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Summary of PIER-Funded Wave Energy Research

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Arnold Schwarzenegger, *Governor*

CALIFORNIA ENERGY COMMISSION

Mike Kane
Principal Author

Mike Kane
Project Manager

Ken Koyama
Manager
Energy Generation Research Office

Martha Krebs
Deputy Director
Energy Research and Development Division

Melissa Jones
Executive Director

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The outcomes presented herein represent an aggregation of original research performed by each of the above investigators operating under contract with the Energy Commission. With considerable diligence they gathered and analyzed the large amount of physical and technology data needed to characterize California's ocean wave resource and helped place it in the context of the state's unique social, environmental and regulatory framework. To the greatest extent possible, the results, graphics and narrative that follow were drawn directly from their respective reports to the Energy Commission.

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Abstract

This report summarizes Public Interest Energy Research Program-funded research in wave energy conversion and discusses the program's view on the next steps for research, as it relates specifically to the California context. To study the potential for wave energy, the waters off the coast of California were first broken into 10 one-degree latitude cells. For each cell, buoy data were statistically analyzed and compiled into a database of wave characteristics including significant wave height, wave period, and estimated wave energy potential. Seasonal and inter-annual variations were also characterized.

The report also reviews wave energy conversion technologies; profiles several companies briefly to illustrate different design approaches; provides information on actual wave WEC devices and their commercial status; and discusses wave energy conversion economics. In addition, the report looks at necessary permits that might be required, and the types of potential environmental impacts at a high level. Finally, the report discusses conclusions along with next steps.

Key Words: Wave Energy, Wave Energy Conversion, WEC, Ocean Power, Ocean Energy

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development to help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

The information from this project contributes to PIER's Renewable Energy Technologies Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Executive Summary

This report summarizes PIER-funded research to assess the potential for ocean wave energy in California. The main focus was to characterize the resource and provide a reasonable estimate of the wave energy potential. In addition, the report assessed technology, economics, and permitting requirements to provide a comprehensive picture of the potential for ocean wave energy in California. It also reviewed the types of potential environmental impacts from wave energy farms.

Project Objectives

The objectives of the PIER-funded research on wave energy included:

- Compile a statistical database of characteristics for waves off the California coastline
- Assess the potential magnitude of the wave energy resource off the coast of California
- Describe current and future wave energy conversion (WEC) technologies, along with the companies developing them (non-exhaustive list)
- Assess potential environmental impacts of WEC technologies
- Study the agencies and laws involved in permitting a WEC project
- Estimate WEC system economics

Project Outcomes

Wave Resource Assessment

A database of deep water (depth >100 meters) wave characteristics has been assembled from buoy data using representative buoys in 10 different regions off the California coast (Figure 1). Wave height, period and average wave energy fluxes (in kW/meter of wave crest) were calculated (Figure 2 and Table 1). The wave resources north of Point Conception are estimated to be in between 26-34 kW/m. This represents a potentially attractive wave climate found relatively close to shore. Although not assessed in detail here, one challenge involves finding good sites for wave farms that are also close to onshore transmission lines.

Wave energy is estimated to be lower south of Point Conception because the Point and the Channel Islands block swells. In order to access more energetic waves south of Point Conception, it would be necessary to go farther offshore, which would increase the cost of wave projects.

