



Electromagnetic Field Study

Electromagnetic field measurements: data acquisition requirements.

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Oregon Wave Energy Trust (OWET) is a nonprofit public-private partnership funded by the Oregon Innovation Council. Its mission is to support the responsible development of wave energy in Oregon. OWET emphasizes an inclusive, collaborative model to ensure that Oregon maintains its competitive advantage and maximizes the economic development and environmental potential of this emerging industry. Our work includes stakeholder outreach and education, policy development, environmental assessment, applied research and market development.

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1. EXECUTIVE SUMMARY

This report describes the recommended data acquisition requirements for obtaining valid electromagnetic field (EMF) assessments of potential wave energy sites in Oregon's near-shore marine environment and focuses on the proposed Reedsport site in particular. The results of this report may be used to determine data acquisition requirements for other wave energy sites, so long as the fundamental processes that comprise the electromagnetic spectrum in a given region are comparable to those in the Reedsport site. These processes include ocean wave activity, local bathymetric conditions, coastal and tidal currents, and knowledge of the Earth's magnetic field strength and direction. In general, this methodology should nominally apply to sites along the Oregon coast, with little or no adaptation.

This study was prepared with the goal of establishing data acquisition requirements based on the underlying temporal variability, frequency content, and general statistical character of EM fields in the near-shore environment. In particular, this report addresses measurement of EM fields that are a result of, or are directly affected by, wave energy conversion equipment and associated cables.

In many ways, the existing EMF environment in the near-shore region varies widely in time, and over location due to the predominant local wave and weather conditions, as well as other geologic and atmospheric factors. The addition of man-made EMF to this environment will serve to increase the potential range of values that could be observed in this environment. Thus, consideration of measurement statistics is important to the assessment and quantification of EM fields.

2. INTRODUCTION

2.1 Purpose

This report describes the factors affecting the statistical variables of natural and proposed anthropogenic sources at wave energy sites. The purpose of the report is to define the minimum data acquisition requirements to ensure that statistically valid results are used for scientific observation because of the potential changes in environmental conditions due the introduction of wave energy conversion equipment into the environment.

2.2 Background

This report describes the anticipated statistical variability at the Reedsport, Oregon site. However, it is of a sufficiently generalized nature to apply to other wave energy sites in Oregon's coastal area. This same approach could also be extended to other potential wave sites, so long as the underlying factors affecting statistics of a given site are modified accordingly.

2.3 Report Organization

This report contains five sections and one appendix. The first section contains the executive summary. The introduction, Section 2, provides the project motivation and background. The methodology for how the results were derived is described in Section 3, followed by a description of recommended data analysis (Section 4) and data acquisition (Section 5) techniques for site assessments. Appendix A contains the acronym list.

3. METHODOLOGY

The results stated in this report were derived by first identifying and describing the physical factors that contribute to the components of naturally occurring and EM fields, with allocations for the expected introduction of EM sources from wave energy converters and cabling that could be introduced into the environment. Statistical methods were derived by adopting scientifically accepted methods in other areas of data acquisition and measurement; such as are commonly used in signal processing and acquisition applications.

4. DATA ANALYSIS TECHNIQUES

The generally accepted technical approach to acquiring and analyzing time-sampled data is based on Fourier analysis, whereas data sets can be represented as a form of energy distribution of a signal over a given time period. The spectral concept is based on Fourier's work that essentially states that many functions can be described over a given interval as an infinite sum of sine and cosine functions and reasonably represented as a spectrum. However, in the application of Fourier analysis to EM fields in the ocean, it must first be established that time-sampled EMF data meets basic suitability criteria for Fourier analysis. While a rigorous analysis could be made for the mathematical properties of the signal itself, it is generally sufficient to know that the signal being analyzed is time-invariant, that is, it is relatively stable over the period being measured, and that sharp discontinuities or abrupt changes to the signal do not occur. Such is the case for the marine environment, where the dominant signals in the sea are indeed slowly changing, driven by oceanic waves, tidal currents, or other geologic scale events. Thus, for the purposes of EMF data analysis, it is a most logical activity to apply Fourier analysis as one primary means of decomposing the resulting spectra into narrow bands for which a suitable interpretation can be applied.

