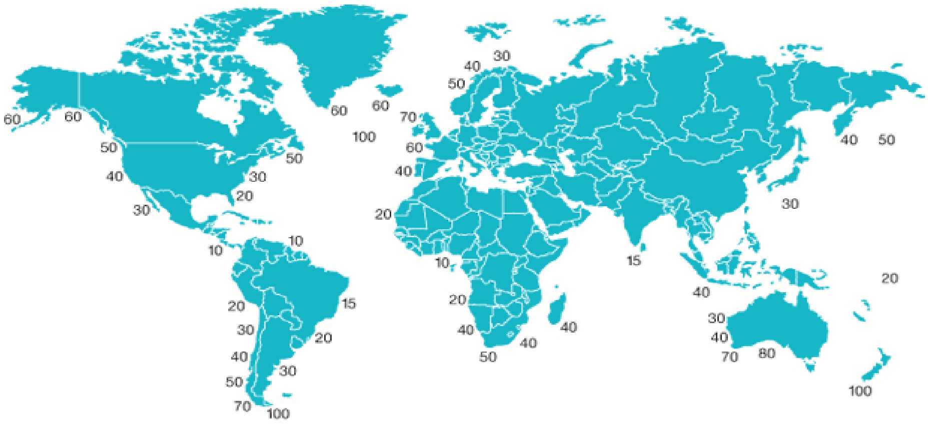
Quantitative assessment of the proposed wave energy demonstration farm off the coast of Portland, Victoria

As a result of the growing concern about increasing carbon dioxide emissions, investigation into developing alternative energy sources, such as wave energy, has increased significantly. Waves along all coasts globally are estimated to have a potential energy of between 1 terrawatt (Falnes, 2007) and 5 terrawatts (Muetze & Vining, 2006), the latter figure being enough to cover current worldwide energy use. Global wave energy maps have been produced showing average energy per wave at various coasts, indicating coasts with the greatest potential for wave energy harvesting (Figure 1.)

Figure 1. Average global wave power levels (kW/m) per year (Eriksson, 2007)



Additional to large amounts of potential energy, wave climate is better able to be forecast than wind energy, with reliable forecasts able to made up to 36 hours in advance (CSIRO, 2012; Muetze & Vining, 2006), and the energy is available 90% of the time (Pelc & Fujita, 2002).

In Australia, it is estimated that along the coast between Geraldton, Western Australia, and the southern tip of Tasmania, there is approximately 1,300 terrawatt hours per year in energy, which amounts to roughly 5 times Australia's current energy requirements (CSIRO, 2012). Limiting the analysis to western and southern coasts is practical as the greatest wave energies are measured on the eastern boundaries of oceans as is visible in average wave power in figure 1 above.

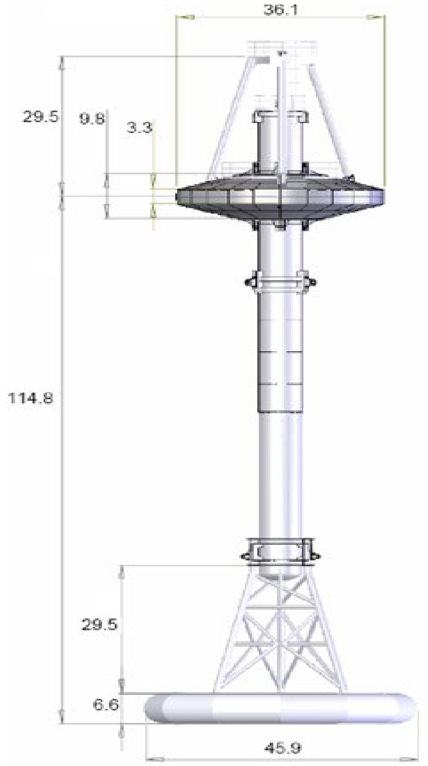
The Victorian Sustainable Energy Authority commissioned a report published in October 2004 (Sustainable Energy Authority, 2004) assessing the Victorian coastline for possible sections able to sustain ocean energy harvesting technologies, identifying the coast between the South Australian border and Cape Otway as holding the most power yielding waves in the State.

In 2009, the Commonwealth Government provided a $66.45 million grant under its Renewable Energy Demonstration Project to the Victorian Wave Project (Victorian Wave Project, undated (a)) (“hereafter called VWP”), to build a wave power plant using technology developed by Ocean Power Technologies Ltd to be built off the coast of Portland, Victoria (Arup, 2012). It is anticipated that, once constructed over 3 stages, the power plant will have the capacity to generate 19 megawatts of electricity, fed directly into the power-grid (Victorian Wave Project, undated (a)).

The development of wave energy technology is still in its relative infancy, and debate continues about the best design for a wave energy device, where to place the devices and how best to maximise their efficiency. The purpose of this paper is to analyse the technology to be used in the VWP power plant and, particularly, to assess whether the proposed location is conducive to producing reliable electrical energy.

Results and Discussion

Victorian Wave Project and the Ocean Power Technologies Pty Ltd 'PowerBuoy®'



The VWP will use the 'PowerBuoy' wave energy system to extract wave energy and convert to electricity (Figure 2.)

The round platform towards the top of the device floats on the surface of the sea water, while the large plate at the bottom, whilst not attached to the sea bed, provides resistance against the force of the waves on the top platform. As Falcão summarises the device in his review of wave energy technologies:

> 'A disc-shaped floater reacts against a submerged cylindrical body, terminated at its bottom end by a large horizontal damper plate whose function is to increase the inertia through the added mass of the surrounding water. The relative heaving motion between the two bodies is converted into electrical energy by means of a hydraulic PTO (power take-off system).' (Falcão, 2010)

Figure 2. Diagram of PowerBuoy wave energy harvester (measurements in feet) (Ocean Power Technologies, undated)

Effectively, the wave passing the device causes the top platform to rise and fall, while the bottom plate remains relatively still. The resultant change in the length of the device causes a hydraulic power take-off system or generator to create electricity.

