. The five different scenarios were:

1. Actual bathymetry;
2. Removal of platform;
3. Removal of platform and wedge in deeper water;
4. Removal of platform and wedge in deeper water with wedge rotated at different angles; and
5. Removal of the focus.

For all the modified scenarios, it was found that the wave quality lessened. When the platform was removed and the ramp was extended toward the wedge, waves began to break on the ramp, resulting in peel angles that were too low to surf. When the wedge was moved further offshore, more surfable peel angles resulted, but they were still lower than the original configuration, especially for smaller wave heights. A greater variation in peel angles was seen when the platform was omitted and the wedge was rotated than when the wedge was rotated with the platform. The focus feature creates a section with a higher peel angle, enabling easier take-off. Removal of this component resulted in low peel angles throughout the ride and a more difficult take-off, achievable only by expert surfers.

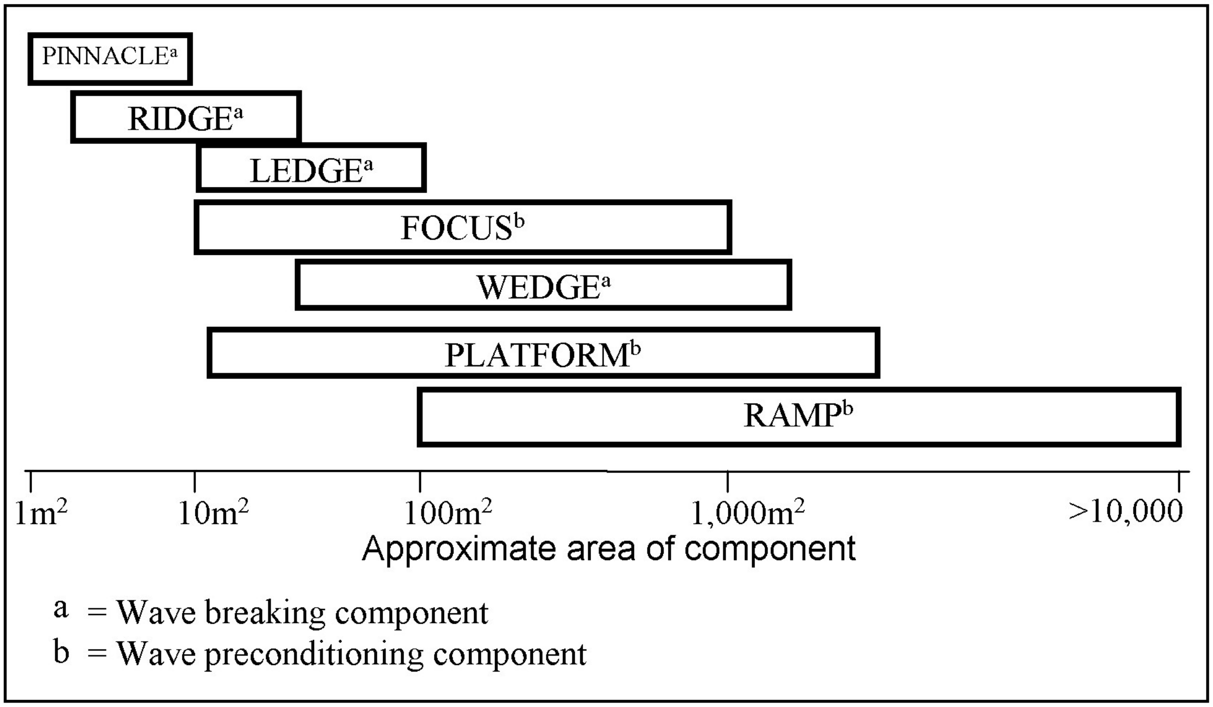



**Figure 3-2. Size (m²) and function of surfing reef components (from Mead and Black, 2001a).**

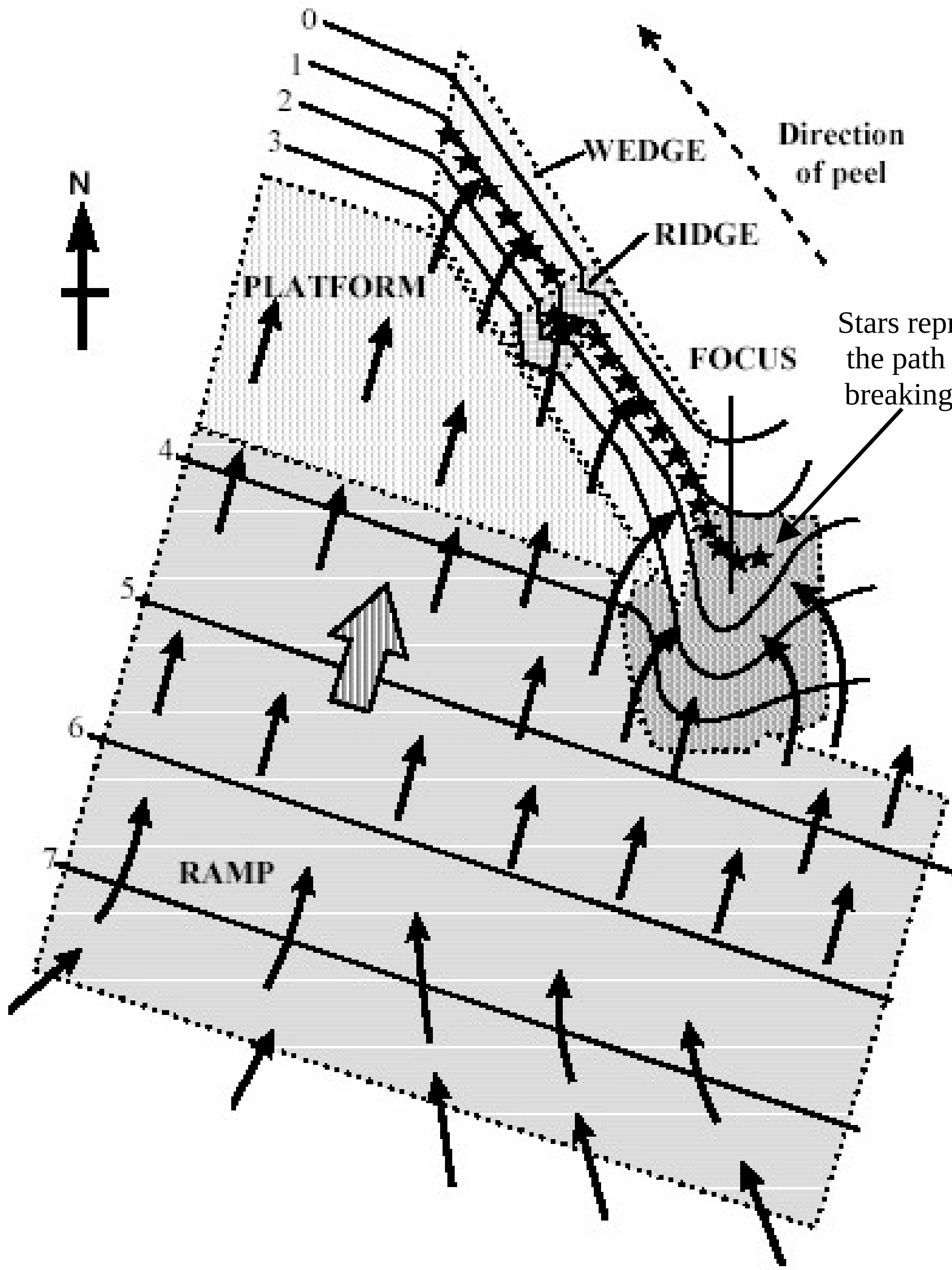



**Figure 3-3. The configuration of large-scale reef components at Bingin Reef, Bali, Indonesia. The large arrow represents the favored orthogonal direction, and the smaller arrows represent the alignment of wave orthogonals as they pass over the various components. Depth contours are in meters (from Mead and Black, 1999).**

## 3.3 SCALE OF REEF COMPONENTS

The seven components identified by Mead and Black (2001a) occur on macro, meso, and micro-scales (Figure 3-4, Scarfe, 2002). On the largest scale, offshore components refract and organize waves before breaking. For example, a ramp can align waves along a whole coast or be a smaller component of a surfing break that aligns a section of the wave prior to breaking on another component (Mead and Black, 2001a). Macro-scale components have an influence on wave direction and shoaling but do not cause waves to break. Meso-scale components focus and orient waves prior to breaking and can cause wave breaking. Micro-scale components are superimposed on meso-scale features and create wave sections between 5 and 40 m (Scarfe, 2002).

### *Example of Scale - Manu Bay Surfing Reef, Raglan, New Zealand*

The Raglan headland is made up of a series of surfing reefs (Figure 3-5). At a macro-scale, the gently sloping, sandy continental shelf acts as a wedge, organizing and refracting swell toward the favored orthogonal direction at each surfing spot. Often even very messy swells produce clean surfing waves at Raglan because of the headland effect (Mead and Black, 2001b). This effect occurs where shorter period local swells are filtered out as the waves refract on the wedge of the headland, resulting in relatively clean, organized, long period waves at the surfing breaks.

Figure 3-6 shows the reef meso-scale components at Manu Bay and The Ledge as defined by Mead and Black (2001b). The Ledge is a section of Manu Bay that only breaks under certain conditions. It is the heaviest and most spectacular of all the Raglan surfing breaks because of the hollow barrels that can be surfed. It is the ridge feature that creates The Ledge because it increases breaker intensity and lowers peel angle for the section.

Micro-scale reef components (Figure 3-7) were identified by Scarfe (2002) at Manu Bay in addition to the meso-scale features identified by Mead and Black (2001b). Refraction modelling by Scarfe (2002) showed how these features refract and focus waves to create the surfing break. In addition, Scarfe (2002) found that the wedge feature is actually made up of various micro-scale components (Figure 3-7). These micro-scale features refract and shoal waves, creating sections with different peel angles and breaker intensities. These micro-scale components act very differently under different conditions. Focuses become ridges, and ridges become focuses, depending on swell direction and size as well as on tide level. This occurs because ridges and focuses are shaped similarly, but oriented differently toward advancing waves.

For the average conditions observed at Manu Bay (Figure 3-8), Focuses 2, 3 and 4 create sections of increased wave height where surfers take off. Generally, the peel angle of the section created by Focuses 2 and 3 is too fast to negotiate (Figure 3-9). However, the increased wave height and breaker intensity at the end of this section create a good take-off area. The take-off area allows the surfer to prepare for the fast section created by the combination of Ridges 3 and 4. Surfers were observed on this section doing a range of maneuvers including reos, floaters, foam bounces, and airs.

A hole at the end of the surfing ride combines with excessive wave refraction to end the ride. The hole also lowers the breaker intensity to a level where it is only suitable for Malibu type waves. If the Manu Bay wedge did not refract quite as much and the hole was not present, then rides would be much longer.

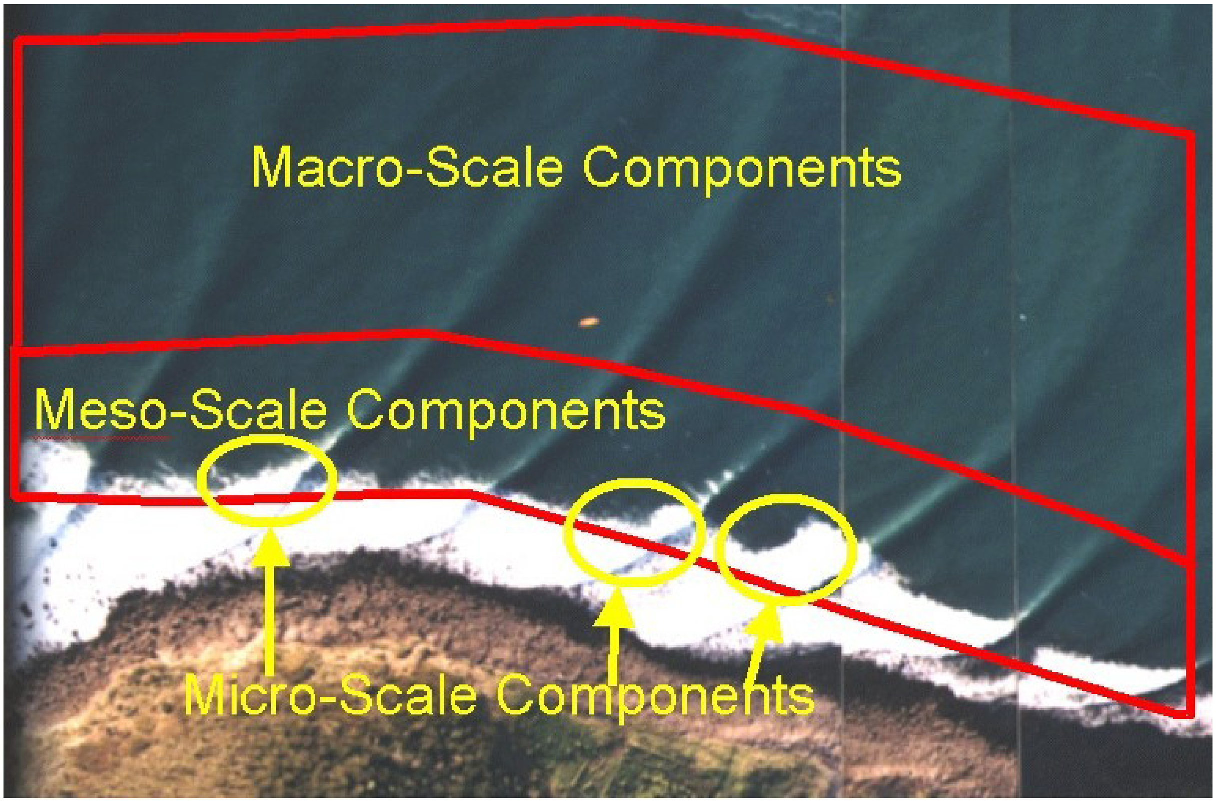



**Figure 3-4. Micro, meso and macro-scale surfing reef components (from Scarfe, 2002).**


**Figure 3-5. Aerial view of the Raglan surfing breaks (from Hutt et al., 2001).**

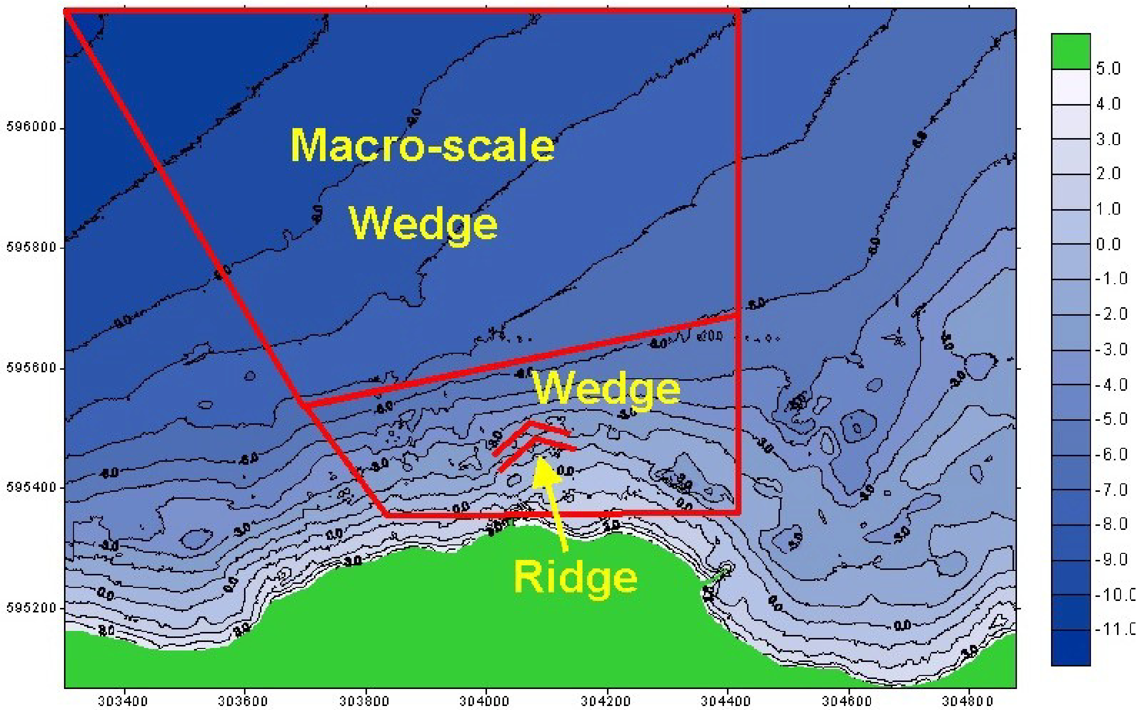



**Figure 3-6. Meso-scale components identified by Mead and Black (2001b; from Scarfe, 2002).**

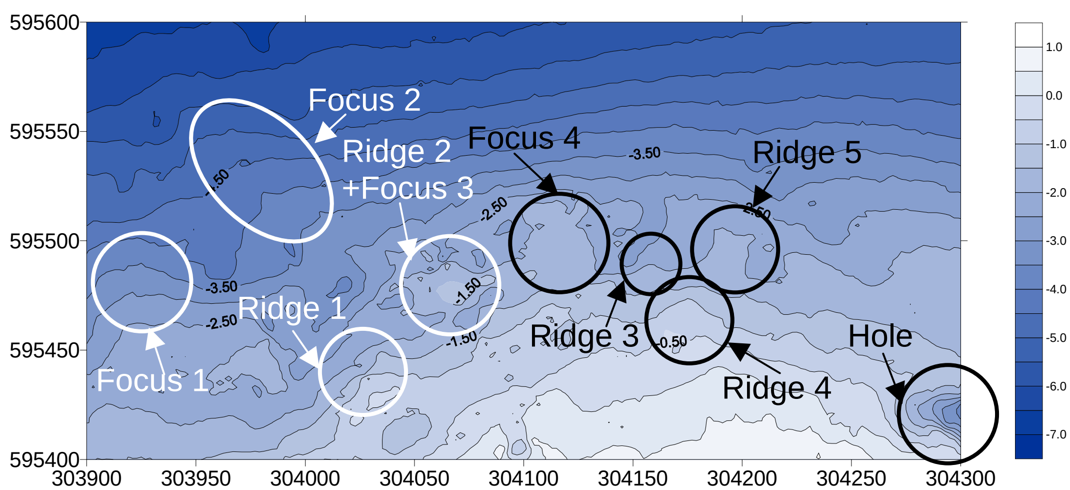



**Figure 3-7. Micro-scale reef components at Manu Bay and The Ledge. Under different ocean conditions and tide heights, these components have different effects on wave breaking. The Ledge components are shown in white; those of Manu Bay are in black (from Scarfe, 2002).**

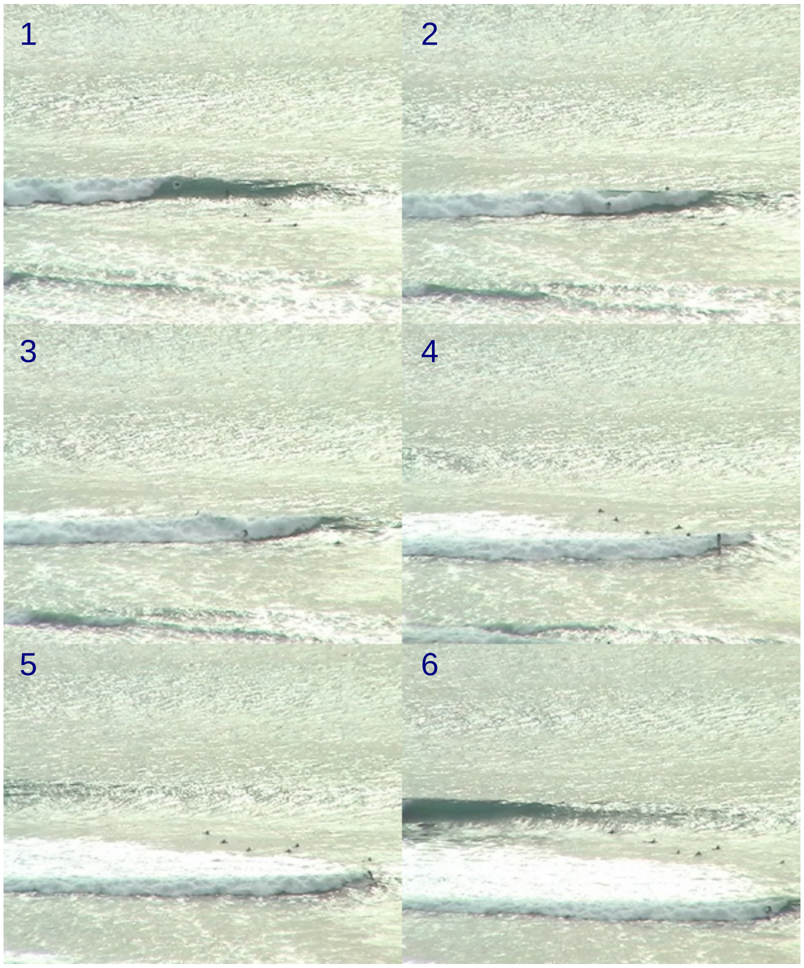



**Figure 3-8 Images of average quality surfing waves at Manu Bay (from Scarfe, 2002). Wave height is approximately 2.0-2.5 m, and tide level is high.**

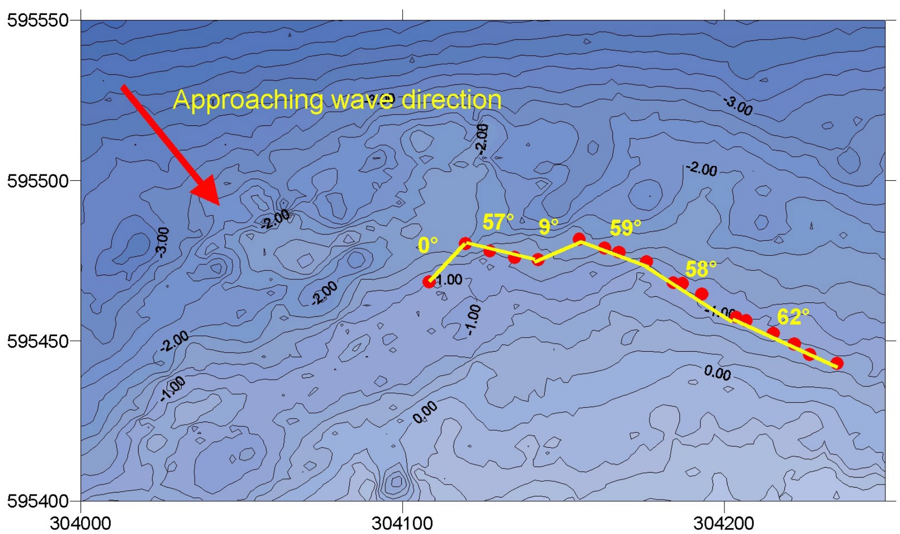



**Figure 3-9. Path of wave and peel angles for surfing ride in Figure 3-8 (from Scarfe, 2002). Wave height is approximately 2.0-2.5 m, and tide level is very low.**

Manu Bay behaves very differently when the tide is extremely low and wave heights are above 2.5 m (Figure 3-10). The skill level required to surf the break increases as breaker intensity and peel angles change dramatically. When these conditions occur, The Ledge can be surfed.

