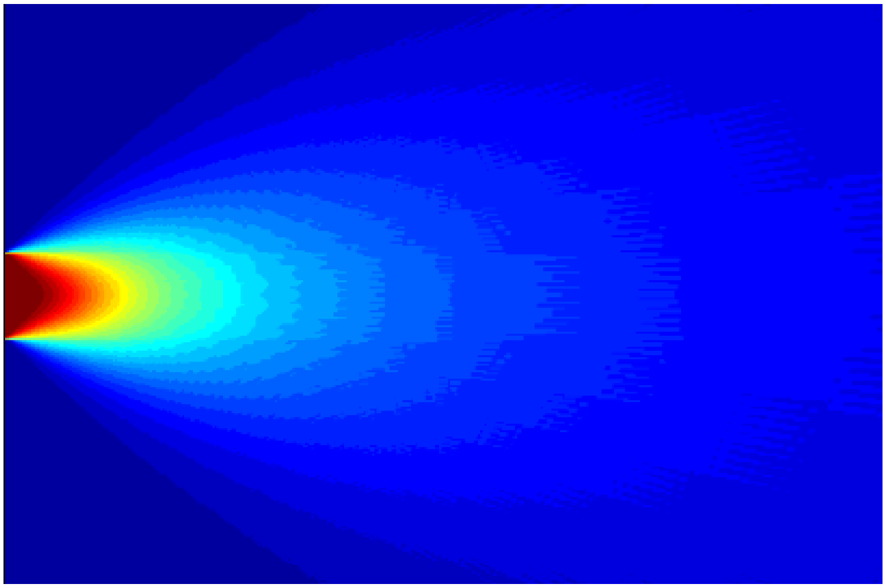
Review of Wave Hub Technical Studies: Impacts on inshore surfing beaches



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Executive summary

Introduction

The Wave Hub is an infrastructure project to provide a grid connected area of sea within which arrays of wave energy conversion devices may be deployed. It is intended to provide up to 4 companies developing such devices the opportunity to test their machines in arrays over several years, to build up experience of operation and maintenance and develop a track record of performance which can then be used for deployments elsewhere in the UK and overseas in future years.

Multiple devices are to be installed for testing purposes only. However, the proposed life of the facility is 25 years and so the best decisions need to be made now with respect to environmental effects.

This report responds to the request by the South West of England Regional Development Agency (SWRDA) for an independent review of the work carried out by the Halcrow Group Limited, specifically that which dealt with coastal processes and the impacts of the devices on the inshore wave climate. Of high relevance is the impact on surfing in Cornwall. Other reviewed information was a scientific publication of Millar et al. (2006). Discussions with the industry, through a spokesperson, Mr Andrew Scott, of xx were held to more fully consider the wave height reduction in the lee of the Pelamis. New information and measurements were provided.

Background

The two key issues of concern to surfers are:

- Total wave height changes at the shoreline; and
- Changes to the wave period, particularly a reduction in period.

In this review, a scientific assessment is made of the available information. For this purpose, a simple model called WaveShadow was developed to examine the expected height losses in the lee of the Wave Hub for comparison to the previous modelling. The benefit of the simple model is that it shows the worst case conditions.

The anticipated level of wave absorption at the Wave Hub was re-assessed to overcome the variability reported by the consultants. This is a critical factor that determines the impact of the hub on total wave height at the shoreline.

General conclusion of the review

The likely scenarios and energy absorption at the Wave Hub, plus the physical wave processes of diffraction, refraction and dissipation, and the likely error bars in the numerical modeling were considered. The review concludes that:

- **Wave height attenuation should be less than 3-6% at beaches in the direct shadow of the wave hub in "clean" (narrow-banded) swell**

Transmission factors of the different WEC devices are still not fully understood and partially commercial in confidence (indeed, a scheme like Wave Hub will help to gain a detailed understanding of device performance) and so the wave transmission factors used for modeling purposes remain uncertain. The conservative approach is to assume that the devices will absorb all suitable surfing wave energy across the full width of the Wave Hub Region, but this is not anticipated to occur in reality. For example, assuming 100% wave height absorption through the Wave Hub, the worst case impact at the shoreline could be as much as 15-30% height attenuation in "clean" narrow-banded swell conditions, compared to the maximum suggested by Halcrow of 13%. The review concludes that:

- **The wave height absorption is dependent on the number of devices connected, but the maximum absorption is highly unlikely to exceed 20% of wave height, assuming a 100% absorption, which is considered to be impractical. As such, the likely maximum impact on wave height at the shoreline is a maximum of 3-6%**

Further studies could be undertaken to attempt to refine the conclusions. It would be beneficial to:

- Record more spectral wave measurements at the site and shorewards. Notably, a wave buoy has been deployed at the new site.
- Undertake more detailed spectral analyses of the measured waves at the site, including directional spreading factors
- Further consideration of the non-linear behaviour of the waves around the various devices, including reductions in wave period by creation of secondary waves
- Undertake sensitivity analyses with the numerical models. However, this has been undertaken to some extent through the modelling of different scenarios (WEC layouts, wave height and period). Further theoretical studies may have limited value as they will be based on the existing limited information on WEC device operation.
- While shoreline modeling has been done by Halcrow, further morphological modeling of the beach response over longer time periods would be beneficial. The Hub behaves like an offshore reef and can change the littoral drift inshore, particularly over long time periods.

However, this review concludes that:

- **While additional analyses should be undertaken to reduce uncertainty, some significant uncertainty would still remain. Wave Hub will provide a better understanding of the WEC devices performances and their impacts as data is obtained from the operation of Wave Hub and lessons are learned. Thus, further theoretical studies may be of limited value to reduce the current level of uncertainty.**

Alternatively,

- **as the impacts of the facility are expected to be low (less than 5% wave height absorption at the shoreline), adaptive monitoring is recommended.**

In general, the studies for the Wave Hub have attempted to confront and minimise uncertainty in the transmission factors and the anticipated behaviour of the waves after they pass through the hub and travel to the beach. It is believed that the worst case scenario approach taken by Halcrow reduces uncertainty significantly. However, the modeling studies have not provided absolute confidence that the results can be accepted outright, without acknowledging the potential error bars.

Specific conclusions are:

- The Millar et al. study is substantially under-estimating the wave height shadow at the shoreline during best surfing times of narrow-band swell
- The Halcrow modeling is closer to the likely outcome, particularly the monochromatic modeling. This occurs because Halcrow have considered the monochromatic conditions that are highly valued by surfers.

Monitoring and further work

Any numerical modeling work has a degree of uncertainty, as models are predictions of the real processes and are based on a combination of real data and assumptions. Key assumptions adopted by the consultants have uncertainties with respect to wave height absorption at the Wave Hub and the impact of the Hub for a variety of sea states.

Given the uncertainties in the numerical predictions and Wave Hub generator type and configuration, guidelines will need to be established and monitoring should be undertaken. One obvious guideline would be to restrict the amount of height being absorbed at the Hub to an acceptable level of say 20%. The alternative would be to restrict the energy reduction at critical beaches to say 5%. Such options need to be determined by regulators and stakeholders, given the uncertainties surrounding the absorption.

An example monitoring programme is presented here for stakeholder consideration. Because of the cost of monitoring, it is recommended that the following 3 options be undertaken in series. That is, recommendation #2 will only be considered if an unwanted impact is discerned after adopting recommendation #1. Similarly recommendation #3 will be triggered by an unwanted effect after doing the monitoring in #2. Each stage would be triggered only if a significant impact is identified when monitoring during the previous stages.

Recommendation #1: Wave measurements on the offshore and inshore sides of the wave hub.

Wave recording instrument locations should be a transect (e.g. east/west), and about 2 km either side of the wave hub zone. The inshore instrument would be placed "downstream" relative to dominant wave direction of the first installed device or downstream of the region where most generators are deployed.

Some preliminary monitoring of the upstream and downstream locations would be needed prior to device installation (e.g. 2-3 months) to gain baseline information and to cross-calibrate the instruments.

Recommendation #2: Wave measurements along a shoreward transect

In addition to the instrument offshore of the Wave Hub, wave recording devices should be placed 2 km, 5 km and 10 km downstream of the Wave Hub along a transect agreed by stakeholders and consultants to be most appropriate and likely to show impact, e.g. predominantly east/west with some southerly rotation.

Recommendation #3: Monitoring of the relative wave heights at critical surf breaks along the impacted shoreline as a function of offshore wave statistics (height, period, direction).

Wave height recording instruments to be placed nearshore in depths of around 10-15 m at say 3 beaches, with at least one in the line of the direct shadow for the most common wave direction. An impact could be discerned in one of two ways by considering the ratio of inshore heights divided by the heights measured offshore of the Wave Hub as follows:

- Knowing the relative heights at these beaches by early monitoring without the wave hub (e.g. 3-6 months prior), an impact could be discerned if this ratio changes after wave hub commissioning.
- The ratio of heights at the nearshore instruments in and out of the shadow could be determined.

It is acknowledged that such monitoring requires care with the analysis to discern an impact, but the review concludes that the monitoring would be feasible and useful.

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Chapter 1 Introduction

1.1 Background

The Wave Hub is an infrastructure project to provide a permitted grid connected area of sea within which arrays of wave energy conversion devices may be deployed. It is intended to provide up to 4 companies developing such devices the opportunity to test their machines in arrays over several years, to build up experience of operation and maintenance and develop a track record of performance which can then be used for deployments elsewhere in the UK and overseas in future years.

The South West of England Regional Development Agency (SWRDA) is leading the infrastructure work and is already working with 3 device developers, with the target of being operational by late 2008.

