Wave resource assessment for Lord's Cove, Newfoundland - winter/spring 2012 survey
Boileau, R.; Baddour, E.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21262967
Technical Report, 2012-07-25

National Research Council Canada / Conseil national de recherches Canada

Report Documentation Page

REPORT NUMBER	PROJECT NUMBER	DATE
OCRE-TR-2012-19	A1-001189	2012-07-25

REPORT SECURITY CLASSIFICATION	DISTRIBUTION
Unclassified	Unlimited

TITLE
Wave resource assessment for Lord's Cove, Newfoundland -- winter/spring 2012 survey

AUTHOR(S)
R. Boileau and E. Baddour

CORPORATE AUTHOR(S)/PERFORMING AGENCY(S)
National Research Council - Ocean, Coastal and River Engineering - St. John's

PUBLICATION

SPONSORING AGENCY(S)
College of the North Atlantic

RAW DATA STORAGE LOCATION(S)	PEER REVIEWED
tbd, \\NRCsjsFS1:\PJ2530\wave data analysis	No

MODEL #	PROP #	EMBARGO PERIOD
		0 Months
PROJECT	**GROUP**	**PROGRAM**
A1-001189-03	---	Marine Energy
FACILITY		

KEY WORDS	PAGES	FIGS.	TABLES
wave buoy data analysis, wave resource characterization, Lord's Cove sea states, wave power, wave energy flux per unit wave crest, wave scatter diagram, wave energy distribution	vii, 12	8	10

SUMMARY
This interim report is an initial step towards characterizing the wave resource outside Lord's Cove, Newfoundland. The report presents the analysis of data collected and transmitted every half hour from a wave buoy outside Lord's Cove during the winter and spring of 2012. The data is limited to the pre-processed parameters provided by an Axys Technologies Ltd. Triaxys Directional Wave Buoy. The results include the omnidirectional wave power and wave energy flux per unit wave crest and directionality represented as wave direction roses. The monthly wave statistics for the theoretical wave power and energy is estimated and presented. Preliminary conclusions and future work are also provided.

ADDRESS
NRC - Ocean, Coastal and River Engineering - St. John's, P. O. Box 12093, Arctic Ave. St. John's, NL A1B 3T5

Canada

National Research Council Canada
Conseil national de recherches Canada

Ocean, Coastal and River Engineering
Génie océanique, côtier et fluvial

UNCLASSIFIED

Wave resource assessment for Lord's Cove, Newfoundland – winter/spring 2012 survey

OCRE-TR-2012-19

R. Boileau and E. Baddour

2012/07/25

Contents

List of Figures

List of Tables

Glossary

ATI	Axys Technologies Inc.
CNA	College of the North Atlantic
H_{mo}	significant wave height as the mean of the one-third highest waves
NRC	National Research Council Canada
T_e	energy period, a mean wave period with respect to the spectral distribution of wave energy transport or wave power level (usually a fraction of peak period)
T_P	peak wave period

1 Introduction

The College of the North Atlantic (CNA) solicited collaboration from National Research Council Canada (NRC) in the design of a wave pump to supply water to the CNA on-shore aquaculture centre at Lord's Cove. As a first step in characterizing the wave resource outside Lord's Cove, data is being collected and transmitted every half hour from a wave buoy at a proposed wave pump location. This wave buoy data is analysed by NRC to assess the theoretical (omnidirectional) power and total energy available for operating a wave pump.

The area under investigation is a site along the southern coast of Newfoundland outside the entrance to Lord's Cove on the Burin peninsula.

1.1 Location

An Axys Technologies Inc. (ATI) wave buoy is deployed approximately one kilometre outside Lord's Cove at 46.86°N latitude, 55.667°W longitude. This location, shown in Figure 1, was selected for proximity to the on-shore aquaculture centre and good exposure to ocean sea states with minimal interference from local bathymetry. The buoy is moored in 30 metres* of water.

