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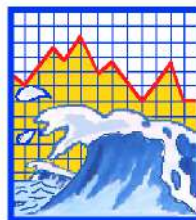
Coláiste na hOllscoile Corcaigh, Éire  
University College Cork, Ireland

# **Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site**

**A Summary of Six Years of Wave  
Measurement from Galway Bay prepared for  
the Sustainable Energy Authority of Ireland  
(SEAI)**

**07/12/2011**

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## Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



**Hydraulics & Maritime Research Centre**

University College Cork

## Document Verification

Page 1 of 1

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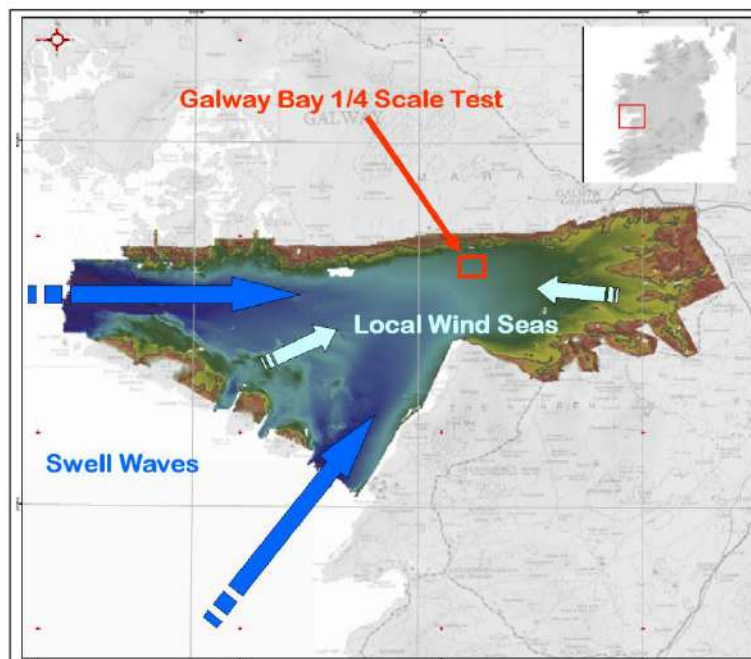
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## 1 Introduction

The benign, quarter scale, wave energy test site in Galway Bay on the west coast of Ireland provides a location for developers of floating WECs to deploy and monitor device prototypes in relatively sheltered conditions, as suggested in Phase 3 of the standard development protocols [1]. This site was established by the Marine Institute in partnership with Sustainable Energy Authority of Ireland, with foreshore leasing granted by the Department of Communications, Marine and Natural Resources. The site has an area of 37 Hectares with water depth of between 21m-24m and a tidal range of 4m. Due to the semi enclosed nature of Galway Bay, illustrated in Fig. 1, the site experiences swell waves from the west and south west as well as the local, fetch limited, wind seas. These wind seas have been shown to be a good representation at quarter scale of combinations of height and period for exposed Atlantic Ocean conditions [2, 3].



**Figure 1 Location and Bathymetry of the 1/4 Scale Wave Energy Test Site in Galway Bay**

The purpose of this document is to collate the data retrieved from the wave measurement buoys that have been operated in Galway Bay and provide graphic representations of the wave conditions that have been experienced at the site on monthly and annual time scales. A description of the wave measurement regime and the outputted data is provided in Section 2. Section 3 explains the format of the plots that have been used to characterise the wave energy resource at the site. A full set of these plots, for the years 2006-2011, is included in the Appendix at the end of the report. A brief summary of the unique wave climate experienced at Galway Bay and how this can be scaled to represent real, open ocean conditions is included in Section 4.



## **2 Wave Measurement in Galway Bay**

### **2.1 Introduction**

Wave measurements have been collected from Galway Bay using individual Datawell Waverider buoys since 2005. The Datawell Waverider is a spherical, surface following buoy which computes the water surface elevation from measurements of its own vertical acceleration. A comprehensive overview of the operating principles of the Waverider buoy can be found in [4].

A non-directional buoy was located at 53° 13.606' N, 9° 16.024' W from November 2005 to November 2008. The collection of data from this buoy was phased out through 2008 once a directional buoy, positioned at 53° 13.7' N, 9° 16.13' W, was installed in April of that year. The data recorded at the test site is transmitted by high frequency radio to a receiving antenna located on the roof of the Marine Institute building in Rinville, Co. Galway. This data is managed and distributed by the Marine Institute and can be accessed through its Data Request program [5]. Details on the data outputs produced by each of the buoys are presented in the next section.

### **2.2 Description of Data**

A brief description of the primary output files from both the non-directional and directional Waverider buoys is included here. Further details can be found in the appendices of [6].

#### **2.2.1 Time Series File [.1RW / .raw]**

The time series provided by the non-directional buoy (.1RW) contains at least 30 minutes of wave elevation sampled at 2.56Hz ( $\geq 4608$  data points). The time series provided by the non-directional buoy (.raw) contains at least 30 minutes of wave elevation, along with lateral motions in the North and West directions, sampled at 1.28Hz ( $\geq 2304$  data points).

#### **2.2.2 Spectral File [1SP / .spt]**

This file contains the representative spectral data for a 30 minute time period. 64 values of the Spectral Density,  $S(f)$  [ $m^2/Hz$ ], are stored in this file, corresponding to the same number of frequency values which range from 0.025Hz-0.58Hz. The 30 minute wave spectrum is produced from the average of 8 spectra which the buoy computes from 200 second samples of the wave elevation data. This process is the same for both the non-directional and directional buoys, though the directional buoy also provides details such as the mean direction and spreading factor at each frequency step.



### 2.2.3 Time Series Statistics File [.1WV / .wvs]

This file contains summary statistics calculated from a zero-down crossing analysis of the time series of surface elevation. Of most interest in the context of this report is the value returned for the maximum wave height observed in a record,  $H_{\max}$ .

## 2.3 Description of Parameters

Important sea state parameters for the characterization of the wave energy resource at the site were calculated from the moments of the spectral density function  $S(f)$  produce by the Waverider Spectral Files [1SP / .spt]. The  $n$ th spectral moment is given by

$$m_n = \int_0^{\infty} f^n S(f) df \quad (1)$$

The following parameters are derived from the spectra recorded at the Galway Bay Test Site for every 30 minute period where measurements exist:

- Significant Wave Height  $H_{m0}$ , also called  $H_s$ .

$$H_{m0} = 4\sqrt{m_0} \quad (2)$$

- Energy Period,  $T_E$ .

$$T_E = m_{-1}/m_0 \quad (3)$$

- Mean zero-crossing period  $T_{02}$ , also called  $T_z$ .

$$T_{02} = \sqrt{m_0/m_2} \quad (4)$$

The value of the maximum wave height,  $H_{\max}$ , for each 30 minute period was also computed from the Time Series Statistics File [.1WV / .wvs]. In theory, for a typical storm event, the value of  $H_{\max}$  is in the region of  $1.8H_{m0}$ - $2.0H_{m0}$  [7].

## 2.4 Data Availability

It is an inherent weakness of in-situ wave buoy measurements that 100% data retrieval is rarely achieved over the course of a monitoring regime. Gaps in the data can occur for a variety of reasons, such as problems with the radio signal, battery issues and the need to remove the buoy for maintenance purposes.

The percentage of data retrieved by the Waverider buoys each month for the period 2006-2011 is illustrated in Figs 2-7.



## Resource Characterisation of the Galway Bay $\frac{1}{4}$ Scale Wave Energy Test Site

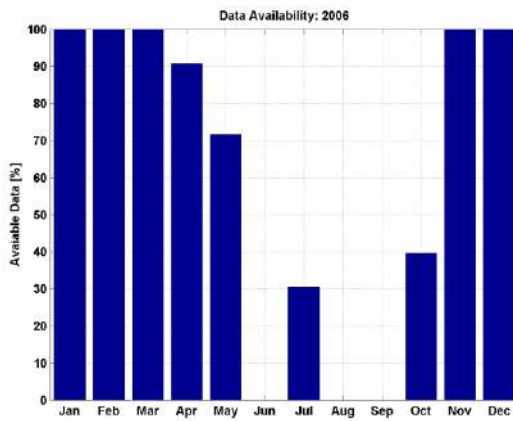


Figure 2 Data Availability: 2006

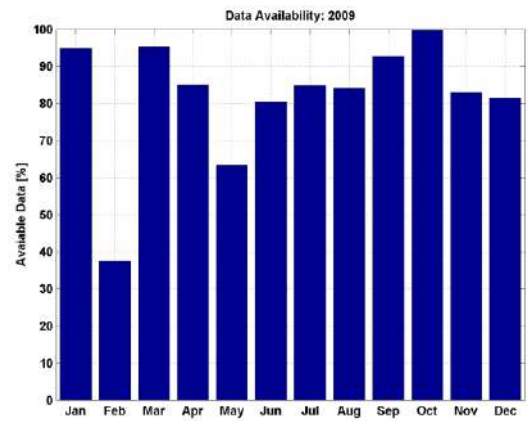


Figure 5 Data Availability: 2009

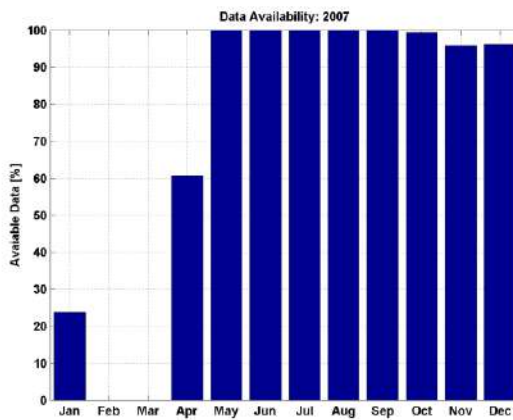


Figure 3 Data Availability: 2007

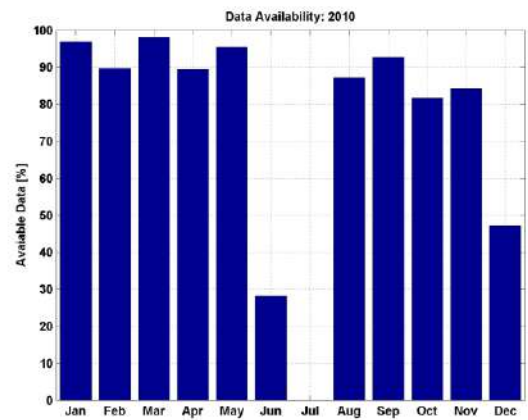


Figure 6 Data Availability: 2010

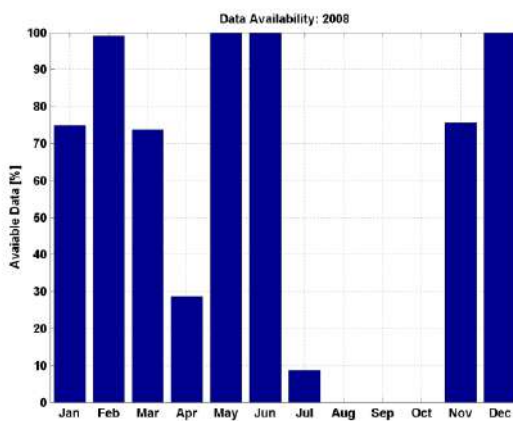


Figure 4 Data Availability: 2008

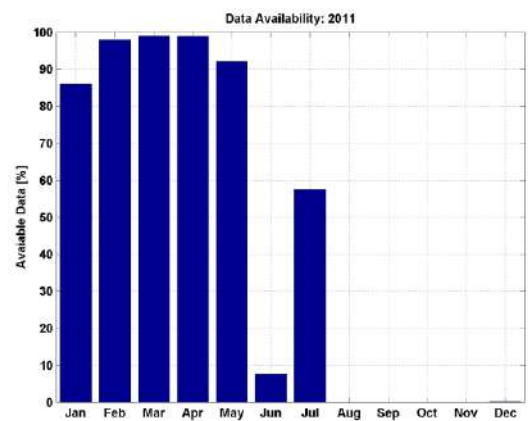


Figure 7 Data Availability: 2011



### 3 Description of Plots

This section provides guidance on how to read and interpret the various plots presented in this report to characterise the wave energy resource at the Galway Bay ¼ Scale Wave Energy Test Site.

#### 3.1 Time Series Plots

These plots highlight the level of variability that can exist in the wave conditions at the site, which has implications for many aspects of WEC operation such as the level of intermittency of output power and the frequency and length of weather windows for deployment and maintenance. A typical plot of wave height ( $H_{m0}$  and  $H_{max}$ ) and period ( $T_E$  and  $T_{02}$ ) against time (dd/mm/yyyy) for one month's worth of measurement is illustrated in Fig. 8.

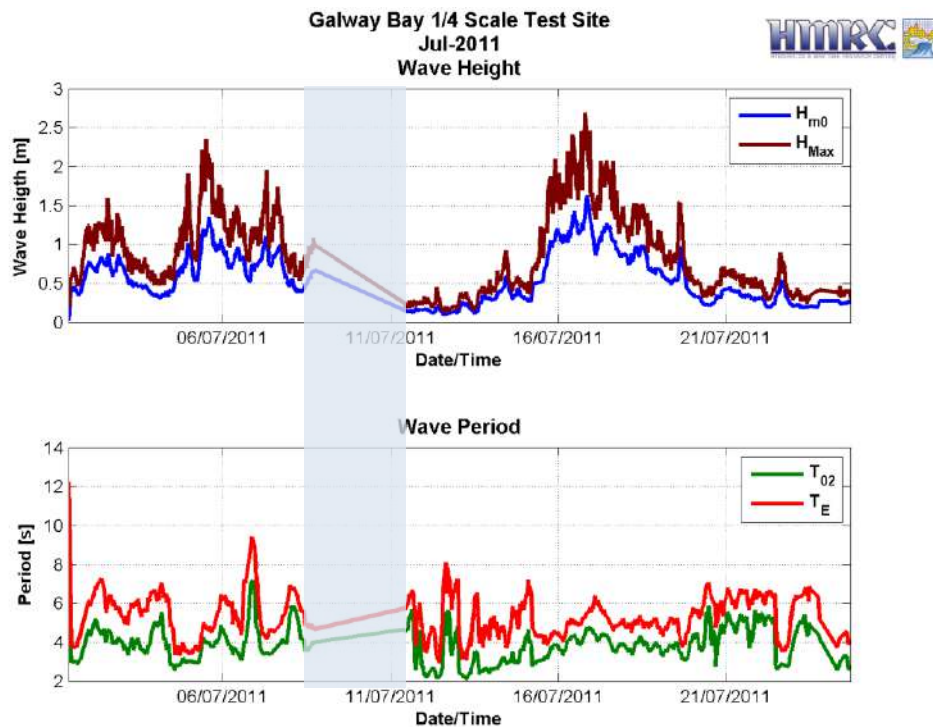


Figure 8 Sample Plot of Wave Height & Period Time Series with gaps in measured data highlighted.

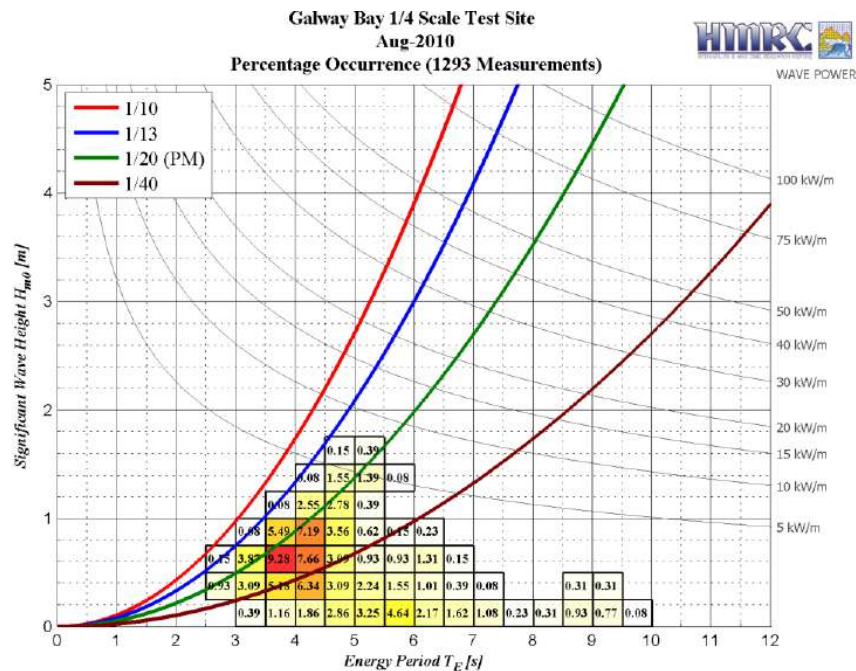
As mentioned in the previous section gaps are found to exist periodically in the dataset of measurements returned from the Galway Bay wave buoys. These gaps are represented in the time series plots by flat episodes with constant slope, such as the highlighted period prior to 11<sup>th</sup> July in Fig. 8.

#### 3.2 Scatter Plots of Percentage Occurrence

Bi-variate scatter plots of important summary statistics provide a useful method of ascertaining an overall understanding of the wave resource at an area of interest. In the



Appendix at the end of this report the sea states experienced at Galway Bay are presented over monthly and annual time frames in terms of the percentage occurrence of particular combinations of significant wave height,  $H_{m0}$ , and the energy period,  $T_E$ . Standard procedure prescribes bin size of 0.5m and 0.5s-1.0s for  $H_{m0}$  and  $T_E$  respectively [8, 9], however in this report smaller bin sizes of 0.25m for  $H_{m0}$  and 0.5s for  $T_E$  were selected to allow for easier visualization of the overall resource at ‘full scale’.



**Figure 9 Sample Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**

A typical scatter plot for August 2010 is presented in Fig. 9. The most commonly occurring sea states over the course of this period are identified by a red-orange colour scale. These plots also provide an approximate indication the level of incident wave power for each sea state (light grey lines). The bold, coloured, lines indicate the limiting steepness for particular combinations of  $H_{m0}$  and  $T_E$ . Of most relevance to this report are the Red 1/10 line, which indicates the maximum steepness for sea states with periods falling within the range most commonly experienced in Galway Bay, and the Green 1/20 line, which illustrates the maximum steepness for sea states with wave spectra which conform to the standard Pierson-Moskowitz shape [7].

## 4 Scalability of the Galway Bay Wave Resource

(Adapted from [3])

It is likely that device developers who will deploy WECs at the Galway Bay quarter scale test site will wish to extrapolate test results to gain an understanding of how their device will operate at full scale. In this section the measured data from Galway Bay is compared the wave conditions recorded at a depth of 50m at the Atlantic Marine Energy Test Site (AMETS), an open ocean location near Belmullet, Co. Mayo, in order to assess whether



they are sufficiently well matched to allow accurate comparisons to be made between performance results derived at the various scales.

#### 4.1 Sea State Occurrence

Values for the summary statistics  $H_{m0}$  and  $T_{02}$  were calculated from the available measurements from the Waverider buoys located at both sites. Froude scaling was then applied to convert the scatter diagram from Galway Bay for 2010 to full-scale (Fig. 10). Visual comparison with Fig. 11 indicates that the Galway Bay and AMETS experience a similar range of sea states. It can be seen that the extreme sea states measured at both sites are analogous, indicating that developers who deploy devices in Galway Bay are likely to discover how their device will respond in the equivalent of the storm conditions experienced off the west coast of Ireland.

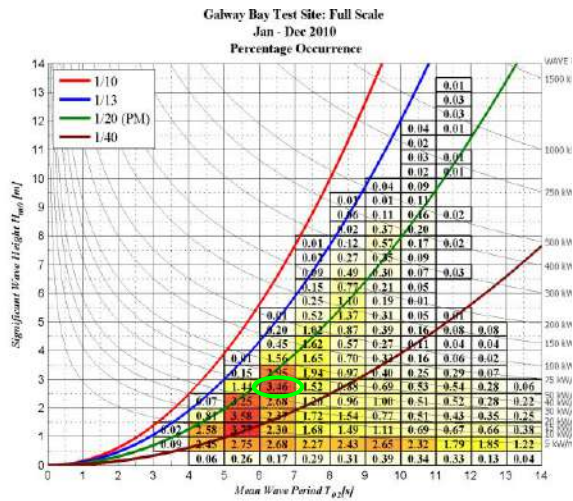


Figure 10 Bi-variate scatter plot for Galway Bay converted to 'full-scale'.

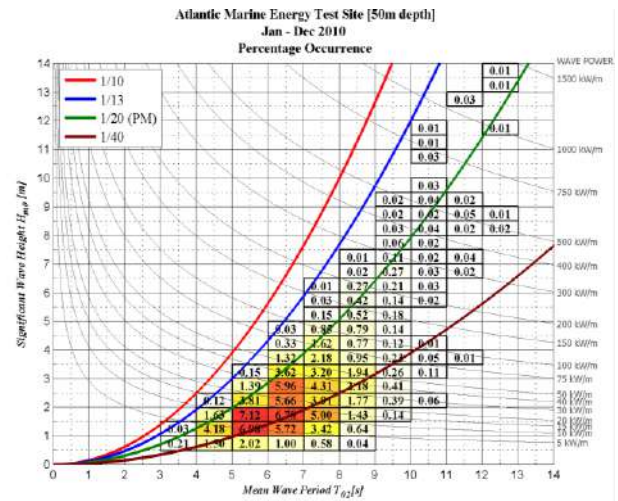


Figure 11 Bi-variate scatter plot for AMETS (Belmullet, Co. Mayo)

It is notable, however, that the Galway Bay scatter diagram displays a much greater contribution from long period sea states with a relatively low significant wave height. The influence of these swell dominated sea states can be seen in the plots of occurrence and exceedance for  $H_{m0}$  and  $T_{02}$  displayed in Fig. 12. The scaled results from Galway Bay exhibit a much greater occurrence of sea states with  $H_{m0} < 1\text{m}$  and  $T_{02} > 9\text{s}$ , which in turn causes the slopes of the  $H_{m0}$  and  $T_{02}$  exceedance lines to be much shallower than their AMETS equivalents.



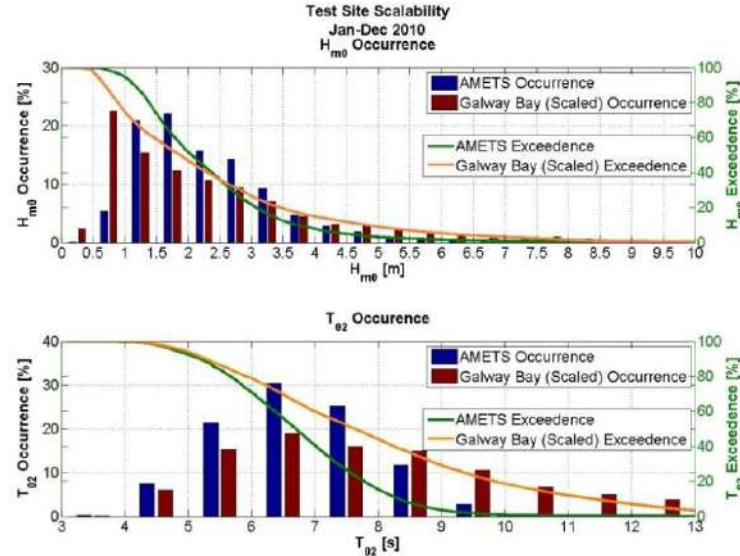


Figure 12 Occurrence and Exceedance of  $H_{m0}$  (top) and  $T_{02}$  (bottom) for AMETS and Galway Bay measurements at full-scale

## 4.2 Average Wave Power

The average wave power per meter of wave crest for a sea state can be calculated using the commonly used formula [7]:

$$P = 0.49H_{m0}^2 T_E \quad (5)$$

The annual average wave power for AMETS from the available 2010 measurements was found to be 33kW/m. The annual average wave power for Galway Bay for the same period was approximately 1.4kW/m. Assuming that Galway Bay is at ¼ scale to open ocean conditions and applying Froude scaling gives a full scale value of approximately 45 kW/m. While this is of the same order of magnitude as the AMETS value it is still noticeably higher, possibly due to the fact that the sea states observed in Galway Bay tend to be of a longer period than the open ocean site, as illustrated in the previous section.

The results of a recent 15 year wave model of the AMETS location give an annual average wave power of approximately 45kW/m at the 50m depth and 60kW/m at 100m [10], indicating that 2010 was a particularly benign year. Correspondingly, the values of annual average wave power in Galway Bay were found to be higher for the other years of study, ranging from 2.0 kW/m to 2.6 kW/m (64kW/m-83kW/m full scale). Longer term datasets or accurate hindcast models are required to ascertain a comprehensive understanding of the scalability of wave power between the two sites in order to remove seasonal bias and the impacts of interannual variability.



### 4.3 Spectral Shape

The presence of these swell waves can also be detected in the analysis of spectral shapes. In Fig. 13 the measured spectra that fall within the range  $0.625\text{m} < H_{m0} < 0.75\text{m}$  and  $3.0\text{s} < T_{02} < 3.5\text{s}$ , which correspond to the circled scatter plot element in Fig. 11, are plotted together, along with the average of the spectral ordinates and the classical Bretschneider spectrum for similar summary statistics. Two distinct components are noticeable; the long period swell identified above along with a wind sea component centered on a frequency of  $0.3\text{Hz}$  which is appropriate for a one quarter scale seaway. Spectra measured by the AMETS Waverider which fall within the equivalent full scale range ( $2.5\text{m} < H_{m0} < 3.0\text{m}$  and  $6\text{s} < T_{02} < 7\text{s}$ ) are plotted in Fig. 14 and are found to conform relatively well with what would be expected from an open ocean site, as evidenced by the likeness of the average spectral shape to the Bretschneider spectrum. It is evident that the long period components that appear so distinctly in Fig. 13 are not as influential here and that it is likely that sea and swell components from benign sites need to be isolated and dealt with separately in any analysis prior to conversion to full scale.

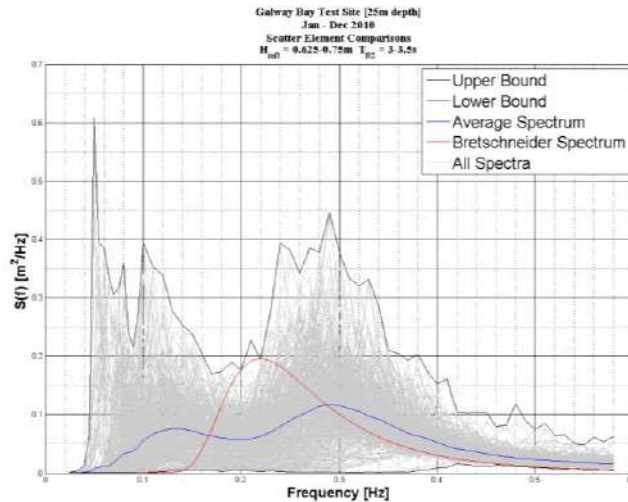
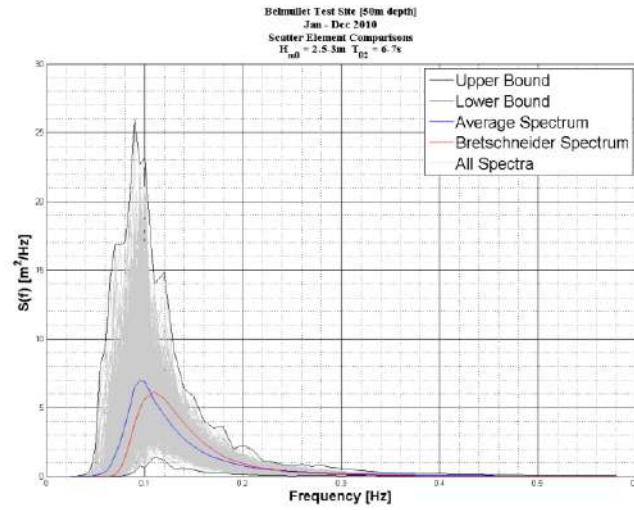


Figure 13 Individual, averaged and theoretical spectra within the range  $0.625\text{m} < H_{m0} < 0.75\text{m}$  and  $3.0\text{s} < T_{02} < 3.5\text{s}$  for the Galway Bay test site



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**Figure 14 Individual, averaged and theoretical spectra within the range  $2.5m < H_{m0} < 3.0m$  and  $6s < T_{02} < 7s$  for the AMETS location (50m depth).**



## 5 References

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- [1] B. Holmes, "Ocean Energy: Development and Evaluation Protocol," Hydraulics and Maritime Research Centre/Marine Institute 2003.
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- [8] European Marine Energy Centre (EMEC), "Assessment of Wave Energy Resource," 2009.
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- [10] M. Curé, "A Fifteen Year Model Based Wave Climatology of Belmullet, Ireland," Report prepared on behalf of the Sustainable Energy Authority of Ireland (SEAI) 2011.