1.2 The Brief

As part of their consents for the project, the SWRDA commissioned Dr Kerry Black of ASR Ltd (New Zealand) to provide an independent review of the work carried out by Halcrow Group Ltd which dealt with coastal processes and the impacts of devices on the inshore wave climate as part of the EIA work. Of high relevance is the impact on surfing in Cornwall. Other information was provided for the review including a scientifically peer-reviewed publication by Millar et al. (2006). The reports are:

Wave Hub Development and Design Phase. Coastal Processes Study Report, Halcrow, June 2006

Modelling analysis of the sensitivity of shoreline change to a wave farm. D. Millar, H. Smith and D. Reeve.

Further background was provided by the Wave Hub article in The Surfers Path (October 2006) by Dr Tony Butt, Physical Oceanography, Centre of Marine Studies, University of Plymouth.

A series of other documents were considered including,

The Pelamis Wave Energy converter: It may be jolly good in practice, but will it work in theory? By R. Rainey, WS Atkins Oil and Gas.

A restricted commercial document by Ocean Power Delivery called “Pelamis Wave Energy Converter, Crib Sheet”.

Pelamis WEC – Recent advances in the numerical and experimental modeling programme. By Pizer, Retzler, Hendenson, Cowieson, Shaw, Dickens and Hart of Ocean Power Delivery.

Wave measurements at St Ives Cornwall, 30 Jan 2005 to 5 October, 2005 by Fugro Oceanor AS.

Wave Hub Development and Design Phase, Interim Coastal Processes Report, May 2006 by Halcrow Group Limited.

Wave Hub Development and Design Phase, Coastal Processes Study Report, June 2006 by Halcrow Group Limited.

The OPD Pelamis: Experimental and numerical results from the hydrodynamic work program. By Pizer, Retzler and Yemm.

For convenience, the SWRDA summary of the consultants' conclusions and numerical modelling is quoted verbatim in Appendix 1.

1.2.1 Surfer concerns

During the consent consultation (including stakeholder meetings with the surfing community to explain the modeling work), support from some surfers was received while a number of concerns were raised from within the surfing community, which included:

- Direct impact on surfing by reduced inshore wave heights
- Effects on the full wave spectrum and particularly on the peak and lower frequency part of the spectrum favoured by surfers
- Effects of the devices on the wave period, which could lead to losses of the "clean" longer-period swells that surfers enjoy for their best surfing days
- Effects of refraction, diffraction and reflection around the devices
- Concerns that the community was not qualified to judge the complex numerical modeling that is being applied to forecast the likely effects
- Monitoring proposals for the system after deployment

Halcrow modeling scenarios were developed in consultation with the British Surfing Association (BSA) and Surfers Against Sewage (SAS) to satisfy as best as possible the needs and concerns of the surfing community. This review comes after those consultations. No judgments are made by this author about the likely acceptance by the community of any identified impacts. This review solely considers the scientific and technical accuracy of the analyses by Halcrow and Millar et al. and re-considers the likely absorption of wave height at the Wave Hub.

1.4 Definitions

To help the reader understand the terminology adopted in this report, some definitions are provided here. The spectral and monochromatic wave definitions are taken from an informative SWRDA summary which was based on Halcrow text.

Spectral waves represent real life conditions where the pattern of waves in the sea is made up of large and small waves moving in many directions. The irregular sea conditions which are simulated in spectral wave modelling are derived from a combination of the generation and development of wind waves (the rippling of the ocean surface by the friction and driving force of the wind), the propagation of swell (waves that have been generated some distance away), and wave transformation near the shore (refraction, diffraction and wave-breaking).

Monochromatic waves represent a theoretical train of regular waves of constant height and period that do not occur alone in real sea conditions. However monochromatic wave modelling provides a useful method for simulating swell wave conditions which result in surfing waves at the coast. Indeed, the most ideal waves for surfing can be considered as monochromatic waves – which are also subject to transformation as they approach the shore.

By limiting the modeling to the part of the spectrum that is most important to surfers, the impact on surfing can be more effectively defined. That is, the monochromatic modeling shows the impact of the Wave Hub on the dominant part of the wave spectrum that is valued by the surfers, even if these waves are embedded within a sea of other waves. As such, the monochromatic modeling shows the effect on the main surfing waves in all conditions. While monochromatic conditions are not common along this coastline, the monochromatic modelling remains relevant to common conditions along the coast.

Wave directional spread represents the breadth of the spread of wave directions in any given swell. Typically, waves spread about a dominant direction in each swell with the directional distribution varying from narrow to broad in “clean” and “irregular” surfing swells respectively.

Energy transmission factor is the percentage amount of energy remaining in the sea after the waves pass through the wave hub. The energy is proportional to the square of the wave height. Thus, for 90% energy transmission, the wave height transmission is 95%. Similarly for 70% transmission, the height transmission is 84% while 40% energy transmission is a 63% height transmission.

1.5 General review comments about the studies

1.5.1 Level of wave absorption

The Wave Hub is proposed to provide a space for testing existing and future wave energy devices. As such, the type and number of devices to be hooked up is not known and so a broad range of energy absorption scenarios were modeled by Millar et al., with transmission factors from 0-90% being considered, i.e. over an order of magnitude variation.

On the contrary, Halcrow model 2 specific layouts and they note the following:

"As the combination of WEC devices at the Wave Hub will change over the design life of the facility and it is unknown at this stage, the Halcrow assessment considered two arrays of WECs, a 'worst case scenario' and 'most likely initial array', in order to determine the impact of the Wave Hub on coastal processes, in particular wave height at the coast. The worst case scenario was intended to provide an envelope which would account for a wide combination of arrays.

- *WEC Device Array No.1: 'Worst case scenario' 4 nr. Wave Dragons. Following a review of the state of the art of WEC devices, the Wave Dragon which is also the largest device was assessed, appears to have the greatest impact on waves and was therefore considered as the worst case scenario. This worst case scenario aimed to provide an envelope which would cover the impacts of a wide combination of WECs layouts.*

- *WEC Device Array No.2: 'Likely initial array'. A combined array of WEC devices comprising: Wave Dragon, FO^3, Powerbuoy and Pelamis. This is a likely array of WEC devices that could be deployed at the Wave Hub (with the exception of the Wave Dragon which at this stage is unlikely to appear).*

"To simulate wave transmission through the floating WEC devices a practical guide for design and construction of the floating structures (PIANC 1994) was applied to estimate wave transmission factor. According to the guide, the transmission coefficient for Wave Dragon is 0.68. The other wave energy devices are very different from the Wave Dragon. For devices of Power Buoy and Fred Olsen, it is reasonable to assume that the transmitted waves are very low immediately after the solid structures. Thus the transmission coefficients for both Power Buoy and Fred Olsen are taken as 0. On the other hand, the waves propagate along the Pelamis for 150m. The transmitted waves immediately after the Pelamis should be low as well. Therefore it was reasonable to assume that the wave transmission coefficient for Pelamis is 0."

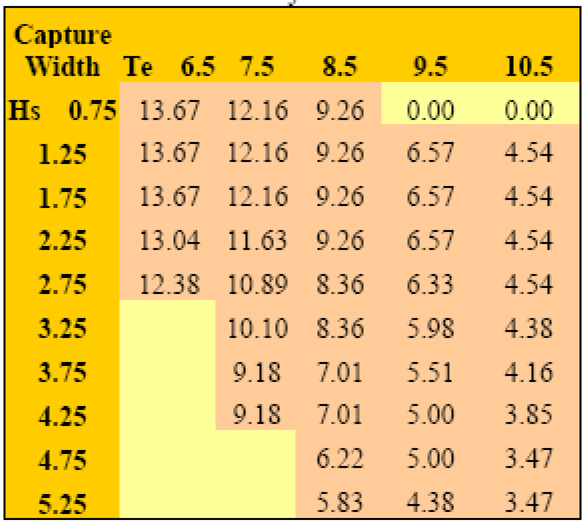
The wave transmission coefficients have been applied only over the width of the WEC devices which face the oncoming wave (the offshore face); no wave absorption was *assumed in the gaps between the devices. Consequently, the Halcrow modelling still allows wave energy to penetrate through the Wave Hub.*

This review concludes that the lack of certainty in the various reports creates some confusion and makes it difficult to judge the effects of the Wave Hub devices when there is an order of magnitude spread in the forecast wave height transmission factors in the two studies. As the actual height transmission will depend on the number of connections to the Wave Hub and the type and efficiency of the equipment, an acceptable level of absorption should be established *a priori*.

While 100% absorption is impossible to achieve physically, the exact absorption will be a complex function of spectral width and instrument type and layout.. Halcrow's zero transmission with gaps between the various WECS depends on the assumptions of spacing and likely connections. However, this is preferred over the broad range of possibilities in the Millar et al. publication.

Most of the studies use a factor called the "capture width" to essentially define the length of wave crest that is absorbed by the instrument. This length varies with wave height and wave period as in the table below. Typically the width is a maximum of around 15 m for the Pelamis and recent measurements from an installation were provided to this reviewer by Ocean Power Delivery confirming that typical capture widths in clean swell are around 12 m with maximum absorption occurring for the waves with periods between 7 and 10 seconds, but this changes with wave height as seen in the table.

Table 2. Section of the Power Table



Capture Width Te	6.5	7.5	8.5	9.5	10.5
Hs 0.75	13.67	12.16	9.26	0.00	0.00
1.25	13.67	12.16	9.26	6.57	4.54
1.75	13.67	12.16	9.26	6.57	4.54
2.25	13.04	11.63	9.26	6.57	4.54
2.75	12.38	10.89	8.36	6.33	4.54
3.25		10.10	8.36	5.98	4.38
3.75		9.18	7.01	5.51	4.16
4.25		9.18	7.01	5.00	3.85
4.75			6.22	5.00	3.47
5.25			5.83	4.38	3.47

Table defining the Capture Width for a Pelamis, as a function of wave height and period.

As illustrated in the table above, Pelamis, and other floating wave energy converters, are tuned to achieve maximum capture efficiency for the most common periods, which are around 7 s on this coastline. There is a sharp drop in absorption with both increased and decreased periods. For example, the absorption is typically reduced by a factor of around 4 between 7 and 11 s.

