Surfability of the Perth Metropolitan Coastline: An Assessment.

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Summary: To predict the surfability or surfing climate of the Perth Metropolitan coastline, offshore wind and wave data together with a wave refraction/diffraction and shoaling model was used. The highest surfability values were predicted at the northern locations where the influence of Rottnest Island diminishes and there are no offshore reef systems. The surfability decreases as we move towards the south. At the southern locations, surfability is very low during the summer months. The construction of the artificial surfing reef at Cable Station would increase the current surfability at this site by a factor of 5.

1. INTRODUCTION

An artificial surfing reef (ASR) is a man-made, submerged structure designed to provide breaking waves suitable for recreational and/or professional surfing (Pattiaratchi, (1)). Two important aspects to be considered in the planning and design of ASR's are the quality of the breaking waves that the reef produces and the number of days that surfable waves occur on the reef. These two aspects jointly define the "surfability", which may also be referred to as the "surfing climate".

For an ASR to be financially and environmentally justifiable, the surfability needs to be significantly improved compared to that of the natural surf break at the same location. In addition, it is desirable that the proposed ASR provides a more consistent and/or higher quality break that locations in the vicinity of the proposed site. To allow comparison of the "before" and "after" situation, an assessment of the surfability is required. Determination of the surfability not only permits a quantification of the degree of improvement to the surfing climate through ASR construction, but may also aid in selecting the optimum location for the ASR.

Assessing the surfability of a stretch of coastline including the ASR involves the following steps: (1) characterise the offshore wave climate in terms of wave height, period and direction; (2) transform offshore wave data to breaking wave data; (3) formulate appropriate criteria to define wave/wind conditions suitable for surfing; and (4) combine (1), (2) and (3) to obtain the surfability. Unfortunately, there is no "on-the-shelf" methodology available to carry out such an investigation; only one reported study is available for guidance (Dally, (2)). The lack of a proper methodology is partly due to the relative novelty of ASR's, but perhaps more importantly due to the subjective nature of surfability. The surfability of location represents a measure of usefulness of that site to a surfer. Different skill levels and/or board designs can be responsible for varying degrees of appraisal for a certain surf break. Some beaches may be highly surfable according to one group of users and unsuitable for surfing according to others. This subjectivity should be borne in mind when assessing surfability.

This paper discusses the methodology and results of an assessment of the surfability of the Perth metropolitan coastline in light of a proposed ASR. It will be demonstrated that construction of the ASR will significantly improve the surfability at the proposed site. In fact, the proposed ASR will promote one of the worst locations for surfing on the Perth metropolitan coastline into one of the best surf sites. The paper does not aim to propose a standard method for surfability assessment—the methodology followed here is far from ideal and there is considerable room for improvement—but to illustrate how a variety of surfability factors can be included in such an assessment.

2. PERTH METROPOLITAN COASTLINE

The nearshore geomorphology and bathymetry off the Perth metropolitan coastline (Figure 1) is dominated by a series of more or less shore-parallel oriented, submarine to emergent, Pleistocene aeolinate ridges that provide extensive sheltering of the mainland coast (Collins, (3)). The water depth over the submerged ridges is generally around 10 m and Garden Island and Rottnest Island are perched on top of them. The ridges terminate at Rottnest Island, leaving the coastline relatively exposed to northwesterly waves. The coastline faces west and consists of alternating sandy beaches and submerged and emerged rocky outcrops. The beaches display a strong seasonal cycle of beach change with barred, narrow beaches in the winter and wide beaches with a high berm in the summer (Masselink and Pattiaratchi, (4)).

The tides along the Perth metropolitan coastline are mixed, predominantly diurnal, and the difference between mean highest high water (MHHW) and mean lowest low water (MLLW) is 0.7 m (Pattiaratchi et al. (5)). Because of the relatively low range of the tide, it is frequently over-ridden by barometric pressure effects on sea level, seiching and shelf waves (Eliot and Clarke, (6)).

