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Electromagnetic Field Study

Estimated ambient electromagnetic field strength in Oregon's coastal environment.

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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.

Record of Revisions

Revision	Date	Section and Paragraph	Description of Revision
Original	September 2010	All	Initial Release

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1. EXECUTIVE SUMMARY

This report describes the estimated ambient (or background) field strength characteristics of the electric and magnetic fields in Oregon's near-shore marine environment, focusing on the coastal area near Reedsport, Oregon. The results may be adjusted for other Oregon coastal locations, subject to one's knowledge of the natural conditions there, including wave activity (wave height, frequency, and direction), bathymetric conditions, coastal and tidal currents, and the Earth's magnetic field strength and direction.

This study was commissioned with the goal of estimating the ambient EM fields along the Oregon coast. The results support the design and specification of instrumentation to assess the potential impacts of anthropogenic electromagnetic (EM) fields from wave energy development. The reader is reminded that the results provided in this report are theoretical. They have not been correlated with field measurements.

A number of external factors contribute to the ambient EM fields along the coast, including geologic and solar-scale conditions, as well as local weather. Thus, the results herein are estimated within the stated assumptions, and cover a broad range of values, within which the measured values would be expected to lie. Specific natural factors affecting ambient EM noise are addressed in a companion report,[1] which states that:

1. EMF levels are highly dependent on physical location;
2. For a given location, EMF levels are highly variable;
3. EMF levels near the shore environment are likely higher than those observed in the deep ocean environment;
4. The distance scale for changes to the EMF field is dependent on individual forcing functions, and may range from meters to thousands of kilometers.

For the Reedsport test site, this analysis concludes that:

1. The estimated electric fields generated by wave motion are expected to range from 6 to 216 μV/m, and will be observed between 0.04 and 0.3 Hz. The maximum induced magnetic fields due to wave motion should be observed over the same frequency regime, and should be observed with magnitudes ranging from 0.02 to 0.54 nT.

[1] Slater, M., Schultz, A. (2010). Ambient electromagnetic fields in the nearshore marine environment. Oregon Wave Energy Trust.

2. The maximum electric fields generated by tidal motion are expected to be 33 µV/m, and the maximum magnetic fields because of tidal sources are expected to be 0.08 nT.

3. Coastal currents are expected to generate electric fields up to 22 µV/m, although higher values may be observed, with potential values in extreme current flows of up to 44 µV/m. The corresponding estimated magnetic field values for these conditions would be 0.06 nT to 0.12 nT.

4. Man-made sources of EM noise may be observed in measured ambient noise data. It is difficult to estimate the potential range of magnitude man-made sources on the existing ambient conditions at the site. Man-made sources are expected to exhibit discrete frequencies at 60 Hz and higher order harmonics of 60 Hz, e.g. 120 Hz, 180 Hz, etc.

2. INTRODUCTION

2.1 Purpose

This report estimates the ambient (or background) electromagnetic (EM) field strength near Reedsport, Oregon. This estimate establishes the basis for the design and specification of EM measurement instrumentation capable of measuring the expected ambient fields. The report presents a simple model that predicts the electric and magnetic fields produced by localized marine sources near the shore. The results of this model establish the sensitivity requirements for the measurement equipment.

2.2 Background

This report describes local estimates for a specific location and builds on the results of companion reports on EM fields in the shallow water marine environment. The focus is on the development of EM effects from localized marine-based sources and does not address non-marine sources of naturally occurring EM fields such as those due to geomagnetic or solar influences. In the measurement scenario, however, the resultant EM fields represent the superposition of atmospheric and terrestrial sources that may propagate into the marine environment on the additive effects of marine-based sources.

2.3 Report Organization

This report has nine sections and three supporting appendices. The first two sections contain the executive summary and introduction, which provides the project motivation and background. Section 3 presents the methodology for how the results were derived, followed by a description of the theory used to estimate EM fields (Section 4). Sections 5, 6, and 7 provide estimates of the EM field magnitudes induced by three marine-based forcing functions – wave action, tidal flow, and coastal current. Section 8 discusses the frequency content of marine-based EM sources. The report conclusions are stated in Section 9. Appendix A describes the application of Ampere's law concerning the estimation of induced magnetic fields from naturally occurring electric fields. Appendix B is an acronym list. Appendix C contains the bibliography.

3. METHODOLOGY

The results stated in this report were derived by first identifying and describing the physical theory of each known factor that contributes to the generation of magnetic and electric fields, then listing the estimated range of values for each factor in or near the area of interest. For example, two primary factors affecting the generation of electric fields in the ocean are the movement (velocity) of seawater as a conductive medium and the local strength of the Earth's magnetic field. Next, these factors were combined to estimate field strength values and superimposed on other naturally occurring sources of EM fields. The results were then summarized to provide the estimated range of values.