Notably, in mixed or windy sea states when the Pelamis is aligned at a more acute angle to longer period waves, the effective period is shortened and absorption of longer periods could occur. Similarly, short waves arriving from the side of the Pelamis may also be absorbed / reflected, similar to a floating breakwater.

The theory suggests that the absorption as a percentage can be calculated knowing the spacing of the instruments (L) and the capture width (w_c), i.e.

$$\boxed{\overline{E}_t(x_0) = \overline{E}_i(x_0)\left(1 - \frac{w_c}{L}\right),}$$

In simple terms, the energy beyond a Pelamis is theoretically said to be determined by the ratio of capture width to gap spacing between the instruments. For a typical capture width of 15 m and a spacing between Pelamis's of 250 m, the fraction of energy absorbed is 15/250 = 6%. As such, even if a Pelamis was placed every 250 m along the full 3000 m of the Wave Hub zone, the energy absorption is around 6% in total.

The theory, of course, is a simplification of reality. Indeed, the capture width will vary with the spread of the waves in the sea state. For example, if waves are coming from a broad directional spread then the absorption characteristics will be different. Of course, Pelamis is not the only instrument that could be connected. The 100% absorption value is unrealistic unless:

- There are many Pelamis instruments deployed in multiple rows in the Wave Hub
- Other wave electricity generators with worse responses are deployed there.

This review concludes that uncertainty remains and commercial sensitivity of the matter would indicate that:

- **it would be appropriate to set a limit for height absorption, particularly in the frequency bands that are favoured by surfers. The Hub would need to be monitored with wave measurement devices both upstream and downstream so that the absorption could be accurately determined and then considered in the context of the maximum allowable impact on surfing waves at the beaches.**

Recommendation:

- **That the anticipated maximum level of allowable energy absorption be specified**
- **That this maximum level be imposed as a restriction on the Wave Hub that cannot be exceeded.**
- **That the Wave Hub be monitored to ensure that the levels are not being exceeded.**

A monitoring programme is recommended later.

1.5.2 Spectral versus monochromatic

The Halcrow study considers both spectral and monochromatic waves, while Millar et al. only consider spectral. As noted by SWRDA in their definitions above

- **most waves suitable for surfing can be considered as monochromatic waves.**

The distinction between monochromatic and spectral proves to be highly important in this review. It is essential to note that spectral covers a very broad range of possibilities, but this is not well noted in the reports, particularly in the Millar et al. publication. The distinction is not black and white. Indeed, ocean wave spectra exhibit a complete range of greys and can be anything from wide to narrow, i.e. on any given day the wave energy could be arriving from a broad range of directions and consist of a broad range of wave periods (i.e. broad spectrum). On the contrary, the waves could be closely aligned with a single direction and have a narrow-banded spectral shape indicative of “clean swell”, as described by surfers. Monochromatic is at one extreme of a narrow spectrum, but there are a myriad of cases with varying spectral widths from this extreme case to the fully “messy swell”.

Surfers greatly value monochromatic to narrow-banded spectral swell. The “messy” (wide spectrum) sea is not as important to surfers, although they still ride waves in these conditions.

In summary:

- **the assessment of impacts on surfing should be focused on monochromatic to narrow-banded spectral swells.**

1.5.3 Selection of the impact statistic

Millar et al. apply two different measures of the impacts, which are:

- *Average wave height change* – this is the change to wave height at each beach when averaged over a long time period and reflects the fact that the wave shadow due to the Wave Hub will move up and down the coast in response to incoming wave directions and periods, causing the average effect on any one beach to be significantly reduced.

- *Maximum wave height change* – this the maximum height change at each beach which reflects the case when the beach is directly in the shadow of the Wave Hub.

Of course, the maximum height change will be considerably larger than the average height change. Particularly in Millar et al., both definitions are used and inter-changed. This creates some confusion.

When selecting a beach to surf at (say from the east of England and driving to Cornwall), a surfer would need to know what beach is in the shadow of the Wave Hub at the time and what will be the drop in wave height, before deciding to surf at that beach. As such, while the average is a helpful statistic, the essential indicator is the maximum height change. The average is a statistic that has limited relevance to day-to-day surfing requirements. The maximum wave height reduction and where it will be prevalent is the important information in such a circumstance. From the modelling study, it is predicted that the location of the maximum impact will move across a stretch of coast depending on wave conditions.

Recommendation:

- **a surfer mostly needs to know the maximum height change on any given day, not a statistical annual average**

Chapter 2 Review of Millar et al

2.1 Introduction

Millar et al. (2006) have used a well-known wave propagation model called SWAN to forecast the impacts of the devices on the coastal wave conditions. The model is available “off-the-shelf” and is free for use. With reputable Dutch scientific backing, it has become a commonly-used model for wave forecasting, particularly in shallow and intermediate water. The model has features that are useful for studies such as these, but it does not incorporate schemes for wave diffraction and it incorporates a number of numerical coefficients that need to be tuned to the cases being modeled.

Millar et al. have used the model without changing any of the in-built methods and have applied standard “default” coefficients in their modeling. Some of their choices are challenged below.

The key findings of Millar et al are summarized in Appendix 1. They conclude:

- **"There is little cause for concern that effects introduced by the Wave Hub will be felt by shoreline users of the sea" (Millar et al, 2006).**

The location of the Wave Hub Exclusion Zone is shown in their Figure 1 (reproduced below). They mostly modeled a representative case of 3.3 m wave height, period of 11 s and waves coming from the westerly direction.

The key findings of their modeling are well summarized in their Figure 9 (reproduced here). It shows that the effect in the lee of the wave hub is large over the first 5-10 km from the devices, but the effect essentially dissipates by the time the shoreline is reached, some 35 km away. Notably, while the devices are 12 miles (20 km) offshore of the nearest land, the distance to the coast in the lee of the devices for a west direction of waves is some 35 km from the Wave Hub exclusion zone.

Their Figure 9 fairly closely summarises all their results, irrespective of wave conditions being modeled. Basically, they find that:

- the effect of the wave hub dissipates with distance and the effect is essentially gone at 40 km.

This then leads to the conclusion that shoreline users won't be aware of the wave hub.

Of course, this is a very strong and confident assertion. My concern is that this assertion is based purely on a model that lacks proper calibration at the time of publication and it is evident that some of the coefficients they have chosen are not acceptable for the case under scrutiny.

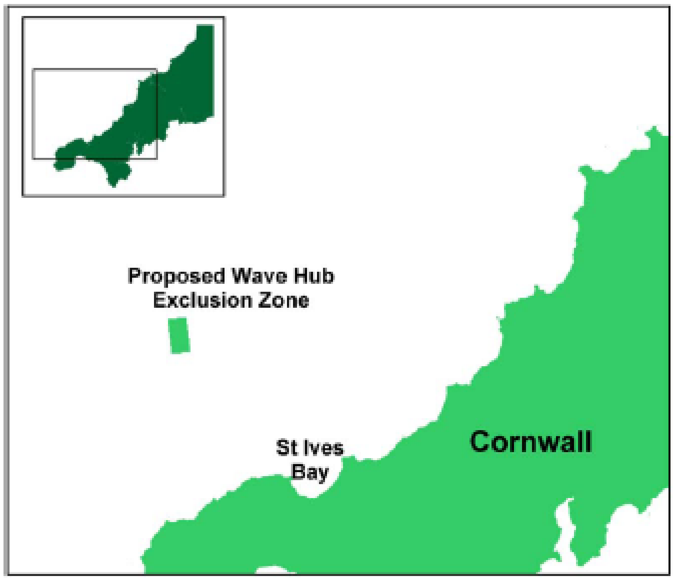


Fig. 1. The area of study off the north coast of Cornwall, and the proposed Wave Hub location.

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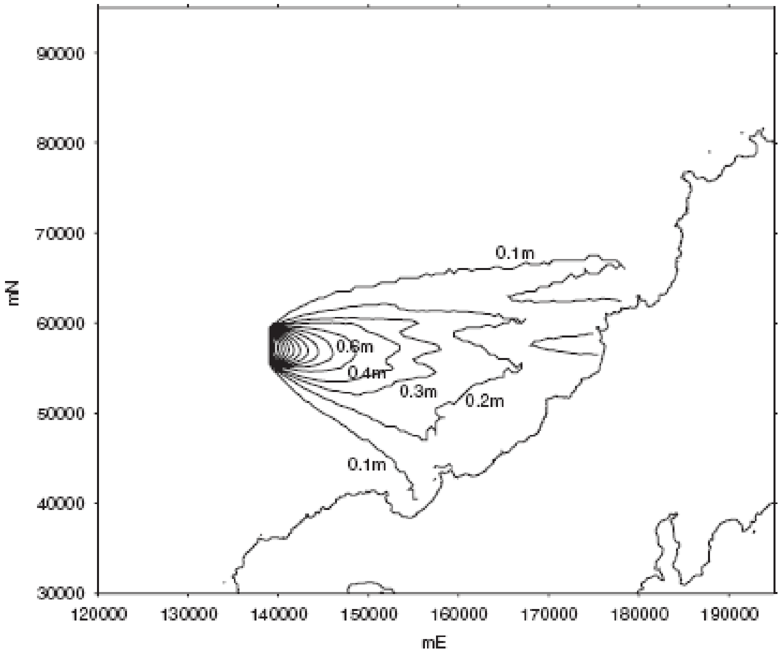


Fig. 9. Changes in significant wave height, ΔH_s, due to the Wave Hub for 0% energy transmission. (Reference state: $H_s = 3.3$ m, $T_m = 11$ s and $D = 1°$).

***Figures 1 and 9 taken from Millar et al.**

2.2 Key points of concern

Here, key points of concern in relation to the Millar et al. study are summarized, with detailed discussion about each in the following sections.