## 6 Appendix

### 6.1 Yearly Wave Measurements

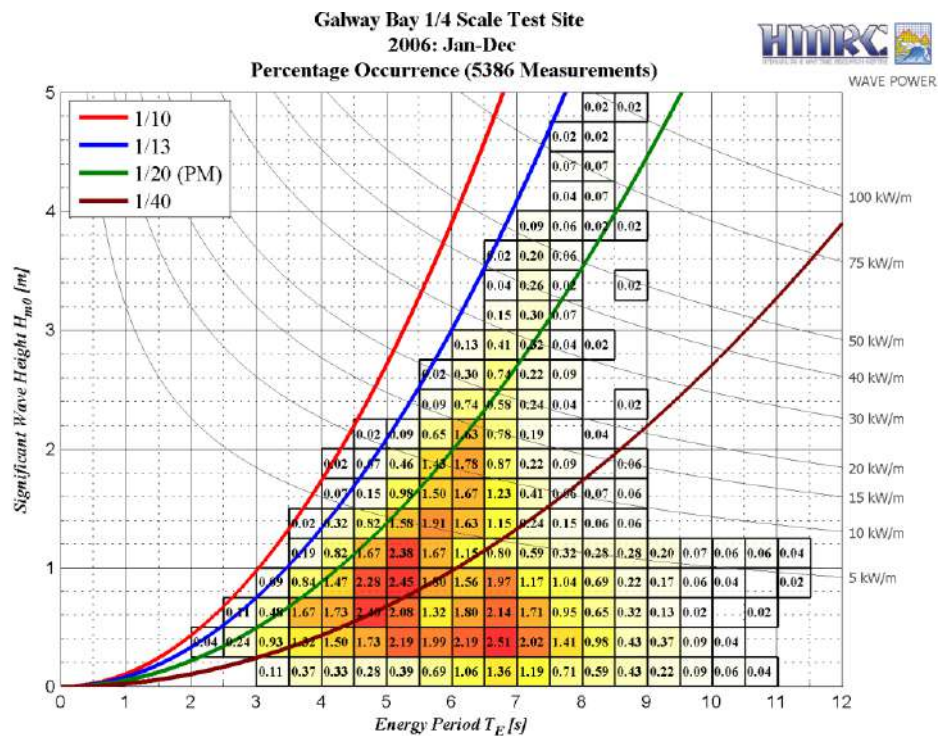


Figure 15 2006: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

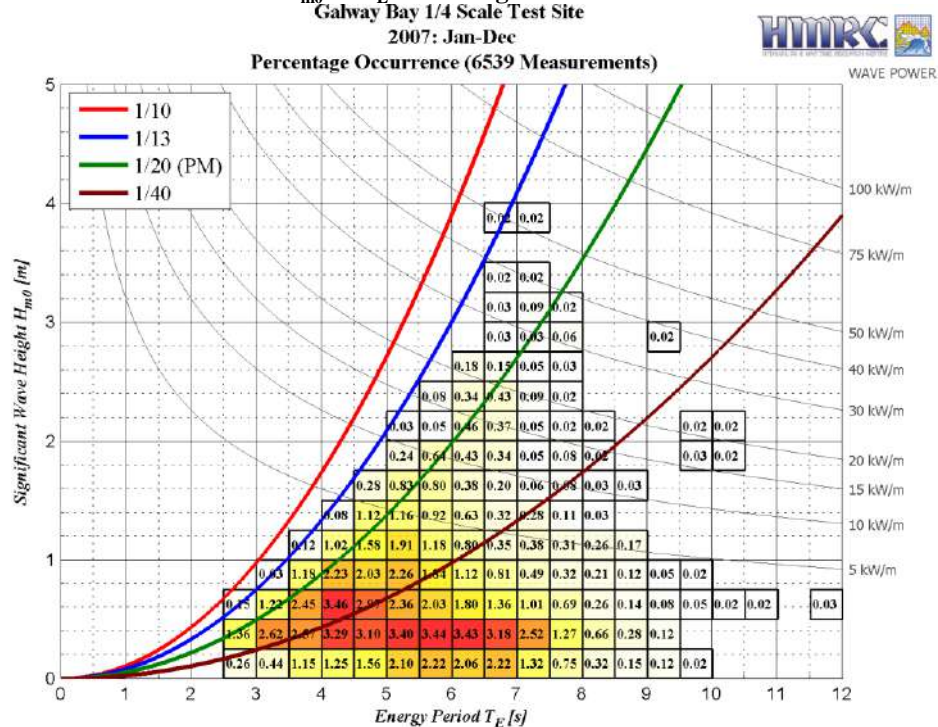


Figure 16 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



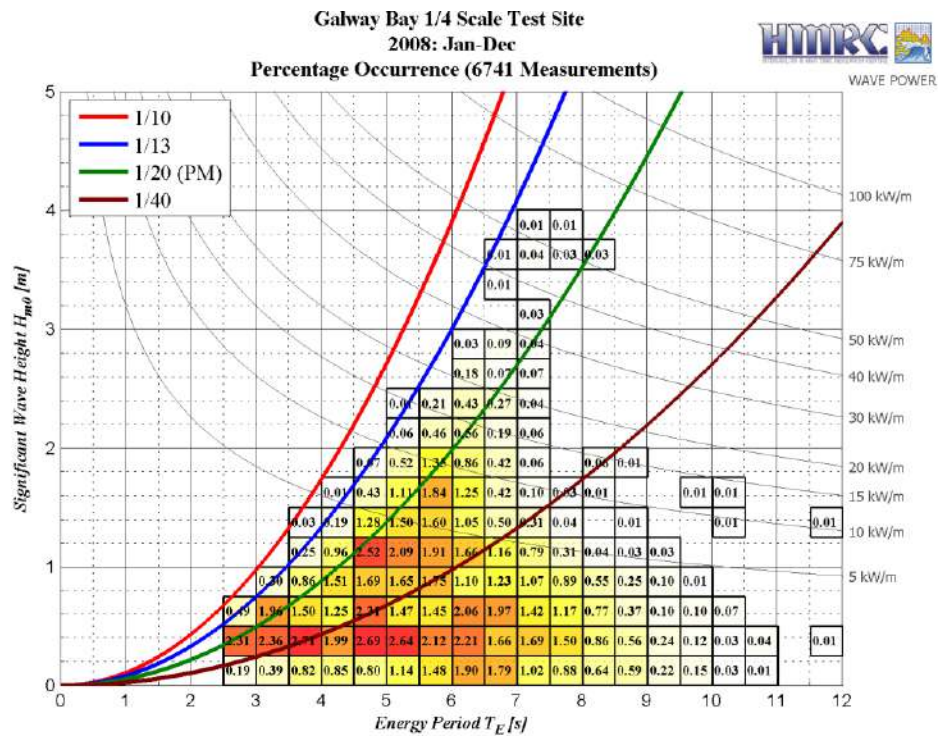


Figure 17 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

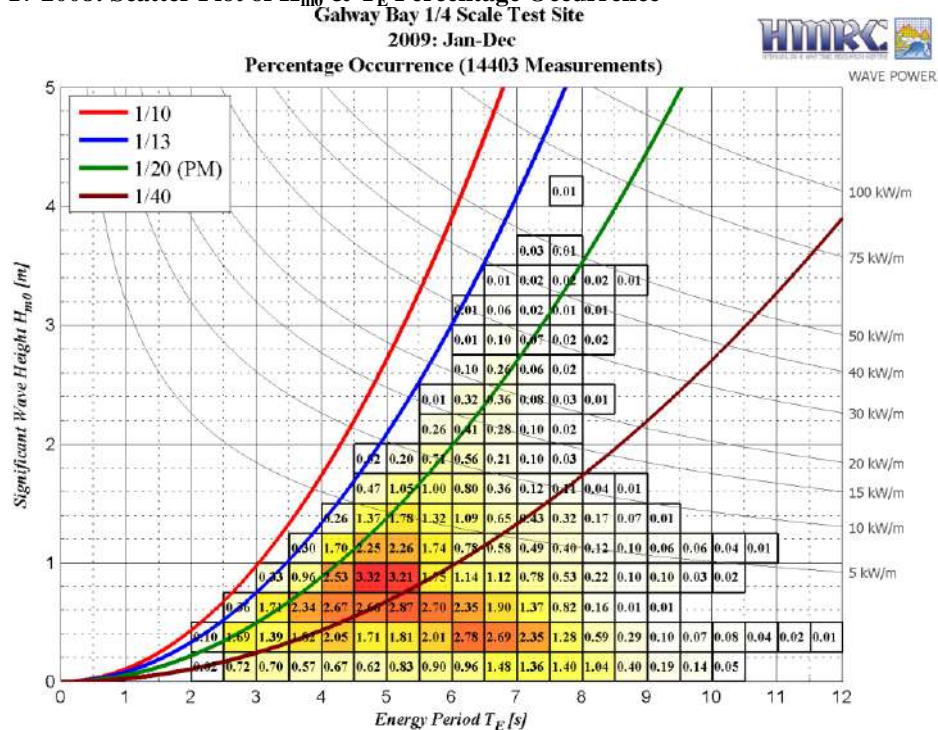


Figure 18 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

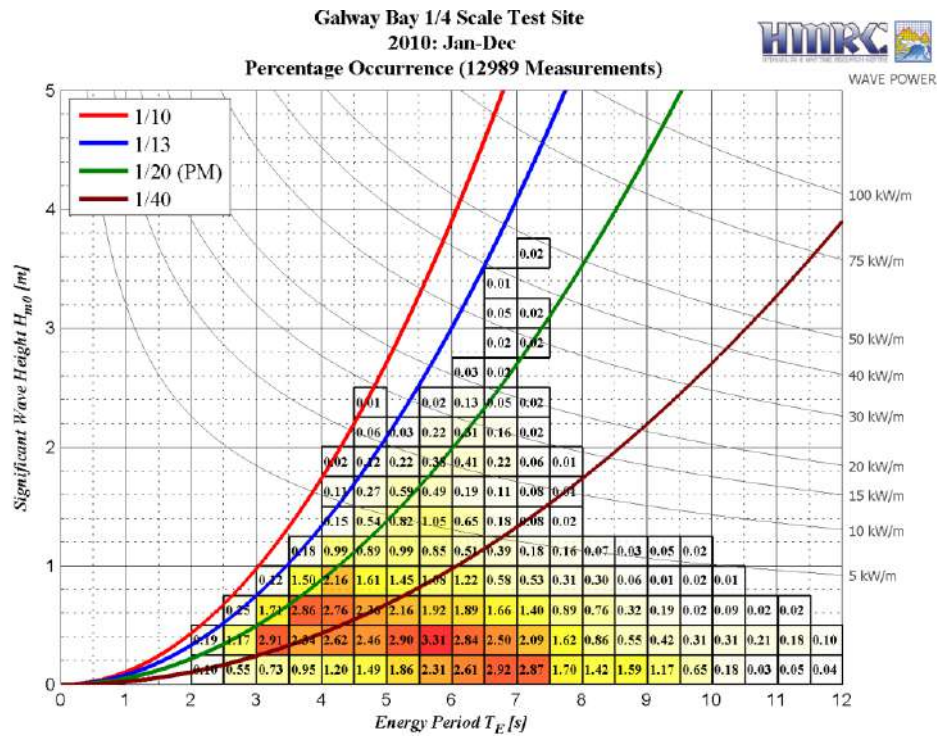


Figure 19 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

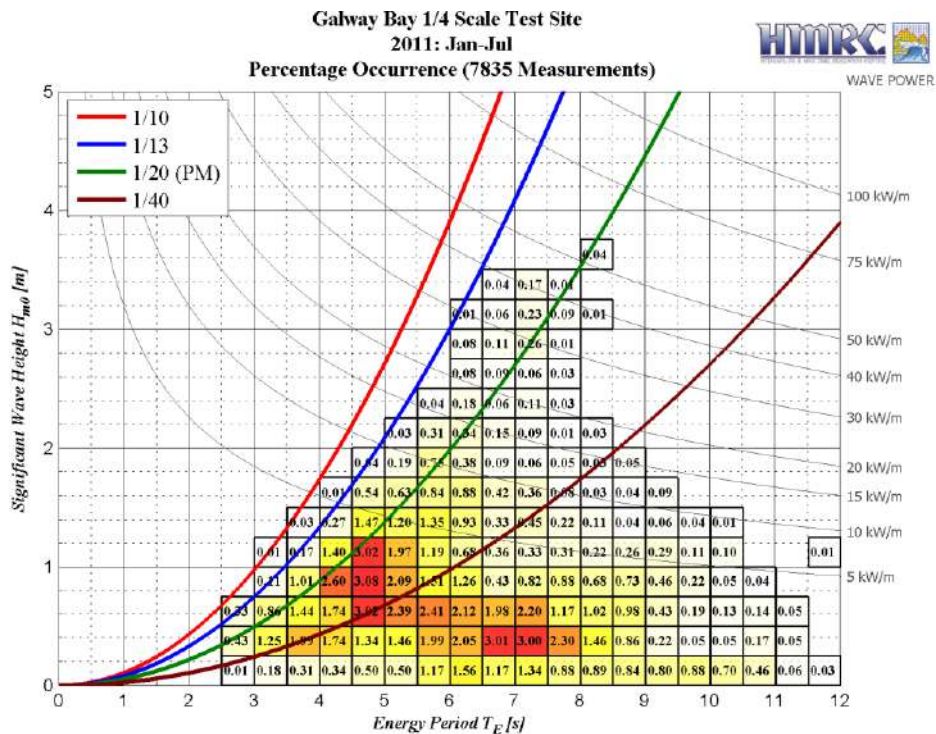


Figure 20 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



## 6.2 Monthly Wave Measurements

### 6.2.1 Time Series: 2006

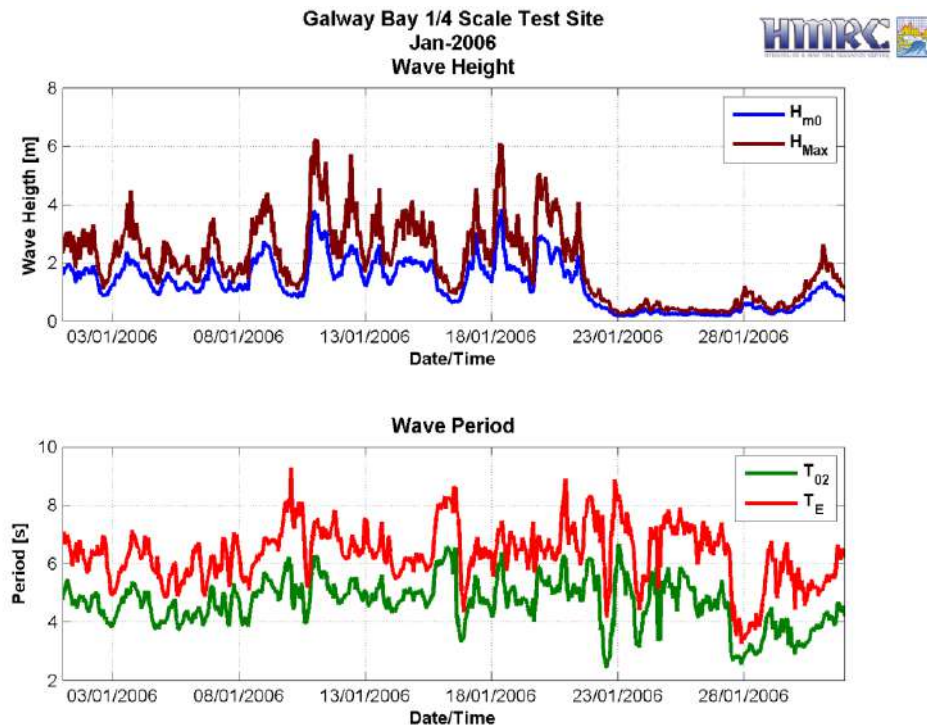


Figure 21 Jan 2006: Wave Height & Period

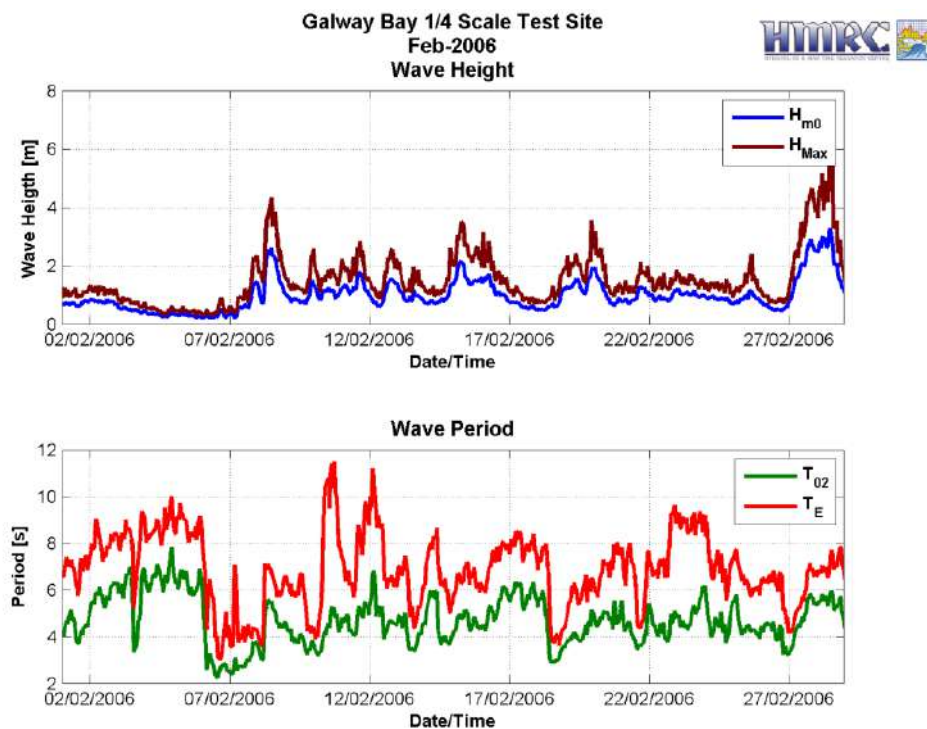
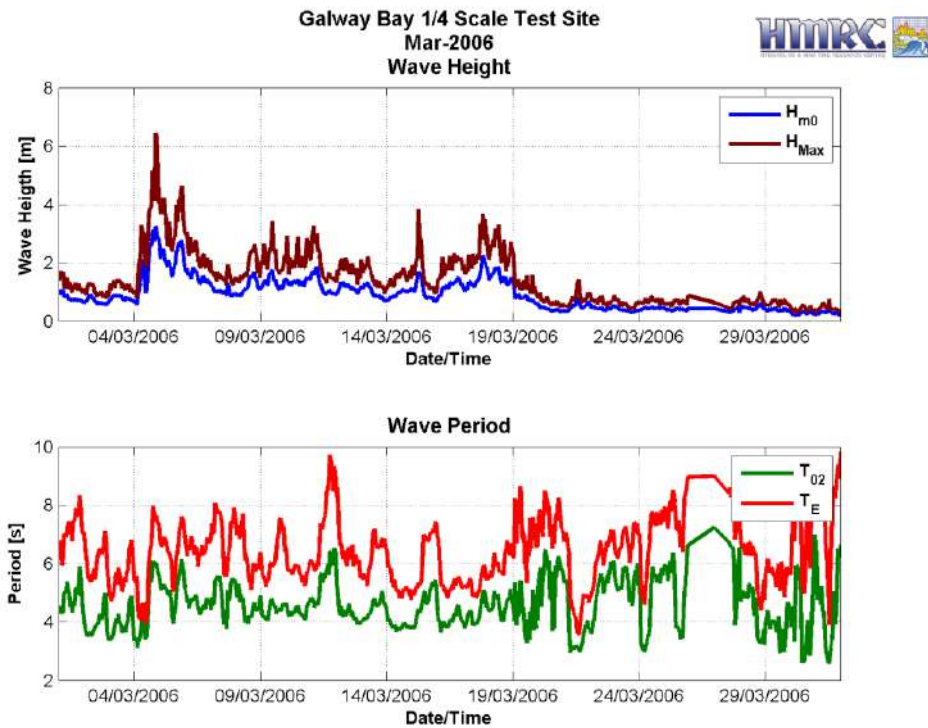


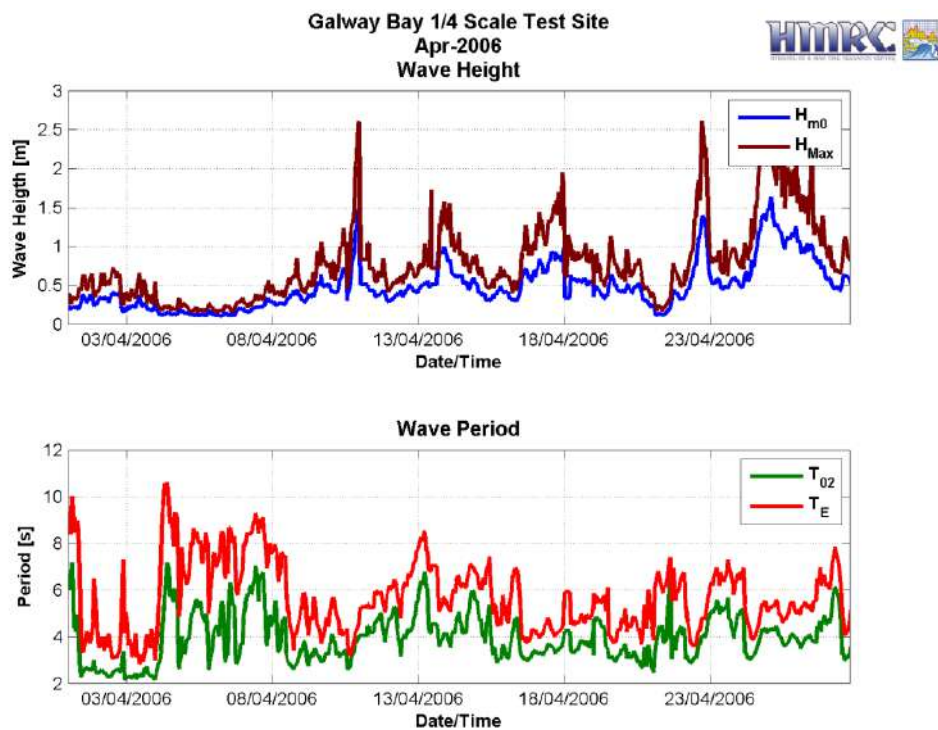
Figure 22 Feb 2006: Wave Height & Period



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 23 Mar 2006: Wave Height & Period**



**Figure 24 Apr 2006: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

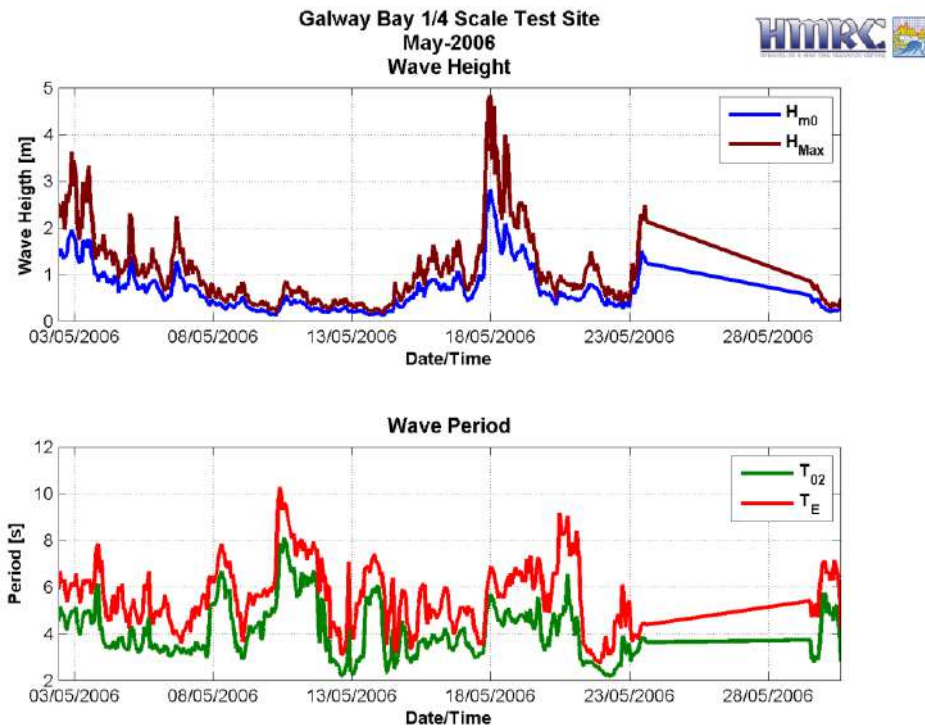


Figure 25 May 2006: Wave Height & Period

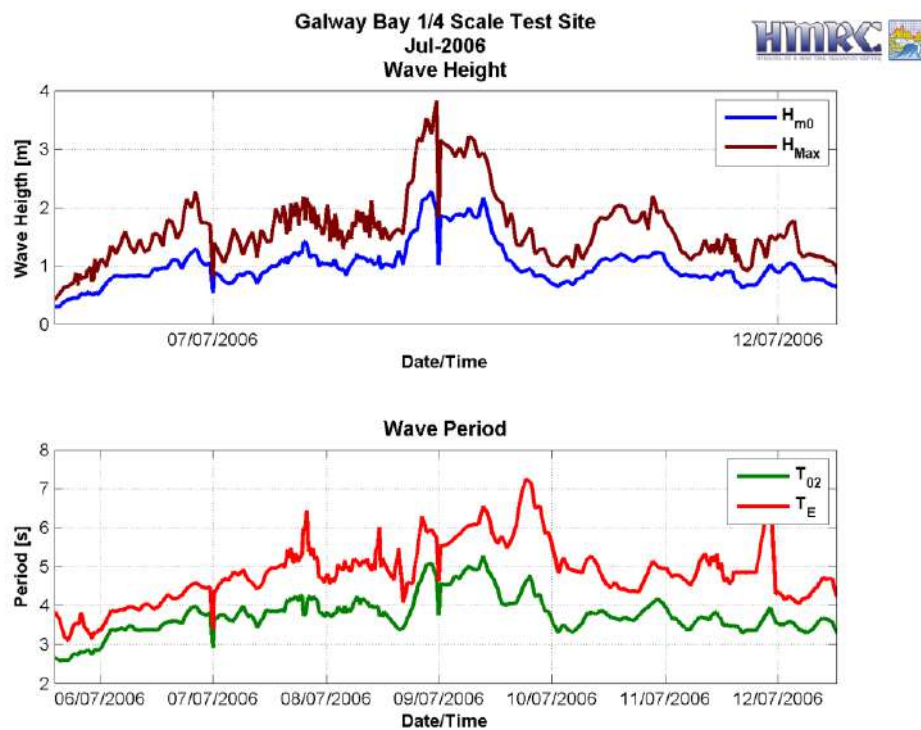
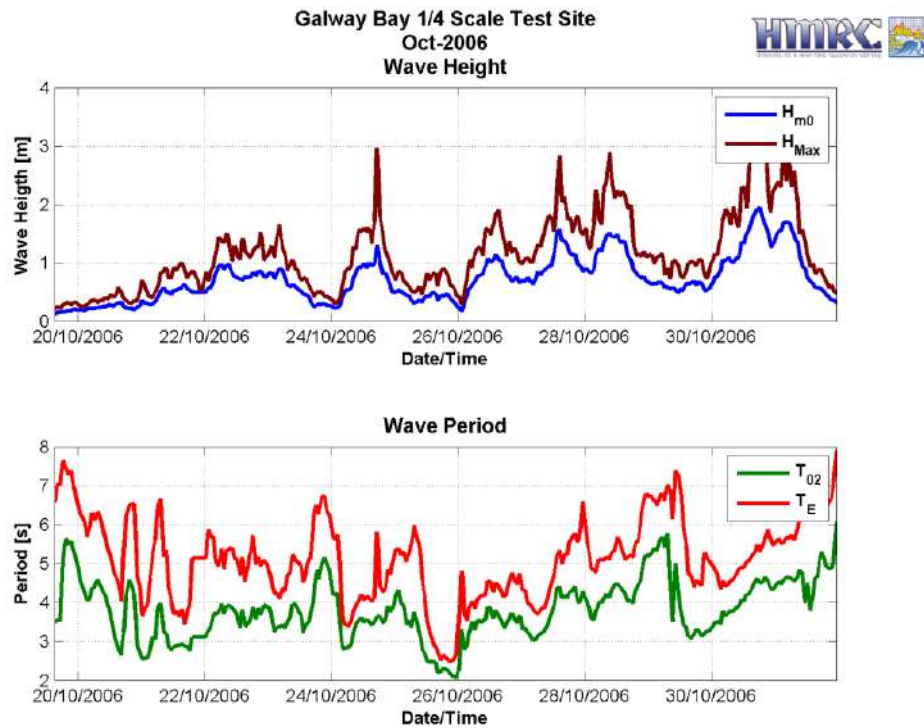


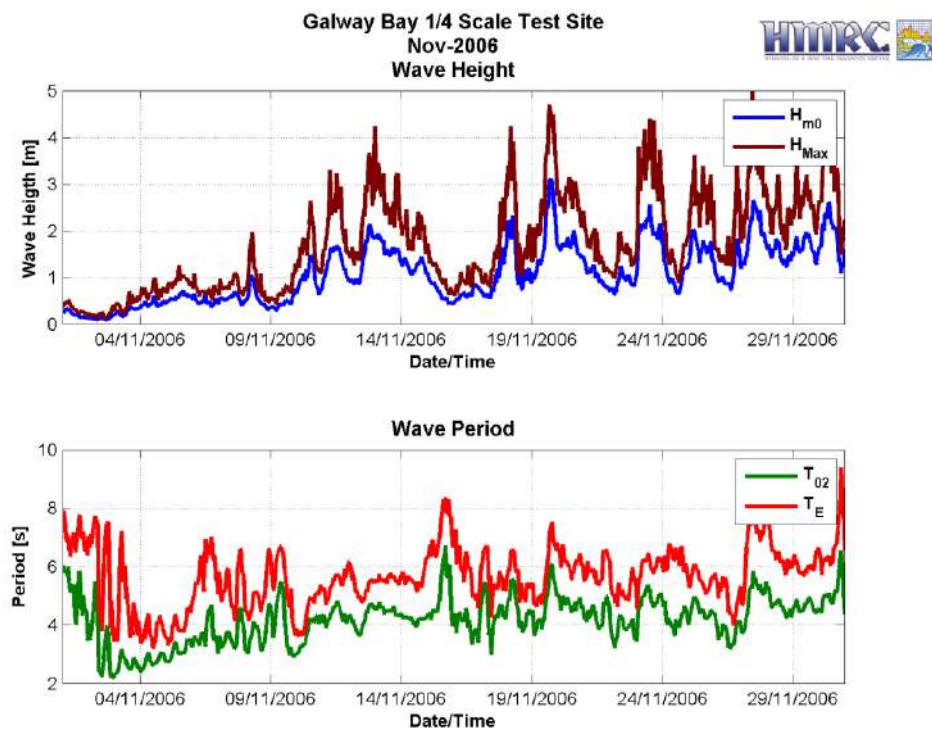
Figure 26 Jul 2006: Wave Height & Period



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 27 Oct 2006: Wave Height & Period**



