The Energy of Ocean Waves– Middle School Sample Classroom Task

Introduction

Ocean waves are an example of mechanical waves in the natural environment. In this task, students use these properties of ocean waves to investigate the relationship between amplitude and energy, and how the energy of ocean waves can have both negative and positive impacts on human society, using examples such as coastal erosion and alternative energy generation. The students use data to associate wave height with the amount of sediment carried by the wave and with the amount of energy produced by wave energy converters. The students also use data to evaluate the components of two specific wave energy converter designs.

This task is derived from data published in the following papers:

Bian, S., Hu, Z., Xue, Z., & Lv, J. (2012). An observational study of the carrying capacity of suspended sediment during a storm event. Environmental monitoring and assessment*, 184(10), 6037-6044.*

Faiz, J., & Ebrahimi-Salari, M. (2011). Comparison of the performance of two direct wave energy conversion systems: Archimedes wave swing and power buoy. Journal of Marine Science and Application*, 10(4), 419-428.*

Silva, D., Rusu, E., & Soares, C. G. (2013). Evaluation of various technologies for wave energy conversion in the Portuguese nearshore. Energies*, 6(3), 1344-1364.*

Standards Bundle

(Standards completely highlighted in bold are fully addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed.)

<u>CCSS-M</u>

MP.1 **Make sense of problems and persevere in solving them.**

MP.3 **Construct viable arguments** and critique the reasoning of others**.**

MP.4 **Model with mathematics.**

8.F.A.2 **Compare properties of two functions each represented in a different way (algebraically, graphically, numerically in tables, or by verbal descriptions**).

8.F.A.3 **Interpret the equation y = mx + b as defining a linear function, whose graph is a straight line**; give examples of functions that are not linear.

8.F.B.4 **Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x, y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models, and in terms of its graph or a table of values.**

8.F.B.5 **Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.**

8.SP.A.1 **Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns** such as clustering, outliers, **positive or negative association, linear association,** and nonlinear association**.**

8.SP.A.2 **Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.**

8.SP.A.3 **Use the equation of a linear model to solve problems in the context of bivariate measurement data,** interpreting the slope and intercept.

NGSS

MS-PS2-3 **Ask questions about data to determine the factors that affect the strength of electric** and magnetic **forces.**

MS-PS4-1 **Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.**

MS-PS4-2 Develop and **use a model to describe that waves are reflected, absorbed, or transmitted** through various materials.

MS-ETS1-1 **Define the criteria and constraints** of a design problem with sufficient precision to ensure a successful solution, **taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**

MS-ETS1-3 **Analyze data from tests to determine similarities and differences among** several **design solutions to identify the best characteristics of each** that can be combined into a new solution to better meet the criteria for success**.**

CCSS-ELA/Literacy

W.8.2 **Write** informative/**explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.**

WHST.6-8.2 **Write informative/explanatory texts, including the narration of** historical events, **scientific procedures/ experiments, or technical processes.**

W.8.2.a & WHST.6-8.2.a
Introduce a topic clearly, previewing what is to follow; organize ideas, concepts, and information into broader categories; include formatting (e.g., headings), graphics (e.g., charts, tables), and multimedia **when useful to aiding comprehension.**

W.8.2.b & WHST.6-8.2.b
Develop the topic with relevant, well-chosen facts, definitions, concrete details, quotations, **or other information and examples.**

W.8.2.c & WHST.6-8.2.c
Use appropriate and varied transitions to create cohesion and clarify the relationships among ideas and concepts.

W.8.2.d, & WHST.6-8.2.d
Use precise language and domain-specific vocabulary to inform about or explain the topic.

W.8.2.e **Establish and maintain a formal style.**

WHST.6-8.2.e Establish and maintain a formal style and objective tone.

W.8.2.f & WHST.6-8.2.f
Provide a concluding statement or section that follows from and supports the information or explanation presented.

W.8.7 & WHST.6-8.7
Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

SL.8.4 **Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.**

Information for Classroom Use

Connections to Instruction

This classroom task is intended to allow students to demonstrate and check their understanding of science and math concepts relating to waves, energy, and both quantitative and qualitative data analysis and interpretation, as indicated by the addressed standards. This task was designed to be used for students at the 8th grade level in math and would fit within a physical science instructional unit on energy and waves or an environmental or earth science unit on ocean waves or alternative energy, consistent with the 8th grade California Integrated Learning Progressions Model (NGSS, vol. 2, Appendix K). Given time constraints, Task Components B and C could be altered or removed from the task to more specifically fit into a unit on alternative energy, with careful attention paid to whether or not the changes affect how fully the task addresses MS-PS4-1 or the cited CCSS-M standards. The task addresses some concepts addressed in 6th and 7th grade math standards (e.g. 6.EE.6, 6.EE.9, 6.NS.5, 6.NS.6, 6.SP.4, and 7.EE.4) but is designed to check for understanding of concepts addressed in the 8th grade standards, such as modeling with functions and more advanced graphing and interpretation of data. Task Components B and D could be simplified for students in lower grades by having students identify comparative relationships in the data (such as "if one variable increases the other also increases" or that "one variable increases faster than the other variable") without having them derive an equation/function, compare functions, or specifically match the data to the relationship, $E \approx A^2$. It should be noted that such changes would affect the alignment of these parts of the task to the cited science standards, and should be noted accordingly.

In a blended math/science course or in a setting where there is collaboration between teachers of different classes, the plotting and data interpretation in Task Components B and E could be used to check for student understanding of both the math and science material. The full task is designed to assess student understanding of wave structure and the associated data interpretation in either a math or science course, and individual task components may be used as necessary within an instructional unit involving waves.

This task includes 8th grade standards for ELA/Literacy related to short research projects, informational writing, and speaking and listening. Students can be formatively assessed on the research standards and on specific informative writing standards on Task components B, C, D, E, F, and G. Task Component G also allows students to demonstrate either all of the standards on informational writing or on the standard for speaking and listening, depending on whether they elect to prepare a report (informational writing) or make a presentation (speaking and listening). Because the 8th grade ELA/Literacy standards and the WHST standards for research and for writing informational texts are almost identical, this task provides an excellent opportunity for interdisciplinary collaboration.

Approximate Duration for the Task

The entire task could take between 7-15 class periods (45-50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:
Task Component A: up to 1 class period, depending if done as homework.

Task Component B: 1–2 class period(s), depending on whether the explanation in III is used as homework.
Task Component C: 1–2 class period(s), depending on whether the description is used as homework.
Task Component D: 1–2 class period(s).
Task Component E: 1–3 class period(s), depending on if part of the task component is used as homework.
Task Component F: 2–3 class periods.
Task Component G: 1–2 class period(s), depending if done as homework

Note that these task component durations only reflect the approximate amount of time students may spend on each component, and do not include additional instructional time that may be embedded within the unit.

Assumptions

It is assumed that students should have a working understanding of electromagnetic generators, ocean waves, and erosion in order to complete this task. It is also assumed that teachers have knowledge of, and are comfortable with, discussion of different designs of wave energy converters as well as the mathematical relationship between amplitude and height and period and frequency.

Materials Needed

In order to create the scale model in Task Component C, students will at minimum need a basin filled with water, rocks to create a "breakwater," and some board, or other tool, to generate waves.

If students decide to do outside research on a wave energy converter design for Task Component G, they will need to have access to the internet or other sources of information.

Although not necessary for completing the task, teachers may choose to read the papers from which this task is derived (see task page one for full references: Bian et al., 2012; Faiz and Ebrahimi-Salari, 2011; Silva et al., 2013), in which case teachers would need to obtain access to the article in the associated journals.

Supplementary Resources

- Information on linear motors, the type of electromagnetic generators found in wave energy converters: http://en.wikipedia.org/wiki/Linear_motor
- Information on wave energy, including a list of wave energy converter designs and a list of related references: http://en.wikipedia.org/wiki/Wave_power

Accommodations for Classroom Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English".

Classroom Task

Context

The coastal environment is a very dynamic place. For example, ocean waves repeatedly crash against beaches and coasts. While this can lead to fun for summertime beach-goers, the high energy of ocean waves interacting with the beach over time can lead to erosion, the loss of land, and the collapse of sea-side cliffs. Because of the serious concerns these beach interactions pose to coastal communities, scientists and engineers use wave properties, such as absorption, transmission, and reflectivity to create solutions to mitigate coastal erosion. Additionally, coastal communities and island nations have started to explore the positive effects of the energy of ocean waves. Specifically, the energy of ocean waves can be harvested by technology as an alternative, renewable energy source. Engineers must design energy-capturing devices that rely on the principles of wave physics to maximize the amount of energy produced, and the design process is on-going at many companies as they optimize the ocean wave energy technology.

In class, you have learned about the energy and movement of waves. Now let us explore the positive and negative effects of ocean waves in human society.

Task Components

A. Draw a visual representation of the cross section of an ocean wave. Ocean waves are typically described by the wave height and the wave period. The wave height is measured from the bottom of a wave (trough) to the top of a wave (crest). On your drawing, indicate and label the still water level, the amplitude, the wavelength, and the wave height. Then write an algebraic equation that relates wave height to amplitude. The wave period is the amount of time it takes for one wave to go by. The wave frequency is the number of waves in a given time period. Write an algebraic equation that relates the period of the wave to the frequency.

B. Ocean waves have enough energy to pick up and carry sand and other sediment. This wave action helps to move sand up and down the beach slope as well as along the length of the beach. This shapes the beach over time. The most drastic changes to beaches happen when storms occur because higher energy waves carry more sediment than lower energy waves. During a big storm, a beach can experience a large amount of erosion.