Focus 2 becomes the main preconditioning feature for the waves when The Ledge is breaking perfectly. Surfers take off on the seaward side of Focus 3 or 4, and the focuses act as ridges, breaking waves on steep seabed gradients. The waves peel quickly along 2.5-3.5 m contours with barrel sections (Figure 3-11), especially when the wind is offshore. The section between Focus 3 and 4 is very fast and often unachievable. Under these conditions Manu Bay produces the highest quality surfing waves.

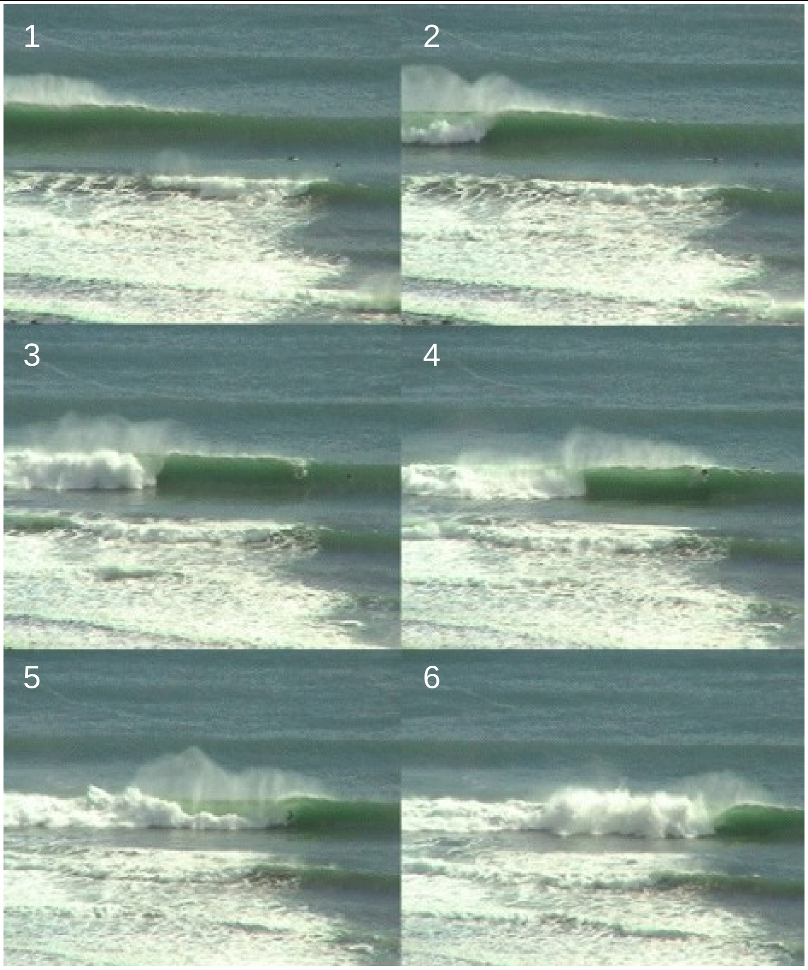



**Figure 3-10. Images of very high quality surfing waves at Manu Bay (from Scarfe, 2002). Wave height is approximately 2.5-3.0 m, and tide level is very low.**

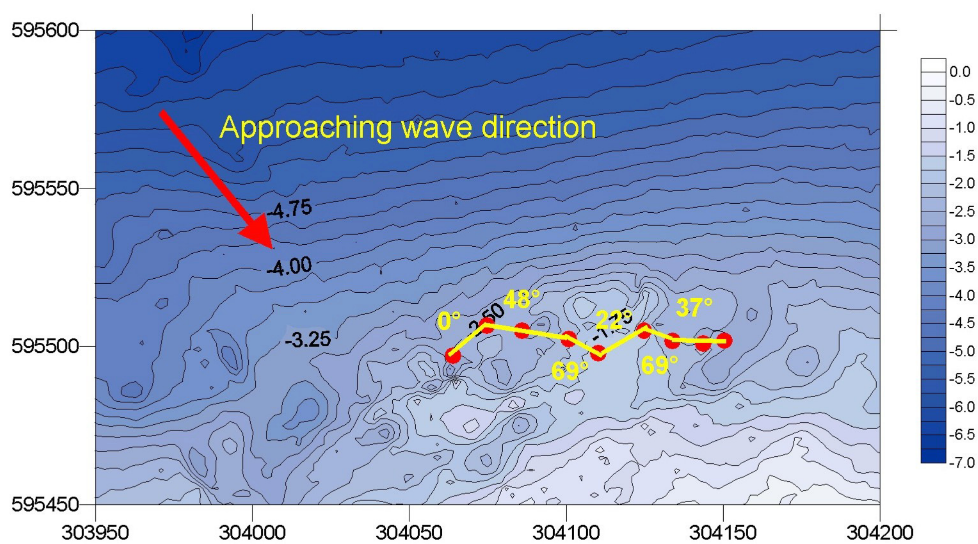



**Figure 3-11. Path of wave and peel angles for surfing ride in Figure 3-10 (from Scarfe, 2002). Wave height is approximately 2.5-3.0 m, and tide level is very low.**

# 4.0 SURFING CONDITIONS AROUND AGUA HEDIONDA LAGOON, CARLSBAD, CALIFORNIA

## 4.1 INTRODUCTION

Surfing conditions around Agua Hedionda Lagoon, Carlsbad, California (Figure 4-1) provide beginner-to-intermediate level waves for surfers in the area. People surf these breaks almost every day, regardless of conditions. A survey by Elwany (not published) showed that on average, surfers travel 18 miles to surf these breaks. They are an important social and economic feature of the Carlsbad beaches and also for the San Diego region. The surfing breaks around Agua Hedionda Lagoon are commonly and collectively referred to as Tamarack, because those who surf in the area park at the end of Tamarack Street. However, each break at Tamarack has its own individual name as well.

This chapter includes numerical modeling of seasonal wave climates to show the effects of continental shelf wave preconditioning on waves around Carlsbad. The Carlsbad Canyon is shown to have a large effect on wave size and a lesser effect on wave direction at Carlsbad. The focusing agrees with anecdotal evidence that waves are smaller during southern summer swell than winter.

The simple planar profile of the Carlsbad beaches does not make for good surfing. The best surfing in Carlsbad is near the jetties and is created by the combined effects of jetties and low relief reefs. The surfing breaks around Agua Hedionda Lagoon vary greatly with tide and swell but are usually best surfed on a medium tide with a swell of less than 1.5 m (www.surfline.com).

There are eight main surfing spots around the lagoon inlet and outlet jetties. From north to south, they are Cherry State, Middles, Main Peak, Spot-land, Green House, Jetties, Southside, and Warm-Water Jetties (Figure 4-2).

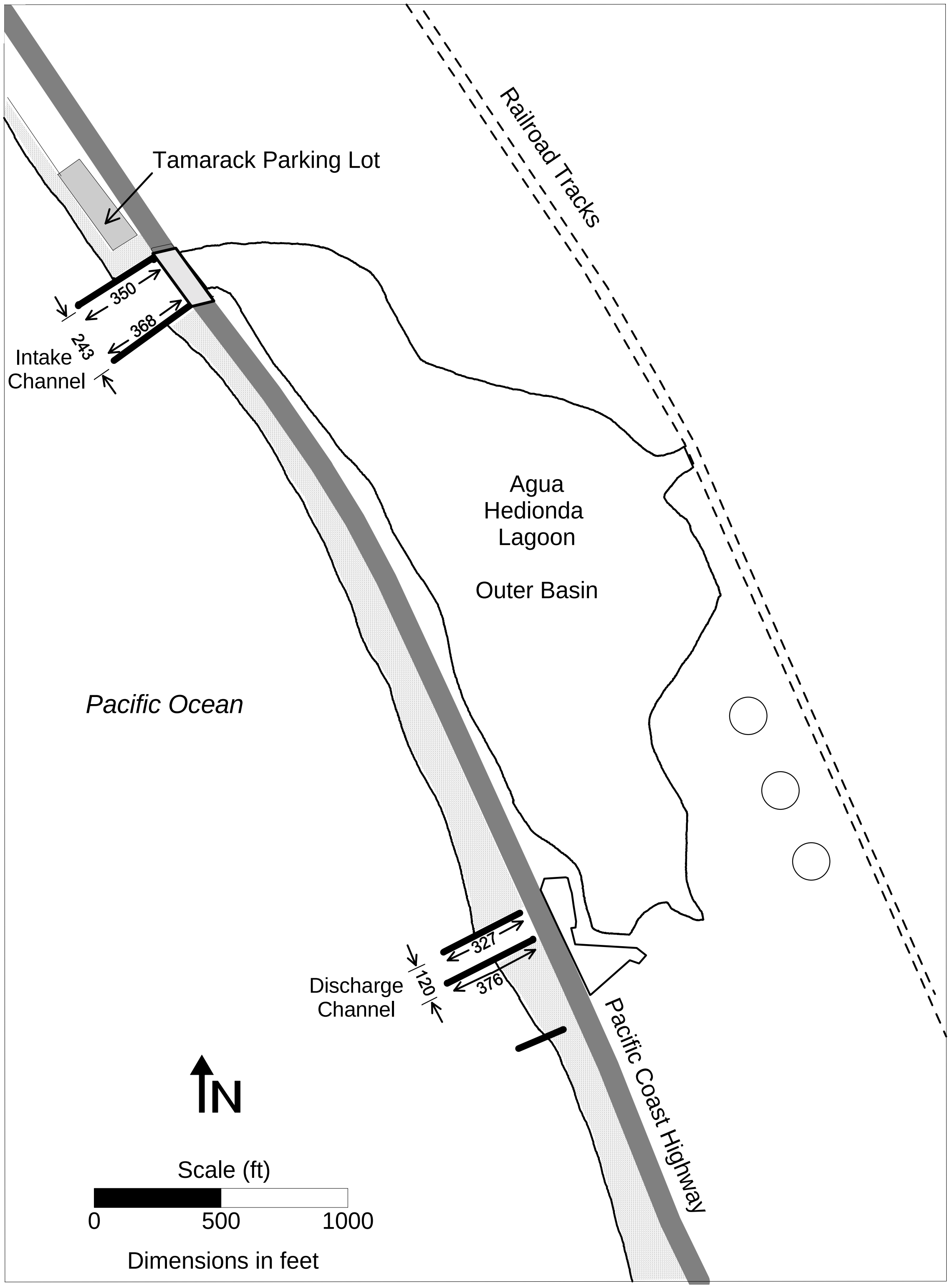



**Figure 4-1. Configuration and scale of the intake and discharge channels of Agua Hedionda Lagoon (from Elwany et al., 1999).**

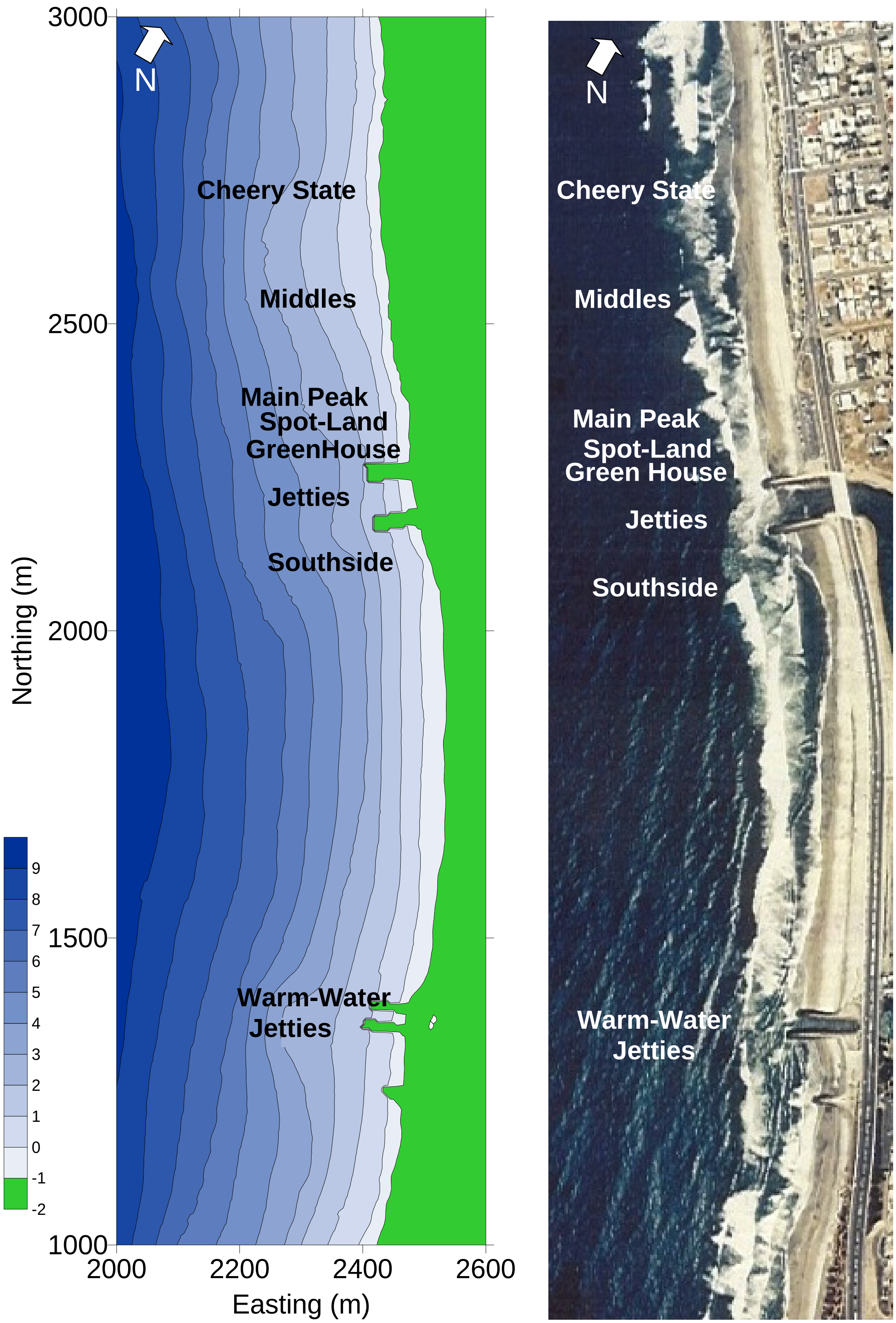



**Figure 4-2. Locations of surfing breaks around Agua Hedionda Lagoon.**

## 4.2 WAVE CLIMATE

The wave climate in Southern California is complex due to sheltering by numerous offshore islands and refraction over complex canyons and shoals (Figure 4-3). Depending on offshore wave direction, height, and period, the focusing or shadowing of wave energy can vary over a relatively small stretch of coast. Therefore, the best surfing spots also vary because they depend upon where the most suitable swells are at a given time. The waves that reach the Carlsbad coastline come from three main sources (U.S. Army Corps of Engineers [USACE], 1986, in Elwany et al., 1999):

- Northern Hemisphere Swell – Waves generated in the north Pacific Ocean that propagate into Southern Californian waters;
- Southern Hemisphere Swell – Similar waves generated south of the equator; and
- Local Seas – Relatively short-period waves generated within the Southern California Bight.

The area around Carlsbad Canyon is an example of a Southern California coastal area that can display very different wave heights and directions over a short distance. The monochromatic numerical model WBEND (Black and Rosenberg, 1992; Black, 2000; Appendix A and B) was to investigate the effect of the canyon on wave refraction. The modeling of Northern Hemisphere swell (Figure 4-4), Southern Hemisphere swell (Figure 4-5), and local seas (Figure 4-6) shows how wave height at Agua Hedionda Lagoon can be reinforced or lessened depending on swell origin. The approximate location of wave focusing agrees with numerical predictions by Jenkins and Wasyl (2001). The modeling shown here is driven by a monochromatic wave from a single grid cell. In reality, the boundary of the model grid would be comprised of a more complex wave train because of the offshore islands. However, the type of modeling used here does show the influence of the canyon, although it was not as difficult or time-consuming as it would have been if it had included island-shadowing effects.

For a given deepwater wave height, the size of surfing waves at Agua Hedionda Lagoon is dependent on swell origin. Maximum wave focusing happens during extra-tropical swells. The location of each surfing break was stable for each scenario.

Wave directions in the surfzone were not found to be highly variable for different swell origins. They were extracted at approximately the breakpoint for the model scenario for each surfing break. The average standard deviation in wave direction for each simulation was only 14°. Even though offshore wave direction varied by 90°, the waves became aligned with the shallow water contours, leading to only a small variation in direction at breakpoint. It is concluded that there will be only a small variation in peel angle for different swell directions. Variations in peel angles are attributed more to differing wave heights and tide levels, which cause wave breaking over different seabed features, than to the origin of the swell.

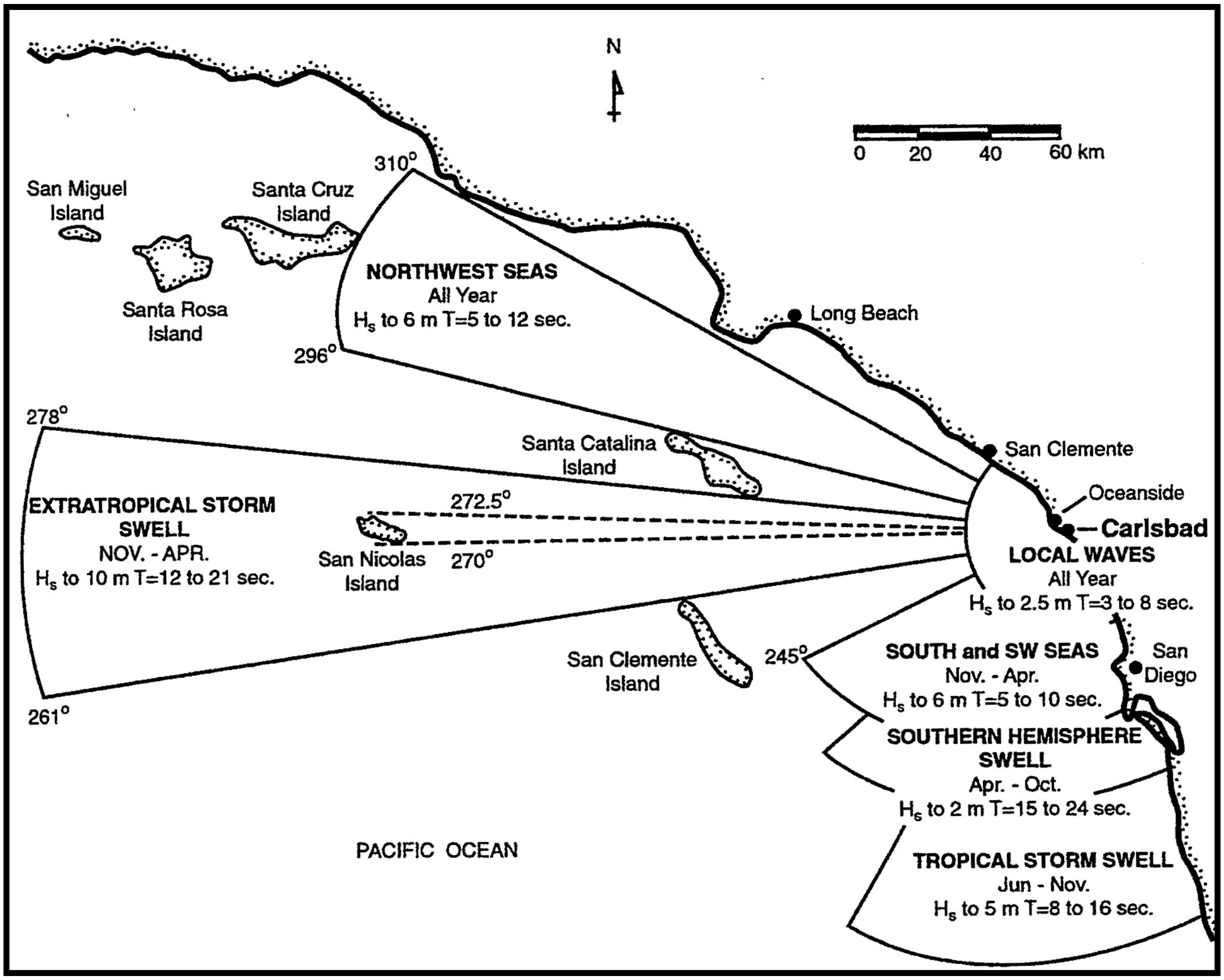



**Figure 4-3. Wave exposure for Carlsbad, illustrating island-shadowing effects (from Elwany et al., 1999).**

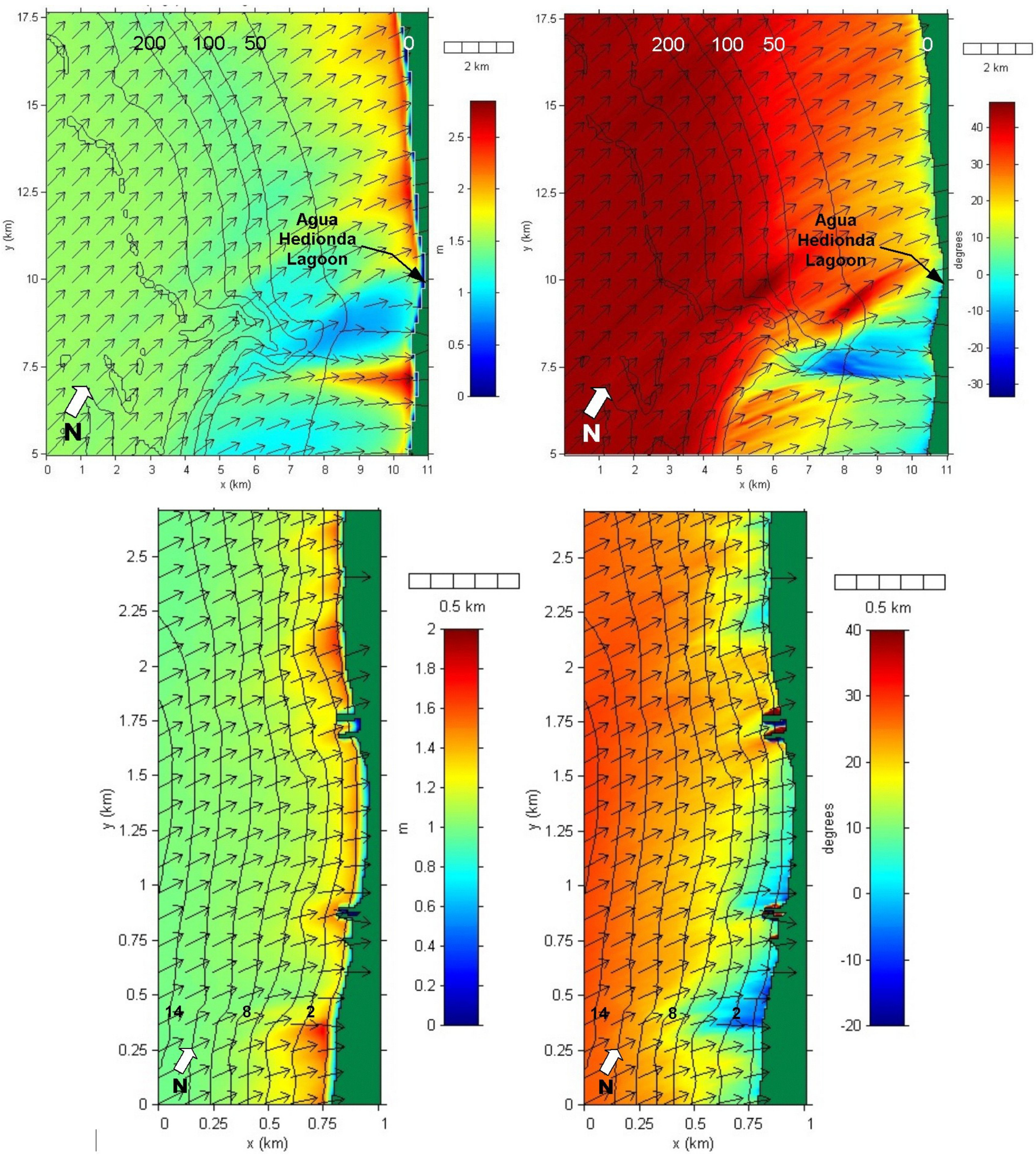



**Figure 4-4. Predicted wave height and angle near Agua Hedionda Lagoon for a deepwater 1.5 m 16 s southern hemisphere swell. (Model wave direction is -45°; true magnetic wave direction is approximately 195°.) The top figure shows wave refraction over Carlsbad Canyon. The bottom shows the wave focusing that creates the surfing breaks in the area.**