**Figure 28 Nov 2006: Wave Height & Period**



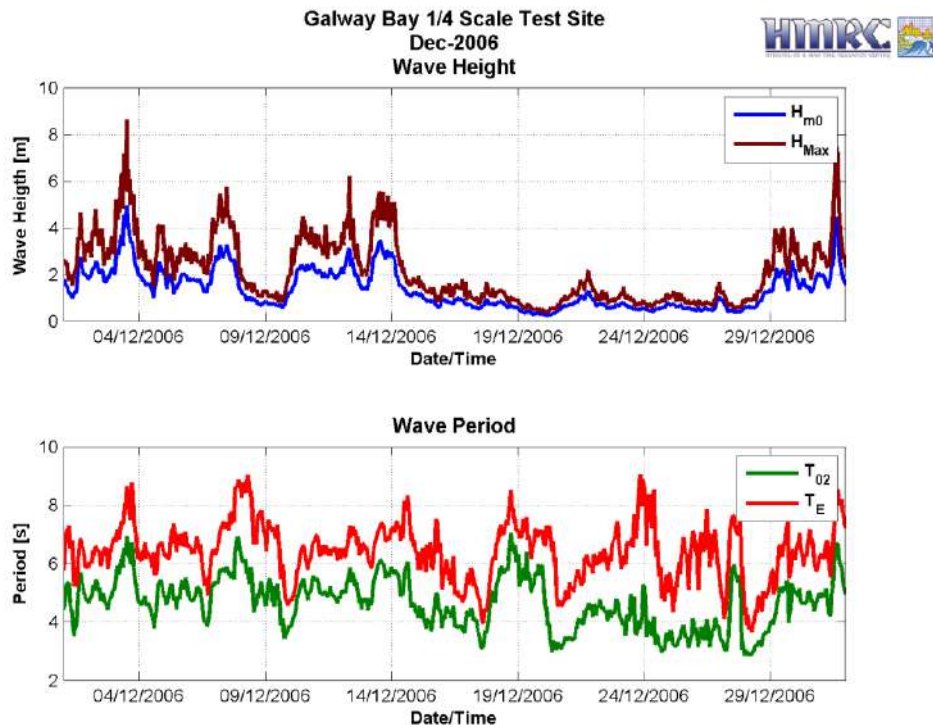


Figure 29 Dec 2006: Wave Height & Period

## 6.2.2 Scatter Plots: 2006

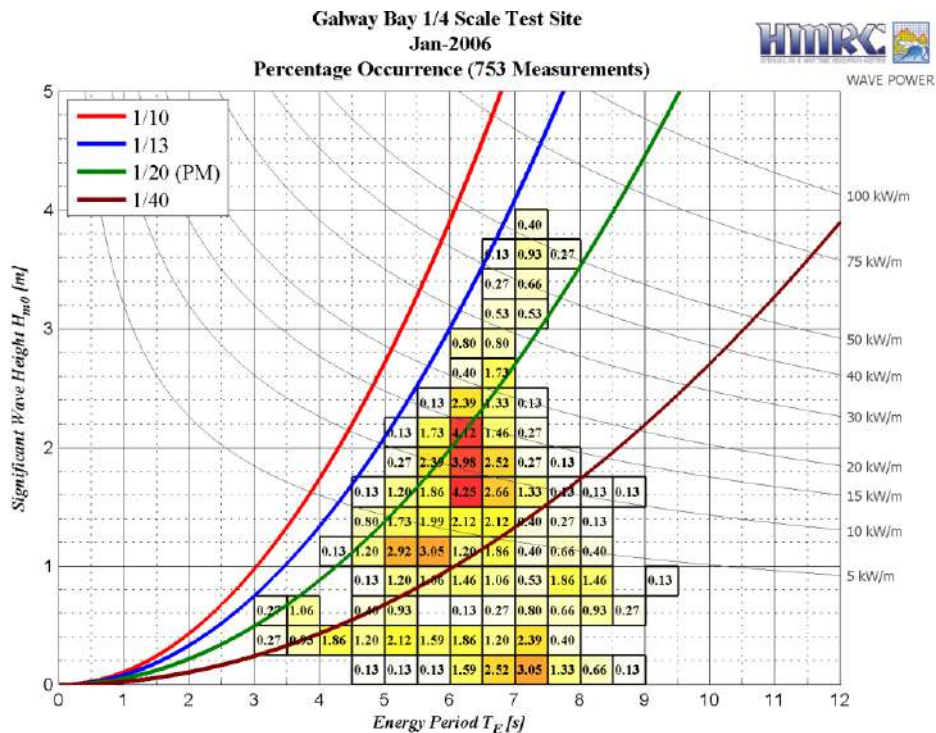


Figure 30 Jan 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

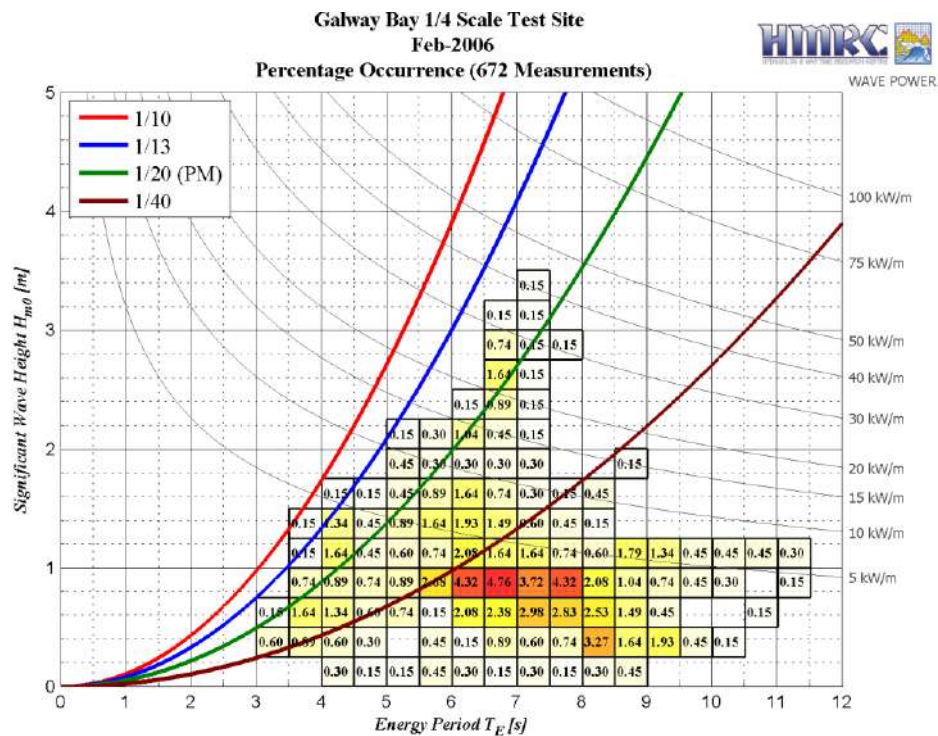


Figure 31 Feb 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

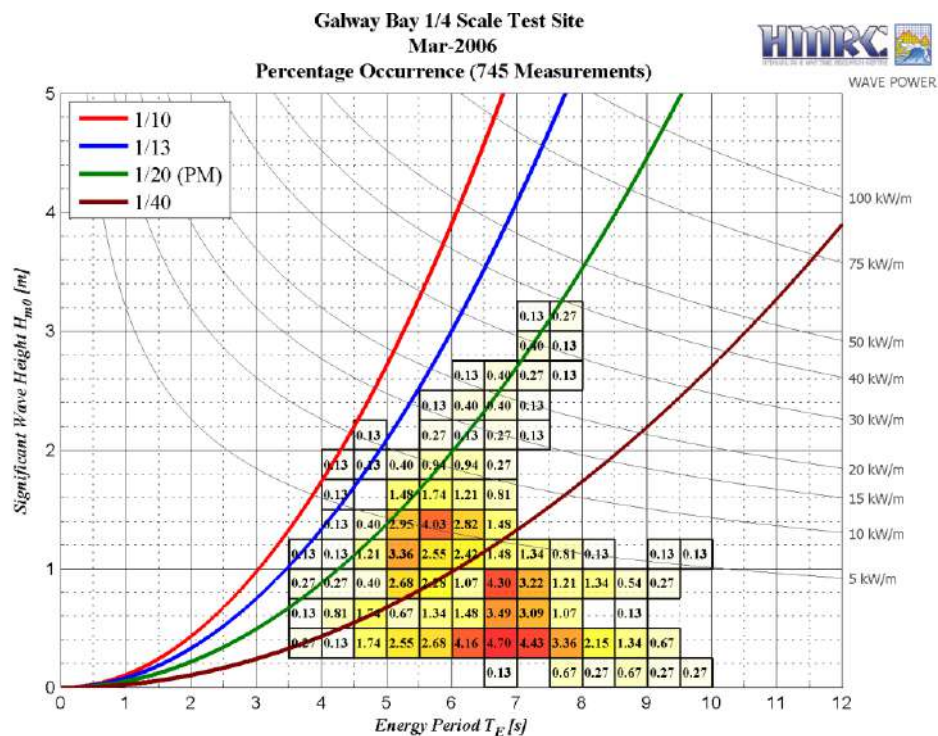


Figure 32 Mar2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

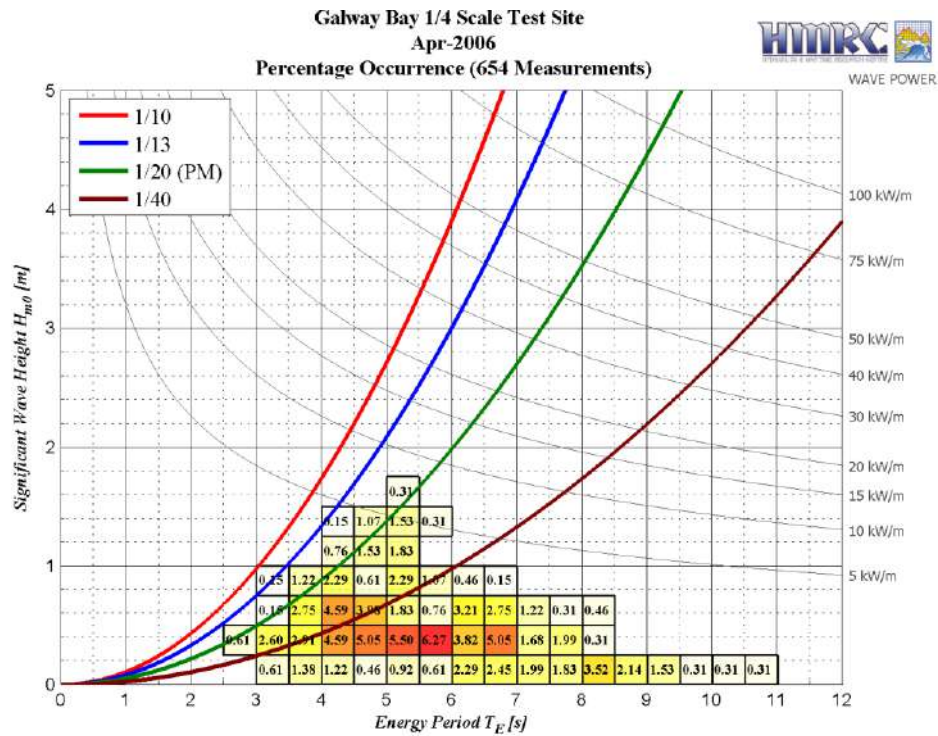


Figure 33 Apr 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

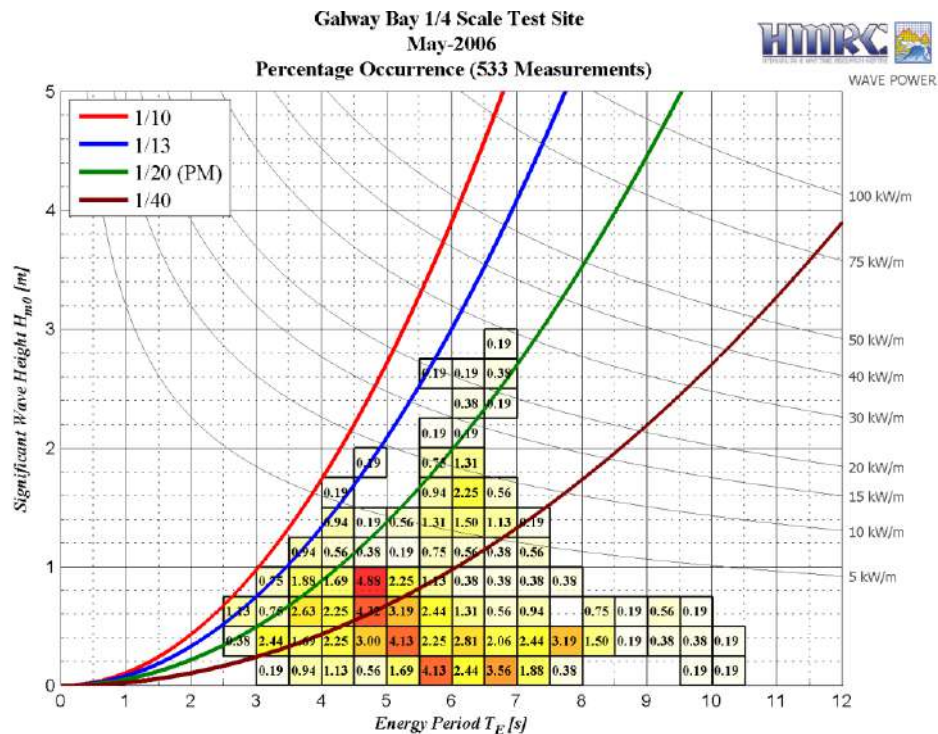


Figure 34 May 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

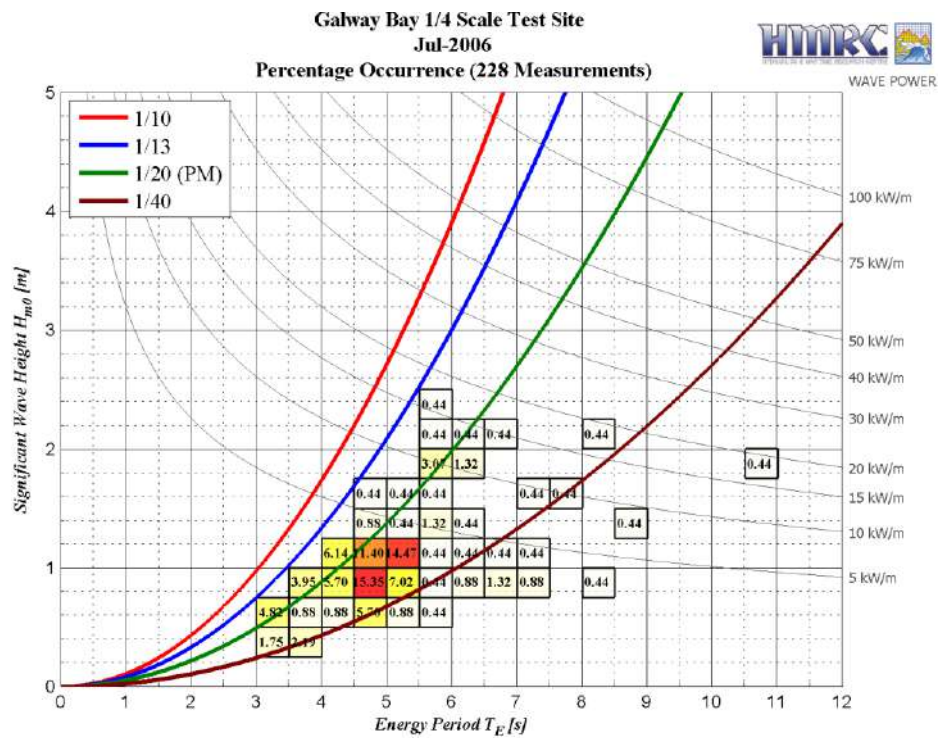


Figure 35 Jul 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

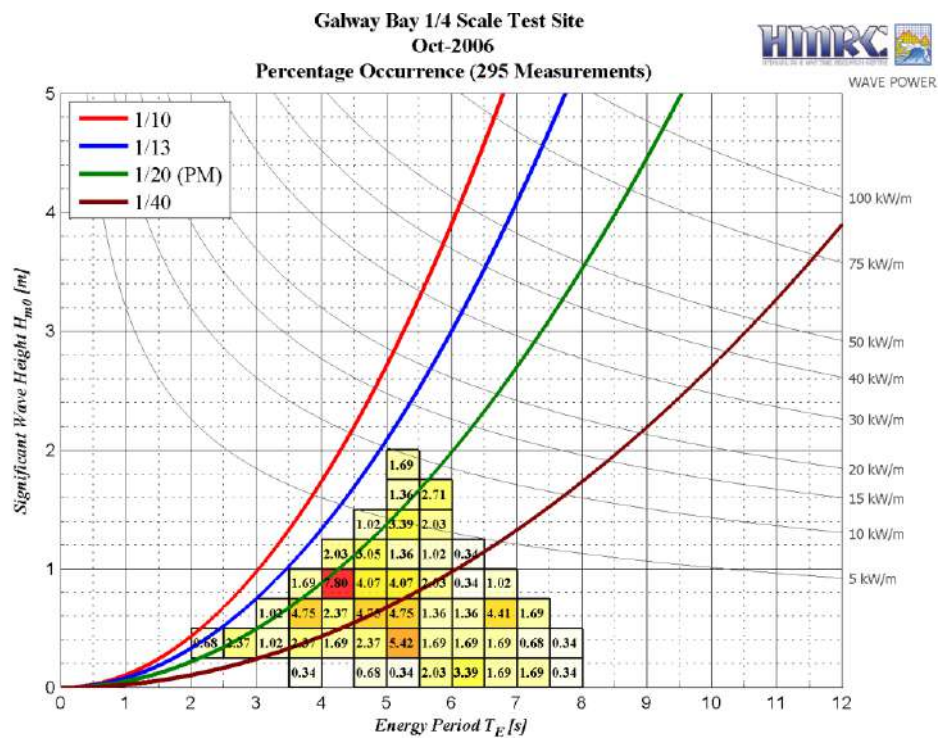


Figure 36 Oct 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

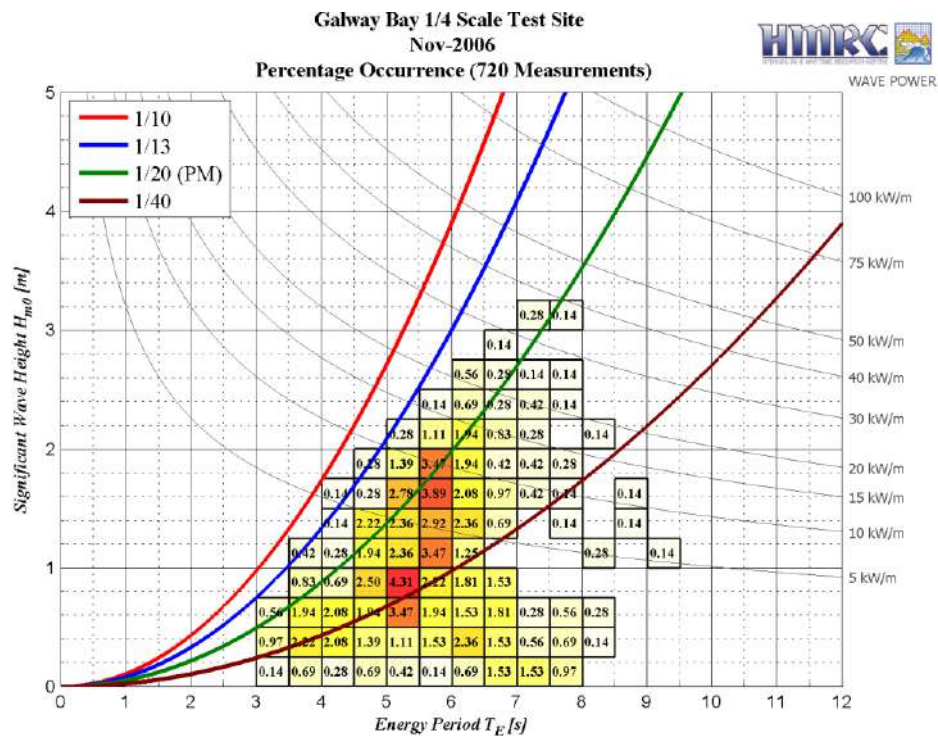


Figure 37 Nov 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

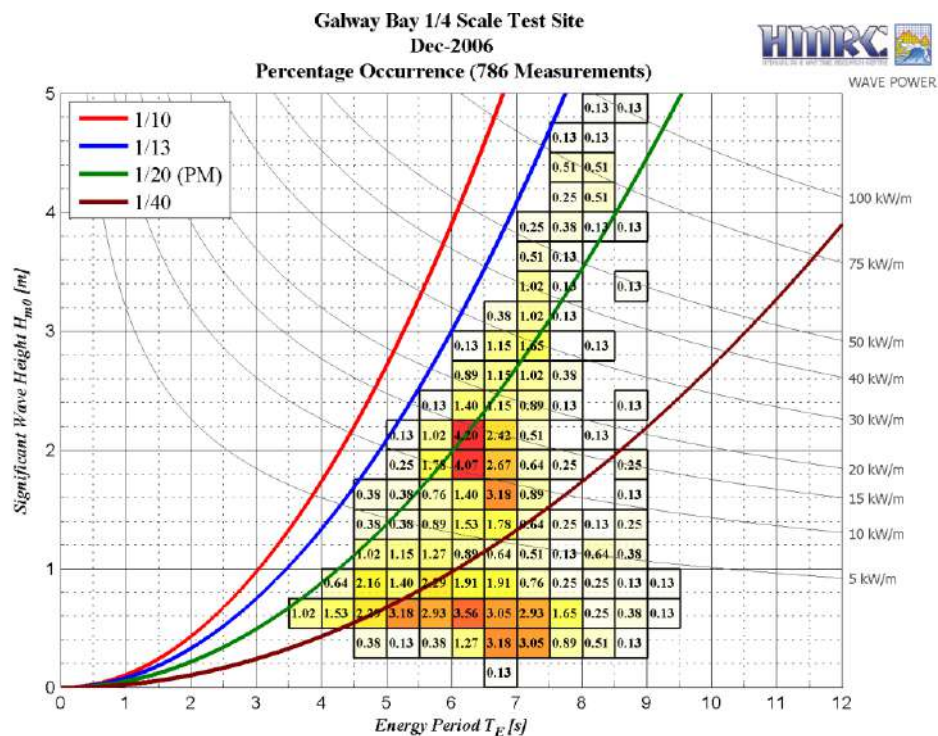


Figure 38 Dec 2007: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



### 6.2.3 Time Series: 2007

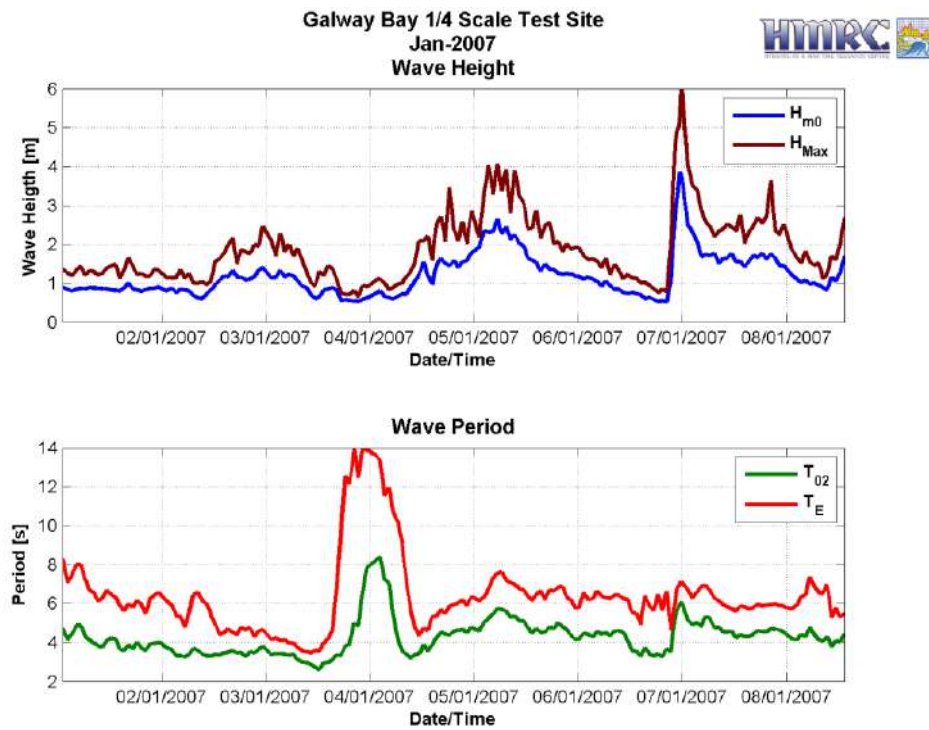


Figure 39 Jan 2007: Wave Height & Period

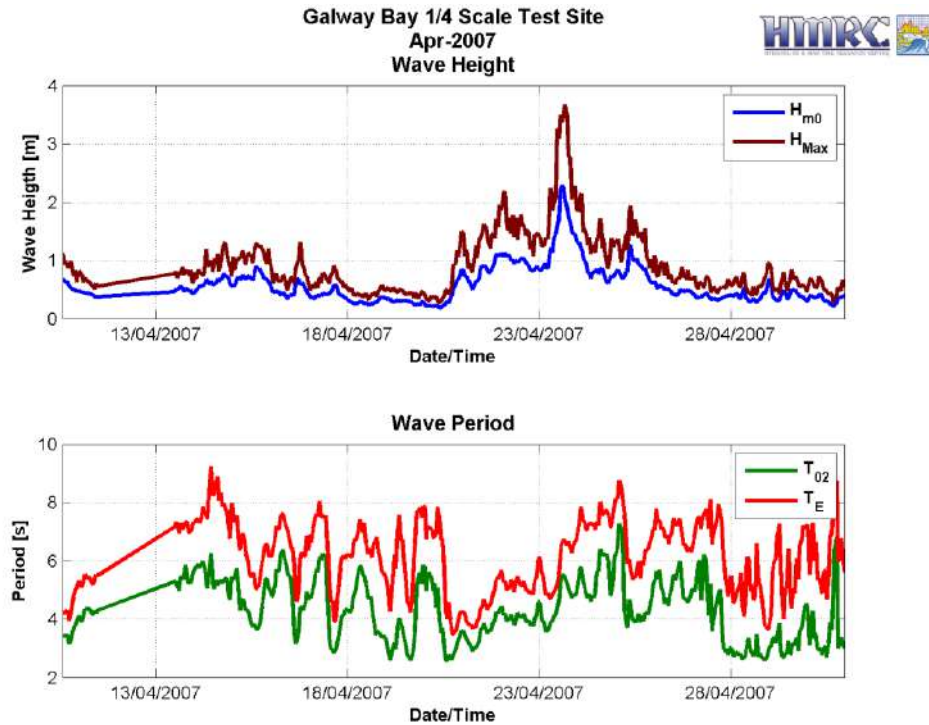
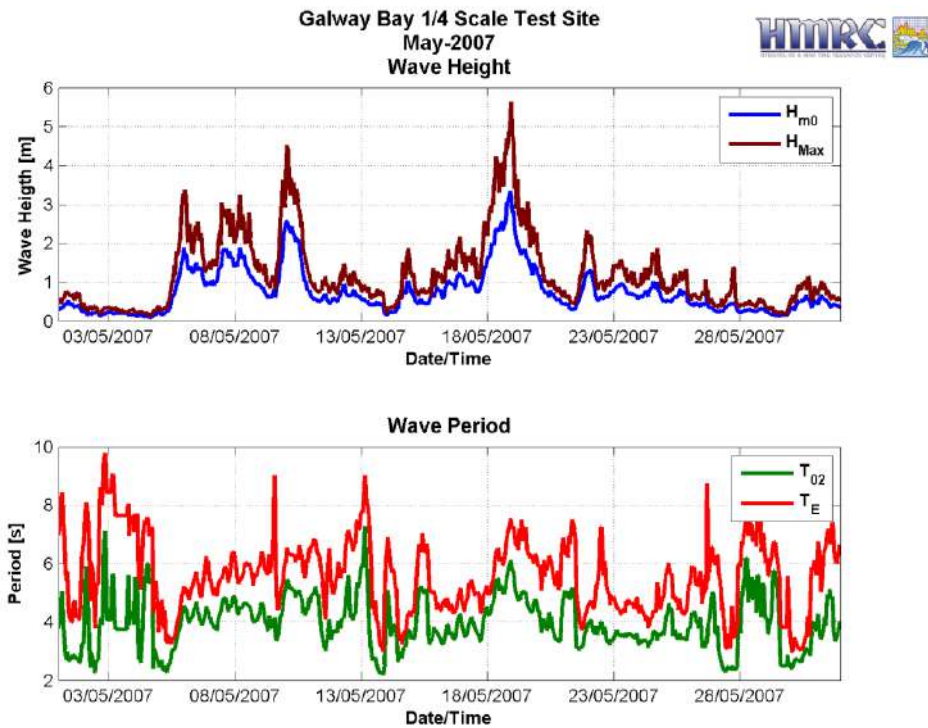


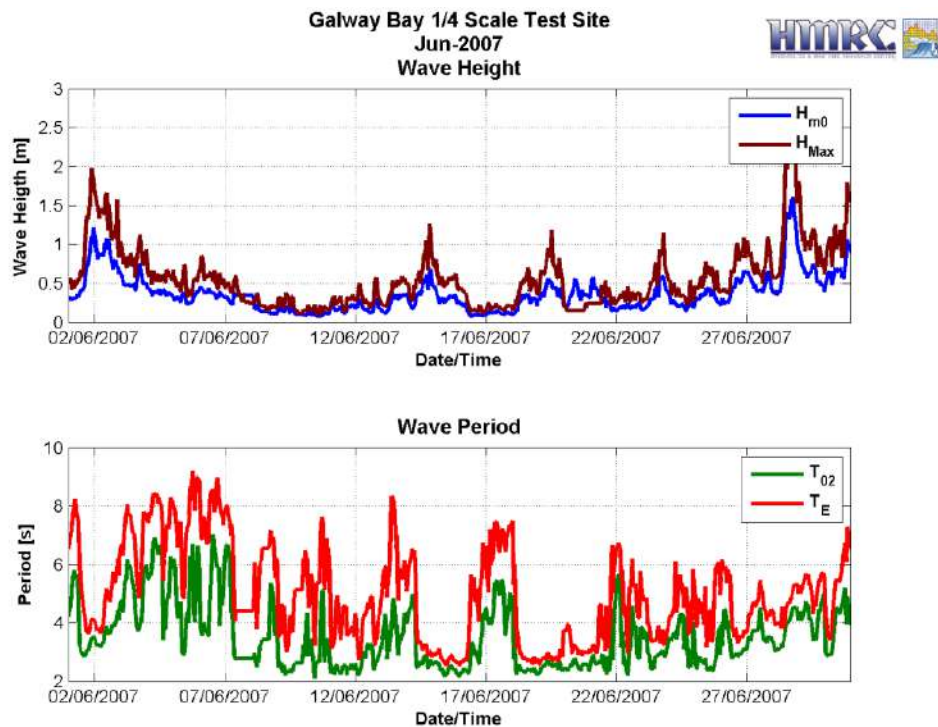
Figure 40 Apr 2007: Wave Height & Period



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



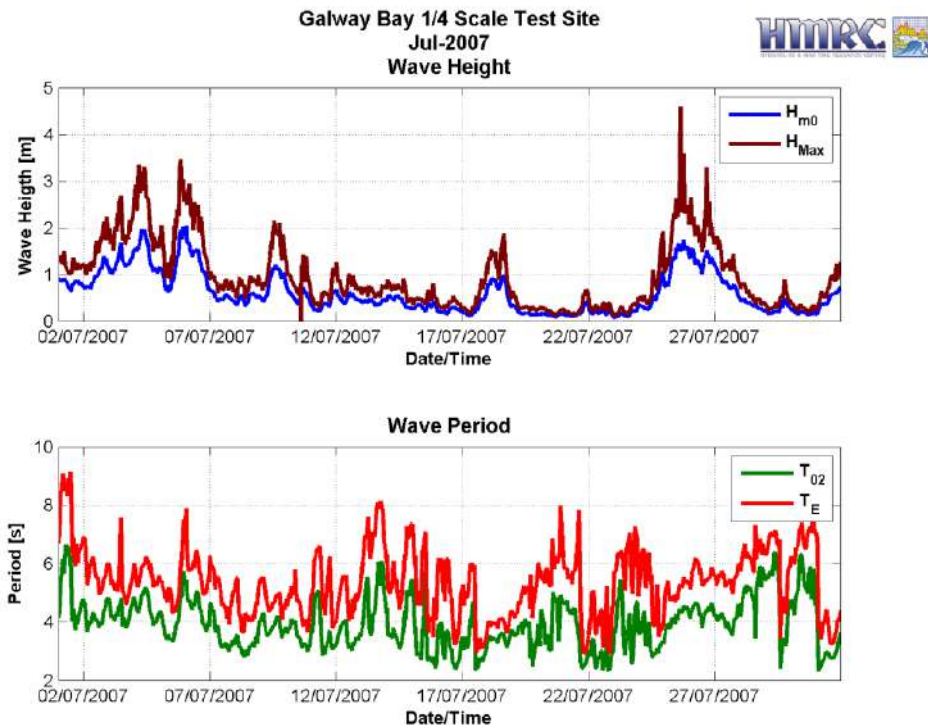
**Figure 41 May 2007: Wave Height & Period**



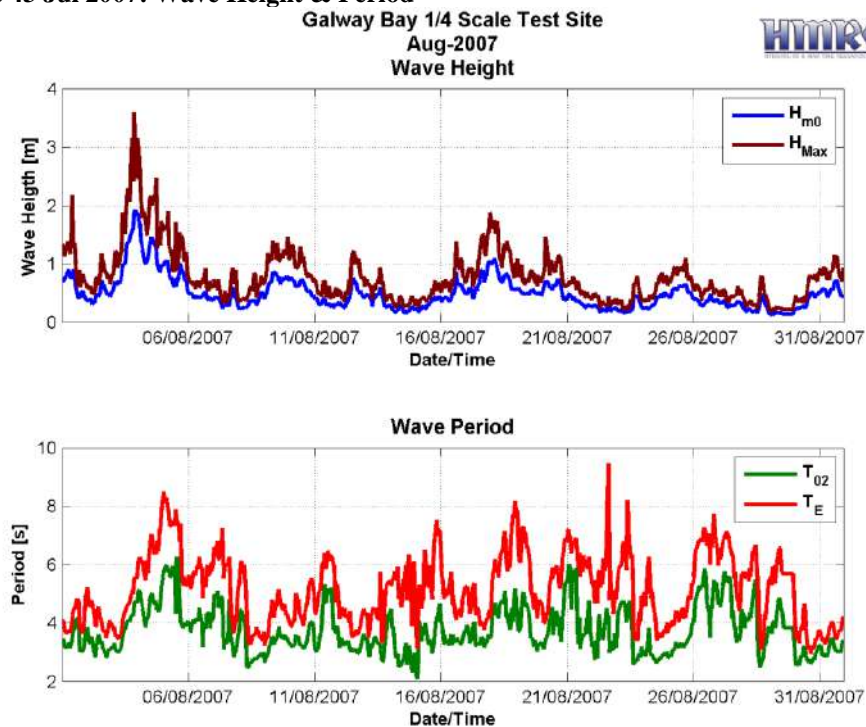
**Figure 42 Jun 2007: Wave Height & Period**



## Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



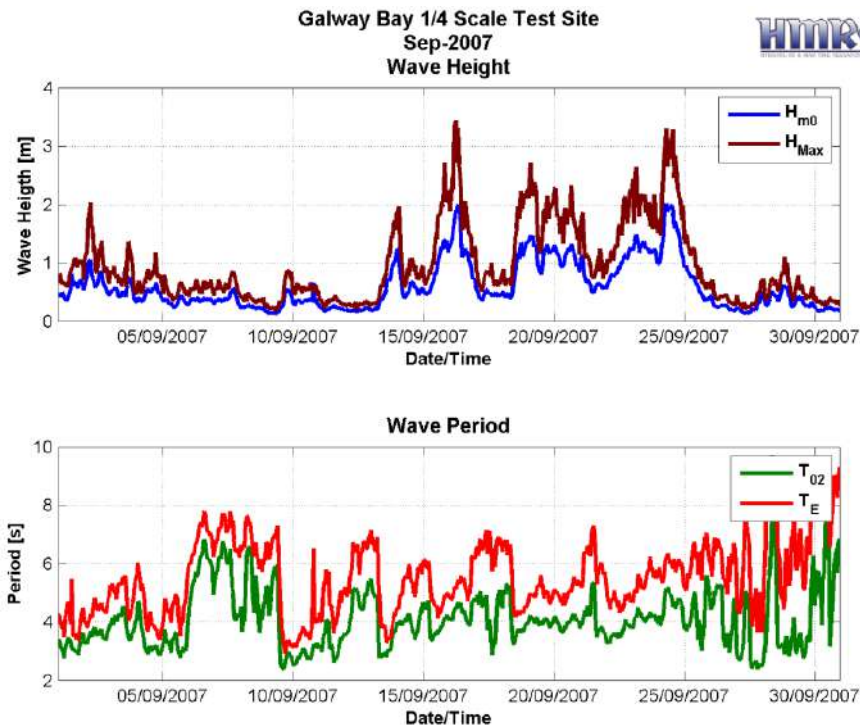
**Figure 43 Jul 2007: Wave Height & Period**



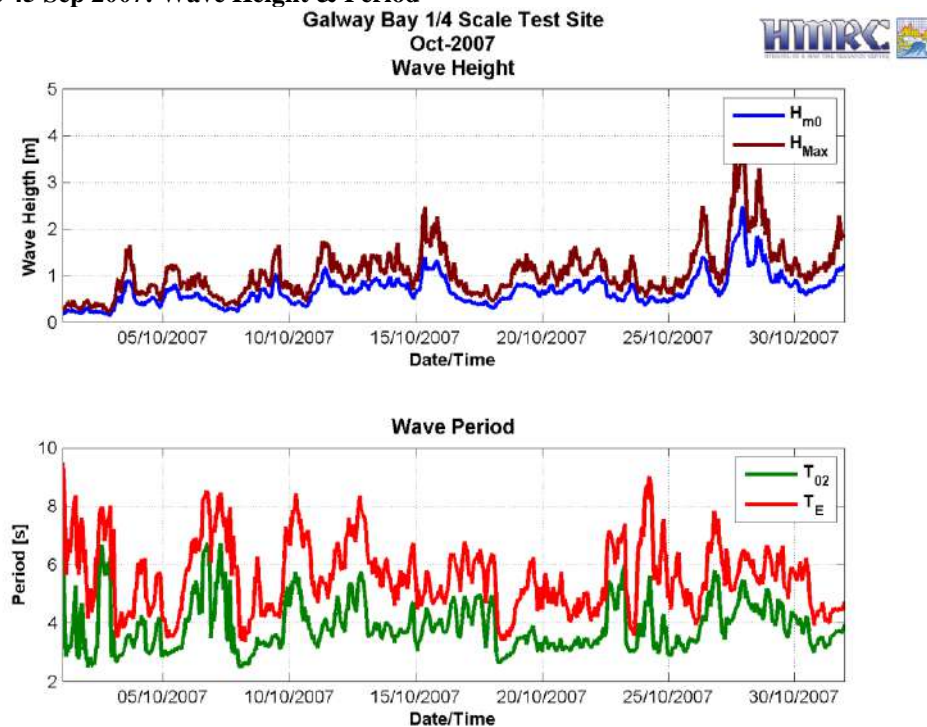
**Figure 44 Aug 2007: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 45 Sep 2007: Wave Height & Period**