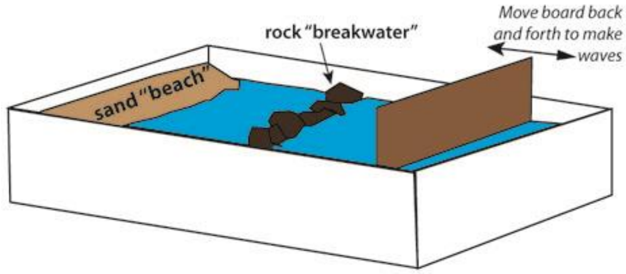
   In order to investigate how much sediment stormy ocean waters can carry away from beaches, scientists gathered data from ocean waters off the coast of the Shandong Peninsula in the Yellow Sea, China, during a storm in the spring of 2010. The numbers in the chart provided (Attachment 1) were derived from the scientists' data. The chart shows maximum wave height values and the amount of sediment carried by the waves from different points in time during the storm. These data are represented on the scatterplot provided (Attachment 2).

   I. Estimate and draw a trend line (approximate line of best fit) for the dataset on the scatter plot and derive an equation for your line. What does your trend line indicate about the relationship or pattern between wave height and the amount of sediment the wave is moving?

   II. Compare your trend line and equation with the trend lines and equations of two of your classmates (or those given by your teacher). Consider the patterns you observe among the trendlines- how are they similar, and how are they different? Describe similarities and differences in the slope, y-intercept, and fit of the data among the trend lines and indicate which trend line is most representative of the dataset.

III. Given that higher energy waves carry more sediment than do lower energy waves, construct an explanation for the relationship between wave energy and amplitude. Use your plot and/or trend line as evidence to support your ideas.

C. People living on or near the coast are worried about the loss of sand due to wave erosion. They cannot stop the waves from coming, but they can build structures that will affect the wave before it reaches the shore. Some beaches are naturally protected by offshore coral reefs, and engineers have created structures called breakwaters that work like coral reefs to protect beaches from the full effect of the ocean wave energy.



Create a scale representation of a beach and breakwater system as shown. Use a board to simulate ocean waves and watch what happens to those waves as they interact with the breakwater. Use your observations of the waves in your scale representation to create a description of how the breakwater affects or changes the wave reflection, absorption, and/or transmission before they reach the beach.

D. Engineers have been working through the design process to produce and refine new technologies to harness the renewable energy of the Earth. Radiation from the Sun and the movement of air and water are all sources of energy that can be transformed into electrical energy for use by human society. Island and coastal communities have come to see ocean waves in a new light as they turn to wave energy as an alternative energy source. Wave energy converters transfer the up and down movement of the ocean surface into electric energy through an electromagnetic generator. What everyone wants to know is "*How much energy can be produced from ocean waves*?"

The data in the chart provided (Attachment 3) show the "actual" energy production for four different wave energy converter designs. All of the data are for a wave period of 10 seconds. The amount of energy produced changes as the wave height increases. The theoretical numbers represent the change in energy as the wave amplitude increases following the relationship:

One unit of energy ≈ (one unit of the amplitude) ^{2} or $E \approx A^2$

The scatterplots for each wave design (Attachment 4) show the theoretical numbers as a line and the actual numbers as points. The wave designs cannot capture all the energy available in the waves. Every design has a wave height above which the amount of energy produced does not increase. Also, some designs are more effective than others, so the amount of energy produced for the same wave height also varies.

I. Discuss whether the pattern of actual data on the energy produced vs. wave amplitude scatter plots reflects the theoretical mathematical relationship between the energy and amplitude of a wave as stated above (that is, do the actual data follow the relationship $E \approx A^2$ as the theoretical data do)? Keep in mind that there is a wave height above which the amount of energy produced does not change. Do not consider the points on each scatter plot above this wave height when answering the question. Use the data tables and/or scatter plots as evidence in your discussion.

II. Describe the usefulness of the different wave energy converter designs. Discuss the amount of energy each design can produce and the range of wave heights for which each design is most effective. Also, consider whether one design is better at producing electrical energy than another by comparing the energy production for the same wave height. Is the design that produces the greatest amount of energy for one wave height also the same design that produces the greatest amount of energy for all the other wave heights?

E. Wave energy converters use electromagnetic generators to transform mechanical wave energy to electric energy. As the wave moves up and down, magnets inside the energy converters also move up and down. These magnets move within coiled copper wires causing electrons to move and electrical energy to be created. There are many different designs for wave energy converters. Each of the designs works in a slightly different way to use the movement of the waves to move the magnets within the electromagnetic generator. The designs of the electromagnetic generators can be different, as well. Because of these differences, some wave energy converters are better than others at converting wave energy to electrical energy.

The diagram provided (Attachment 5) shows the design of two different wave energy converters: the *Power Buoy* (PB) and the *Archimedes Wave System* (AWS). The data chart provided (Attachment 6) shows the variation in the voltage and energy production for each system at different points in time over one wave period.

I. Graphically represent the voltage and energy data. Choose and create a graphical representation that best shows the range in the data (the maximum and minimum values) and that has an appropriate scale, axis labels, unit labels, legend, and title. Representations such as bar graphs, line plots, stem and leaf plots, or other data displays should be considered. Use this plot as evidence to make a claim for which wave converter design is more effective at transferring the wave energy to electrical energy. Use these data to construct an argument for why this converter design is more effective.

II. Consider the situation where the differences in energy production are entirely caused by differences in the design of the electromagnetic generator. Based on this situation, create a list of which aspects of the electromagnetic generators are different, and describe why each of those differences might account for the measured differences in voltage.

III. Create two questions that you could ask about the components of the electromagnetic generators that could be answered by changes in the voltage data, such as a measured increase or decrease in the voltage due to a change in a component. The questions should be created such that the answers would help you increase the output of the electromagnetic generators. Describe how the changes could be tested, how these questions would be answered by the changes in the data, and why these questions are relevant to better device design.

F. Now consider that the differences in energy and voltage between the *Power Buoy* and *Archimedes Wave System* are a result of differences in the whole wave converter design rather than in the design of the electromagnetic generator. Data for how much the wave moved up and down as well as data for how much the magnets moved up and down in each wave converter design are shown in Attachment 7. These data are plotted on the scatter plots in

Attachments 8 & 9:

- The vertical movement of the ocean surface over time
- Vertical movement of the *Power Buoy* magnets over time
- Vertical movement of the *Archimedes Wave System* over time

I. Using these plots as evidence, argue for how differences in the design of the wave energy converters could account for the differences in the measured energy and voltage values. Cite specific similarities and differences in the design of the wave energy converters in your argument.

II. Based on what you know about how ocean waves move and how the period and amplitude affect the energy of a wave, modify the design of either the *Power Buoy* or *Archimedes Wave System* to improve the amount of energy produced from the ocean waves. You may keep any parts of either design that you feel are the best, change any parts that you feel are not working, and/or add new parts to the design. Include a description for the reasoning behind your changes.

G. Not all wave converter designs are created equal, and no one design will be universally used by all communities. Based on what you have learned from the data presented in the previous task components and what you learn from any research you may do on your own, develop a list of criteria that should be considered when an island or seaside community decides to shop around for a wave energy converter design to use to generate renewable energy for their population. Consider specific details related to the nature of the waves as they interact with the design (such as the range in wave height and period with which the converter performs best), the nature of the design itself, the cost of the design, the durability of the design, and human and environmental factors that are important to the community. Make statements about which criteria you think are most important to the community, so that when faced with a decision between two non-ideal designs, the tradeoffs of possible choices can be weighed. Compile your list and recommendations into a presentation or report that you will provide to the community members at the next town hall meeting.

Alignment and Connections of Task Components to the Standards Bundle

Task Component A asks the students to draw an ocean wave and to connect the general components of a wave (amplitude, wavelength, frequency) to the components of an ocean wave (wavelength, period, height). This addresses parts of NGSS core idea of **PS4.A: Wave Properties as it relates to MS-PS4-1,** and partially addresses one part (one Appendix F bullet) of the NGSS practice of **Developing and Using Models**. By developing algebraic equations relating height to amplitude and frequency to period, students are partially addressing the CCSS-M content standard **8.F.5** (students are not asked to describe the relationships but rather are given the descriptions and asked to make a sketch), and fully assessed on **8.F.4** and the CCSS-M practice **MP.4.** Mathematically relating the components of an ocean wave with the standard components of a mechanical wave enhances assessment of the science standards associated with waves whereas the science context provides a practical use for developing mathematical relationships.

Task Component B asks students to analyze a plotted dataset relating wave height to the amount of sediment carried by the wave, to consider different equations that model the relationship between the two components, and then to qualitatively relate that relationship to the known relationship between wave height and wave energy. This partially addresses parts of the NGSS core idea of **PS4.A: Wave Properties as it relates to MS-PS4-1**, parts of the practices of **Analyzing and Interpreting Data and Constructing Explanations and Designing Solutions**, and the crosscutting concept of **Energy and Matter**, and fully addresses one part (bullet) of the NGSS practice **Using Mathematics and Computational Thinking** and crosscutting concept of **Patterns, as they relate to MS-PS4-1**. By drawing a trend line, deriving an equation that models the relationship between sediment carried and wave height, and comparing classmates' trend lines, students are partially addressing CCSS-M content standards **8.F.3**, **8.F.5**, **8.SP.1**, **8.SP.3**. Students can also demonstrate their understanding of CCSS-M **8.F.2**, **8.F.4**, **8.SP.2,** and the CCSS-M practices of **MP.1**, and **MP.4**. By choosing and evaluating a trend line and equation to model the relationship between the data components, the students are using the math to enhance the assessment of the relationship between wave amplitude and energy, while the dataset provides a realistic context in which an interpretation of the fit of the data is essential part of mathematically modeling the data effectively. As students make comparisons, cite similarities and differences, and describe relationships in **Task Component B**, they are addressing **W.8.2, W.8.2.b, WHST.6-8.2**, and **WHST.6-8.2b**, writing to inform or explain.