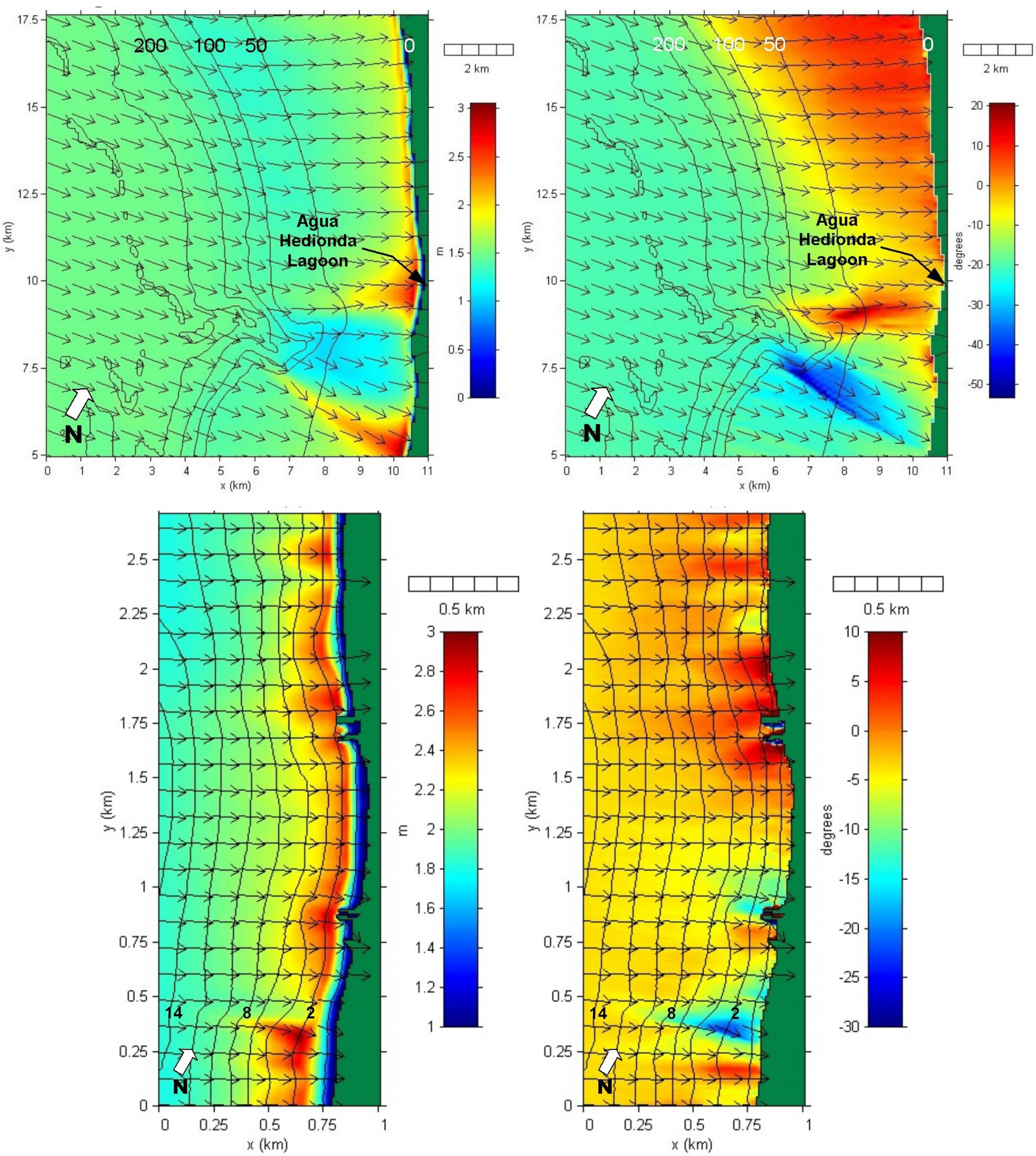



**Figure 4-5. Predicted wave height and angle near Agua Hedionda Lagoon for a deepwater 1.5 m 21 s extratropical storm swell. (Model wave direction is -20°; true magnetic wave direction is approximately 260°.) The top figure shows wave refraction over Carlsbad Canyon. The bottom shows the wave focusing that creates the surfing breaks in the area.**

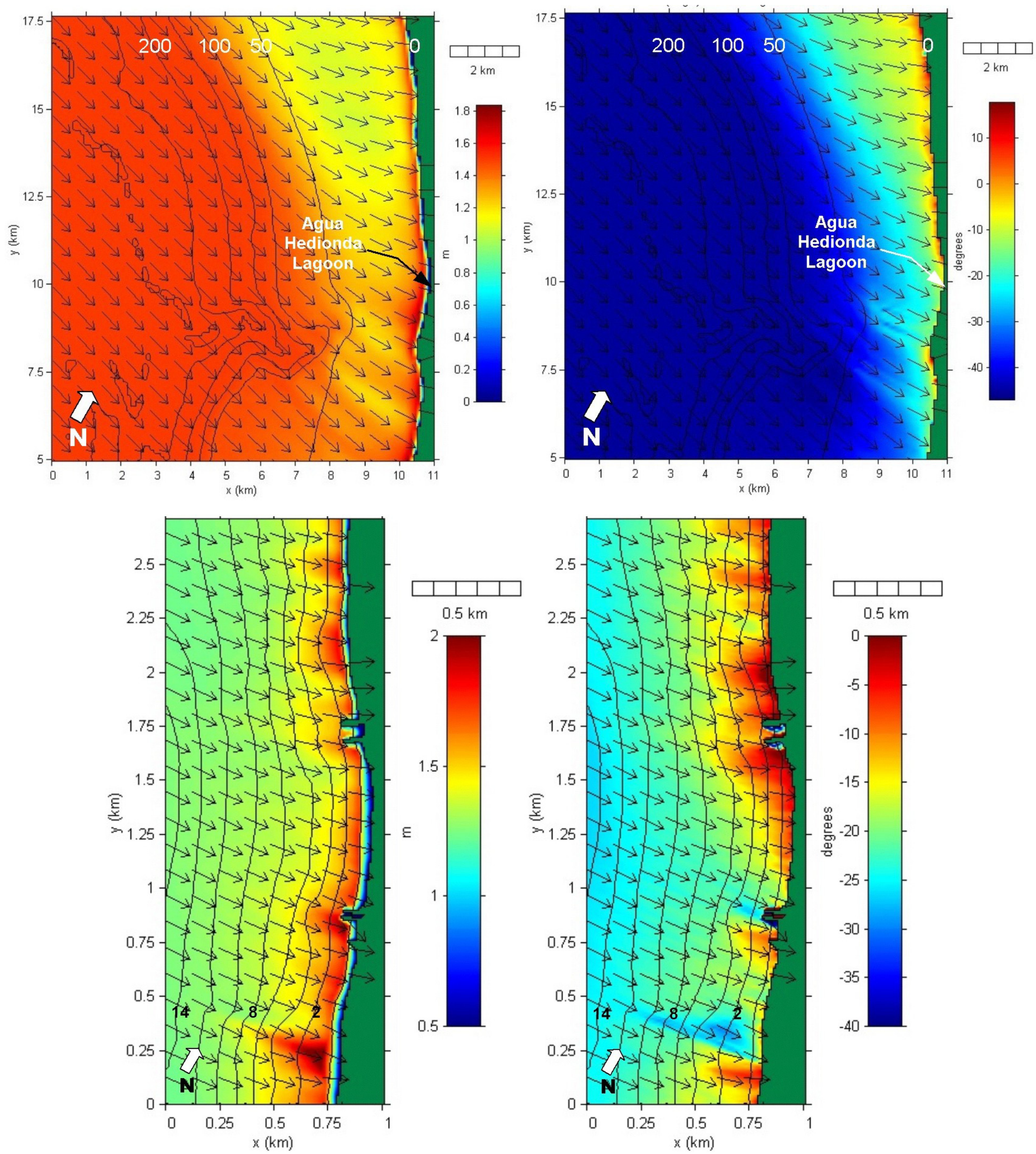



**Figure 4-6. Predicted wave height and angle near Agua Hedionda Lagoon for a deepwater 1.5 m 12 s northwest sea swell. (Model wave direction is -45°; true magnetic wave direction is approximately 285°.) The top figure shows wave refraction over Carlsbad Canyon. The bottom shows the wave focusing that creates the surfing breaks in the area.**

## 4.3 DESCRIPTION OF SURF BREAKS

Surfing breaks Jetties and Southside are contained in the same peak in the model simulations (Figures 4-4, 4-5 and 4-6). The sixth southern peak shown at the bottom of Figures 4-4, 4-5 and 4-6, is a surfing break called Terra Mar Cove. This break is created by reef and not influenced by the jetties, and therefore, not considered in this study.

Middles, Main Peak, Spotland and Green House are all made up of sand-covered reef, and colloquial tales suggest that this reef is the reason for the surfable waves. Anecdotal evidence indicates that surfing conditions are best at Tamarack when there is a great deal of sand. At these times, the reefs may be completely or partially covered. Many surfing breaks exist where a combination of sand and reef acts together to produce good surfing waves. Scarfe (2002) showed that sand and reef formations create preconditioning components at Raglan, New Zealand, which modify the waves before they break on the boulder reefs (Figure 4-7). Therefore, the quality of waves is dependent on the sand built up at the time.

Southside is a righthander that begins to work on a larger swell at a low tide. It also breaks left, but righthanders are generally longer rides. The take-off is between the two jetties, and the righthander wraps onto the beach around the southern jetty. This break is discussed in detail in Section 5.3.2.

In-Between is a break between the two jetties. It breaks right and left and is peaky and shifty as the waves break over the ebb delta.

Warm-Water Jetties is the premier surfing site at Carlsbad (www.surfline.com). This surfing break exists because of the delta formed by the jetty. This break is discussed in detail in Section 5.3.1. The break works best at the end of summer during the first month of northwest swells, before the sand is pushed down the beach (www.surfline.com). Sand builds up on the side of the jetties during the summer months (www.surfline.com).

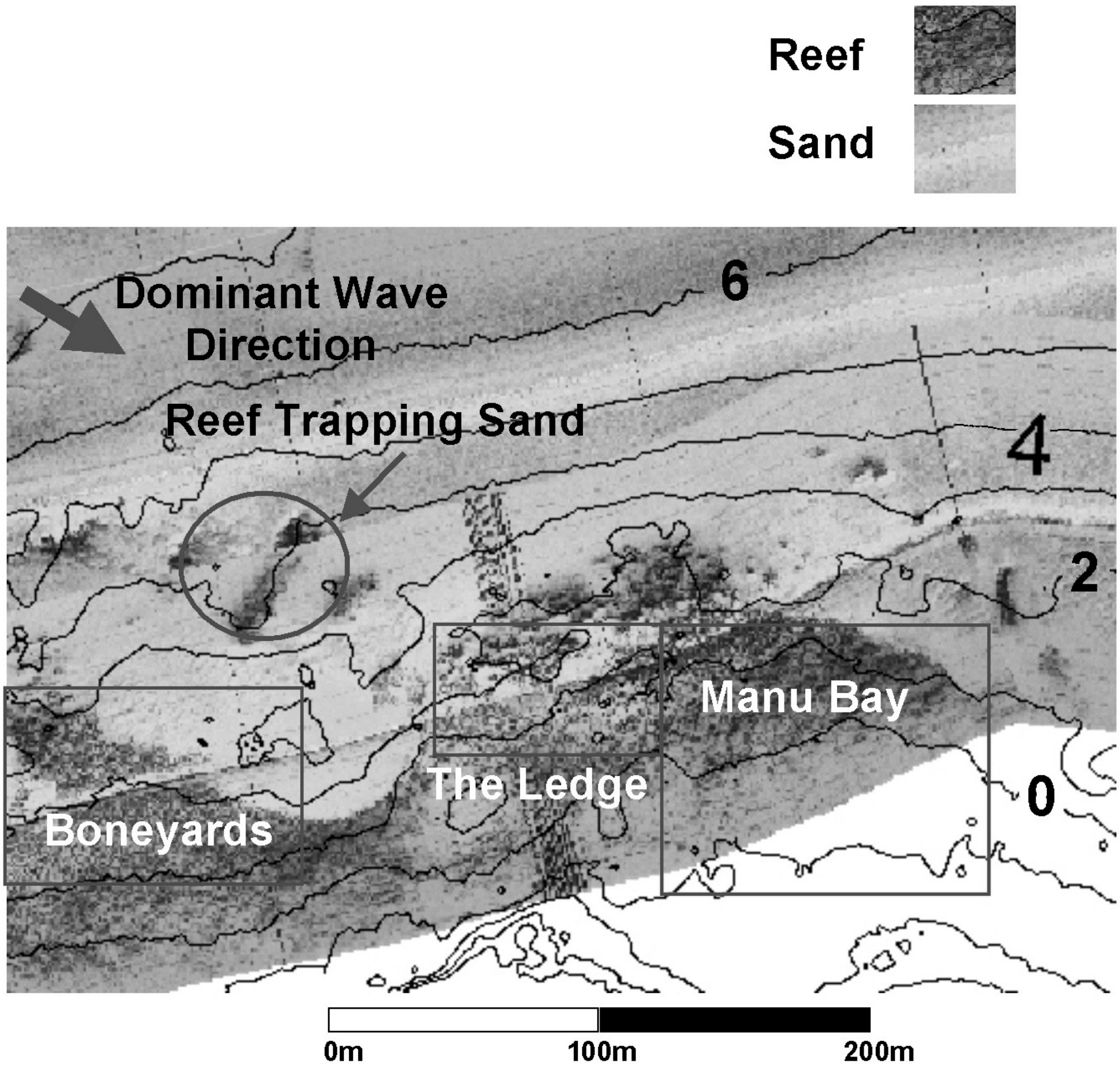



**Figure 4-7. Side-scan imaging of Manu Bay, Raglan, New Zealand, showing a reef trapping sand to create a focus feature that is identified in Figure 3.7 (from Scarfe, 2002; Scarfe et al., 2003). Depth contours in meters relative to chart datum which approximates mean low low water.**

## 4.4 WAVE BREAKING INTENSITY

Wave breaking intensity has been calculated at Mainpeak using the empirical formula of Mead and Black (2001c; Equation 1). Seabed gradients were measured from historical beach profile data (Station CB830, Figure 4-8, Elwany et al., 1998) for the calculations. Equation 1 requires the orthogonal gradient, but this is assumed to be close to the shore-normal beach gradient for the simple Carlsbad bathymetry. Significant refraction observed at some surfing breaks requires the path of the wave orthogonal to be used for gradient calculations. Waves do not refract dramatically at Carlsbad.

There is more than a decade of recorded profile data for Station CB830, and a typical profile can be seen in Figure 4-9. The presence of the offshore bar complicates the measurement of seabed gradient, because the bar gradient is steeper than the general beach profile. For this reason, two gradients were measured, one for the general offshore profile, and one for the bar profile, for each survey. The dates of the profile surveys used are:

- April 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993;
- May 1996, 1997, 1998, 1999; and
- October 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1996, 1997, 1998, 1999.

The offshore profile has an average breaking intensity of 4.4 (max 5.1 min 3.8, $\sigma = 0.4$) over the time of the surveys. No variation was observed between summer (4.5) and winter (4.4). The average breaking intensity of the nearshore bar is slightly higher at 4.0 (max 2.5 min 5.7, $\sigma = 0.8$) and shows some variation between summer (4.2) and winter (3.8). Winter profiles are generally steeper because sand moves offshore during this period. The breaking intensity for the offshore profile and nearshore bar over time can be seen in Figure 4-10andFigure 4-11.

The surfing breaks at Tamarack rarely barrel because the beach gradient is too low. The breaking intensity at Tamarack does not even feature on the Mead and Black (2001c) classification schedule (Table 2.1). Observations at the site show that waves do not generally break from top to bottom immediately, but from top to approximately halfway down the wave face. Barreling waves have been observed, but they do not generally plunge from top to bottom. To surf inside a barreling wave that breaks from top to halfway down, the wave needs to be at least twice the height of the surfer.

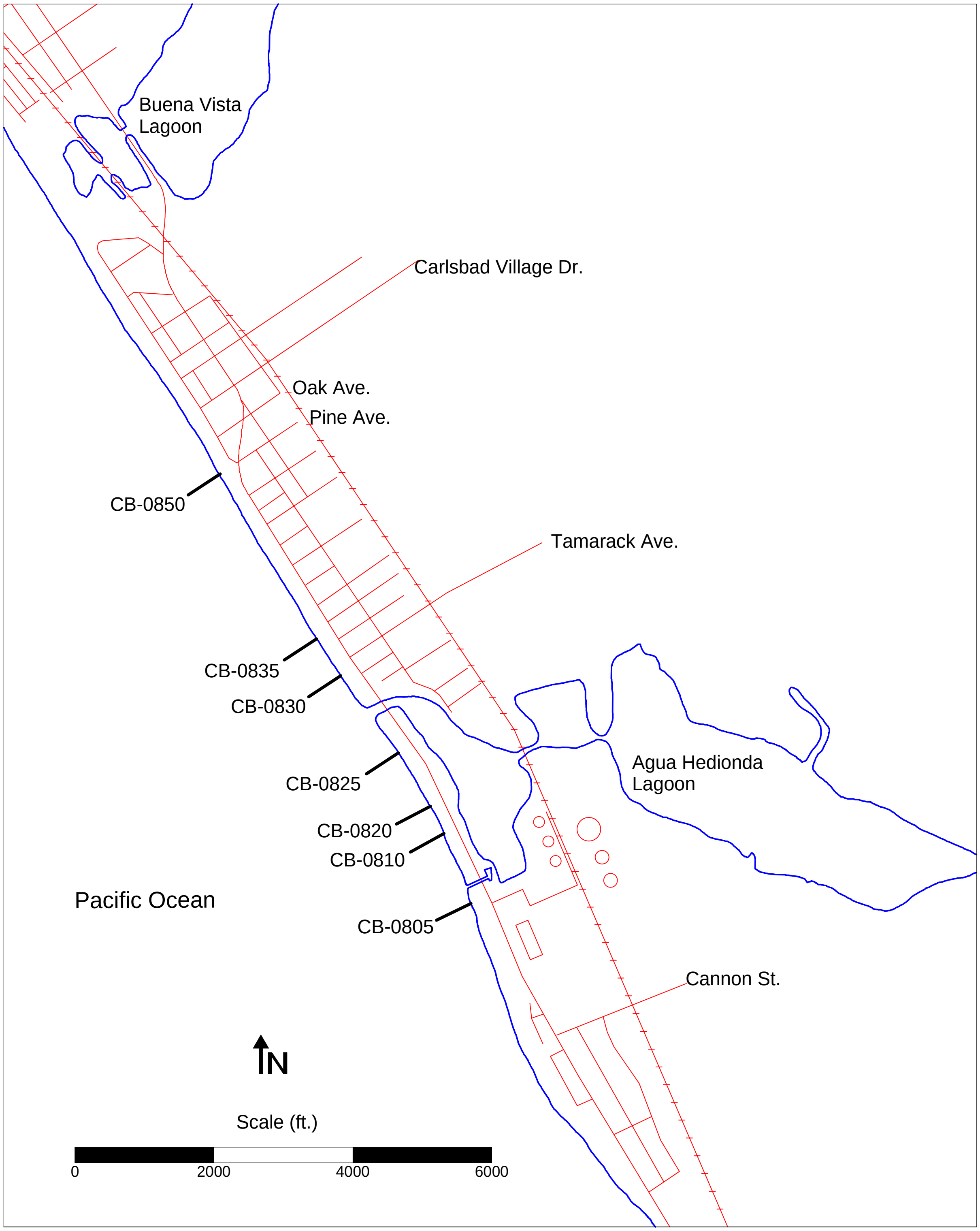



**Figure 4-8. Location of beach profile data in Carlsbad (from Elwany et al., 1998).**

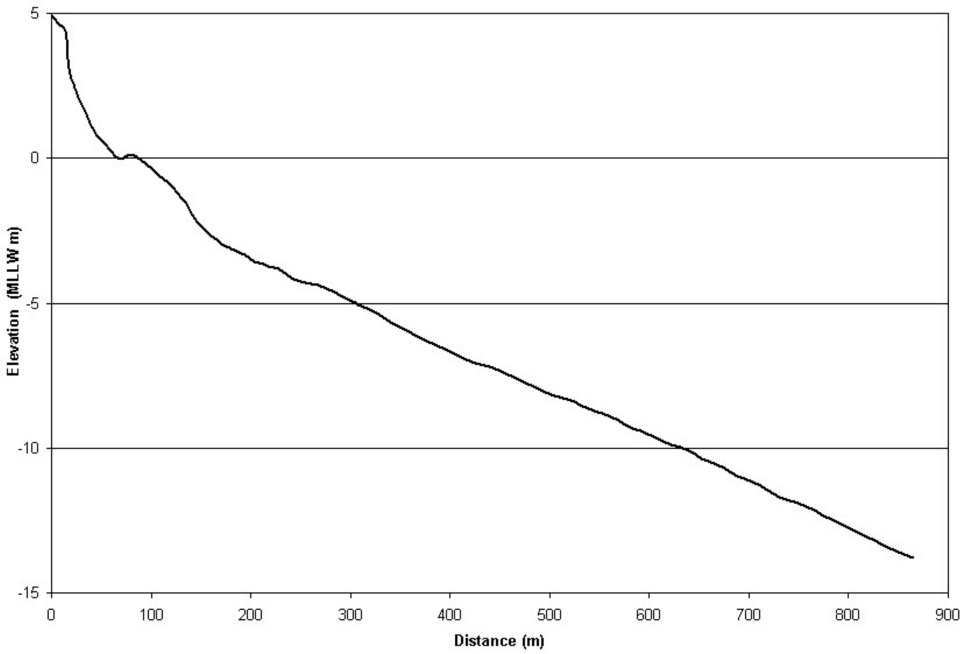



**Figure 4-9. Profile CB830 showing nearshore bar (April 1988) modified from Elwany et al. (1998).**

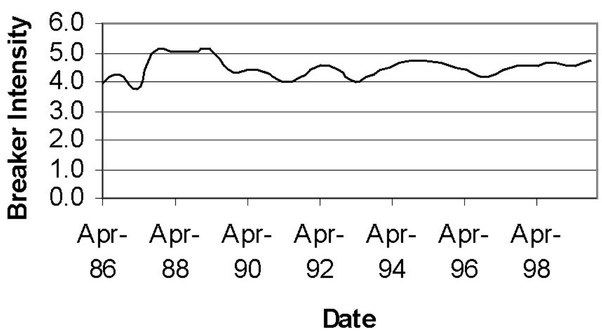



**Figure 4-10. Breaking intensity over time of offshore profile for CB830.**

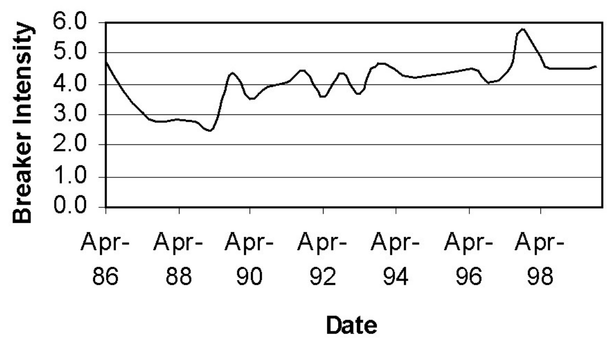



**Figure 4-11. Breaking intensity over time of nearshore bar for CB830.**

# 5.0 CLASSIFICATION OF JETTY SURFING BREAKS

Four types of surfing breaks created by jetties have been identified. The two defining variables in the type of jetty break are the delta effect (preconditioning, wave breaking or none) and the size of the jetty (longer/shorter than surfzone width).