The Millar study is workmanlike, but

- No calibration of the model against nearshore waves at the time of publication in the key regions to the north-east of St Ives Bay. The study is entirely numerical, with no description of wave data or measurements (except for a fleeting mention of Seven Stones).

- The selected wave periods are mostly too short

- Their selected wave directional distribution coefficient (which describes the messiness of the swell) uses “default” model values and is not representative for favoured surfing conditions, including no consideration of the monochromatic cases.

These matters, especially the third aspect, lead to considerable uncertainty in the results.

2.2.1 Lack of model calibration

They note that the closest wave buoys are over 450 km to the west of the Cornish coastline and therefore can’t be used for input to the model as boundary conditions. As a consequence, they choose to use numerically-hindcast wave climates (Wavewatch III, WW3) for the model boundary conditions. Confidence would have been improved if the computer generated WW3 data had been compared to the measurements from the offshore wave buoys, or if existing comparisons (if they exist) had been referenced.

Also, the model results are not compared to any inshore measurements within the zone of influence of the Wave Hub, and so no calibration of the model is undertaken. Lack of calibration would normally preclude publication because the reader has low confidence in the model results. Given the demand for confidence in the results by the public and the concern about the effects of the Wave Hub on the shoreline, this fundamental lack of data is an important oversight.

Above all else, there is no information about the shape of the spectrum during favoured surfing conditions. They go on to model particular directional spectra without a supporting analysis. It is my understanding that further data has since become available and that the authors would be interested in doing an analysis. It would be important to consider that surfers are mostly riding a small segment of the spectrum (i.e. around the peak) and so the analysis would need to consider the presence of primary waves for surfing, as well as the overall shape of the spectrum.

2.2.2 Selection of wave periods

While not specifically discussed in the paper, it appears that Millar et al. have used a mean spectral wave period (denoted T_m). This period combines all the waves that are present and represents the combined average of “swell” and “sea”. However, surfers typically ride the largest 1/10th of the waves in a swell (ASR observations) and the period associated with these waves is typically longer than the mean period and more closely-aligned with the peak spectral period. While the period plays a secondary role in the results, it would have been sensible for Millar et al to consider this factor --- at least separating the waves into “sea” and “swell” as done by Halcrow. The swell is preferred by surfers while the sea is just local wind chop. When combined, the chop shortens the average wave period and adversely affects the calculation of surfable wave heights.

2.2.3 Selection of the directional distribution coefficient

The primary weakness in the Millar et al work is their selection of the directional distribution coefficient. Their Figure 4 (reproduced below) shows the effect of the coefficient DSPR, an essential input to the model. This coefficient tells the model about the spread of the incoming wave directions around the mean direction. The model does not assume all waves in a given swell are coming from exactly the same direction. Instead it applies a distribution about the mean direction determined by the DSPR coefficient. In Figure 4, a DSPR exceeding about 20 represents a very messy swell. For example, at DSPR=30 (the value chosen by Millar et al.), the amount of energy coming from 45 degrees either side of the swell directions is substantial and the energy doesn’t drop to below 20% until some 65 degrees from the peak direction. This is indeed a very broad and messy swell, which is a long way from monochromatic. Most disappointing is that the selection of DSPR=30 was only justified in the paper by noting that it was “the default”. Such a default may be applicable in the Dutch North Sea under storm conditions, but it is not suitable for surfing assessments of close to monochromatic “swell” conditions. It is not adequate to simply select the default. The choice should have been justified by examining measured wave conditions.

Indeed, virtually all of their conclusions can be explained by this one choice. If the swell is very broad and messy, one would anticipate that waves would come into the lee of the wave hub from a broad range of angles and eventually the effect of the hub would dissipate with distance away (as found by Millar et al). On the contrary, with a narrow banded swell, the shadow should be longer and more defined with distance from the hub.

There are two fundamentally important coefficients in a model such as SWAN which are:

- Initial input spread of the wave directions (discussed above)
- Wave height and angle “diffusion” coefficients which determine how much smoothing of the predicted height occurs due to processes such as diffraction, wave breaking under winds, non-linear frequency interactions etc. This parameter

leads to a smoothing of the effect of the wave hub with distance from the hub and so it is very important.

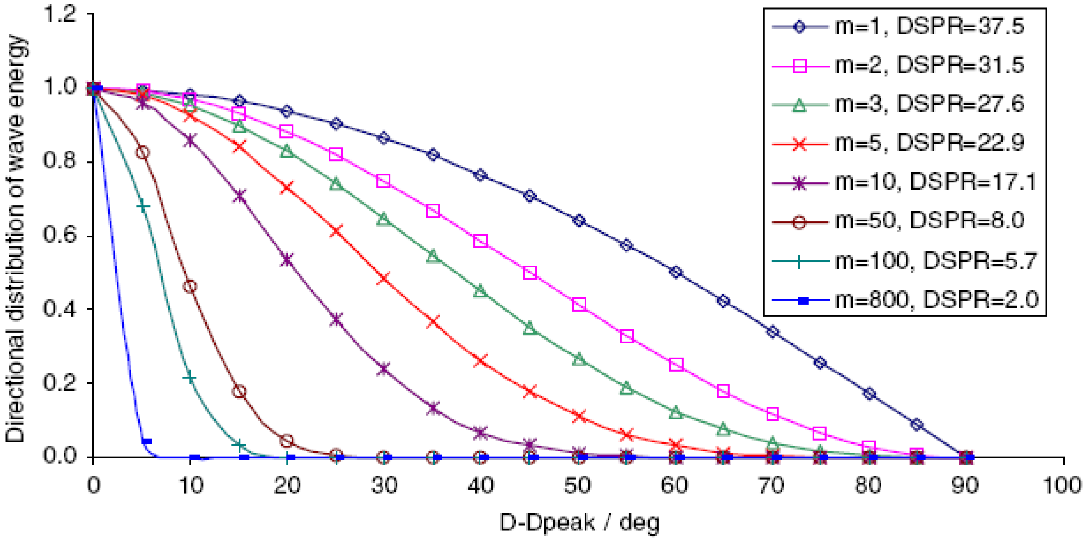


Fig. 4. Variation of directional distribution of incident wave energy with *m* and DSPR.

*Figure from the publication of Millar et al.

2.2.4 Demonstration of the principles with Model WaveShadow

To further demonstrate these important factors, a simple numerical model was written for the review called WaveShadow. Full refraction/diffraction models are already available to the author in the 3DD Suite of Numerical Models (© Black, 2001). However, the new model was written to make the explanation very clear and not subject to the selection of model coefficients that are not validated. The Wave Shadow model shows the worst case impacts.

WaveShadow simply takes an input wave climate and finds the amount of shadowing in the lee of a structure by treating the wave distribution as a series of individual waves with different directions. Basically, the method is very similar to that adopted by Black and Andrews (2001) to successfully predict shadowing behind a reef to determine impacts on the beach morphology. The sea state is broken up into a range of directions (with an occurrence weighting determined by the selected DSPR value) and then the waves head shorewards at that angle. Some waves will be blocked by the wave hub, others will come in from the sides and penetrate into the lee of the hub. The final result is the amount of energy in open water versus the amount in the lee of the wave hub. The model is extremely simple with no refraction, diffraction or bed friction. Nevertheless, it meets the goal of explaining the results of Millar et al and the likely effects on the coast.

2.3 Energy conservation

"Energy conservation" occurs in model WaveShadow, as required by the physical laws of physics (in the absence of wave breaking or bed friction). Moreover, energy conservation should occur in all accurate numerical models. Specifically, an amount of energy is lost by the waves at the Hub. This total loss remains the same through all ("hub-parallel") cross-sections to shorewards.

That is, a certain amount of height is lost at the Hub. To shorewards, this can be spread over a narrow or broad length of coast. A model which keeps the shadow on a narrow band (such as the Halcrow monochromatic wave modeling) will indicate a larger height loss impact, but at a smaller number of beaches. The broad Millar et al. model will spread the loss over a large area with a correspondingly small height loss at each beach within that area. As such, the spreading of the energy loss of waves beyond the wave hub has a profound effect on the predicted likely impacts.

The worst case extremes are:

- *No spreading of the wave shadow with distance downstream.* In this case, the impact at the beach will be along approximately 3 km of perpendicular coastline (same length as the wave hub zone) and the height loss will be unchanged from the loss at the hub

- *Considerable spreading of the wave shadow.* In this case, impacts at any individual beach will be very small as the shadow has diffused over a long length of coast.

All cases in between the extremes are possible and so the modeling's primary purpose is to determine the amount of spreading of the wave shadow with distance downstream of the hub.

Wave spreading and its impact on the shoreline effects

To determine whether the results from Model WaveShadow are comparable to the results of the Millar et al. modeling, simulations were done with m=2 as adopted by Millar et al. (their Figure 4 above) and 0% transmission (Fig. 1a). Careful inspection of Figure 1a shows that Model WaveShadow predicts the same height changes in the lee of the wave hub as Millar et al. This confirms that the two models give the same results when the adopted settings are the same.

Both models show a large shadow out to 5 km from the wave hub, but a strong dissipation of the effect beyond that. Indeed, Figure 1b presents the forecast reduction (as a percentage in the wave height) versus distance along a transect in the lee of the wave hub. Table 1 summarises these results at 5, 10 and 20 km downstream and shows a very close agreement between the two models, when the same directional spreading function is adopted.

Table 1: Percentage wave height reduction with distance from the wave hub for the 0% transmission case of Millar et al. and the prediction of WaveShadow.

Distance from wave hub (km)	Reduction in wave height predicted by Millar et al (%)	Reduction in height from WaveShadow with m=2 (%)
5	30	29
10	18	17
20	8	8

Thus, it is evident that even a very simple model can produce the same general results as those obtained by Millar et al., certainly well within the anticipated error bands. Thus, it is possible to further consider the effect of the directional spread parameter on the predictions of Millar et al. using model WaveShadow.