Task Component C asks students to use a scale representation of a breakwater-beach-wave system to investigate the effect a breakwater has on ocean waves in terms of wave reflection, absorption, and/or transmission. This partially addresses the NGSS performance expectation of **MS-PS4-2** and part of the associated practice of **Developing and Using Models** and part of the crosscutting concept of **Structure and Function**. As students simulate and observe ocean waves and describe their observations, they can demonstrate their understanding of parts of **W.8.7** and **WHST6-8.7**, conducting short research projects to answer a question, as well as on **W.8.2** and **WHST.6-8.2**.

Task Component D asks students to compare energy data produced from wave energy converters at different wave heights and to use the data to comment on the usefulness of the different wave energy converter designs. Comparing the actual data values in the plots with the theoretical values derived from the mathematical relationship $E \approx A^2$, the students partially address the NGSS performance expectation of **MS-PS4-1** and parts of the associated crosscutting concept of **Patterns** and practice of **Using Mathematics and Computation Thinking**. By describing the usefulness of various designs by comparing the plots and data charts of the energy produced (with different scales of energy and amplitude), students address parts of the NGSS practices of **Constructing Explanations and Designing Solutions** and **Analyzing and Interpreting Data** and the crosscutting concept of **Structure and Function**. By comparing the theoretical relationship vs. actual values and by evaluating the fit of the actual data to the $E \approx A^2$ relationship, students can demonstrate their understanding of the CCSS-M content standards of **8.F.2** and **8.F.4,** and parts of the CCSS-M practice of **MP.3** (as the task has no requirement to critique the reasoning of others). As in Task Component D, evaluating the fit of actual data to a model dataset that followed a defined mathematical relationship, the students are using the math to enhance their performance regarding the relationship between wave amplitude and energy while the dataset provides a realistic context in which to evaluate the fit of data to an equation that defines a relationship between variables. As students discuss data and construct explanations based on data in **Task Component D**, they are partially addressing on **W.8.2, W.8.2.b, WHST.6-8.2**, and **WHST.6-8.2b**, writing to inform or explain.

Task Component E asks students to compare the voltage and energy data of two specific wave energy converter designs and to consider how differences in the electromagnetic generator used in each design would lead to the difference in the data. By asking students to make and justify a claim for which design is a more effective design, students partially address the NGSS practice **Engaging in Argument from Evidence.** By specifically asking questions about the data regarding components of the electromagnetic generator, students can demonstrate their understanding on parts of NGSS performance expectation of **MS-PS2-3** and part of the associated practice of **Asking Questions and Defining Problems** and the crosscutting concept of **Cause and Effect**. This also partially addresses parts of the NGSS practice of **Analyzing and Interpreting Data** and the crosscutting concept of **Structure and Function.** By choosing a plotting method for the data, constructing the plot for the voltage and energy data, and using the data to make a decision about which design is more effective in transforming wave energy to electrical energy, students can demonstrate their understanding of the CCSS-M content standard of **8.SP.1**, the CCSS-M practices **MP.4,** and parts of **MP.3** (as the task has no requirement to critique the reasoning of others). By being presented with the problem of how to best present the voltage and energy data on a graph, the science context is enhancing the math understanding, whereas the dataset and plot are important points of evidence essential for demonstrating the science practice and standards. As they create and explain graphic representations of data in **Task Component E**, students partially address **W.8.2, W.8.2.a, W.8.2.b, WHST.6-8.2**, **WHSt.6-8.2a, and WHST.6-8.2b**, writing to inform or explain; and as they create and explain research questions, they can partially address **W.8.7** and **WHST6-8.7.**

Task Component F asks students to compare the vertical displacement data for two specific wave energy converter designs, to consider how differences in the converter design would lead to the difference in the data, and to decide which parts of each design to keep when developing a new design. This partially addresses the NGSS performance expectation of **MS-ETS1-3** and part of the associated practice of **Analyzing and Interpreting Data** and the disciplinary core idea of **ETS1.C: Optimizing the Design Solution**. This also partially addresses parts of the NGSS practices of **Constructing Explanations and Designing Solutions**, **Engaging in Argument from Evidence,** and the crosscutting concepts of **Cause and Effect,** and **Patterns**. By evaluating and comparing data on the graphs, students partially address CCSS-M content standards of **8.F.2** and **8.F.5**. The interpretation of the plotted data is essential for evaluating the design solution while the data plots provide an example of a situation where the positive and negative values can be used to indicate distance above or below a set height. As students explain similarities and differences and explain their reasoning in **Task Component F**, they are addressing part of **W.8.2, W.8.2.b, WHST.6-8.2**, and **WHST.6-8.2b**, writing to inform or explain.

Task Component G asks students to develop and communicate the criteria and tradeoffs that should be considered when an island or seaside community decides to shop around for a wave energy converter design. This partially addresses the NGSS performance expectation MS-ETS1-1 and partially addresses parts of the associated practice of **Asking Questions and Defining Problems**, the core idea of **ETS1.A: Defining and Delimiting Engineering Problems**, and the crosscutting connection of **Influence of Science, Engineering, and Technology on Society and the Natural World**. By communicating their findings in a presentation or report, students demonstrate part of the NGSS practice of **Obtaining, Evaluating, and Communicating Information**. By creating a report or presentation, students can demonstrate either **W.8.2, W.8.2a, W.8.2b, W.8.2c, W.8.2d, W.8.2e, W.8.2f, WHST.6-8.2, WHST.6-8.2a, WHST.6-8.2b, WHST.6-8.2c, WHST.6-8.2d, WHST.6-8.2e,** and **WHST.6-8.2f,** writing to inform or explain or on **SL.8.4**, presenting claims and findings orally.

Together, **Task Components A, B, & D** address the NGSS performance expectation of **MS-PS4-1.** The task components assess and integrate the core idea of **PS4.A: Wave Properties** and parts of the crosscutting concept of **Patterns,** and the practice **Using Mathematical and Computational Thinking** in the context of this particular performance expectation by relating the general structure of a wave to the structure of an ocean wave and by using the mathematical models to describe patterns in plots of data to make a connection between wave height (amplitude) and wave energy through information on the amount of sediment carried by a wave and the amount of energy produced by a wave energy converter.

Evidence Statements

Task Component A

- Students draw a visual representation that shows an ocean wave and correctly indicates and labels the still water level, wave height, the wave amplitude, and the wavelength.
- Students express the relationship between wave height and amplitude as H=2A.
- Students express the relationship between period and frequency as F=1/P or as P=1/F.

Task Component B

- I. Students draw a trend line on the scatterplot and correctly derive an equation for the trend line.
- I. Students describe the relationship between wave height and amount of sediment the wave is carrying as increasing proportionally (i.e. as the wave height increases, the amount of sediment it can carry also increases).
- II. In their description, students
  - Include a statement that compares the student's trendline with those obtained from peers or the instructor.
  - Describe patterns observed among the trendlines, including the similarities and/or differences in slope, y-intercept, and/or fit of data as evidence in support of the statement.
  - Identify one of the trend lines as most representative of the dataset.
- III. Students construct an explanation that states that as the wave amplitude increases the energy of the wave increases.
- III. In their explanation, students identify and describe evidence from the data they analyzed, including the positive slope of the trendline or the observation from the graph that the amount of sediment carried increases with increasing wave height.
  - Students demonstrate reasoning that connects the evidence, including the idea that because the amount of sediment carried increases with wave height and because higher energy waves carry more sediment, the amount of energy of the wave must also increase with wave height.

Task Component C

- In their description, students include a statement that the breakwater changes the waves through reflection transmission, or absorption.
- In their description, students cite at least two observations that connect physical structures to wave property functions from the model as evidence. Examples include:
  - Waves that hit the breakwater bounced off the breakwater.

- The amplitude of the wave was smaller after interacting with the breakwater.
    - The waves that hit the breakwater did not continue beyond the breakwater to the beach.
- In their description, students include a line of reasoning that connects the observations from the physical structures of the model to the processes of absorption, transmission, or reflection. Examples include:
    - The wave bounced off the breakwater due to reflection and did not continue past the breakwater.
    - The amplitude of the wave was smaller after interacting with the breakwater because most of the wave energy was absorbed and only a small amount of the wave energy was transmitted.

Task Component D

- I. Students use their analysis to describe that the actual measured energy values match the theoretical values in most of the designs (possible exception of the Pelamis design).
- I. Students use their analysis to cite as evidence the observation from the plots that the actual data points lie along the theoretical line (possible exception of the Pelamis design).
- I. Students use their analysis to describe that because the actual values follow the theoretical values, the energy produced from ocean waves follows the $E \approx A^2$ relationship.
- II. Students cite the scale and range of data from the plots in support of their analysis of various solutions. Students describe:
    - The *Pelamis* design as operating within a wave height range of 0-6m to produce a max energy of 750 kW;
    - The *Aqua Buoy* design as operating within a wave height range of 0-4.5m to produce a max energy of 250 kW;
    - The *Wave Dragon* design as operating within a wave height range of 0-3m to produce a max energy of 7,000 kW;
    - The *Wave Energy Converter SSG* design as operating within a wave height range of 0-5kW to produce a max energy of 20,000 kW.
- II. In their description, students include a statement describing one wave design as more effective than the others in producing energy and cites differences in the energy production for a specific wave height as evidence, as a result of their analysis and interpretation of the data about the wave energy converter designs. Examples include:
    - The *Aqua Buoy* produces the least amount of energy for all wave heights.
    - The *Pelamis* design produces more energy than the *Aqua Buoy* for all wave heights.
    - The *Wave Energy Converter SSG* produces the maximum amount of energy for the greatest wave heights, but less than the *Wave Dragon* for waves equal to or less than 3m in height.
    - The *Wave Dragon* produces the greatest amount of energy for wave heights from 0-3m.