The use of Fourier analysis has dominated signal analysis for decades, and continues to be one of the most effective toolsets for quantifying and understanding time-sampled data, including observations of natural phenomena. In order to use Fourier processing on a data set, it is first necessary to sample the real data under sufficient conditions to enable subsequent analyses. The underlying assumption with Fourier analysis is that uniformly time-sampled data is available for processing. Uniform time sampling is routine in today's digital world, where use of the Discrete Fourier Transform (DFT) and the Fast Fourier Transform (FFT), a special case of the DFT, are commonplace. For example, the National Data Buoy Center uses FFT processing to analyze wave buoy data¹ statistically.

¹ <http://www.ndbc.noaa.gov/wave.shtml>

5. DATA SAMPLING REQUIREMENTS

A number of important parameters are required to fully characterize and specify the data acquisition requirements. The following sections describe each of these parameters more fully, and provide recommended conditions for each.

5.1 Sampling Rate

The Nyquist–Shannon sampling theorem states that if a function $F(t)$ contains no frequencies greater than or equal to y Hertz, then the function can be completely determined from a uniform series of points spaced $1/2 y$ seconds apart. Another way to re-state the theorem is to say that sampling of a real signal with a series of uniformly spaced samples in time will completely represent the signal if the signal bandwidth is less than one-half the sampling rate, $f_s/2$, where f_s is the sampling frequency. Therefore, the time-sampled data should be sampled at a minimum rate to ensure that the highest frequency of interest is less than $f_s/2$.

A minimum data-sampling rate of 1 kHz is recommended for EMF sensors, which will allow reconstruction of signals containing frequencies up to 500 Hz. A sampling rate of 1 kHz would allow characterization of AC power cables operating at a power frequency of 60 Hz to be monitored and enable characterization of the power frequency harmonics up to the eighth harmonic (480 Hz).

5.2 Data Filtering

One primary issue associated with data sampling and Fourier analysis is the phenomenon of aliasing, which involves the creation of false artifacts in the band of interest from signals outside the band of interest. There is a fundamental assumption in Fourier analysis that the signal of interest be band-limited, that is, it is assumed to not have any energy above a certain frequency, namely the sampling frequency (f_s) by which the original time-sampled data set is created. If adequate steps are not taken during the sampling process, energy above the sampling frequency will be falsely translated into the band of interest, which then becomes part of the spectrum of interest, and will not be discernable from it. Since the acquired signal from real EM fields are truly not band-limited, and will undoubtedly contain frequency content above the sampling

frequency, it is a certainty that aliasing could be a factor in EM field analysis. The most common means to overcome the problem of aliasing is to introduce a filter during the data sampling process to attenuate unwanted signals to the point that they effectively do not appear in the measurement band of interest. All EM data sampling should employ anti-aliasing filtering as part of the sampling process.

5.3 Sampling Duration

Sampling duration is another important factor in the interpretation of acquired data. Not to be confused with sampling rate, that is, how far apart in time (usually fractions of a second) each uniformly spaced sample is made as described in the preceding section, sampling duration is a measure of how long an observation period is required to fully represent the signal of interest. For a truly stationary, time-invariant signal that persists for an infinitely long period, sampling duration is not critically important, since the signal being analyzed simply does not change over that time. The simple answer is to sample continuously over a long period, thus ensuring that all events over the period are captured. This is the most conservative approach, but it comes at the practical expense of storage space and battery life. Consideration should be made for understanding the underlying signals of interest, and the phenomena that creates the signal in the first place. By way of example, many physical activities that contribute to the generation of EM fields are represented on a number of time scales. Ocean waves are a dominant contributor to EM fields in the near-shore environment. Typical wind-driven wave and swell activities occur between 0.05 and 1 Hz, or conversely, over periods of 1 – 20 seconds or more. However, wave conditions along Oregon's coast are frequently dominated by distant storms, wherein large swells traverse the ocean and crash on Oregon's beaches. Wave conditions can typically occur over a period of hours or days without any substantial change. Thus, continuous measurement would undoubtedly produce very similar results from hour to hour.

The longest period ocean waves measured near Reedsport typically do not exceed 25 seconds. The measurement of a series of such long-period waves over time should capture approximately tens of cycles to ensure a robust statistical data set, although longer periods would be preferred. For example, the capture of ten each waves, nominally 25 seconds in duration, would require 250 seconds of measurement. Increasing the measurement period to 20 or 30 minutes would provide

a robust set of data from which to form a reasonable statistical representation of EM fields generated by ocean wave activity. The Coastal Data Information Program (CDIP) at the Scripps Institution of Oceanography computes ocean wave spectral parameters using 26 to 30 minute data measurement periods². For the typical long-period, 25-second waves observed on the Oregon coast, 30-minute recordings would represent approximately 72 waves, from which statistically significant parameters are derived and reported by CDIP.