**Figure 46 Oct 2007: Wave Height & Period**



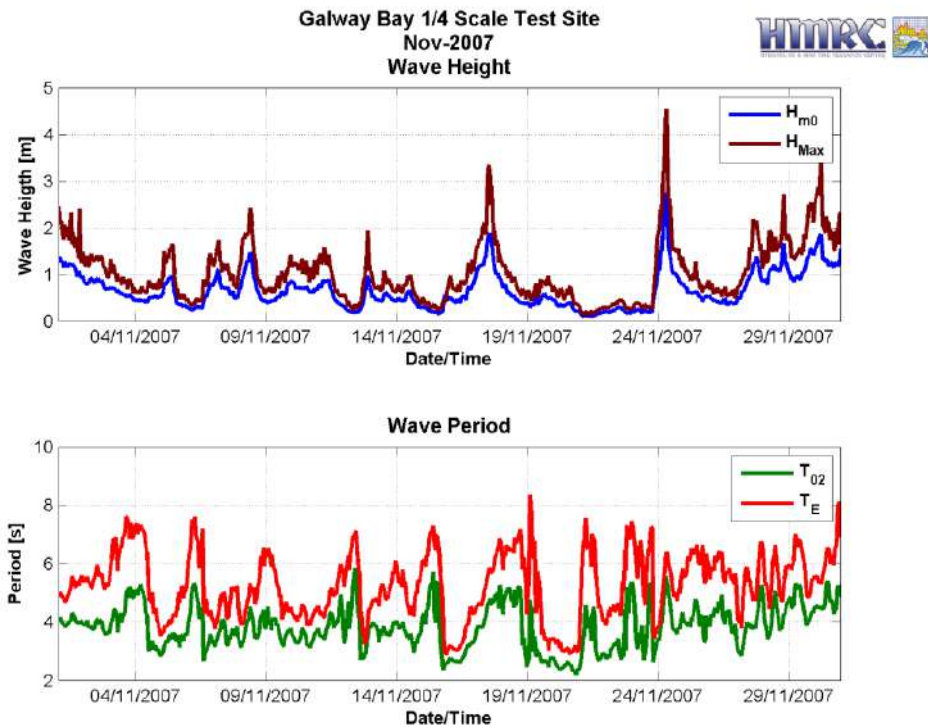


Figure 47 Nov 2007: Wave Height & Period

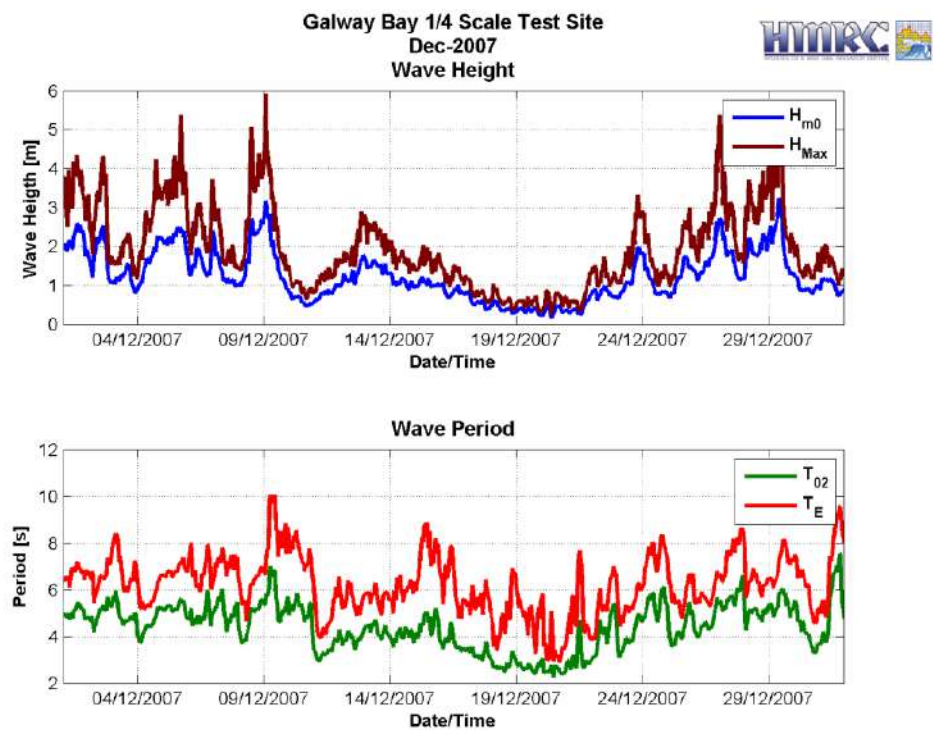


Figure 48 Dec 2007: Wave Height & Period



## 6.2.4 Scatter Plots: 2007

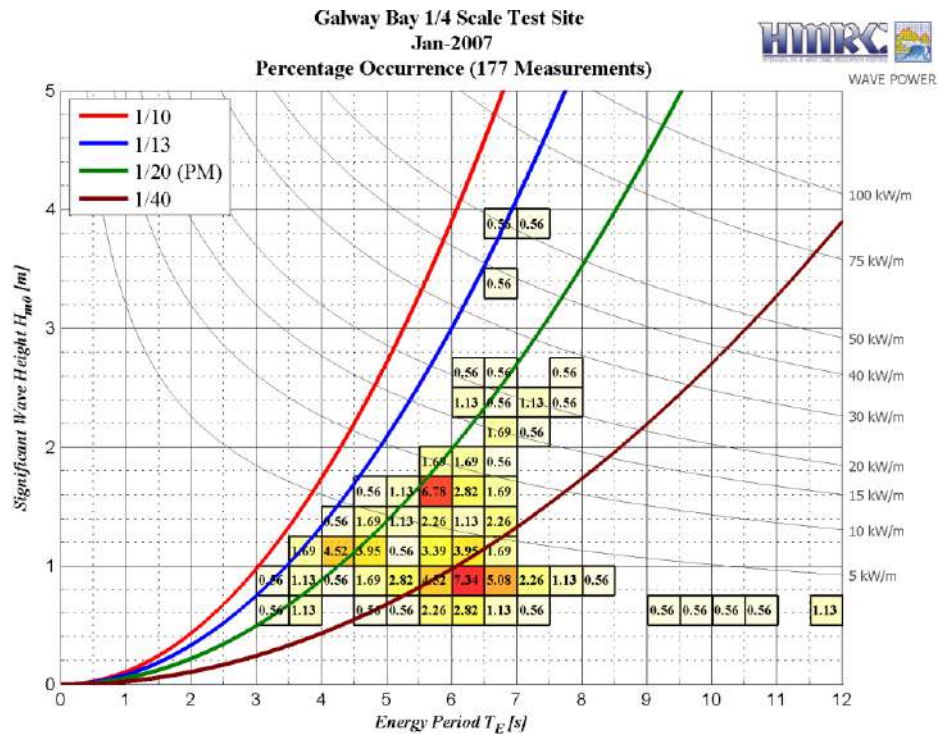


Figure 49 Jan 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

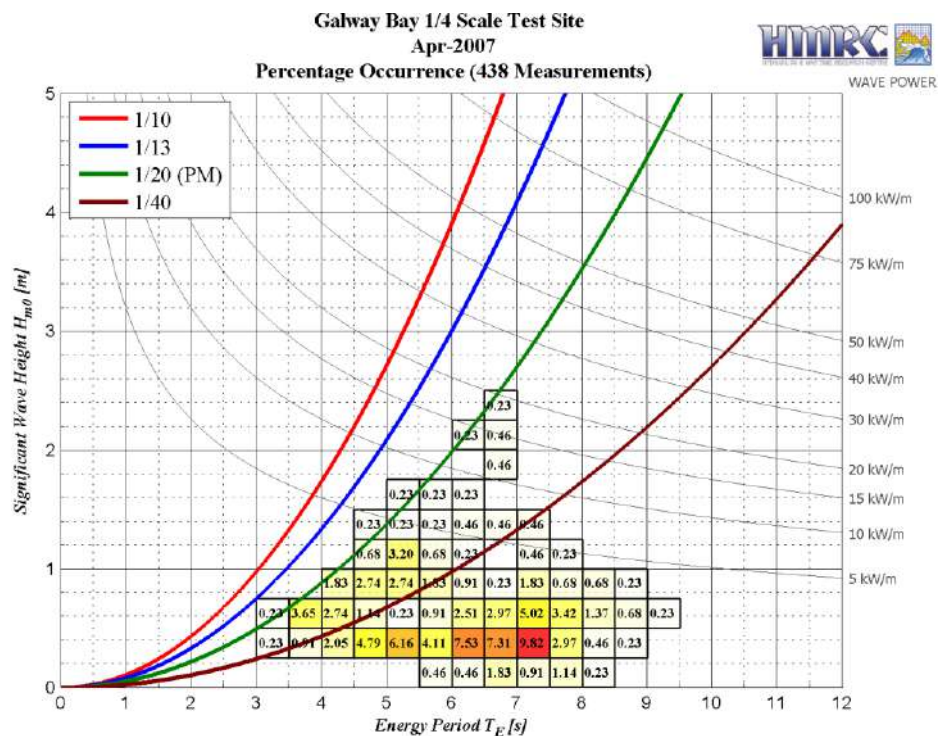


Figure 50 Apr 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



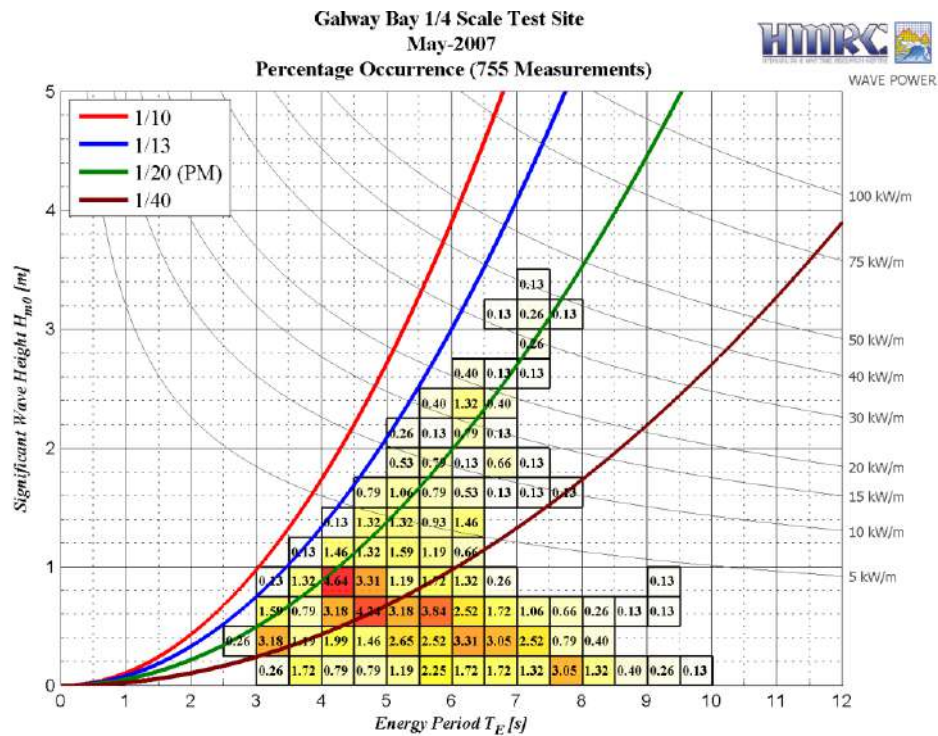


Figure 51 May 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

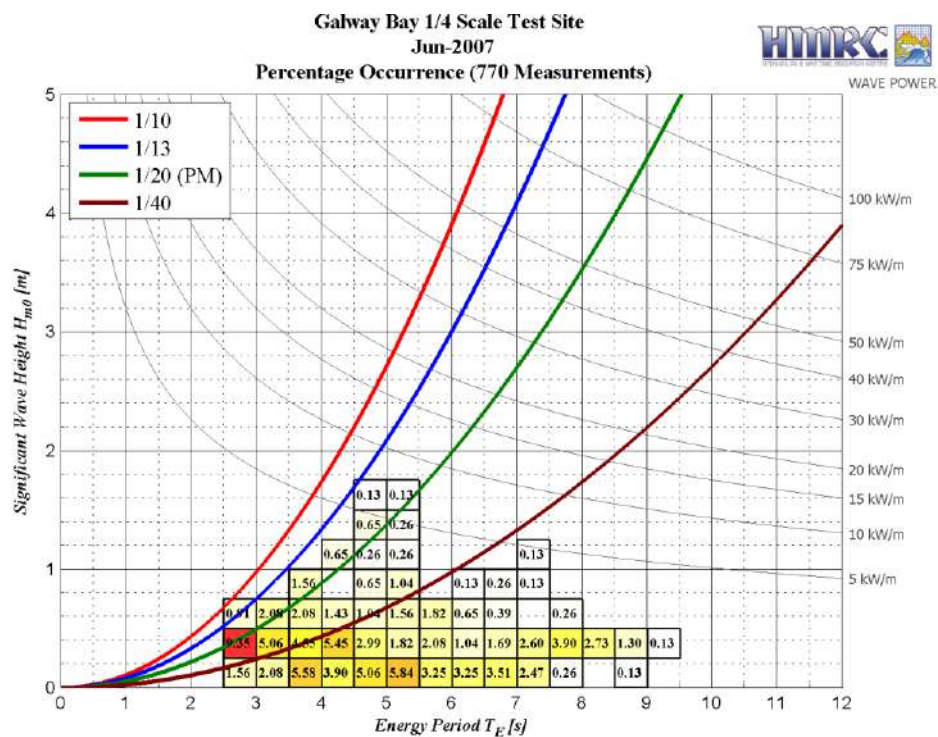


Figure 52 Jun 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

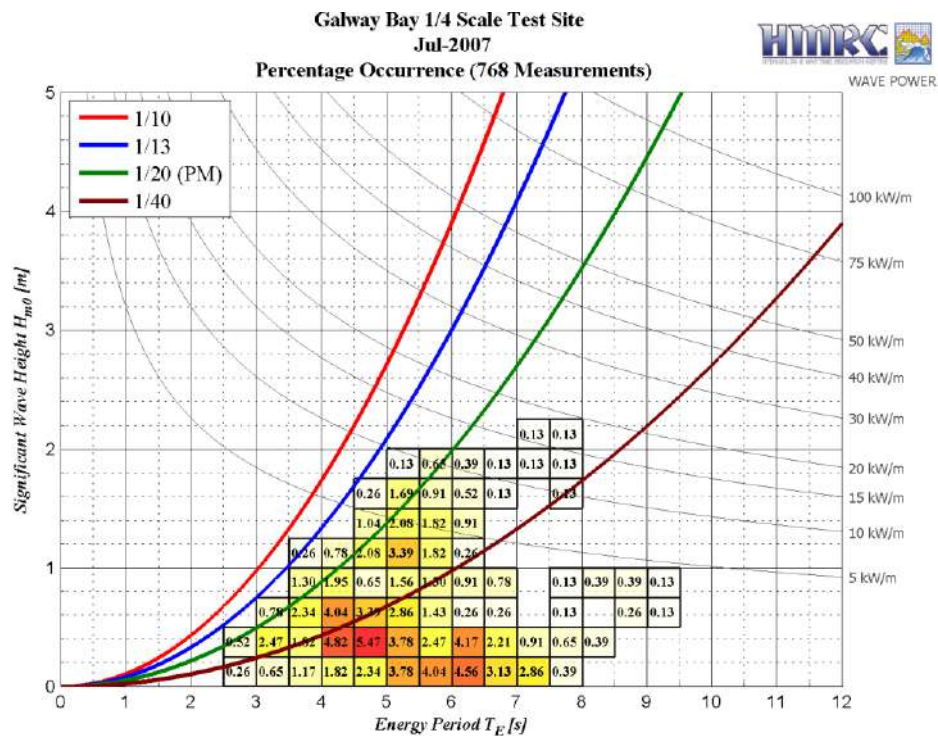


Figure 53 Jul 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

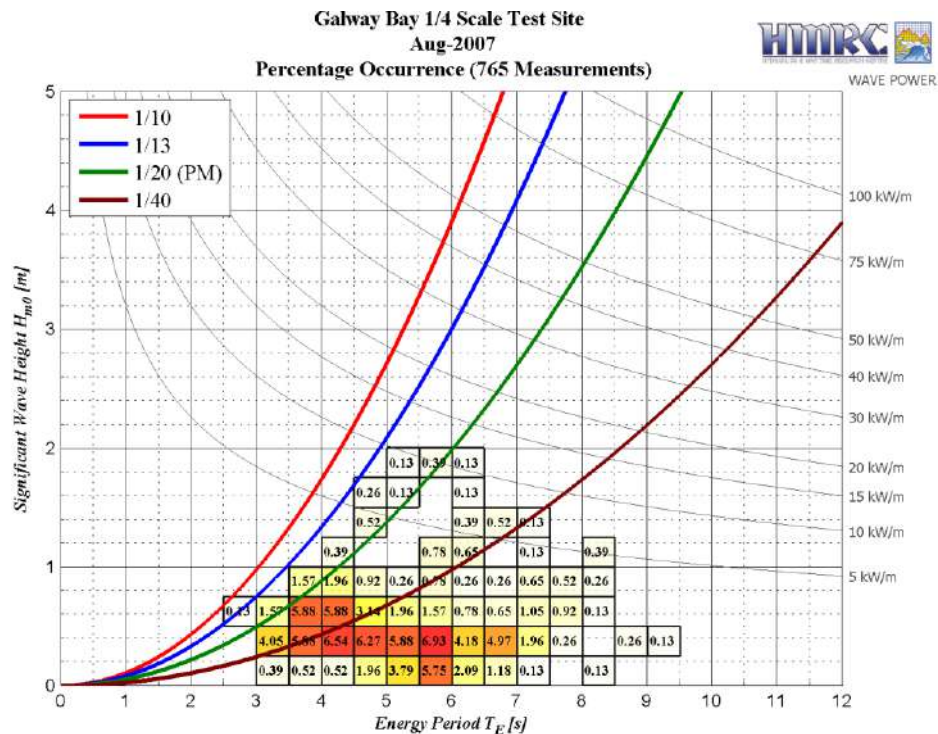


Figure 54 Aug 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

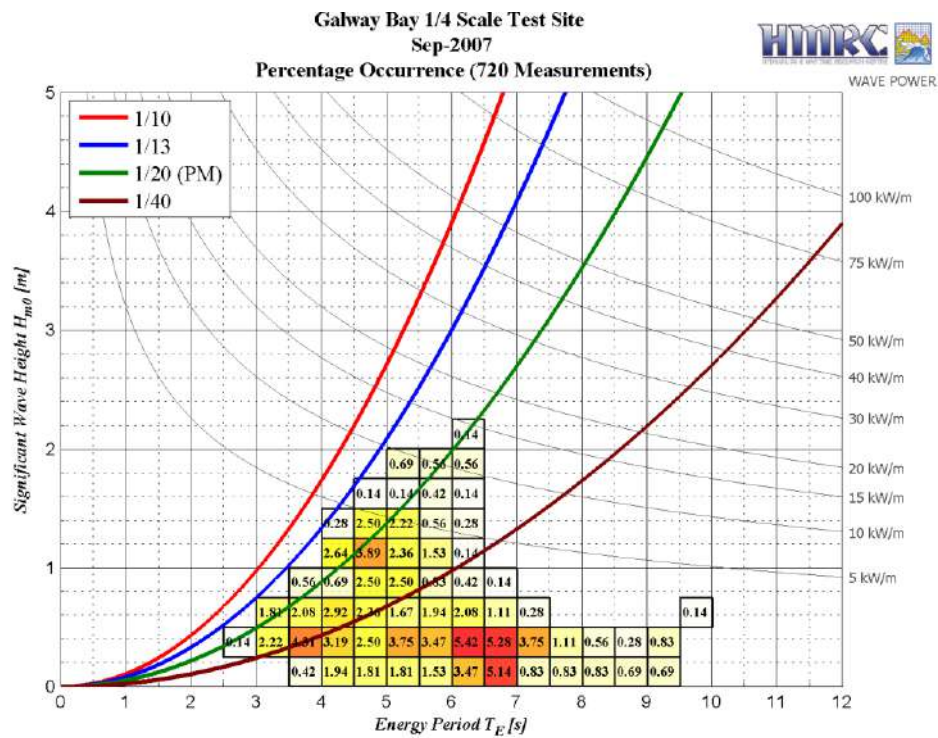


Figure 55 Sep 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

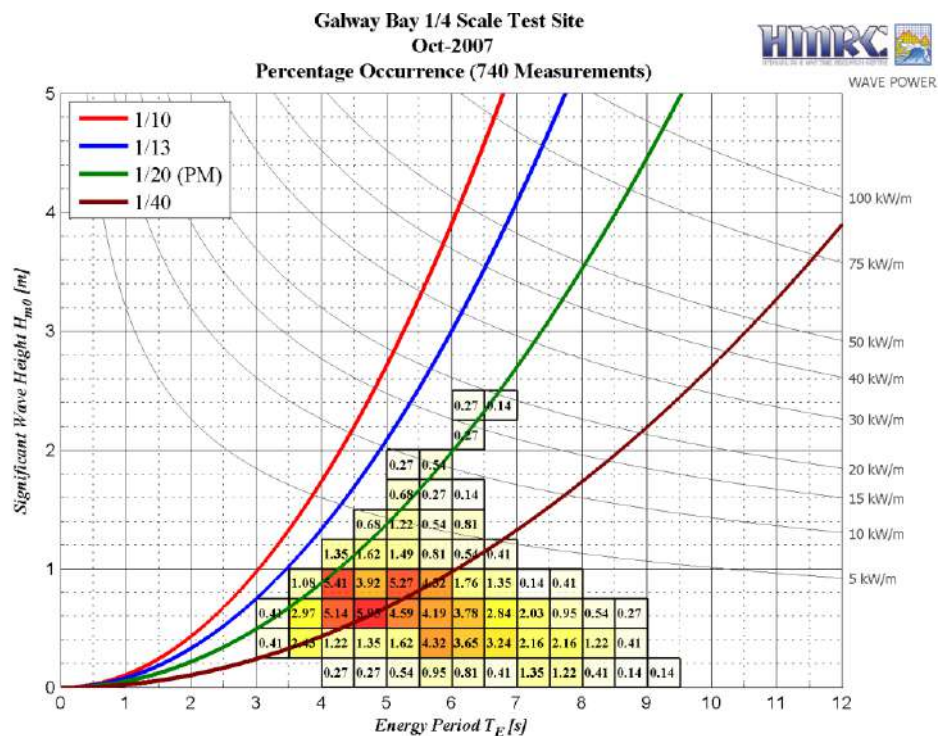


Figure 56 Oct 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

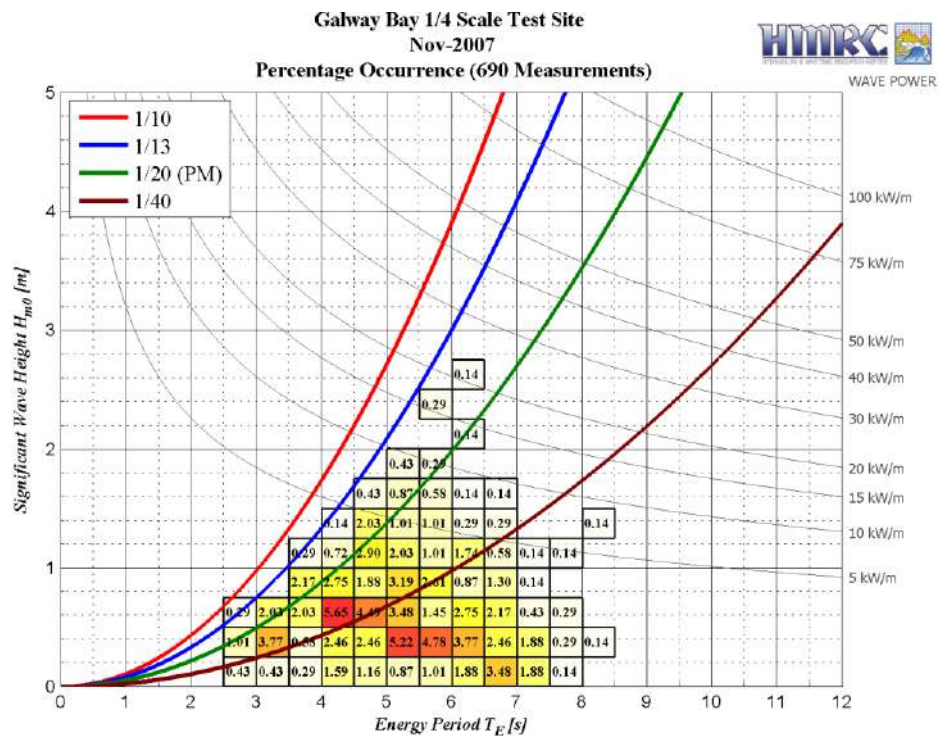


Figure 57 Nov 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

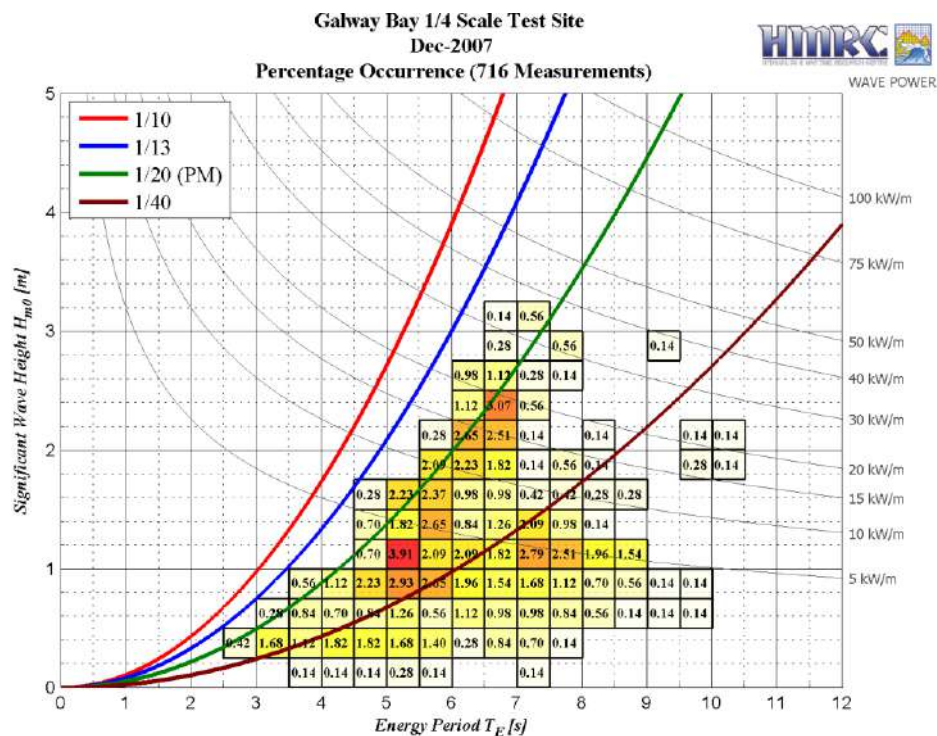


Figure 58 Dec 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



### 6.2.5 Time Series: 2008

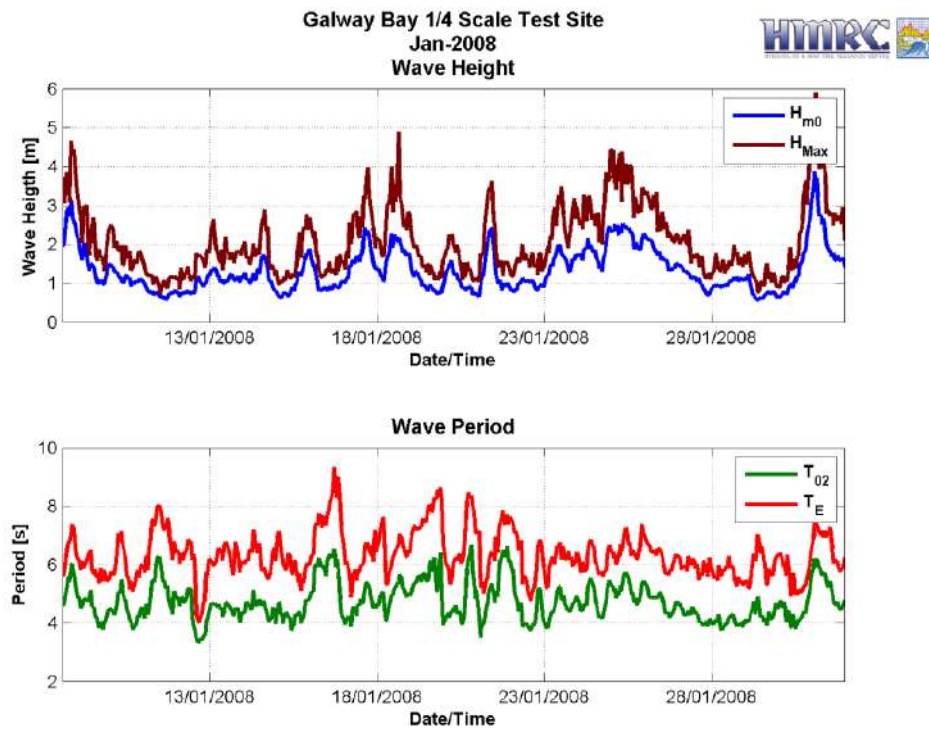


Figure 59 Jan 2008: Wave Height & Period

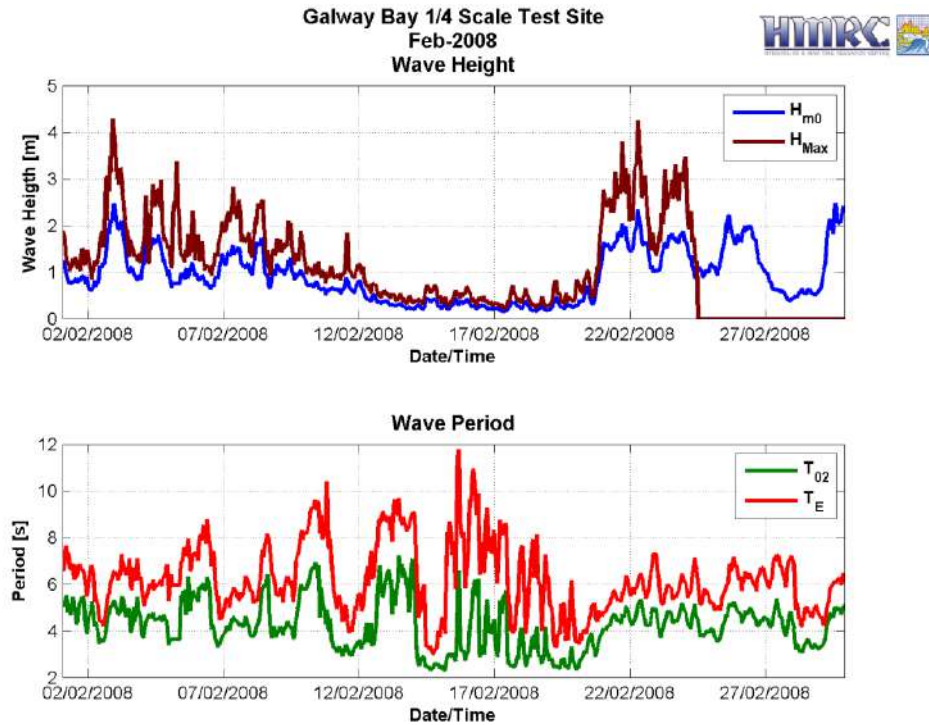
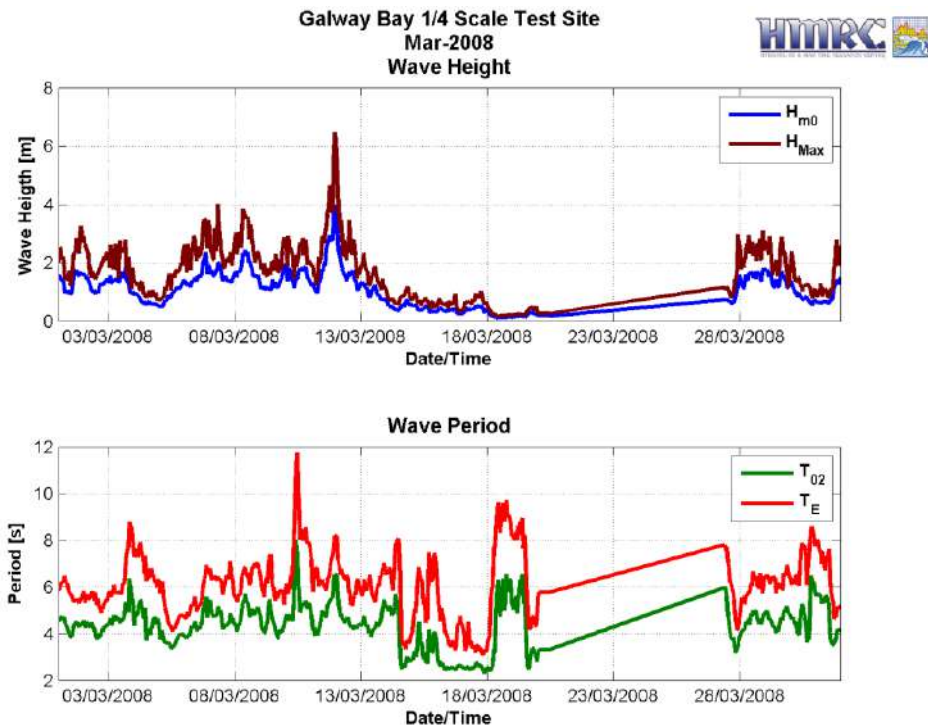


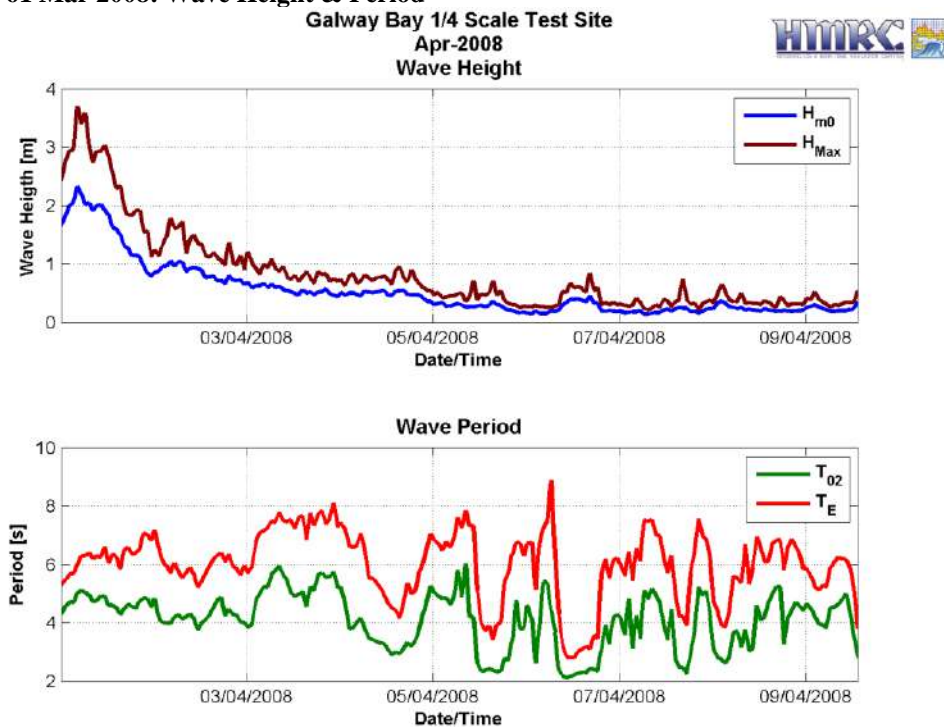
Figure 60 Feb 2008: Wave Height & Period



# Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site

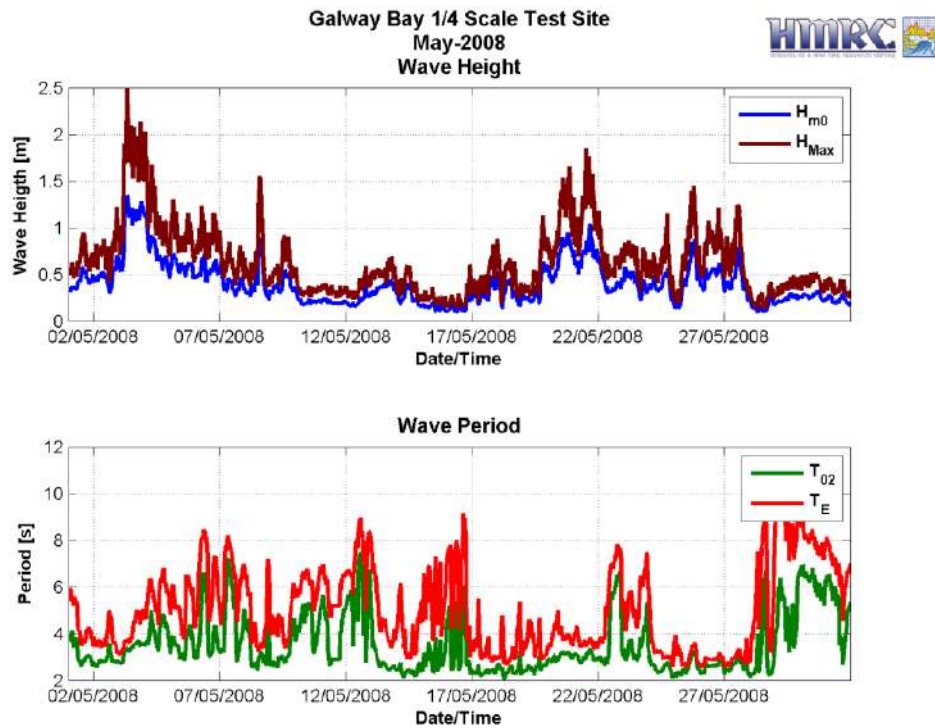


**Figure 61 Mar 2008: Wave Height & Period**

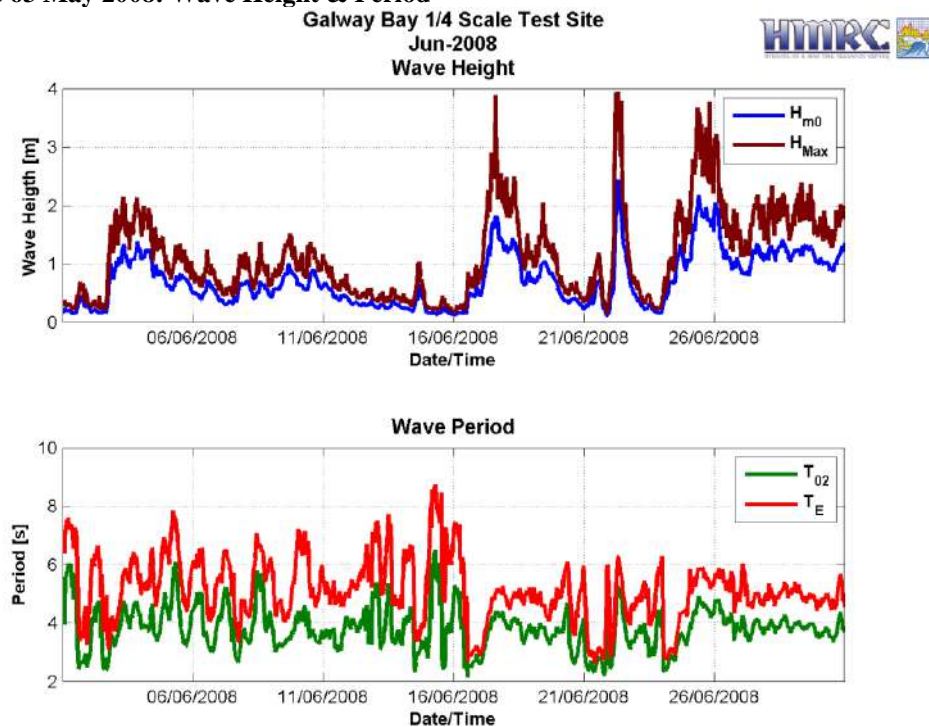


**Figure 62 Apr 2008: Wave Height & Period**





**Figure 63 May 2008: Wave Height & Period**



**Figure 64 Jun 2008: Wave Height & Period**



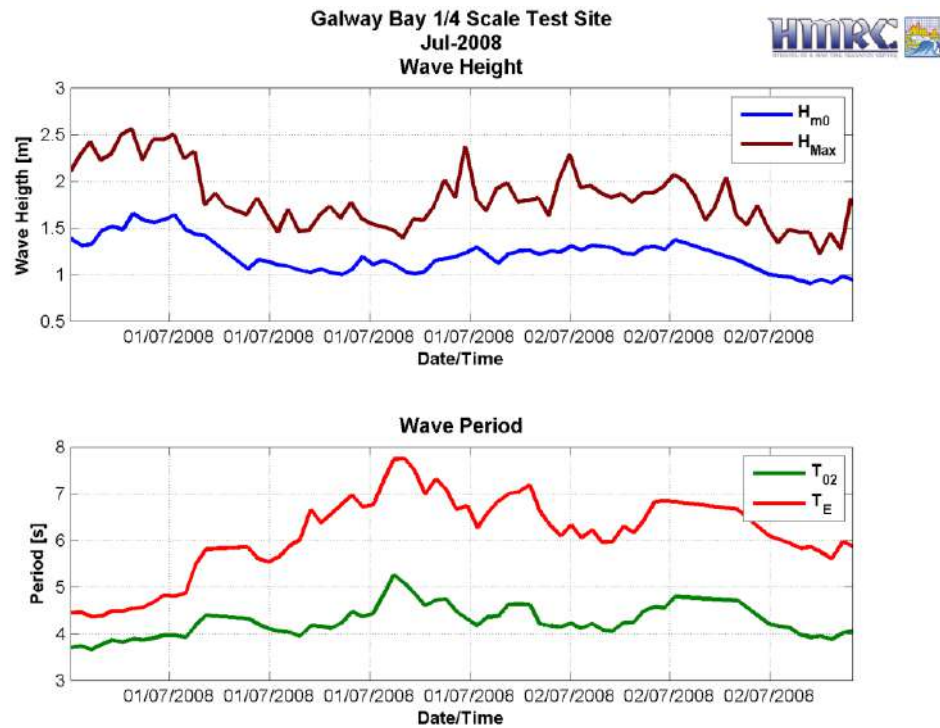


Figure 65 Jul 2008: Wave Height & Period

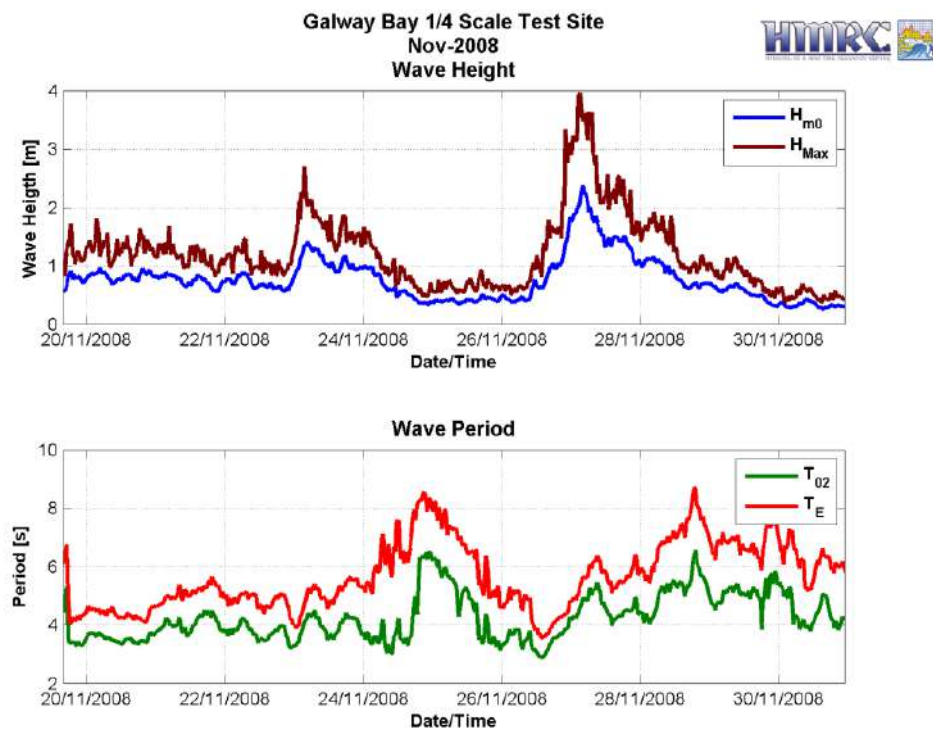
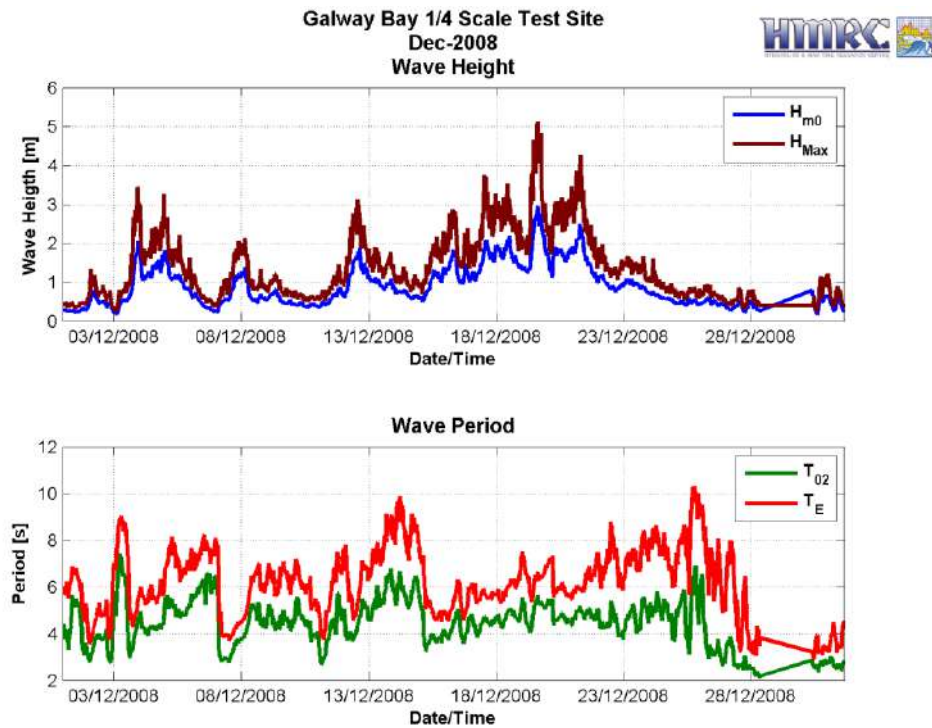


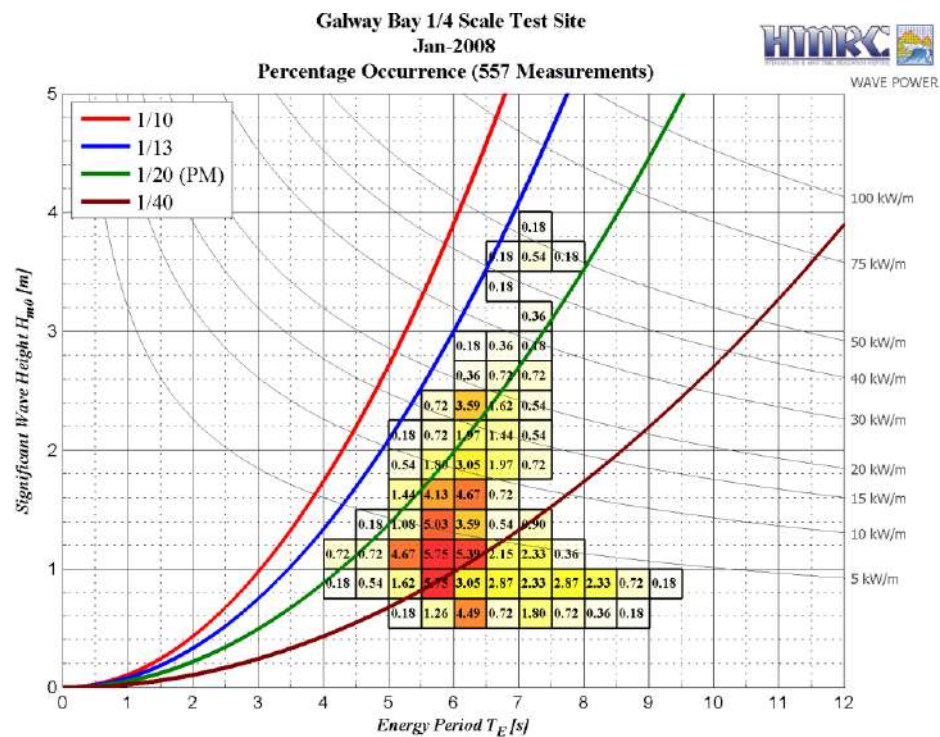
Figure 66 Nov 2008: Wave Height & Period





