QUANTIFICATION OF SURFING AMENITY FOR BEACH VALUE AND MANAGEMENT

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Abstract

Surf breaks are the product of complex interactions of nearshore bathymetry, wave characteristics (height, period and direction), tide level, local wind conditions, and, if present interactions with shoreline structures (ASBPA, 2011). The subjectivity of location-based ‘Surf Amenity’ to an individual is often dependent on the wave height, direction and period, tide level and wind conditions, crowding, beach access as well as the individuals skill level and preferred mode of wave riding.

Over 2.5 million Australians and 3.5 million Americans are reported to surf on a regular basis and it is estimated that expenditures to local businesses, including fuel and food add between $30-122 per surfer per surf session to the coastal economy (Lazarow et al., 2007). Understanding the key metocean and bathymetric mechanisms that provide amenity at a surf location is an essential tool for beach management authorities in order for them to protect and maintain this valuable resource.

The advent of regular observations by coastal management authorities through historic imagery, video monitoring, hydrographic survey, directional wave measurements as well as local wind and tide gauges means that there is usually a multitude of data sources to gain a working understanding of local coastal processes. This paper outlines various methods for the analysis of available coastal data in order to define surf amenity at specific sites which may then be utilised to inform beach management practises to maintain or enhance surf amenity into the future. A new method for assessing site-based surf amenity is introduced which aims to reduce the inherent subjectivity usually involved in such evaluations.

Introduction

The value that surfing has to a Local Government Area through providing recreation for its constituents, as a successful industry and through tourism enhancement has in recent years become more recognised. Although difficult to determine, the number of surfers in Australia lies somewhere between 240,000 and 3.5million (ABS, 2011/2 & (Leeworthy, Bowker, Hospital, & Stone, 2005) and was continuing to grow at a rate between 12-15% from 2006 (Surfing Australia, 2006). This growth is due, in part to the increase in affluence and leisure time of Australian society, cheaper international manufacture of surfing equipment and the global marketing of surfing as a highly-paid sporting career and a healthy lifestyle. Surfing today represents a very profitable market, an increasing growth industry, and plays a major part in the tourism strategies for many coastal locations (Lazarow, 2008).

Anthropogenic change to the coastal environment through development and mismanagement has the power to influence surfing amenity in both a positive or negative way. Recognition and understanding of the metocean conditions, bathymetric planforms and coastal processes that induce surfing amenity on a particular beach is a practical tool for local and state government authorities in order to preserve or even improve surfing amenity of their coastline. There has been several high-profile examples of negative impacts to surfing amenity resulting from coastal engineering projects including; Copacabana Beach, Brazil, Mammoth County, New Jersey and Delray Beach, Florida. In these instances specifically, oversights were made in sediment sourcing resulting in dissimilar sediment being utilised for nourishment campaigns, changing the morphology-type of the beach (Benedet, 2007) and hence wave breaking processes affecting surfing amenity.

In Australia, the over-nourishment of the Coolangatta embayment in the early 2000's due to the Tweed Entrance Sand Bypassing Project (TRESBP) resulted in a well-publicised negative surfing impact to the world-famous Kirra. Conversely, the project increased surf amenity in the adjacent beaches of Snapper Rocks, Rainbow Bay and Greenmount creating what became known as the 'Superbank'. In this instance, a break well-known for its long, hollow (steep and powerful) peeling waves suited to a more advanced user group was replaced by a longer, more consistent, user-friendly break suited to a wider range of skill levels.

The necessity of the project to replace sediment eroded from the embayment over the previous 40 years (following an earlier, up-drift coastal engineering project) for infrastructure protection and storm buffer outweighed recreational amenity impacts. However, due to the formation of the Superbank, regular international surfing contests, local, interstate and international surf tourism have positively impacted the local economy. Any knowingly-adverse interference with this new, well recognised geomorphic planform would be met with hostile social response, not only from surfing groups but from local business owners whose livelihoods rely on the steady stream of surfers visiting the area. Such is the importance placed on surf amenity that the TRESBP has formed an Advisory Committee which includes respected members of the local surfing community to advise on current geomorphic conditions prior to the commencement of nourishment campaigns as a key part of the project. The City of Gold Coast (CoGC) also recently completed 'Project Kirra' re-instating a length of the breakwater at the famous beach following advice from local surfing groups, recognising the value surfing has to the city.

Although the TRESBP project resulted in a positive outcome for surfing, there are those amongst the surfing community who view the formation of a new surf break (the Superbank) which caters to a greater number of surfers incommensurate for the demise of a more challenging (albeit more fickle) break, Kirra. Understanding the concerns and aspirations of each of these surfing user groups and the metocean and geomorphic conditions that provide amenity for each is a useful tool in planning and monitoring coastal engineering works.

Surfing Science

In order to quantify surf amenity for a particular user group it is essential to try and define what it actually means to each group. Amenity, by its very nature is a subjective term; it is defined as ‘a feature that increases attractiveness or value’. Coastal engineers, oceanographers, mathematicians and scientists understand non/linear wave theories, wave breaking processes and have also quantified the physics required for an individual to successfully catch and ride a wave. However the science behind the suitability of a wave for recreational surfing is only, in academic terms a new science. James ‘Kimo’ Walker began investigating components of natural reefs and their relationship to producing ‘surfable’ waves in the early 1970’s in Hawaii. There was little interest in his work at the time until the latter part of last century when there was a movement in providing surf amenity through the advent of artificial reefs. His early studies are still referenced widely and terms that were coined are still being used in these new studies.

Recreational surfing can be qualified with a series of descriptive parameters including the wave peel angle, breaker intensity as well as breaking wave height (Mead, 2003).

Peel Angle

The peel angle of a wave is defined as the angle between the trail of the broken wave (‘white water’) and the crest of the unbroken wave as it propagates shoreward. Figure 1 provides an example of the estimation of peel angles using aerial photography.

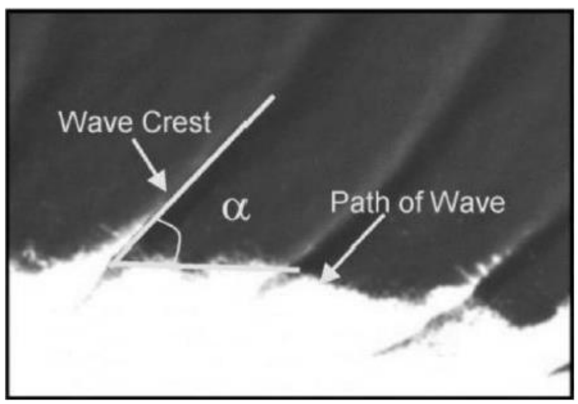


Figure 1: Estimation of wave peel angle using aerial photography (Mead, 2001).

The peel angle ranges between 0˚ and 90˚ and can be used to ascertain the suitability of a wave to an individual surfer’s skill level. Larger peel angles suit beginners (70°-90°) and small peel angles (30°-50°) are more challenging for the wave rider and are suited to more advanced surfers. The peel angle governs the down-the-line velocity (speed) of the surfer as the wave breaks progressively along the wave crest. A small peel angle therefore is associated to a fast down-the-line velocity and larger peel angles with slower down-the-line velocities.

Peel angles less than about 25˚ and approaching 0˚ are described as ‘close-outs’ in surfing terms and mean a large section of the wave crest breaks simultaneously and thus cannot be surfed (Mead and Black, 2001) due to the speed required by the surfer to stay laterally clear of the breaking white water. The down-the-line velocity experienced by the surfer may be defined by the relationship of the wave celerity and the peel angle (Henriquez, 2004),

$$V_s = \frac{c}{\sin \alpha}$$

Where: c is the wave celerity; and α the peel angle.