Other long period phenomena, including tides and coastal currents, can persist for hours or days. In order to effectively capture changes these variables, measurements should be made to fully encompass at least one full period of each measured phenomenon. Longer sampling periods will serve to reduce the random noise in the data, which will emphasize measured events and minimize the effects of noise on the resulting spectra. It should be noted that in a time-sampled signal, random spectral noise is reduced by the square root of the number of samples acquired. Thus, thus within reason, more samples of a signal provide a better data set than do fewer samples.

² <http://cdip.ucsd.edu/?nav=documents&sub=index&xitem=waves>

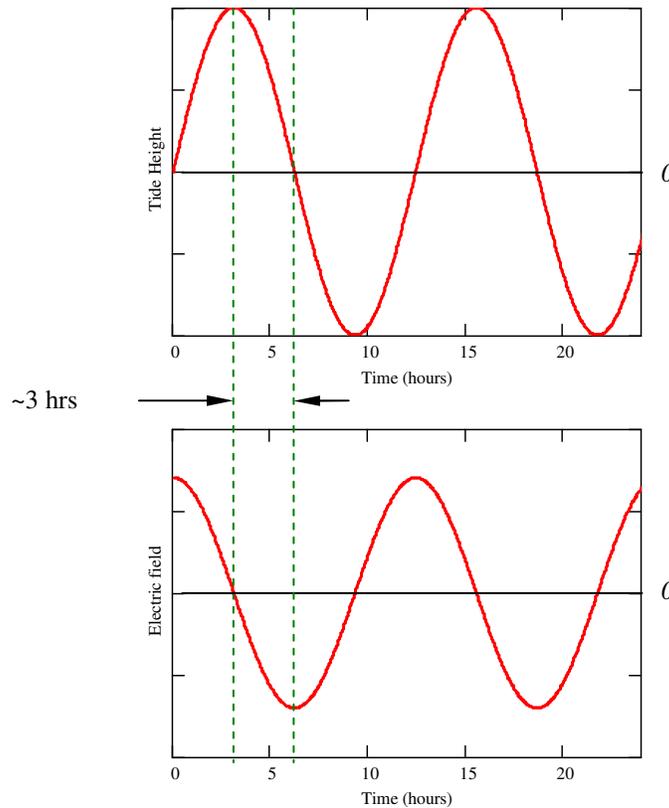


Figure 1 – Typical Tidal Time Series

The highest frequency in the spectral distribution of the tidal flow is approximately 2.3×10^{-5} Hz (e.g., one diurnal, nominal 12-hour period, see Figure 1). Application of the Nyquist–Shannon sampling theorem implies that the sinusoidal form of the tide induced fields can be reconstructed if the sample period is less than $\frac{1}{2 \times 2.3 \times 10^{-5} \text{ Hz}} = 6$ hours (i.e. the Nyquist rate). Therefore, an appropriate period for sampling the sensors is a quarter of the tide period, or approximately every three hours.

Higher frequency phenomena, including man-made sources of EM noise from wave energy equipment will produce much higher frequencies (e.g. 60 Hz and harmonics), and would therefore not be the limiting factor for sampling duration requirements.

5.4 Sampling Periodicity

Over periods of weeks and months, average wave conditions have been shown to change drastically with the seasons, with modest activity in the summer months, and very energetic

conditions in the winter. Figure 2 shows ten-year average wave periods for NDBC Station 46050, located to the west of Newport, Oregon. In the long term, it is recommended that measurements be made over the course of the seasons to ensure that a broad range of minimum and maximum conditions is assessed.