A *Type One* jetty break (Figure 5.1) occurs where waves break shoreward of the end of the jetty. The jetty length is longer than the surfzone width. Trapped sediment accumulates against the jetty, creating a fillet that acts as a wedge component. Energy from along the wave crest converges against the jetty, creating a peak in wave height and a take-off zone. The wave then peels along the wedge feature.

A *Type Two* jetty break (Figure 5.2) is created by the ebb tidal delta. Waves are preconditioned over the delta before breaking further inshore. The shoaling and refraction over the delta forms peaks in wave height and rotates waves suitably for surfing. Surfing waves are then formed by a combination of wave height peak, wave angle oblique to seabed contours, and bar formations created by rip currents.

A *Type Three* jetty break (Figure 5.3) is also created by an ebb tidal delta. The delta provides stable contours for waves to break over rather than acting as a preconditioning component. Some preconditioning will happen over the delta but the dominant process that creates high quality surfing waves is the wave breaking function.

A *Type Four* jetty break (Figure 5.4) is an example of a jetty construction that does not change the existing surfing conditions. The jetty is not sufficiently long to trap enough sediment and change beach width significantly. The surfing conditions exist because of other natural features, such as reef, that create surfable waves.

Jetty surfing breaks do not always fit perfectly into the four jetty types described here. Just as wave-breaking type involves a continuum between spilling, plunging, and collapsing (Komar, 1998), so do the types of jetty surfing breaks. For example, the major difference between a Type One and a Type Four jetty break is the length of the jetty relative to the surfzone width. A 75 m long jetty may behave as a Type One jetty for small swells. As the swell increases, so does surfzone width, and the surfing break may behave more like a Type Four jetty break. Surfing conditions around jetties can be further complicated by other structures, such as attached and detached breakwaters. This study does not consider jetties which are complicated by other structures.

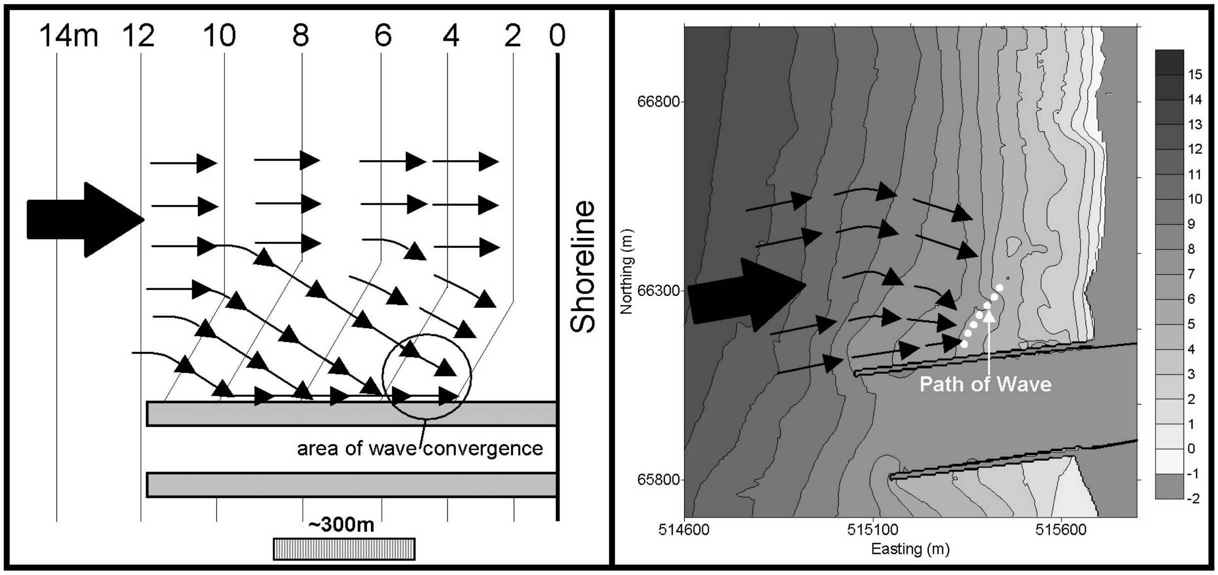



**Figure 5-1. Schematics and sample bathymetry of a Type One jetty surfing break.**

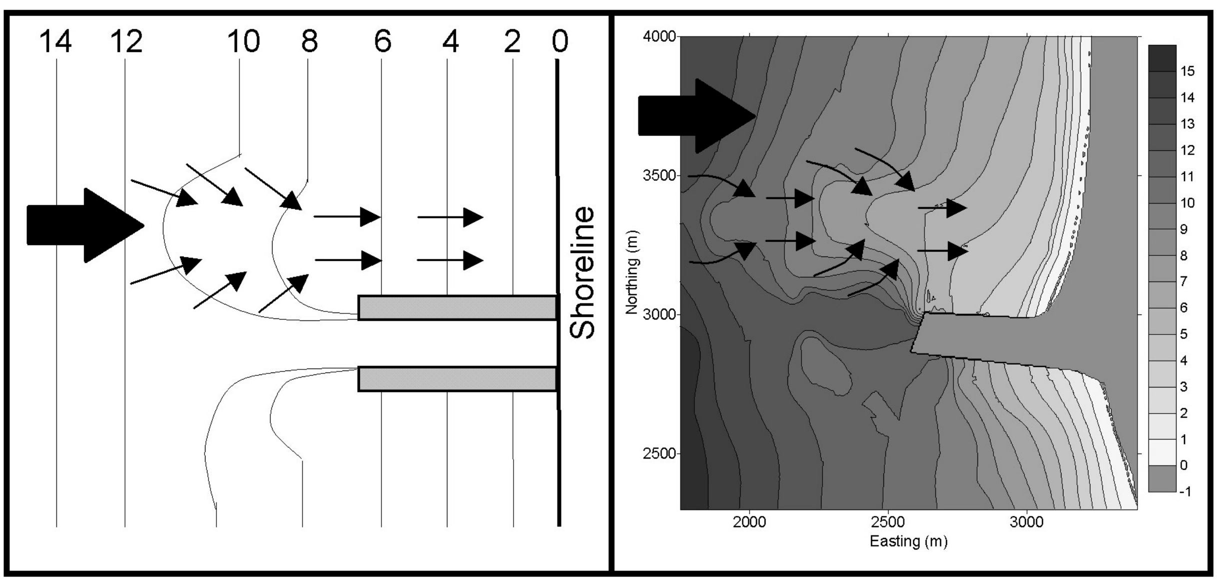



**Figure 5-2. Schematics and sample bathymetry of a Type Two jetty surfing break.**

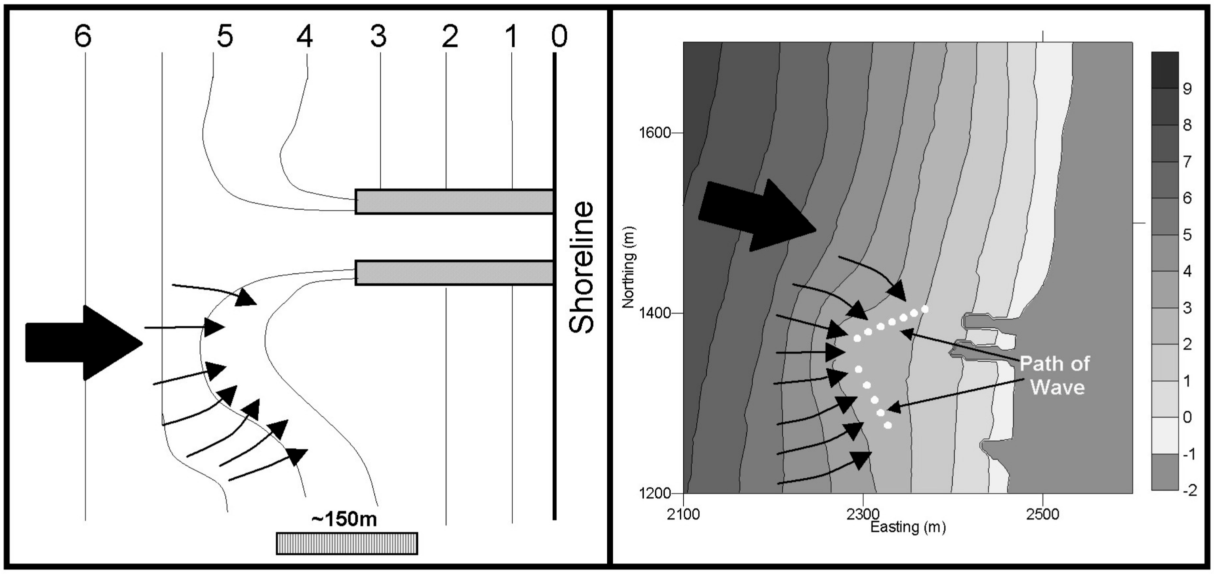



**Figure 5-3. Schematics and sample bathymetry of a Type Three jetty surfing break.**

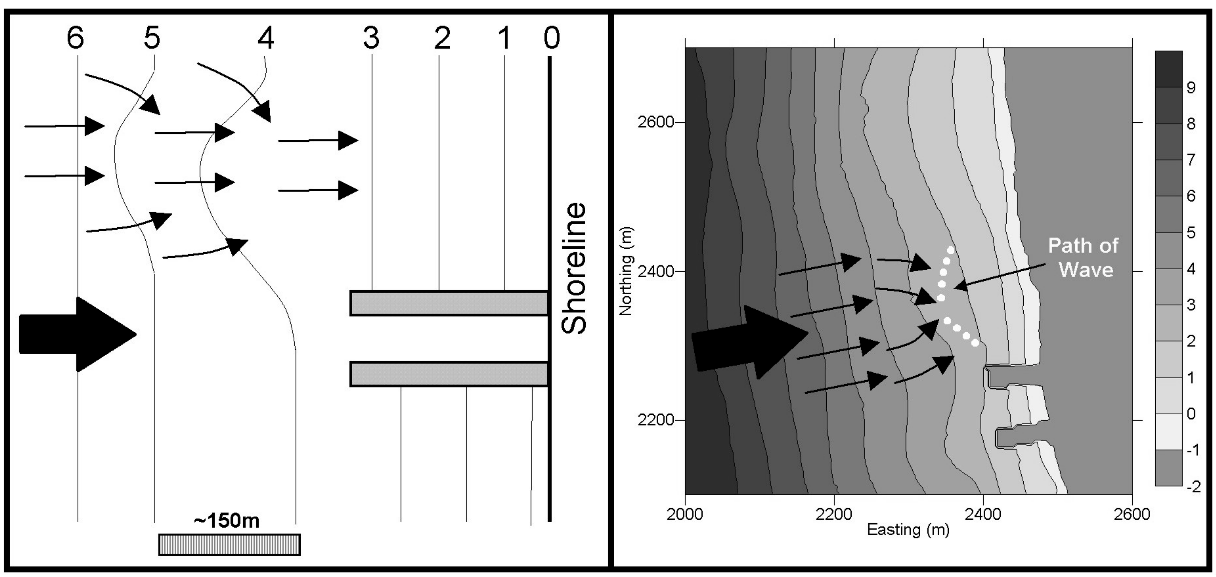



**Figure 5-4. Schematics and sample bathymetry of a Type Four jetty surfing break.**

## 5.1 TYPE ONE JETTY

Peeling waves are created at a Type One jetty by a combination of three main mechanisms: wave reflection, wave convergence, and wedge contours aligned obliquely to the wave crests. Waves approaching at an angle to the jetty travel unbroken along the jetty wall. Energy from along the wave crest group together as it reflects off the jetty and back toward the rest of the wave crest, creating a peak in wave height.

Another mechanism that creates surfing waves is caused by the permanent rip current alongside the jetty. The jetty provides a stable feature for the development of a rip which scours out a channel abutting the jetty. Wave energy in the channel refracts away from the jetty and toward take-off, reinforcing the peak created by the wave reflection. The focused wave energy eventually breaks when the water depth becomes shallow enough. A wedge component is created by the fillet against the jetty. The wedge allows the wave to continue peeling until the break point reaches the shore parallel contours and closes out.

### 5.1.1 Case Study: Mission Bay North Jetty, Mission Beach, San Diego, California

The North Jetty (Figure 5-5), completed in 1950, stabilizes the mouth of Mission Bay and impounds sediment on the north side (Shaw, 1980). The jetty is 1000 m long with approximately 550 m of the construction exposed to wave action on the north side. The other 450 m are abutted by land on the north side.

Quality surfing waves can be surfed here on lower tides, even when the beach to the north has relatively poor surfing conditions. The waves at this jetty peel for a significantly longer time than at the beach and with higher intensity. The take-off point is reasonably consistent, whereas the beach breaks are very “shifty.” A similar style break can be surfed on the south side of the southern jetty also but is not considered in this study.

The three diagrams in Figure 5-6 show that the Mission Bay North Jetty surfing break is made up of a meso-scale Ramp/Wedge configuration. The first diagram shows the seabed contours around the jetty. The second shows the contours with predictions from WBEND of wave direction propagating over the components. The third is a simplified schematic of the components with refraction patterns.

Figure 5-7 shows a set of waves traveling along the jetty. The wave energy from along the wave crest groups when the waves approach obliquely to the jetty. This focusing can be seen in Figure 5-8, Figure 5-9, Figure 5-10, and Figure 5-11, creating the take-off point with increased wave height. The combination of wave focus and wedge makes the wave peel as a lefthander. Righthand waves can be surfed, but are significantly shorter than lefthand waves. Numerical modeling in Figure 5-12 shows the peak in wave height from refraction over the wedge. The simulation over-predicts wave height because WBEND does not account for reflection of structures.

The two diagrams in Figures 5.9 and 5.10 show that a strong rip current 5-10 m wide is permanently present between the take-off and the jetty. This channel allows surfers to easily reach the take-off zone and pushes it away from the jetty, making surfing a little safer.

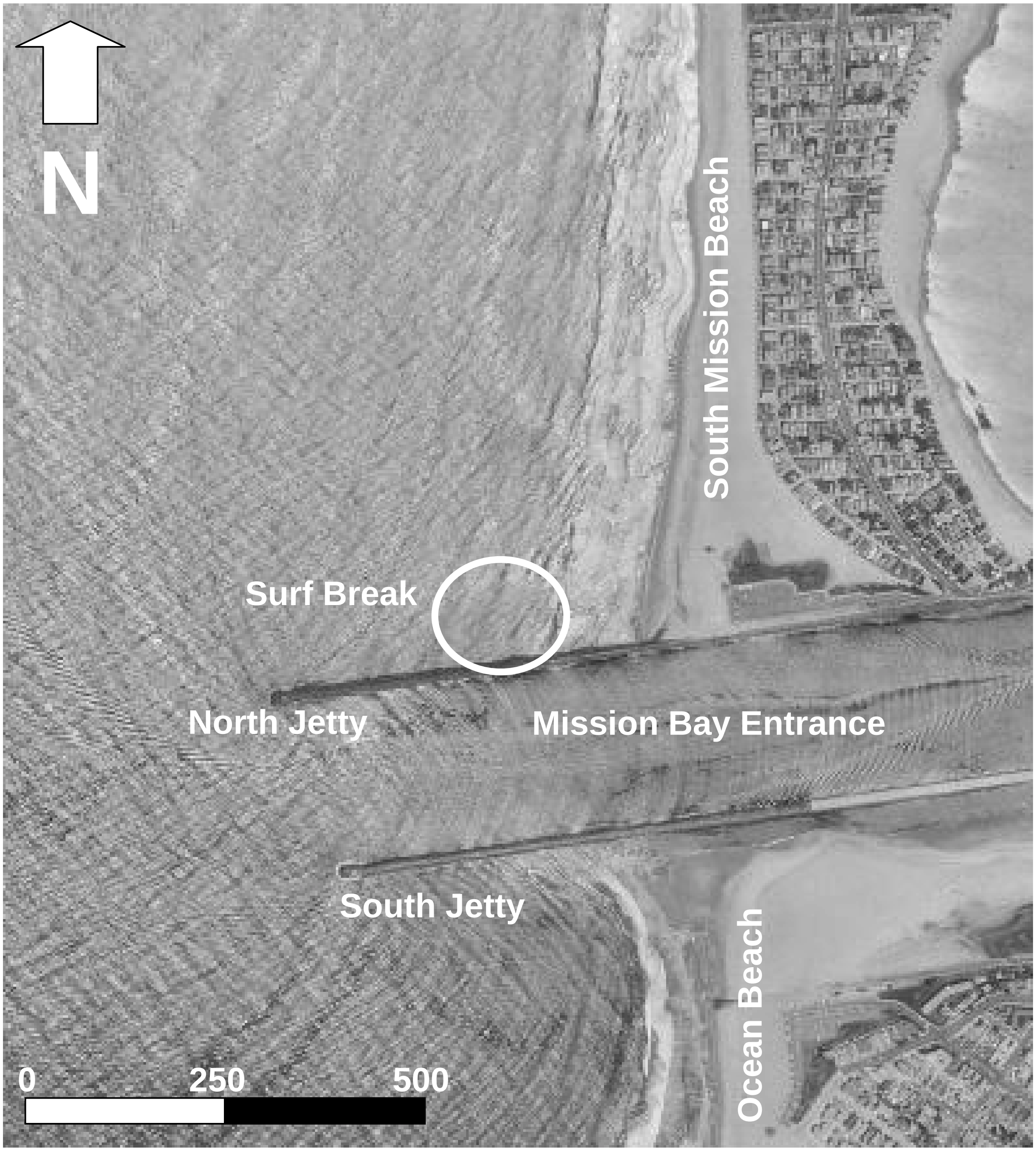



**Figure 5-5. Aerial image of Mission Bay Jetties and North Jetty surf break.**

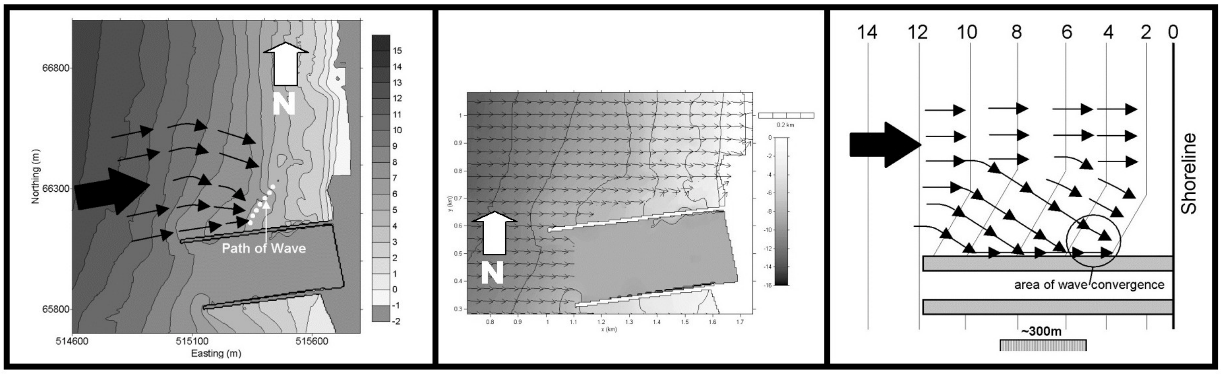



**Figure 5-6. The Ramp/Wedge configuration of meso-scale components that create the surfing waves at South Mission Beach. Three diagrams illustrate how the surfing break produces quality waves. The first diagram shows the bathymetry; the second, numerical predictions of wave angles over depth contours; and the third, idealized schematics of surfing break components.**

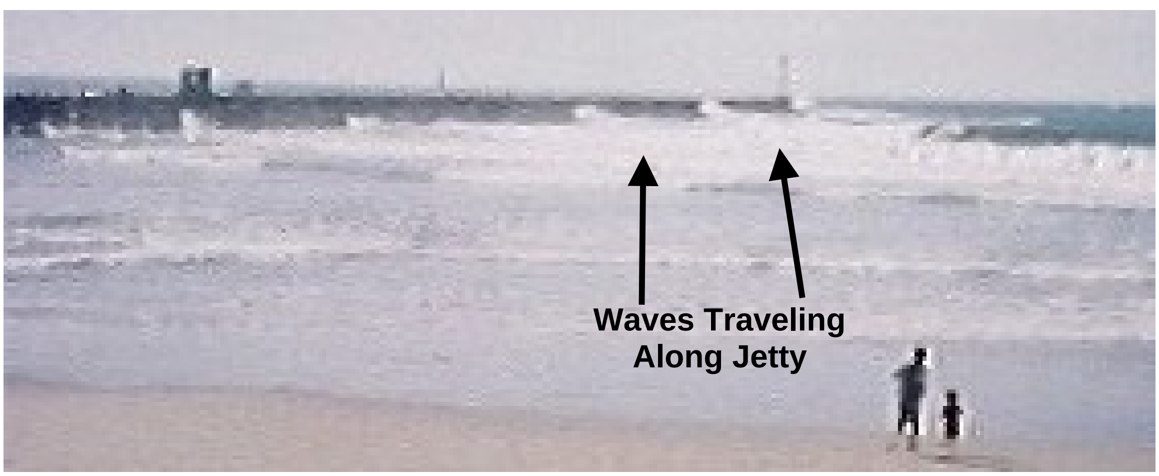



**Figure 5-7. Wave energy groups together as it travel along the jetty because of refraction over the wedge, reflection off the jetty, and presence of the rip current next to the jetty.**