Having validated the simpler model, four cases of directional spread were selected from Figure 4 of Millar et al. for assessment of the effect of this parameter on the results. These were:

- m=2; DSPR=31.5 messy swell (essentially the Millar et al. case of DSPR=30).
- m=10, DSPR=17.1 reasonable surfing swell
- m=100; DSPR=5.7 very clean swell approaching monochromatic
- m=800; DSPR=2.0 exceptional swell, essentially monochromatic

In Figure 2a with m=10 (signifying a reasonable surfing swell), the heights are significantly reduced (13% reduced) at 20 km from the wave hub (Table 2). For the really clean and close to monochromatic cases (Figs. 3 and 4), a strong wave height shadow extends to 20 km, with between 39-85% height reduction (Table 2). Indeed, the reduction is so severe that surfing would be substantially affected on beaches in the direct shadow.

Given that surfers prefer approximately monochromatic conditions, Millar et al. appear to be substantially under-estimating the impact of the wave hub on beaches in the direct shadow. For 0% transmission, m=100 and no diffraction effects, the worst case modeling indicates that the percentage reduction in height at the beaches (some 25-35 km away) could be as much as 30% during optimal surfing conditions.

Table 2. Percentage reduction in height with distance from the wave hub for various values of m (the directional spread) and for the monochromatic Halcrow case from their Figure 4.4.

Distance from wave hub (km)	**m=2**	**M=10**	**m=100**	**m=800**	**Halcrow mono**	**Halcrow spectral**	**Millar et al**
5	29	49	96	100	86	48	30
10	17	28	71	99	74	26	18
20	8	13	39	85	54	11	8

The primary technical outcomes are:

- **The main factor determining the predicted wave height patterns from the Millar et al. study is the assumed directional spread of the input wave directions**

- **The factor describing this spread as selected by Millar et al. is unsuitable for the near monochromatic wave conditions favoured by surfers.**

- **If the effect of diffraction was included in the WaveShadow model, the impacts would be smeared along a longer length of coast with a smaller height drop at each affected beach. Further modeling could be undertaken to include diffraction, but this would be beyond the scope of the current review.**

In relation to the environmental effects:

- **The Millar et al. study is flawed by the lack of consideration of the input wave directional distribution during favourable surfing conditions and by the selection of a directional spread coefficient which only considered "messy" surfing conditions**

- **The impact of the wave hub on beaches in its direct lee is anticipated to be noticeably more severe during good surfing conditions than that predicted by Millar et al.**

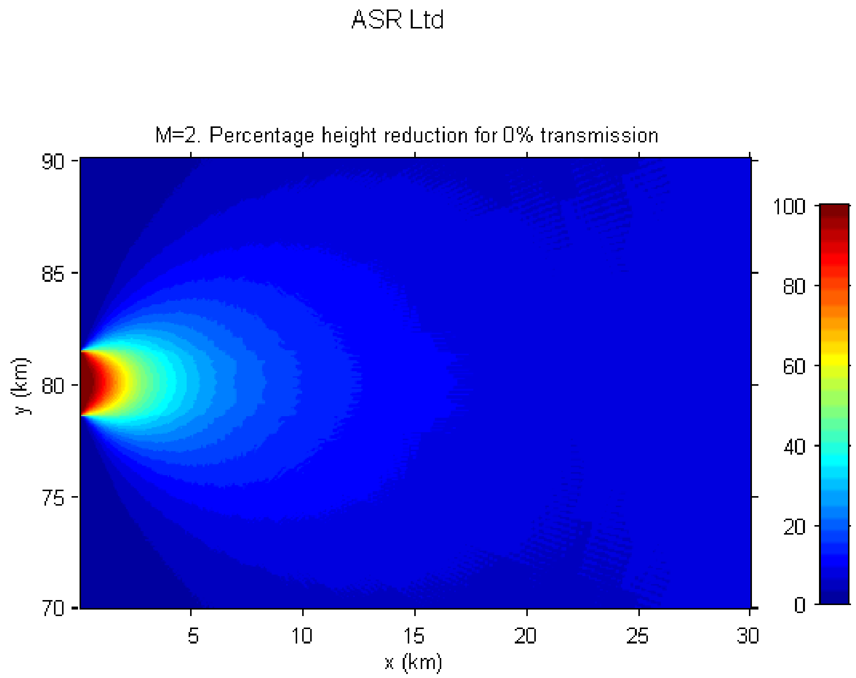


Figure 1a. WaveShadow prediction of percentage height reduction in the lee of the wave hub for m=2 and 0% transmission.

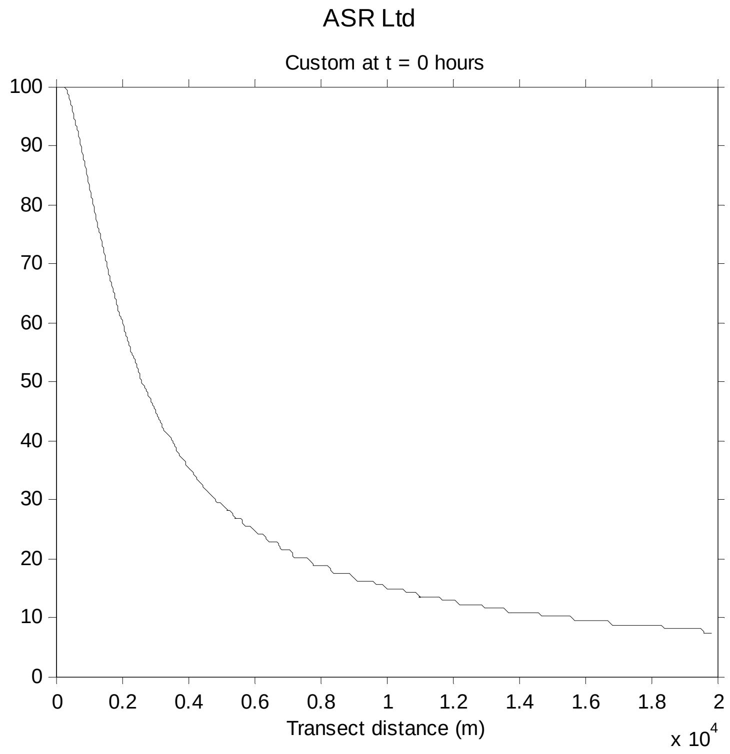


Figure 1b. Predicted decay in the shadow behind the wave hub using WaveShadow with m=2 and zero transmission. The percentage height loss increases from 100% in the lee of the wave hub to 8% at 20 km.

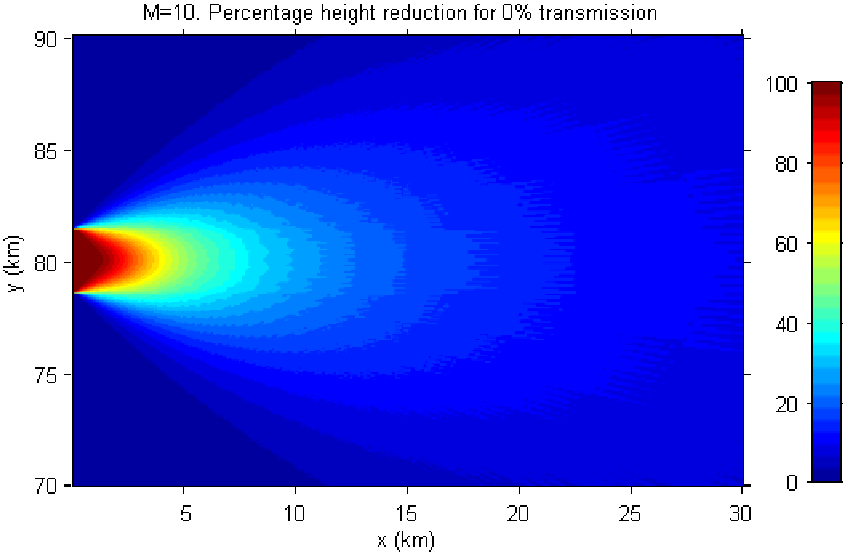


Figure 2a. WaveShadow prediction of percentage height reduction in the lee of the wave hub for m=10 and 0% transmission.

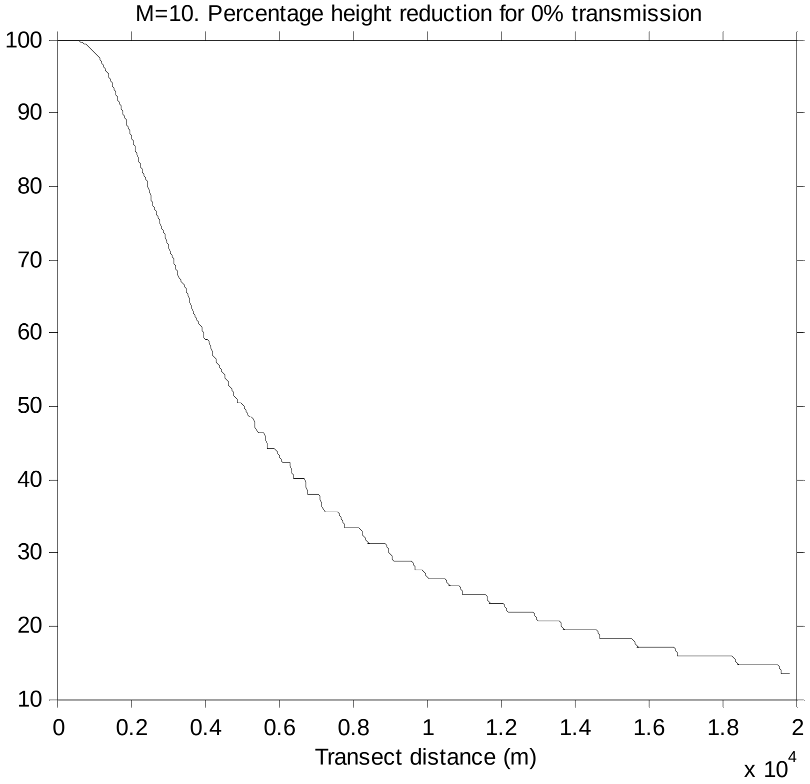


Figure 2b. Predicted decay in the shadow behind the wave hub using WaveShadow with m=10 and zero transmission. The percentage height loss increases from 100% in the lee of the wave hub to 13% at 20 km.