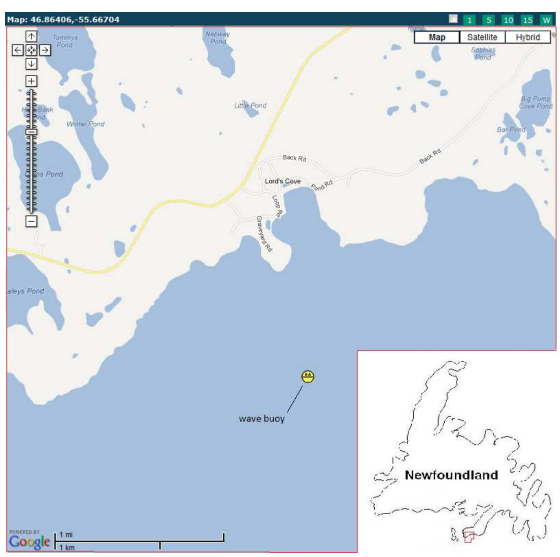


Figure 1: Map of wave buoy location

*all units SI unless otherwise noted

1.2 Data acquisition date range

The wave buoy was first deployed on January 10, 2012. Data was collected from January 10 to February 26, when the buoy moved off-station after breaking its mooring. The buoy was captured and deployed again on May 1 within 100 metres of its original position. The results presented here include only data for the dates in Table 1.

Table 1: Data aquisition dates

start date	end date	samples (days)	note
2012-01-10	2012-02-26	2000 (42)	winter data range
2012-02-26			mooring failure
2012-05-02	2012-06-21	2371 (50)	spring data range

This report describes the method used to collect and process data and a preliminary analysis of the wave environment at Lord's Cove, Newfoundland in winter and spring 2012. It is important to note that the results presented here are based strictly on pre-processed wave buoy data. When the buoy is retrieved, further spectral analysis may be performed on the raw data if other parameters are needed.

The following section describes the assumptions and methods for analysing wave data. Section 3 gives information on the wave buoy instruments and pre-processed parameters. Section 4 presents the first two seasons of data and calculated estimates for average theoretical power and energy over that period. These results are summarized and discussed in Section 5. Plans for future work are discussed in Section 6

2 Assumptions and approach to analysis

For the purpose of the wave energy characterization of this site, the surface of the sea is assumed to be a stationary[†] and ergodic[‡] Gaussian random process. These assumptions imply that the data at the same location for one period of time (read: month or season) can be taken as typical for another year in the same period, so that the mean, moments and variance are all taken as constant.

In this case, data is sampled for 20 minutes at 30-minute intervals over a period of months – typical sea states change over a period of hours or days, so this sample rate is presumed to be adequate for capturing the wave environment.

The buoy is restricted by its mooring to lie within a radius of 50 metres and, according to observations by the deployment crew, it is on a locally flat plateau, so the assumption of stationarity should be irrelevant.

[†] joint probability distribution is invariant in time or space

[‡] statistical properties (mean, variance) can be characterized by a single, “sufficiently long” sample

Small amplitude linear wave theory is assumed for the calculation of wave parameter relations. The methodology for wave resource assessment and characterization of this site is based on *in situ* measurements via a single-line moored buoy.

Following the method for typical wave resource assessments proposed by Saulnier & Pontes in 2009 [1] and other presentations in the *Inventory of Canada's marine renewable energy resources* [2], the Lord's Cove data has been characterized by the average wave power and total energy flux per unit crest length.

The data analysed for this interim report is limited to the pre-processed parameters provided by the ATI Triaxys Directional Wave Buoy. The results are presented seasonally. (These can easily be reproduced in monthly increments for finer detail.) The mean power and energy are calculated month by month.

The main interest of the present study is the determination of the directionally-unresolved (omnidirectional) wave power and wave energy flux per unit width. These are typically used as base measures of the primary resource under consideration.

3 Measurement and pre-processing

An ATI *Triaxys*™ Directional Wave Buoy (Figure 2) is being used to collect and pre-process wave data. The buoy instruments measure wave height (heave), period and direction and internal device temperature. The accuracies for the instruments are given in Table 2.