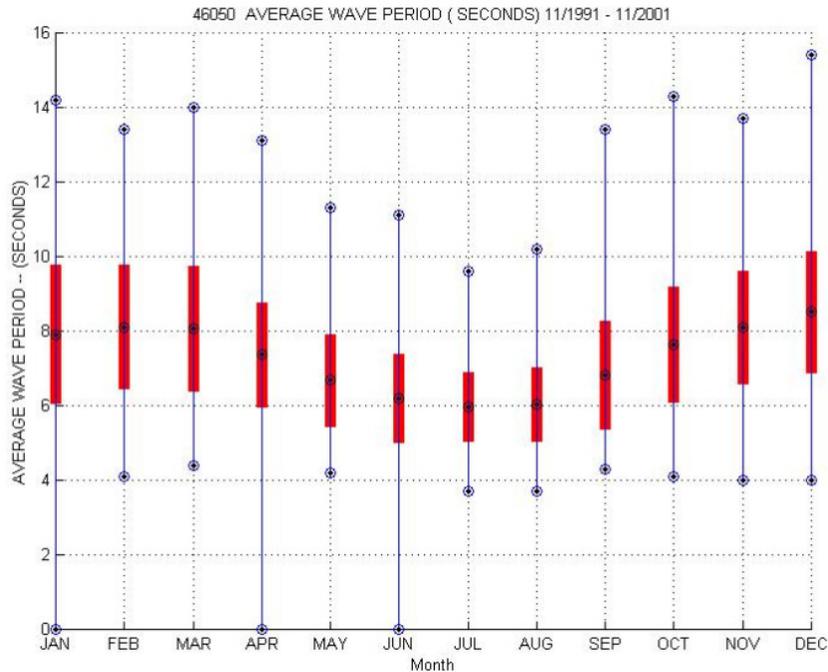


Figure 2 – Average Wave Period, NDBC Station 46050, Nov 1991 to Nov 2001

Initially, it is recommended to sample continuously as much as possible to capture time-cycles that may not yet be fully understood. While some segments of the ambient noise spectra may be well understood (*e.g.* due to wave cycles), others may be less understood, and continuous data sampling, if practical, should be considered to assist in the identification of unknown sources of naturally occurring EM conditions.

As an alternate to the continuous sampling approach, longer-term monitoring could benefit from periodic sampling, such as several minutes each hour or 30-minute periods every three hours. This technique would provide periodic snapshots in time to directly capture higher frequency events, while allowing periodic sampling for the analysis of longer-term events such as tidal cycles and coastal or surface currents. This hybrid approach could be adopted to sample higher frequency content for shorter periods, coupled with periodic gaps in measurement to conserve storage space and battery power without a significant loss in the ability to observe long period

events (hours, days, or weeks). Decimation techniques of the time-sampled data can reduce the processing load for acquired data, while still providing the necessary low-frequency spectral resolution.

5.5 Spectral Processing and Presentation

Most EM data reported in literature is presented in spectrum level, that is to say, with a nominal 1 Hz bandwidth, *e.g.* spectrum levels per “root Hz.” This approach is strongly recommended for EM site characterization results, which provides a standardized bandwidth to enable repeatable comparisons of a given site over time, and to compare results from site to site. DFT processing parameters should be selected to enable nominal 1 Hz bandwidth reporting directly. Alternative processing can be made to enable a much finer bandwidth resolution for long-period phenomena, with optional power summation methods applied to report 1 Hz bandwidths. Finer spectral results would be required for very long period phenomena, including tidal and coastal current observation periods. Above 1 Hz however, spectrum levels should be computed directly. Regardless of processing methodology, all EM data should be presented in the recommended frequency resolution to enable direct comparison of results.

APPENDIX A – ACRONYMS

ASW	anti-submarine warfare
B-field	magnetic field
CA	California
CDIP	Coastal Data Information Program
CGS	centimeter-gram-second
CMACS	Centre for Marine and Coastal Studies
COWRIE	Collaborative Offshore Wind Research into the Environment
DFT	Discrete Fourier Transform
DoI	Department of Interior
EA	Environmental Assessment
E-field	electric field
EIS	Environmental Impact Statement
EM	electromagnetic
EMF	electromagnetic field
FFT	Fast Fourier Transform
KHz	Kilohertz, thousand cycles per second
Hz	Hertz, cycles per second
MKS	meter-kilogram-second
MMS	Minerals Management Service
NDBC	National Data Buoy Center
ODFW	Oregon Department of Fish and Wildlife
OPT	Ocean Power Technologies
OR	Oregon
OWET	Oregon Wave Energy Trust
PSD	Power spectral density
SI	International System of Units
SIO	Scripps Institution of Oceanography
UK	United Kingdom
WA	Washington
WEC	Wave Energy Converter