Task Component E

- I. Students create a graphical display that is an appropriate method of display for the data; they select and create a graphical display that correctly represents the range in the data, and includes a relevant scale, axis labels, unit labels, legend, and title.
- I. Based on their graphical representation, students make the claim that the AWS is more effective at translating the wave energy into electrical energy.
- I. Students identify and describe evidence from the plot to support the claim, including, the larger range in energy values or higher maximum energy value for the AWS over the PB.
- I. Students evaluate the evidence for relevance and sufficiency for supporting the claim.
- I. Students construct an argument that connects the relevant evidence with reasoning, including the idea that because the AWS has a larger range or higher maximum energy value, it is more effective at transferring wave energy into electrical energy.
- II. In their description, students identify the number, orientation, and/or types of magnets

and/or the number of copper wire coils as the components that may differ between the two wave energy converter designs.

- II. In their description, students include that the coil of wire and the magnets are the essential components in an electromagnetic generator for making electricity, such that the changes in these components will affect the voltage generated.
- III. Students develop two relevant questions that link a change in a component with a predicted change in the voltage data.
- III. Students describe a realistic method for answering the questions.
- III. Students describe a specific cause and effect relationship between the change in the component and the predicted effect on the voltage produced. Examples include:
    - Stronger magnets in the electromagnetic generator of the AWS design would produce a higher voltage relative to the PB design;
    - Many fewer loops in the coils of the electromagnetic generator of the PB design relative to the AWS design would produce a lower voltage.

Task Component F

- I. Students make a cause and effect claim between an aspect(s) of the wave energy converter design and the differences in the amount of energy produced, noting that an effect may have more than one cause if appropriate to the claim.
- I. Students identify evidence to support the claim, including
    - Patterns in the similarities and/or differences between the wave energy converter designs, establishing that the design feature attributed to the difference in energy produced is present in one design and not the other.
    - The differences in energy produced and voltage outputs, to establish the magnitude of the difference
- I. Students evaluate the evidence for relevance and sufficiency for supporting the claim, including an evaluation of whether the evidence supports causation or correlation.
- I. Students synthesize the relevant and sufficient evidence with reasoning to argue for why the energy design feature causes the difference in energy produced (e.g. the rope in the PB design does not transfer all the downward motion of the wave to the magnets because the rope that is connected to the buoy can bend as the wave goes down).
- II. Students create (e.g., sketch) and describe the new design, identifying the components of the *Power Buoy* and *Archimedes Wave System* designs that are useful/kept, and identifying new parts of the design that were added.
- II. Students describe the new design, providing sound scientific reasoning for the choice(s) to keep, change, or add a design component, as related to the energy of ocean waves and the utility of the design to capture that energy.

Task Component G

- Students develop and present (oral presentation or written report) a list of criteria that addresses factors specific to the type of ocean waves (height and/or period), the choice of wave energy converter design, human considerations, and environmental considerations.
- In their presentation or report, students make statements evaluating the importance of one criterion over another or defining potential trade-offs between competing criteria.

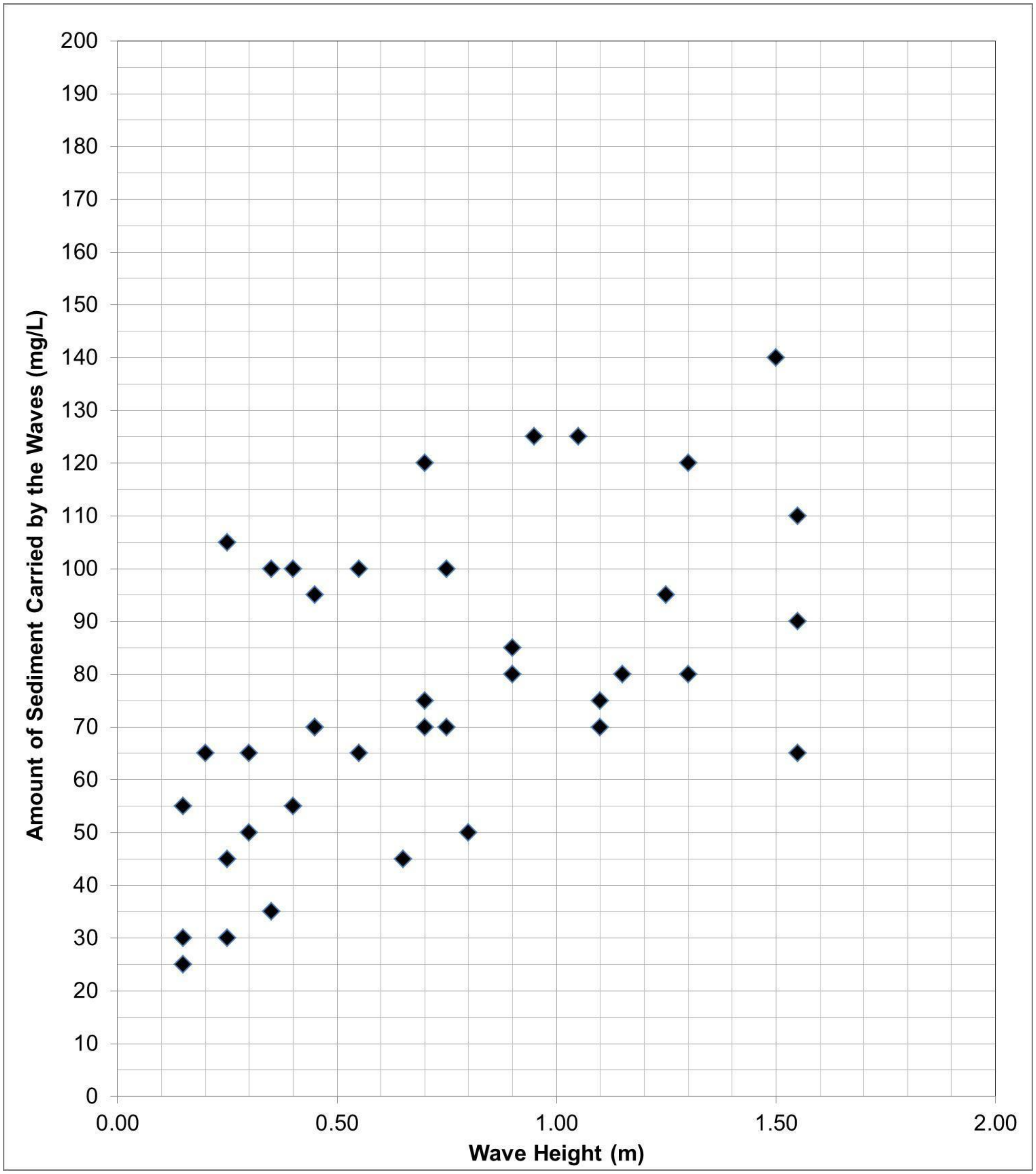
Attachment 1. Sediment Load and Wave Height Data Chart for a Spring 2010 Storm Event Off of the Coast of Shandong Peninsula in the Yellow Sea, China

Amount of Sediment Carried by the Waves (mg/L)	Wave Height (m)
25	0.15
30	0.15
30	0.25
35	0.35
45	0.25
45	0.65
50	0.30
50	0.80
55	0.40
55	0.15
65	0.55
65	0.20
65	0.30
65	1.55
70	1.10
70	0.70
70	0.45
70	0.75
70	0.45
75	0.70
75	1.10
Table Continued	
75	1.75
80	1.15
80	1.30
80	0.90
85	0.90
90	1.55
95	1.25
95	0.45
100	0.40
100	0.35
100	0.75
100	0.55
105	0.25
110	1.55
120	0.70
120	1.30
125	0.95
125	1.05
140	1.50

Data are derived from:

Bian, S., Hu, Z., Xue, Z., & Lv, J. (2012). An observational study of the carrying capacity of suspended sediment during a storm event. Environmental monitoring and assessment, 184(10), 6037-6044.

Attachment 2. Sediment Load and Wave Height Scatter Plot for a Spring 2010 Storm Event Off of the Coast of Shandong Peninsula in the Yellow Sea, China



Attachment 3. Data Chart of the Energy Production of Wave Energy Converters at Different Wave Amplitudes

Amplitude (m)	Aqua Buoy		Pelamis		Wave Dragon		Wave Energy Converter SSG	
	Actual	Theoretical	Actual	Theoretical	Actual	Theoretical	Actual	Theoretical
0.25	0	3	0	7	360	263	198	198
0.50	11	12	29	29	1190	1050	794	794
0.75	26	26	65	65	2620	2363	1786	1786
1.00	47	47	116	116	4200	4200	3175	3175
1.25	73	73	181	181	6020	6563	4961	4961
1.50	106	106	240	261	7000	9450	7144	7144
1.75	144	144	326	355	7000	12863	9724	9723
2.00	198	188	384	464		16800	12701	12700
2.25	239	238	473	587		21263	16074	16073
2.50	250	294	557	725		26250	19845	19844
2.75	250	355	658	877		31763	20000	24011
3.00		423	711	1044		37800		28575
3.25		496	750	1225		44363		33536
3.50		576	750	1421		51450		38894
3.75		661	750	1631		59063		44648
4.00		752	750	1856		67200		50800

All energy measurements are in kJ units.