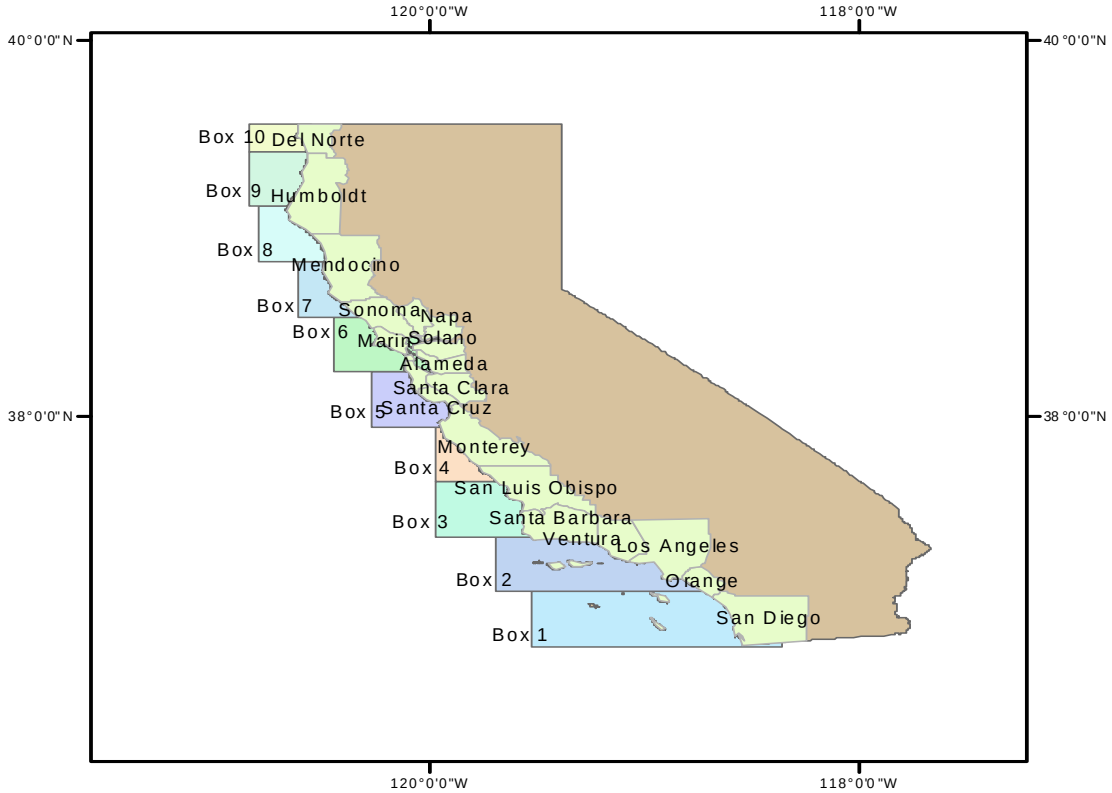

Figure 1. Location of 10 one-degree latitude cells used for analysis

Source: PIER

The estimated deep water wave energy resource from the vast California coastline implies a *theoretical potential* on the order of 38 gigawatts. However, not enough is known about constraints to the development of wave energy in California to provide a realistic estimate of how much of this potential could actually be developed. An initial estimate of the *technical potential* shows that up to 20%, or about 7-8 gigawatts shows promise for development. Slightly more than half of this potential is in *primary* sites, defined as locations with the following attributes: reasonable permitting process (expected), good wave conditions and water depths greater than 50 meters within 10 miles of the coast. *Secondary* sites were defined as locations for which it is expected to be difficult to obtain permits (e.g., marine sanctuaries) or sites that have to be located further offshore because of wave shadowing effects (e.g., Channel Islands in Southern California). Secondary sites likely would be developed only in the longer term, if at all, due to their higher costs and expected permitting constraints.

Factors that limit the technical potential relative to the theoretical potential include, device spacing within wave farms and inter-wave farm spacing, exclusions due to sensitive marine habitat, shipping lanes and other uses, and access to the transmission grid. Grid interconnection constraints were not evaluated as part of this study, but are expected to present further limitations as to where wave power plants could be located. In particular, access to the

transmission system is limited in parts of northern California where some of the better wave resources can be found.

For smaller projects it may be possible to interconnect to the sub-transmission or distribution grid, which may facilitate siting. These and other issues need to be better understood to provide a more refined estimate of the ultimate potential for wave energy in California.