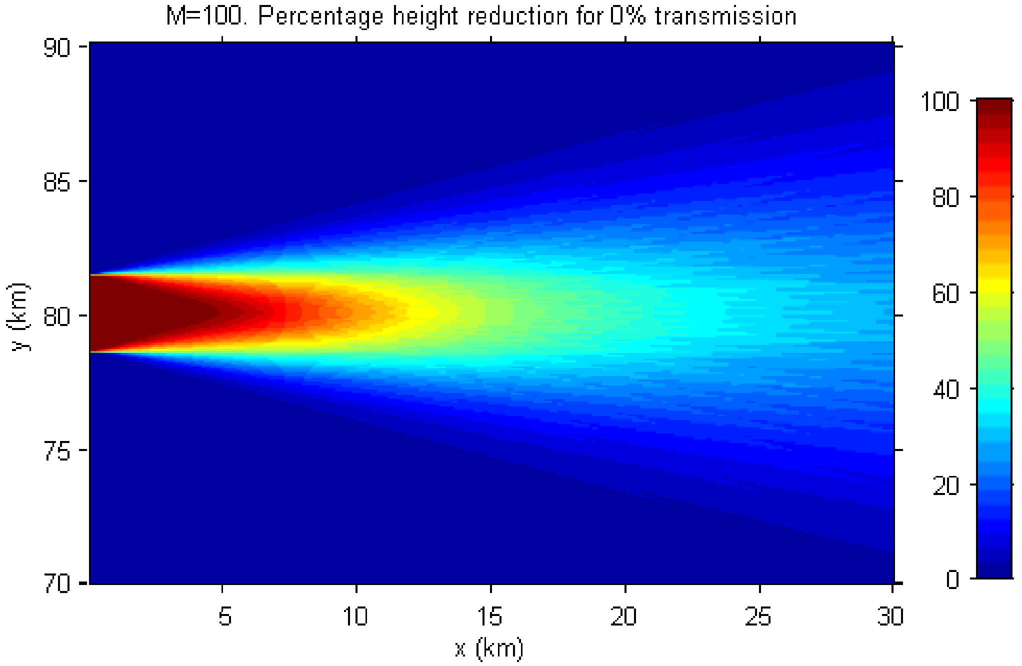


Figure 3b WaveShadow prediction of percentage height reduction in the lee of the wave hub for m=100 and 0% transmission.

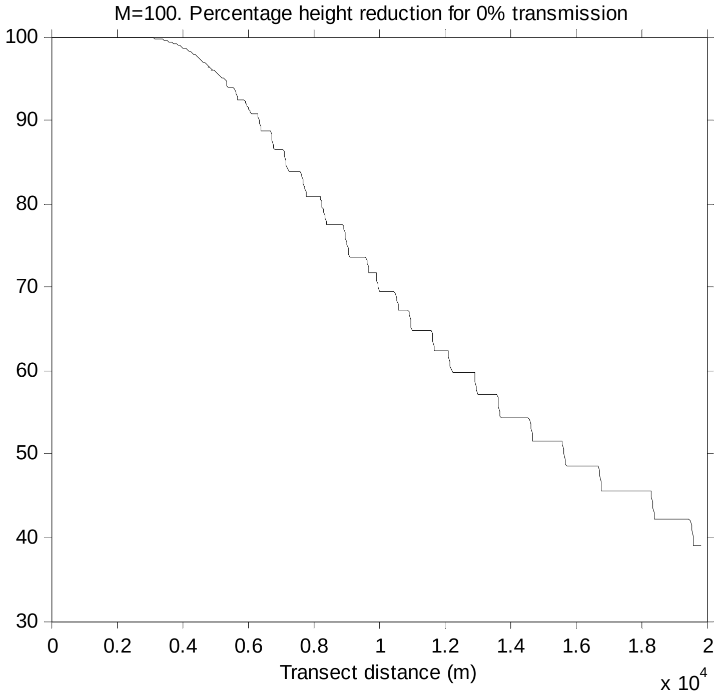


Figure 3b. Predicted decay in the shadow behind the wave hub using WaveShadow with m=100 and zero transmission. The percentage height loss increases from 100% in the lee of the wave hub to 39% at 20 km.

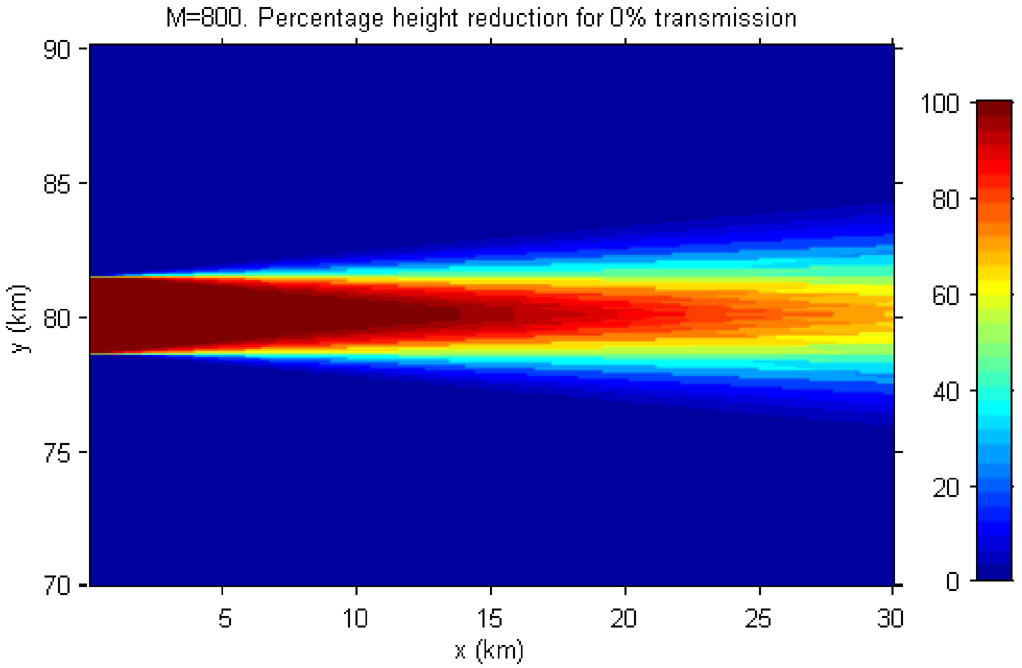


Figure 4b WaveShadow prediction of percentage height reduction in the lee of the wave hub for m=800 and 0% transmission.

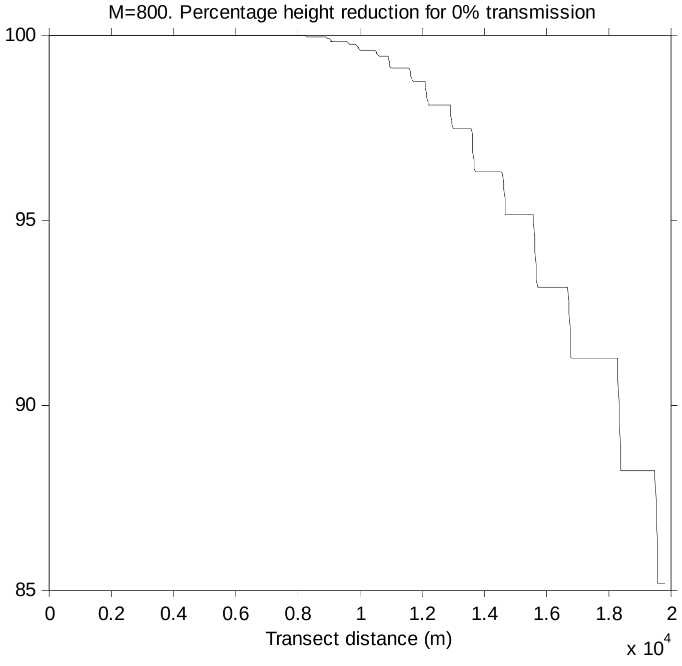


Figure 4b. Predicted decay in the shadow behind the wave hub using WaveShadow with m=800 and zero transmission. The percentage height loss increases from 100% in the lee of the wave hub to 85% at 20 km.