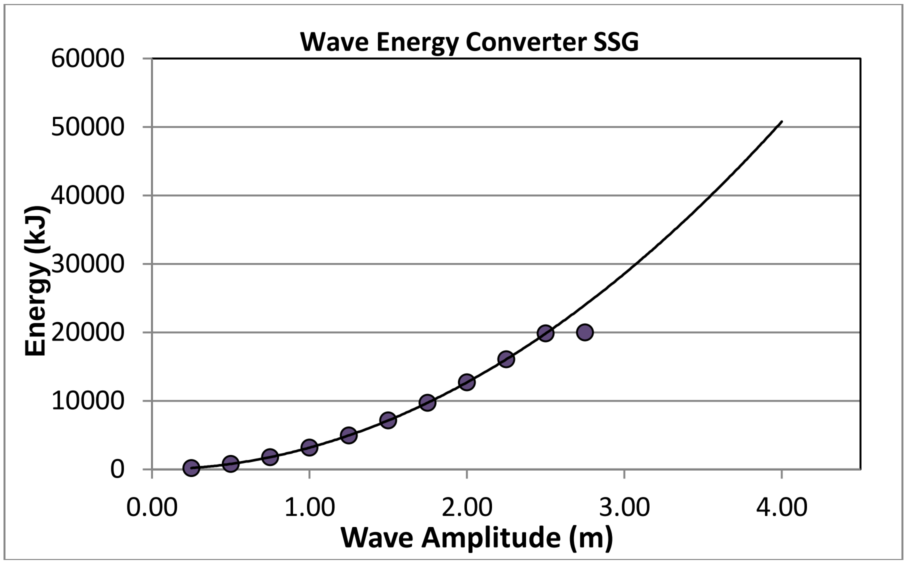
Energy data are derived from simulations of the various wave energy converter designs. The simulations were run for waves with a period of 10s and various amplitudes. The theoretical values are calculated following the relationship that: one unit of energy is proportional to one unit of amplitude squared. The energy values from the original data source are represented as power (kW; power= energy/time= J/s=w), which is proportional to energy, and therefore proportional to amplitude, as per the energy/amplitude relationship presented here. The theoretical energy values were calculated using a "conversion value" derived from power values taken from a consistent 10 second period, and the amount of energy produced for an amplitude of one meter.

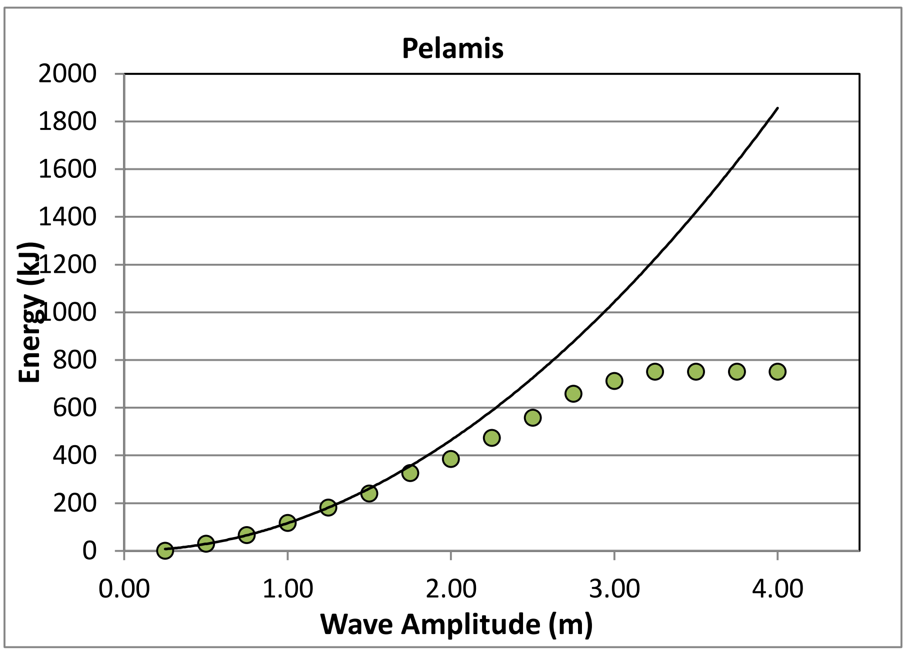
Both the actual and theoretical values were modified to present energy in kJ here, instead of power measurements- however, similar relationships for the purposes of this task should be derived whether students refer to power vs. amplitude or energy vs. amplitude.

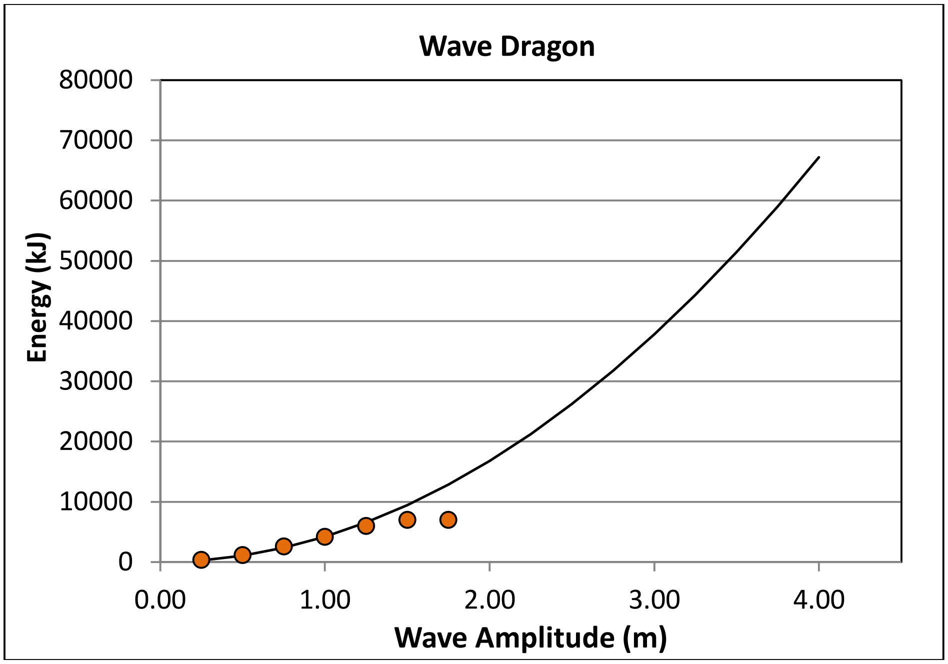
Data are modified from:

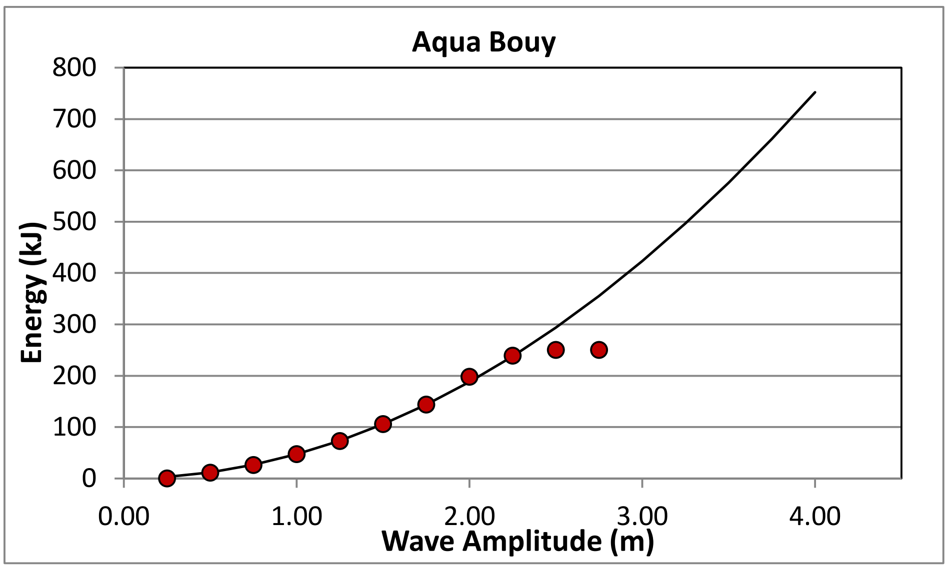
Silva, D., Rusu, E., & Soares, C. G. (2013). Evaluation of various technologies for wave energy conversion in the Portuguese nearshore. Energies, 6(3), 1344-1364.