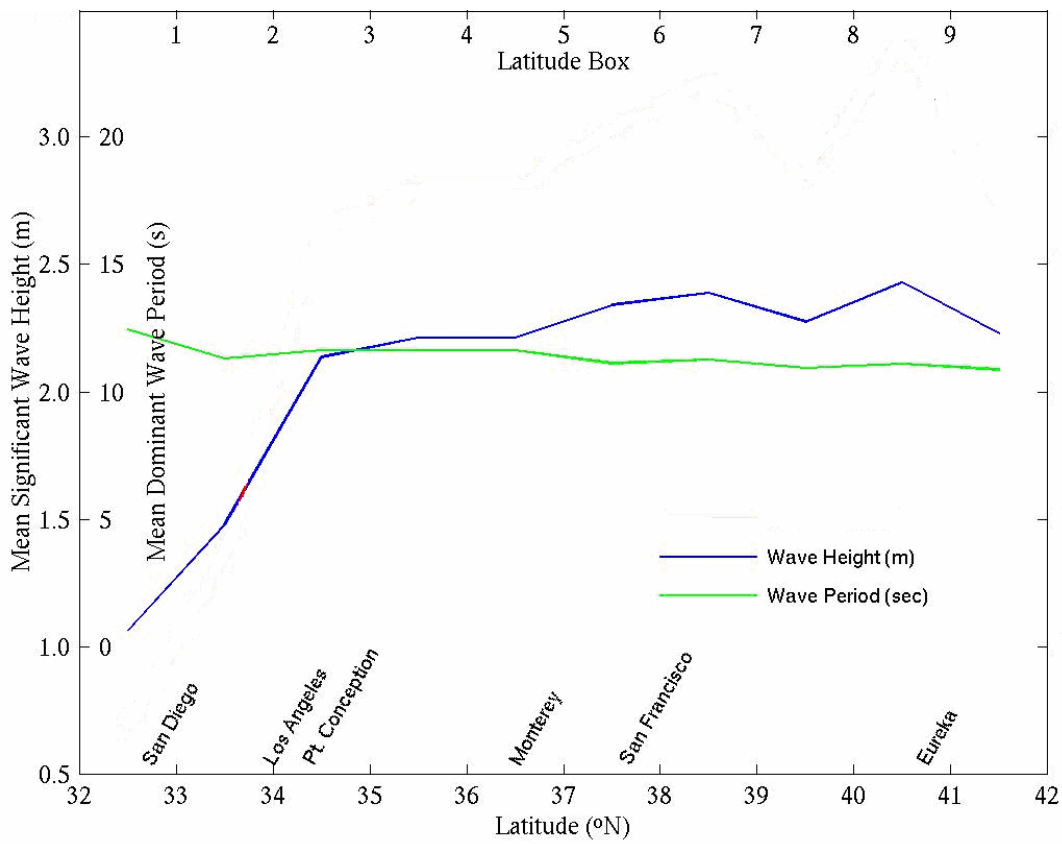

Figure 2. Summary of deep water wave characteristics (significant wave height and dominant wave period)

Source: PIER

Table 1. Deep water wave energy flux potentials for each cell

Cell	Buoy's Used	Wave Energy Flux (kW/m)
1	Several	7
2	Several	13
3	NDBC 46011	26
4	NDBC 46028	30
5	NDBC 46042	30
6	NDBC 46013	30
7	NDBC 46014	32

8	NDBC 46030	29
9	NDBC 46022	34
10	NDBC 46027	27

Source: PIER

Wave Energy Conversion (WEC) Technology and Economics

Several wave energy conversion designs and technologies were profiled, along with some of the companies developing them (Table 2).[1] In general, the most advanced WEC technologies are just now entering initial commercial deployment, in projects that are 2-3 MW in size (representing the deployment of 1-4 devices). Most WEC technologies are still in the prototype stage. Of the devices reviewed, the Pelamis from Ocean Power Delivery appears to be the most mature, followed by the Energetech Oscillating Water Column (OWC).

Table 2. Examples of WEC technologies in development (not a complete list)

Company & WEC Name	Device Type & Size	Apparent Commercial Status (Q1 2007)
AWS Ocean Energy Archimedes Wave Swing	Submerged point absorber, 2 MW	Refined/Commercial prototype
Energetech OWC	Oscillating water column, 1-2 MW	Commercial prototype
Ocean Power Delivery Pelamis	Floating, hinged attenuator, 750 kW	Market entry (3-4 unit "farms")
Ocean Power Technologies PowerBuoy	Floating point absorber, 40 kW	Initial system prototype
Wave Dragon	Floating overtopping, 29 kW	Initial system prototype

As an emerging technology, wave energy does not have a commercial track record to aid in estimating project economics. In 2004, the Electric Power Research Institute published detailed economic analyses of two hypothetical wave farms in the 100-150 MW range. One is based on the Pelamis, the other on the Energetech OWC, to be sited of the coast of San Francisco with a wave resource of 21 kW/m. The studies' assumptions were for commercial scale plants based on today's technology but at a larger scale of manufacturing, i.e., they were not meant to represent mature technology costs that could be expected from further development and deployment of the technology over time. Uncertainties in the cost estimates were reported to be +35% / -25%.