The speed a surfer can reach under their own power depends mainly on the skill level of the rider, the mode of wave riding and the surfer's equipment; this will be discussed further in the paper.

Breaking Intensity

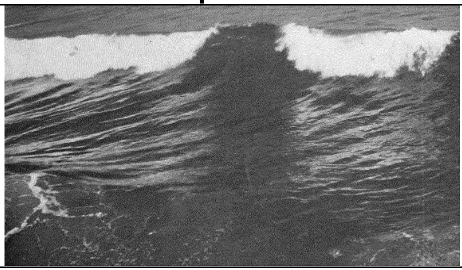
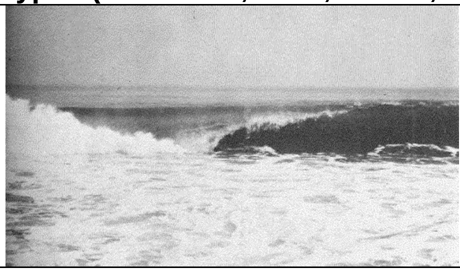
When waves propagate towards the shore or a shallow bathymetric feature (e.g. reef, sandbar), shoaling occurs up to the point when the ratio of the wave height to the wavelength is large, steepening the wave until it becomes unstable and breaks. The breaking wave height, $\mathbf{H_b}$ is defined as the height between the wave trough and the wave crest prior to the point of the crest overtopping (breaking). Wave breaking can be classified into four main types; spilling, plunging, collapsing and surging (Table 1).

Waves suitable for surfing generally break in the range between spilling and plunging types. When these waves are combined with an appropriate peel angle, surfing amenity is enhanced. Mead (2003) concluded that several factors including wave height, wave period, wind strength and direction can also affect the wave steepness and thus breaker intensity; however the biggest influence on the shape of breaking waves is induced from changes in the bathymetry. In fact, the seabed or offshore toe slope of artificial or natural structures will govern the breaker type. Galvin (1968) and Battjes (1974) implemented the so called breaker type index and Iribarren Number (or surf similarity parameter), respectively, which allows the classification of the breaker type as a function of wave steepness and seabed slope (limits are presented in Table 1)

$$\xi_b = \frac{\beta}{\sqrt{H_b/L_\infty}}$$

Where: β is the bottom slope; H_b the wave height at breakpoint; and L_∞ the deep water wavelength.

Table 1 Description of four main breaker types (After SPM, 1977; Galvin, 1968)

Spilling Breaker	**Plunging Breaker**
• Bubbles and turbulent water spill down front face of wave. • The upper 25% of the front face may become vertical before breaking • Iribarren Number: $\xi_b < 0.4$	• Crest curls over a large air pocket. • Smooth splash-up usually follows • Iribarren Number range: $0.4 < \xi_b < 2.0$
 **Surging Breaker** • Wave slides up beach with little or no bubble production. • Water surface remains almost plane except where ripples may be produced on the beach face during runback • Iribarren Number: $\xi_b > 2.0$	 **Collapsing Breaker** • Breaking occurs over lower half of wave. • Minimal air pocket • Usually no splash-up. Bubbles, foam present • Iribarren Number: $\xi_b > 2.0$

Metocean Monitoring

Local governments as well as state and federal authorities are continually monitoring metocean conditions at varying levels of both spatial and temporal resolution. Collation and analysis of all available data relevant to a particular coastline is a valuable tool in understanding coastal processes and informing beach management schemes.

The following sections describe varying aspects of metocean monitoring data and methods available for its analysis in relation to the quantification of surfing amenity.

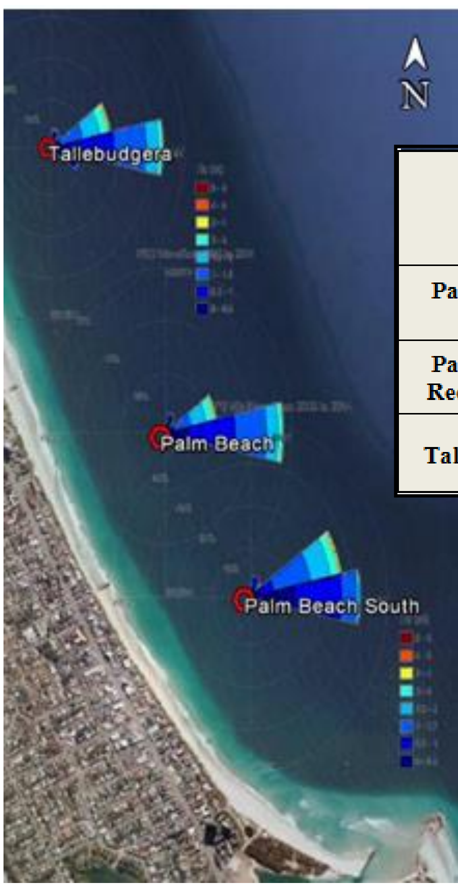
Wave Data

Directional wave data along the Australian Coastline is generally undertaken by state environmental authorities or local governments. In some states or smaller coastal towns, port authorities will maintain wave measuring devices for their ongoing port operations. Generally, these authorities are willing to work with local governments on coastal management projects and will make the data available free of charge or for a nominal fee.

Depending on the location of the wave measuring device in relation to the beach that is being studied, it may be necessary to transform the wave data into the desired location of the study in order to gain a long-term representation of local conditions. If the measured data is not representative of the wave conditions at the beach you wish to analyse due to coastal processes such as refraction, sheltering or shoaling, a numerical transformation of the wave data from the recording device to the beach needs to be undertaken to gain an accurate representation of the local wave climate.

Transformation of wave data between two sites can be performed in one of two ways; implicit matrix transformation from locally recorded data or by the utilisation of a spectral wave model. There are several proprietary wave models that can be used in this instance (MIKE21 SW, SWAN, WW3, TELEMAC) some of which are open source (free). The use of these models needs to be undertaken by qualified and experienced modellers as a tool for coastal process understanding. Ensuring sufficient model boundary conditions; a representative bathymetry of sufficient resolution, adequate wave and tide data is fundamental in gaining beneficial results.

Only following the successful calibration of a model, validated to recorded data in proximity to the study site, can analysis of the results be undertaken. Extraction and analysis of long term wave parameters at the study site will give mean wave conditions at this location (needed as part of the surf amenity analysis), an example of such an analysis can be seen in Figure 2.



Site	Mean Hs (m)	Mean Tp (sec)	Dominant Wave Direction (deg)/(%time)
Palm Beach South	0.91	8.6	80°-85° 42.8%
Palm Beach Reef Inshore	0.98	8.6	90°-95° 50.3%
Tallebudgera	1.02	8.6	90°-95° 32.36%

Figure 2: Wave roses of long-term modelled (SWAN) wave data (left) and associated statistics (right) at different extraction sites at Palm Beach (QLD, Australia)

Conversely, if numerical models are unavailable, a simple transformation matrix can be produced if there is a sufficiently long wave record, measured in close proximity to the site. Using a 3D interpolation of wave height, direction and period from the long-term offshore wave data into the nearshore site, is a more simplistic approach to attain a longer dataset at the study site. Once this has been achieved, analysis of long term transformed wave parameters at the study site will give mean wave conditions for use in the surf amenity analysis.