**Figure 5-8. Surfing waves at Mission Beach Jetty. The surfing break always breaks best as a lefthand wave. Notice the focusing of wave energy.**

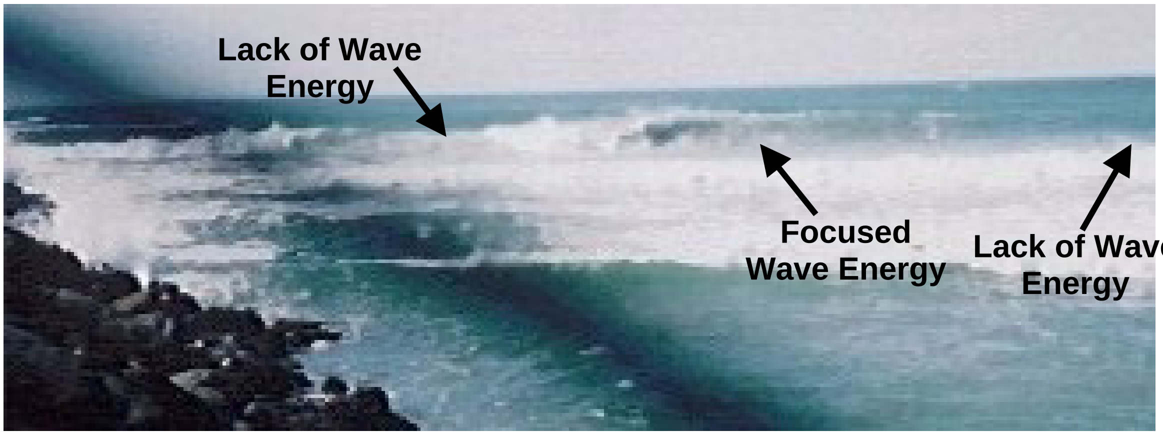



**Figure 5-9. Surfing waves at Mission Beach Jetty. Notice the focusing of wave energy.**

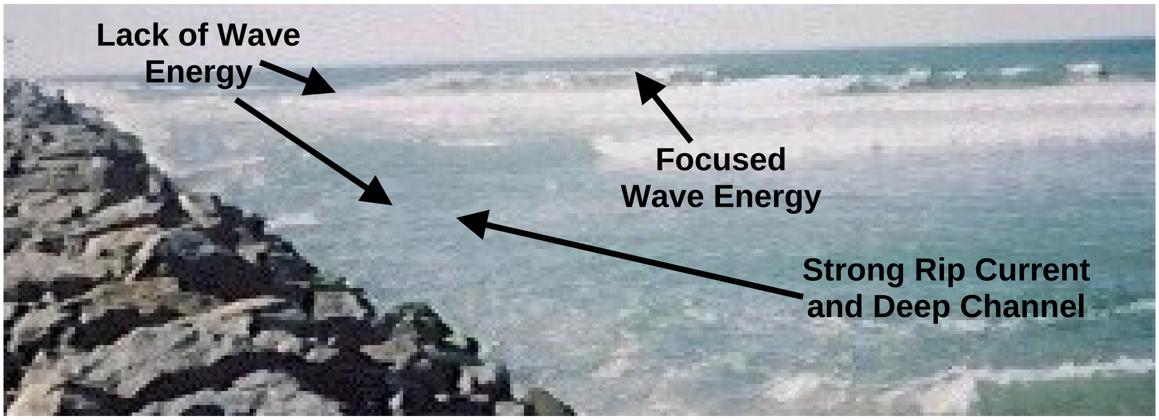



**Figure 5-10. Surfing waves at Mission Beach Jetty. There is a strong rip current that is present on the jetty side of the surfing break. Surfers use this to help them to get to the take-off zone.**

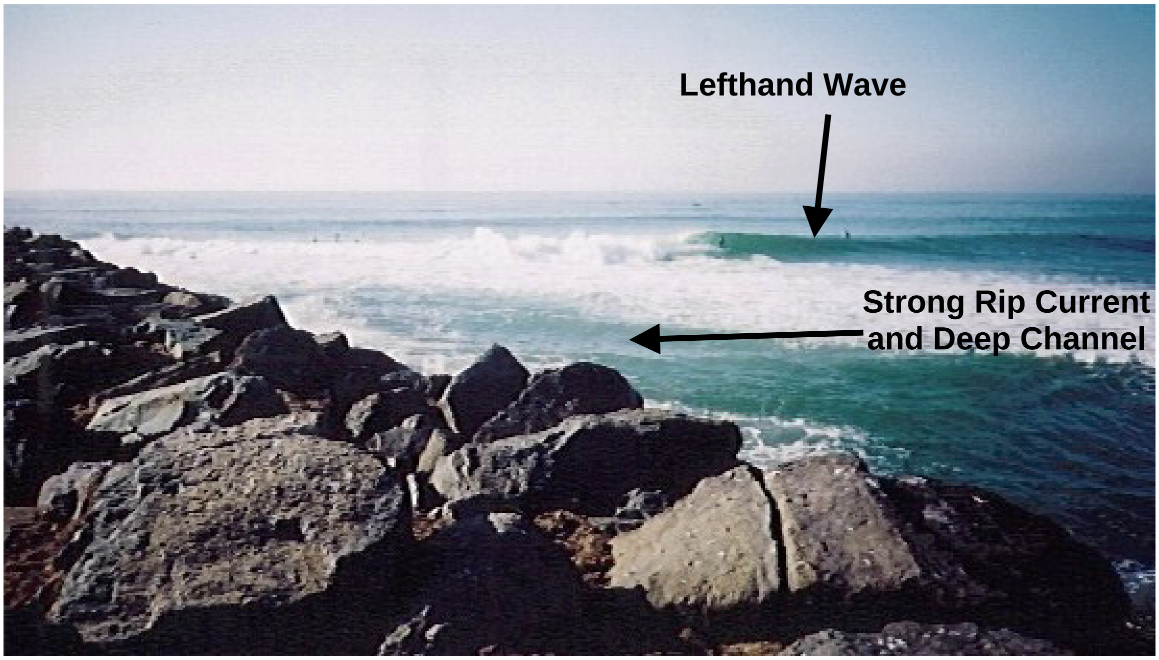



**Figure 5-11. Surfing waves at Mission Beach Jetty showing rip current location.**

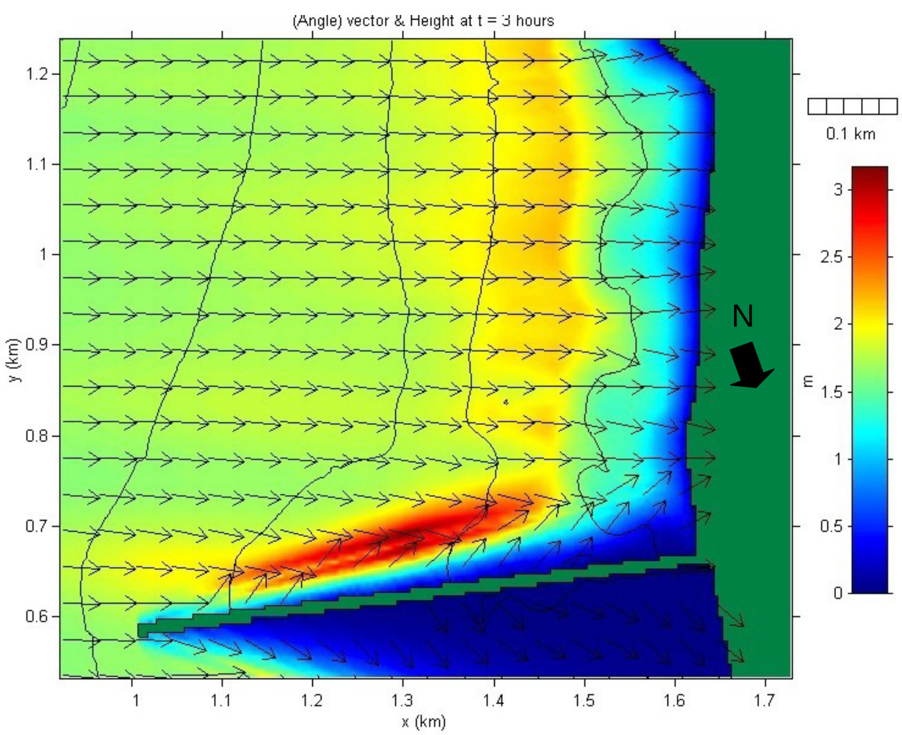



**Figure 5-12. Predicted wave height and angle at South Mission Beach for a 1.5 m, 15 s, 0° wave. The true magnetic wave direction is approximately 270°.**

## 5.2 TYPE TWO JETTY

Jetties are likely to have ebb tidal deltas, but some of these deltas are larger than others. The delta of a Type Two jetty break has a large influence on the preconditioning of waves before they break further inshore. Waves are modified over the delta with other types of jetty breaks, but this is not the dominant process that creates the surfing waves.

The delta of a Type Two jetty break creates surfing waves through two main processes. First, waves are focused and height is significantly larger than if the delta was not present. Second, the waves are rotated obliquely to the shoreline, increasing the wave peel angle and chance of surfable waves.

The configuration of surfing break components (Mead and Black, 2001a and 2001b) that is formed by the delta can be simple or complex. Ramps, wedges, focuses, ridges and platforms can all be created by deltas. The general effect of these components on the waves is to cause the waves to be focused and rotated. Deltas are constantly changing with fluctuations in sediment supply, wave climate, and the configuration of the reef components.

### 5.2.1 Case Study: "The Poles," Atlantic Beach, Florida

"The Poles" jetty break in Atlantic Beach, Florida (Figure 5-13) is used here as an example of a Type Two jetty break. It is a surfing break located on the south side of the St. John's River. The surfing break has anomalously large waves for the region, formed by wave preconditioning over the river's southern delta formation (Raichle, 1998). The jetty has created both a distinct delta formation and a surfing break. A delta would have been present before jetty construction, but significantly different surfing waves would have been produced, since the shape of the delta would have been different.

#### *Meso-Scale Configuration of Surfing Break Components*

The three diagrams in Figure 5-14 show how "The Poles" is made up of a meso-scale Ramp/Focus/Wedge configuration. The general effect of a Ramp/Focus/Wedge configuration has been described by Mead and Black (2001b). First, the ramp aligns waves to the favored orthogonal direction in preparation for convergence of wave energy on the focus. The peak of the wave energy then breaks further offshore than the rest of the wave, creating an easier takeoff point for the surfer who can then ride the wave breaking along the wedge.

#### *Micro-Scale Configuration of Surfing Break Components*

Although "The Poles" has a meso-scale Ramp/Focus/Wedge configuration, there are micro-scale features that affect how much waves increase in size over the delta and where along the shore the waves focus for different swell conditions. The micro-scale surfing break components of "The Poles" are shown in Figure 5-15. They change over time as the delta evolves, but at the time of the survey, there were nine main micro-scale components. Scarfe (2002) observed that micro-scale components act differently for different tide and swell conditions. Numerical modeling of "The Poles" in the following figures also shows this phenomenon.


**Figure 5-13. Aerial image of the jetties at the help create "The Poles" surfing break (Raichle, 1998).**

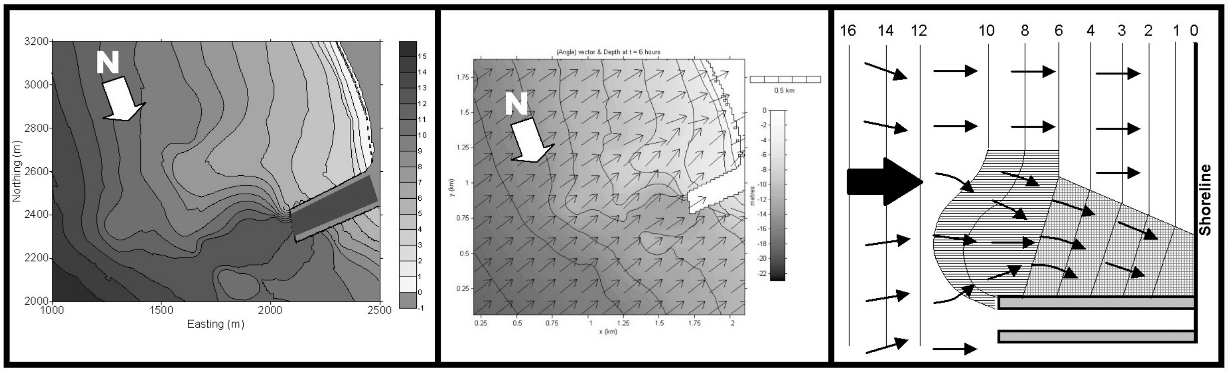



**Figure 5-14. The Ramp/Focus/Wedge configuration of meso-scale components that make up “The Poles” surfing break. Three diagrams are shown to illustrate how the surfing break produces quality waves. The first diagram shows the surveyed bathymetry; the second, numerical predictions of wave angles over the depth contour; and the third, idealized schematics of the surfing break components.**

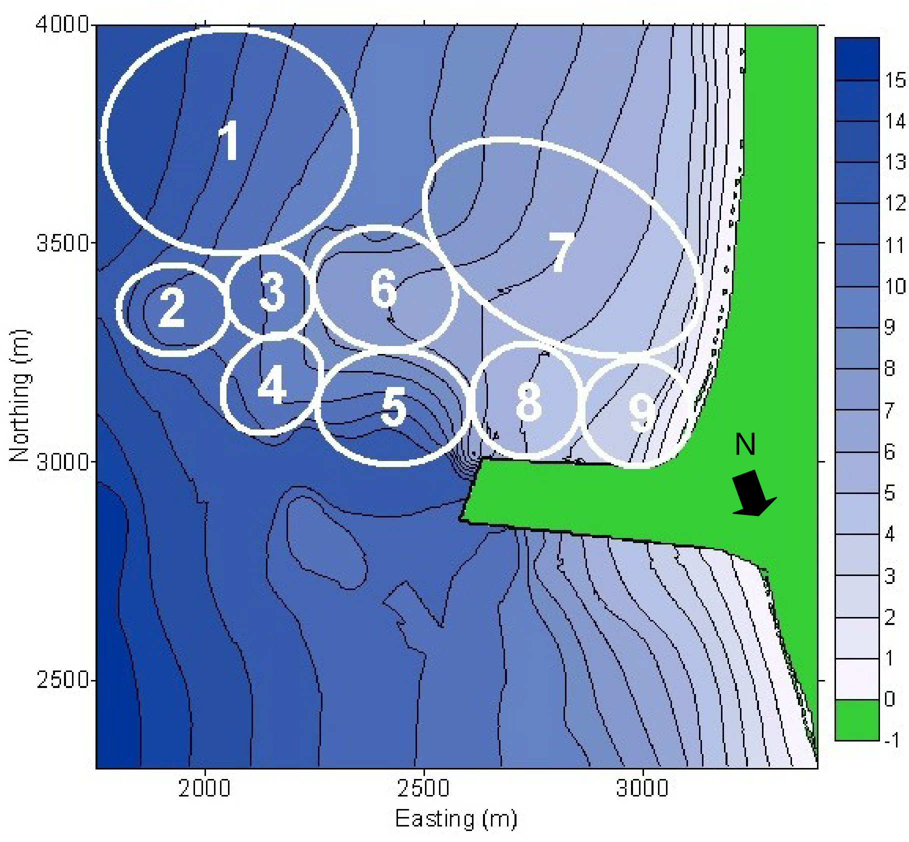



**Figure 5-15. The seven micro-scale components that make up “The Poles” surfing break. The areas marked 1, 3, and 8 are ramps; 2, 4 and 6 are focuses; and 7 and 9 are wedges.**

Figure 5-16, Figure 5-17, and Figure 5-18 show a 2 m, 15 sec period wave for three different wave directions. Analysis at a meso-scale shows that the waves shoal along the ramp, converge on the focus, and refract on the wedge for all simulations. However, the width, location and intensity of the focused band of wave energy varies between simulations, because the influence of each micro-scale component changes for different wave directions.

In Figure 5-16, Focus 2 converges wave energy, which passes over Ramp 3 without dramatically modifying the direction. The wave then reaches Focus 6, where wave energy is further reinforced. Focus 4 does not focus the wave in this scenario, because the wave direction is not aligned with the favored orthogonal direction. Focus 4 in the simulation becomes part of Wedge 5, rotating the wave south. This rotated band of wave energy then combines with the band of wave energy created by Focus 2 and 6, resulting in a wave that peaks at around 5.3 m. The waves are not largely modified over Ramp 8 because ramps only have a subtle effect, working to shoal and maintain wave directions. Wedge 7 rotates the wave north, where it is further combined with the large band of wave energy. It is the combined transformation of waves over the micro-scale features that has created the anomalously large waves.

A wave approaching from a different angle can be seen in Figure 5-17, resulting in a wider, but not as large, wave peak that breaks further north than Figure 5-16. This happens because the favored orthogonal direction of each component is aligned differently to the offshore wave direction. It is only after analyzing the alignment of micro-scale components that the reasons for different focusing patterns can be seen. Each micro-scale component can work independently or in conjunction with other components to create the large, focused wave heights.

In Figure 5-16, the 35° wave direction was aligned with Focus 2, whereas in Figure 5-17, the 10° wave direction is aligned with Focus 6. The result is more classic wave refraction patterns around Focus 6 for the lower wave angle. This is shown by the symmetrical blue and red wave angles in the lee of the component.

Focus 6 is the dominant feature creating the peak in wave heights when the wave angle is 10°. This feature is both shallow and large relative to the other focusing components, and therefore has more effect on wave refraction and shoaling. When waves are properly aligned with Focus 6, the most significant refraction and shoaling happens over this feature. When the wave angle is 35°, the wave focusing is an effect of the combined functions of each micro-scale component without any one feature dominating.

In Figure 5-17, Wedge 5, Focus 2, and Focus 4 all combine to create a second band of wave energy that combines with the peak created by Focus 6. The cumulative effect is a wave that peaks at around 4.7 m. Although Focus 2 is not aligned perfectly with the incoming wave, focusing still happens. Focus 4 and Wedge 5 rotate the focused wave southward toward the main peak. Without these features to rotate the waves, the peak from Focus 2 would continue north past the jetty.

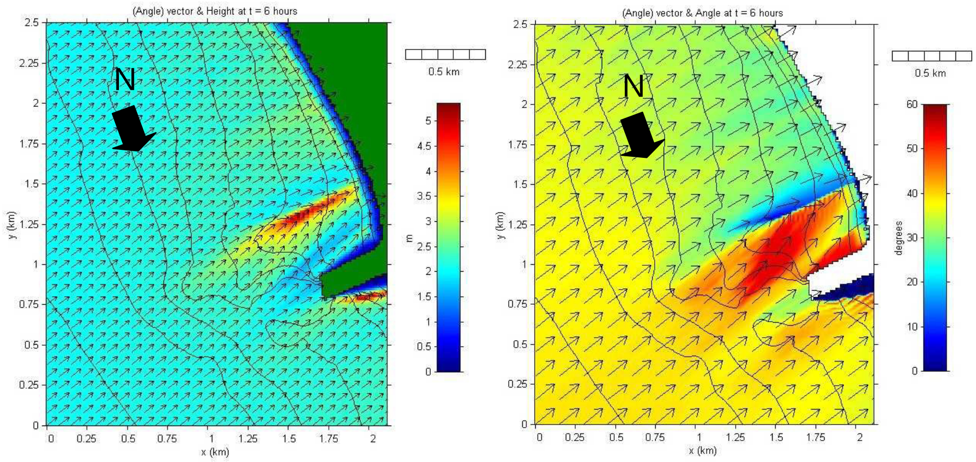



**Figure 5-16. Predicted wave height and angle at "The Poles" for a 2 m, 15 s, 35° wave. The true magnetic wave direction is approximately 55°.**

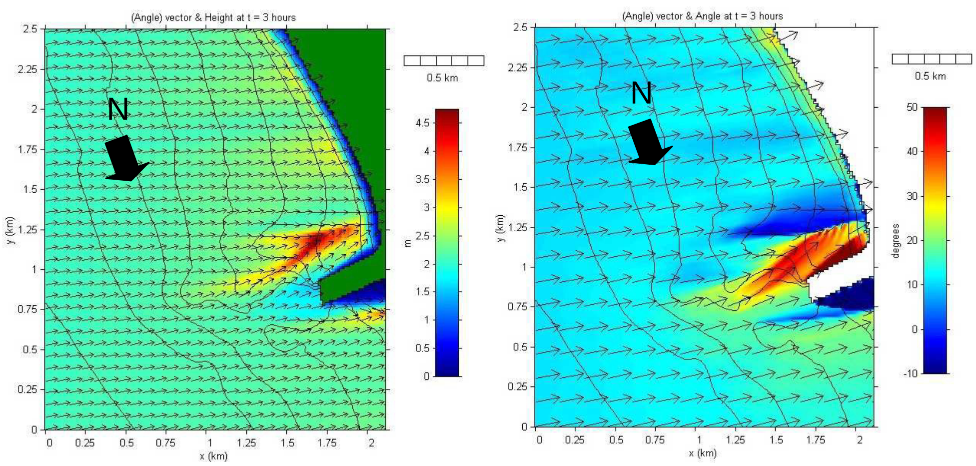



**Figure 5-17. Predicted wave height and angle at "The Poles" for a 2 m, 15 s, 10° wave. The true magnetic wave direction is approximately 80°.**

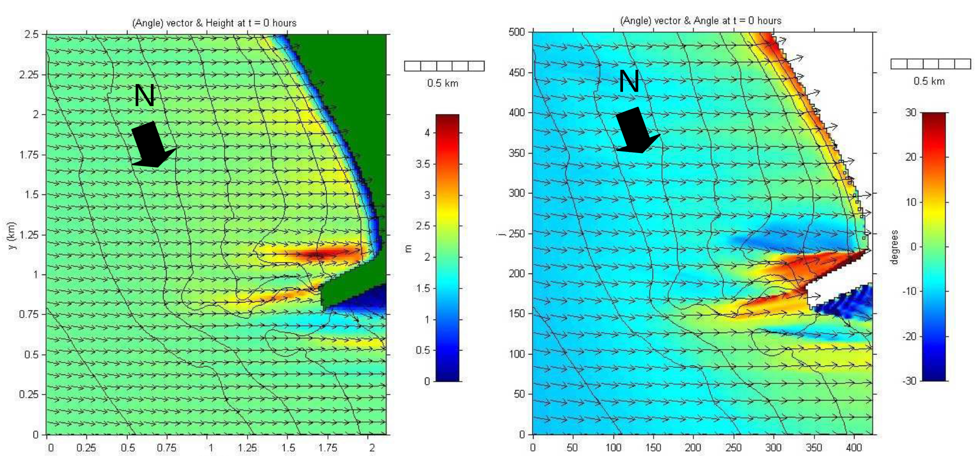



**Figure 5-18. Predicted wave height and angle at "The Poles" for a 2 m, 15 s, -10° wave. The true magnetic wave direction is approximately 100°.**

The more southerly wave shown in Figure 5-18 has quite different refraction patterns. For this wave direction, Focus 2, Focus 4, and Wedge 5 do not affect the surfing wave. Waves passing over these features are focused into the jetty mouth, not into the beach. The result is a wave that peaks smaller than in the other two scenarios (4.3 m) and right against the jetty wall. The main features that create the high energy band are Ramp 1 and Focus 6. Since the wave energy is focused against the jetty wall, refraction and reflection will happen, making it similar to what happens with a Type One jetty. This highlights the ways in which different jetty break types act differently under various conditions, showing that the differentiation between jetty types is not absolute. If the delta was not present, then this surfing break would be a Type One. It must be noted that this is strictly a numerical study of “The Poles,” and it investigates the general characteristics of the surfing break. In order to perfectly understand the wave behavior, field experiments would be required. Included in the study would be measured wave statistics and breakpoint locations (see Scarfe 2002; Scarfe et al., 2002 and 2003) as well as an analysis of bar and rip formations and their effects on the surfing waves.