**Figure 67 Dec 2008: Wave Height & Period**

### 6.2.6 Scatter Plots: 2008



**Figure 68 Jan 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

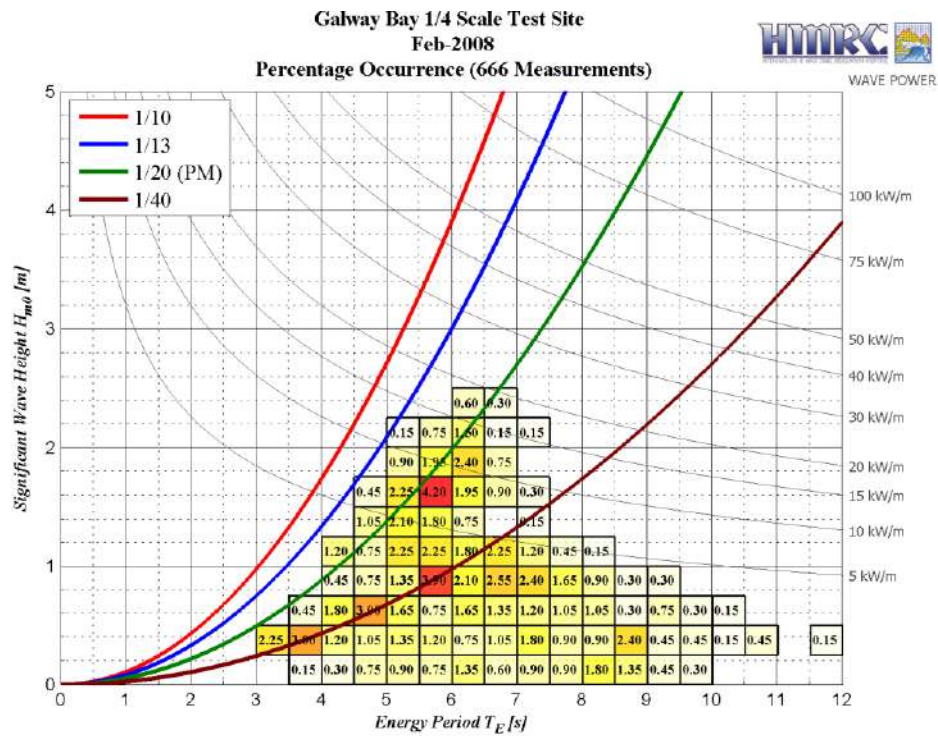


Figure 69 Feb 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

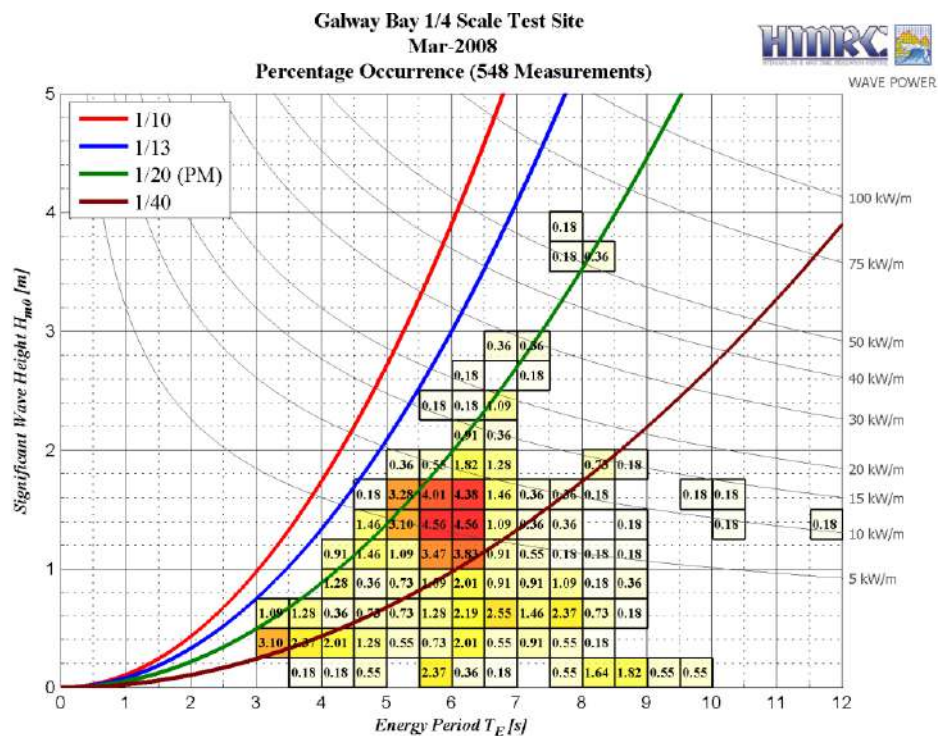


Figure 70 Mar 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site

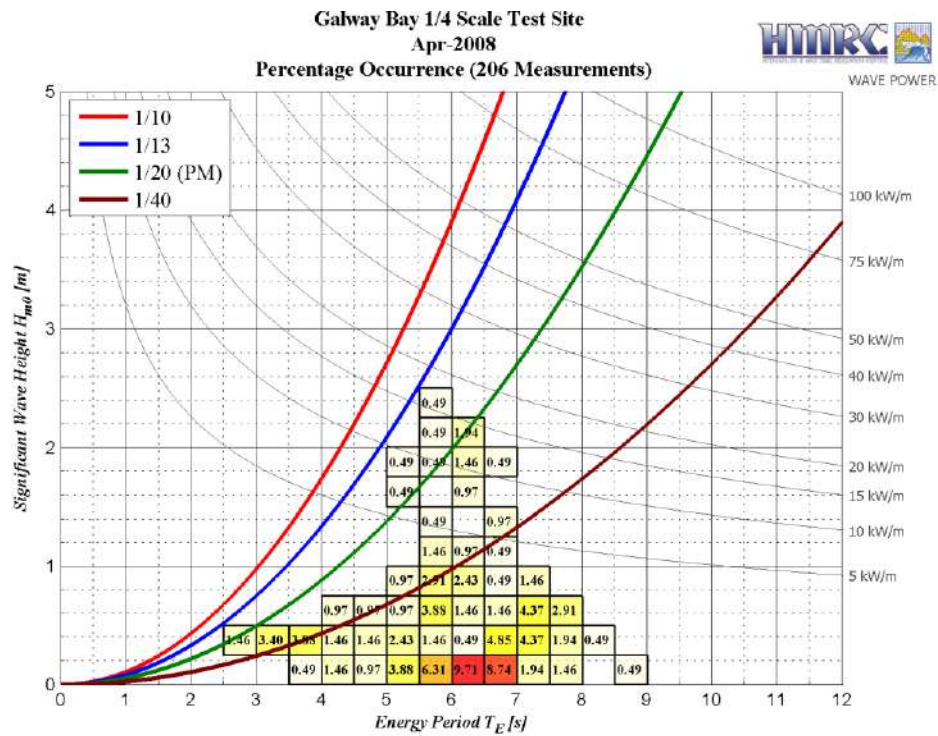


Figure 71 Apr 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

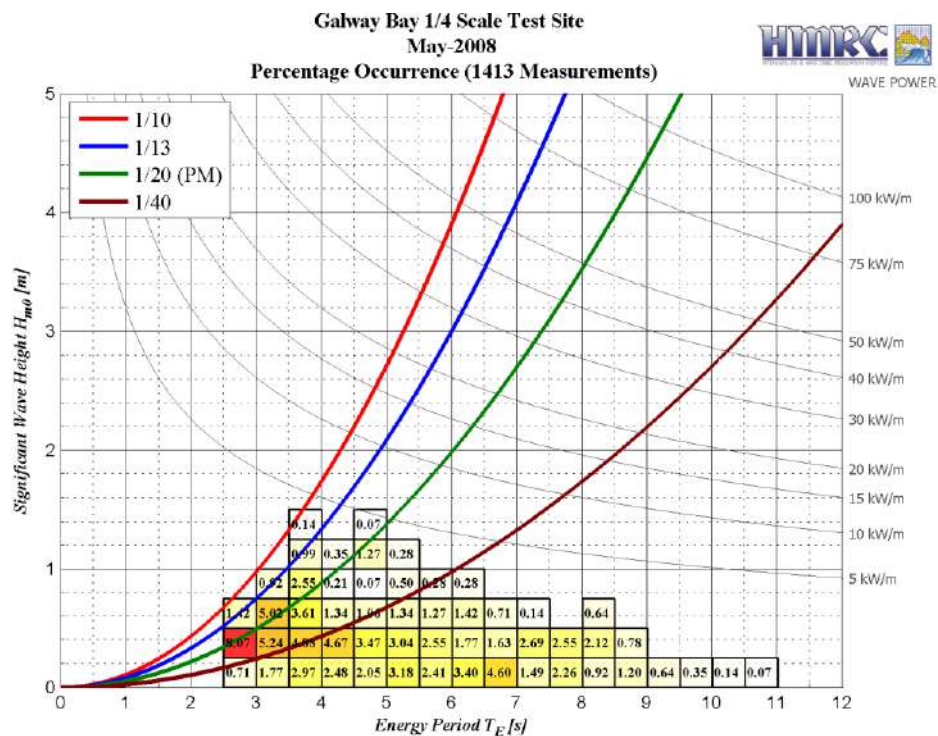


Figure 72 May 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



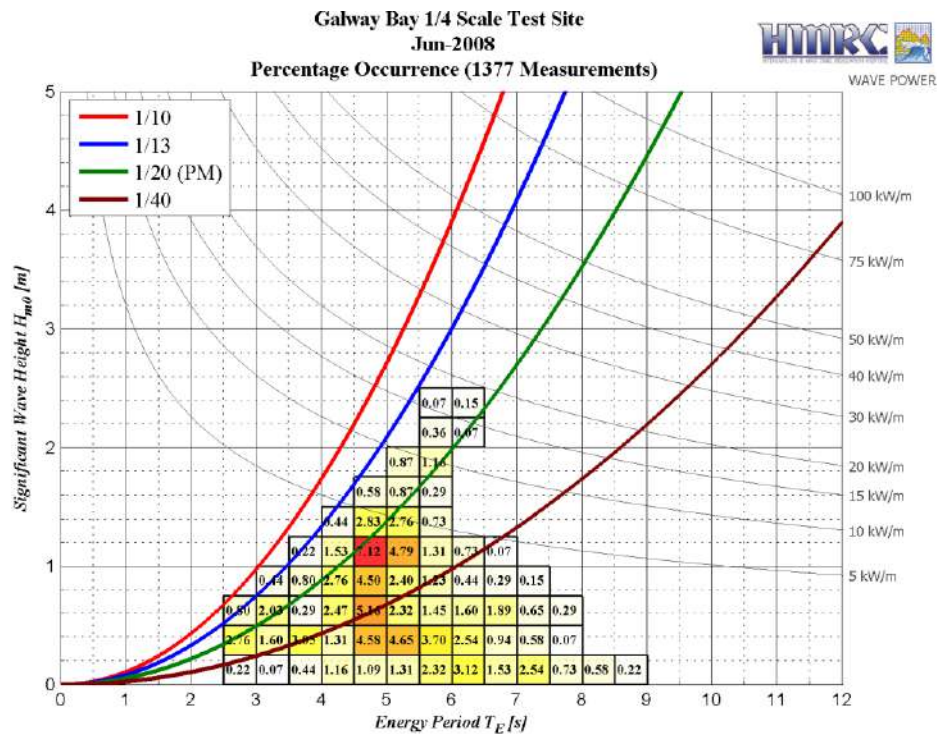


Figure 73 Jun 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

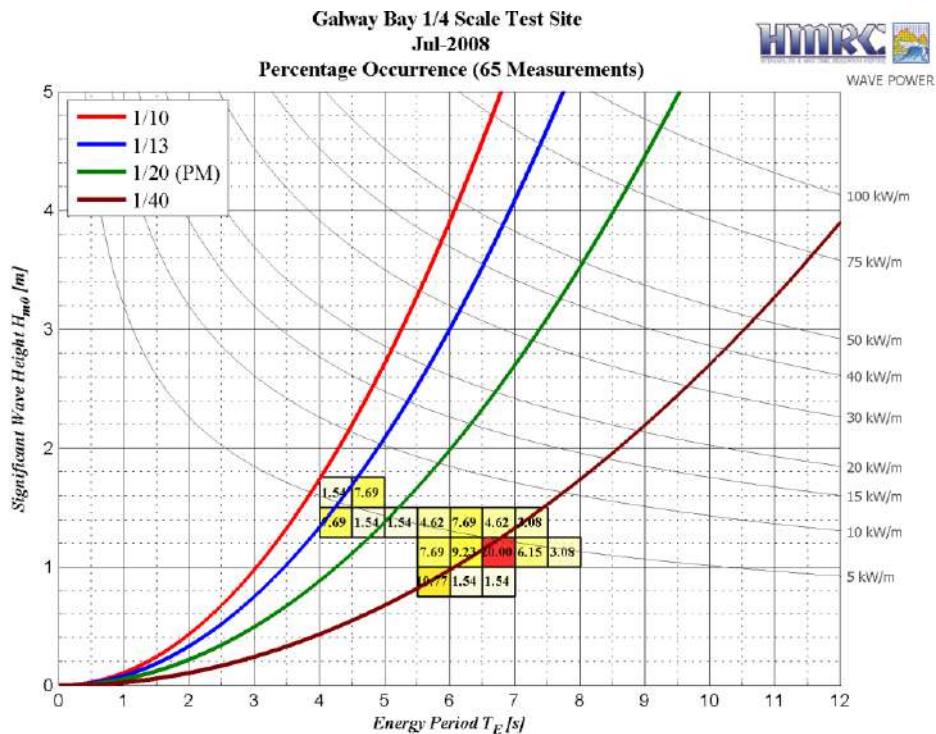


Figure 74 Jul 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

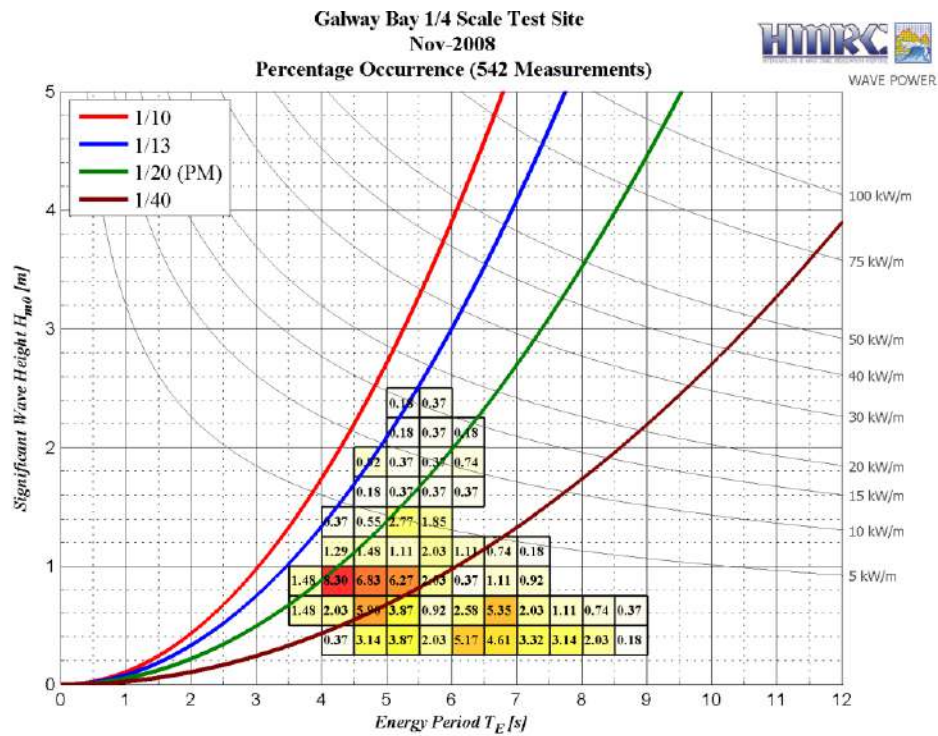


Figure 75 Nov 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

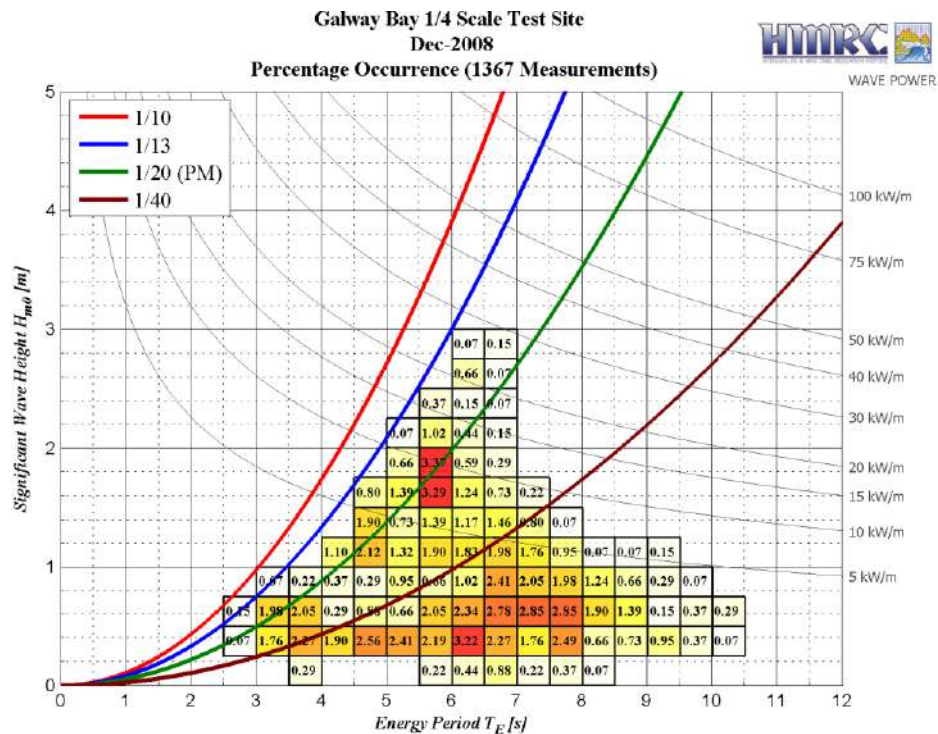


Figure 76 Dec 2008: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



### 6.2.7 Time Series: 2009

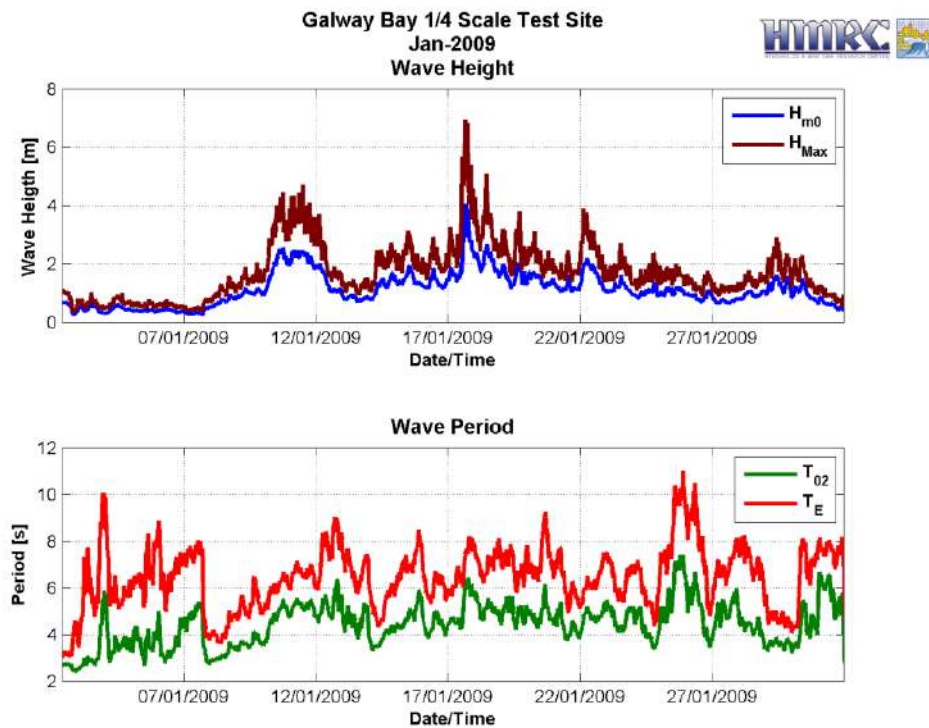


Figure 77 Jan 2009: Wave Height & Period

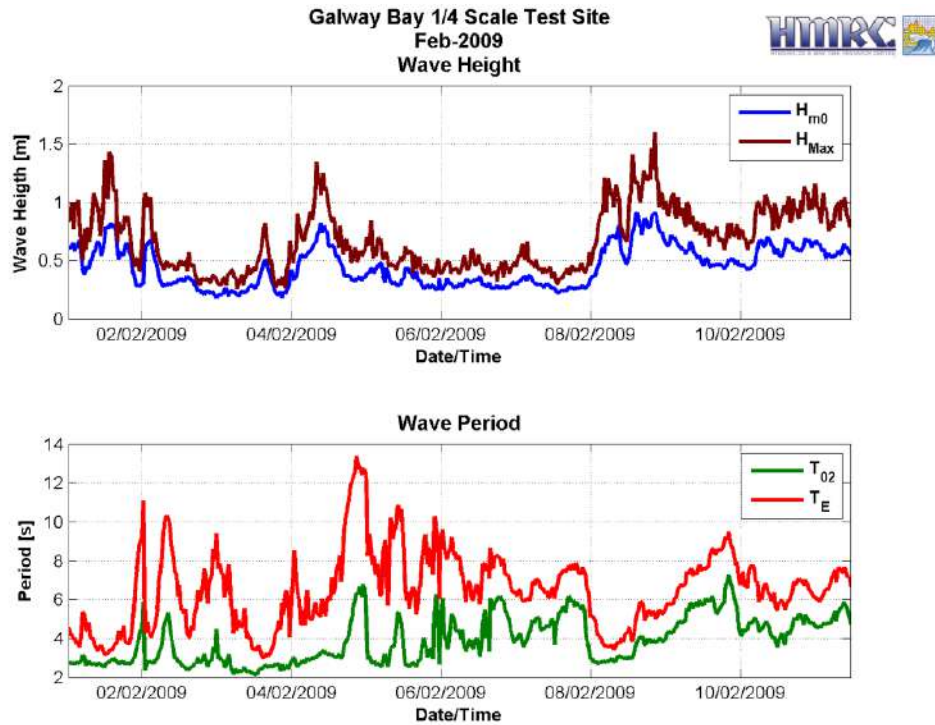


Figure 78 Feb 2009: Wave Height & Period



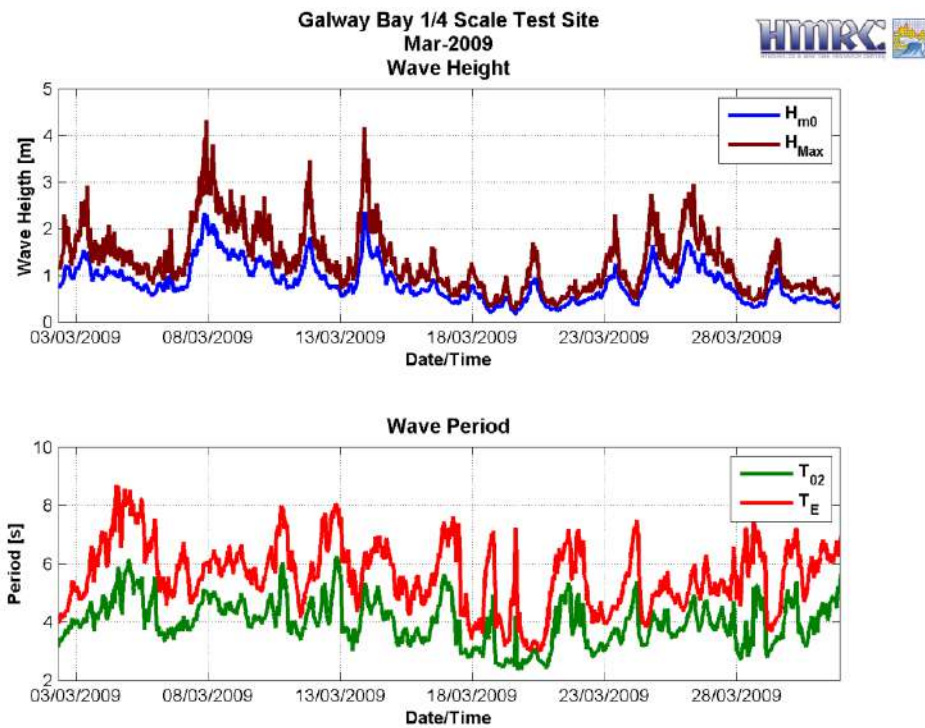


Figure 79 Mar 2009: Wave Height & Period

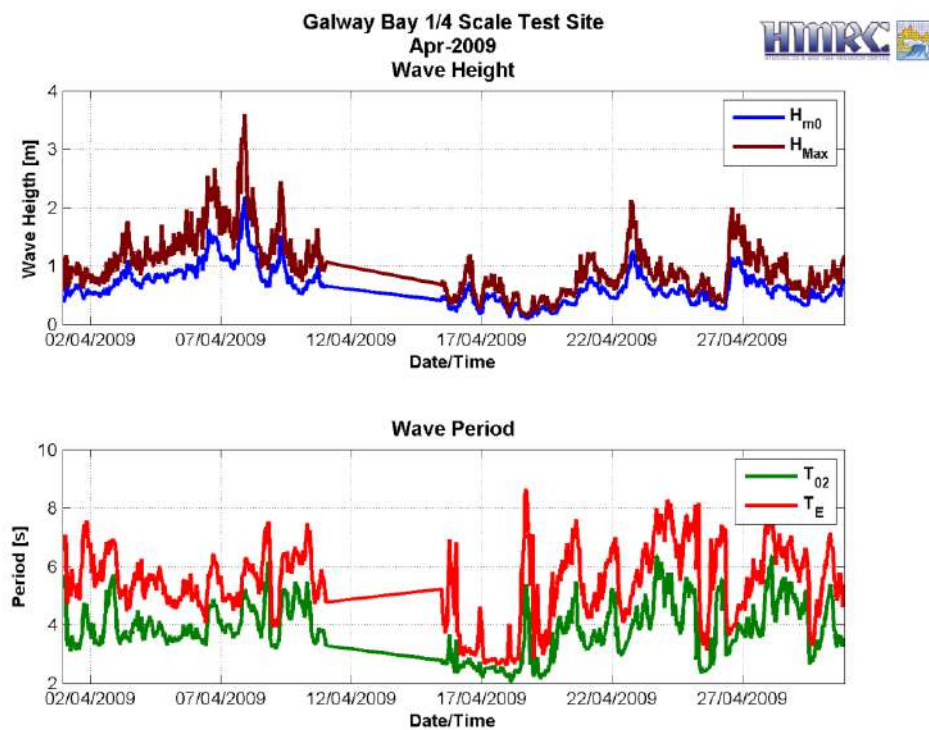
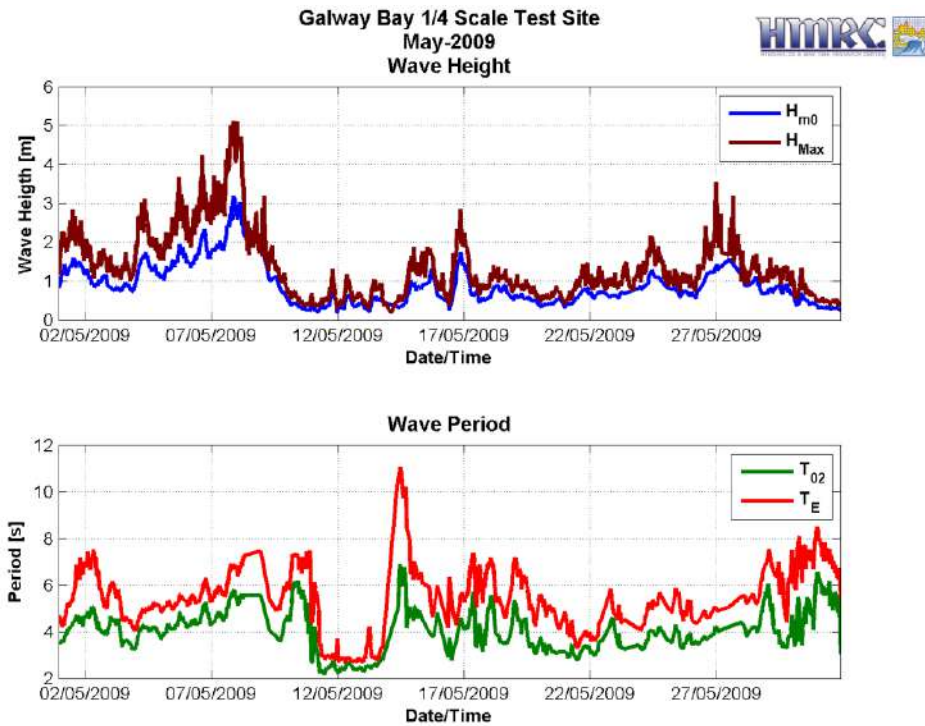


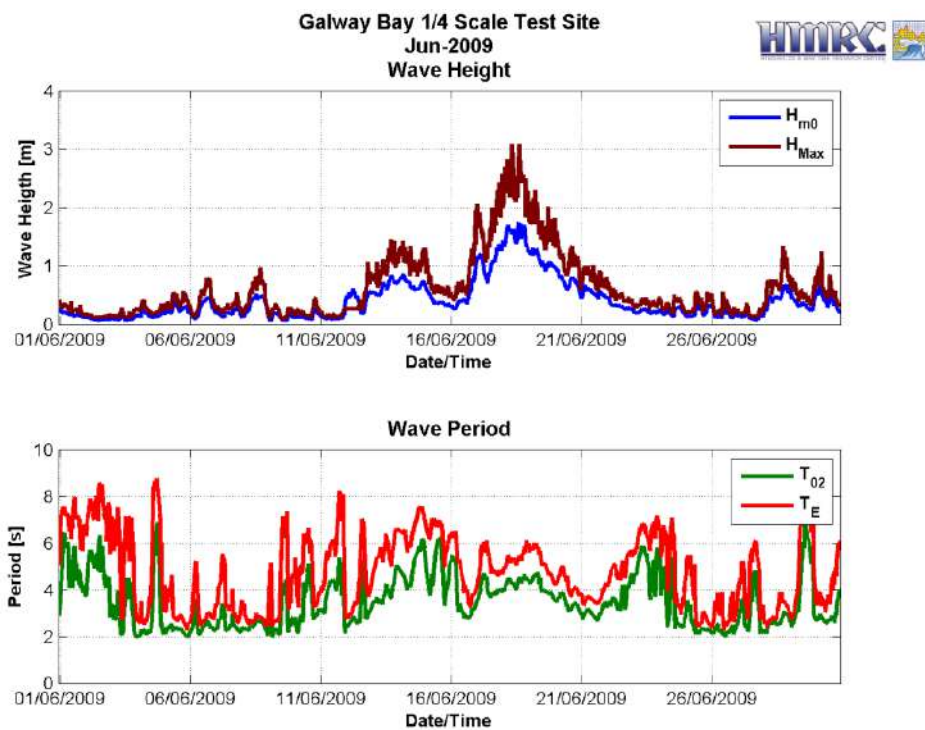
Figure 80 Apr 2009: Wave Height & Period



# Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



**Figure 81 May 2009: Wave Height & Period**



**Figure 82 Jun 2009: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

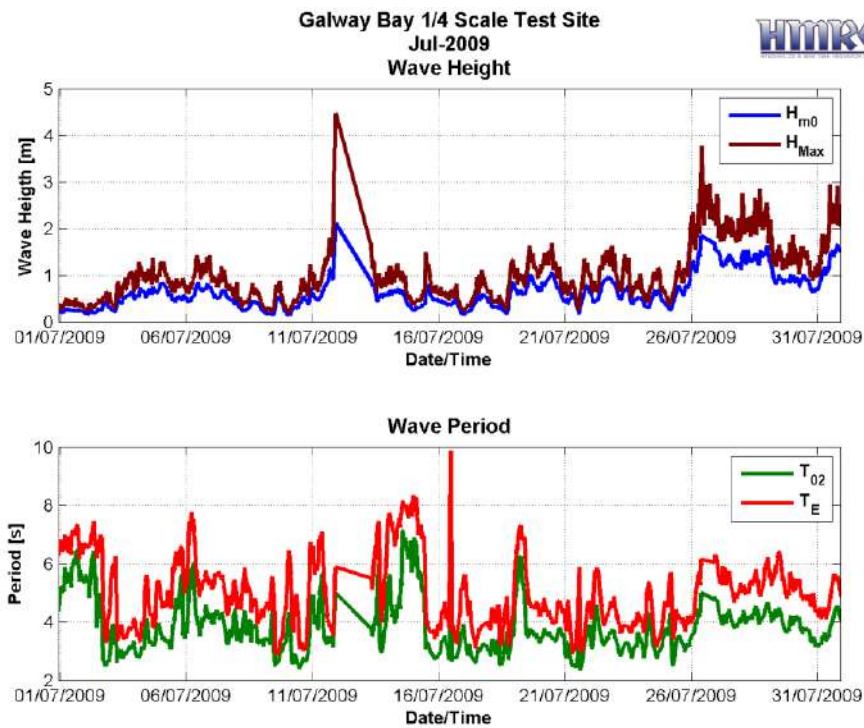


Figure 83 Jul 2009: Wave Height & Period

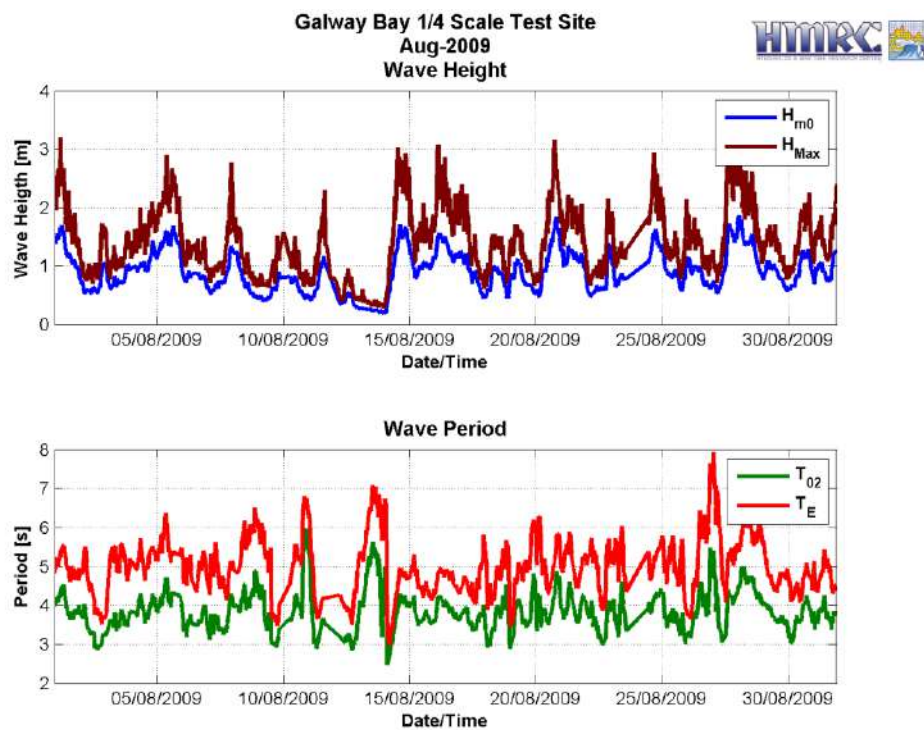
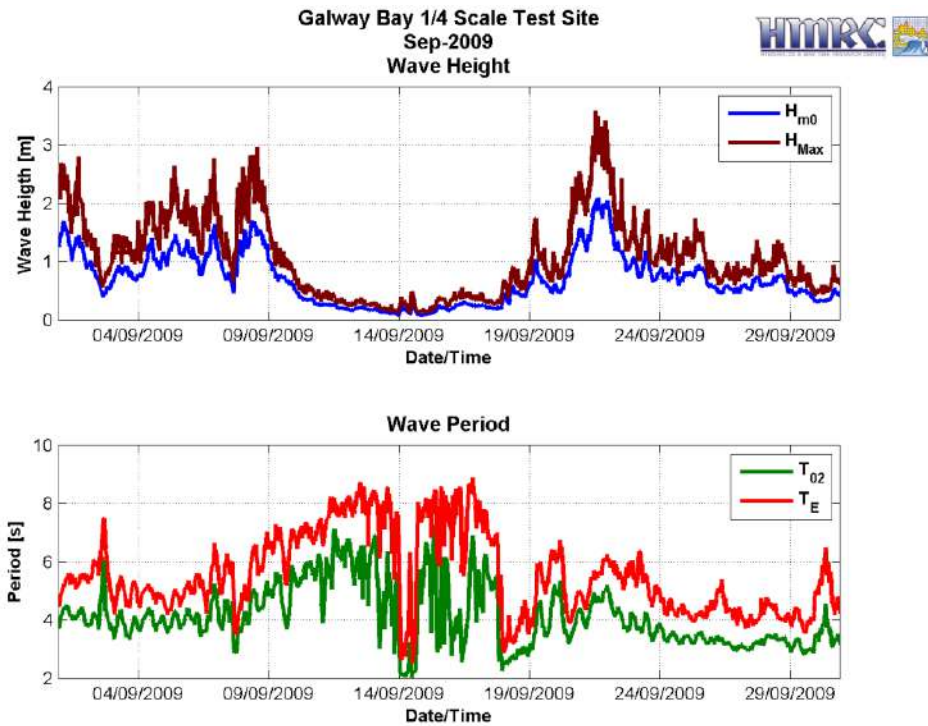