Wind Conditions

In general surfing terms, amenity is maximised when wind direction is directly opposing (at 180°) to that of the breaking wave direction, this is known as 'offshore' surfing conditions. During these offshore conditions, wind speeds may be up to 25-30knots and still provide surfing amenity. As the wind direction moves away from a directly offshore state, wind speed must decrease to ensure surfing amenity is maintained. Table 2 displays ideal wind conditions for surfing as a function of beach orientation (assuming waves break parallel to shore), wind speed and direction.

Table 2: Ideal wind conditions for the provision of surf amenity

Max. Wind speed (knots)	Max. Wind speed (m/s)	Symbol
<5	2.6	
<10	5.1	
<15	7.7	
MAX	25	
<15	7.7	
<10	5.1	

Survey Data

Bathymetric survey information of the study site is another key dataset in order to understand local wave breaking and attempt to quantify surf amenity. It is the interaction of the incoming wave conditions with the bathymetric undulations that cause the wave breaking patterns of which surf amenity is reliant. Gaining an understanding of the arrangement of the seabed contours in the areas within and adjacent to the wave breaking zone is fundamental.

Depending on the amount of coastal infrastructure and boating activity near the study site, local governments will usually have some form of regularly updated bathymetric information available for examination.

The highest quality hydrographic survey data will usually be undertaken via vessel-based multi-beam sonar (Figure 3), resulting in detailed two-dimensional maps of the seabed around the study site.

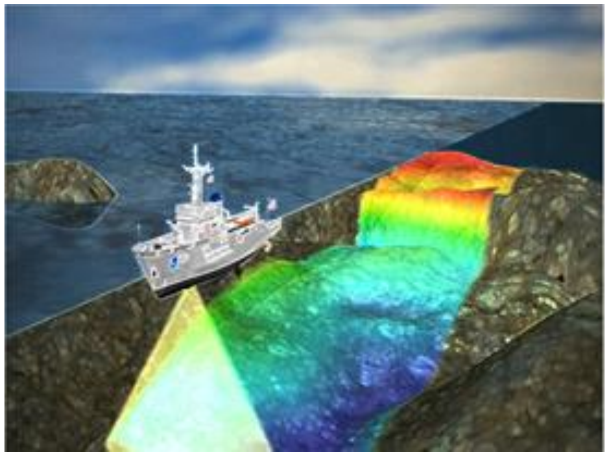


Figure 3 Example of multi-beam survey vessel and bathymetry map. (NOAA, 2015)

Invariably, these are usually uncommon for surf zone surveys, due to the relatively calm conditions required for their undertaking and the costs involved. However due to the dynamic nature of surf-zone geomorphic formations (especially on open coasts) this data should only be viewed as representational of a moment in time.

A common form of cost-effective bathymetric survey undertaken by local governments are shore-normal transect surveys. Here, position and ground height (x, y, z) data is taken at regular intervals in consecutive shore-perpendicular lines usually starting from the upper beach and continuing to a distance offshore. This data provides a representation of the beach profile along that transect location, an example of which can be seen in Figure 4.

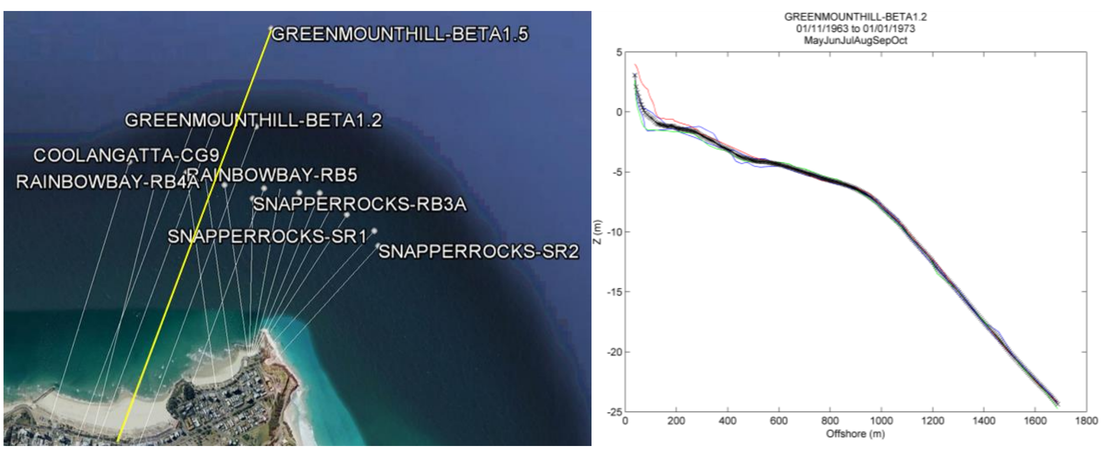


Figure 4 Example of shore-normal hydrographic transect survey locations taken on the southern Gold Coast (top) and beach profile data attained (bottom)

Analysis of the seabed topography for surfing amenity quantification will differ depending on the permanence of the structure or obstruction to the uniformity of these contours. In locations such as seen in Figure 4, a permanent structure, in this case a rocky outcrop or headland has a semi-permanent effect on the alignment of the longshore-transported sediment and in turn the contour at which waves will begin to break. Computation of the alignment of the contour (or isobath) at which wave breaking is induced under average wave conditions will give an indication of the average peel angle at the study site.

Locating the depth contour at which wave breaking will be induced is most appropriately performed with the use of non-linear wave models (Boussinesq, or similar). However for a surf amenity assessment, empirical calculations are deemed to be sufficient, given the general nature of such studies. These calculations are based on attaining the wave breaking height, which is influenced by shoaling and refraction which, in turn is due to the alignment of the offshore profile (found through hydrographic survey data). The Shore Protection Manual (1977) contains basic shoaling and refraction nomograms which can be used to attain wave breaking height (**H_b)** which will in turn give you wave breaking depth.

In cases where only transect data is available, interpolation of neighbouring transects onto a two-dimensional grid may be performed on data taken at a similar time stamp to give a true indication of temporal geomorphic configuration An example of such an interpolation technique for the transects detailed in Figure 4 can be seen in Figure 5. The data for each adjacent transect was selected for the summer period 2001-2. The black line represents approximate contour at which wave breaking will occur under mean wave conditions (**H_s** =1.1m, **T_p** = 9sec).

Figure 5 2D Contour map based on the interpolation of shore-normal hydrographic transect surveys taken on the southern Gold Coast

Simple geometric calculations can then be undertaken between the dominant wave direction (

Figure 2) and the wave breaking isobath alignment to give an indication of average peel angle for the site at the time for which the contour map was created.

Photogrammetric

In the absence of sufficient bathymetric survey data, the use of historic plan-view aerial imagery may be used to estimate geomorphic plan-forms based on wave breaking patterns and visual sandbank alignment. Geo-rectification of the historic image can be used for analysis as seen in Figure 6.