Such device designs are termed as two-body heaving (Falcão, 2010) point absorbers (Drew et al, 2009). Given the infancy of research into the most efficient converters, there are still a number of vastly different designs for energy converters, all of which have advantages and drawbacks (World Energy Council, 2010).

The greatest strength of point absorbers is that the direction of waves in relation to the device is not important to the device's ability to generate electricity. Data obtained Sustainability Victoria (discussed below) for the purpose of exploring the potential of wave energy in the South West Victoria used buoys able to detect the direction of waves hitting the buoy, presumably for this purpose. While other designs of device need to be faced so that waves hit the device front on for power generation, point absorber operators have no such concern.

However, the greatest reported drawback to two-body heaving systems is the overall energy conversion efficiency given wavelengths and periods are rapidly varying. Again citing Falcão, point absorbers using traditional transmissions (such as that reportedly used in the PowerBuoy) have a peak operating point where a peak efficiency of around 80% of energy to electricity conversion can be obtained (Falcão, 2010) The peak operating point for such devices is when stroke length of the hydraulic pump matches the height of the waves, and the device naturally oscillates at the same frequency as the period of the waves hitting them (Drew et al, 2009; Muetze & Vining, 2006). Any deviation from this and efficiency rates drop.

The Victorian Wave Project website promotes its PowerBuoy as having the ability to 'tune' to each wave (Victorian Wave Project, undated (b)). By this it is presumed to mean that the device can tune its oscillating action to resonate with the period of the waves moving it. There is no detail to explain how this works in the literature seen at the time of writing, while PowerBuoy patent documents viewed describe a load applied to the system to adjust its frequency (Ocean Power Technologies, 2008), seemingly similar to the dampening loads described by Drew et al (2009) and Korde (2000) as being required to enable efficient energy conversion as less than ideal wave periods.

In an early article in journal nature, S.H Salter (inventor of the 'Salter's Duck' wave energy device) reached the conclusion that first step in progressing wave energy conversion technology was to “get away from the idea of an object bobbing up and down”, and to instead focus on developing technology that could more efficiently harness the forward and backward motion of waves (Salter, 1974). Falnes' review of wave-energy extraction (Falnes, 2007) reaches a number of conclusions including that:

- floating point devices operate at the greatest efficiency when resonance between wave period and device timing is obtained;
- Devices of only moderate size will have only small ranges of wave period where the device cannot resonate without requiring some dampening of the stroke length of the power take-off system and reducing efficiency as a result; and
- economic converters should ideally have a large working area relative to their size and a

large oscillating speed, specifications which don't apply to floating point oscillating systems.

In light of the above and the continuing development of different wave energy harnessing devices, it is not entirely evident whether the technology proposed to be used is the best technology or that best suited to the location. However, such demonstration power plants as this may be the next step in obtaining data to assist future development of the technology in this area, and operations using the PowerBuoy in other countries have reportedly been successful.

Location of Victorian Wave Project

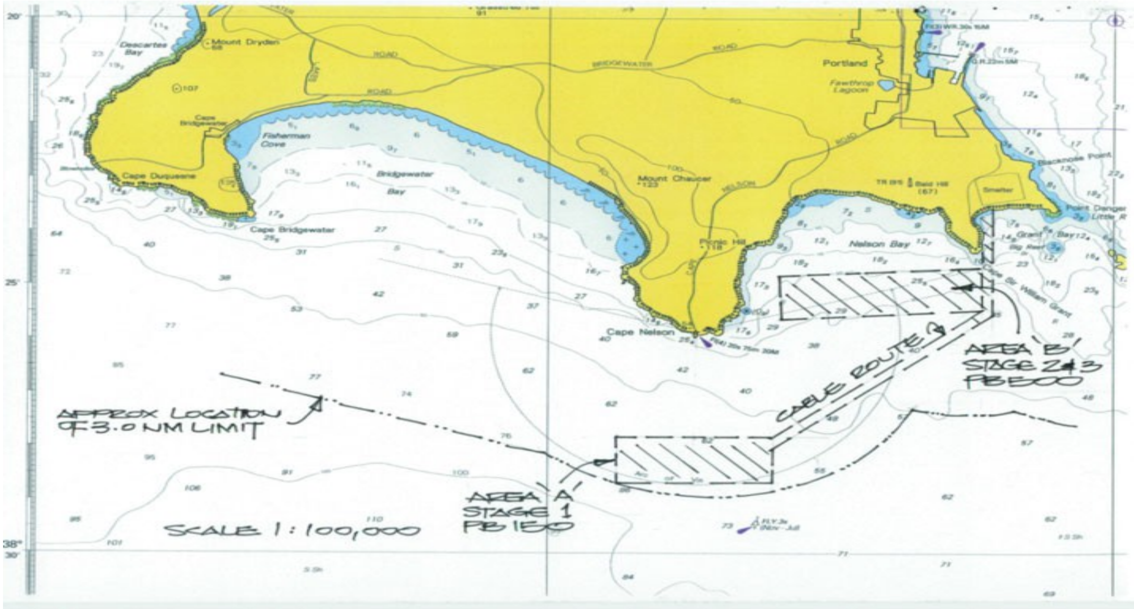


Figure 3. Proposed location of wave energy farm south of Portland, Victoria. Note Cape Bridgewater to the west, the location of Sustainability Victoria's recently finished wave data gathering exercise. (Victorian Wave Project, undated (c))

The project is to be installed in two sections off the coast south of Portland, as per figure 3.

From Figure 1 above, it can be seen that the south west coast of Western Australia has greater wave power level per meter of wave-front (60 – 70 kW/m) to the 50kW/m average power near the site of Victorian Wave Project site. However, as is discussed in a CSIRO report, accurate measurements of wave energy, particularly in Australia, needs considerable development before being dependable, and data obtained for the purpose of that report showed that, within the 50th percentile of wave energy flux based on previous measurements, the proposed location of the project has a higher energy flux than the south west tip of Western Australia (CSIRO, 2012).