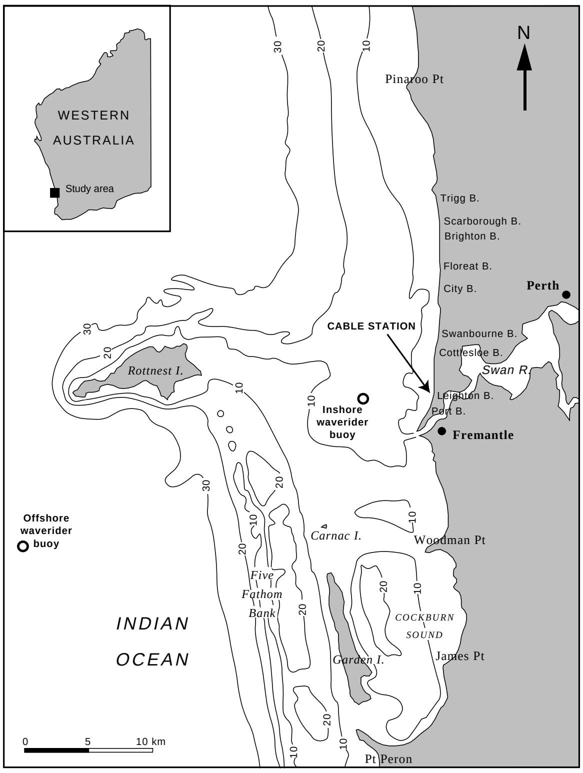

Figure 1 – Location map showing bathymetry and study sites.

The offshore wave climate is classified as moderate to high energy swell and is prevailing from the southwest (Davies, (7)). Modal significant wave height is 2 m with a maximum of 2.5 m in the winter and a minimum of 1.5 m in the summer (Lemm, (8)) (Figure 2). Closer to shore, the swell is refracted and diffracted by the offshore reef systems and greatly attenuated by shoaling across the inner continental shelf. As a result, the inshore wave height is about 40% of that outside the reef system (WNI, (9)). A highly variable wind wave climate is superimposed on the swell regime. During winter, mid-latitude depressions pass the coastline from west to east and generate northwesterly to southwesterly storm waves. The summer season is dominated by strong sea breeze activity and locally-generated wind waves incident from the south are generated by the sea breeze (Masselink and Pattiaratchi, (10); Pattiaratchi et al., (5)).

The surfability of seven study sites and the ASR was investigated (refer to Figure 1 for locations). The sites were selected to represent a range of incident wave conditions and a spectrum of surfabilities was expected. Since the degree of sheltering by Rottnest Island decreases in the northward direction, inshore wave energy increases toward the north. In addition, discontinuities in the reef are responsible for alongshore variations in the wave energy level. Trigg and Brighton Beach are situated at the northern end of the study area and experience maximum wave energy levels. Rhythmic bar/rip morphology is typically present and, according to Perth standards, the surf breaks are highly surfable. Floreat Park, City Beach and Cottesloe are located further to the south and are hence more protected from the predominant southeasterly swell. Bar morphology is commonly present in the winter, but in the summer incident waves break directly on the beach. Surfable waves mainly occur in the winter, although waves peeling of groins are occasionally surfed in the summer. Cable Station is situated further to the south and is even more sheltered. However, under high-wave conditions, usually following the peak of winter storms, waves break on the reef, providing excellent surfing conditions. More commonly, waves pass the reef unbroken and break on the beach. Cable Station is the site for the first ASR. Port Beach is the southernmost beach in the Perth metropolitan area. Although nearshore bars are present in the winter, waves are small and surfability is low.

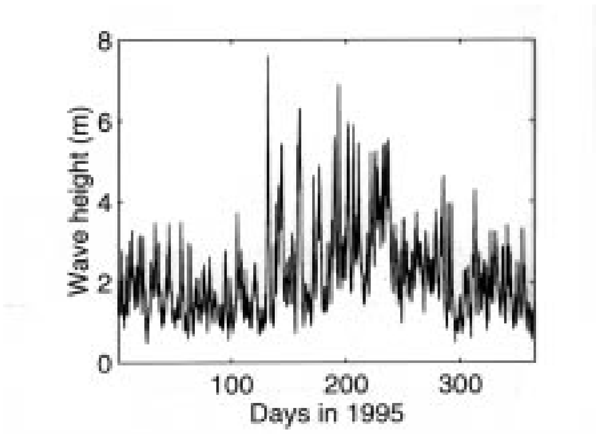

Figure 2 – Time series of offshore significant wave heights recorded in 1995.