Table 2: ATI Triaxys wave buoy instrument range and resolution

Data	Range	Resolution	Accuracy
Heave	20 m	0.01 m	better than 2%
Period	1.6 to 33.3 s	0.5 s	not stated
Direction	0 to $360°$	$1°$	$\pm 1°$
Temperature	not stated	$1°$C	not stated

The location of the buoy is restricted by the mooring to a swing radius. The swing about the mooring point is less than 100 metres. When the mooring broke in February, the buoy was tracked by its own satellite transmissions and retrieved by boat. It was re-deployed in May within 100 metres of the original position – the spring buoy location data is plotted in Figure 3.

The ATI buoy collects time traces for location (latitude, longitude), device temperature and wave height, period and direction at 4 hertz and stores these data on board. It pre-processes the data by performing spectral analysis to produce the calculated parameters shown in Table 3. This pre-processing reduces the bandwidth so that the results can be transmitted via satellite or radio more economically. For this deployment,

Figure 2: ATI wave buoy

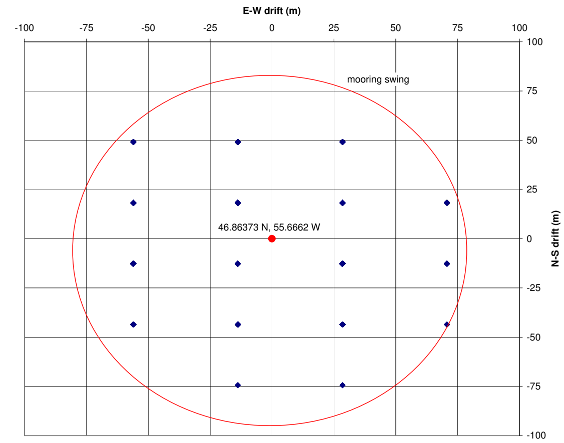


Figure 3: Mooring swing (spring 2012)

the buoy is set to record and process 20-minute data samples at half-hour intervals and to transmit the parameters via InmarsatD satellite on the internet. The half-hourly data is used for the analysis in this report.

The significant wave height (`Hmo`) and peak period (`TP`) collected by the wave buoy from January to June are shown in Figures 4 and 5. The data is presented as time series, as recommended by Saulnier and Pontes [1], with 30-minute intervals.

Table 3: ATI spectral analysis parameters

parameter	description
DateTimeStamp	data acquisition period end time
Hmax (m)	maximum wave height in metres
Hmo (m)	significant wave height (mean of highest 1/3 waves)
Hav (m)	mean wave height (all waves)
TP (s)	peak period in seconds *a.k.a.* dominant period – the period of the highest spectral frequency band from a Fourier analysis.
T13 (s)	significant period based on the average of the highest third of the waves.
Tave (s)	average period
MeanDirection (degrees)	mean wave direction
Spread (degrees)	range of directions during acquisition period