In order to be economically viable to extract wave energy, the location of the wave energy farm mush have a median annual wave power in excess of 30kW/m (Sustainable Energy Authority, 2004). The Ocean Power Technology website states that it's PowerBuoy devices are optimised to harness wave energy at 20kW/m or greater (Ocean Power Technology, undated (a)).

The previous study by the Sustainable Energy Authority, when assessing the viability of wave energy extraction from the Portland to Cape Otway region of Victoria, didn't have wave energy data from this region, and relied on data obtained from Cape Sorrell, Tasmania, as being indicative of what could be expected along the South West coast of Victoria. Using this method, it was concluded that the South West coast of Victoria was a viable location of wave energy extraction, having a median wave power of or greater than 30kW/m (Sustainable Energy Authority, 2004)

However, Sustainability Victoria have recently finalised wave data from two special purpose wave buoys, one of which was located off the coast at Cape Bridgewater, a short distance to the west of Portland and the proposed site of the Victorian Wave Project wave farm (see Figure 3). The buoy deployed had the ability to measure wave height, wave period and wave direction at this location. It was deployed for 2 years between January 2011 and January 2013 (despite a disruption between 19 November 2011 and 12 December 2011), and reported average wave data at that location every 10 minutes, providing a wealth of wave data for this area (Sustainability Victoria, 2013)

In assessing the data in order to provide a broad overview of wave energy statistics at this location for this project, the months of January and June were taken as being representative of average wave energy in Summer (typically yielding lower wave power energy) and Winter (typically yielding higher wave power energy). Further, the analysis of a full month of data would demonstrate the variability in wave power over the course of hours and days, as opposed to seasonal variability, which impacts upon the efficiency of wave energy converters, which is discussed above.

Analysis of the data was limited to ascertaining the average, maximum and minimum wave heigh and wave period, plus the value of one standard deviation from the average wave and average wave period, as shown in Table 1.

	Ave. Sig Wave Height (m)	1 Std Dev of Sig Wave Height (m)	Max Sig Wave Height (m)	Min Sig Wave Height (m)	Ave Wave Period (s)	1 Std Dev Wave Period (s)	Max Wave Period (s)	Min Wave Period (s)
June 2011	2.985	1.299	6.46	0.89	7.71	1.072	10.55	4.21
Jan 2012	2.277	1.085	6.52	0.75	7.356	1.179	11.37	4.17
June 2012	2.82	0.911	5.8	0.95	7.717	1.415	11.79	4.25
Jan 2013	2.23	0.692	4.19	0.61	7.56	1.24	11.21	4.13

Table 1. Average, maximum, minimum and standard deviation of wave height and wave period from Sustainability Victoria wave buoy data for months of January and June. Data summarised from Sustainability Victoria, 2013.

The following graphs for both significant wave height and wave period detail average measurements of both factors over 10 minute intervals. The graphs demonstrate the variability of both factors. All data has been summarised from the data obtained from Sustainability Victoria (2013).

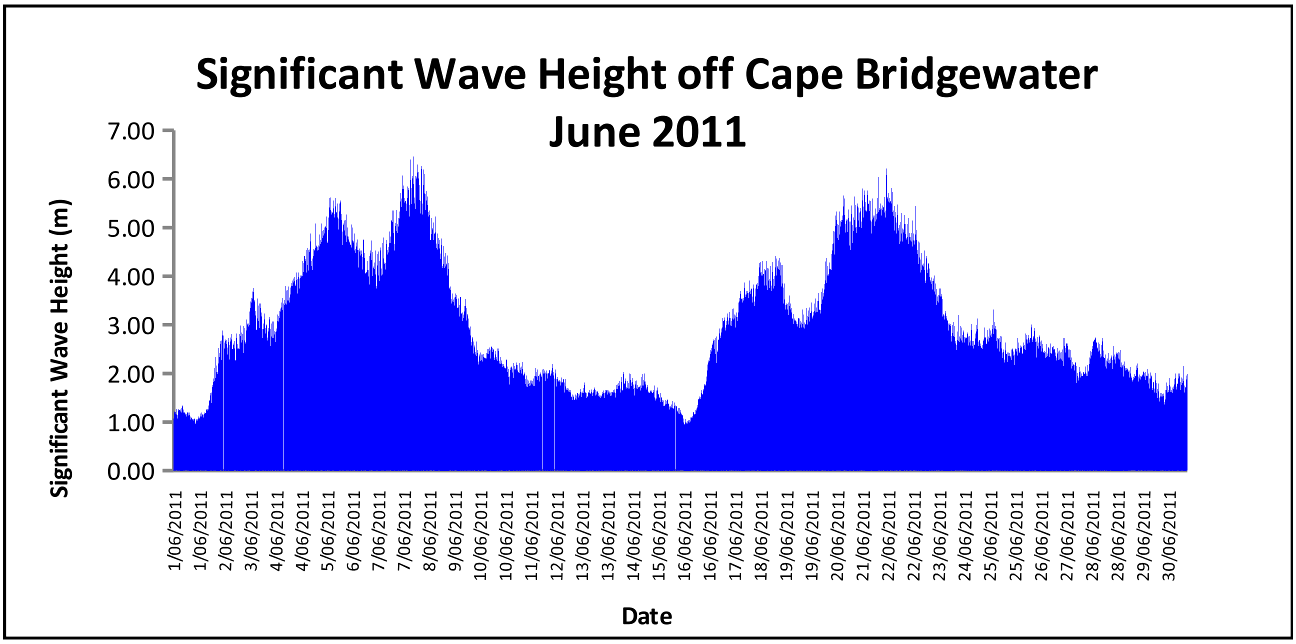


Figure 4. Significant Wave Height off Cape Bridgewater in June 2011.