4. THEORY

The motion of electrically conductive seawater, which moves due to naturally occurring, physical oceanic processes, induces ambient EM noise in the marine environment. Regardless of the process, any motion of seawater in the Earth's magnetic field induces electric voltage potentials, which creates an impressed electrical current. Surface waves, tidal flows, internal waves from flow over bottom features, and costal ocean currents cause water to move in the coastal environment. The impressed electrical current creates weak magnetic influences. Similarly, changes in the prevailing magnetic field induce changes in the electric field. Magnetic storms, electrical storms, and solar events (e.g. solar flares) represent common changes in the prevailing magnetic field.

4.1 Electric and Magnetic Fields Induced by Sea Motion

When a conducting fluid such as seawater flows through the Earth's magnetic field, an electric field is generated in the seawater, as shown schematically in Figure 1.

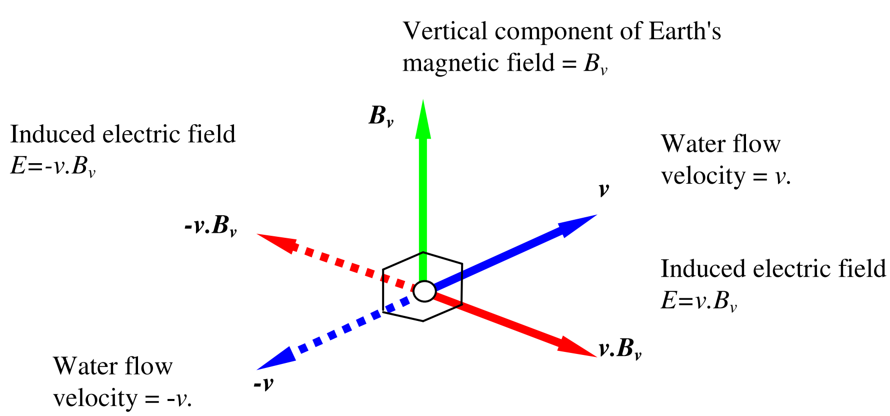


Figure 1 – Vector Diagram for Induced Electric Field

The force imparted to a charge moving at velocity v is the vector sum of the magnetic and electric forces, which is given by the Lorentz equation:

$$F = q\left(\vec{E} + \vec{B} \times \vec{v}\right) \qquad 1)$$

where q = charge (C)

$\vec{E}$ = applied electric field (V/m)

$\vec{B}$ = applied magnetic field (T)

$\vec{v}$ = velocity (m/sec)

Referring to Figure 1, the magnetic force is given by:

$$F_{mag} = q\left(\vec{B}_v \times \vec{v}\right) = q\left|B_v\right|\left|v\right|\sin(\theta) \qquad 2)$$

where: $\vec{B}_v$ = vertical component of earth's field (~ 50 μT)

θ = angle between flow velocity and magnetic field (90 deg)

Equation 2) can be rearranged to give the magnitude of the electric field induced by the fluid motion:

$$\frac{F_{mag}}{q} = E_{ind} = B_v v \qquad 3)$$

The electric field generated will be mutually perpendicular to both the velocity and magnetic field vectors as shown in Figure 1.

A magnetic field will also be produced, which is described by Maxwell's fourth equation (Ampere-Maxwell Law):

$$\vec{\nabla} \times \vec{B} = \mu_0\left(\vec{J} + \varepsilon_0 \frac{d\vec{E}}{dt}\right) \qquad 4)$$

where μ_0 = permeability of free space ($4\pi \times 10^{-7}$ N/A^2)

ε_0 = permittivity of free space (8.85×10^{-12} F/m)

$\vec{J}$ = current density (A/m^2)

This equation shows that the induced magnetic field has two components, one from the current, or flow of charge, and the other from the rate of change of the electric field with time. Thus, an oscillating electric field produces a magnetic field and similarly, an oscillating magnetic field produces an electric field (Faraday's Law).

As described in the companion report, the induced electric field can be estimated using the conversion factor of .514 V/m/knot/T (volts per meter per knot per tesla). The expected location of the wave energy converter test ground is near Reedsport, Oregon, (lat / long = 43.754780°N, -124.233214°W) and the horizontal and vertical components of the earth's magnetic field at this location are 21.37 and 47.58 µT (see Figure 2), with a total magnetic intensity of 52.2 µT. Thus, with a uniform flow of 1 meter per second in this area, a maximum steady state electric field of 52.2 µV/m would be expected.