Attachment 4. Power vs. Wave Amplitude Scatter Plots for Wave Energy Converters

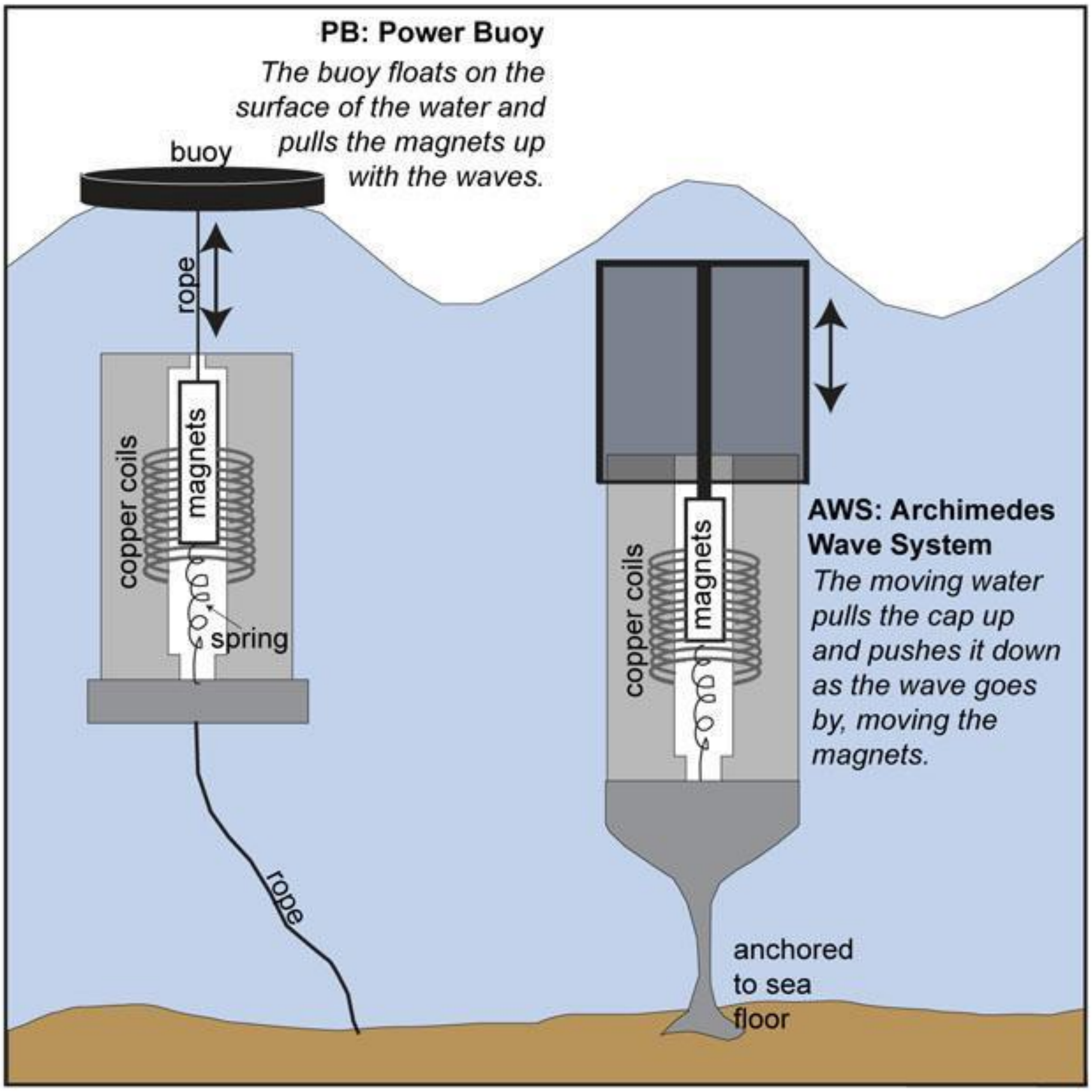





Wave Dragon
80000
70000
60000
50000
40000
30000
20000
10000
0
Energy (kJ)
0.00
1.00
2.00
3.00
4.00
Wave Amplitude (m)


Aqua Bouy
800
700
600
500
400
300
200
100
0
Energy (kJ)
0.00
1.00
2.00
3.00
4.00
Wave Amplitude (m)

Attachment 5. Schematic Diagrams Showing the Basic Design of the *Power Buoy* and *Archimedes Wave System* Wave Energy Converters.



Attachment 6. Voltage and Energy Production Data Chart for the *Power Buoy* and *Archimedes Wave System* Wave Energy Converters

Voltage (v)	
PB	AWS
50	190
55	270
110	270
165	320
200	350
200	670
345	670
370	700
375	710
415	720
545	890
	900
	910
	920

Energy (kJ)	
PB	AWS
1	20
11	20
4	25
10	20
18	150
60	150
40	125
85	155
73	160
79	255
119	245
	250
	265

Energy and voltage data are from simulations of the two wave energy converter designs and represent data from one wave period.

Data are derived from:

Faiz, J., & Ebrahimi-Salari, M. (2011). Comparison of the performance of two direct wave energy conversion systems: Archimedes wave swing and power buoy. Journal of Marine Science and Application, 10(4), 419-428.

Attachment 7. Data Chart of the Vertical Movement of the Magnets in the *Power Buoy* and *Archimedes Wave System* Designs Relative to the Wave Movement Over One Wave Period

Power Buoy		
Time (s)	Vertical Movement of Ocean Surface (m)	Vertical Movement of Magnets (m)
0.50	-1.70	-0.55
1.00	-1.00	-0.65
1.50	0.00	-0.50
2.00	1.00	0.20
2.50	1.75	0.85
3.00	2.00	1.25
3.50	1.75	1.30
4.00	1.00	0.90
4.50	0.00	0.40
5.00	-1.00	0.00
5.50	-1.75	-0.25
6.00	-2.00	-0.45
6.50	-1.75	-0.55
7.00	-1.00	-0.60
7.50	0.00	-0.65

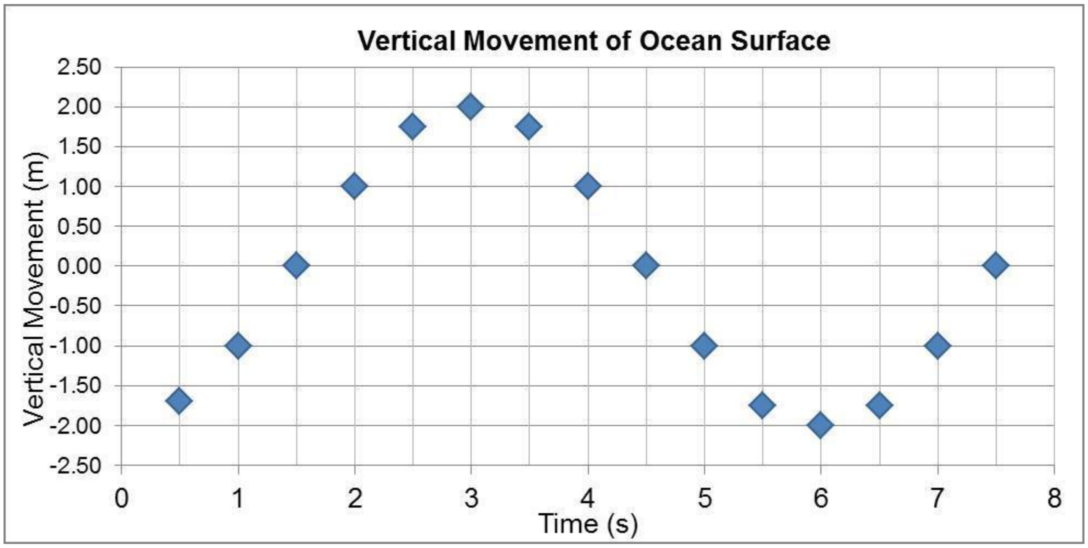
Archimedes Wave System		
Time (s)	Vertical Movement of Ocean Surface (m)	Vertical Movement of Magnets (m)
0.50	-1.70	-2.10
1.00	-1.00	-2.10
1.50	0.00	-1.55
2.00	1.00	-0.65
2.50	1.75	0.40
3.00	2.00	1.30
3.50	1.75	1.75
4.00	1.00	1.65
4.50	0.00	1.10
5.00	-1.00	0.15
5.50	-1.75	-0.90
6.00	-2.00	-1.65
6.50	-1.75	-2.10
7.00	-1.00	-2.05
7.50	0.00	-1.40

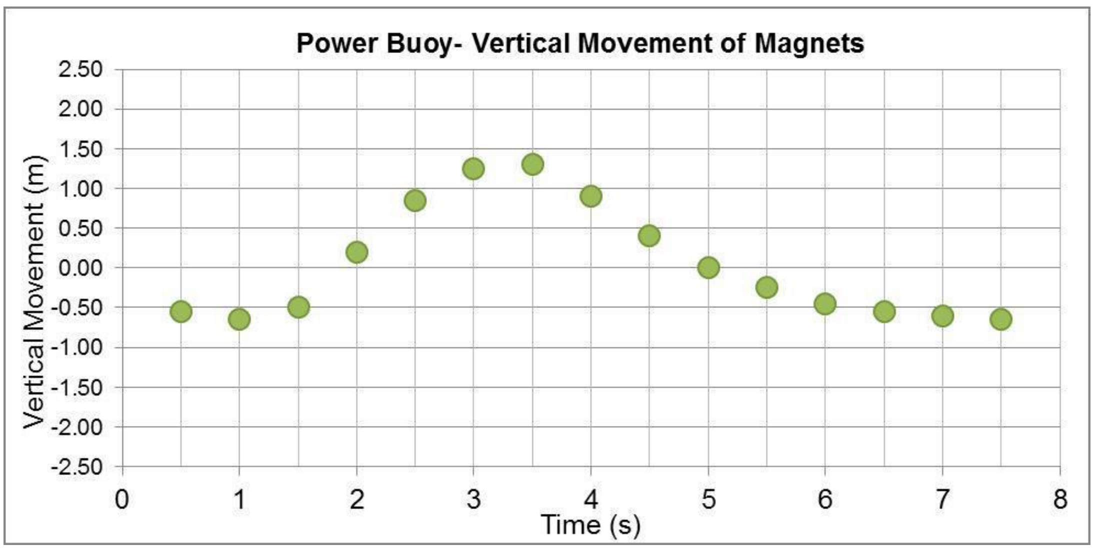
Displacement data are from simulations of the two wave energy converter designs.

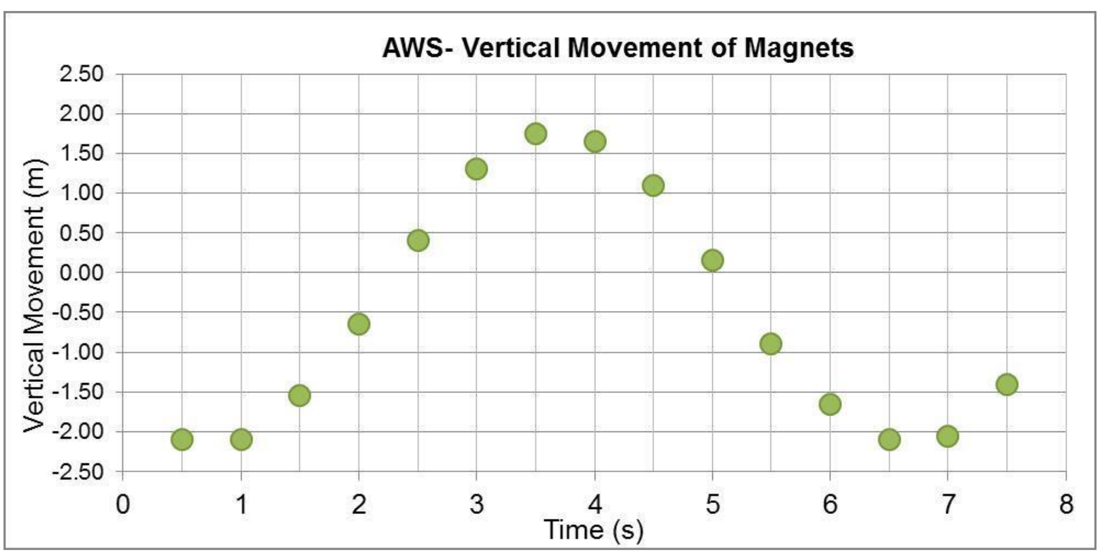
Data are derived from:

Faiz, J., & Ebrahimi-Salari, M. (2011). Comparison of the performance of two direct wave energy conversion systems: Archimedes wave swing and power buoy. Journal of Marine Science and Application, 10(4), 419-428.