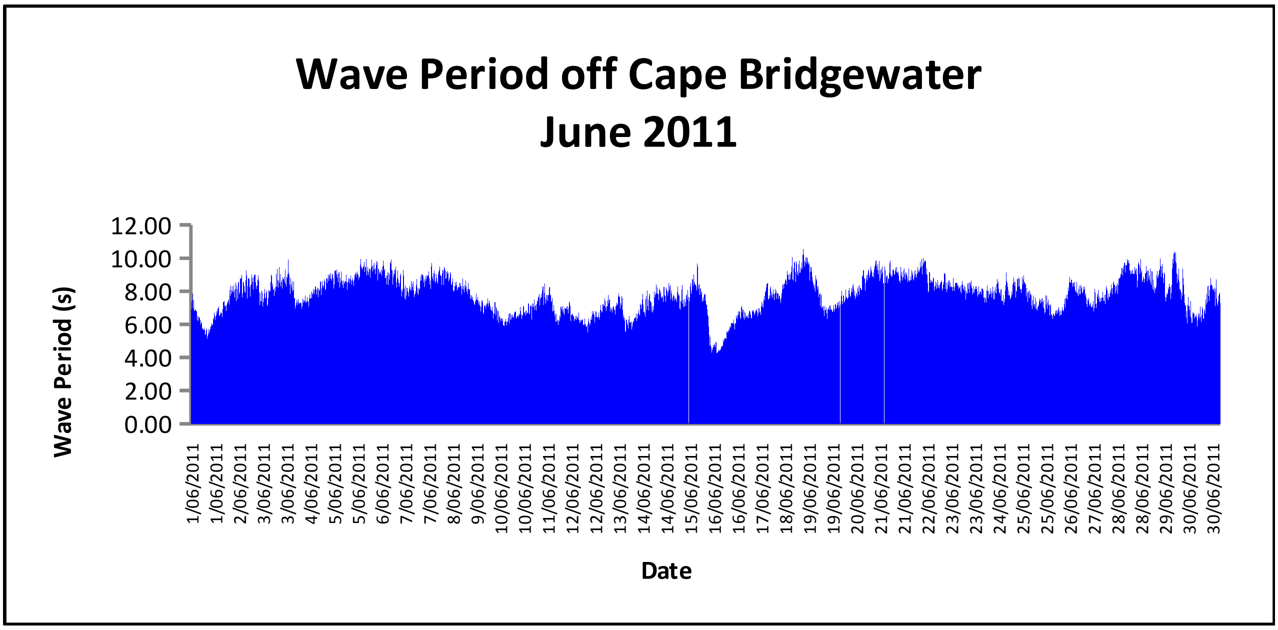


Figure 5. Wave period off Cape Bridgewater in June 2011.

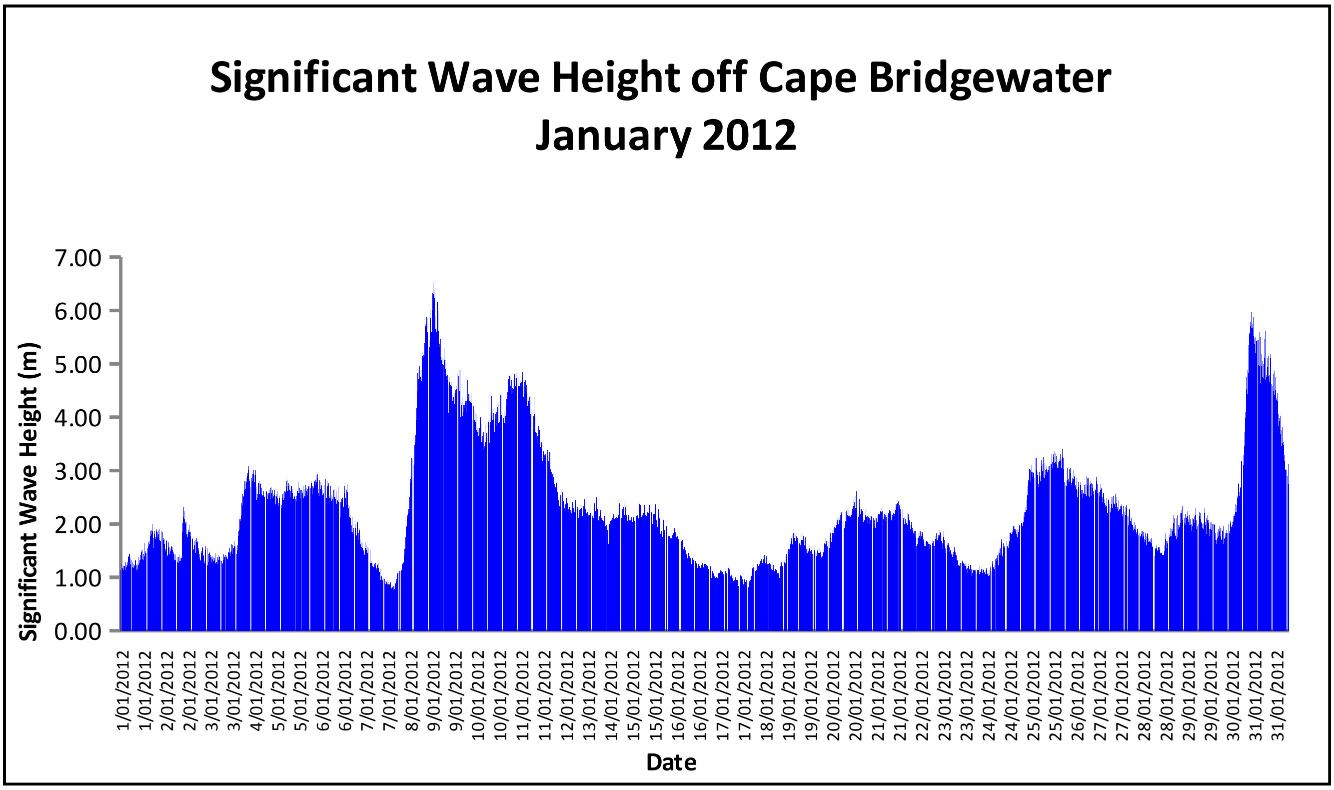


Figure 6. Significant Wave Height off Cape Bridgewater in January 2012.