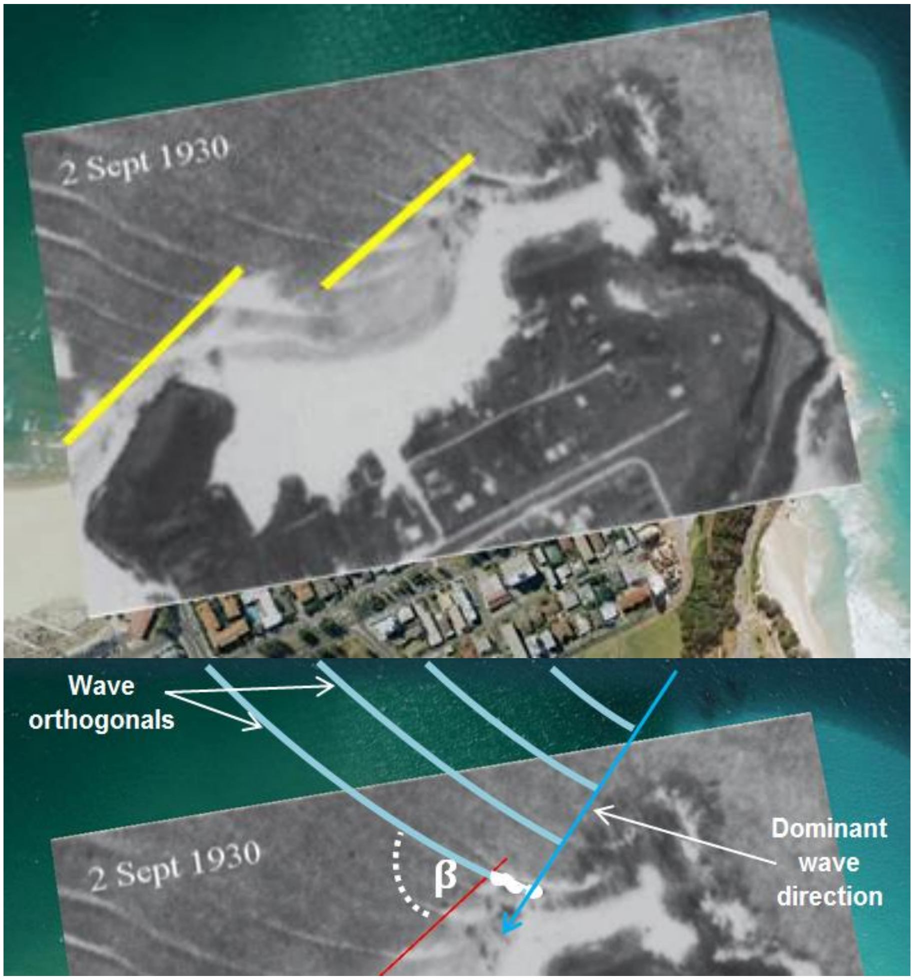


Figure 6 Historic aerial image of Snapper Rocks/Greenmount (2nd September 1930) rectified into Google Earth to approximate sandbank alignment from breaking wave patterns; yellow line (top) and the method used for peel angle calculation (below)

It should be noted that the calculated peel angle using the method described above represents a mere snapshot in time and should be used only to identify patterns of change at the study site that may occur due to the following:

- Seasonal impacts
- Coastal management impacts
- Impacts due to interruption to sediment supply
- Coastal development impacts.

An example of a photogrammetric surf amenity investigation taken on a Gold Coast beach based on a series of geo-rectified historic plan-view photographs of the study site can be seen in Figure 7. The figure makes a link between peel angle and surfer ability based upon work undertaken by ASR (Mead, 2003) for the design of artificial surfing reefs.

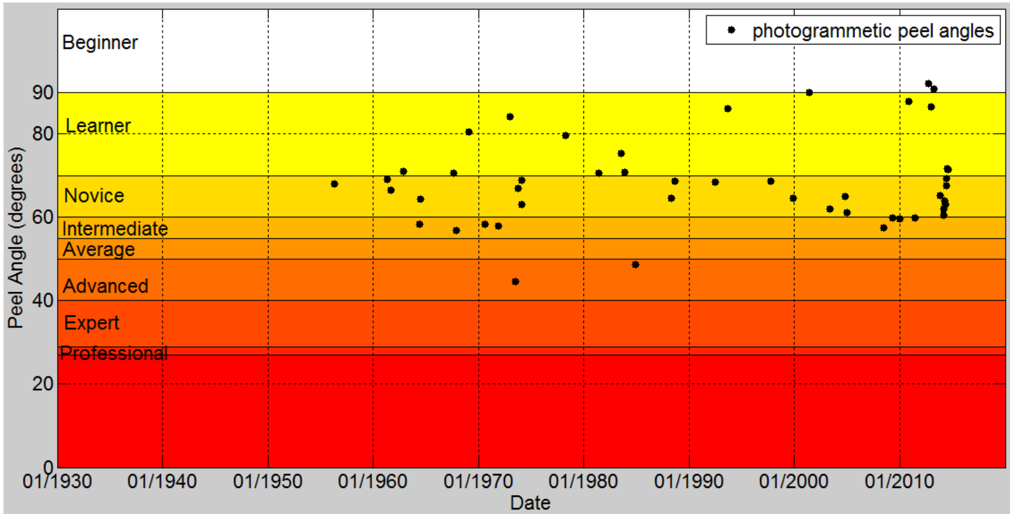


Figure 7 the black dots represent peel angles taken from historic photography. The data is overlain on Mead's (2003) relationship between peel angle and surfer ability

As is the case for the bathymetric survey data, calculation of peel angles using this method should only be undertaken for semi-permanent geomorphic planforms; point-breaks, reefs, structure-sandbank interaction. Quantification of surf amenity based upon peel angles cannot currently be performed on beach breaks due to their dynamic and highly variable nature.

Coastal Imaging

Coastal imaging systems such as ARGUS (www.planetargus.com) and Coastalcoms (www.coastalcoms.com) have started to become an attractive way for local governments, emergency services and port corporations to monitor the coastal environment in real-time as well as maintain databases of historical imagery. Presently, these systems have not been developed to measure (or quantify) surf amenity. However, it may be possible in the future (or if so subsidised) to quantify individual wave peel angles or geomorphic planforms through intensive interrogation of the stored images and video.

Professor Andrew Short has spent significant time classifying all of Australia's 10,685 beaches by their most common ('modal') beach state. His beach classification system identified two extreme beach states; fully dissipative and highly reflective with four predominant intermediate stages occurring between them. The two extremes correspond respectively to flat, shallow beaches with relatively large volumes of sand in the underwater profile and to steep beaches with small volumes of sand in the underwater profile. The intermediate states between these two extremes are the most commonly observed along surfing beaches and are detailed in Figure 8 to Figure 11.

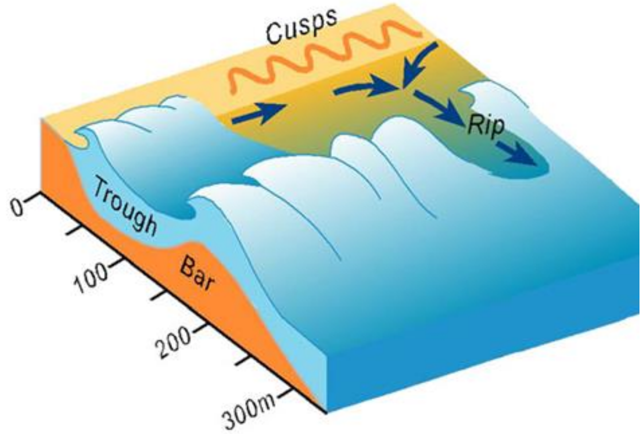


Figure 8 Longshore Bar and Trough (LBT): Characterised by a linear offshore bar separated from the beach by a deep trough. Occur after periods of high wave energy. Waves will 'close-out' on the outermost bar due to the low peel angle (<30°) and are not considered desirable for surfing. (http://www.ozcoasts.gov.au/)