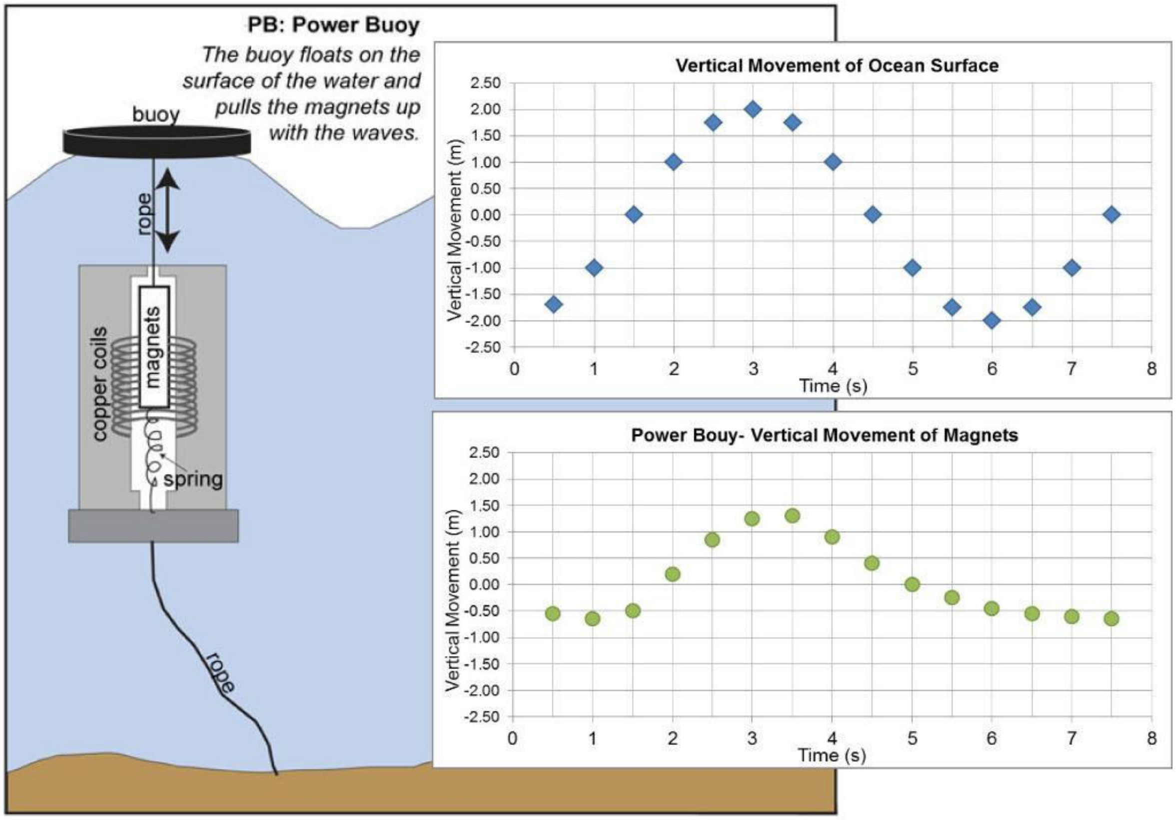
Attachment 8. Scatter Plots showing the Vertical Movement of the Magnets in the *Power Buoy* and *Archimedes Wave System* Designs Relative to the Wave Movement Over One Wave Period

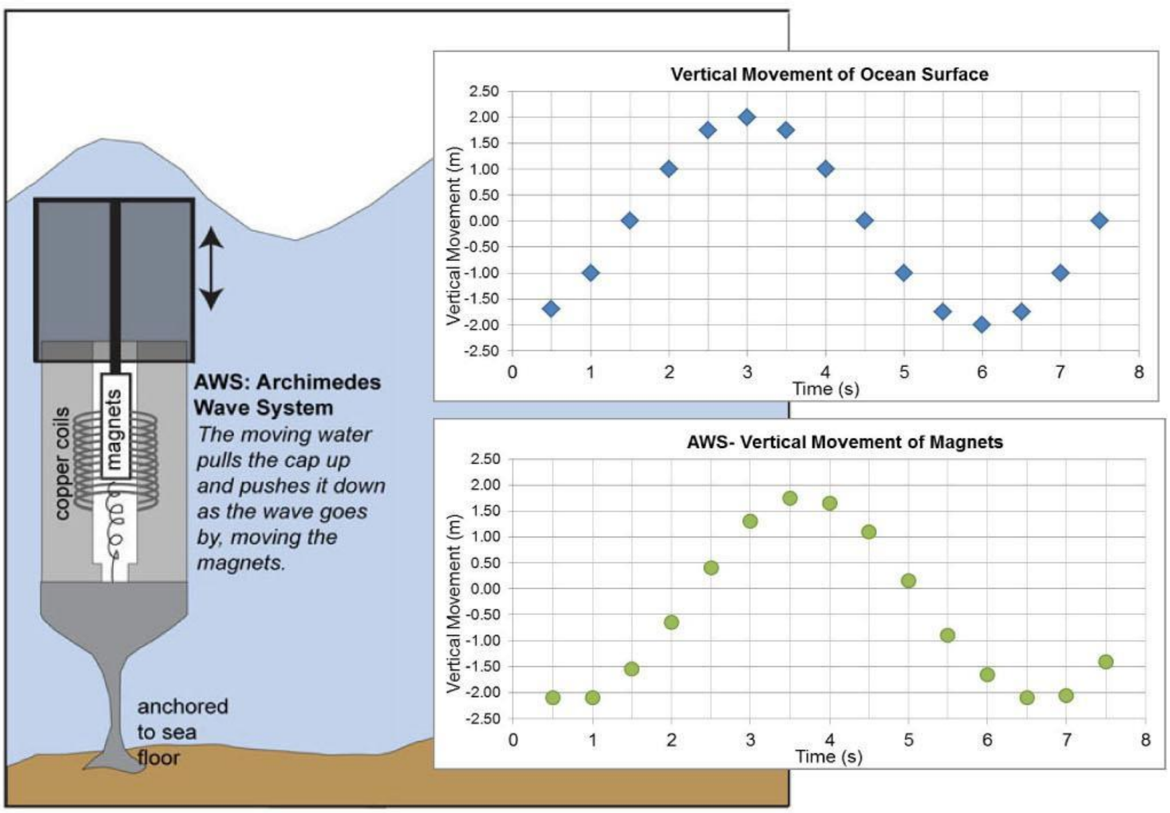






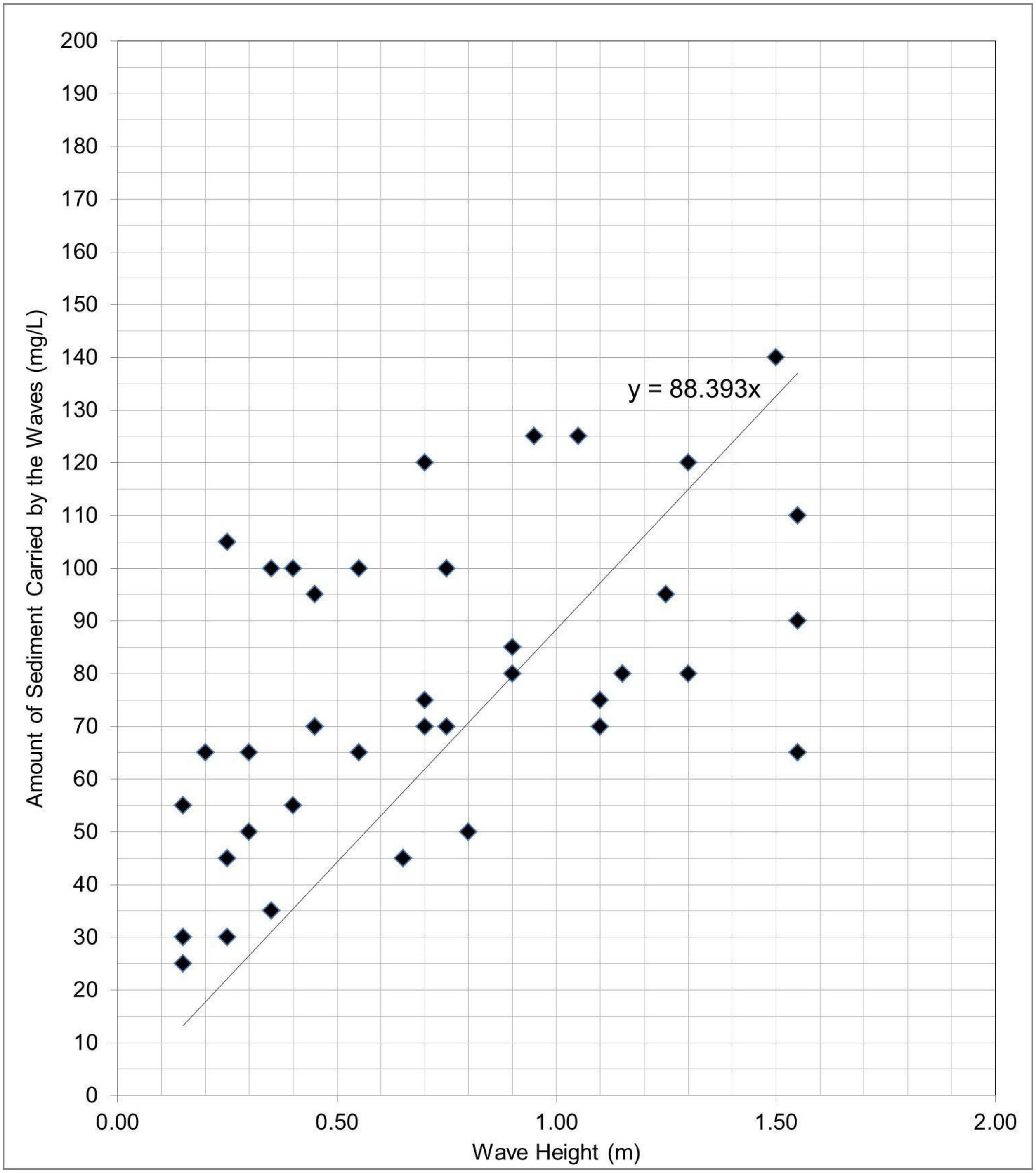
Attachment 9- Comparison of Power Buoy vs. Archimedes Wave System (Data and Design)