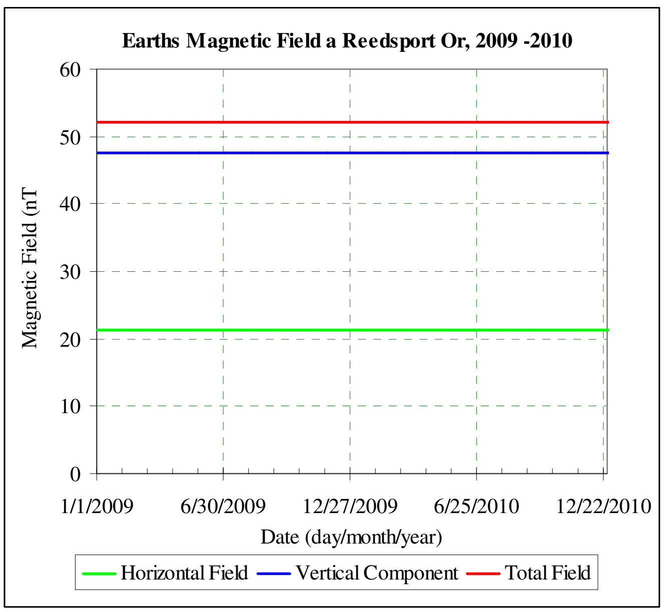


Figure 2 – Earth's Magnetic Field at Reedsport, OR from from 2009 to 2010

Location Lat/Long 43.754780°N, - 124.233214°W

Source: http://www.ngdc.noaa.gov/geomag/magfield.shtml

4.2 Mechanics of Progressive Ocean Surface Waves

The surface motion of the sea in the open ocean is described as a progressive wave, where energy, but not matter, is transferred from one location to another. The surface waves result from the wind interacting with the sea surface. The period and height of surface waves depend on the wind speed, the duration of the wind, and the distance (fetch) over which the wind blows.

In deep water, the wave motion at the surface is sinusoidal and the 'particle motion' beneath the wave is circular, with the orbit diameter decreasing with distance from the surface (see Figure 3). The orbit diameter decays to near zero at a depth equal to half of the wavelength at the surface. As the wave moves into shallower water, the wave orbits begin to interfere with the seabed, the wavelength shortens, and the wave height increases producing a wave in the form of a trochoid. The wave orbits now become elliptic where the vertical axis decreases in magnitude with depth, resulting in just linear displacement at the seabed.

If the depth is greater than one-half of the wavelength of the corresponding deep-water wave, then the wave is considered a deep-water wave. Similarly, the shallow water condition prevails if the depth is less than one-twentieth of the deep-water wavelength. If the depth is between these limits, then an 'intermediate' situation occurs. If either the deep or shallow water condition occurs, then approximations can be applied to simplify the equations. However, this will not be possible for the intermediate depth case and the complete equations must be used.

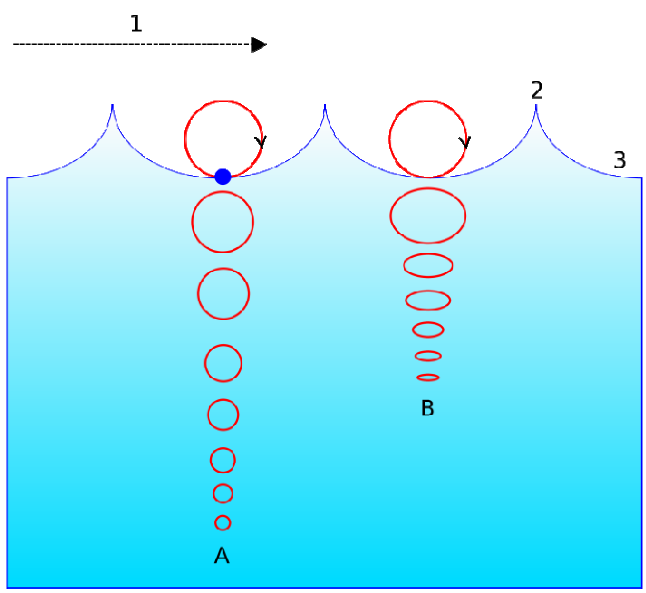


Figure 3 – Elliptical Motion of Surface Gravity Waves As a Function of Depth

Source: http://commons.wikimedia.org/wiki/File:Wave_motion-i18n.svg, public domain

In deep water, the surface wave profile is sinusoidal, with a period T_p and the corresponding wavelength in deep water is given by:

$$\lambda_{deep} = \frac{gT_P^2}{2\pi} \qquad 5)$$

where: g = acceleration due to gravity (9.806 m/s^2)

The deep-water 'wave number' is defined by:

$$k_{deep} = \frac{2\pi}{\lambda_{deep}} \qquad 6)$$

The wave dispersion (ω) is defined by:

$$\omega = \sqrt{gk \tanh(kd)} \qquad 7)$$

In deep water, $\tanh(kd) \rightarrow 1$, thus $\omega \rightarrow 2\pi f$, which is commonly known as the angular wave frequency.