The large river mouth is jetted; anecdotal local knowledge suggests that the wave amplification is a result of the jetty itself (Raichle, 1998). Identification of surfing break components from the bathymetry, as well as from numerical modeling, show that it is actually the delta that creates the large waves rather than the jetty, which agrees with the findings of Raichle (1998). It is likely that the jetty structure further amplifies waves that are directly next to the jetty, but the delta has the largest effect.

## 5.3 TYPE THREE JETTY

Type Three jetty surfing breaks occur when the ebb delta of the jetted inlet is shallow enough to initiate wave breaking. Preconditioning occurs over the delta, but not to the same extent as with Type Two breaks. The dominant process creating the surfing break is the wave breaking on the delta. If the water was not shallow enough to break waves, quality surfing waves would not be created solely by wave preconditioning. These types of breaks can be affected by tides, as the water may become too deep to cause wave breaking on the delta. Depending on delta and nearshore bar configuration, the delta may act as a preconditioning component, turning the break into a Type Two spot when the tide is high. This will not always occur, and waves can break further nearshore in an unsurfable manner. This can be observed at some Type Three breaks, where at high tide preconditioning over the delta occurs but wave breaking does not.

The water going in and out of the jetty also affects wave breaking, since these types of breaks occur close to jetty structures. Strong currents can be observed, especially when the tidal prism is large and combined with river outflow. Outgoing water delays wave breaking and causes waves to break in shallower water, increasing breaker intensity.

### 5.3.1 Case Study One: "Warm Water Jetties" at Tamarack, Carlsbad, California

"Warm Water Jetties" is located offshore of the southern, jetted outlet channel of the Agua Hedionda Lagoon in Carlsbad, California. Both of the jetties are 120 m long and were completed in 1954 (Figure 5-19; Shaw, 1980). There is another set of jetties 800 m to the north that stabilizes the intake channel. Water from the lagoon is used for cooling by the SDG&E Encina Power Plant and discharged through the outlet channel. The water directly around the jetties is significantly warmer than that of the neighboring beach, hence the name of the surfing break. A delta formation has formed seaward of the outlet jetties on an otherwise simple plane beach profile, creating the surfing break (Figure 5-20 and Figure 5-21). The delta provides some relief in bathymetry to produce surfable waves and is essentially a Ramp/Focus configuration. "Warm Water Jetties" is described as the best of all the surfing breaks around the lagoon but is very fickle and dependent on the sediment build up which continually changes.

The Ramp/Focus configuration can be seen in Figure 5-22. A small groin can be seen just south of the jetties, which is used to hold nourishment material. The ramp acts to reduce the directional spread of waves approaching the shore compared to the spectrum of offshore directions and steepens the waves by the shoaling process (Mead and Black, 2001b). The focus then converges wave energy toward the apex of the focus component. The wave peels over the focus as a consequence of height reinforcement at the peak, with subsequent loss of wave height on the adjacent part of the wave crest (Mead and Black, 2001b). The peak of the wave crest will break first because the wave is larger than the adjacent wave section, resulting in peeling. One of the best examples of this is Pipeline in Hawaii (Mead and Black, 2001b), where waves peel largely due to extreme focusing of wave energy.

**Figure 5-19. Outlet jetties for Agua Hedionda Lagoon that create the surfing break "Warm Water Jetties."**


**Figure 5-20. Lefthand wave breaking at "Warm Water Jetties."**

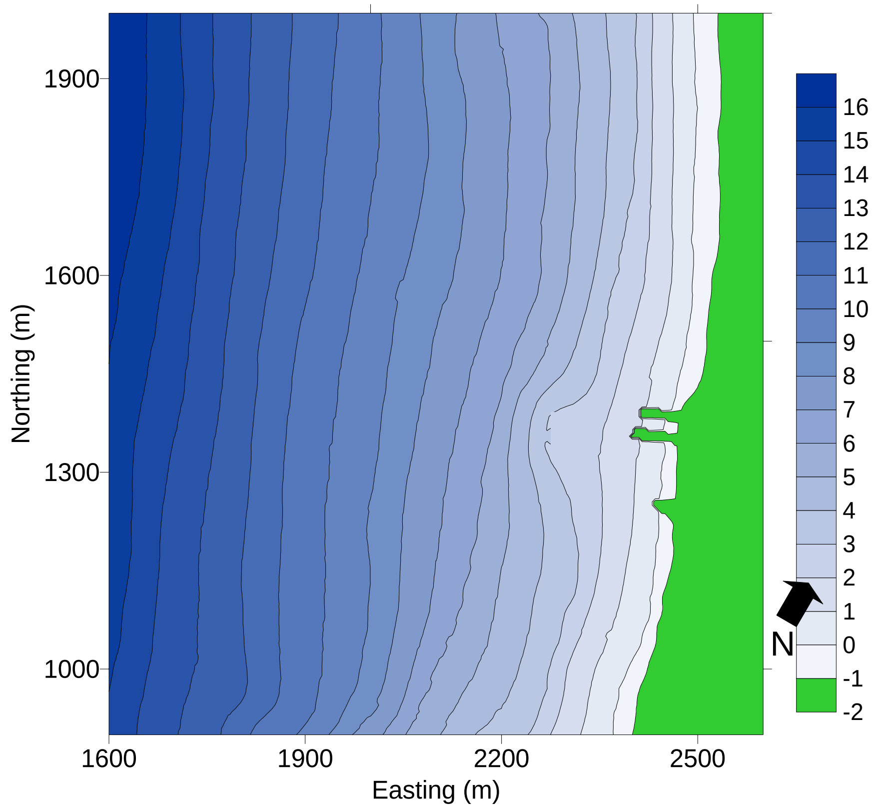



**Figure 5-21. Bathymetry of the “Warm Water Jetties” surfing break showing the delta formation on an otherwise plane beach. The survey datum is mean sea level.**

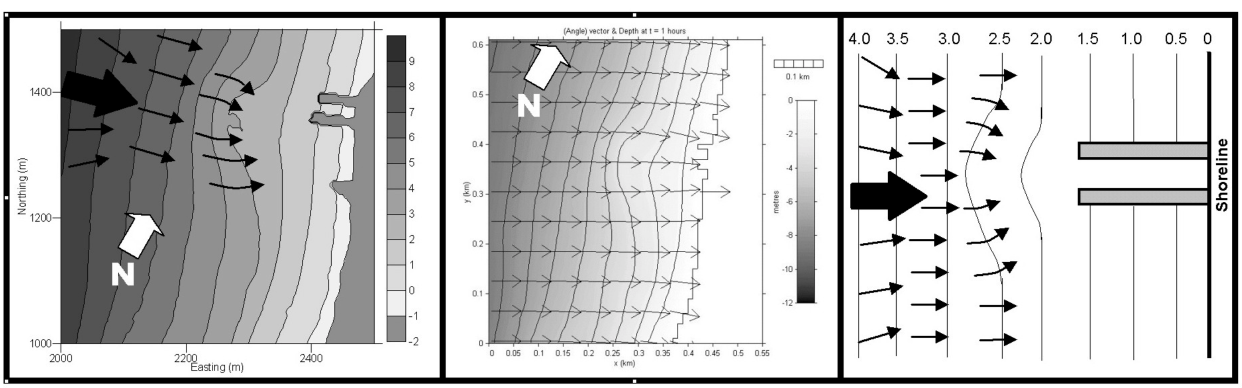



**Figure 5-22. The Ramp/Focus configuration of meso-scale components that make up the Warm Water Jetties surfing break. Three diagrams are shown to illustrate how the surfing break produces quality waves. The first diagram shows the surveyed bathymetry; the second, numerical predictions of wave angles over the depth contour; and the third, idealized schematics of the surfing break components.**

After initial analysis of the delta feature, it was unclear whether it acted as a wedge or as a focus. Numerical modeling for different wave directions was used to resolve the problem, and the results can be seen in Figure 5-23, Figure 5-24 and Figure 5-25. Waves were seen to converge over the delta, with an increase in wave direction to the south and a decrease to the north, indicating wave focusing. This is shown by the blue and red/orange bands in the plots of wave angle and is indicative of a focusing component. The wave height peaks on the apex of the focus feature, and the result is lower wave energy area to the north and south for all simulations.

Both lefthand and righthand waves can be ridden at “Warm Water Jetties.” The quality of surfing rides at “Warm Water Jetties” varies with tide, swell and delta shape. As already stated in Section 4.0, surfing conditions are best the when there is a lot of sand. It is possible that from time to time, smaller-scale wedge features appear inshore of the delta creating longer surfing rides. This would change the configuration from a Ramp/Focus to a Ramp/Focus/Wedge. More investigations would be required to prove the presence of any wedge, including surveys at different times of the year and precise measurements of wave breakpoints.

It is predicted that out of the three simulations, the longest surfing rides will occur when the wave direction is from 220°. This conclusion is based on the fact that the largest deviation in wave angle occurs to the north of the focus of any of the simulations. The angle between the wave direction and contours is relatively acute for the other two simulations, suggesting low peel angles. In Figure 5-25, the angle on the north side of the focus is significantly lower, and resulting peel angles will be higher. The wave will break as a lefthander. For the simulations in Figure 5-23 and Figure 5-24, lefthand and righthand waves will occur, but they will not be as long as the lefthand rides shown in Figure 5-25. An angle of 300° would not produce rides as long as 220°, even though the angle is the same relative to focus orientation. This is because the focus feature is asymmetrical, and the north side has a more oblique angle to the ramp contours, refracting waves to a greater extent and increasing the peel angle. However, this break is known to be best when breaking as a righthander so the sand build up at the time of the survey was not ideal or the survey did not represent the shape of the seafloor perfectly.

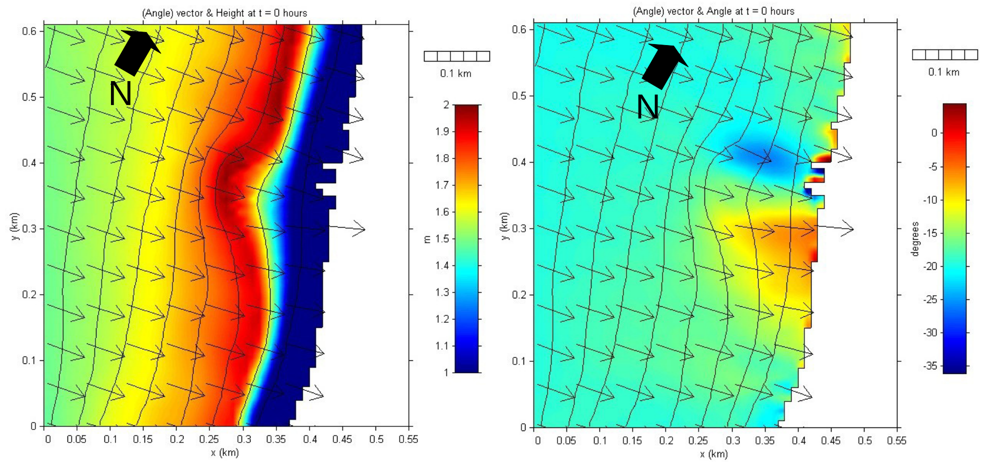



**Figure 5-23. Predicted wave height and angle at "Warm Water Jetties" for a 1.5 m, 14 s, -20° wave. The true magnetic wave direction is approximately 260°.**

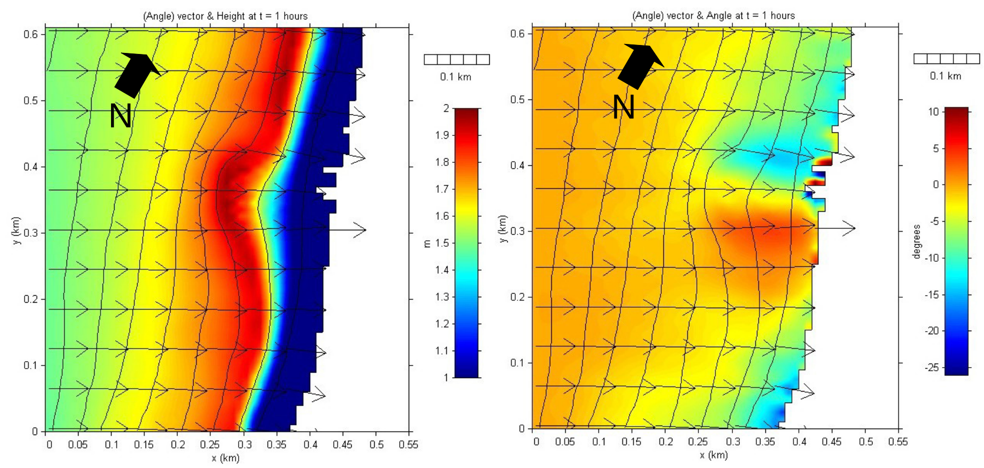



**Figure 5-24. Predicted wave height and angle at "Warm Water Jetties" for a 1.5 m, 14 s, 0° wave. The true magnetic wave direction is approximately 240°.**

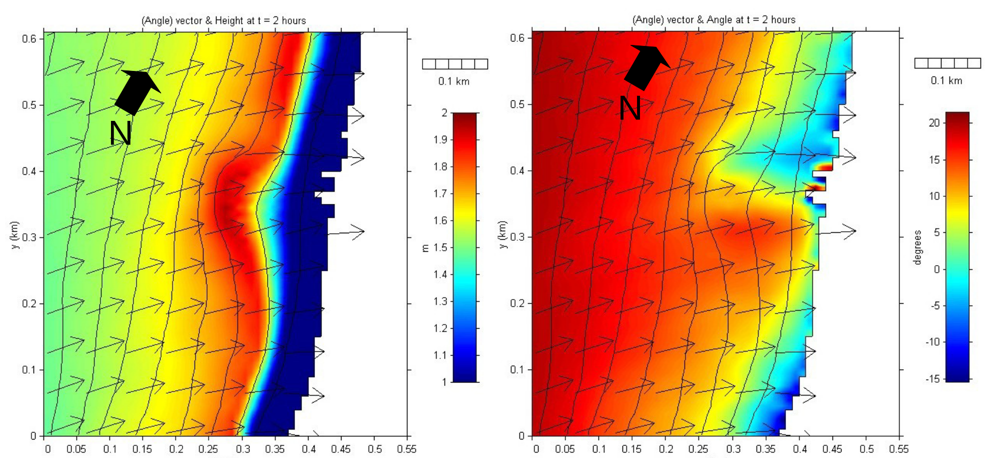



**Figure 5-25. Predicted wave height and angle at "Warm Water Jetties" for a 1.5 m, 14 s, 20° wave. The true magnetic wave direction is approximately 220°.**

### 5.3.2 Case Study Two: "Southside" at Tamarack, Carlsbad, California

"Southside" is located offshore of the northern jetted inlet channel of the Agua Hedionda Lagoon in Carlsbad, California. Both jetties are 150 m long and were completed in 1954 (Shaw, 1980). Although a large volume of the water that enters through the inlet channel is output through the southern channel, enough is discharged through the northern jetty to create a small delta that produces good quality surfing waves. The mechanics of "Southside" are very similar to those of "Warm Water Jetties" with a delta-formed Ramp/Focus configuration of features (Figure 5-26). Waves are generally righthanders that break directly offshore of the southern jetty and in toward the beach (Figure 5-27). Lefthanders do break, but the rides generally are not as long as those of righthanders.

Depending on the buildup of sediment in the lee of the focus, righthand waves can be ridden almost all the way to shore. The buildup of sediment at the time of the survey (Figure 5-28) does not appear to allow for these long rides. If the beach to the south of the jetty was more scoured and linked together with the delta, then longer rides would be possible. This eroded profile would have obvious negative impacts on beach recreation, but improve surfing conditions. A mock bathymetry showing this scoured profile can be seen in Figure 5-29. For the current bathymetry, the angle between the shallow water contours and the waves in the numerical modeling results (Figure 5-30, Figure 5-31 and Figure 5-32) would produce very low peel angles.

The simulation in Figure 5-30 is expected to provide the longest rides among the three simulations. There are two reasons for this. First, the focus feature extends much further offshore than the delta at "Warm Water Jetties," possibly because of the trapping of sand by the reefs at Tamarack. This creates a shadow zone south of the delta when waves come from a northward direction. As a result there is a gradient in height along the wave crest, promoting peeling waves. The second reason for the longer rides is that the wave direction is at a greater angle to the contours, suggesting higher peel angles. In Figure 5-31 and Figure 5-32, wave heights are larger than in Figure 5-30 because the waves are aligned more closely to the orientation of the focus feature, but this does not guarantee better surfing waves.

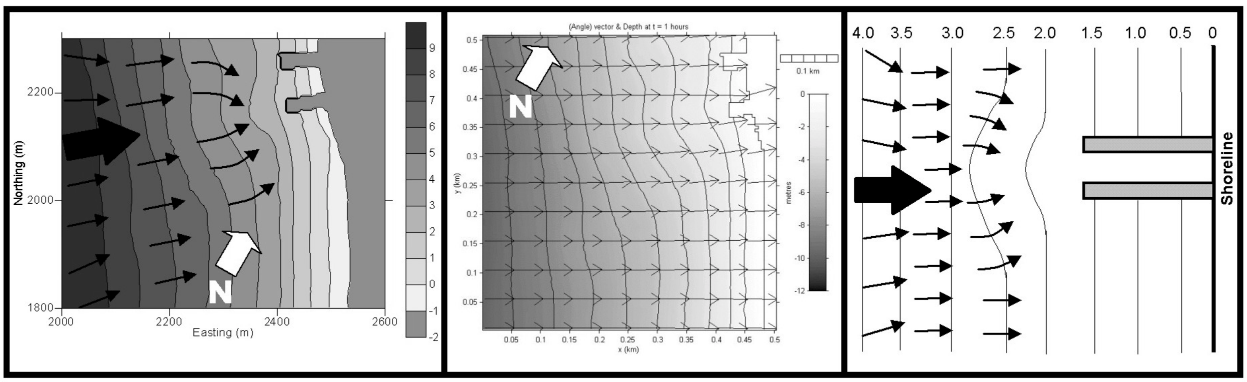



**Figure 5-26. The Ramp/Focus configuration of meso-scale components that make up the Southside surfing break. Three diagrams are shown to illustrate how the surfing break produces quality waves. The first diagram is of the surveyed bathymetry; the second shows numerical predictions of wave angles over the depth contour; and the third gives idealized schematics of the surfing break components.**

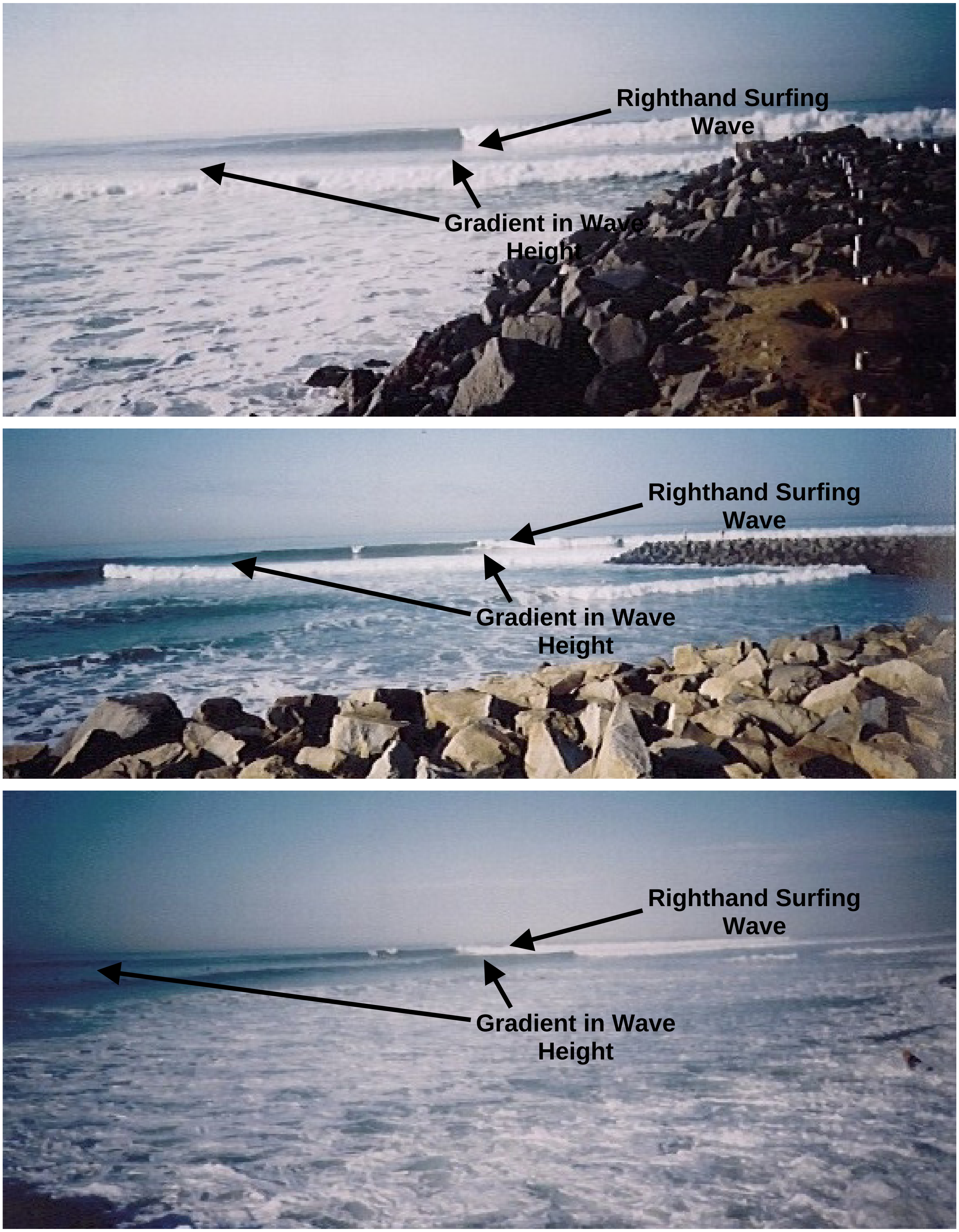



**Figure 5-27. Surfing waves breaking at "Southside." Note the gradient in wave height along the wave crest that promotes righthand peeling.**