3. METHODS

3.1 Wave/wind data

The surfability of the Perth metropolitan coastline was assessed using one year (1995) of offshore wave data (significant wave height H_s and period T_s). These data (Figure 2) were collected every 20 minutes south of Rottnest Island in 48 m water depth and were re-sampled at daily intervals using block-averaging. Directional wave data was not available. Therefore coincident wind data collected at Rottnest Island was used to subdivide the 1995 wave data into three directional classes: -15^{o} (southwest), 0^{o} (west) and 15^{o} (northwest). Wind data were averaged daily and the predominant wind direction was used to allocate the wave direction for each day. If the wind was from the south, the swell direction was southwest (-15^{o}), whereas for wind from the north, the swell direction was northwest (15^{o}). For the remaining wind directions, the swell direction was considered west (0^{o}). The results were satisfactory as the seasonal variation in wave incidence was well represented; during summer, swell was mainly from the southwest, whereas waves during winter storms were incident from the northwest.

3.2 Wave transformation and breaking

The daily wave data were transformed across the nearshore region using RCPWAVE, a linear wave propagation model designed to predict coastal processes on a regional scale (Ebersole, (11)). This model was selected for the present study because despite its simplicity, it considers all relevant wave transformation processes and can handle large amounts of input data. The model domain was 60 km (longshore) by 40 km (cross-shore) and the grid size was 100 m by 100 m. The daily wave data (height, period, direction) were input as the boundary forcing for RCPWAVE.

Linear theory underestimates wave heights in very shallow water (Mase and Iwagaki, (12)). Therefore, RCPWAVE was only used to shoal waves up to a distance of 400 m from the shoreline, generally at a depth of less than 10 m. Further transformation of the waves up to the breakpoint was accomplished using the following equations:

$$H^2 c_g = \text{constant} \quad \text{for} \quad gHT^2/h^2 < 30 \qquad (1)$$

$$Hh^{3/7} = \text{constant} \quad \text{for} \quad gHT^2/h^2 > 30 \qquad (2)$$

where H is wave height, c_g is the wave group velocity, h is water depth, T is wave period. The first part of the algorithm (Equation 1) represents linear shoaling (as carried out by RCPWAVE) and the second part (Equation 2) is the non-linear (cnoidal) shoaling proposed by Shuto (13). A second non-linear shoaling equation was also proposed by Shuto (13) for the region $gHT^2/h^2 > 50$, but it was decided not the implement this equation to avoid overestimation of the breaker height (cf. Dally, (2)). Nearshore wave transformation up to the break point was computed using cross-shore increments of 10 m. Wave refraction was not considered in the nonlinear shoaling region; the wave angle was considered constant (ie. wave angle at 400 m).

The occurrence of wave breaking was determined using the criterion of Weggel (14):

$$H_b/h_b = b - aH_b/gT^2 \qquad (3)$$

in which

$$a = 43.8[1 - \exp(-19.5\tan\beta)] \qquad (4)$$

$$b = 1.56/[1 + \exp(-19.5\tan\beta)] \qquad (5)$$

where H_b is breaker height, h_b is breaker depth, g is gravity and tan β is beach gradient. When the breaker criterion is exceeded, the breaker height is considered as the wave height of the preceding offshore cell.

Breaker conditions could not always be computed for the ASR site. On a "normal" beach profile, waves will eventually break as water depth decreases. However, an offshore reef with a deeper section behind it will only experience wave breaking when the breaker criterion over the reef is exceeded. Thus, for the ASR, breaker conditions are only computed if wave breaking occurs on the reef.

3.3 Surfability

Surfability depends upon a number of criteria. The relevance of the height of the breaking wave is obvious, and generally the larger the breakers, the better the surfing. Following the surfability study of Dally (2), a minimum significant wave height of 1.5 m is considered a prerequisite for surfable waves.