The phase velocity (V_P) of the wave is given by:

$$V_P = \frac{\omega}{k} = \sqrt{\frac{g\lambda}{2\pi}\tanh(kd)} = \frac{1}{k}\sqrt{gk \tanh(kd)} \qquad 8)$$

The group velocity (V_g) is given by:

$$V_G = \frac{\partial \omega}{\partial k} = \frac{\partial}{\partial k}\left(\sqrt{gk \tanh(kd)}\right) \qquad 9)$$

Evaluating this differential yields:

$$V_G = \frac{1}{2\omega}\left(\frac{\omega^2}{k} + gkd\left(1 - \tanh(kd)^2\right)\right)$$

which reduces to $$V_G = \frac{V_P}{2}\left(1 + \frac{gkd}{V_p}\left(1 - \tanh(kd)^2\right)\right) \qquad 10)$$

From equation 10) it is observed that in deep water, the hyperbolic term tends to unity and the group velocity tends to half of the phase velocity.

The maximum vertical and horizontal components of the water particle velocity are then, as a function of depth:

$$v_{vert} = \frac{H\omega}{2} \frac{\sinh(k(d-z))}{\sinh(kz)} \qquad 11)$$

$$v_{horiz} = \frac{H\omega}{2} \frac{\cosh(k(d-z))}{\sinh(kz)} \qquad 12)$$

where z = distance from surface

As a deep-water wave passes into shallow water, the wave height increases, but the total energy of the wave (kinetic + potential energy) remains near constant. The energy of a wave can be shown to be dependent on the square of the wave height; therefore, the local wave height (H_{local}) as the wave approaches shore can be approximated using:

$$H_{local} = \sqrt{H^2_{deep} \frac{V_{deep}}{V_{local}}} \qquad 13)$$

where H_{deep} = wave height in deep water

V_{deep} = phase velocity in deep water

V_{local} = local phase velocity

As a wave comes ashore its height increases until the wave breaks, which occurs when the wave height exceeds approximately 78% of the local water depth.

All equations required to determine the electromagnetic fields induced at the seabed, or any other depth, by surface waves have now been defined. However, numeric iteration is required to determine the local wavelength as the deep-water wave moves into shallower water. An alternative approach is to use an approximation that gives the local wavelength as a function of the prevailing depth, as developed by Fenton and McKee (1990). This expression is:

$$\lambda_{local} = \lambda_{deep}.\left(\tanh\left(\frac{\omega_{deep}^{2}.d_{local}}{g}\right)^{\frac{3}{4}}\right)^{\frac{2}{3}} \qquad 15)$$

In the next section, these relationships are used to estimate the maximum EM fields in this environment.

5. ESTIMATED EM FIELDS INDUCED BY SURFACE WAVE MOTION

One of the most dominant factors in the generation of naturally occurring EM fields in the near-shore environment is wave activity, which creates motion in the sea, and hence, induces an EM field in the presence of the Earth's magnetic field. Ocean surface waves produce elliptical water particle motion in shallow water, with the greatest velocities in the horizontal direction along the direction of wave propagation. Motion is greatest at the ocean surface, and diminishes towards the bottom. Therefore, since the highest velocities are near the ocean surface, the highest values of electric field strength will likewise occur at the surface. The values are reduced as wave activity diminishes away from the ocean surface, towards the bottom. The resultant EM field occurs at the wave frequency, which provides an electric field spectrum over the same regime as the wave motion itself.

As a means to estimate the resultant EM field at Reedsport, measured joint distributions of significant wave height vs. period were examined at a nearby buoy location considered representative of the Reedsport site (Station 46229 - UMPQUA OFFSHORE, OR (139), located at 43.769 N 124.551 W)[2]. Data from this buoy were modeled as a surrogate for wave conditions at the Reedsport site, with corrections made for shallow and intermediate water depth conditions. Using the mathematical relationships developed in Section 4.2, maximum water velocities were estimated as a function of wave conditions and water depth, from which maximum induced electric and magnetic field magnitudes were computed.

From equations (11) and (12) it is evident that water particle motion due to wave motion is maximum at the sea surface, and diminishes at deeper depths. The resulting EM fields are directly proportional to wave height, but inversely proportional to wave period. Thus, the ratio of wave height to wave period dictates the overall magnitude of the induced EM field due to surface waves. In Figure 4, the estimated horizontal component of water velocity is shown as a function of depth, using the average significant wave height and wave period for 2009 at the Reedsport site using data from Station 46229 site corrected for the estimated water depth at the

[2] http://cdip.ucsd.edu/?nav=historic&sub=data&stn=139&stream=p1&xitem=product34&xyrmo=200912&xwait=2

site of 56 m[3]. The maximum horizontal velocity occurs at the surface (0.67 m/s), and minimum occurs at the bottom (0.18 m/s). The same wave in 28 meters of water (half the depth) produces a horizontal velocity at the surface of 0.79 m/s, and 0.46 m/s at the bottom. As the wave moves shoreward into shallower water, the horizontal velocity increases in magnitude—thus increasing the magnitude of the induced electric and magnetic fields. Furthermore, as wave size increases, the magnitudes likewise increase. Using data from the maximum daily wave at Station 46229 from May 2007 through December 2009[4], wave height of 17.37 meters, and a period of 18 seconds, the estimated horizontal velocity at the surface was 4.1 m/s.