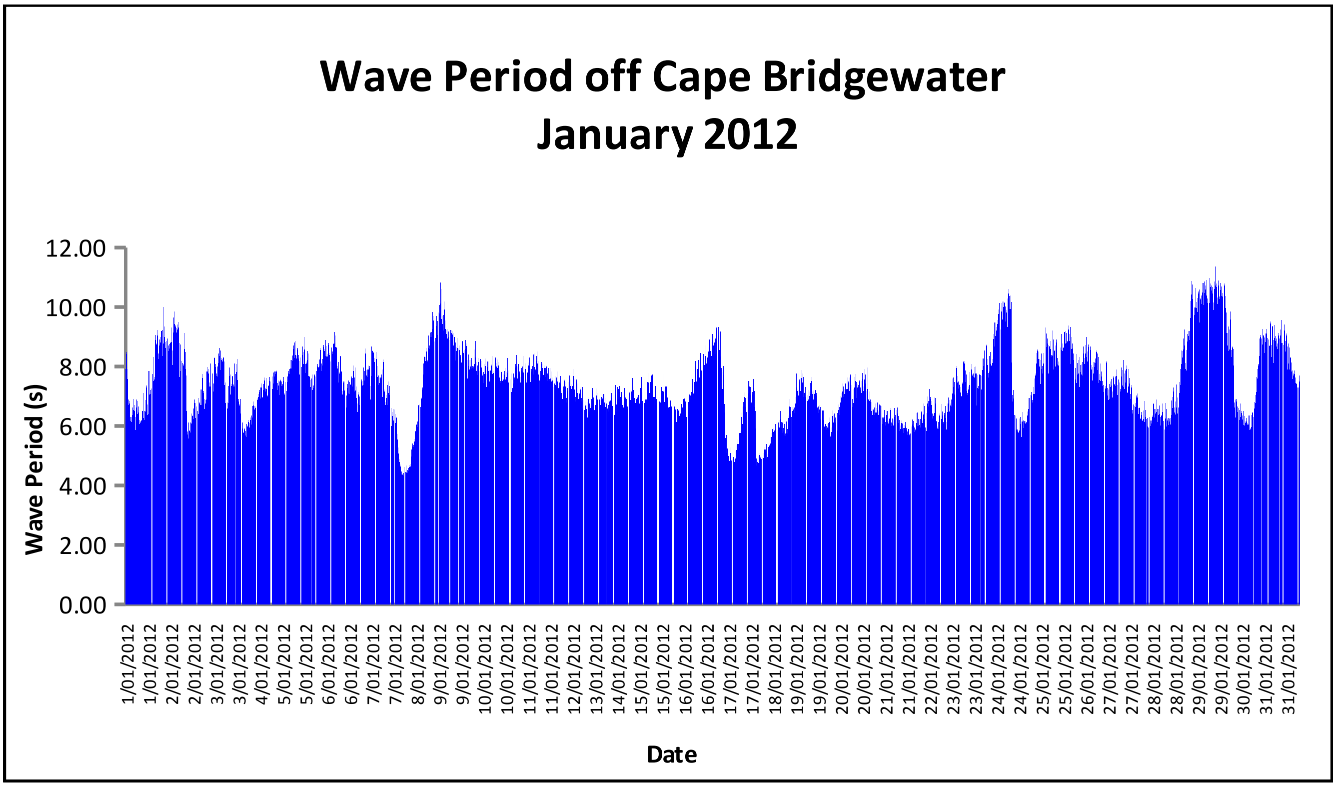


Figure 7. Wave period off Cape Bridgewater in January 2012.

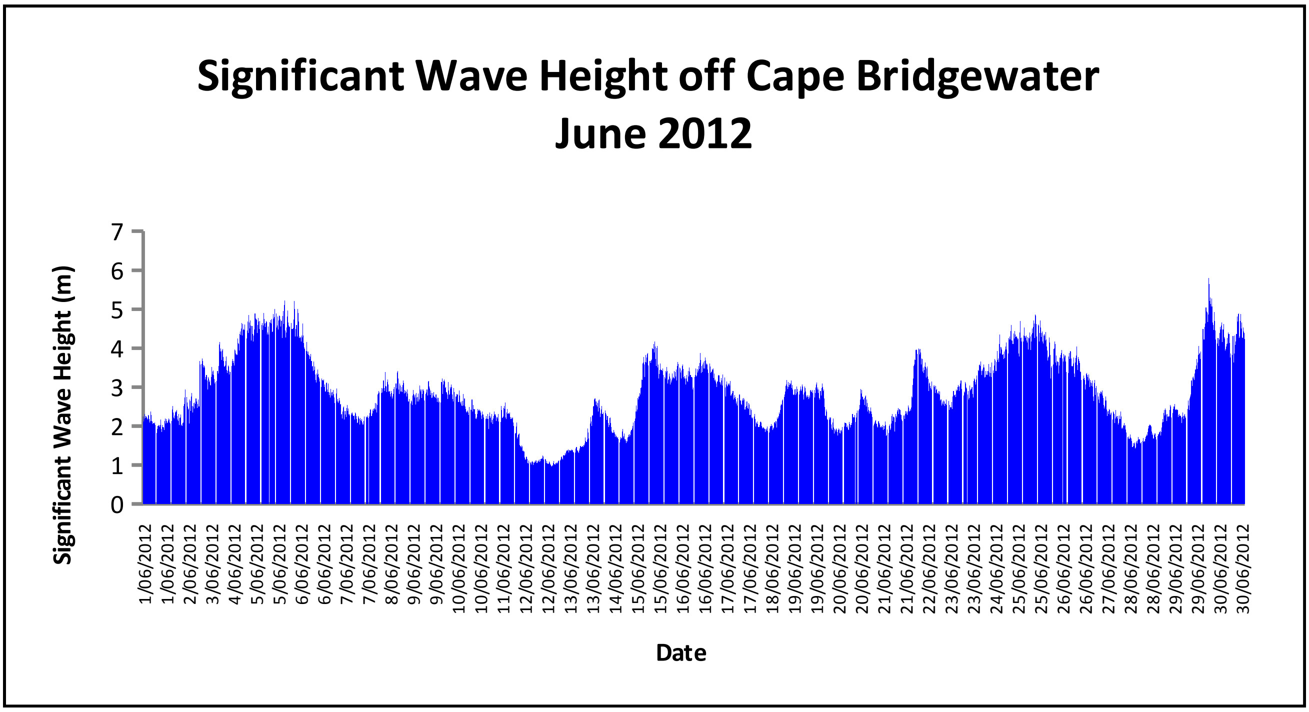


Figure 8. Significant Wave Height off Cape Bridgewater in June 2012.