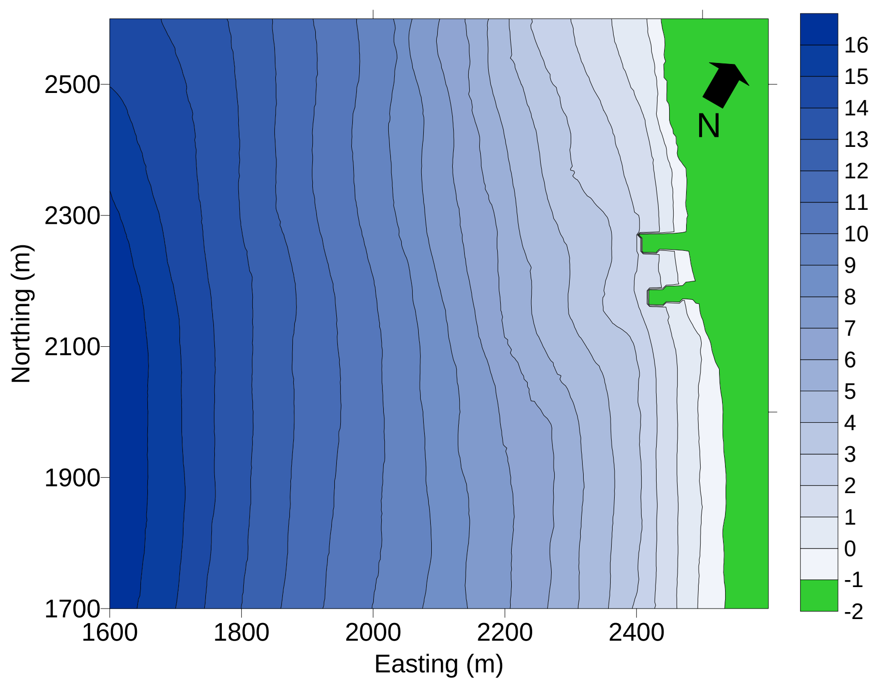



**Figure 5-28. Bathymetry of "Southside" surfing break and the delta formation that creates the surfing break.**

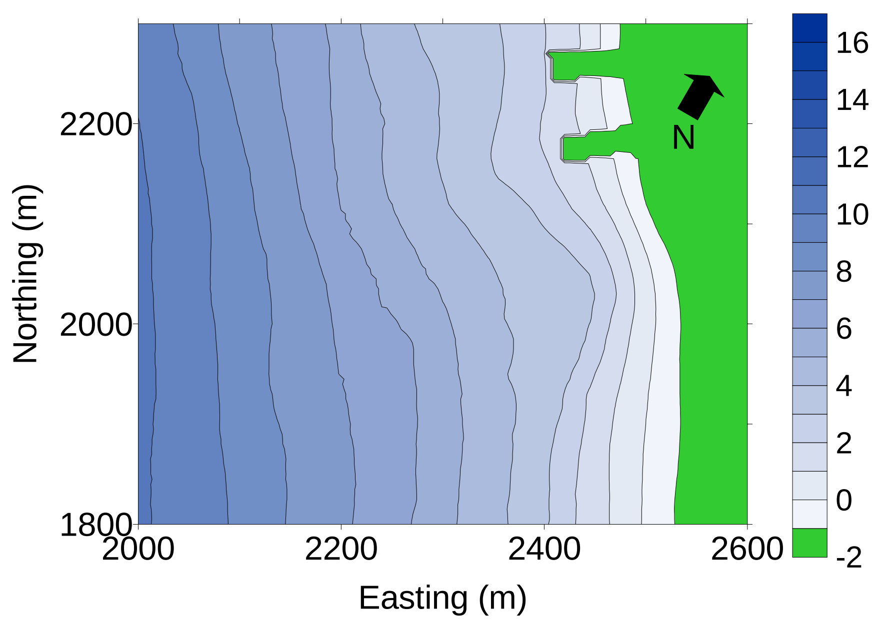



**Figure 5-29. Mock bathymetry of "Southside" surfing break that would produce longer surfing rides.**

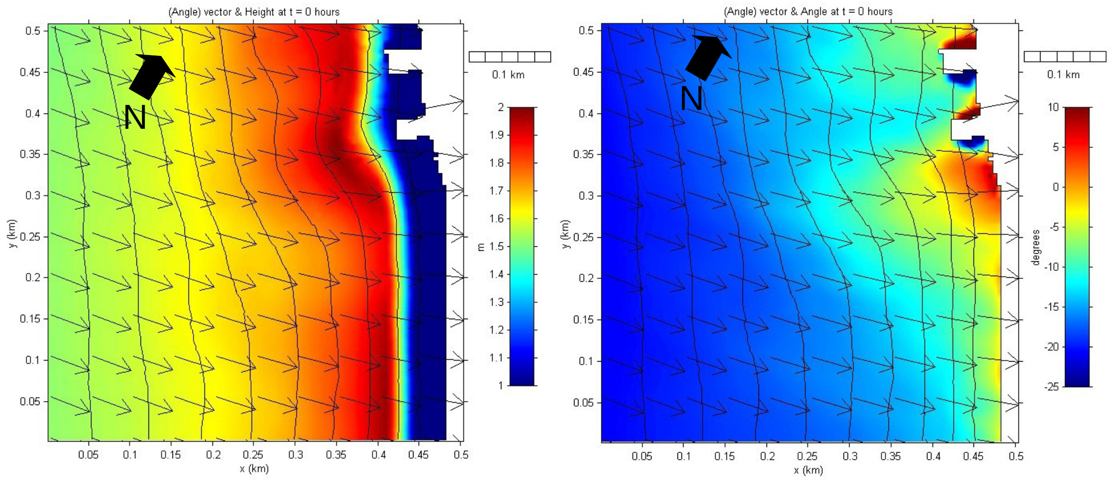



**Figure 5-30. Predicted wave height and angle at "Southside" for a 1.5 m, 14 s, -20° wave. The true magnetic wave direction is approximately 260°.**

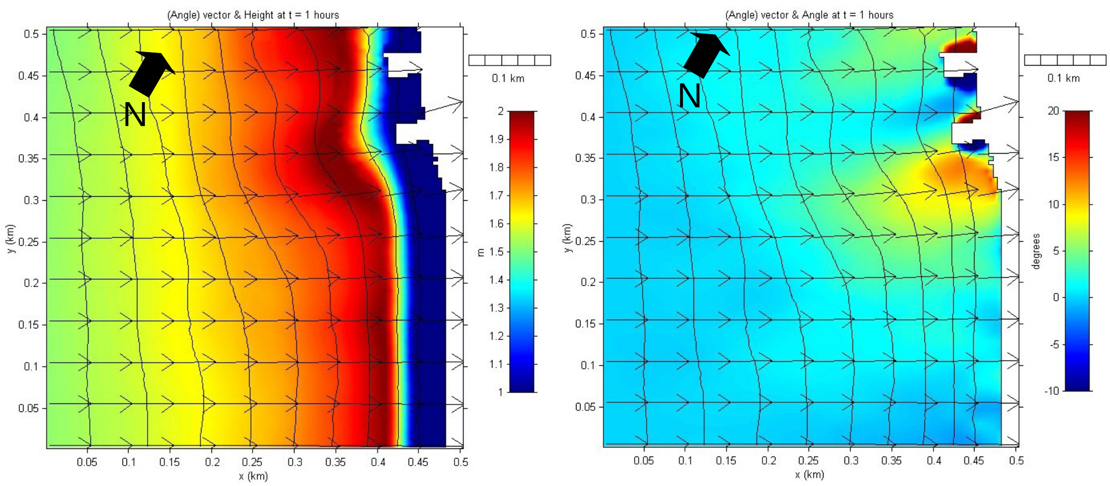



**Figure 5-31. Predicted wave height and angle at "Southside" for a 1.5 m, 14 s, 0° wave. The true magnetic wave direction is approximately 240°.**

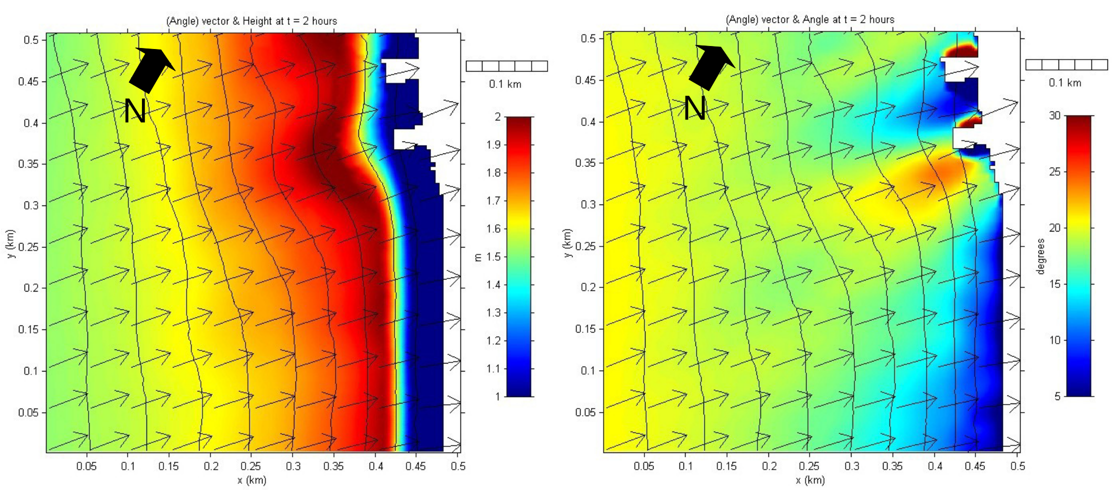



**Figure 5-32. Predicted wave height and angle at "Southside" for a 1.5 m, 14 s, 20° wave. The true magnetic wave direction is approximately 220°.**

## 5.4 TYPE FOUR JETTY

A *Type Four* jetty break is an example of a jetty construction that does not change the existing surfing conditions. The jetty is not sufficient to trap enough sediment and change beach width significantly. The surfing conditions exist because of other natural features, such as reef, that create surfable waves.

### 5.4.1 Case Study: Tamarack, Carlsbad, California

A combination of side-scan surveying and sub-bottom profiling by Elwany et al. (1998) proved the existence of natural reefs that help to create the surfing breaks at Tamarack. The reefs extend from the shore to about 12 m deep, and from the inlet to the jetty to 1 km north, creating the three breaks called Spotland, Main Peak and Middles. The reefs do not protrude significantly above the natural beach shape around the Carlsbad beaches, but still provide enough relief to improve surfing conditions.

The jetty has acted to increase the beach width slightly, but not enough to affect the surfing conditions. It is likely that the reef features provide consistent trapping of sediment and stable bars. If the reefs were not present, then the sand could be too mobile to create the stable bars needed to create good surfing waves. Surfing conditions are expected to be similar without the jetties. It should be noted that the surfing break at “Southside” is expected to be improved, if not created, by the jetties.

Main Peak and Middles are created by a combination of sand bars and reef that produces focusing features in the surfzone. The breaks are a Ramp/Focus configuration that causes shifty peaks of high wave energy (Figure 5-33). The focusing features have only a subtle impact on the convergence of wave energy, forming surfing waves because of a small variation in wave height and some localized rotation of wave directions (Figure 5-34). Examples of good surfing conditions at Mainpeak and Spotland can be seen in Figure 5-35 and Figure 5-36. The surfing rides experienced at these breaks are only brief because of the shapes of the focus features; longer surfing rides would be experienced if the focus contours were at a more oblique angle to the ramp contours.

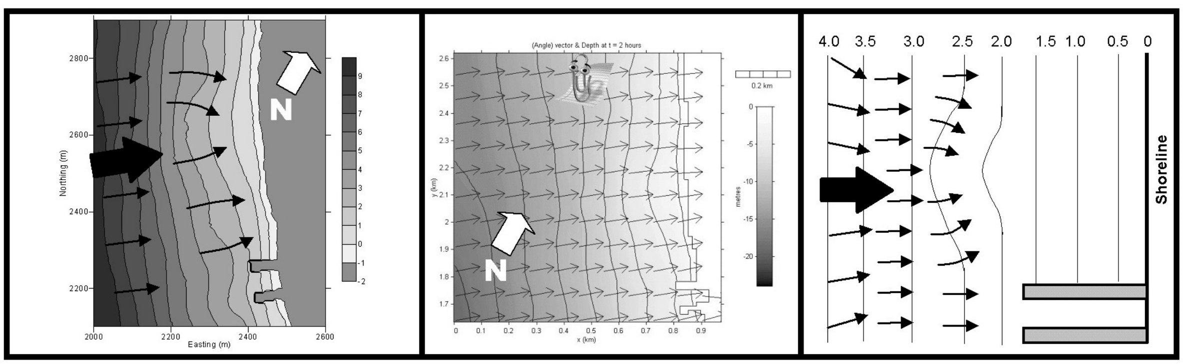



**Figure 5-33. The Ramp/Focus configuration of meso-scale components that make up Main Peak and Middles surfing breaks. Three diagrams are shown to illustrate how the surfing break produces quality waves. The first diagram is the surveyed bathymetry; the second, numerical predictions of wave angles over the depth contour; and the third, idealized schematics of the surfing break components.**

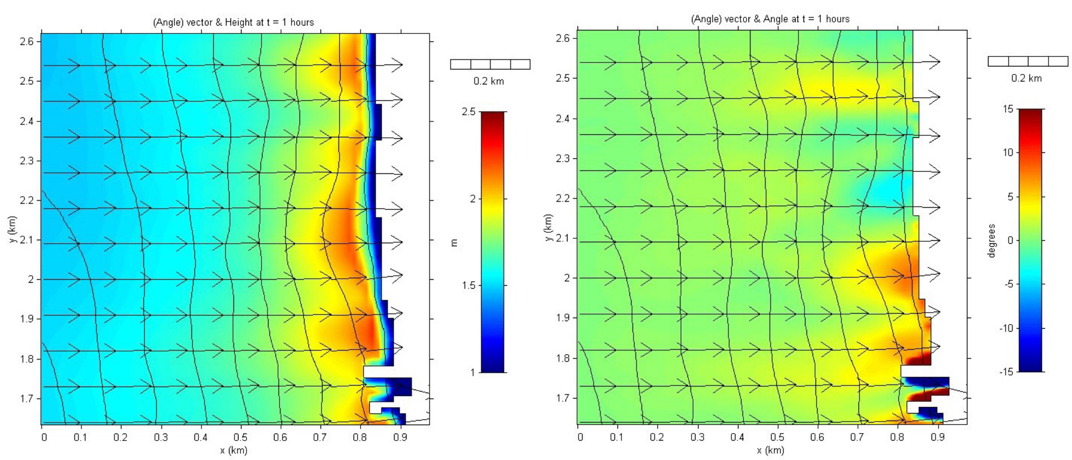



**Figure 5-34. Predicted wave height and angle at "Main Peak" and "Middles" for a 1.5 m, 14 s, 0° wave. The true magnetic wave direction is approximately 240°.**

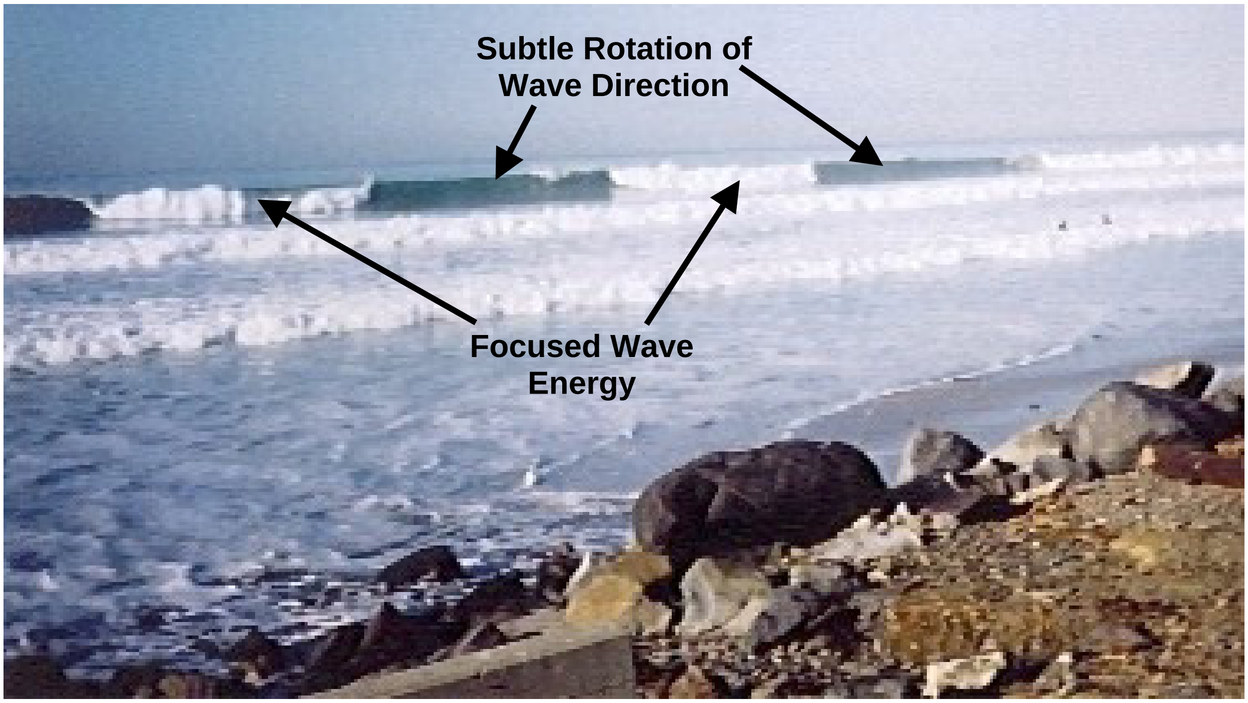



**Figure 5-35. Short surfing rides are created at "Main Peak," Tamarack because of focusing of wave heights.**

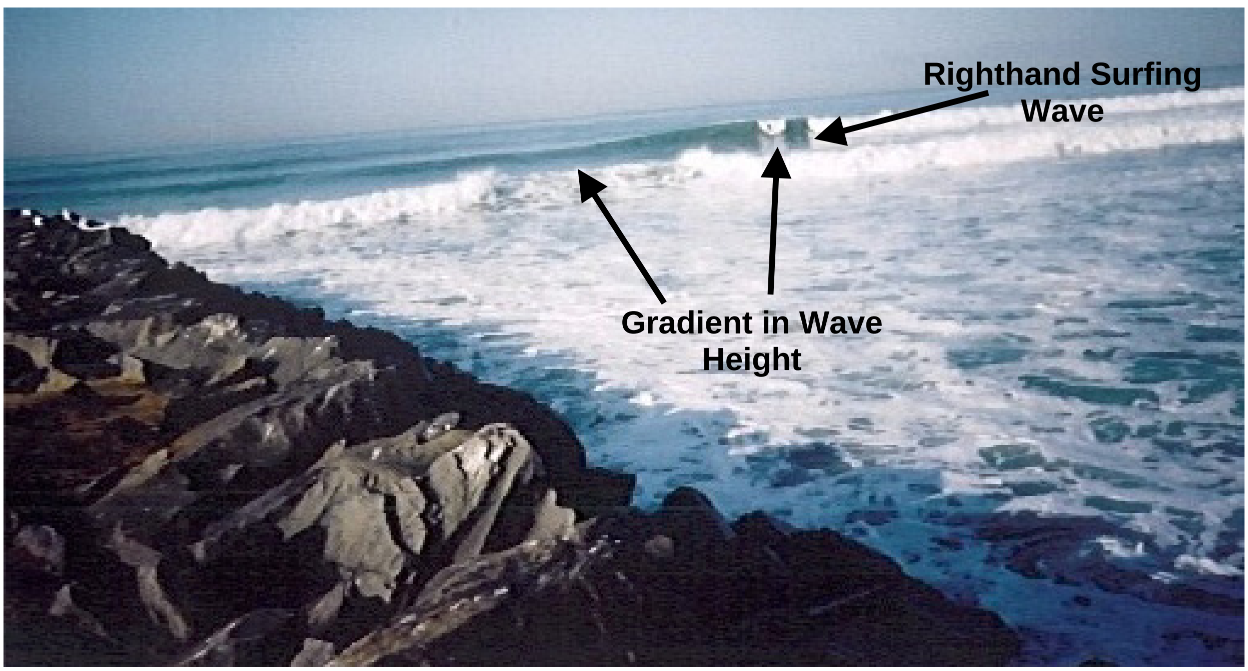



**Figure 5-36. An example of a wave breaking at "Spotland," Tamarack. Note the gradient in wave height that promotes peelings.**

# 6.0 CONCLUSIONS

Jetties are built to stabilize inlet navigation channels by reducing the volume of sand trapped in these channels. Jetties also stabilize the positions of the navigation channels, possibly increasing tidal outflows to flush sediment from the channels and reduce shoaling. Issues that are commonly discussed when building and modifying jetties are performance, local and downdraft beach erosion and accretion, and ecological effects. However, as people become more aware of the social and economic value of surfing, the effect of coastal projects on surfing breaks is becoming another consideration.

The economic benefit of having a surfing break at a beach is enormous. Money spent on food, beverages, surfing equipment, clothing, and accommodations sustains many small coastal communities. Recent attempts to quantify the economic value of beach recreation, including surfing, are impressive. It is critical that preservation and enhancement of surfing breaks is considered in any projects undertaken in the coastal environment.

The primary objective of this study is to determine how jetties influence surfing conditions. This study has identified four main types of surfing breaks present around jetties. The classification types can be used to better understand the impact of jetty construction or modification on neighboring surfing breaks. Previously the specific physical processes that create the surfing conditions around jetties had not been articulated in the scientific literature.

The report is written for coastal scientists, engineers, and planners who possess little knowledge of surfing and surfing terminology. By generating more scientific information about surfing waves and surfing breaks, this report enables those who design and construct coastal structures to incorporate the effects on surfing into their projects. Through a better understanding of surfing science, the concerns of surfing communities can be more completely satisfied through environmental impact reporting.