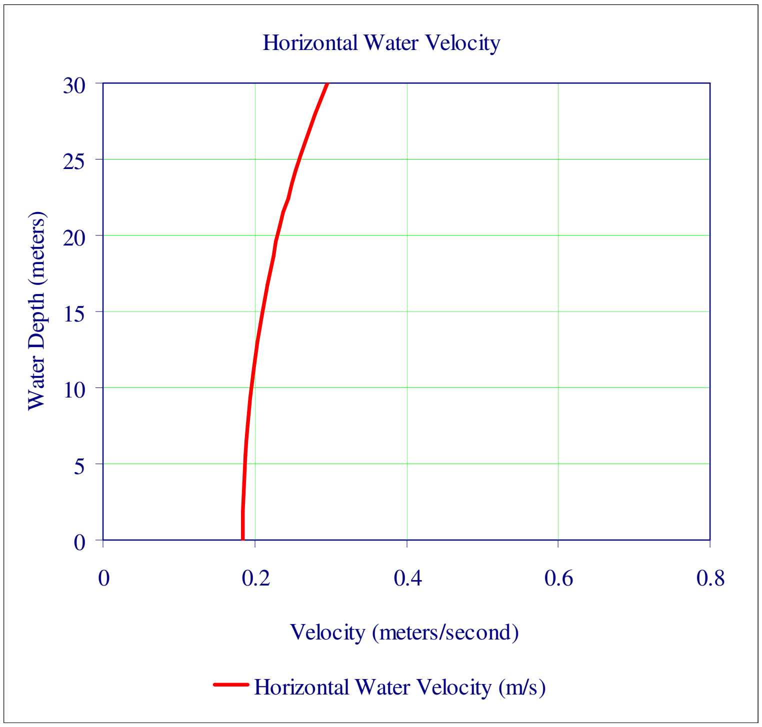


Figure 4 – Horizontal Component of Water Velocity as Function of Depth
Hs = 2.25m, Tp = 11s, d = 56m

Once the water velocity is known, the maximum electric field magnitude can be computed. The maximum electric field occurs at the water surface, and is computed as the product of maximum water velocity and the strength of the earth's magnetic field at the site (52.2 μT). For the maximum daily wave described above, the expected peak electric field produced is estimated at

[3] http://cdip.ucsd.edu/?nav=historic&sub=data&stn=139&stream=p1&xyrmo=200912&xitem=product35

[4] http://cdip.ucsd.edu/?nav=historic&sub=data&stn=139&stream=p1&xyrmo=200912&xitem=product33

216 μV/m at the surfaces, and 147 μV/m at the sea bottom. Using the 2009 average wave data (Hs = 2.25m, Tp = 11.01s, depth = 56m), an electric field of 35 μV/m is estimated at the surface.

Once the electric fields are known, the induced magnetic field can also be computed once the conductivity of the surrounding seawater is known by application of Ampere's law (See Appendix A). Assuming that the conductivity of the seawater at the site is 4 S/m (siemens per meter), an electric field of 216 μV/m at the surface from the daily maximum wave will induce a magnetic field of 0.54nT. Using the more typical average wave data from 2009 (Hs = 2.25m, Tp = 11.01s, depth = 56m), the induced magnetic field at the surface is estimated at 0.09 nT.

Table 1 – Estimated EM Fields at Reedsport Site for Selected Wave Conditions

Condition	Wave Height, Hs (meters)	Wave Period, Tp (seconds)	Maximum Induced E-field (μV/m)	Maximum Induced B-field (nT)
2009 Minimum Wave	0.49	15.38	6.4	0.02
2009 Maximum Wave	10.77	25.00	127	0.32
2009 Mean Wave	2.25	11.01	35	0.09
2007-2009 Maximum Daily Wave	17.37	18.00	216	0.54
Assumptions: Water depth: 56 m Water conductivity: 4 S/m Earth's magnetic field strength 52.2 μT Maximum field magnitude is at sea surface Data source: http://cdip.ucsd.edu/?nav=historic&sub=data&stn=139&stream=p1&xyrmo=200912&xitem=stn_home				

From Table 1, it is concluded that the maximum prevailing electric field at the sea surface due to wave motion at the Reedsport site will vary between 6 and 216 μV/m, and the corresponding maximum induced magnetic field will vary from 0.02 to 0.54 nT (20 to 540 pT).