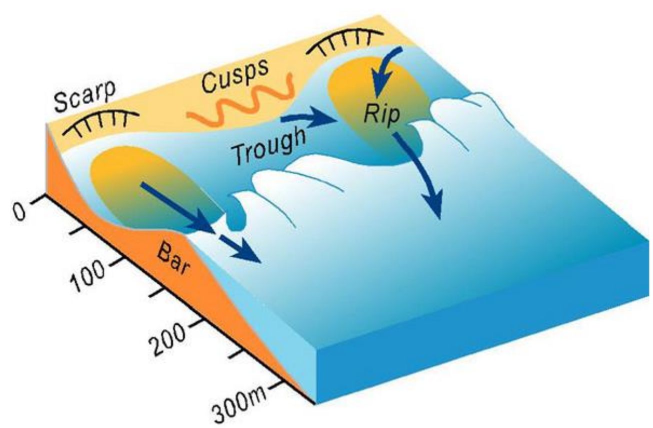


Figure 9 Rhythmic Bar and Beach RBB): Moderate wave energy state. Defined by a rhythmic (undulating in plan) bar, trough and beach. Rip channels occur between the breaker zones. Rhythmic features allow for peel angles within the amenable range. (http://www.ozcoasts.gov.au/)

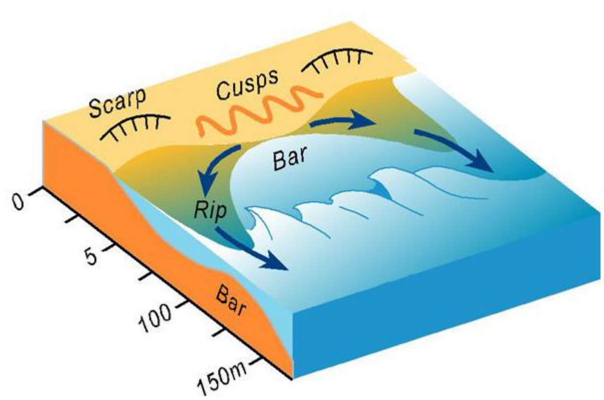


Figure 10 Transverse Bar and Rip (TBR). Following the RBB formation, during periods of low wave energy, the inner bar begins to weld to the shore. These shore-attached bars adjacent to deeper rip channels can also produce peeling rides within the amenable range although are typically shorter than offshore RBB formations due to their proximity to the shoreline. Typically TBR formations produce the best surf amenity on higher tides under small wave conditions (Hs ~1m), when waves can pass over the remnants of the outer bar without dissipation. (http://www.ozcoasts.gov.au/)

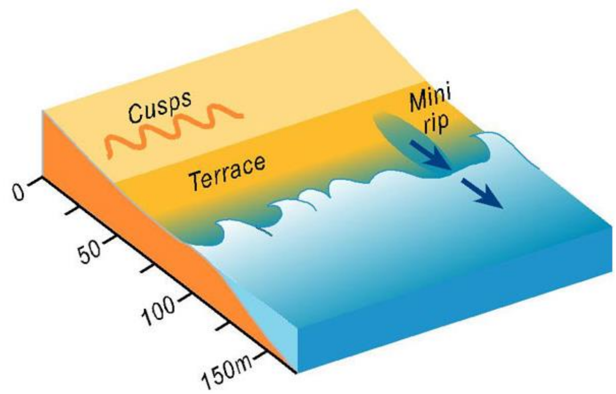


Figure 11 Low Tide Terrace (LTT). Low energy beach state with moderately steep beach face, joined at the low tide level to an attached bar or terrace, the bar usually extends between 20-50 m seaward and continues alongshore, attached to the beach. It may be flat and featureless, have a slight central crest, called a ridge, and may be cut every several tens of metres by small shallow rip channels, called mini rips. The rips, however, are usually shallow, ephemeral or transient meaning they will flow strongly for a few minutes then dissipate (Short, 2013). Utilized by surfers under high tide conditions, waves will break into the adjacent 'mini-rips' intersecting the sand bars providing surf amenity if the plan form has conducive peel angle orientation.(http://www.ozcoasts.gov.au/)

Depending on the location, open beaches are generally quite dynamic and at any time the beach state will most probably be a combination of two to three of these described intermediate states depending on current and antecedent wave energy. Positive surf amenity within each of the above states is one in which waves break at peel angles within the amenable range (approx. 27°-90°) with winds within the limits described in Table 2.

Surf Amenity

Defining the amenity of a surf spot is a subjective investigation. The mode of surf riding undertaken by the individual, board type and surfer ability play the largest factors in determining the suitability of surf spots to each individual. However, the methods outlined in this study and previous investigations can give an 'envelope' of metocean and bathymetric conditions deemed suitable for surfing at a location.

The results of Walker (1974) study linking wave height, peel angle and surfer ability, can be seen in Figure 12.

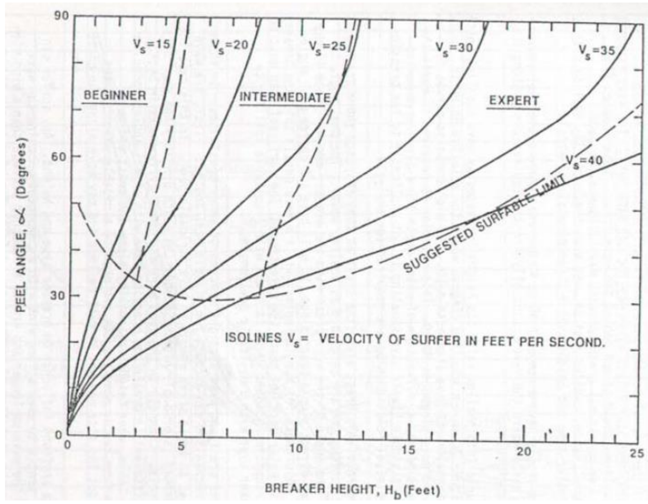


Figure 12 Classification of surfing skill by peel angle and wave height (Walker, 1974)

Following this original work Hutt (2001), attempted to update this relationship due to the advancement in surfboard design and the discovery of more challenging surfing locations. Hutt's work also expanded on the original classification of three different surfer skill levels as seen in Table 3 and Figure 13.

Table 3 Relationship of skill level of surfers, peel angle and wave heights. (Hutt et al., 2001).

ID	SURFER RATING	PEEL ANGLE LIMIT (deg)	Min. /Max. Wave Height
1	Beginner surfers not yet able to ride the face of a wave and simply moves forward as the wave advances.	90	0.7 / 1.0
2	Learner surfers able to successfully ride laterally along the crest of a wave.	70	0.65 / 1.5
3	Surfers that have developed the skill to generate speed by 'pumping' on the face of the wave.	60	0.6 / 2.5
4	Surfers beginning to initiate and execute standard surfing manoeuvres on occasion.	55	0.55 / 4.0
5	Surfers able to execute standard manoeuvres consecutively on a single wave.	50	0.5 / >4.0
6	Surfers able to execute standard manoeuvres consecutively. Executes advanced manoeuvres on occasion.	40	0.45 / >4.0
7	Top amateur surfers able to consecutively execute advanced manoeuvres.	29	0.4 / >4.0
8	Professional surfers able to consecutively execute advanced manoeuvres	27	0.35 / >4.0
9	Top 44 professional surfers able to consecutively execute advanced manoeuvres	Not reached	0.3 / >4.0
10	Surfers in the future	Not reached	0.3 / >4.0

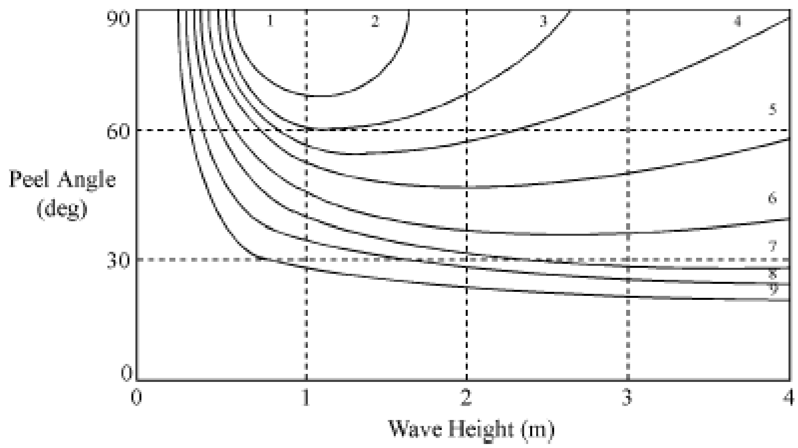


Figure 13 Relationship of skill level of surfers, peel angle and wave heights.(Hutt et al., 2001).