The geometry of the breaking wave is also an important factor with regards to surfability. Galvin (15) identified four types of breakers: surging, collapsing, plunging and spilling. Breaking waves at the transition plunging/spilling are favoured by most surfers, whereas collapsing and surging breakers are generally considered unsuitable for surfing. Breaker type can be predicted using the surf similarity parameter or Irribarren Number:

$$\xi_b = \tan\beta / \sqrt{H_b / L_o} \qquad (6)$$

where L_o is the deep water wave length given by:

$$L_o = gT^2/2\pi \qquad (7)$$

Spilling breakers occur for $\xi_b < 0.4$, plunging breakers occur when $\xi_b = 0.4–2$, and surging/collapsing breakers occur for $\xi_b > 2$ (Battjes, (16)). Following Dally (2), surf zone conditions for which $\xi_b < 0.3$ were considered unsuitable for surfing. Under these conditions, the surf zone is extremely dissipative with multiple lines of gently spilling breakers. Surf zone conditions for which $\xi_b > 2$ were also deemed unsurfable due to the prevalence of collapsing and surging breakers. Selection of the appropriate tanβ to compute ξ_b proved to be a problem. Employment of the gradient taken from the 100 m by 100 m bathymetry yielded unrealistically low values for ξ_b due to the low nearshore gradient. Especially in the winter, nearshore bar morphology is present along the Perth metropolitan coastline and waves will be breaking off the seaward-facing slope of the bar. On the basis of an examination of literature on bar morphology an overall value of 0.025 was assumed. The hypothetical bar is not considered in the wave refraction/shoaling program, but is only used to obtain ξ_b .

Several investigations have indicated the importance of wind speed and direction with regard to wave breaking (Galloway et al., (17); Douglass, (18); Baker and King, (19)). These studies demonstrate that offshore breezes promote the formation of plunging breakers by holding up the wave breaking process, whereas onshore winds speed up wave breaking and promote spilling breakers. Offshore winds are preferred by surfers, because these winds promote plunging breakers and do not generate locally-generated wind chop obscuring the incident swell. Inclusion of wind speed and direction in the surfability analysis is desirable, for example by modifying ξ_b depending on wind characteristics (offshore winds $\rightarrow$ increase ξ_b ; onshore winds $\rightarrow$ decrease ξ_b). Unfortunately, quantification of wind effects on wave breaking is currently unavailable. In an attempt to crudely include the wind conditions in the surfability analysis, days for which onshore winds with velocities exceeding 5 m/s prevailed were considered un-surfable.

Two important aspects of breaking waves from a surfing point of view are the peel angle and the peel rate. Dally (2) defines a rideable wave as one upon which a surfer can maintain a mean board speed as fast as or faster than the speed of incipient breaking of the wave, ie. the peel rate. The peel rate V_p of a breaking wave is defined Walker (20) as:

$$V_p = c_b \sin\alpha \qquad (8)$$

where c_b is the celerity of the waves at the break point and α is the angle between the incident wave crest and the bottom contours, ie. the peel angle. If the peel angle is very small, the peel rate is very large; the breaking wave will "close-out" and is not rideable. A minimum peel angle of 30^o is generally required surfing (Walker, (20)). Large peel angles are generally associated with non-uniform bottom contours, eg. wave breaking on the edge of a bar/reef. Peel rate and angle are important factors that need to be considered in the design process of an ASR (Pattiaratchi, (1)); however, they are too small-scale to be incorporated in an assessment of the overall surfability of the coastline.

4. RESULTS AND DISCUSSION

4.1 Predicted wave climate

The predicted wave fields, for a 10 second swell wave field computed using RCPWAVE, for waves originating from the southwest (-15^o, Figure 3) and north-west (+15^o, Figure 4), clearly indicates the sheltering of the coastline by Rottnest Island. It also shows the concentration of wave energy on particular sections of the coastline due to refraction effects offshore. For example, under south-westerly swell conditions, there is a concentration of wave energy in the Trigg/Scarborough region (Figure 3) whilst under north-westerly swell, there is concentration of wave energy at City Beach and Cables (Figure 4).