The maximum amplitudes observed for induced electric fields due to wave motion are computed as the product of the magnitude of the water velocity and magnetic field vectors. Direction is important, since the electric field is mathematically defined as the cross-product between the water velocity field and the magnetic field.

Near Reedsport, the earth's magnetic field is largely vertical, and the dominant wave direction is from the west. The resultant dominant electric field would be produced in the horizontal plane, that is, more-or-less parallel to the ocean surface. Data from Station 46229 reported that the dominant direction for waves at this site were from the west (270 degrees), with over one-third of all waves in 2009 arriving from that direction[5]. Wave periods at that same location in 2009 ranged from a maximum of 25 seconds to a minimum of 3.45 seconds. Significant wave heights over this same time ranged from 0.49 meters to 10.77 meters. It should be noted that significant wave height and wave periods do not represent the worst-case conditions, but instead represent a statistical representation of that condition of the highest one-third of waves during the observation period.

[5] http://cdip.ucsd.edu/?nav=historic&sub=data&stn=139&stream=p1

6. ESTIMATED EM FIELDS INDUCED BY TIDAL MOTION

Tidal flows produce bulk movement of seawater, which induces EM fields in the sea in the same manner as surface waves, albeit at a much longer period (hours, not seconds). Depending on location, tides may be either diurnal (1 tide/day) or semidiurnal (2 tides/day). The Reedsport area experiences a semidiurnal tide, with a maximum tidal swing of approximately 3 meters. Reviewing December 2009 tide tables for the Umpqua River Entrance, 58 tidal cycles from December 1 through December 31 are expected, with an average period of 12.42 hours[6]. Using the same wave theory as developed above for surface waves, the expected maximum velocity, and thus the EM field values can be estimated. With a basic period for the semidiurnal tide is 12.42 hours, which implies a deep-water wavelength that is much greater than the depth of the oceans; so tide waves are always shallow water waves.

Table 2 – Estimated EM Fields at Reedsport Site for Maximum Tidal Conditions

Parameter	Value	Units
Depth	56	m
Wave period	12.42	hours
Maximum wave height (tide)	3.0	m
Maximum horizontal velocity	0.63	m/s
Maximum electric field	33	µV/m
Maximum magnetic field	0.08	nT

This demonstrates that the maximum fields generated by the tide at the Reedsport will be lower than the typical maximum surface wave contribution, but not substantially so. Since these are estimated current conditions based on theory, specific current measurements near the test site could be used to improve the estimates made here.

[6] http://www.winchesterbayfishing.net/tides.htm

7. ESTIMATED EM FIELDS INDUCED BY COASTAL CURRENTS

Another source of seawater motion is coastal currents. One such observation is that of the measured ocean surface currents near the Reedsport site, which are available online. While surface current observations do not fully describe the sub-surface coastal current "corkscrew" conditions along the coast, they do serve to estimate the maximum electric and magnetic field conditions on the ocean surface because of such currents. There may be cases where internal waves could produce substantial velocities, and thus induce significant EM fields, although no specific data were found to quantify these for the Reedsport site. It would be useful to analyze any current measurements made near Reedsport to determine the maximum surface velocities as that data is collected and becomes available.

A review of the coastal surface currents near Reedsport indicated that currents can vary in magnitude and direction over a period of hours or days. Daily averaged surface current data from 1 December to 26 December 2009 at a location within 4 miles of the Reedsport site (124.30233W, 43.78352N) varied significantly over the course of the month. Primary velocity vectors varied in strength and direction daily, although the along-coast velocities appeared to be stronger than the cross-coast velocities[7]. In December 2009, a maximum daily velocity of 43 cm/s (0.43 m/s) was observed on December 16, resulting in an estimated electric field magnitude of approximately 22.4 µV/m, and corresponding magnetic field strength of 0.056 nT. Cursory review of other coastal sites over the same time period indicated that occasional surface velocities can exceed 80 cm/s (0.8 m/s), thus producing a maximum estimated electric field of 42 µV/m, and maximum estimated magnetic field of 0.1 nT.

[7] http://bragg.oce.orst.edu/

8. FREQUENCY SPECTRUM OF OCEAN INDUCED EM FIELDS

Various sources of oceanic electromagnetic fields will create EM noise over a relatively broad frequency spectrum. Surface waves are expected to be the dominant source of EM fields at the Reedsport site. While single wavelengths were modeled here for simplicity, in practice, the spectral content of wave action in general is not at all monotonic, and will create diffuse spectra over the observed range of values. Because the earth's magnetic field is very slowly changing, it can be considered essentially constant with regard to induced frequency content. Thus, EM energy developed by marine sources such as surface waves will exhibit the same frequencies as are observed in the wave spectra itself. In the Reedsport area, the typical minimum and maximum wave periods observed range from 3.5 seconds to 25 seconds, which will span the 0.04 to 0.3 Hz regime, and will occasionally cause noise above and below these values due to the random processes involved.