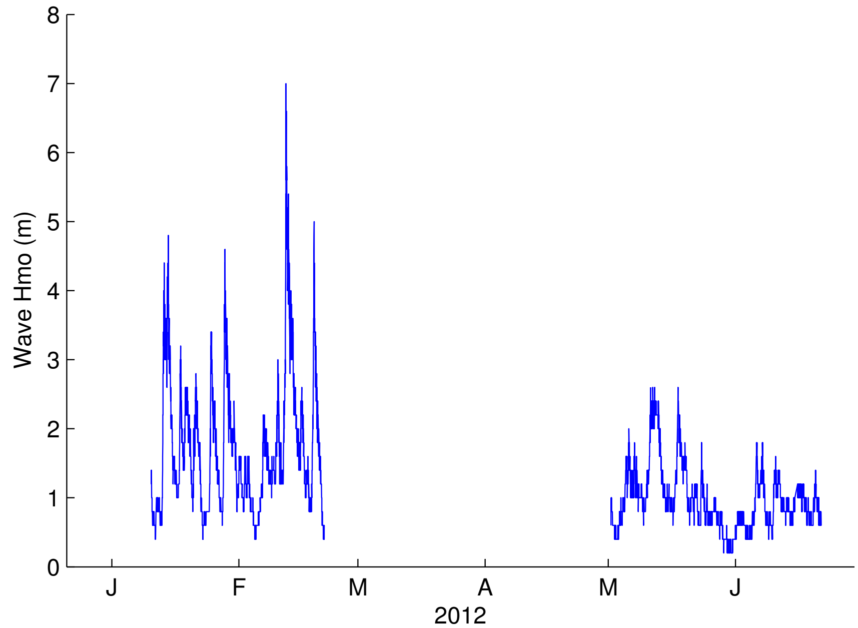


Figure 4: Time series for significant wave height (30-minute intervals)

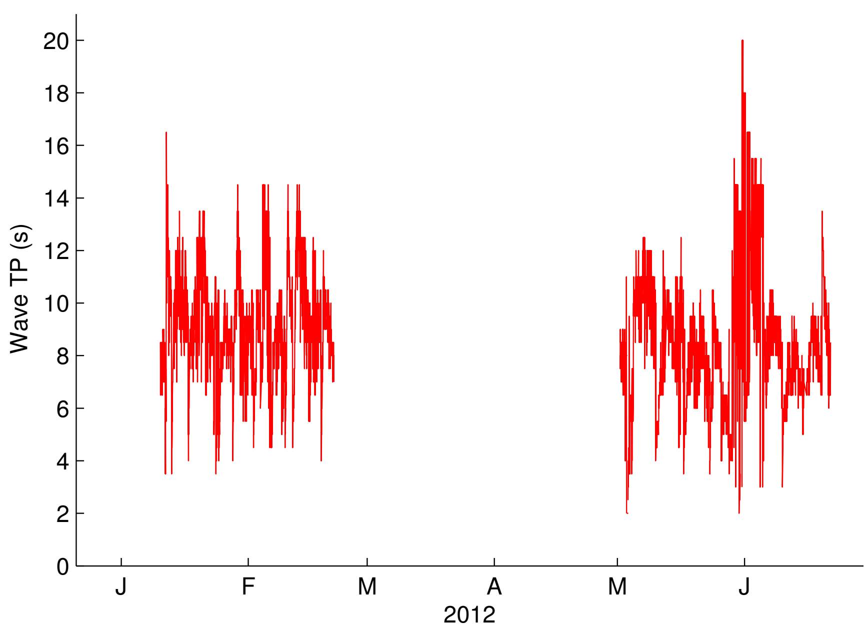


Figure 5: Time series for peak period (30-minute intervals)

4 Results

All calculations and results in this report are based on the ATI parameters `Hmo`, `TP` and `MeanDirection` only. Location data was used to confirm the dates for data collection. Temperature data was not used.The particular, water density is assumed to be average sea surface density (1027 kg/m^3) for comparison with [2].

The time series of these parameters are post-processed in Mathworks *Matlab*™ using scripts to produce the standard wave scatter tables and histograms of the probability densities for height and period for each season (see [1], [2]). The average wave power for each sea state is tabulated and the total wave energy is calculated. These results and the methods for generating them are provided in the following sub-sections.

4.1 Wave environment

The wave environment is described by seasonal wave scatter diagrams, probability densities and wave direction roses.

The wave scatter diagram is a joint histogram of wave height and period. Typically, the occurrences are binned by significant wave height vs peak period. The significant wave height H_{mo} is the ATI parameter `Hmo`. In this analysis, the "energy period," T_e, arguably a conservative value recommended by Cornett [2], is used in place of peak period. Energy period is calculated from the peak period , T_P (ATI parameter `TP`), per Cornett:

$$T_e = 0.9 \cdot T_p \qquad \text{energy period} \tag{1}$$

The wave scatter diagram is presented in Tables 4 and 5 as relative (percent) occurences for each season. The information in the wave scatter diagram is further summarized in the probability densities for each parameter (Figures 6 and 7).