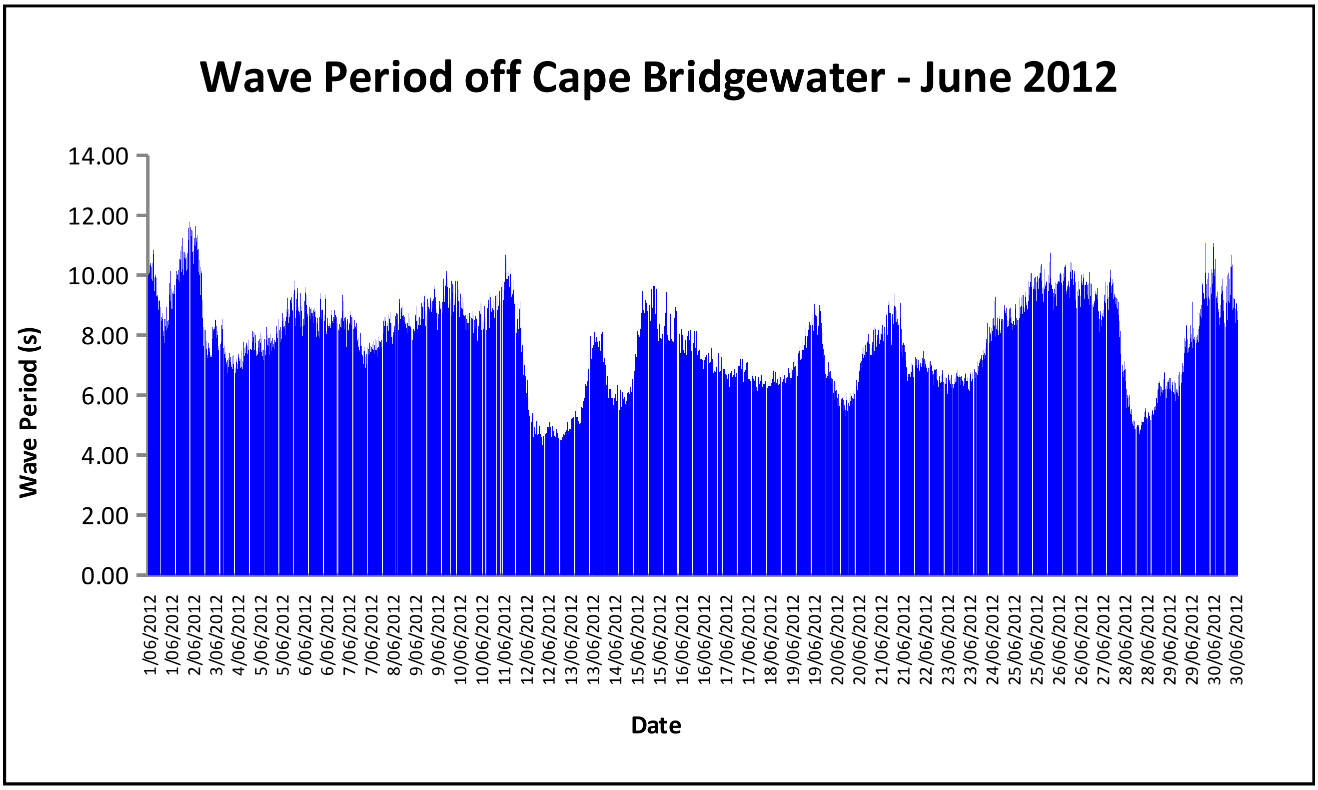


Figure 9. Wave period off Cape Bridgewater in June 2012.