The tides are caused by the gravitational influence of the moon and sun upon the oceans. The magnitude of the tide is therefore dependent on the astronomical motion of the moon and sun. The wave amplitude (tide range) as a function of time can be described by a summation of various sinusoidal functions that relate to the lunar and solar motion. As described in Section 6, the typical tidal period at Reedsport is approximately 12.42 hours (2.2×10^{-5} Hz). Coastal currents would create noise at even lower in frequencies, since there is no regular hourly or daily pattern that is readily discerned in the data. It would be expected that periods of days or weeks would result, creating EM noise in the regime of 10^{-5} Hz (daily) to 10^{-6} Hz (weekly) regime.

Figure 5 graphically depicts the estimated ambient electric field values in the Reedsport, Oregon ocean environment. Results in the crosshatched areas represent maximum expected values. The grey line on the chart represents the minimum expected measurable levels based on current electric field measurement technologies available. The chart in the figure was derived from a deep-ocean model (Keys 2003) and due to the complex motions of the near-shore environment, both the electric and magnetic field noise levels are expected to be substantially higher than deep ocean levels. Above approximately 10 Hz (periods less than approximately 10^{-1} seconds), it will be difficult to fully characterize existing ambient electric field conditions below the physical limits of the measurement instrumentation, nominally below approximately 1 nV/m. It is important to note that this measurement threshold is also at the lowest expected limit of sensitivity for the most sensitive of marine species, thus lower level measurements may not provide much additional information.

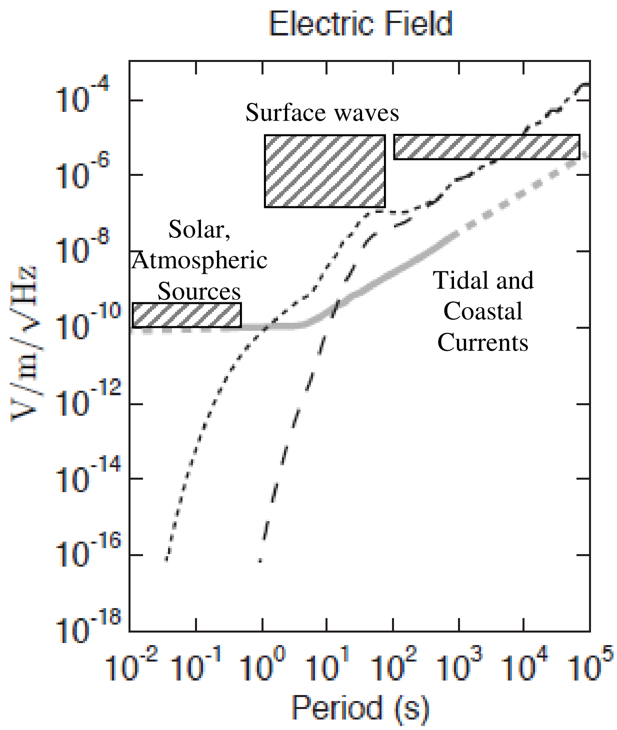


Figure 5 – Estimated Electric Field Range of Values at Reedsport, OR

Man-made sources of EM fields may be observed in the ambient noise data. In North America, 60 Hz sources are commonplace, and are tied to earth ground at virtually "everywhere" there is development. The resistive character of the Earth's crust will undoubtedly allow 60 Hz and other electrical power frequencies to propagate into nearby areas, including the near-shore marine environment. The specific magnitude of this noise is difficult, if not impossible to estimate, thus it will need to be determined by conducting actual measurements at the site. It is expected that a 60 Hz narrowband tone will be detected in the ambient noise spectra at the Reedsport site. In addition, harmonics of 60 Hz may also be observed, such as 120 Hz, 180 Hz, and higher order harmonics. At least one electric field measurement in the near-shore environment in Europe revealed strong 50 Hz power line frequencies, including detection of an electric commuter train operating at a distance (Dalberg 2001).