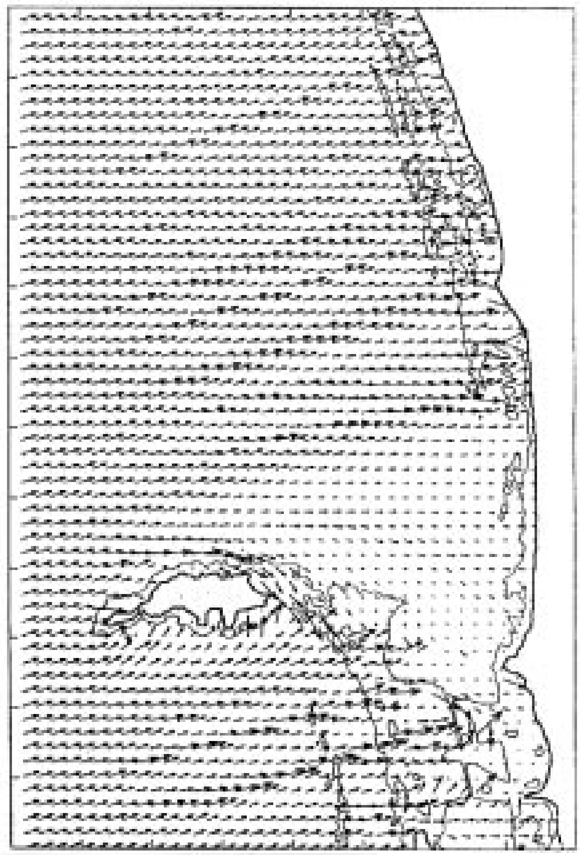

Figure 3 - Example of output of RCPWAVE for 10 s swell waves from the southwest (15^o).

4.2 Prediction of surfability

For each of the seven study sites and the ASR, the annual time series of offshore wave and wind conditions was transformed into a time series of breaker conditions (height and period) using RCPWAVE, Shuto's (13) non-linear shoaling equation and Weggel's (14) breaker criterion. Subsequently, an annual time series of ξ_b was derived using breaker conditions and a beach gradient of 0.025. A summary of the seasonal wind and wave climate recorded in 1995 (Figure 2) and input into the model is presented in Table 1.

	No. of Days with offshore winds	Mean offshore wave height (m)	Mean offshore wave period (s)
Summer	33	1.6	7.5
Autumn	45	1.6	8.7
Winter	29	2.7	9.6
Spring	13	1.9	8.9
Annual	120	2.0	8.7

Table 1 – Summary of wind and wave climate for 1995.

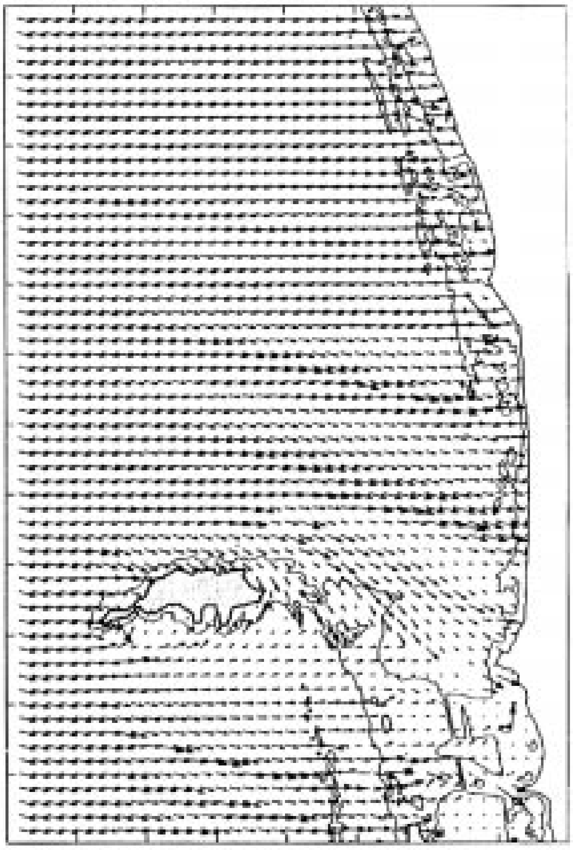

Figure 4 - Example of output of RCPWAVE for 10 s swell waves from the north west (-15°).