The relationships outlined in these tables are a good starting point to understanding surfer capability in relation to wave breaking characteristics. Due to the variability of breaking waves in the ocean it is very rare for a parameter such as peel angle and breaking wave height to remain constant on a single ride. Even on long point breaks (with a constant geomorphic alignment) that have extended offshore platforms for wave alignment, peel angles will invariably decrease as the waves progress due to localised refraction at breaking. It should be noted that a decrease in peel angle between consecutive sections may mean that surfer skill groups confined by the minimum peel angle defined in Table 3 may in fact be able to surf at a lower peel angle due to the momentum of the rider as they enter the next section of the ride.

MOORES (2001) and SCARFE (2002) introduced Wave Section Length as an additional parameter for the quantification of surfing amenity. A new 'wave section' begins when there is a change in breaking wave height (**Hb**), peel angle (**α**), or breaking intensity (**BI**), and is said to have a section length of **SL**. The longer the section length having homogeneous wave parameters, the more amenity that is provided and the wave viewed as 'perfect'.

Surf amenity quantification may be undertaken by the development of non-linear numerical wave models. Analysis of wave breaking patterns within the modelled domain for a given incoming wave spectrum and bathymetry can give an indication of the number of possible waves that can be ridden and length of ride for each of the skill level groups identified in the previous section. Development of such a model has been used for recent surf amenity studies for the comparison of pre and post coastal management and construction activities, (Mortensen, 2010).

Quantification of wave breaking patterns, including; breaking wave height, section length and peel angle could also be undertaken by the analysis of coastal imaging data. However, at present surf amenity analyses of this type are still only in developmental stages.

The dynamic nature of breaking waves in an ocean environment means that true quantification of surf amenity is not just the identification of periods when the surfing amenity constraints of peel angle, wave height/direction and skill level are met.

Therefore, an interim method for such quantification needs to be developed for real-time analysis of metocean conditions. Score card-type systems have been used in the past that simply rate daily surf conditions on a poor to ideal scale. However biases based on the assessor's individual skill level, surfing mode and wave-type preference have always skewed any real quantitative results. The methods described in the following section have been developed to reduce the amount of invariable subjectivity that will be introduced into assessments of this nature.

As with most sports, developments in equipment design, sports science and leisure time mean that general skill levels (as a whole) have improved with time. Surfing is no different and as such, re-visiting Hutt's (2001) table (Table 3) should be undertaken to include not only the advancement in (the most popular wave riding mode) short-board surfing but also to the wider array of surf-craft and wave riding modes that have grown in popularity; such as Stand Up Paddle-boarding (SUP), body-boarding, body-surfing and longboarding. The first step in the development of new surf amenity assessment criteria was to broaden the surfer skill level categories developed by Walker (1974) and furthered by Hutt (2001) and Scarfe (2002).

Due to their performance capabilities, each wave riding mode has its own limitation as far as speed that can be attained under human power, regardless of the rider's skill level. Hence, different wave riding modes have been separated into similar groups based on minimum and maximum wave heights as well as the initial minimum peel angle that can be ridden by the user, Table 4. This means that, for example an advanced bodysurfer will be in the same competency grouping as a beginner short board surfer due to the limitations that bodysurfers have in being able to ride waves with peel angles less than 60°. It should be also noted that as a surfer's competency level progresses the lower limit of wave heights decreases as the surfer is now more capable of generating speed.

Table 4 Wave riding competency level based on user group, peel angle as well as minimum and maximum wave heights