Wave direction is presented as a polar histogram of `MeanDirection` data binned by 30° increments in the wave direction rose for each season in Figure 8. Each rose shows the direction in degrees from whence the wave approaches.

Table 4: Wave Scatter Diagram (%) for Lord's Cove – Winter 2012

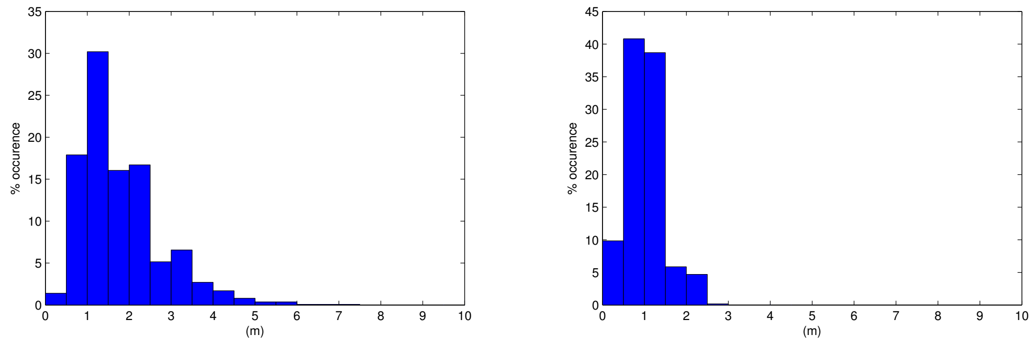
$T_e(s)$	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	15 - 18	18 - 21	21 - 24	24 - 27	27 - 30	>30	**sum**
$H_{mo}(m)$												
>10												
9 - 10												
8 - 9												
7 - 8			0.1									**0.1**
6 - 7				0.1								**0.1**
5 - 6			0.1	0.6	0.1							**0.7**
4 - 5			0.8	1.1	0.6							**2.5**
3 - 4		0.1	3.8	5	0.4							**9.3**
2 - 3		1.8	10.4	9.2	0.5							**21.9**
1 - 2		7	27.8	11	0.5							**46.3**
0 - 1		2.4	9.9	5.5	1.6							**19.3**
sum		**11.2**	**52.7**	**32.5**	**3.6**							**100**

2000 samples (42 days)

Table 5: Wave Scatter Diagram (%) for Lord's Cove – Spring 2012

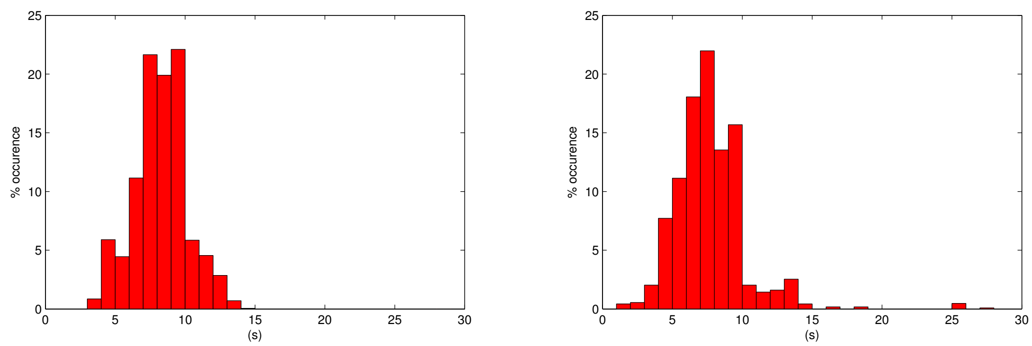
$T_e(s)$	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	15 - 18	18 - 21	21 - 24	24 - 27	27 - 30	>30	**sum**
$H_{mo}(m)$												
>10												
9 - 10												
8 - 9												
7 - 8												
6 - 7												
5 - 6												
4 - 5												
3 - 4												
2 - 3		1	2.7	1.1								**4.9**
1 - 2		9	23.2	12.3								**44.5**
0 - 1	1	10.9	27.6	5.7	4.6	0.2	0.2		0.5	0.1		**50.6**
sum	**1**	**20.9**	**53.6**	**19.1**	**4.6**	**0.2**	**0.2**		**0.5**	**0.1**		**100**