Examples of these time series are given for Trigg and Port Beach in Figures 5 and 6. Application of the surfability criteria ($H_b > 1.5$ m; $0.4 < \xi_b > 2$; including the wind effects) for each of the sites yielded the number of days that surfable conditions prevailed in 1995. The results are subdivided into the summer and winter season and are listed in Table 2.

As expected, the mean breaker heights decrease from > 2m in north to < 0.5 m in the south (cf. Figure 1 and Table 2). This reflects the sheltering effects of Rottnest Island on the region. The three northern sites: Trigg, Thirds and Brighton have high surfability values during both winter and summer months. All the other locations have low values of surfability during the summer months. This is because the lower swell heights experienced during the summer months (Figure 2). At the three 'middle' sites: City Beach, Floreat and Cottesloe, the annual surfability values range between 15% and 20% during the winter whilst at the two southern sites: Cables* and Port Beach the annual surfability values are < 10%. At the Cables location, the construction of the artificial surfing reef has a marked effect, increasing the annual surfability by a factor of 5 from 5% to 25%. The surfing reef also increases the breaking wave height from 0.4 m to 1.7 m (Table 2).

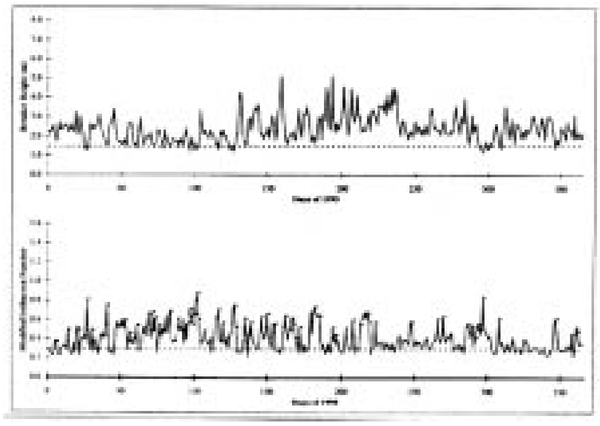

Figure 5 – Predicted breaker height and modified Irribarren number for Brighton Beach in 1995.

	Percentage Surfability			Annual mean breaking wave height (m)
	Annual	Summer	Winter	
Trigg	36	27	50	2.5
Thirds	68	53	57	2.6
Brighton	67	50	77	2.4
Floreat	20	3	41	1.9
City Beach	20	2	43	1.8
Cottesloe	15	0	35	1.2
Cables*	5	0	10	0.4
Cables ASR	25	13	46	1.7
Port Beach	7	1	17	0.7

Table 2 – Summary results of surfability along the Perth Metropolitan coastline (Cables* is the existing reef and Cables ASR is after the construction of the artificial reef).

4. CONCLUSIONS

To predict the surfability of the Perth Metropolitan coastline offshore wind and wave data together with a wave refraction/diffraction and shoaling model was used. The results reflect the influence of offshore reef systems and Rottnest Island in sheltering the incoming swell. The highest surfability values were predicted at the northern locations where the influence of Rottnest Island diminishes and there are no offshore reef systems. The surfability decreases as we move towards the south. At the southern locations, surfability is very low during the summer months. The construction of the artificial surfing reef at Cable Station would increase the current surfability at this site by a factor of 5.

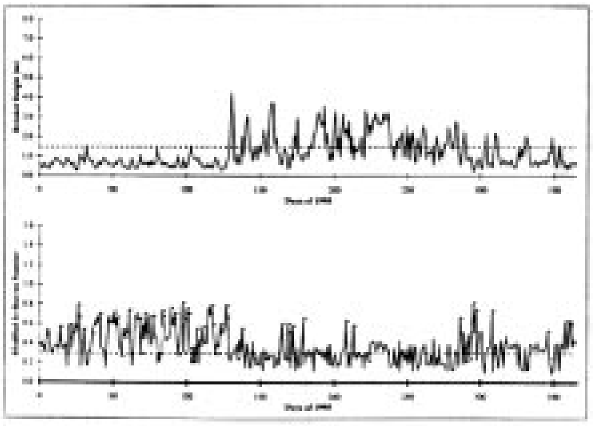

Figure 6 – Predicted breaker height and modified Irribarren number for Cottesloe Beach in 1995.

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