ID	Wave Riding Competency Level	Peel Angle Limit (*based on Hutt et al, 2001*)	min Wave Height (m)	max wave height (m)	Craft-type/User-group/wave-riding mode								
					Shortboard (Surf & Knee-board)	Bodyboard (Drop-knee & Prone)	Longboard (Performance & Traditional)	Stand-Up Paddleboard (SUP)	Wave-ski	Alaia/Paipo/Finless	SLS Board (Prone & Kneeling)	SLS padlle ski	Body-surf
1	**LEARNER**	**90**	**0.25**	**0.75**	Learner surfers not yet able to catch an unbroken wave or transverse the wave face. The rider requires either external assistance or pushes off the sand to catch the wave. The rider may be able stand-up following catching the broken wave directly to the beach usually at a shallow depth. The riders are unable to duck-dive or negotiate the surf zone unassisted in order to reach the line-up.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. The rider requires either external assistance or pushes off the sand to catch the wave. The rider remains prone following having caught the broken wave directly to the beach usually at a shallow depth. The riders are unable to duck-dive or negotiate the surf zone unassisted in order to reach the line-up.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. The rider requires either external assistance or pushes off the sand to catch the wave. The rider may be able stand-up following catching the broken wave directly to the beach usually at a shallow depth. The riders are unable to duck-dive or negotiate the surf zone unassisted in order to reach the line-up.	The rider is unable to catch either a broken or unbroken wave from a standing position. They are unable to negotiate the surf-zone in a standing position. The rider is able to stand-up and paddle in the flat water outside of the surf-zone.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. They are unable to negotiate the surf-zone. The rider is able to paddle in the flat water outside of the surf-zone.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. The person pushes off the sand to catch the wave. The rider remains prone following having caught the broken wave directly to the beach usually at a shallow depth for a very short period before the wave passes them by.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. The rider requires either external assistance or pushes off the sand to catch the wave. The rider remains prone following having caught the broken wave directly to the beach usually at a shallow depth. The riders are unable to negotiate the surf zone unassisted in order to reach the line-up.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. They are unable to negotiate the surf-zone. The rider is able to paddle in the flat water outside of the surf-zone.	Beginner surfers not yet able to catch an unbroken wave or transverse the wave face. The person pushes off the sand to catch the wave. The rider remains prone following having caught the broken wave directly to the beach usually at a shallow depth for a very short period before the wave passes them by.
2	**BEGINNER**	**60**	**0.5**	**2**	Beginner surfers able to successfully ride across the open face of a wave. These surfers are in the process of learning to change direction of their craft as they traverse the wave. They are able to paddle into the wave under their own power	Beginner surfers able to successfully ride across the open face of a wave. These surfers are in the process of learning to change direction of their craft (without sliding out) as they traverse the wave. They are able to paddle into the wave under their own power	Beginner surfers able to successfully ride across the open face of a wave. These surfers are in the process of learning to change direction of their craft as they traverse the wave. They are able to paddle into the wave under their own power	Beginner surfers able to successfully ride across the open face of a wave. These surfers are in the process of learning to change direction of their craft as they traverse the wave. They are able to paddle into the wave under their own power standing up, these surfers may still be unable to paddle though the break standing up	Beginner surfers able to successfully ride across the open face of a wave. These surfers are in the process of learning to change direction of their craft as they traverse the wave. They are able to paddle into the wave under their own power , these surfers may still be unable to paddle though the break	Intermediate surfers able to transverse the wave face without sliding out. The surfer is able to padlle into an unbroken wave under their own power.	Intermediate surfers able to transverse the wave face prone. The surfer is able to paddle into an unbroken wave under their own power.	intermediate to advanced surfers able to transverse the wave face and change direction without nosediving. Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Intermediate to advanced surfers able to transvers the wave face. The surfer is able to catch the wave under their own power in deep water. Advanced riders are able to perform manouevours and maintain their position in front of the curl of the wave. Due to limitations of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.
3	**NOVICE**	**45**	**0.4**	**2.5**	Intermediate surfers able to change direction and gain speed as they traverse the open face of the wave. They are able to perform manouveurs that require only a small, slow changing of board direction; mid-face bottom and top turns as well as down-the-line floaters. Due to the dimensions of a kneeboard, this is the most advanced level to be attained	Intermediate surfers able to change direction and gain speed as they traverse the open face of the wave. They are able to perform spinning manouveurs (360/reverse) and can maintain a transverse line across the wave face.	Intermediate surfers able to change direction and gain speed as they traverse the open face of the wave. They are able to perform manouveurs that require only a small, slow changing of board direction; mid-face bottom and top turns.	Intermediate surfers able to change direction and gain speed as they traverse the open face of the wave. They are able to perform manouveurs that require only a small, slow changing of board direction; mid-face bottom and top turns. They are able to navigate the surf zone standing up.	Intermediate surfers able to change direction and gain speed as they traverse the open face of the wave. They are able to perform manouveurs that require only a small, slow changing of board direction; mid-face bottom and top turns.	Advanced surfers able to paddle into steeper waves, gain speed across the wave by pumping their craft or maintaining a "high-line". These surfers are able to perform consecutive manouveurt whilst mainting speed.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Advanced surfers able to paddle into and ride waves in a kneeling position, gain speed across the wave by pumping their craft or maintaining a "high-line". These surfers are able to perform consecutive manouveurs whilst mainting speed.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle
4	**ADVANCED**	**35**	**0.3**	**4**	Advanced surfers able to perform consecutive manouveurs whilst maintaining speed. They are able to maintain speed in the tube and exit if the wave is conducive.	Advanced surfers able to perform acute turns whilst maintaining speed. They are able to maintain speed in the tube and exit if the wave is conducive. They are able to transition to a drop-knee position.	Advanced surfers able to gain speed across the wave by pumping their or maintaining a "high-line". These surfers are able to "walk-the-board" in the correct cross-over manner to successfully perform manouveurs on the nose.These surfers are able to perform consecutive manouveur whilst mainting speed.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Advanced surfers able to gain speed across the wave by pumping their board or maintaining a "high-line".They are able to perform powerful and sliding manouveurs on shorter craft, close to the riders own height.These surfers are able to perform consecutive manouveur whilst mainting speed.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Advanced surfers able to gain speed across the wave by pumping their craft or maintaining a "high-line". These surfers are able to perform consecutive manouveurt whilst mainting speed.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle
5	**EXPERT**	**<30**	**0.25**	**>4**	Advanced surfers able to perform consecutive manouveurs in the critical section of the wave (and above the lip), whilst maintaining speed and flow. They are able to control their speed in the tube and exit if the wave is conducive. They can take off on steep reef/slab waves.Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Advanced surfers able to perform manouveurs in the critical section of the wave (and above the lip). They are able to control their speed in the tube and exit if the wave is conducive. They can take off on steep reef/slab waves. They are able to gain speed in a drop-knee position. Due to limitation of this mode of wave-riding, waves with a more acute peel angle are unable to be ridden.	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle	Wave-riding mode unable to transverse wave face at sufficient speed to meet wave peel angle

The details given for the competency level of each wave-riding mode detailed in Table 4 need to be understood clearly in order to recognise each user group. From here, the assessor is then asked to rate the conditions for each one of the competency level groups on a scale from 0-5 (un-surfable to perfect conditions for that group), Figure 14 & Table 5.

The fact that the assessor has to make a judgement based on another groups competency level, removes a great deal of the subjectivity when compared to rating the conditions for themselves. This is due to the assessor having to 'remove themselves' from the task and make an assessment as someone of that skill level. It has been found that the most experienced and advanced surfers tended to make the best judgements as to the amount of amenity provided for the 5 competency level groups. This is most probably attributed to the fact that they themselves have progressed through each of the competency levels at some point. Assessors who were also competent in a wide range of wave-riding modes were also better placed for the quantification process. An example of an Amenity Quantification Assessment Sheet can be seen in Table 5.

The long-term result of the assessment sheet can be used to link metocean (Figure 14) and bathymetric planforms/beach states to surf amenity for the different Competency Groups. The impacts of seasonal changes, coastal management and infrastructure works can also be linked to a decline or increase in surf amenity for each of the user groups. The assessment can also be used to quantify the effects of diminishing one user group's amenity in order to improve that of another group.

Conclusion/Recommendations

This paper has identified certain metocean and geomorphic conditions that induce amenity for wave-riding in a variety of modes. It provides a guide for local and state coastal management authorities for the recognition of surf amenity at beaches within their jurisdiction. Several methods are introduced based on the extent of available metocean and bathymetric data for the quantification of surf amenity.

A new, inexpensive and useful method has been introduced that builds on previous surf amenity studies to attempt to remove the subjectivity from the quantification of amenity at a study site. The method was developed in order to aid coastal management authorities in their assessment and quantification of surfing amenity in order to inform future coastal management and infrastructure projects.

It is recommended that utilisation of this new assessment approach is undertaken by experienced surfing stakeholders, preferably local to the study site. It has been found that the inclusion of local surfing stakeholders such as; boardriders clubs, surf lifesaving clubs and local surfers as key stakeholder's in coastal management and infrastructure projects can aid in the overall success of the project.

The popularity of surfing and its value to coastal communities within Australia has been studied and recognised by local coastal governments. As such recognition (and the possible quantification) of surfing amenity at a location within the government boundary is a key element for its preservation and possible improvement.

T a b l e 5 E x a m p l e o f a (d u m m y) S u r f Amenity Quantification Assessment Sheet for Middleton Beach, WA: July, 2015.