9. CONCLUSIONS

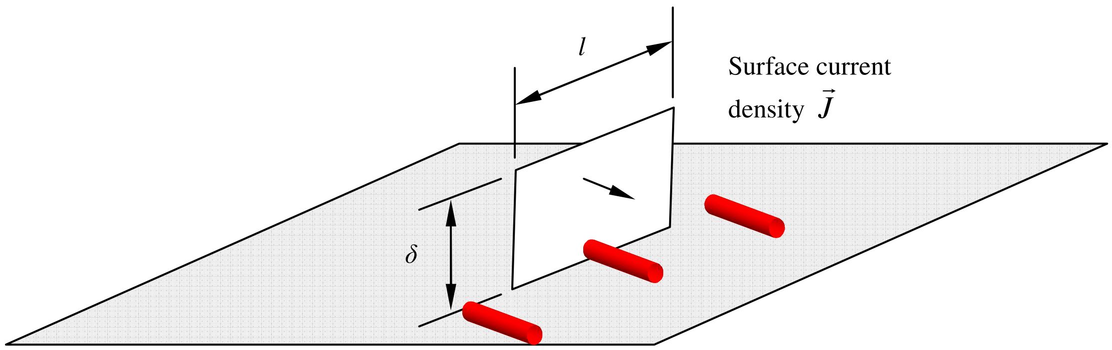
This study was commissioned with the goal of estimating the existing electric and magnetic field strength levels near the Reedsport, OR wave energy test site. This estimate of levels is one input factor to the requirements specification of EM sensors required to characterize the site.

Based on this analysis it is concluded that at the Reedsport test site:

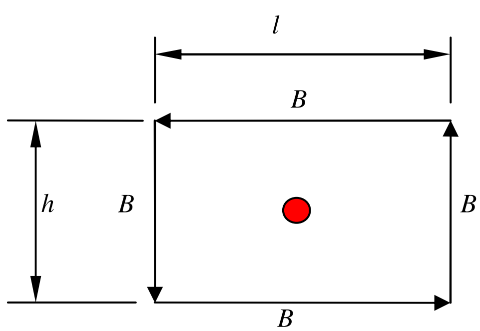
1. The estimated electric fields generated by wave motion are expected to range from 6 to 216 μV/m, and will be observed between 0.04 and 0.3 Hz. The maximum induced magnetic fields due to wave motion should be observed over the same frequency regime, and should be observed with magnitudes ranging from 0.02 to 0.54 nT. The maximum values are expected at the sea surface, and will diminish at deep depths towards the bottom. However, wave induced EM fields will nonetheless be detectable at the ocean bottom at the test site.
2. The maximum electric fields generated by tidal motion are expected to be 33 μV/m, and the maximum magnetic fields because of tidal sources are expected to be 0.08 nT.
3. Coastal currents are expected to generate electric fields up to 22 μV/m, although higher values may be observed, with potential values in extreme current flows of up to 44 μV/m. The corresponding estimated magnetic field values for these conditions would be 0.06 nT to 0.12 nT.
4. Man-made sources of EM noise may be observed in measured ambient noise data. It is difficult to estimate the potential range of magnitude man-made sources on the existing ambient conditions at the site. Man-made sources are expected to exhibit discrete frequencies at 60 Hz and higher order harmonics of 60 Hz, e.g. 120 Hz, 180 Hz, etc.

The methods used in this report could be extended to estimate EM noise levels at other locations along Oregon's coast subject to local knowledge of wave, water current, and magnetic field conditions. Furthermore, the comparison of measured values to the natural conditions would be useful in refining the level of precision of estimated results for this site and others.

APPENDIX A – DETERMINATION OF THE INDUCED MAGNETIC FIELD BY APPLICATION OF AMPERE'S LAW



The 'ordinary' current density $\vec{J}$ is given by $\vec{J} = \frac{I}{\delta l}$ with units of A/m^2. Consider the current density to be equivalent to many parallel conductors as shown above. The *surface* current density is given by $\vec{J}_S = \vec{J}l$ and has units of A/m.



Applying Ampere's Law to the rectangular current loop gives:

$$\oint \vec{B}dl = \underbrace{\int \vec{B}dl}_{\text{TOP}} + \underbrace{\int \vec{B}dl}_{\text{BOTTOM}} + \underbrace{\int \vec{B}dl}_{\text{SIDES}} = \vec{B}l + \vec{B}l + 0 = \mu_0 I = \mu_0 \vec{J}_S l$$

Thus $$\vec{B} = \frac{\mu_0 \vec{J}_S}{2}$$

APPENDIX B – ACRONYMS

ASW	anti-submarine warfare
B-field	magnetic field
CA	California
CGS	centimeter-gram-second
CMACS	Centre for Marine and Coastal Studies
COWRIE	Collaborative Offshore Wind Research Into the Environment
DoI	Department of Interior
EA	Environmental Assessment
E-field	electric field
EIS	Environmental Impact Statement
EM	electromagnetic
EMF	electromagnetic field
Hz	Hertz, cycles per second
MKS	meter-kilogram-second
MMS	Minerals Management Service
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 Institute of Oceanography
UK	United Kingdom
WA	Washington
WEC	Wave Energy Converter

APPENDIX C – BIBLIOGRAPHY

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