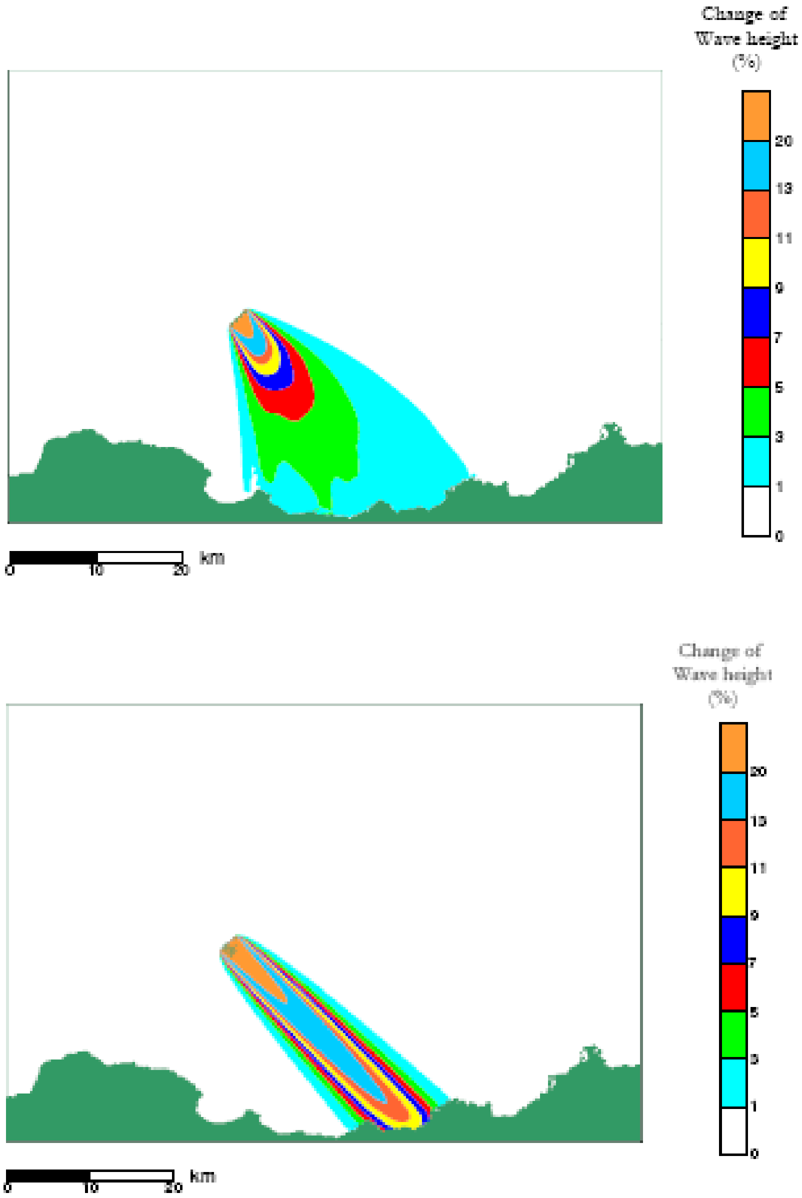
Chapter 3 Review of the Halcrow Report

3.1 Introduction

Halcrow have adopted a substantially different approach to Millar et al.:

- Different numerical models
- Focused on monochromatic conditions, although one spectral case is presented.
- Adopted considerably longer wave periods
- Focused on a single wave direction (from 270°T)
- Considered 2 specific layouts of devices, rather than considering the effects for a range of different potential transmission coefficients.

Their results are well summarized in two of their figures for Device Layout 1, which have been reproduced here. Figure 5a shows the Halcrow result for spectral waves, while Figure 5b shows the case for monochromatic waves. Layout 1 consists of 4 Wave Dragons each spanning 250 m perpendicular to the wave fronts (270°T).



Figures 5a,b. Spectral and monochromatic predictions by Halcrow for Device Layout 1.

3.2 Key points of concern

Key concerns with the Halcrow report include:

- Lack of detail in the presentation of methods
- Lack of calibration
- Not enough discussion on the effects of wave direction

- High reliance on 2 cases of device layout, although Halcrow have taken a worst case approach given the current knowledge of likely connections within the Wave Hub
- Directional spread and numerical diffusion
- Inadequate description of the wave hub scenarios on the results
- Simplistic presentation of results

3.2.1 Lack of detail in the presentation of methods

Halcrow have presented virtually no information about model parameters, including bed friction, diffusion coefficients and input wave directional spreading parameters. This makes it impossible to consider their modeling decisions and results in any detail. Such a lack of information puts a cloud over their modeling and reduces the confidence of a technical reader in their study. While many readers are unwilling to "wade through a mass of technical information", it is essential to always summarise the adopted methods, at least in an Appendix for the confidence of technical readers.

Halcrow note that the more detailed level of information was not appropriate for the intended audience of the EIA and that detailed information was made available to any parties that required it for consenting purposes. I would agree with this, but have concerns about the coefficients and application of the models for this particular study. For example, if Millar et al. had not been specific about their methods and coefficients, it would have been difficult to identify the weaknesses in their modeling that related to coefficient selection – notably this review made no criticism of the model itself.

3.2.2 Calibration

As in Millar et al., no calibration of the wave models to the local conditions is presented, just references to previous applications and calibrations of the numerical codes. While the previous calibrations are undoubtedly impressive, numerical models are best when they are calibrated to the local environment.

3.2.3 Selection of wave directions

Halcrow have summarized the wave heights and periods to be modelled and have undertaken a quality analysis of the wave conditions at the site, including breaking down the statistics into sea and swell.

The following wave rose was provided in the report and additional information was provided in the report on wave conditions at the site.

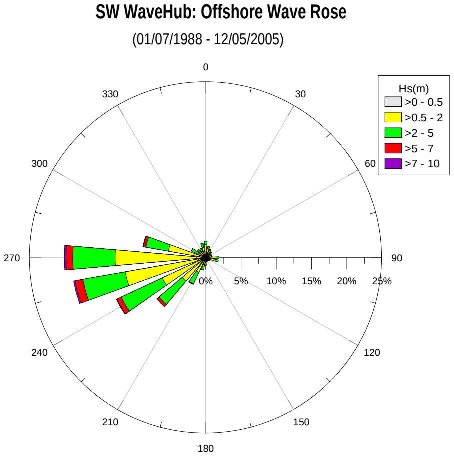


Figure 3.4: Offshore wave rose (Met Office wave data)

It appears that all of their modeling is focused on 270^{o}T for the wave direction. Notably, in this direction the coast is some 35 km from the wave hub, but the distance is shorter for waves with a more northerly orientation, such as the waves from 300^{o}T (even if they are rare) As the effect of the hub is seen to dissipate with distance away, the choice of 270^{o}T is influential on the results. Moreover, it is well known by surfers that the quality and height of waves at various beaches and headlands will vary considerably with input wave direction. Limited consideration of this is given by Halcrow. From the wave rose above it is clear that the predominant direction of approach of long period high quality surfing waves from the Atlantic is from 270 degrees and therefore the devices will be facing this direction.

3.2.4 High reliance on 2 layout cases

Unlike Millar et al., Halcrow have attempted to be very specific with the layouts of devices. But they only consider two cases where they impose transmission coefficients on each device in the layouts. Clearly, this is an attempt to “put some reality” into the situation by looking at likely scenarios rather than developing general results. The worst case scenario modelled was intended to provide a threshold of impacts based on current state of the technology and available information, providing an envelope that would comprise a combination of potential WEC layouts.

Both Halcrow’s limited specific scenarios and Millar et al’s generalist arguments about wave absorption create some confusion. Wave Hub, as a demonstration scheme and test facility, will provide an important advance by providing in situ measurement of transmission factors and shoreline impacts through monitoring. Such knowledge will be of great benefit for the establishment of new systems worldwide as one of the objectives of Wave Hub is to obtain real information on WEC performance and associated impacts.

3.2.5 Directional spread and numerical diffusion

Returning to the issue of directional spread, Halcrow neglect to mention what value of DSPR or m was adopted in their modeling. However, it may be inferred from the rate of height change, by comparison to the results of model WaveShadow. In Table 2, the change in height with distance from the hub is shown for the various cases of WaveShadow, with the results taken from Halcrow's spectral and monochromatic cases. It would appear that the Halcrow spectral modeling is most closely aligned with the directional spread case of m=10, which is referred to by this author as reasonable surfing conditions. Thus, their modeling has adopted a more appropriate directional spread parameter than Millar et al., but there is no theoretical discussion or examination of data by Halcrow to justify this value.

Their "monochromatic" modeling appears to be most closely aligned somewhere between the WaveShadow cases of m=100 and m=800. However, their results show no precise agreement. It is highly likely that the deviations relate to numerical diffusion or wave diffraction in their model, which both act to smooth out the height differences with distance from the hub. Numerical diffusion is an unwanted factor in modeling as it arises purely from the applied mathematics - it is not a physical process. As such, any numerical diffusion creates a smoothing of the heights that may not be occurring in reality. On the contrary, the process of diffraction is an important physical process that tends to smooth out wave height gradients as seen in their modeling. Without further information about the Halcrow methods, one can only assume that the deviation from WaveShadow may indicate some numerical error in the monochromatic results of Halcrow or the correct inclusion of the effects of diffraction. Noting again, WaveShadow

As noted before, smoothing of the heights tends to spread the impact across more beaches while reducing the percentage height reduction at any single beach. At face value, the Halcrow diagrams show the impact being nearly always felt along the same short length of coast. The maximum reductions in wave heights at the shore are predicted to be localised and to extend over a few kilometres. However, depending on wave conditions, this point of maximum impact is predicted to move between Portreath, St Agnes and Perranporth.

If the numerical diffusion factor is playing a role, then any underestimate of effects due to numerical errors at those beaches would be of great concern for local surfers.

3.2.6 Presentation of results

While a range of heights and periods were modeled by Halcrow (see their Table 4.1 below), they **a**ppear to consider only one input direction and so the impacts are predicted to always occur along the same short length of coast in the monochromatic modeling and, at a location more westerly in the spectral modeling (Figs. 5a,b) which is apparently due to the more westerly direction of the monochromatic waves modelled .

While the Halcrow report says, “The maximum surfing wave height reductions at the shore will be very localised and are predicted to extend over a few hundred metres”, their Figures (e.g. Figure 5b reproduced in this report) shows the impact spreading over 10-15 km of coast.

In general, the Millar et al. modeling considers the broad range of possible cases that can occur and they find that the effects of the wave hub are distributed along a broad length of coast, as the wave directions change through time. However, it is clear that the Millar et al. modeling is substantially under-estimating the wave shadow intensity. The Halcrow modeling is less comprehensive in the number of cases simulated, but is predicting the change to the wave shadow in the lee of the hub better than Millar et al. for surfing assessments.

Extract from Halcrow Coastal Processes Study: Although a range of wave conditions occur at the site a summary of the “snap-shot” representative wave conditions, which were used during modelling to define typical and extreme wave conditions at the site, has been provided in Table 4.1.