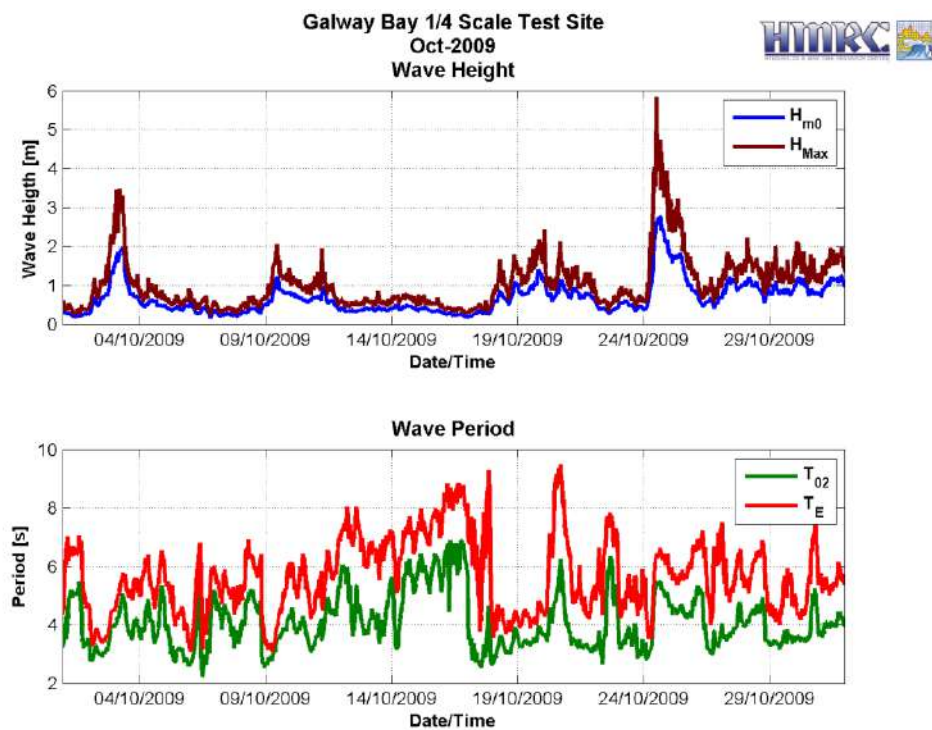
Figure 84 Aug 2009: Wave Height & Period



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 85 Sep 2009: Wave Height & Period**



**Figure 86 Oct 2009: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

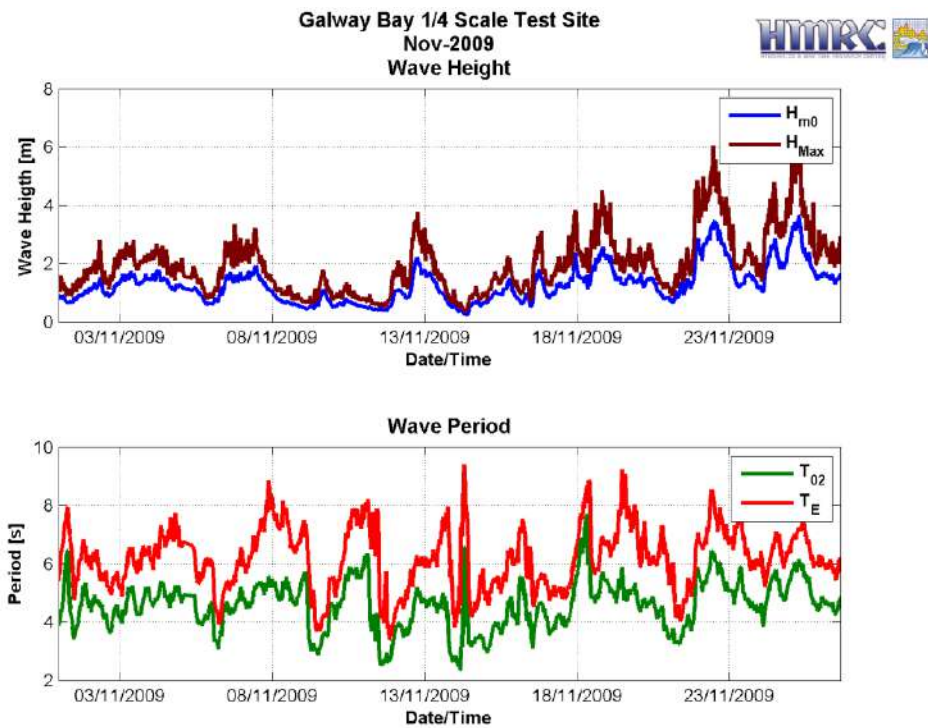


Figure 87 Nov 2009: Wave Height & Period

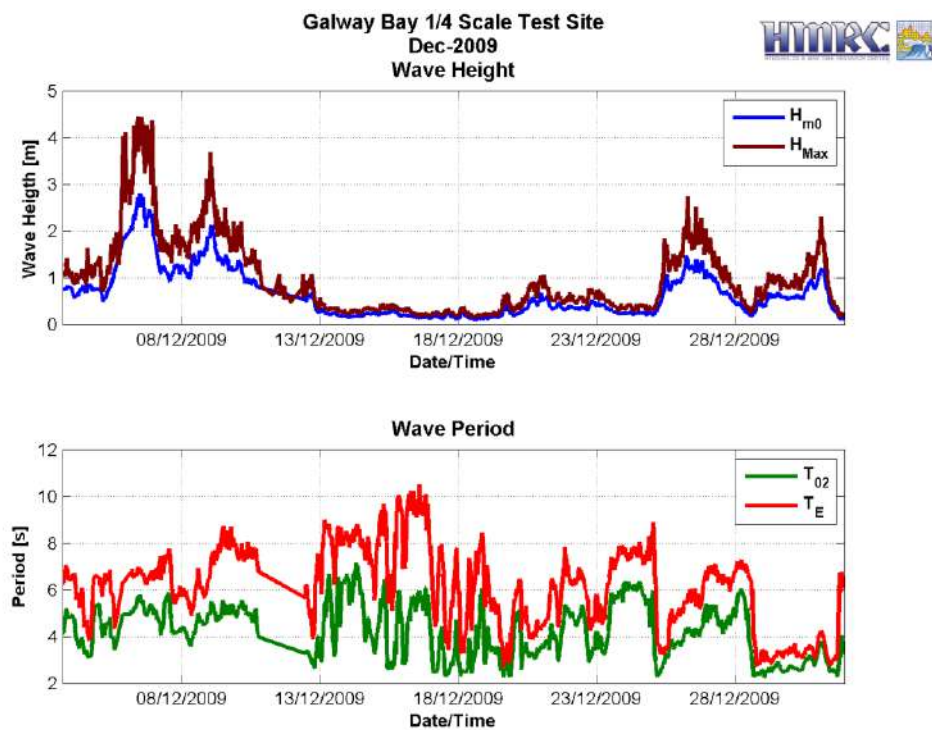


Figure 88 Dec 2009: Wave Height & Period







# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

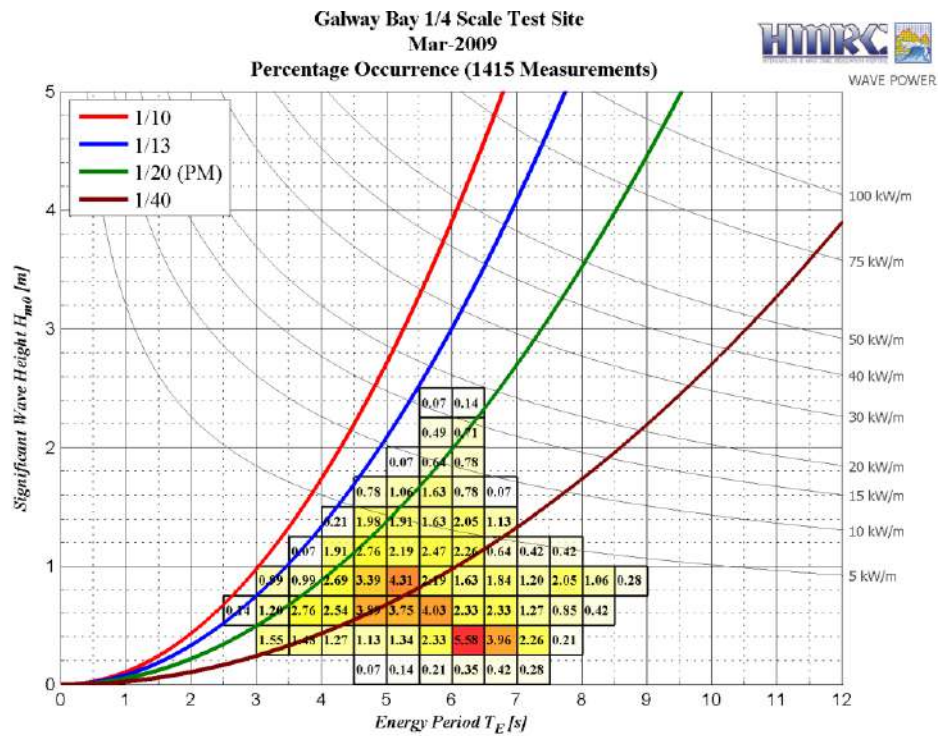


Figure 91 Mar 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

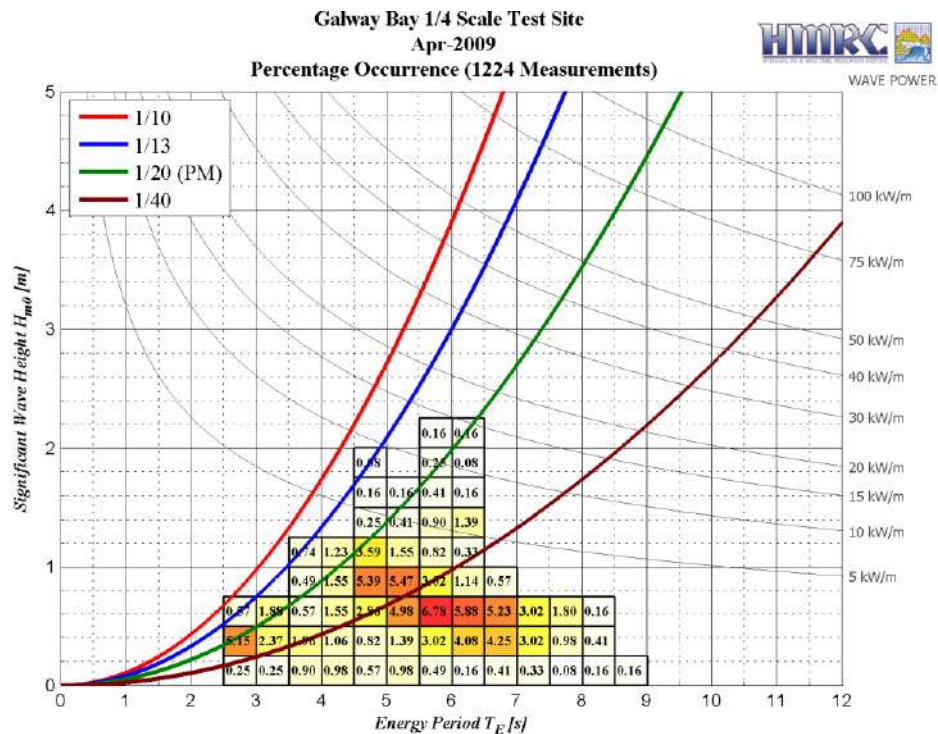


Figure 92 Apr 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

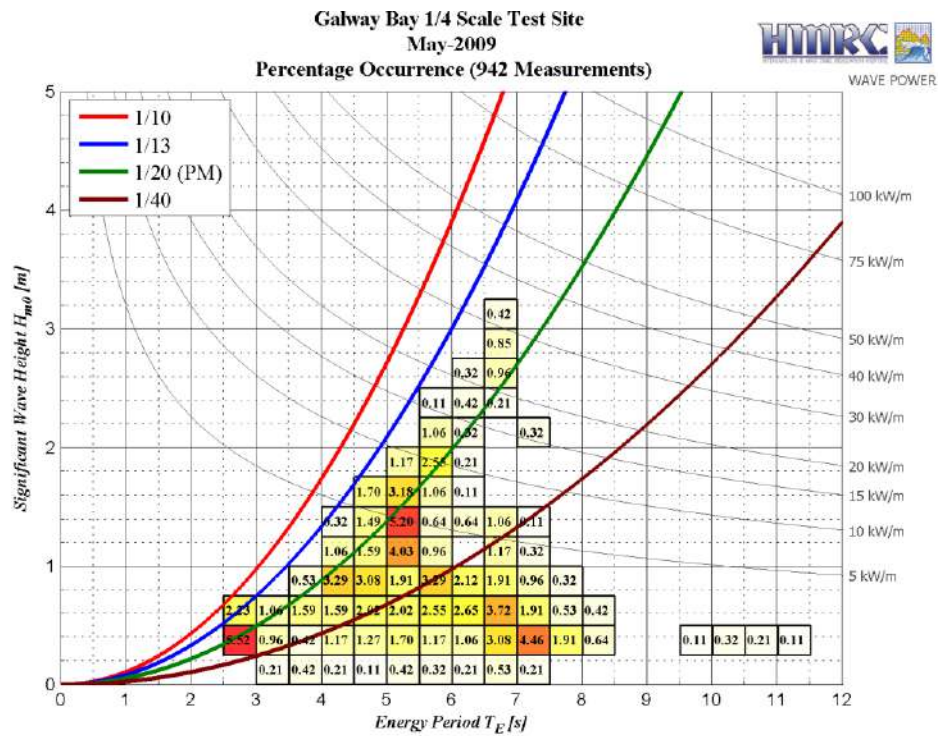


Figure 93 May 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

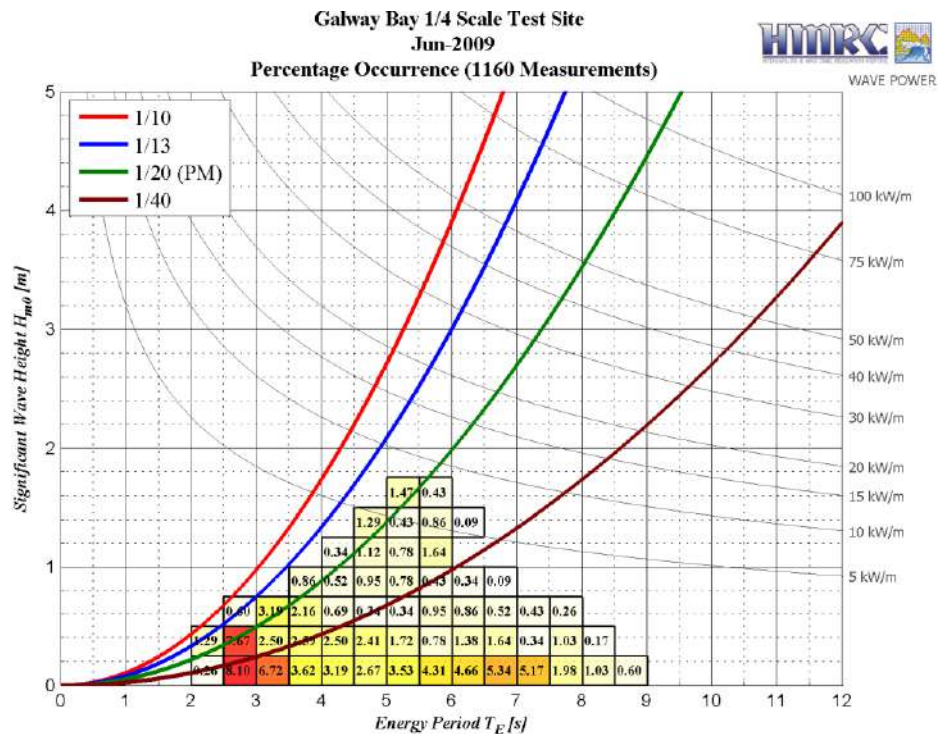


Figure 94 Jun 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

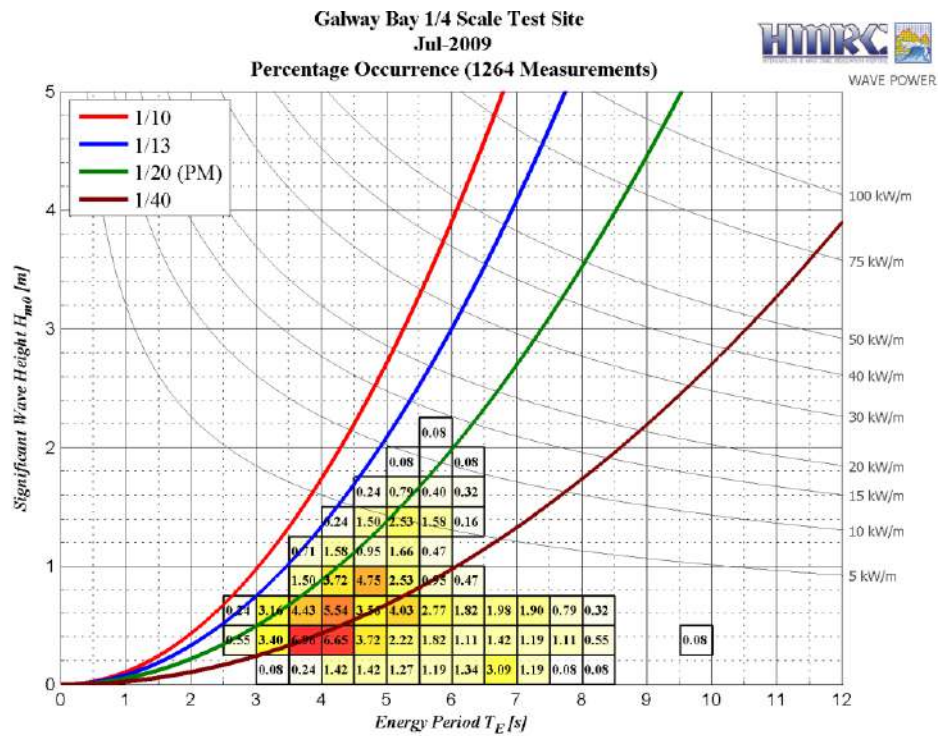


Figure 95 Jul 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

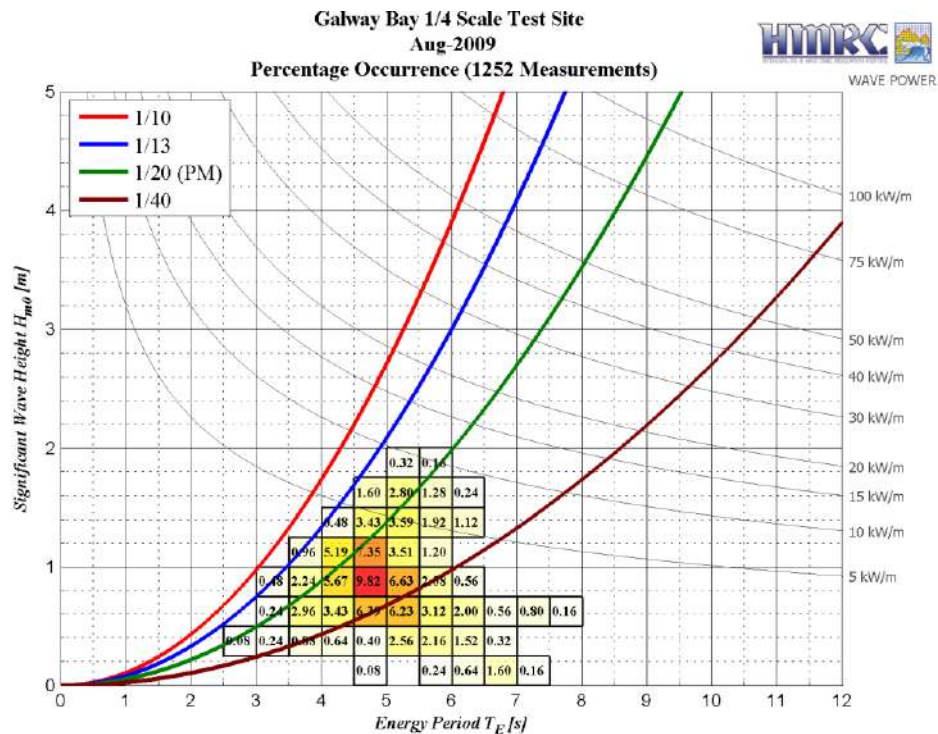


Figure 96 Aug 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

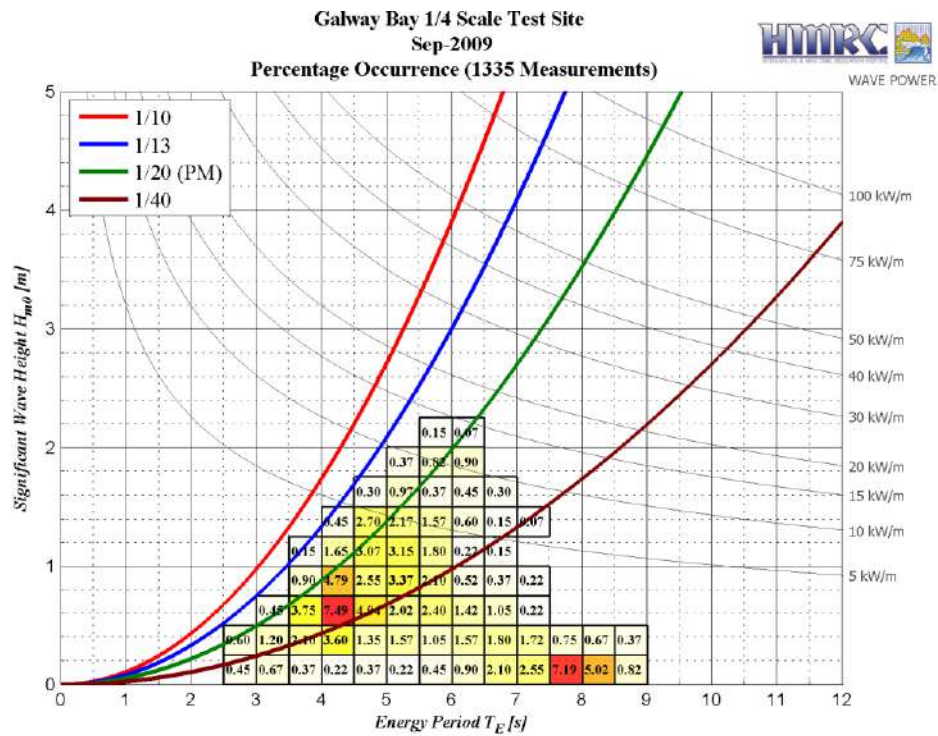


Figure 97 Sep 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

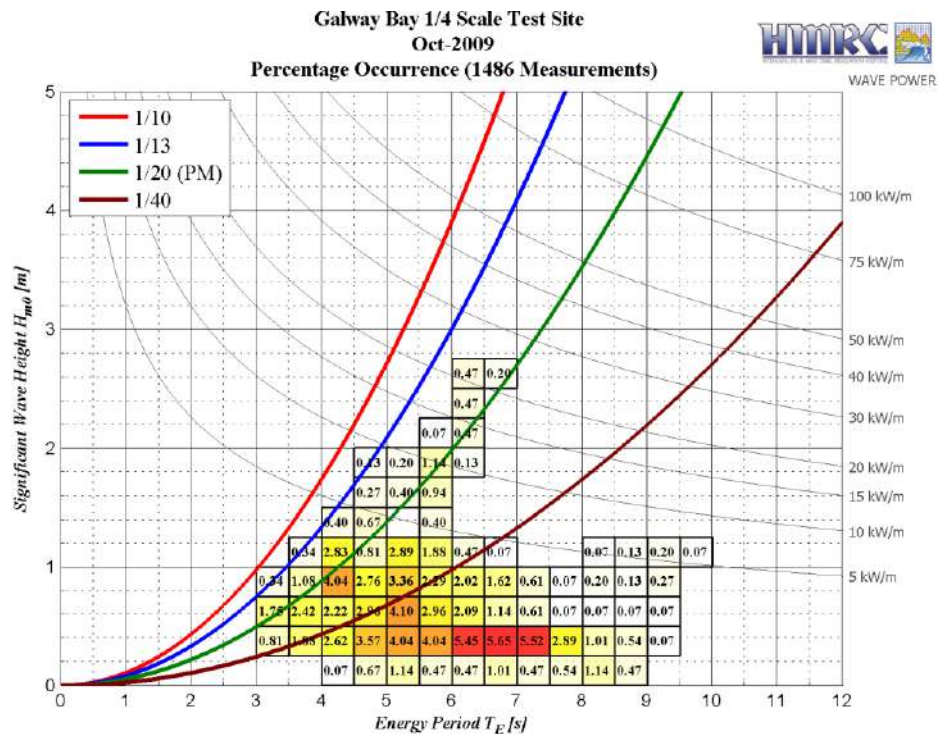


Figure 98 Oct 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

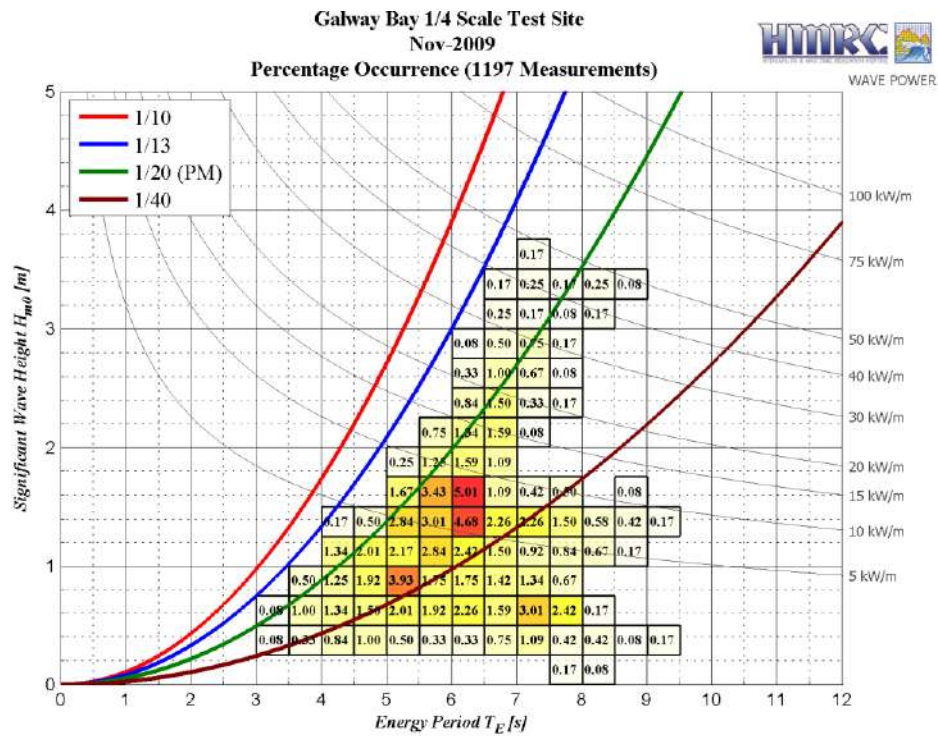


Figure 99 Nov 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

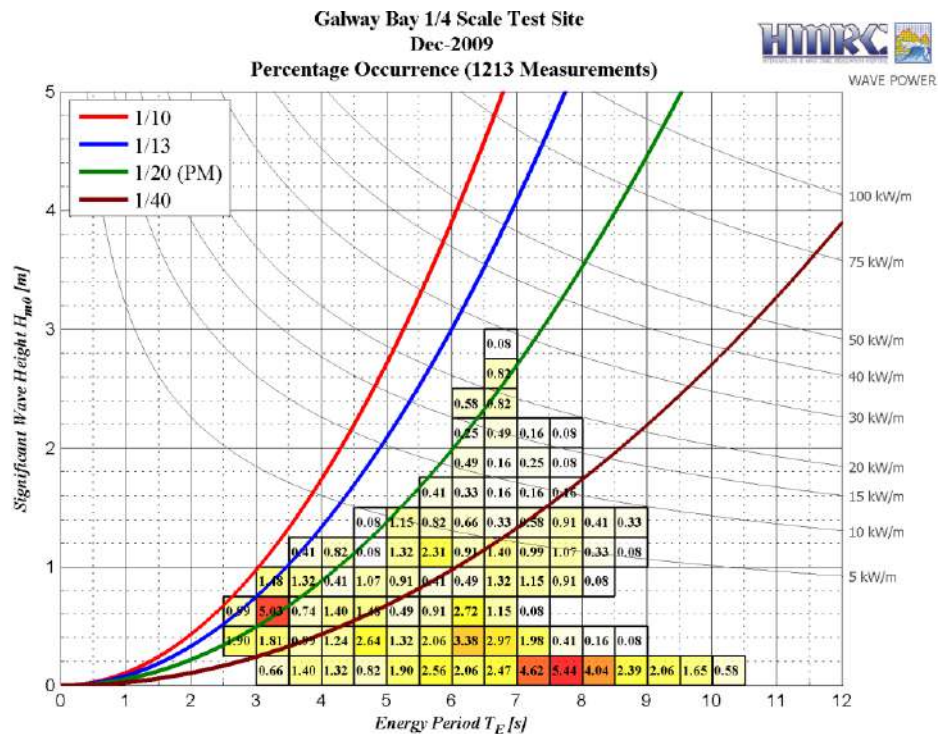
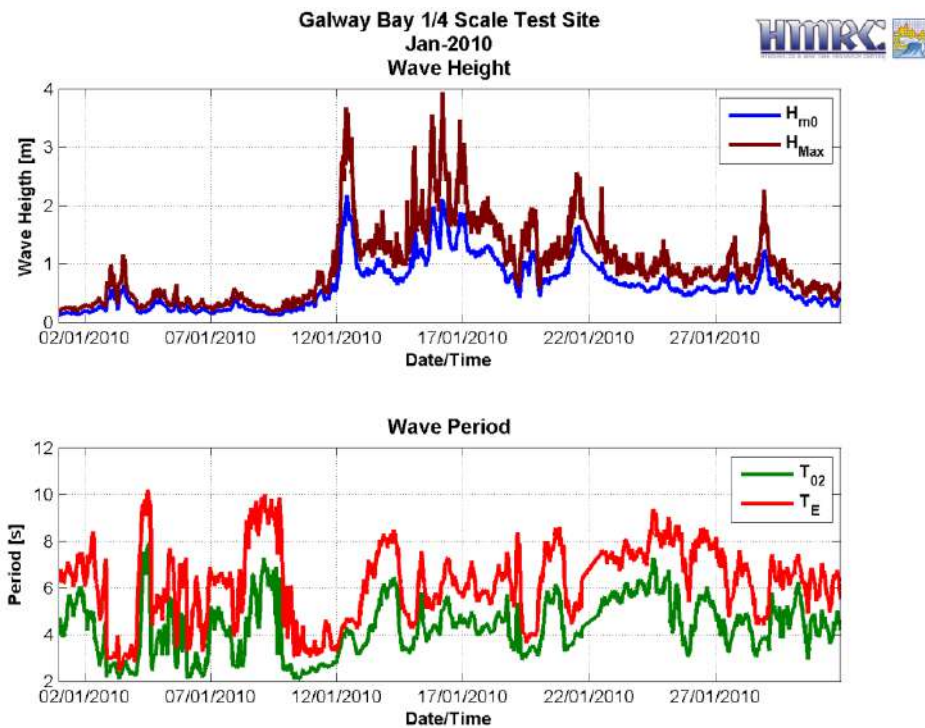


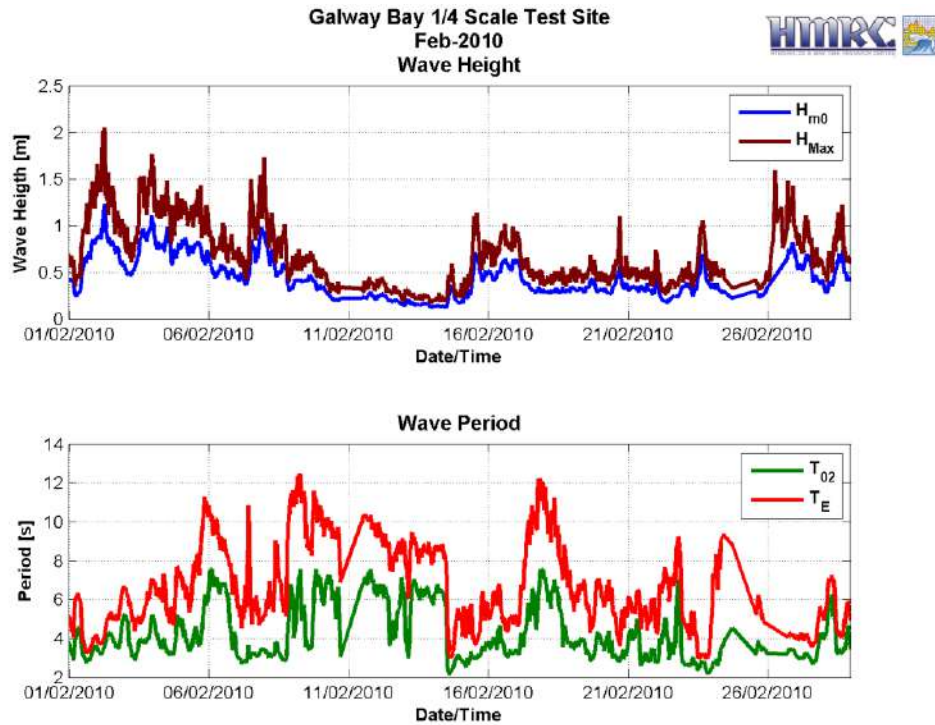
Figure 100 Dec 2009: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



### 6.2.9 Time Series: 2010



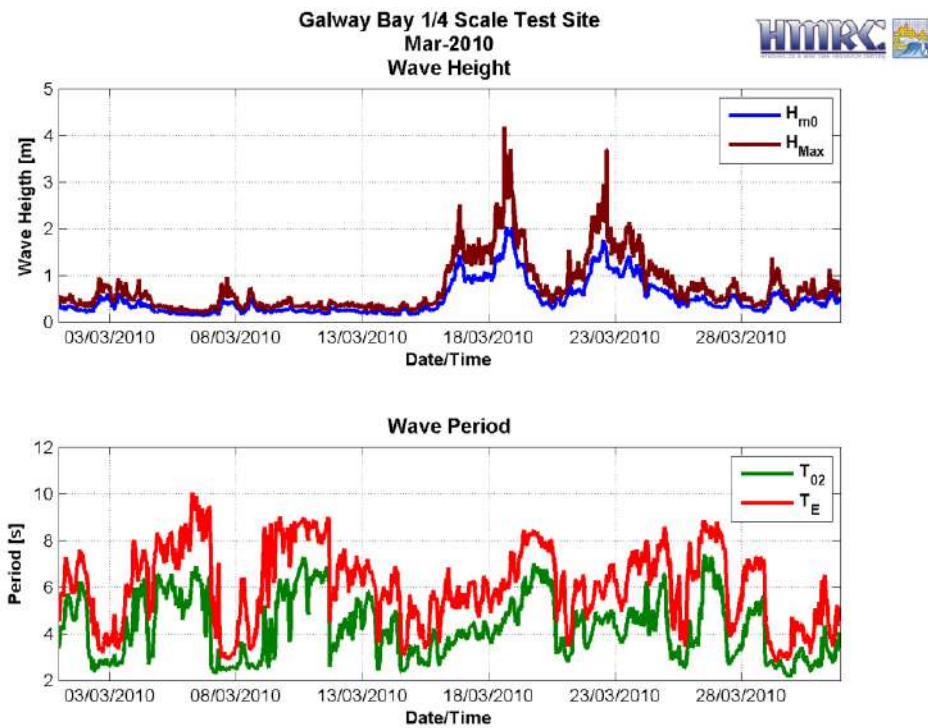
**Figure 101 Jan 2010: Wave Height & Period**