## 6.1 CHARACTER OF SURFING WAVES

Not all waves that break on a coastline can be surfed. This report shows how desirable surfing waves can be described scientifically using the four major surfing wave parameters. The skill level of a surfer and the types of maneuvers that can be performed are dependent on the wave parameters. The parameters are:

- breaking wave height ($H_B$),
- wave peel angle ($\alpha$),
- wave breaking intensity ($B_I$), and
- wave section length (SL).

## 6.2 CHARACTERISTICS OF SURFING BREAKS

The bathymetric features of the seafloor that transform waves into quality surfing breaks are ramps, platforms, wedges, focuses, ledges, ridges and pinnacles. Depending on the size, orientation, and configuration of the components at a surfing break, surfing waves with different wave parameters will be produced. The most common configurations are Ramp/Wedge, Ramp/Platform/Wedge, Ramp/Focus/Wedge, and Ramp/Ledge/Platform.

## 6.3 SURFING CONDITIONS AROUND AGUA HEDIONDA LAGOON, CARLSBAD, CALIFORNIA

Investigation of surfing conditions around the inlet and outlet jetties of Agua Hedionda Lagoon revealed a beach where jetties have improved surfing conditions. It has been shown that the jetties and natural reefs have created the bathymetric features necessary for surfing waves. The investigation included:

- A review of Carlsbad's wave climate;
- Refraction modeling of waves over the continental shelf to see the effects of Carlsbad Canyon on wave climate at Agua Hedionda Lagoon; and
- Classifying the breaking intensity of waves at Carlsbad.

## 6.4 CLASSIFICATION OF THE JETTY SURFING BREAK TYPE

Four types of surfing breaks around jetties have been identified. The two defining variables in type of jetty break are the effect of the delta on the creation of the surfing break (preconditioning, wave breaking, or none) and the size of the jetty (longer/shorter than surfzone width).

A *Type One* jetty break occurs where waves break shoreward of the end of the jetty. The jetty length is longer than the surfzone width. Trapped sediment accumulates against the jetty, creating a fillet that acts as a wedge component. Energy from along the wave crest converges against the jetty, creating a peak in wave height and take-off zone. The wave then peels along the wedge feature.

A *Type Two* jetty break is created by the ebb tidal delta. Waves are preconditioned over the delta before breaking further inshore. The shoaling and refraction over the delta cause peaks in wave height to form and rotate waves suitable for surfing. Surfing waves are then formed by a combination of wave height peak, wave angle oblique to seabed contours, and bar formations created by rip currents.

A *Type Three* jetty break is also created by an ebb tidal delta. The delta provides stable contours for waves to break over rather than acting as a preconditioning component. Some preconditioning will occur over the delta, but the dominant process that creates the surfing waves is the wave breaking.

A *Type Four* jetty break is an example of a jetty construction that does not change the existing surfing conditions. The jetty is not sufficiently long enough to trap adequate sediment to change the beach width significantly. The surfing conditions exist because of other natural features that create surfable waves, such as reef.

## 6.5 RECOMMENDATIONS

This study is based on a compilation of existing data (Appendix B). The surfing breaks discussed in this report have only been described in general to show how the different types of jetty surfing breaks behave. This report does not present detailed mechanics of the surfing breaks under different wave and tide conditions or with seasonal and temporal changes in bathymetry. More investigations are required to further clarify some of the findings about specific surfing breaks.

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## APPENDIX A – DESCRIPTION OF THE MONOCHROMATIC WAVE REFRACTION MODEL WBEND

This program was written by Dr. Kerry Black. Further information on the model and its previous applications can be found from the ASR Ltd website (www.asrltd.co.nz) or by emailing enquires@asrltd.co.nz.

## A.1 LIST OF NOTATIONS

| | |
|---|---|
| $x,y,z$ | orthogonal space dimensions |
| $F$ | wave power ($Wm^{-1}$) |
| $\theta$ | wave angle (radians) |
| $F_D$ | combination of bed friction ($F_f$) and wave breaking ($F_b$) dissipation terms |
| $F_f$ | bed friction coefficient |
| $E$ | wave energy ($Jm^{-2}$) |
| $Cg$ | wave group speed ($ms^{-1}$) |
| $\rho$ | fluid density ($kgm^{-3}$) |
| $g$ | gravitational constant (9.81 $m^2s^{-1}$) |
| $H$ | wave height (m) |
| $k$ | wave number ($m^{-1}$) = $2\pi/L$, $L$ = wavelength (m) |
| $\omega$ | wave radian frequency (Hz) |
| $\Psi$ | smoothing function for wave height or wave angle |
| $\varepsilon$ | eddy viscosity coefficient ($m^2s^{-1}$) |
| $\varphi$ | wave height (m) or wave angle (°) |
| $C_f$ | friction coefficient |
| $H_L$ | friction term expressed as wave height loss per unit path length $s$ |
| $s$ | unit path length (m) |
| $f$ | frequency (Hz) |
| $H_f$ | wave height associated with spectrum band of frequency f (m) |
| $H_{rms}$ | root-mean-square wave height (m) |
| $\Delta f$ | spectral bandwidth (Hz) |
| $S(f)$ | spectral density ($m^2.s$) |
| $N_f$ | number of frequencies in the spectrum |
| $\omega_{av}$ | average radian frequency (Hz) |
| $k_{av}$ | average wave number ($m^{-1}$) |
| $\gamma$ | breaking ratio |

## A.2 GENERAL DESCRIPTION

Model WBEND (Black and Rosenberg, 1992a, Black, 1997) is a two-dimensional numerical wave refraction model for monochromatic waves or a wave spectrum over variable topography. The model applies a fast, iterative, finite-difference solution of the wave action equations to solve for wave height, wave period, breakpoint location and longshore sediment transport. WBEND provides for:

- variable bathymetry;
- time-varying boundary conditions;
- the wave spectrum;
- options to “enhance” the wave shoaling to overcome the limitations of linear theory;
- a range of friction formulae for different physical conditions;
- third-order differential approximations to eliminate grid scale “wiggles”;
- a “diffusion” scheme to parameterize diffraction;
- longshore sediment transport on beaches;
- continuity of style throughout the suite of linked models and support software;
- software tools for data input, model output manipulation and graphical presentation;
- graphical output using the Matlab routine Plot3DD[1].

## A.3 MODEL EQUATIONS

WBEND is a two-dimensional wave propagation model that uses, as a basis for refraction, the wave action equation for the conservation of wave power in two dimensions given by,

$$\frac{\partial}{\partial x}(F\cos\theta)+\frac{\partial}{\partial y}(F\sin\theta)=-F_D \qquad \text{(A4.1)}$$

where $x$ and $y$ are orthogonal co-ordinates, $\theta$ is the wave angle and $F_D$ $(=F_f+F_b)$ is a combination of the bed friction ($F_f$) and wave breaking ($F_b$) dissipation terms. $F$ is the wave power which, for Airy waves, is

[1] Plot3DD, Gorman, R.M. (1995)

$$F = EC_g = \frac{1}{8}\rho g H^2 C_g \qquad \text{(A4.2)}$$

where $E$ is the wave energy, $C_g$ is the group speed, $\rho$ is the fluid density, $g$ is gravitational acceleration and $H$ is the wave height.

The wave angle is obtained from the equation for conservation of wave number

$$\frac{\partial}{\partial x}(|k|\sin\theta) - \frac{\partial}{\partial x}(|k|\cos\theta) = 0 \qquad \text{(A4.3)}$$

The model solves equations A4.1 and A4.3 for wave power and wave angle respectively using a shoreward marching iterative scheme (Black and Rosenberg, 1992b). Height and angle are directly obtained on a regular finite difference grid, which eliminates the need for interpolation, as required when a ray tracking procedure is used.

To obtain the wave number $k$, the dispersion relation for linear waves,

$$\omega^2 = gk\tanh(kh) \qquad \text{(A4.4)}$$

is solved using an iterative *Newton-Raphson* technique, given the radian frequency $\omega$ and depth $h$.

A formulation based on the horizontal eddy viscosity in the hydrodynamic model 3DD (Black, 1995) is used to smooth the height and angle solutions. This has the effect of spreading energy along the wave crests, similar to the process of diffraction. While solving the wave action and conservation of wave number equations, heights and angles are smoothed by the function $\psi$ given by,

$$\psi = \varepsilon\left(\frac{\partial^2\varphi}{\partial y^2}\right) \qquad \text{(A4.5)}$$

where $\varepsilon$ is the eddy viscosity coefficient and $\varphi$ is either wave height or angle. The dominant wave direction is along the model's $x$-axis, and so the term acts primarily along the wave crests. The eddy viscosity coefficient is set by calibration. Simulations of several different environments (e.g., Black and Rosenberg, 1992b; Hutt, 1997; McComb et al., 1997) have indicated that appropriate values are in the range $0.02 < \varepsilon < 0.06$.

For monochromatic cases, the wave-energy frictional dissipation term is given by,

$$F_f = \frac{\rho C_f}{6\pi}\left(\frac{H\omega}{\sinh(kh)}\right)^3 \qquad \text{(A4.6)}$$

where $C_f$ is the friction coefficient.

For a wave spectrum, mean bed orbital velocity is obtained from the variance in the spectrum, using the linear theory transform function to relate sea surface wave height and period to bed orbital motion. The transform function is applied to each spectral estimate and then the spectrum is re-constituted to obtain total bed orbital variance. The friction term adopted in the model, expressed as a height loss $H_L$ per unit path length $s$, becomes,

$$\frac{\partial H_L}{\partial s} = \frac{2.83 C_f H_f H_{rms} \omega_f^2 \omega_{av}}{3\pi g C_g \sinh^2(k_f h)\sinh(k_{av} h)} \qquad \text{(A4.7)}$$

where $H_f$ is the height of the wave associated with the spectral band of frequency $f$, radian frequency $\omega_f$ and wave number $k_f$ given by,

$$H_f = 2.83(S_f \Delta f)^{1/2} \qquad \text{(A4.8)}$$

where $S_f$ is the spectral energy density of the band with frequency $f$, and $\Delta f$ is the bandwidth.

$H_{rms}$ is the root-mean-square wave height calculated from the total variance in the spectrum as,

$$\begin{aligned} \langle \eta^2 \rangle &= \sigma^2 = \int_0^\infty S(f)df = \sum_0^{f_n} S_f \Delta f \\ H_{rms} &= 2.83\sigma \\ H_s &= 4\sigma \end{aligned} \qquad \text{(A4.9)}$$

while the average radian frequency $\omega_{av}$ is given by,

$$f_{av} = \frac{\sum H_f f}{\sum H_f} \quad \text{and} \quad w_{av} = 2\pi f_{av} \qquad \text{(A4.10)}$$

The summations are across all $N_f$ frequencies in the spectrum. The corresponding wave number $k_{av}$ is defined by the dispersion relation as,

$$\omega_{av}^2 = g k_{av} \tanh(k_{av} h) \qquad \text{(A4.11)}$$

The group speed $C_g$ is the speed coinciding with the frequency $\omega_{av}$ and wave number $k_{av}$.

When solving in the model, the wave path length is assumed to consist of a series of straight line segments across each cell of width $\Delta x$ for a wave travelling at angle $\theta$. Thus the path length is

$$\Delta s = \Delta x / \cos\theta \qquad \text{(A4.12)}$$

The total height loss is summed across the model grid, row-by-row, after initially solving eqn A4.1, assuming $F_D = 0$.

Wave breaking is assessed by checking whether height exceeds a depth limitation, that is if,

$$H > \gamma h \qquad \text{(A4.13)}$$

where $\gamma$ is user selected and is typically of order 0.6-0.8.

### A.3.1 Model Grids and files

The model adopts a rectangular grid for bathymetry. The *x*-direction is positive to the east and corresponds with increasing '*I*', while the *y*-direction is positive northwards and corresponds with increasing '*J*'. The cell (1,1) is located at the bottom left corner of the grid and the maximum coordinate cell ($I_{max}$ , $J_{max}$) is at the top right corner. The model assumes the shoreline is at the eastern side of the grid (maximum *I*). Wave angle is defined relative to the left ("east") of the grid and is positive anti-clockwise (Cartesian axes).

Model WBEND requires three input files which are:

1. Information file;
2. Wave height, period and angle file, or spectrum file; and
3. Bathymetry file.

One information file controls the model by providing the input data and output file names. More information on the options used in the information file can be found in the WBEND user's manual (Black, 1997).

WBEND has three types of boundary conditions that can be used: the probability file listing wave events and their probability of occurrence; the spectrum file containing spectral densities and frequencies for a sea surface spectrum; and the sediment transport contour file for calculation of surf zone littoral drift. WBEND produces several output files, outlined in detail in the user's manual. The binary file, *filename.out*, was the main file used for the present study. This contains depths, wave heights, wave periods, and bottom orbital motion over the full grid for each simulated event.

# APPENDIX B – BATHYMETRY SOURCES AND NUMERICAL MODEL CALIBRATION

## A.1 BATHYMETRY SOURCES

### A.1.1 North of Agua Hedionda Lagoon

The survey (NGVD29) by Elwany et al. (1993) of an area north of Agua Hedionda Lagoon was provided by Tim Norall of EcoSystems Management Associates, Inc in Carlsbad. This survey was used for the model calibration.

### A.1.2 Offshore of Agua Hedionda Lagoon

The survey (MSL) published in Jenkins and Wasyl (2001) was enlarged and digitized. No northing and easting coordinates were shown in the chart but absolute position is not necessary for the modeling since the model grid is relative to an i, j grid with 0,0 as the origin. A scale bar accompanied the chart which was used for dimensions.

### A.1.3 Mission Beach

The Mission Beach bathymetry was compiled form a variety of sources. Depths beyond 12 m (NVGD29) came from a multi-beam survey by Thales-Geosystems (Jerry Wilson). Depths between 6 and 12 m were digitized from the navigational chart. Depths shoreward of 6 m were surveyed for this report using a total station and swimmer with a prism pole.

### A.1.4 "The Poles", Atlantic Beach, Florida

Bathymetry for "The Poles" was digitized from an enlarged chart published in Raichle (1998). No northing and easting coordinates were shown in the chart but absolute position is not necessary for the modeling since the model grid is relative to an i, j grid with 0,0 as the origin. A scale bar accompanied the chart which was used for dimensions.

### A.1.5 Carlsbad Canyon

The survey published in Jenkins and Wasyl (2001) was enlarged and digitized. No northing and easting coordinates were shown in the chart but absolute position is not necessary for the modeling since the model grid is relative to an i, j grid with 0,0 as the origin. A scale bar accompanied the chart which was used for dimensions. This bathymetry is assumed to be sourced from a navigational chart.

## A.2 WBEND MODEL CALIBRATION

WBEND has various coefficients that can be changed to calibrate the numerical model for different locations. The commonly accepted value for each variable was used in this study.

- Angle eddy viscosity = 0.04
- Height eddy viscosity = 0.30
- Bed friction = 0.01
- Wave gamma = 0.78

A good calibration was found when these values were used in conjunction with existing bathymetry and wave data from Elwany et al. (1993). Directional wave data from three sensors was used, two in 13 m and one in 8 m. One of the 13 m sensors was used to drive the model and the other two were used for calibration. The model back-refracts from the 13 m boundary condition to the 20 m depths at the edge of the grid. Waves are then refracted shoreward resulting in wave heights and directions at the two calibrations sites. The results can be seen in Figures B-1. and B-2.

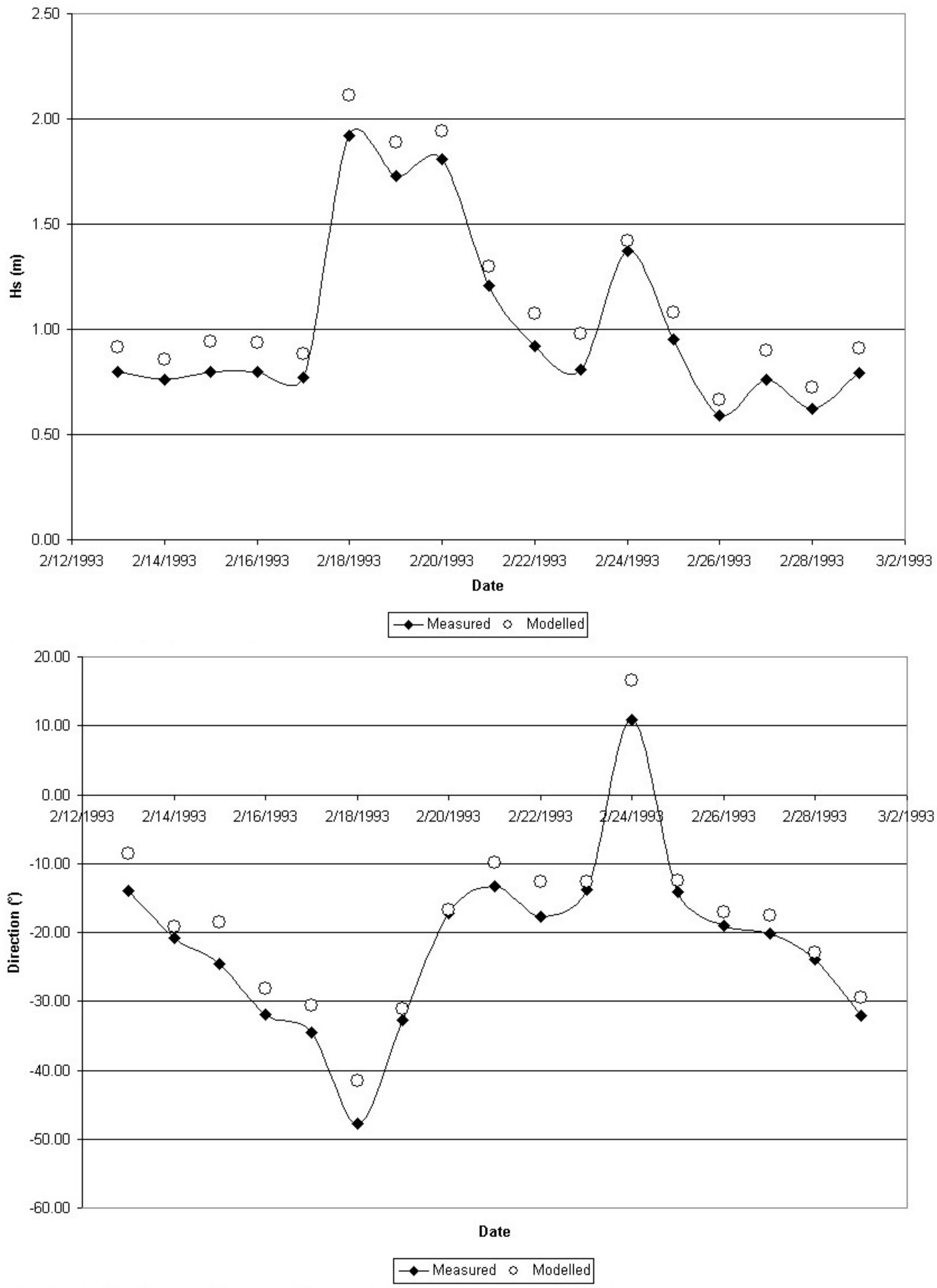


**Figure B-1. Modeled and measured wave heights and directions for the 8 m sensor.**

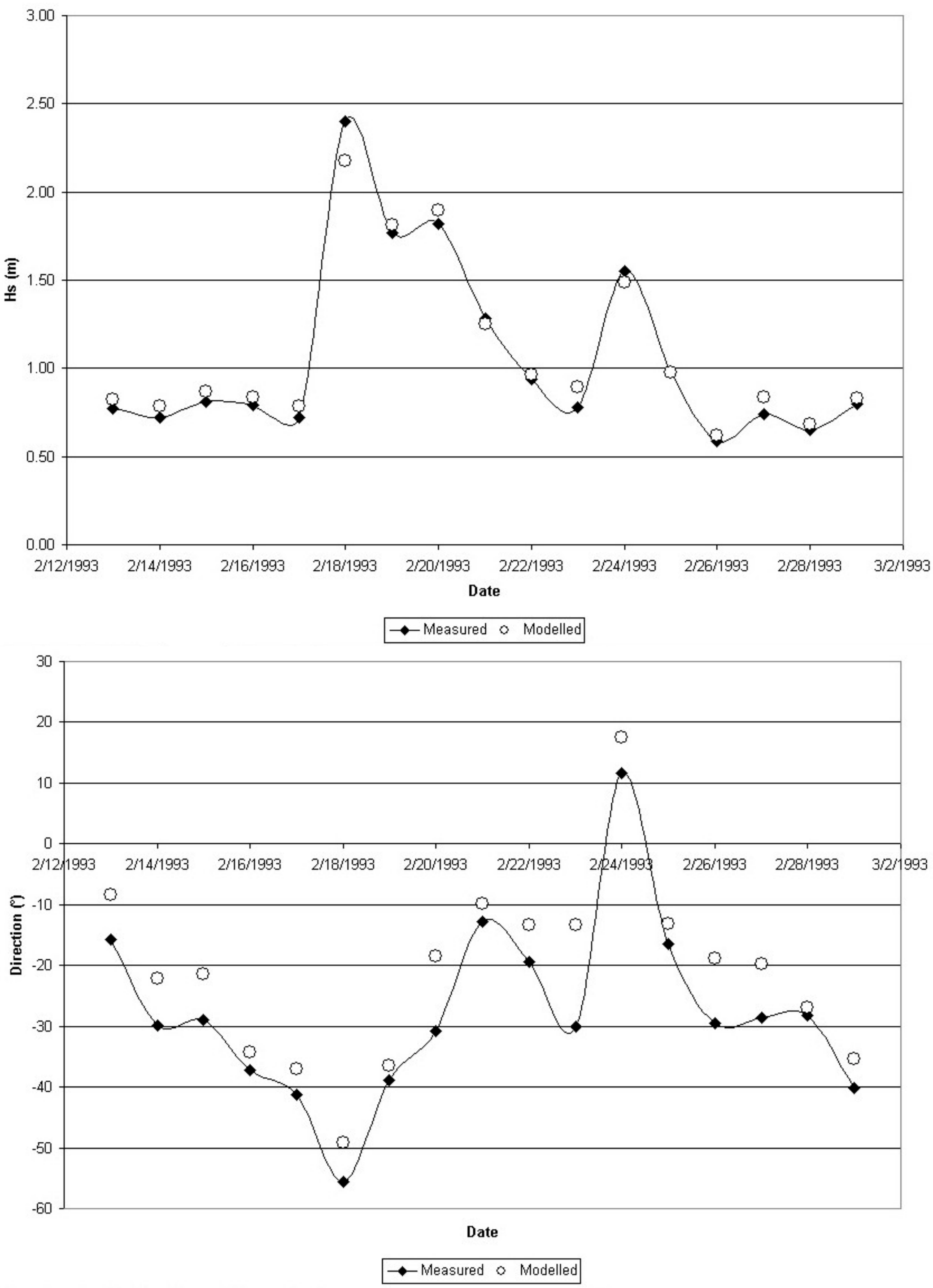


**Figure B-2. Modeled and measured wave heights and directions for the 13 m sensor.**