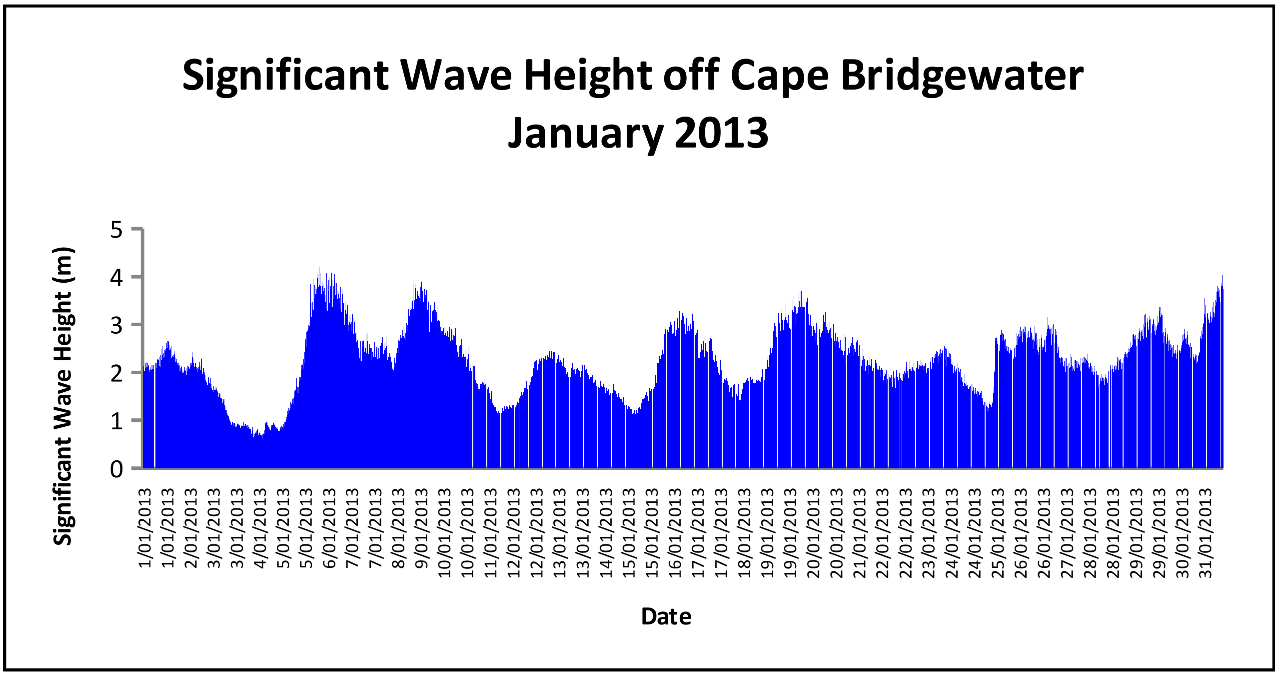


Figure 10. Significant Wave Height off Cape Bridgewater in January 2013.

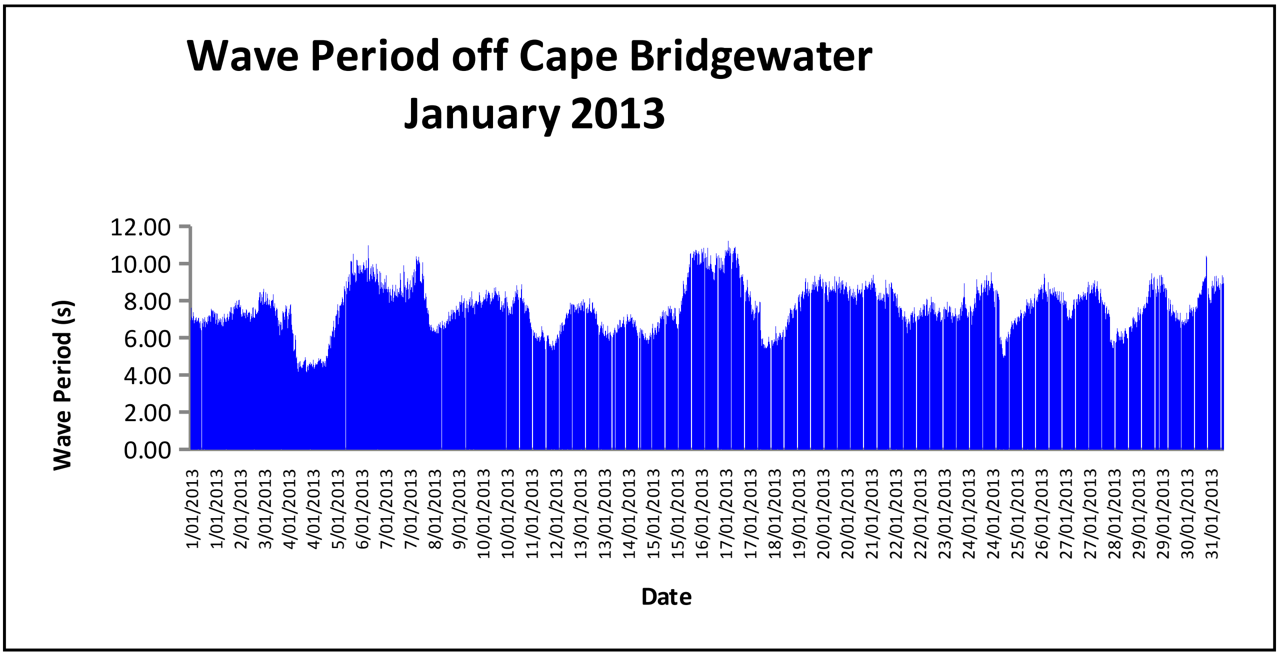


Figure 11. Wave period off Cape Bridgewater in January 2013.

In assessing potential wave power without specific wave velocity data being known, the Sustainable Energy Authority (2004) used the equation which will be used here, being:

$$P=\left(\frac{p.g.H^2}{16}\right)*\left(\frac{g.T}{4\Pi}\right)$$

where:

P = potential wave power (kW/m)
p = density of sea water (1026 kg/m^3)
g = acceleration due to gravity (9.81 m/s^2)
H = significant wave height (m)
T = wave period (s)

In calculating the potential wave power for each month of data, use has been made of the following parameters:

1. Average significant wave height and average wave period;
2. Upper standard deviation of wave height and wave period; and
3. Lower standard deviation of wave height and wave period.

Using these parameters is believed to provide a better indication of wave power throughout the month by not limiting the data calculation to just the average height and period (which can be influenced by anomalous wave events such as storms), and to provide a better estimate of the range of potential wave power expected to reach a power generator.

	Ave. Wave Height & Period (kW/m)	Std Dev above Height & Period (kW/m)	Std Dev below Height & Period (kW/m)
June 2011	33.74	79.15	9.27
Jan 2012	18.71	47.35	4.3
June 2012	30.14	62.45	11.28
Jan 2013	18.46	36.9	7.34

Table 2. Average, Upper Standard Deviation and Lower Standard Deviation potential wave power. Data summarised from Sustainability Victoria (2013).

The results in Table 2 demonstrate the difference between average potential wave power in winter and summer months and the large variance between the smallest potential power obtained from the lower end of the middle two-thirds of the waves measured and largest potential power obtained from the upper end of the average two-thirds of waves.

When the average potential wave power for each month is compared to average wave height and wave period data in table 1, small variances in the wave weather are shown to result in significant differences in the amount of energy that may be harvested, particularly in significant wave height.