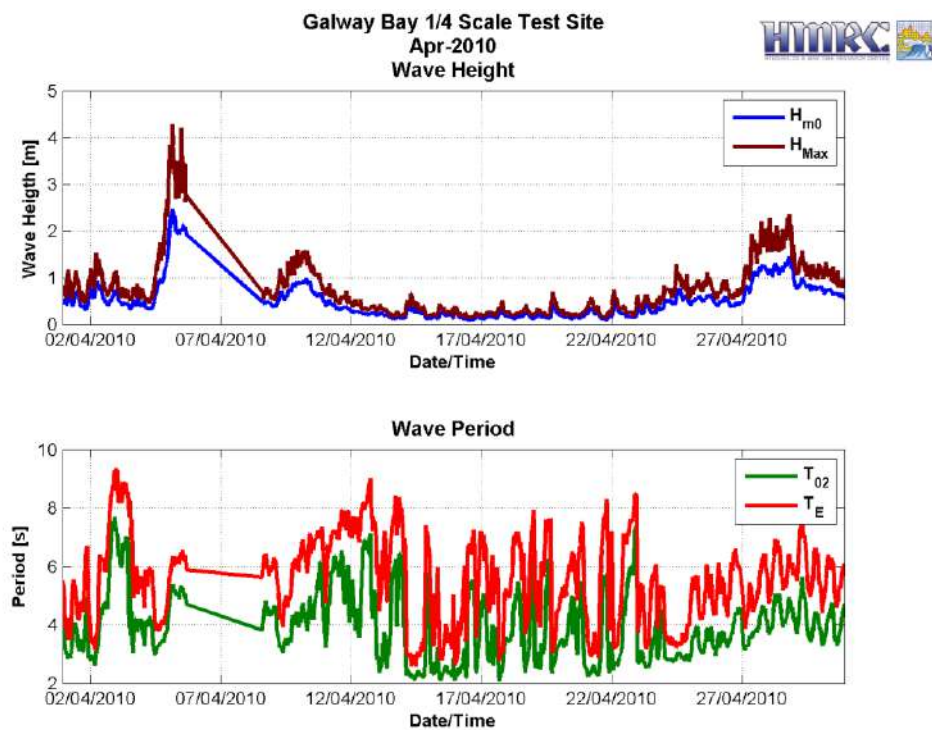
**Figure 102 Feb 2010: Wave Height & Period**



# Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



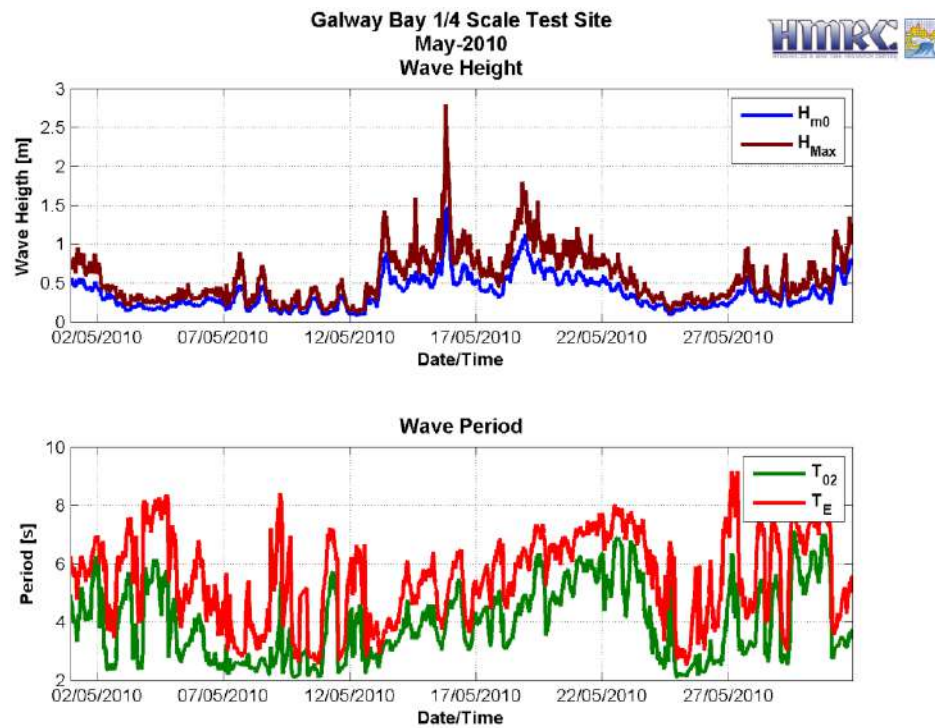
**Figure 103 Mar 2010: Wave Height & Period**



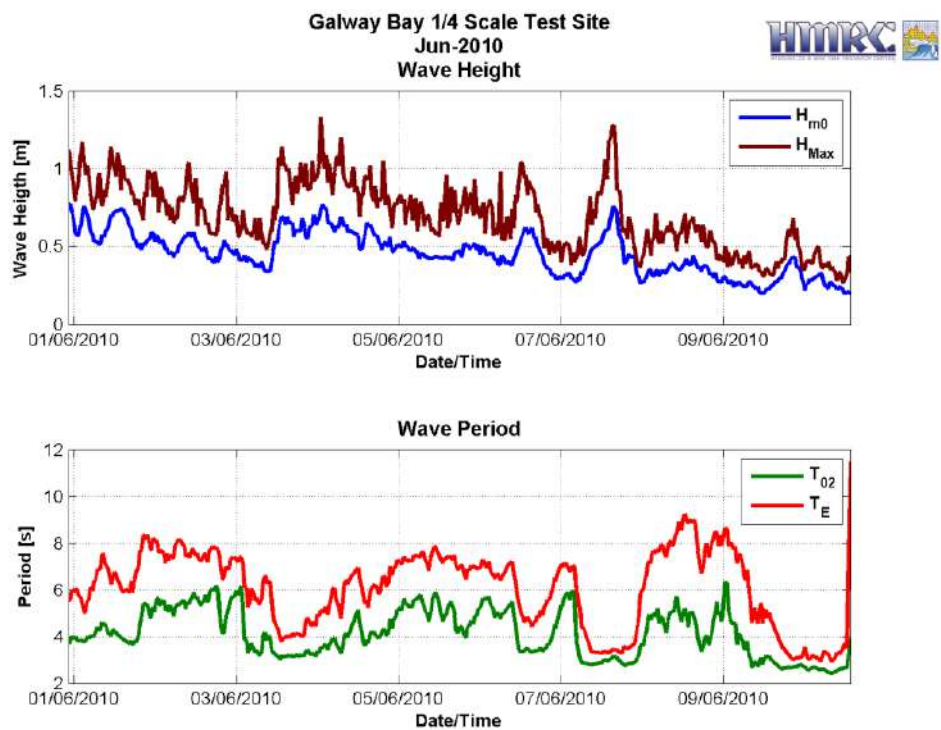
**Figure 104 Apr 2010: Wave Height & Period**



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 105 May 2010: Wave Height & Period**



**Figure 106 Jun 2010: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

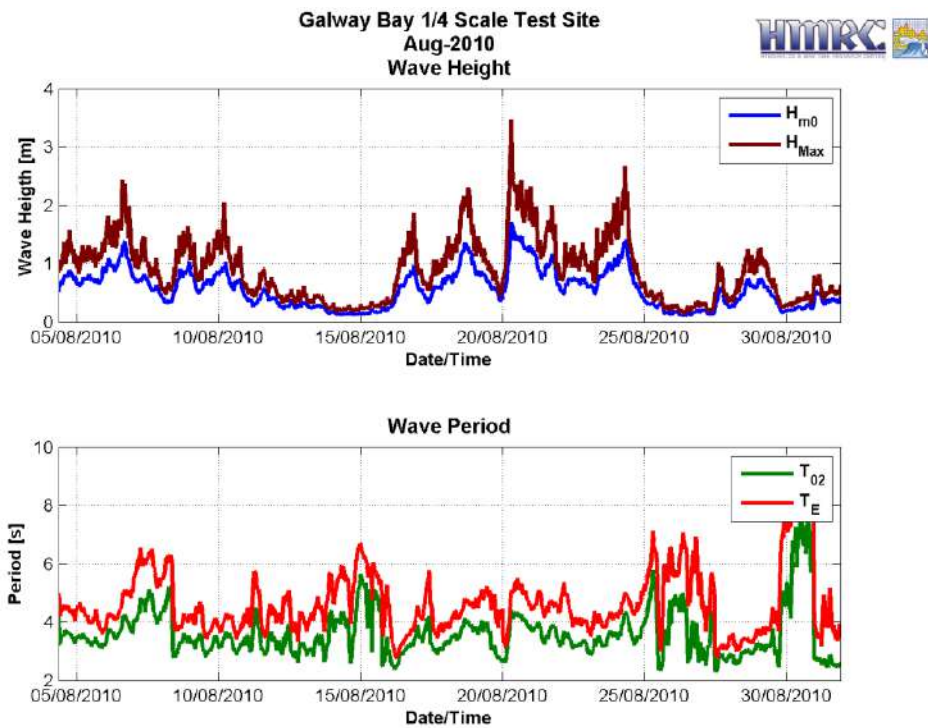


Figure 107 Aug 2010: Wave Height & Period

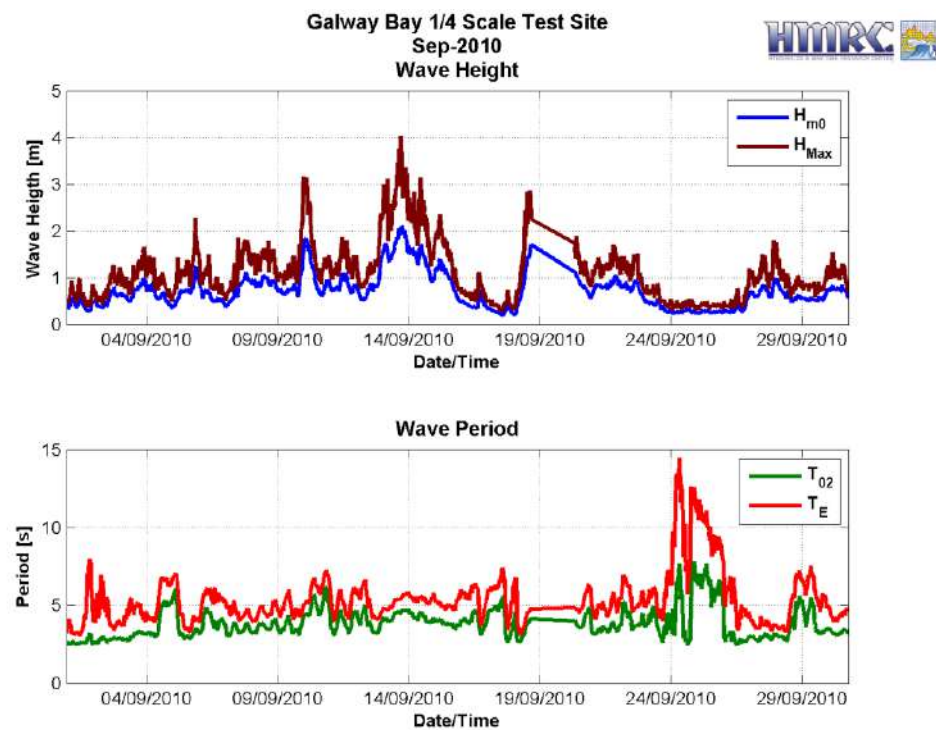
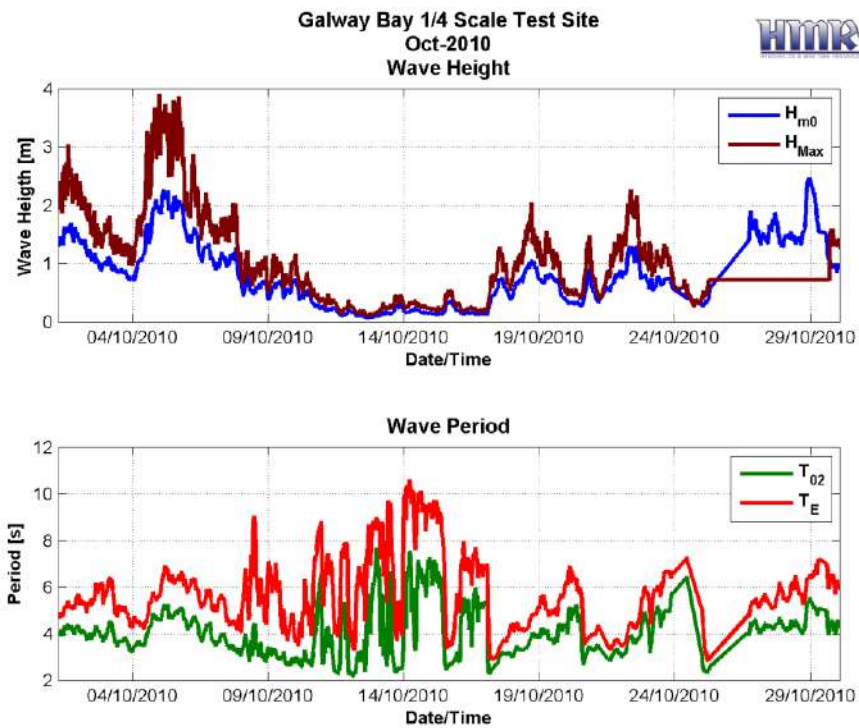


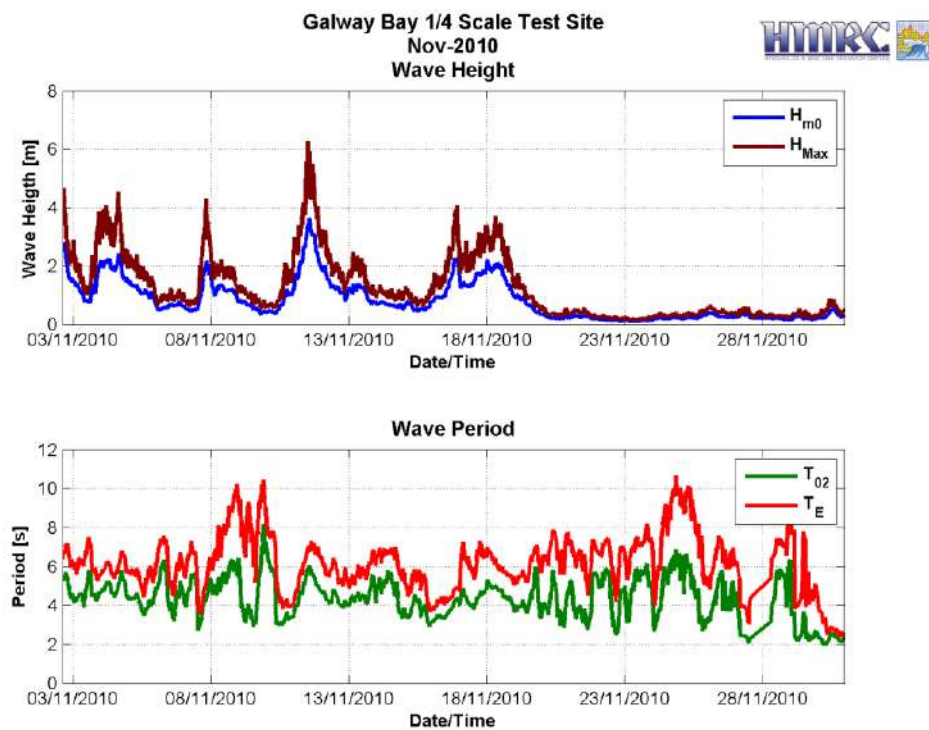
Figure 108 Sep 2010: Wave Height & Period



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site



**Figure 109 Oct 2010: Wave Height & Period**



**Figure 110 Nov 2010: Wave Height & Period**



## Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

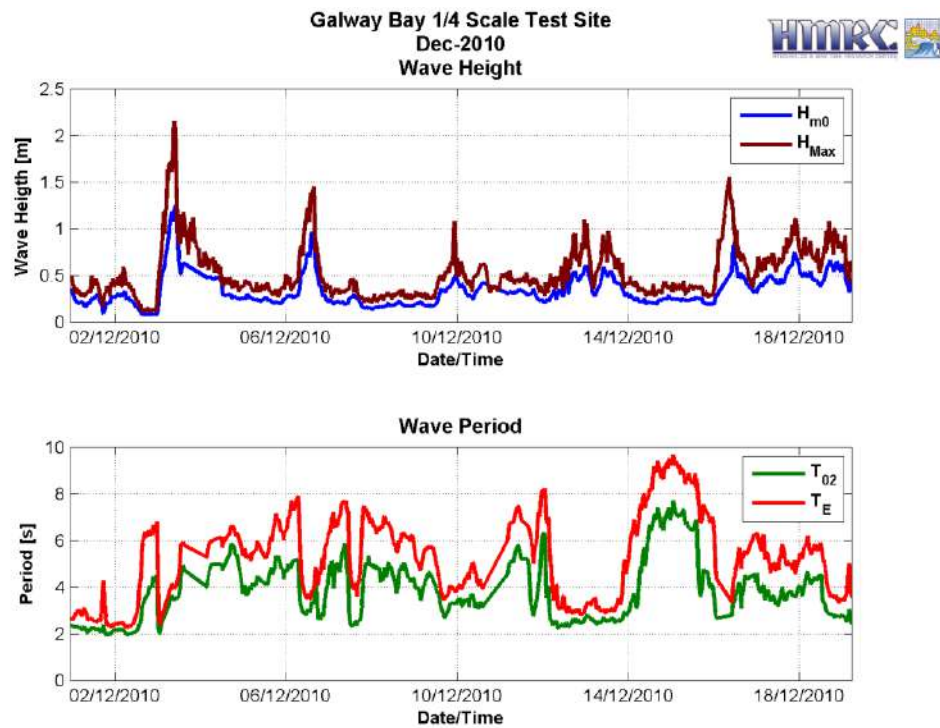


Figure 111 Dec 2010: Wave Height & Period

### 6.2.10 Scatter Plots: 2010

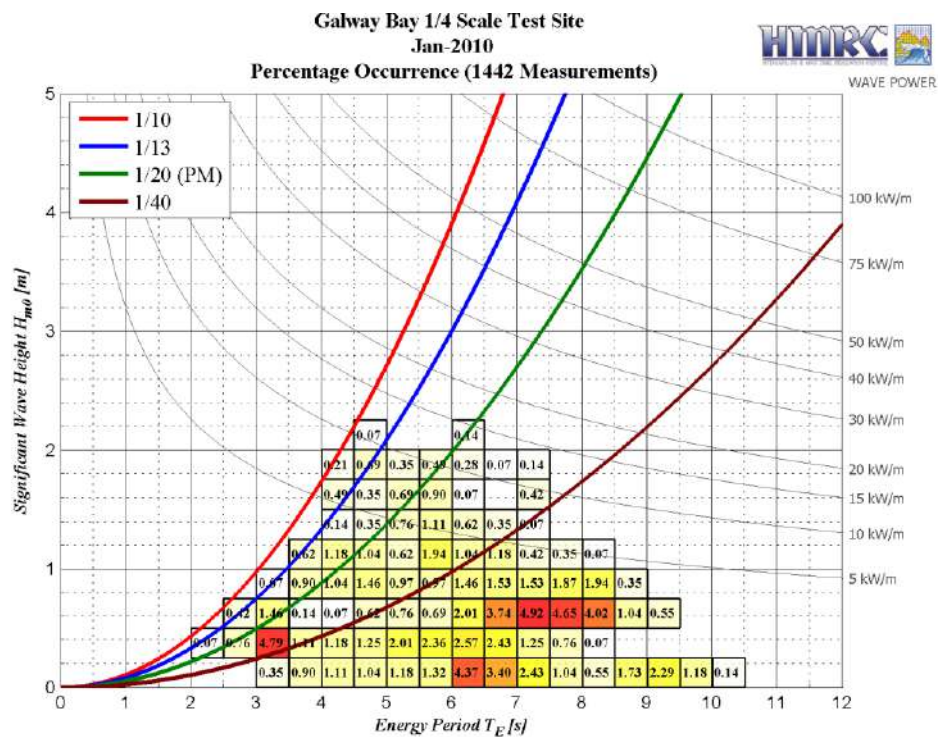
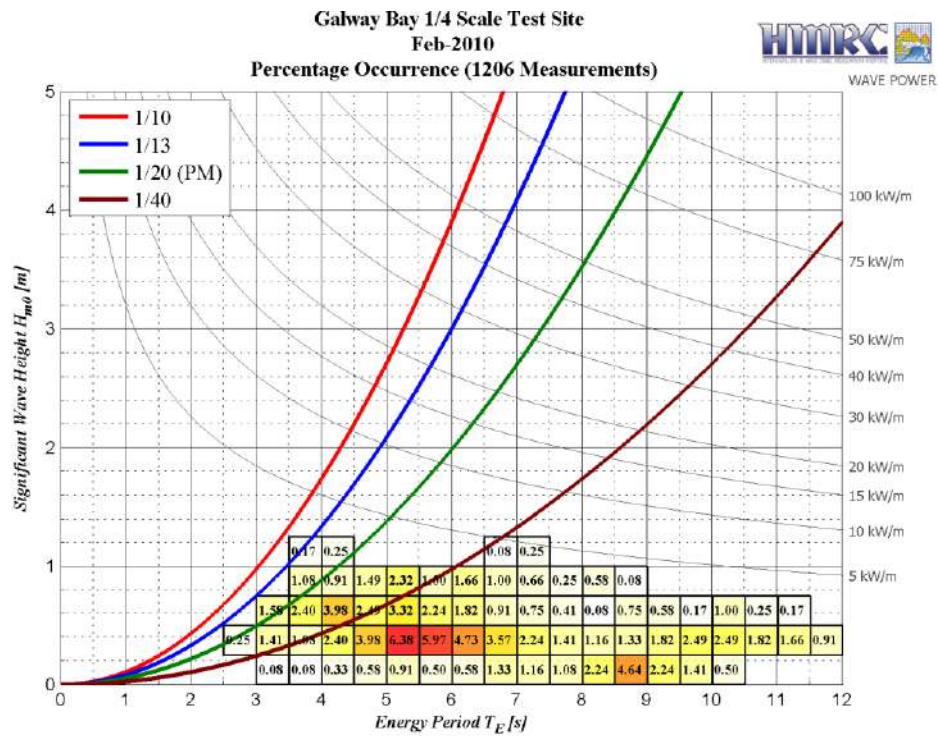


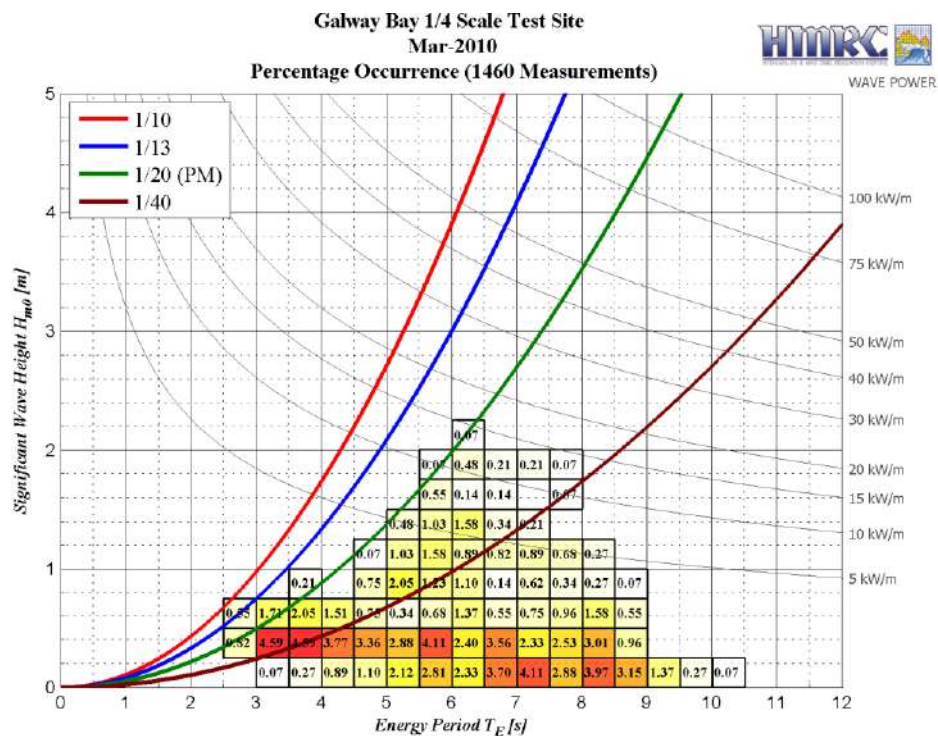
Figure 112 Jan 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



## Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



**Figure 113 Feb 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



**Figure 114 Mar 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



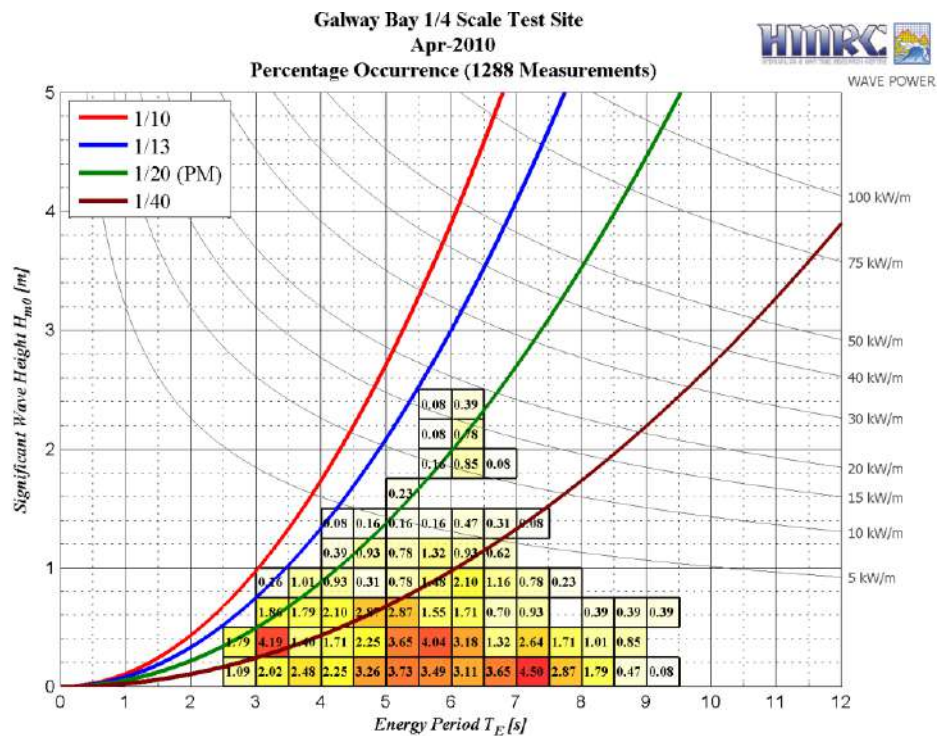


Figure 115 Apr 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

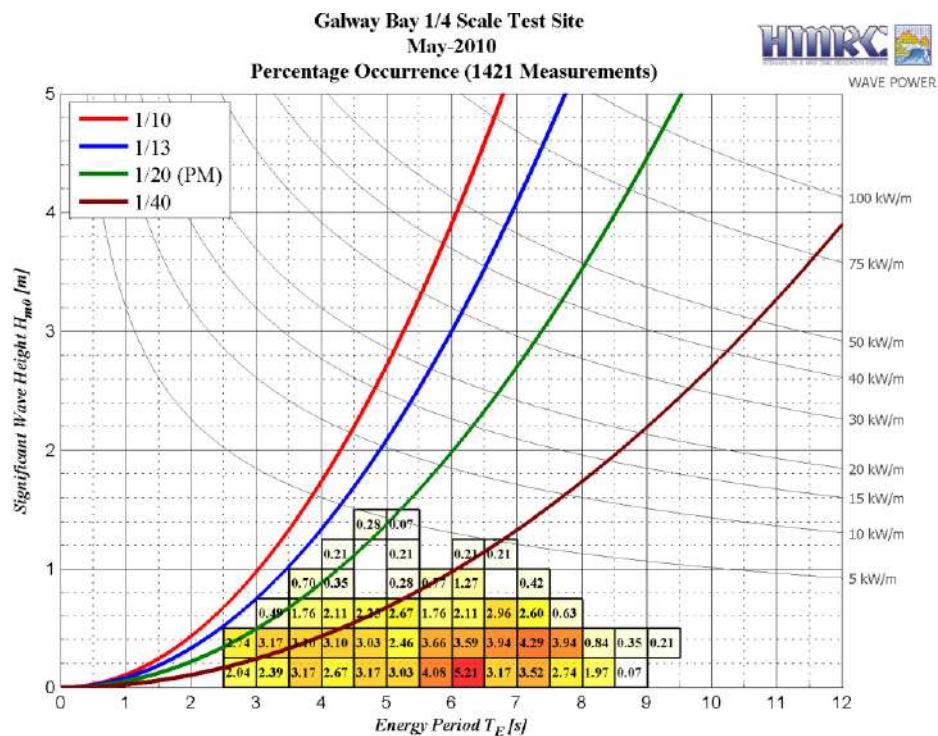
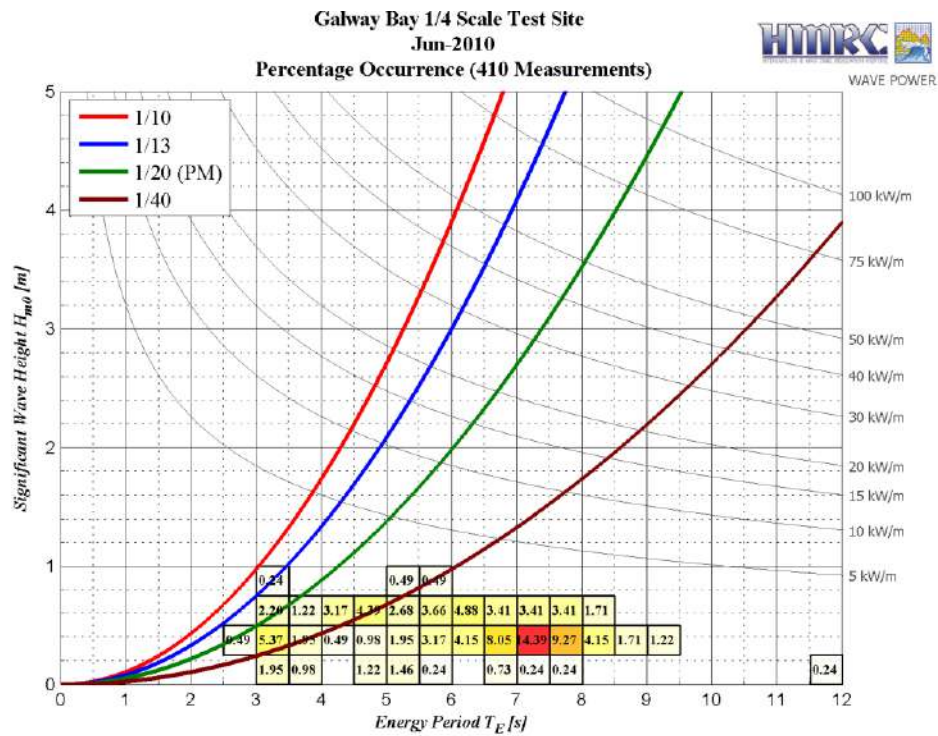


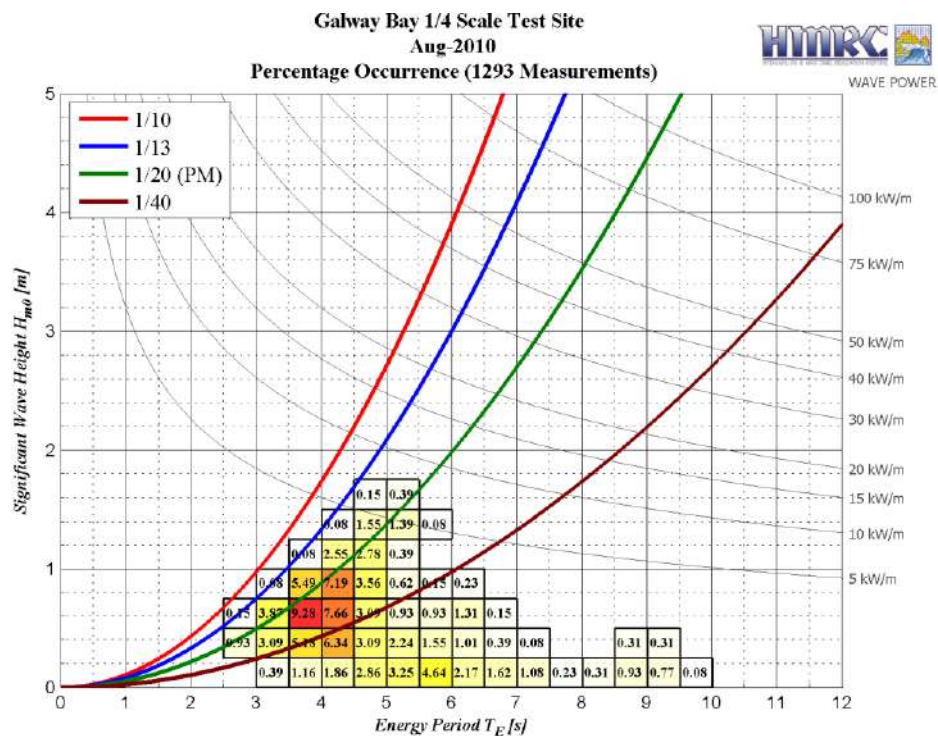
Figure 116 May 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



## Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



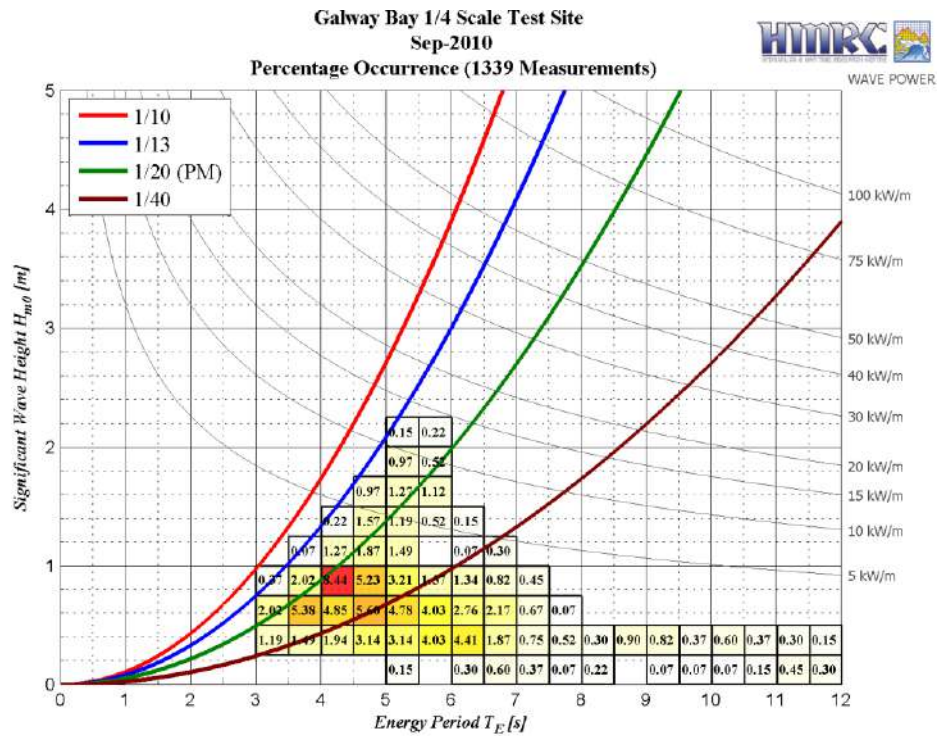
**Figure 117 Jun 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



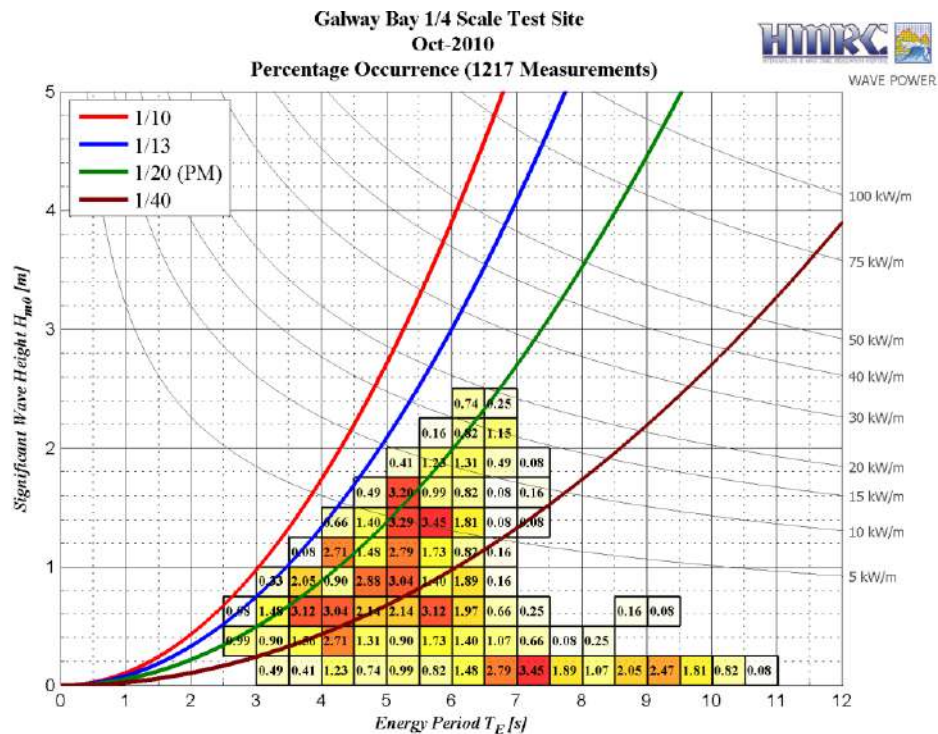
**Figure 118 Aug 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



## Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



**Figure 119 Sep 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



**Figure 120 Oct 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence**



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

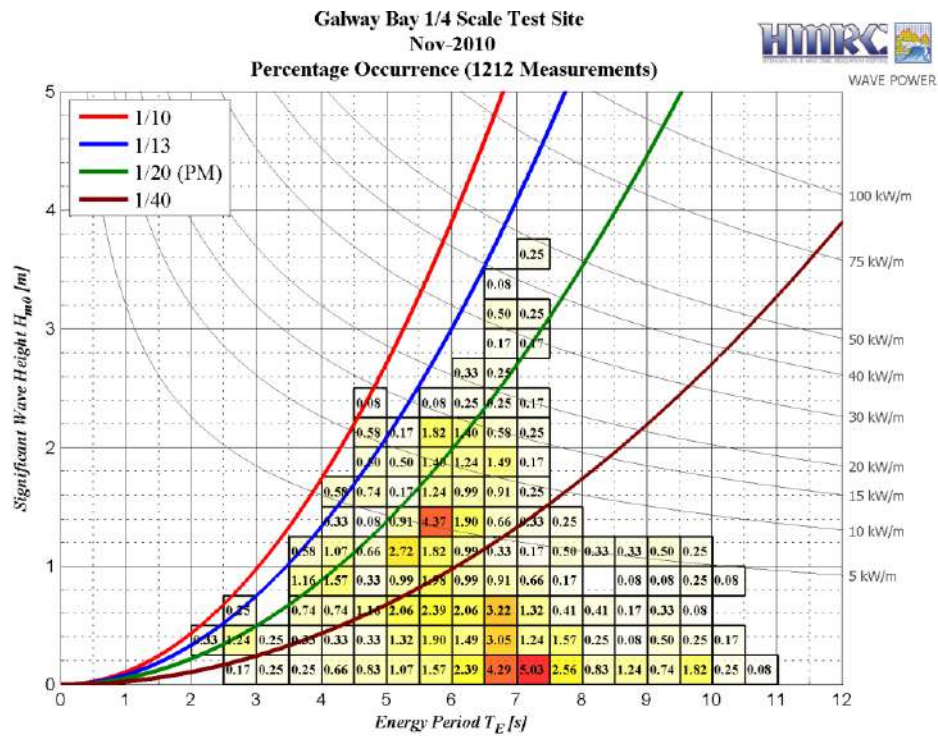


Figure 121 Nov 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

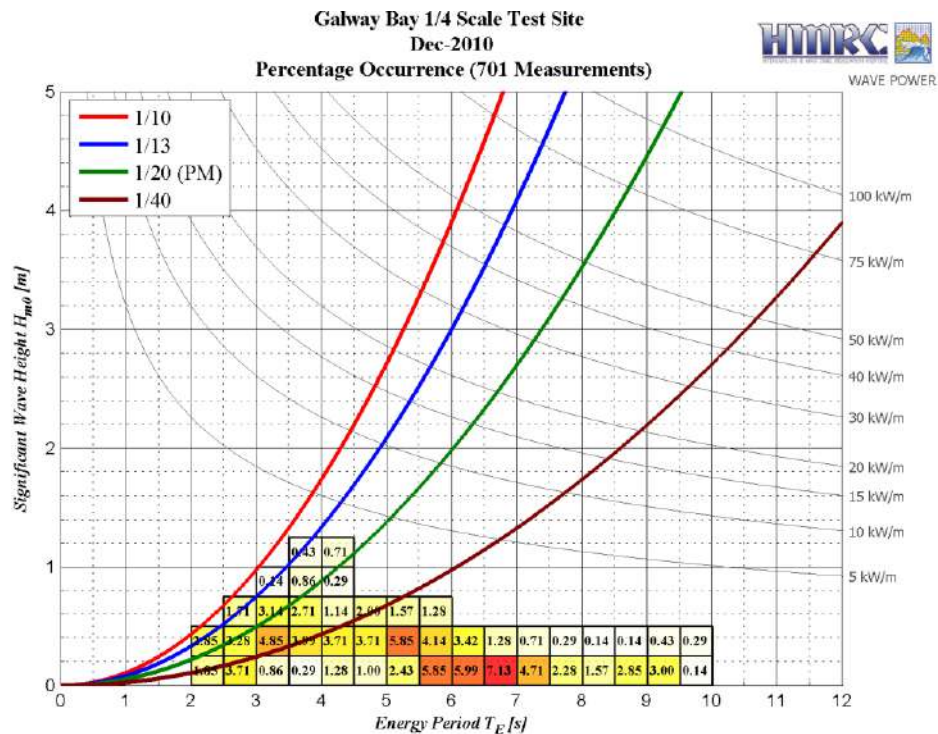
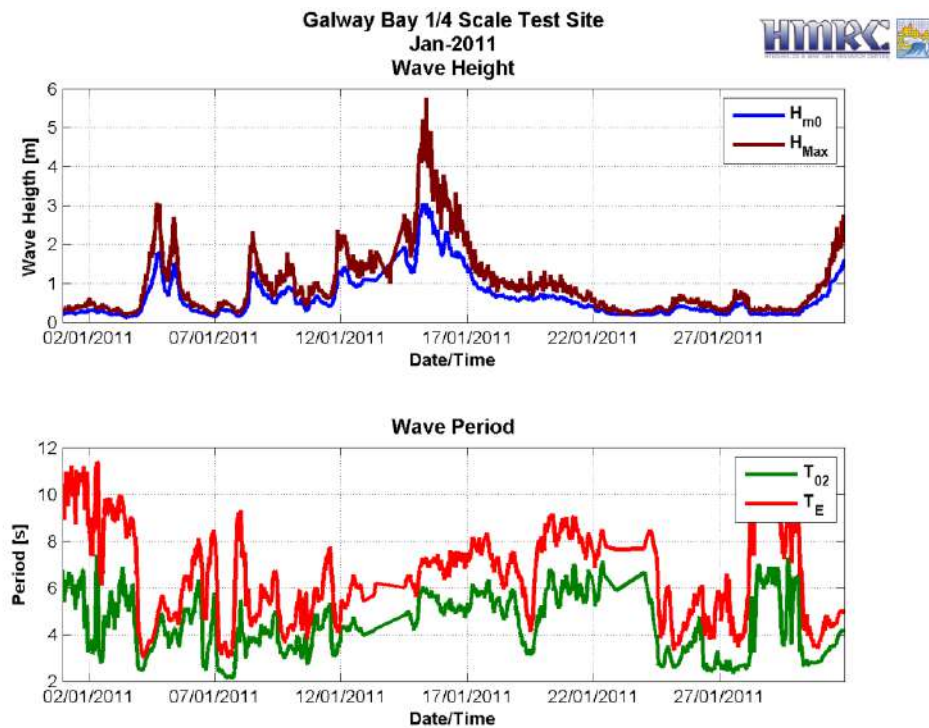


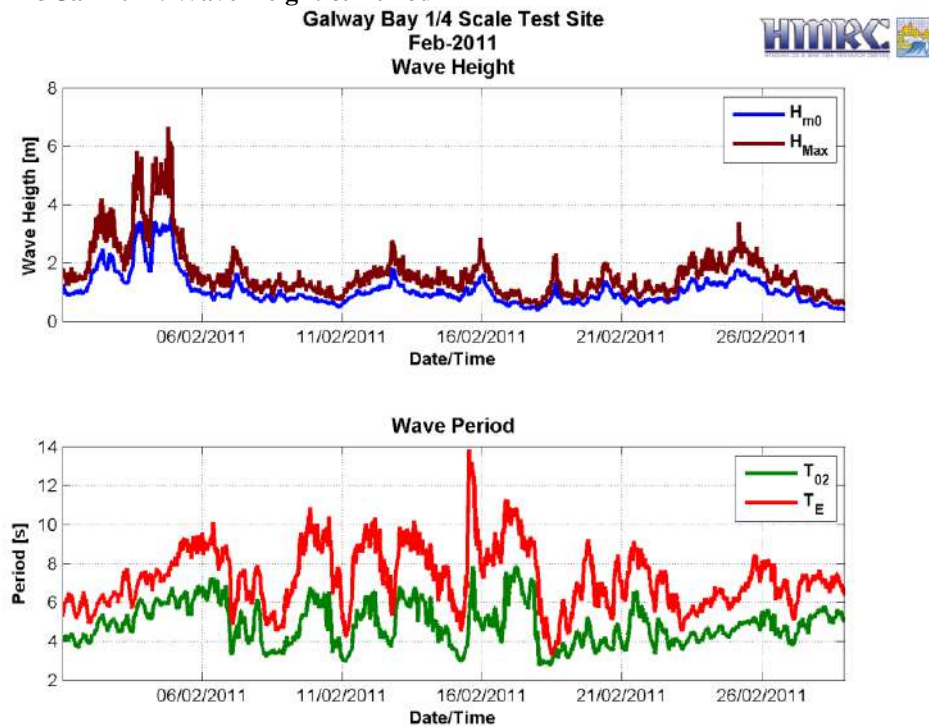
Figure 122 Dec 2010: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



### 6.2.11 Time Series: 2011

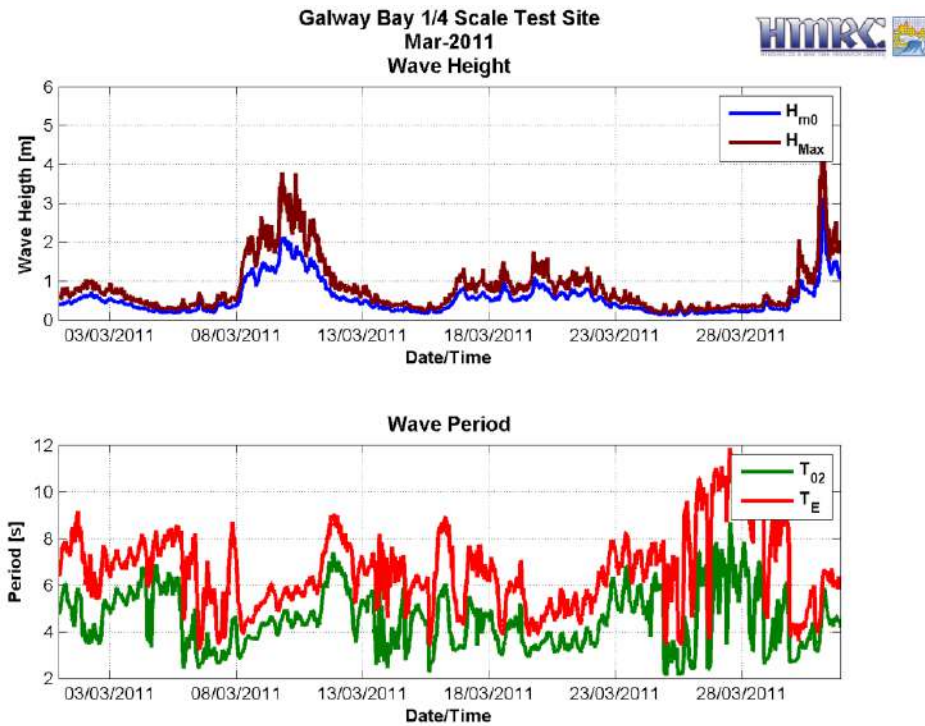


**Figure 123 Jan 2011: Wave Height & Period**

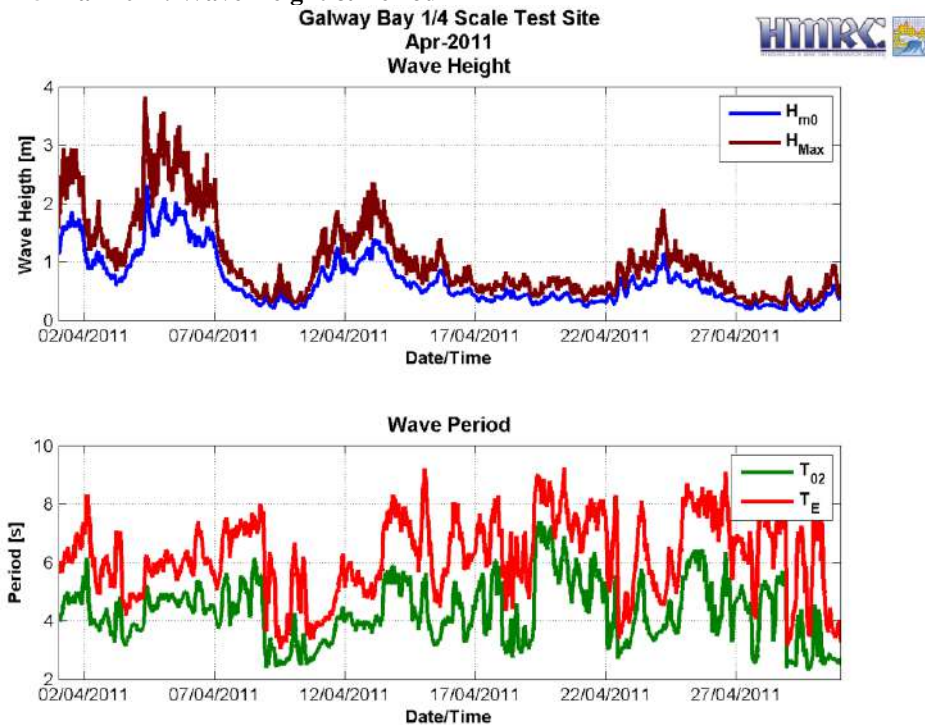


**Figure 124 Feb 2011: Wave Height & Period**





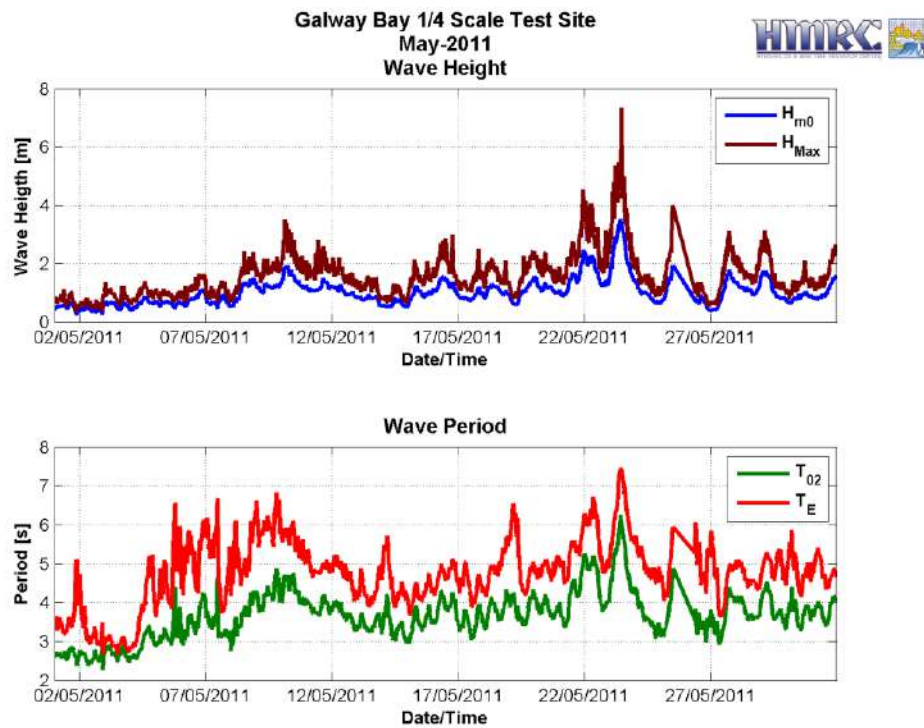
**Figure 125 Mar 2011: Wave Height & Period**



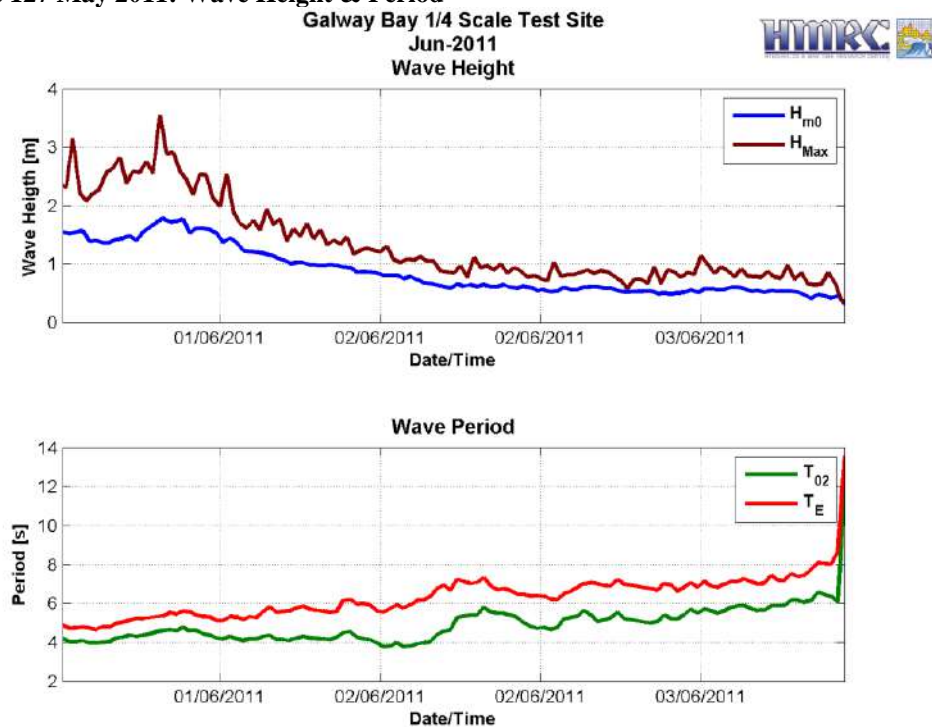
**Figure 126 Apr 2011: Wave Height & Period**



# Resource Characterisation of the Galway Bay ¼ Scale Wave Energy Test Site



**Figure 127 May 2011: Wave Height & Period**



**Figure 128 Jun 2011: Wave Height & Period**



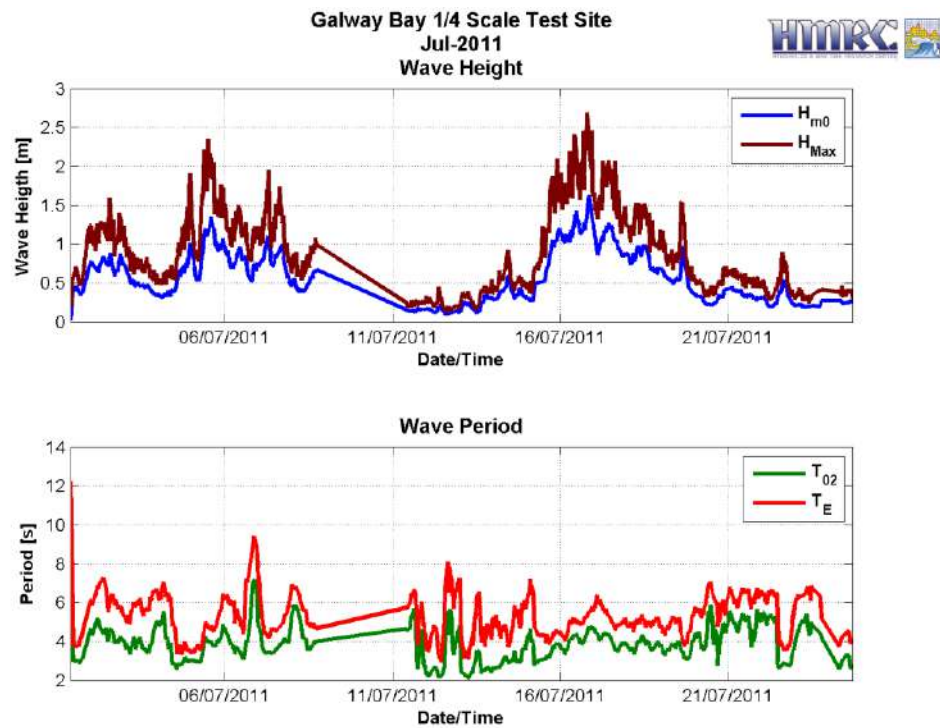


Figure 129 Jul 2011: Wave Height & Period

## 6.2.12 Scatter Plots: 2011

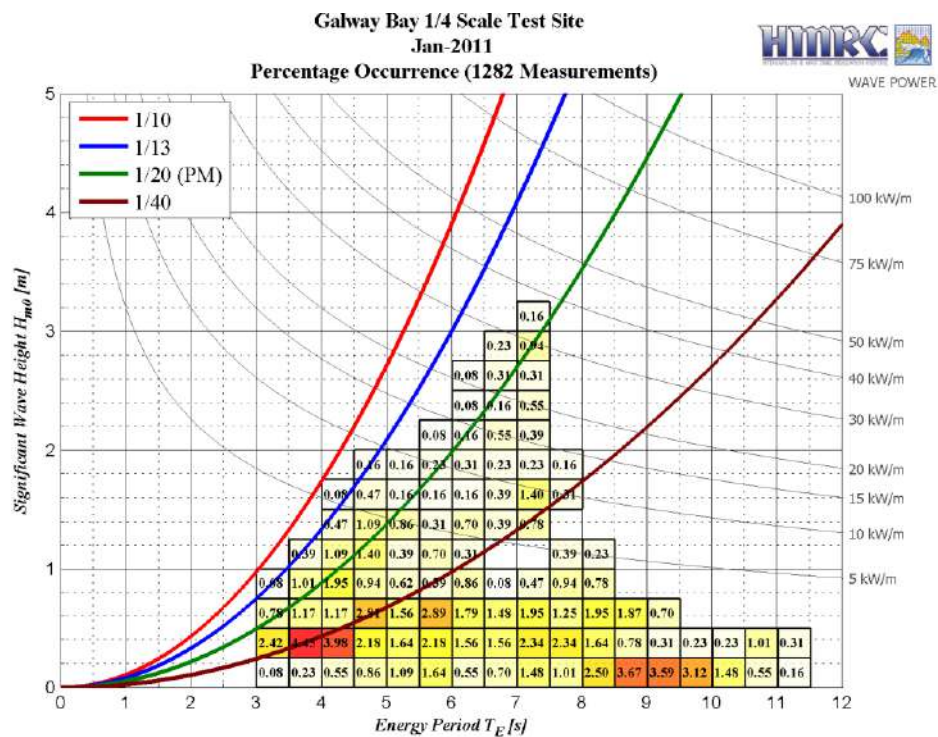


Figure 130 Jan 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

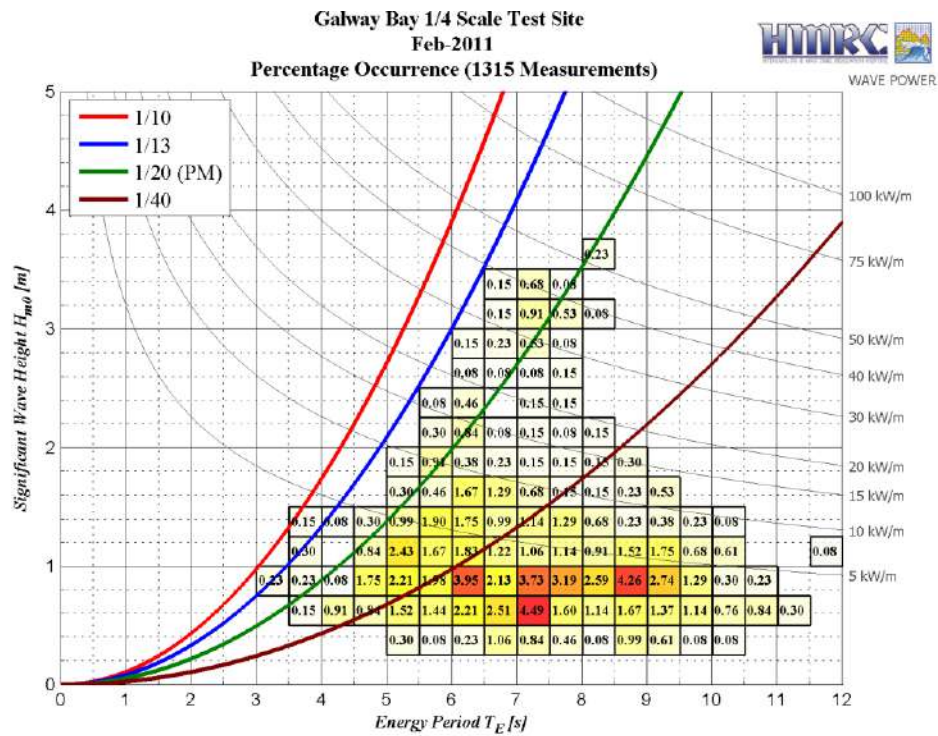


Figure 131 Feb 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

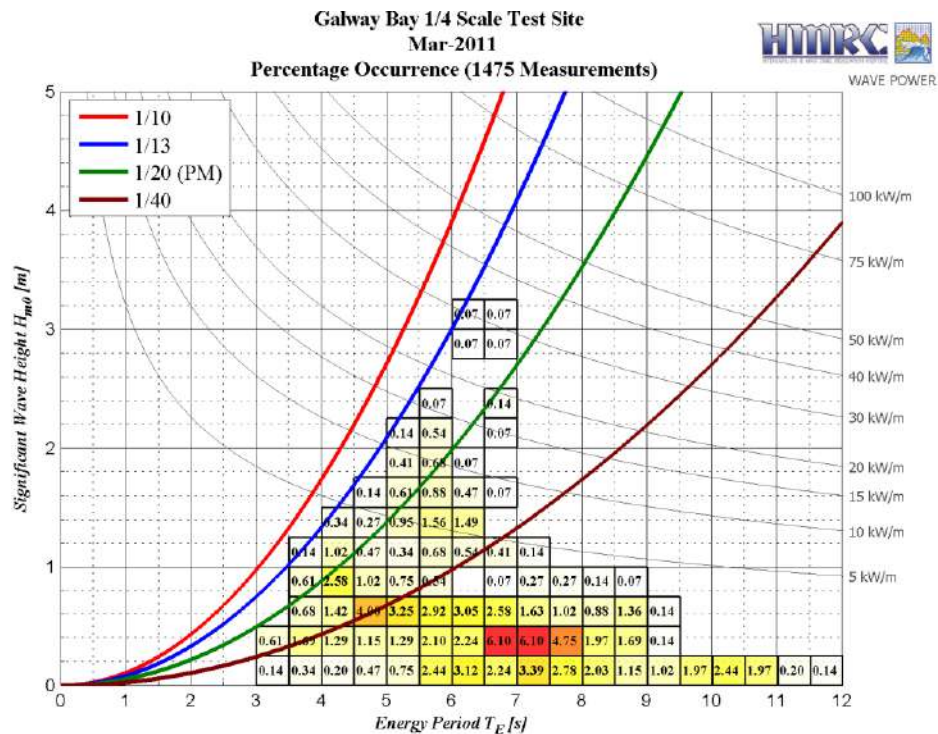


Figure 132 Mar 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

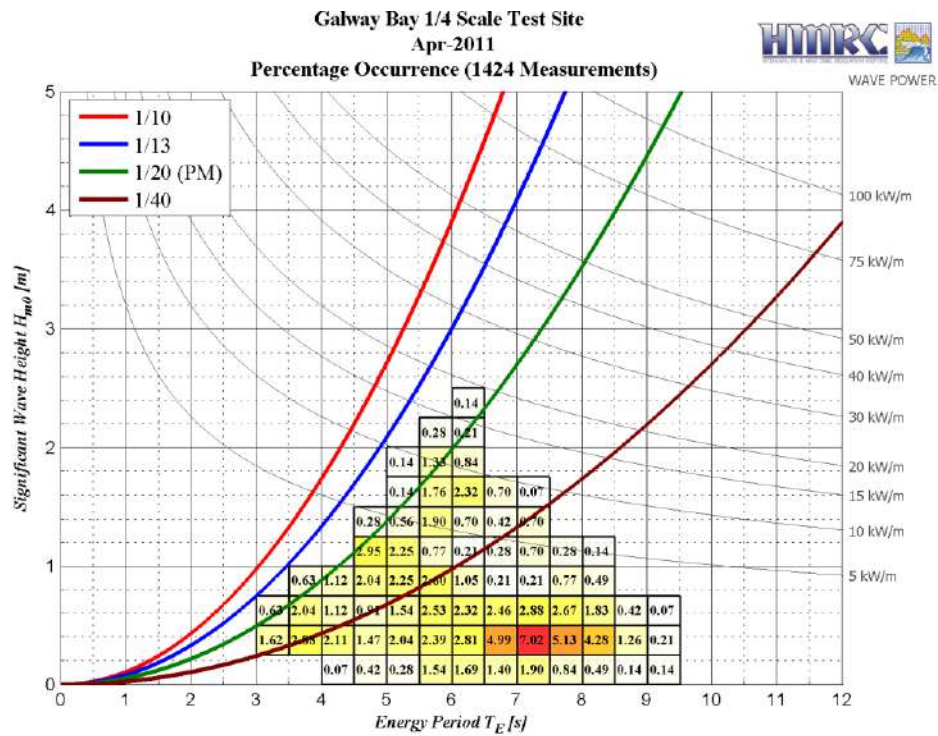


Figure 133 Apr 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

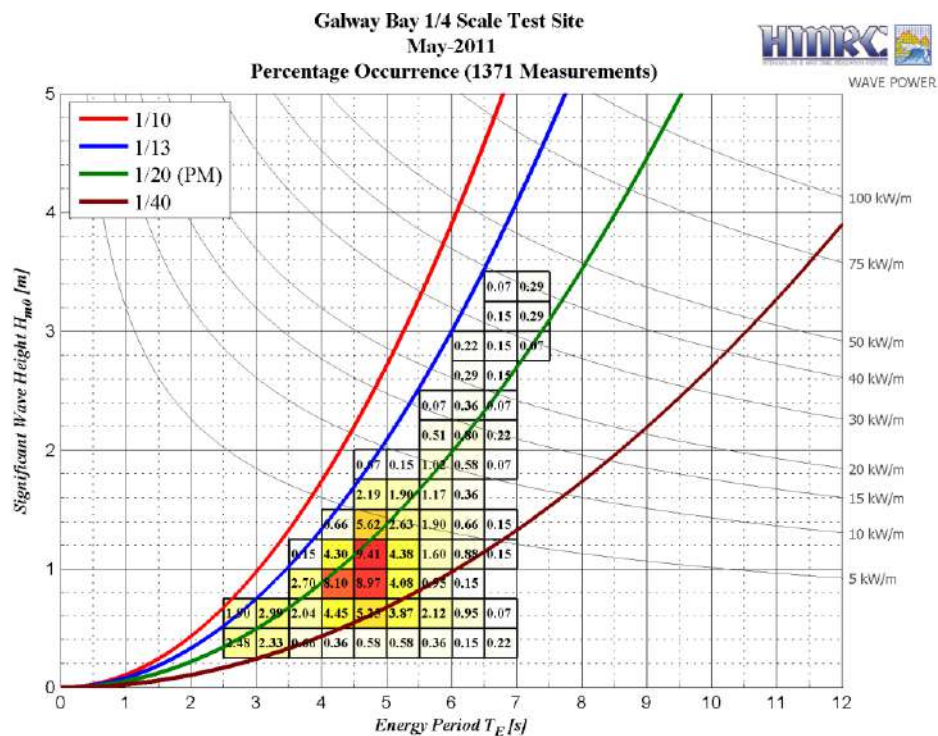


Figure 134 May 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence



# Resource Characterisation of the Galway Bay 1/4 Scale Wave Energy Test Site

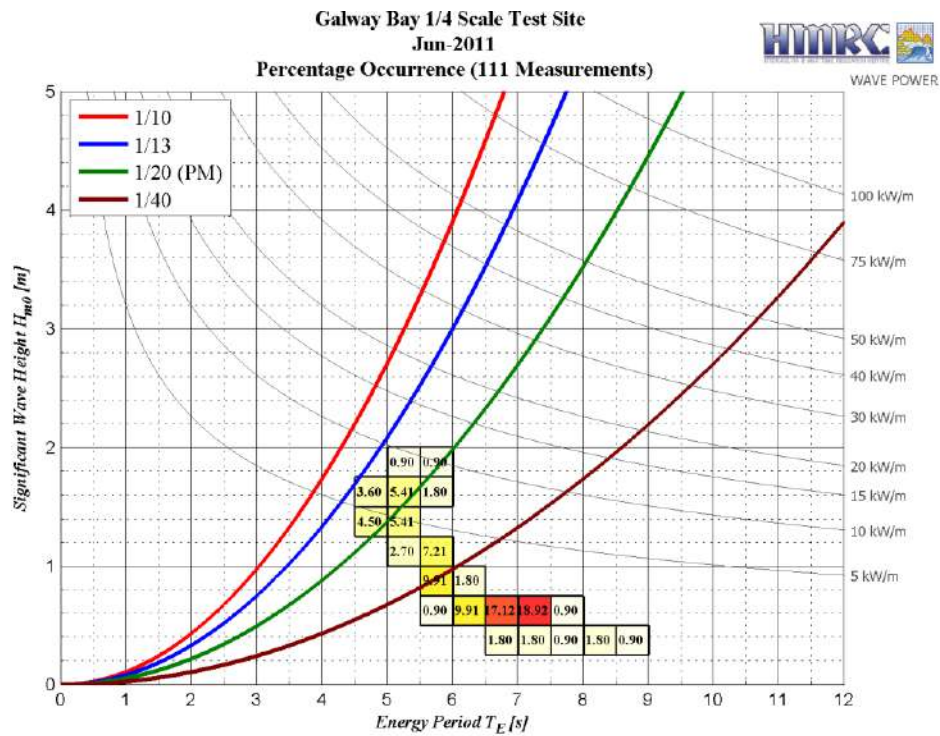


Figure 135 Jun 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence

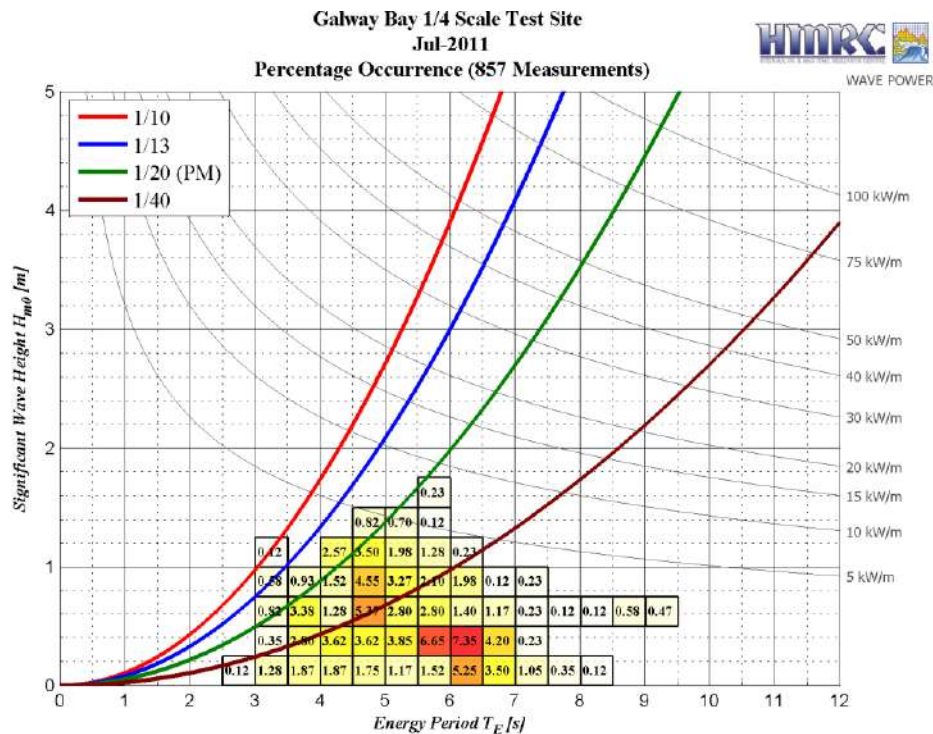


Figure 136 Jul 2011: Scatter Plot of  $H_{m0}$  &  $T_E$  Percentage Occurrence