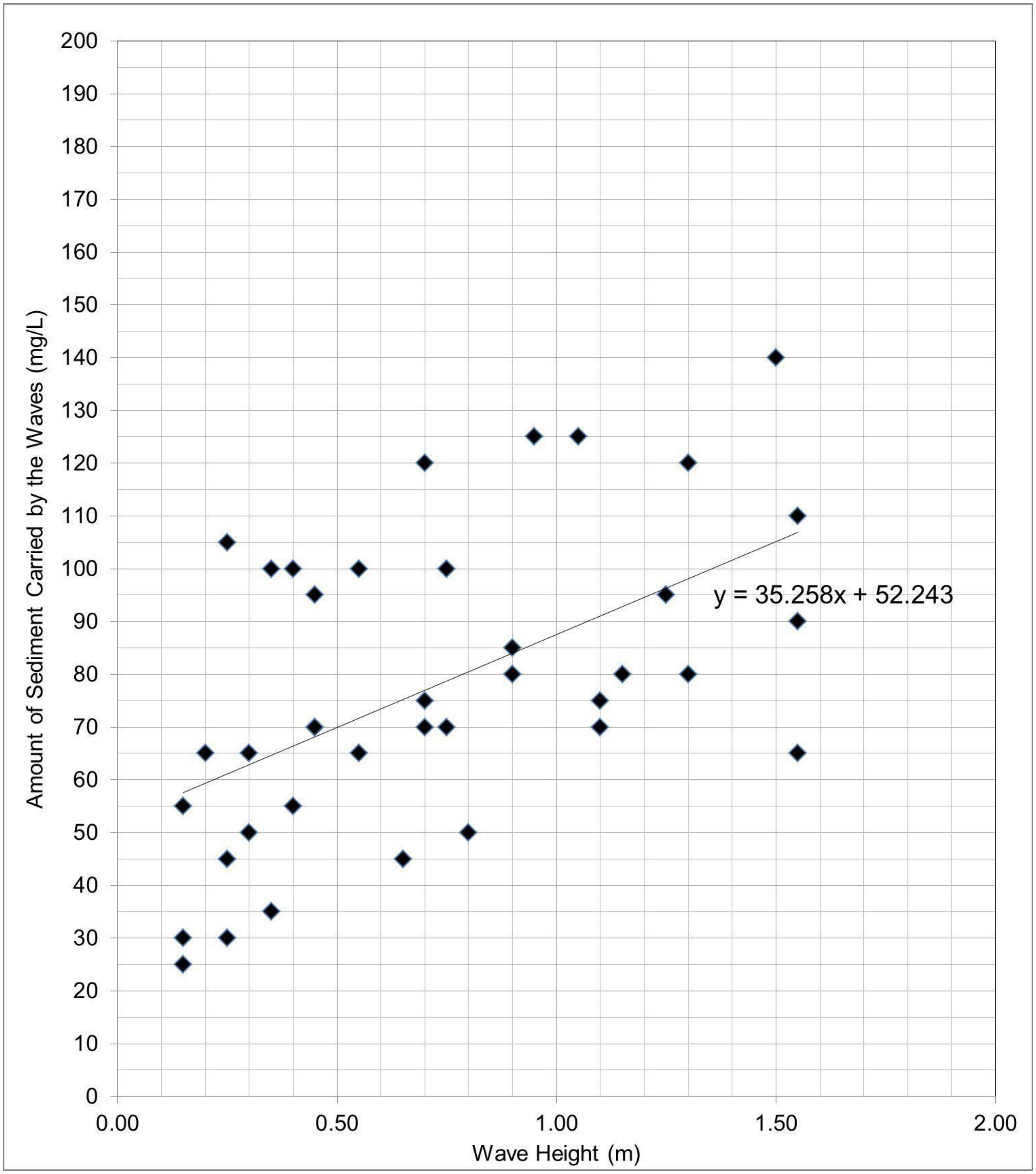


<u>Sample Answer Plots:</u>

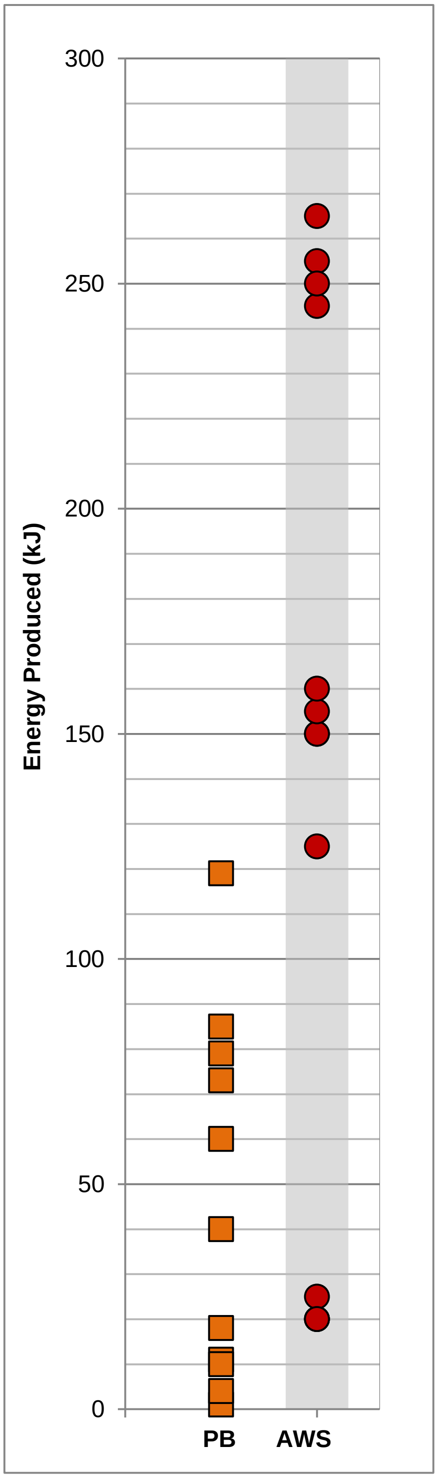
Sediment Load and Wave Height Scatter Plot (*with Trend line*)

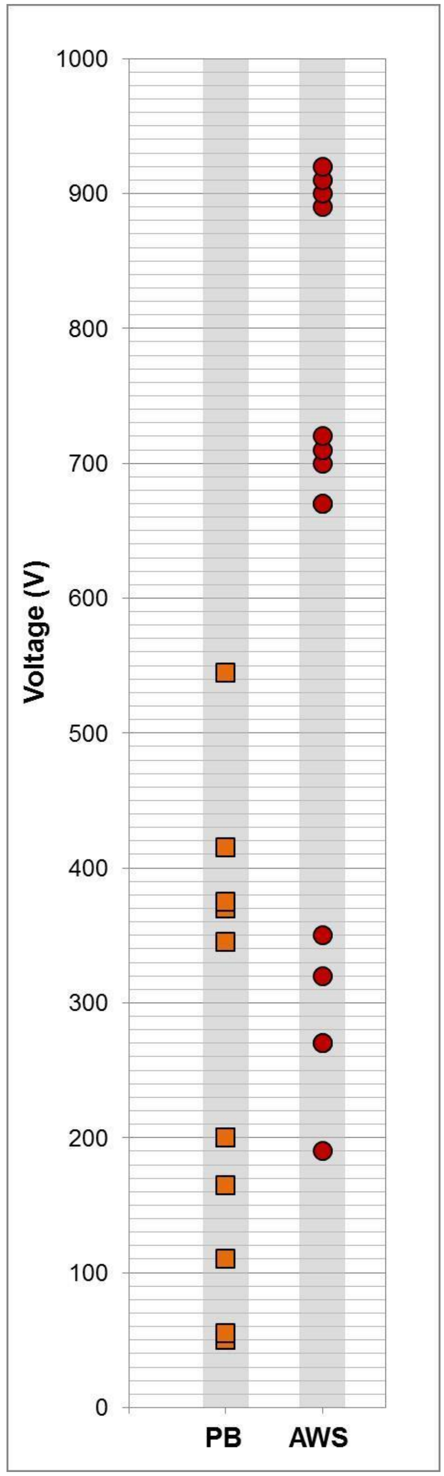


Sediment Load and Wave Height Scatter Plot (*with Trend line*)



Example of the Dot Plots of the Voltage and Energy Production Over One Wave Period for the *Power Buoy* and *Archimedes Wave System* Wave Energy Converters





Example of the Bar Graph Plots of the Voltage and Energy Production Over One Wave Period for the *Power Buoy* and *Archimedes Wave System* Wave Energy Converter