2371 samples (50 days)



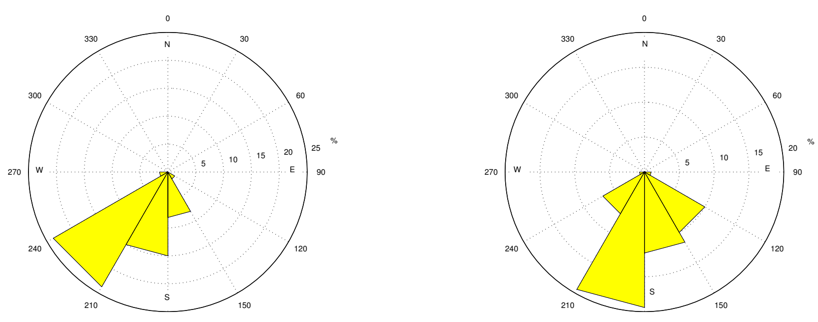
(a) winter 2012 (b) spring 2012

Figure 6: Probability densities of significant wave height



(a) winter 2012 (b) spring 2012

Figure 7: Probability densities of peak period



(a) winter 2012 (b) spring 2012

Figure 8: Wave direction roses

4.2 Wave power

For a wave at a given period and height, theoretical power in a sea state can be calculated based on the general equation [2]:

$$P \simeq \frac{\rho g}{16} H_s^2 C_g \left(\frac{1}{T_e}, h\right) \qquad \text{power} \tag{2}$$

where ρ is density (for average surface sea water, in this case), g is the gravitational constant, H_s is significant wave height, C_g is group velocity and h is water depth.

For an arbitrary depth, the wave length must be solved using an implicit equation:

$$L = T\sqrt{\frac{g}{k} tanh(kh)} \qquad \text{wave length} \tag{3}$$

where $k = 2\pi/L$ is the wave number, from which group velocity can be calculated using:

$$C_g = \left(1 + \frac{2kh}{sinh(2kh)}\right)\frac{L}{2T} \qquad \text{group velocity} \tag{4}$$

The average theoretical power is calculated for each sea state in the range of observed typical wave height (0 to 7 metres) and period (0 to 15 seconds), as shown in Table 6. As expected, power increases with period and height. (Only omnidirectional power is calculated here.)

Table 6: Variation in power per unit wave crest width with peak period and significant wave height for Lord's Cove wave buoy site in 30-m water (kW/m)

$T_e(s)$	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15
H_{mo}					
6 - 7	28	84	146	231	300
5 - 6	20	60	104	165	215
4 - 5	13	40	70	111	144
3 - 4	8	24	42	67	87
2 - 3	4	12	22	34	44
1 - 2	1	4	8	12	16
0 - 1	*negl.*	*negl.*	1	1	2

This table does not represent the likelihood of achieving any particular power, however.

4.3 Wave energy

Total wave energy for a period of time t is calculated from the average theoretical wave power:

$$E = P_{avg} \cdot t \qquad \text{total energy} \tag{5}$$

The energy is calculated for each sea state and duration observed in the first half of 2012. Since we don't have complete data, Tables 7 and 8 show relative energy for the available data. Total energy per unit crest width for the most common observed sea state was 671 MJ/m (186 kWh/m[§]) in winter and 74.6 MJ/m (20.7 kWh/m) in spring.