Hs (m)	**T (s)**	**Description**	**Probability of occurrence**
1	7	“Small” surf wave conditions	Average probability of occurrence of 38% in a particular summer (1 May until 31 August). 45 days/122 days. Average probability of occurrence of 28% in any particular year. 100 days/365 days.
1.6	5.4		Mean wave conditions over the whole year
2	10		Average probability of occurrence of 8% in a particular summer. 10 days/ 122 days Average probability of occurrence of 13% in any particular year. 48 days per year.
3	12		Average probability of occurrence of 3% in any particular year. 13 days per year.
4	14		Average probability of occurrence of approx 1% in any particular year. Approx 3 days per year.
4	16	“Big” surf wave conditions	Average probability of occurrence of 0.3% in any particular year. Approximately 1 day per year.

10	12		1 in 1 year return period wave conditions

Table 4.1: Wave scenarios considered during modelling by Halcrow

Chapter 4 Overall conclusions

Table 2 which summarises the modeling in Chapter 2 shows the height reduction as a function of distance along a transect in the lee of the wave hub for the WaveShadow, Halcrow and Millar et al. modeling. To put all the models on common ground, the Table presents the percentage height attenuation as a function of distance from the hub at 5, 10 and 20 km. The models should show the same general behaviour beyond the wave hub, but the adopted settings are different for each. For example:

- The Halcrow and Millar et al spectral modeling is reasonably well aligned, although Halcrow predict a somewhat stronger height shadow.
- The Halcrow monochromatic modeling shows a wave height shadow which is 7 times more pronounced than the Millar et all modeling at 20 km from the hub
- The extreme cases of monochromatic with the WaveShadow modeling show that the wave shadow could be more pronounced than that predicted by Halcrow's monochromatic modeling.

In general, Table 2 indicates that the effect at the shore could be greater than forecast previously. While the Halcrow monochromatic results are within the error bars, the WaveShadow modeling indicates that the height attenuation could be higher and as much as 15-30% in the worst case conditions of a narrow band swell for a 100% absorption. It is not anticipated that the Wave Hub will absorb all wave energy and so adaptive monitoring of wave height transmission is recommended to ensure that shoreline impacts are not excessive.

Neither Halcrow nor Millar et al. consider the effect of the devices on wave period. Consequently, monitoring of the wave period is also recommended.

4.1 Further studies

Further studies could be undertaken to attempt to refine the results. It would be beneficial to

- Record more spectral wave measurements at the site, which is currently underway
- Undertake more detailed spectral analyses of the measured waves, including directional spreading factors
- Further consideration of the non-linear behaviour of the waves around the various devices, including reductions in wave period by creation of secondary waves and interfering diffraction patterns, although wave periods are not forecast to be substantially changed.

- Undertake sensitivity analyses with the numerical models This has been undertaken to some extent through the modelling of different scenarios (WEC layouts, wave height and period). Further theoretical studies at this stage are considered to be of limited value as they will be based on the existing limited information on WEC device operation, layout and spacing.

- While shoreline modeling has been done by Halcrow, further morphological modeling of the beach response over longer time periods would be beneficial if monitoring information is available. The hub behaves like an offshore reef and can change the littoral drift inshore, particularly over long time periods.

4.2 Monitoring

As discussed above and given the uncertainties in the numerical predictions, guidelines will need to be established and monitoring should be undertaken. One obvious guideline would be to restrict the amount of height being absorbed at the Hub to an acceptable level of say 20%. The alternative would be to restrict the energy reduction at critical beaches to say 5%. Such options need to be determined by regulators and stakeholders.

An example monitoring programme is presented here also for stakeholder consideration. Because of the cost of monitoring, it is recommended that the following 3 options be undertaken in series. That is, recommendation #2 will only be considered if an unwanted impact is discerned after adopting recommendation #1. Similarly recommendation #3 will be triggered only by an unwanted effect after doing the monitoring in #2.

Recommendation #1: Wave measurements on the offshore and inshore sides of the wave hub.

Wave recording instrument locations should be a transect (e.g. east/west), and about 2 km either side of the wave hub zone. The inshore instrument would be placed “downstream” relative to dominant wave direction of the first installed device or downstream of the region where most generators are deployed.

Some preliminary monitoring of the upstream and downstream locations would be needed prior to device installation (e.g. 2-3 months) to gain baseline information and to cross-calibrate the instruments.

Recommendation #2: Wave measurements along a shoreward transect

In addition to the instrument offshore of the Wave Hub, wave recording devices should be placed 2 km, 5 km and 10 km downstream of the Wave Hub along a transect agreed by stakeholders and consultants to be most appropriate and likely to show impact, e.g. predominantly east/west with some southerly rotation.

Recommendation #3: Monitoring of the relative wave heights at critical surf breaks along the impacted shoreline as a function of offshore wave statistics (height, period, direction).

Wave height recording instruments to be placed nearshore in depths of around 10-15 m at say 3 beaches, with at least one in the line of the direct shadow for the most common wave direction. An impact could be discerned in one of two ways by considering the ratio of inshore heights divided by the heights measured offshore of the Wave Hub as follows:

- Knowing the relative heights at these beaches by early monitoring without the wave hub (e.g. 3-6 months prior), an impact could be discerned if this ratio changes after wave hub commissioning.
- The ratio of heights at the nearshore instruments in and out of the shadow could be determined.

It is acknowledged that such monitoring requires care with the analysis to discern an impact, but the review concludes that the monitoring would be feasible and useful.

Appendix 1: SWRDA summary of predicted impacts

Combined University of Cornwall (Millar et al, 2006)

CUC have published a peer reviewed research paper in the journal "Ocean Engineering", as part of a PhD research work, under Dean Millar's supervision.

Consultation with Ocean Prospect, RegenSW, SAS and the BSA was conducted throughout the modelling process. CUC's research was undertaken independently from Halcrow's study and was not commissioned by SWRDA.

Model:

- Model type = SWAN (Simulating Waves Nearshore)
- Set up / calibration data = 1 year of Wavenet data 1 year.

Wave scenarios modelled (see notes):

- Spectral waves.

WEC scenarios modelled:

- 4 km variable (as %) energy transmitting / absorbing obstacle.
- Unachievable scenario (i.e. complete energy absorption by WECs giving largest possible impact on surfing waves) = 0% transmission, 100% absorption.
- Optimistic target scenario (i.e. an array of densely spaced, high efficiency WECs) = 70% transmission, 30% absorption.
- More realistic scenario (i.e. an array of widely spaced, lower efficiency WECs) = 90% transmission, 10% absorption.

Model results (all for spectral waves):

- Unachievable scenario 0% transmission, 100% absorption = 1.19% (Newquay Bay) – 6.5% (Perranporth) average change in significant wave height.
- Optimistic target scenario 70% transmission, 30% absorption = 0.36% (Newquay Bay) – 1.96% (Perranporth) average change in significant wave height.
- More realistic scenario = 90% transmission, 10% absorption = 0.12% (Newquay) – 0.65% (Perranporth) average change in significant wave height.

Conclusions of Millar et al.

- 0.3% annual average wave height reduction.
- 2.3% maximum wave height reduction (for 12 hour period at a specific location, Perranporth).
- 0.7% annual average wave height reduction on surfing beaches in the study area.
- 1.26% maximum wave height reduction on surfing beaches (Perranporth).

- “There is little cause for concern that effects introduced by the Wave Hub will be felt by shoreline users of the sea” (Millar et al, 2006).

Halcrow (Halcrow, 2006)

Halcrow’s modelling was commissioned by SWRDA as part of the detailed design studies supporting the Wave Hub consent application and environmental impact assessment made under the Electricity Act.

Consultation comprised three meetings held jointly with the British Surfing Association (BSA) and Surfers Against Sewage. All meetings hosted by the BSA at their Fistral Beach office, Newquay. The meetings allowed the BSA and SAS to jointly direct the modelling (including WEC scenarios and small and big wave scenarios) and assess the model results.

Model:

- Model type = MWAVE.
- Set up / calibration data = 13 months wave rider buoy data Jan 2005 to April 2006 and 17 years Met Office wave model data.

Wave scenarios modelled (see notes):

- Spectral waves (10m @ 12s).
- Monochromatic waves (1m @ 7s to represent small waves and 4m @ 16s to represent big waves).
- Monochromatic waves (various other wave heights and periods).

WEC scenarios modelled:

- Theoretical worst case scenario (4 wave overtopping devices (e.g. Wave Dragon)).
- Theoretical typical case scenario (1 wave overtopping device (e.g. Wave Dragon) + 2 large point absorber devices (e.g. FO^3) + 20 small point absorber devices (e.g. Powerbuoy) and 6 attenuator devices (e.g. Pelamis)).

Model results (also see Figures 1 to 6):

- Spectral waves + WEC worst case = 0% to 5% wave height reduction.
- Spectral waves + WEC typical case = 0% to 3% wave height reduction.
- Monochromatic waves + WEC worst case for wave heights and periods representing small and big waves = 0 to 11% wave height reduction.
- Monochromatic waves + WEC typical case for wave heights and periods representing small and big waves 0% to 5% wave height reduction.
- Monochromatic waves + WEC worst case for other wave heights and periods = 0 to 13% wave height reduction.
- Monochromatic waves + WEC typical case for other wave heights and periods = 0% to 7% wave height reduction.

Conclusions of Halcrow

The maximum surfing wave height reductions at the shore will be very localised and are predicted to extend over a few hundred metres which, depending on wave conditions, will move between Portreath, St Agnes and Perranporth.

Model Results Comparison

Comparing Halcrow (Halcrow, 2006) and CUC (Millar et al, 2006) model results for spectral waves (i.e. real life sea conditions) shows general agreement between model results, i.e.,

- Halcrow's modelling results for spectral waves (based on the typical case WEC scenario) = 0-3% wave height reduction.
- CUC's modelling results for spectral waves (based on 4km variable wave energy transmitting obstacles) = 0-2.3% wave height reduction.