If the assertion made by the Sustainable Energy Authority report that 30kW/m potential wave energy is required for economically viable exploitation of the energy in that location was taken as the benchmark for whether the Victorian Wave Project will be successful, the data summarised will be a cause for concern. Although in summer months the average power meets this criteria, the winter months do not and are considerably lower than the 30kW/m limit. However, even in summer months, if one were to look at wave energies up to one standard deviation above the average wave power, there will be periods where this criteria is met.

Should the optimal wave energy stated to be required by Ocean Power Technologies of 20kW/h or more is used, summer months have provided an average wave energy just below this level, whilst winter averages are 50% above this required level. However, even in winter months, there will be periods where the devices do not work to optimal levels, as for more than half of the summer months, resulting in the conclusion that the plants ability to provide electrical energy throughout the year will regularly include periods, even in winter months but more so in summer months, where the output is hampered.

Conclusion

Such wave energy demonstration plants are no doubt advantageous to the continuing research into efficient, clean electricity production. However, the type of device being used in the VWP plant, the average wave energy calculations for representative summer and winter months used to indicate the range of wave energies throughout the year, and variability of both significant wave height and wave period between seasons and within a month, raise concern about the ability of the devices to efficiently provide reliable energy throughout the year.

BIBLIOGRAPHY

Arup, T 2012, *Victorian Wave power project in murky water*, Sydney Morning Herald, viewed 10 May 2013, www.smh.com.au/environment/energy-smart/victorian-wave-power-project-in-murky-water-20120120-1qacy.html

CSIRO 2012, *Ocean Renewable Energy: 2015 – 2050, An analysis of ocean energy in Australia,* CSIRO, viewed 6 May 2013, www.csiro.au/~/Media/BEA2D11E313C498BAD26624B0BE911F9.ashx

Drew, B, Plummer, A and Sahinkaya, M 2009, 'A review of wave energy converter technology', *Journal of Power and Energy*, vol. 223, pp. 887 – 902, viewed 7 May 2013, http://pia.sagepub.com/content/223/8/887.full.pdf+html

Eriksson, M 2007, 'Modelling and experimental verification of direct drive wave energy conversion', *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology*, vol. 287, viewed 16 May 2013, http://www.diva-portal.org/smash/get/diva2:169996/FULLTEXT01

Falcão, A 2010, 'Wave energy utilization: A review of the technologies', *Renewable and Sustainable Energy Reviews*, vol. 14, pp. 899-918, viewed 7 May 2013, http://mhk.pnnl.gov/wiki/images/5/58/Wave_Energy_Utilization.pdf

Falnes, J 2007, 'A review of wave-energy extraction', *Marine Structures,* vol. 20, pp. 185-201, viewed 6 May 2013, www.sciencedirect.com/science/article/pii/S0951833907000482

Korde, U 2000, 'Control system applications in wave energy conversion', *OCEANS 2000 MTS/IEEE Conference and Exhibition (Volume:3),* viewed 10 May 2013, https://www2.lirmm.fr/lirmm/interne/BIBLI/CDROM/ROB/2000/OCEANS2000/Cd-rom/xxxx/techdoc/SP015.pdf

Muetze, A and Vining, J 2006, 'Ocean Wave Energy Conversion – A Survey', *Industry Applications Conference, 2006. 41st IAS Annual Meeting. Conference Record of the 2006 IEEE (Volume:3)*, viewed 20 May 2013, www2.warwick.ac.uk/fac/sci/eng/staff/am/.../ias37p2.pdf

Ocean Power Technologies Inc undated (a), *Global Resources*, Ocean Power Technologies Inc, viewed 8 May 2013, http://www.oceanpowertechnologies.com/resources.html

Ocean Power Technologies Inc undated (b), *Technology*, Ocean Power Technologies Inc, viewed 8 May 2013, http://www.oceanpowertechnologies.com/technology.htm

Ocean Power Technologies Inc undated (c), *Mark 3 PowerBuoy*, Ocean Power Technologies, viewed 8 May 2013, http://www.oceanpowertechnologies.com/mark3.html

Ocean Power Technologies Inc 2008, *Apparatus and method for optimizing the power transfer produced by a wave energy converter (wec)*, Google Patents, viewed 10 May 2013, http://www.google.com/patents/EP1425510B1?cl=en&dq=apparatus+and+method+for+optimizing+the+power+transfer+produced+by+a+wave+energy+converter&hl=en&sa=X&ei=k6KoUYLIOMasigLDr4C4Ag&ved=0CDsQ6AEwAQ

Pelc, R and Fujita, R 2002, 'Renewable energy from the ocean', *Marine Policy*, vol. 26, pp. 471-479, viewed 10 May 2013, http://mhk.pnnl.gov/wiki/images/3/3d/Pelc_%26_Fujita_2002.pdf

Salter, S 1974, 'Wave Power', *Nature*, vol. 249, pp. 710 – 724, viewed 6 May 2013, www.mech.ed.ac.uk

Sustainable Energy Authority 2004, *Wave and Tidal Power Assessment for the Victorian Coastline; Report No. J121/R01*, Sustainable Energy Authority, viewed 6 May 2013, http://www.sustainability.vic.gov.au/resources/documents/wave_and_tidal_power_assessment_for_the_victorian_coastline1.pdf

Sustainability Victoria 2013, *Wave resource monitoring data set – Cape Bridgewater*, Sustainability Victoria, provided upon request to Sustainability Victoria and used with Sustainability Victoria's permission, received 10 May 2013

Victorian Wave Project undated (a), *About the Project*, Victorian Wave Project, viewed 8 May 2013, http://victorianwaveproject.com.au/about-the-project

Victorian Wave Project undated, (b) *Project Operation,* Victorian Wave Project, viewed 8 May 2013, http://victorianwaveproject.com.au/about-the-project/scope

Victorian Wave Project undated (c), *Proposed Location*, Victorian Wave Project, viewed 8 May 2013, http://victorianwaveproject.com.au/about-the-project/location

World Energy Council 2010, *2010 Survey of Energy Resources*, World Energy Council, viewed 27 May 2013, www.worldenergy.org/documents/ser_2010_report_1.pdf