Table 7: Wave energy distribution (%) – Winter 2012

T_e (s)	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	> 15	**sum**
H_{mo} (m)							
> 8							
7 - 8			0.5				0.5
6 - 7				1.2			1.2
5 - 6			0.3	5.1	0.6		5.9
4 - 5			2.7	6.6	4.5		13.7
3 - 4		0.1	8.3	17.3	1.8		27.4
2 - 3		1.2	11.6	16.1	1.1		30.0
1 - 2		1.6	11.1	7.0	0.4		20.1
0 - 1		0.1	0.4	0.4	0.1		1.0
sum		**2.9**	**34.9**	**53.7**	**8.5**		**100.0**
							2000 samples (42 days)

Table 8: Wave energy distribution (%) – Spring 2012

T_e (s)	0 - 3	3 - 6	6 - 9	9 - 12	12 - 15	> 15	**sum**
H_{mo} (m)							
> 3							
2 - 3		2.4	11.2	7.1			**20.7**
1 - 2		7.6	34.1	28.6			**70.4**
0 - 1		1.0	4.5	1.5	1.5	0.4	**9.0**
sum		**11.0**	**49.8**	**37.2**	**1.5**	**0.4**	**100.0**
							2371 samples (50 days)

[§]kilowatt-hour per metre

5 Summary results and discussion

This report presented typical wave resource statistics based on the data available for Lord's Cove in the winter and spring seasons only. The presentation follows recommended guidelines [1], and previous work on a national wave atlas [2], so that these data can be compared with other sites.

For 2012, it can be seen that the *most common* sea state was (1-2 m, 6-9 s) in winter (27.8% of the time) and (0-1 m, 6-9 s) in spring (27.6%). In comparison, the 2012 sea state that contributed the *most energy* was (3-4 m, 9-12 s) in winter and (1-2 m, 6-9 s) in spring. The energy may be of more importance in the design of a wave pump to produce flow with fewer or shorter interruptions.

The average wave power and total wave energy per metre wave crest for each month are summarized in Table 9.

Table 9: Monthly wave statistics for Lord's Cove for winter/spring 2012

	Jan	Feb	Mar	Apr	May	Jun
average power (kW/m)	18.52	22.14	n/a	n/a	5.61	3.46
total energy (kWh/m)	13 781	15 411	n/a	n/a	4 177	2 488
total days	21	21	0	0	30	20

Certain trends can be seen in wave direction at the wave buoy site: waves were focused from the southwest this winter and veered to south-southwest this spring. Direction was not considered in the power calculations; these results only include omnidirectional power, which is considered suitable as a base measure for a wave resource.

These results are based on the assumptions given in Section 2. The limitation of data to one year *does not allow for large variation in weather between years*. Historically, there is a large seasonal variation in weather in this region and, therefore, a large variation in sea states. To this date, only two seasons have been analysed, and they are consistent with historical observations.

It is too early to determine dominant sea states for design purposes without having a complete set of seasonal data and confirming the shape of the wave spectrum from the raw data.

6 Future work

The analysis completed for this report will be repeated after summer and fall data have been collected.

This analysis may be re-run with further refinement as needed to support the process of designing the wave pump. An extreme storm event could skew energy contributions for a rare sea state that may be masked by the resolution of the histograms. Even if not targeted for energy extraction, extreme conditions should be identified for ensuring survivability of the device.

In addition, power exceedence (the likelihood that power will be above a certain value) will be plotted. Exploitable power will be defined and calculated. A realistic estimate of exploitable power may be taken from Folley *et al*'s definition [3]. Although this definition is arbitrary, it can identify important sea states to target for design purposes.

Raw data will be recovered from the wave buoy when it is retrieved (date to be determined). Our assumptions will be checked against the wave spectra from analysis of the raw data. Knowledge of the spectra will be used to model the Lord's Cove sea states in numerical and scale model tests.

While directional power was not resolved here, it may be considered depending on the type of wave pump to be designed.

References

[1] J. Saulnier and M. T. Pontes, "Guidelines for wave energy resource assessment and standard wave climate," in *Institution of Civil Engineers Coasts, Marine Structures & Breakwaters conference*, Sep. 2009.

[2] A. Cornett, "Inventory of Canada's marine renewable energy resources," Tech. Rep. CHC-TR-041, National Research Council Canadian Hydraulics Centre, April 2006.

[3] M. Folley, B. Elsaesser, and T. Whittaker, "Analysis of the wave energy resource at the European Marine Energy Centre," in *Institution of Civil Engineers Coasts, Marine Structures & Breakwaters conference*, Sep. 2009.