Surfers Beach : Middleton Beach Observations														
July, 2015							AMENITY PER USER GROUP ID:							
Date	**Time**	**Observer**	**wind D**	**wind S**	**Wave height**	**Period**	**1**	**2**	**3**	**4**	**5**	**Surfers**	**Photo**	**Comment**
1 WED	830	AS	W	10K	1.2	MED	3	1	0	0	1	0	YES	STILL AND CLEAN MINIMAL SHAPE. SW 2.8 SWELL 13 SEC
2 THUR	830	AS	SW	10K	1.5	MED	2	1	0	0	1	0	YES	LITE OFFSHORE CLEAN MINIMAL SHAPE. S/SW SWELL 2.5 12 SEC
3 FRI	800	AS	SW	5K	1.2	MED	3	1	0	0	1	0	YES	STILL AND CLEAN MINIMAL SHAPE. SW 2.8 SWELL 13 SEC
4 SAT	1500	AS	SSW	5K	1.5	MED	3	1	0	0	0	0	NO	CLEAN OFFSHORE NO SHAPE. SW 2.5M SWELL 12 SEC
5 SUN	830	AS	W	10K	1M	MED	3	1	0	0	0	0	YES	STILL CLEAN OCEAN. STRAIGHT S/SW 2.1 SWELL 14 SEC
6 MON	815	AS	SW	15K	1.2M	MED	3	1	0	0	1	0	YES	CALM AND STILL. NO SHAPE. SW 2M SWELL 12 SEC
7TUE	830	MR	SW	15K	<0.5	MED	1	0	0	0	0	0	YES	NO WAVES
8WED	830	MR	SW	10K	0.5	MED	2	0	0	0	0	0	YES	NO WAVES
9THU	830	MR	S	5K	1	SHORT	1	0	0	0	0	0	yes	COLD WINDY RAINING AND NO WAVES…
10FRI	840	MR	W	5K	0.5	MED	2	0	0	0	0	6	YES	GRANNY GROMMETS - SHORE BREAK STRAIGHT DUMPERS
11Sat	1300	MR	SW	5K	0.5	MED	2	0	0	0	0	0	yes	SHORE DUMPERS NO SHAPE
12Sun	600	MR	WSW	5K	0.5	MED	2	0	0	0	0	0	NO	
13MON	700	MR	W	5K	>0.5	MED	1	0	0	0	0	0	YES	SHORE DUMPERS NO SHAPE COLD MORNING 3DEGREES!
14TUE	850	MR	CALM	CALM	1	MED	1	0	0	0	0	0	yes	SHORE DUMPERS NO SHAPE
15WED	830	AS	CALM	CALM	1	MED	1	0	0	0	1	0	no	
16THU	830	AS	W	10K	1	MED	1	0	0	0	0	0	no	
17FRI	830	PB	WSW	10K	0.75	MED	2	1	0	0	1	2	no	
18SAT	630	AS	W	15K	0.5		2	0	0	0	0	4	no	
19SUN	900	AS	SW	15K	0.5		2	0	0	0	0	0	no	SHORE DUMPERS NO SHAPE
20 Mon	1615	PB	SW	20K	<0.5		1	0	0	0	0	0	no	Cold front. Wave buoy on South coast showing 3m SW swell & building
Tue21	1630	PB	SW	15K	1m	med	2	0	0	0	0	2	yes	Back of cold front. Very straight waves. Zero shape.
Wed 22	1615	PB	W	12K	<0.5	med	2	0	0	0	0	0	yes	2.5m SW on Eclipse Wavebuoy
Thurs 23	1230	PB	N	15+	<0.5		1	0	0	0	0	0	no	3m+ SW swell on Eclipse wavebouy (EWB)
Fri 24	1200	PB	NW	15+	1m	med	2	0	0	0	1	0	Yes	3m+ on EWB. Granny grommets surfing in the morning
Sat 25	1100	PB	W	10K	1m	med	2	0	0	0	1	0	no	3m SW swell outside
Sun 26	1130	PB	SW	15K	2m	med	2	0	0	0	1	2	yes	no shape . 3.5m S/Sw swell
Mon 27	1615	PB	W	20K	1m	med	2	0	0	0	1	2	yes	no shape . Low tide . 1.4m south swell
tue 28	745	pb	W	CALM	1m	med	2	0	0	1	2	0	yes	fast runners
wed 29	1700	PB	W	8K	1.5m	med	2	0	0	1	2	2	yes	fast runners
thurs 30	940	PB	N	5K	1.25	MED	1	1	0	1	2	3	NO	fast runners

Wave height: height of set wave face just before breaking (m)

Period : Short = local wind generated sea (0-5sec) Medium= longer fetch wave generated to the east.(6-10sec) Long = typically swell from S and SW (>11sec)

Amenity: On a scale from **0-5** (unsurfable - epic) for each of the User Group IDs described in the User Group tab

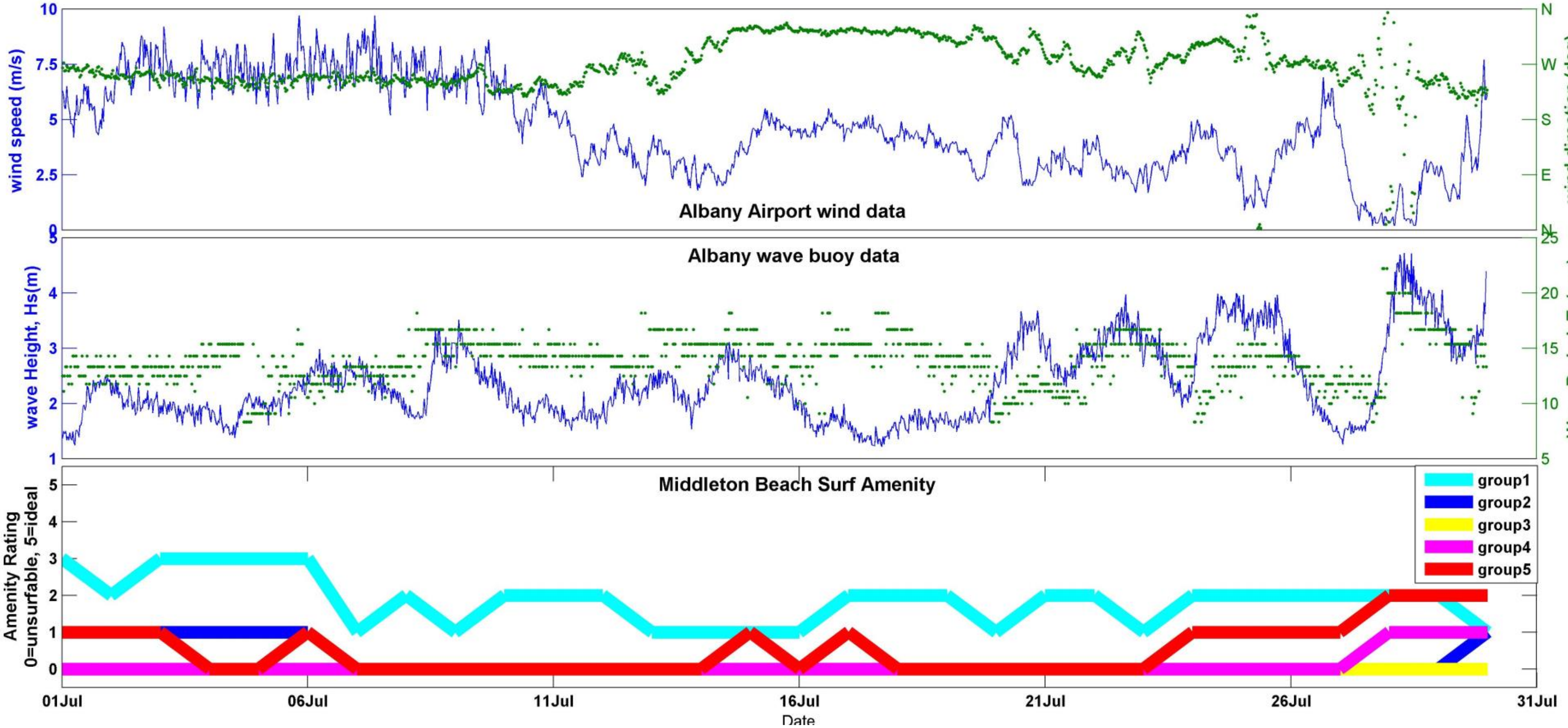


Figure 14 Example of a (dummy) Surf Amenity Quantification Assessment Sheet for Middleton Beach compared to metocean data attained at nearby gauging stations; Albany Airport, Albany Waverider buoy, WA: July, 2015.

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