The economic analyses showed a levelized cost of electricity (LCOE) in the range of 10-11 ¢/kWh ($2004), assuming incentives similar to those currently available for wind power are

[1] The companies listed in Table 2 are examples only, and there are numerous other companies developing WEC technologies.

available to wave power.[2] When a range of wave resource values was considered (from 8-38 kW/m) the LCOE ranged from about 7-20 ¢/kWh for the same financial assumptions.

Initially, LCOEs are expected to be higher than these values for two basic reasons. First, the deployment of relatively unproven technologies entails greater risks for investors, which is typically reflected in a higher cost of capital. For example if the 6.9% real fixed charge rate used to develop the above estimates was instead 10%, the LCOEs for the Pelamis and the OWC would be about 15¢/kWh and 12¢/kWh, respectively. At a fixed charge rate of 15%, the LCOEs are about 19¢/kWh and 16¢/kWh, respectively. Second, initial deployments of the technology will likely involve much smaller wave farms. Thus, it is not unreasonable to expect that if California is chosen for early commercial projects, that the LCOE for these projects will exceed 15¢/kWh, and possibly 20¢/kWh. However, the purpose of these early projects may be to demonstrate the technology and document WEC performance (including environmental impacts) and the LCOE may therefore be less important than other aspects of such projects.

Conversely, it can be expected that if wave power is successfully commercialized and deployed more broadly, the cost of electricity will dip below these levels. There is substantial empirical support for such "learning curve" effects, and it is reasonable to expect that wave energy, like wind power and solar power, will have opportunities for reaping the benefits of manufacturing economies of scale and technology improvements.

Permitting and Regulatory Issues

The potential types of environmental impacts of WEC technologies were reviewed at a high level, along with a review of the necessary permits that would be needed for development.

The construction, operation, and decommissioning of structures on water and on land have the potential to affect terrestrial and marine environmental resources. During the construction phase of a project, impacts could come from:

- Directional drilling through the shoreline
- Cable burial on the ocean floor
- Set down of anchors or installation of other permanent structures into the seafloor
- Drilling into the seabed for heavy-uplift anchors
- Cable laying and other operational activities
- Additional onshore transmission to connect to the nearest grid interconnection point

[2] The net effect of incentives was expressed in the real fixed charge rate used in the analysis, which was 6.9%.

Once the wave farm is installed, the main impacts are expected to result from increased operational activity to maintain the facility, as well as the direct impacts of the WECs themselves. Potential operational environmental issues posed by wave energy projects include:

- Coastal processes
- Ocean effects
- Onshore effects
- Water quality
- Air quality
- Visual resources
- Use conflicts
- Geology

There is also the potential for catastrophic loss, which may also have environmental consequences. These all need to be better understood to fully assess the potential for wave energy in California. Pacific Gas & Electric has taken some initial steps to evaluate the potential for a wave energy project off the coast of Mendocino and Humboldt counties. More recently, Finavera Renewables announced that they had received a Federal Energy Regulatory Commission Preliminary Permit, valid for three years, to allow them to conduct various studies associated with a proposed 100MW wave power project in Coos County, Oregon. These studies should begin to shed light on the specific impacts that can be expected from a real project.

The environmental permitting process for projects located offshore California is complex, involving a variety of federal, state and local jurisdictions. It is expected that wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny. Wave energy projects may be located completely in state waters, or more likely, in both state and federal waters.

Conclusions and Recommendations for Further Work

Using the buoy data assembled, the deep water wave energy fluxes north of Point Conception are, in general, higher than those south of Point Conception and are estimated to range from 26-34 kW/m. The next steps in assessing California's wave resource potential are to validate the buoy data assembled thus far and conduct a more comprehensive assessment of the suitability of the waters of the coast for WEC project development. Specifically, it is recommended that a Geographical Information System (GIS) survey be conducted as part of a comprehensive assessment, to screen out areas where development is not feasible, for example, for environmental reasons or usage conflicts. For the areas not screened out by the GIS analysis, more detailed environmental impact assessments may need to be conducted to assess whether or not permits for development could actually be obtained. Then different WEC designs will need to be assessed for the wave environments in the remaining areas, and to determine if

certain designs are more appropriate, e.g., given the specific environmental issues that may arise in California.

It may also be important to assess the wave resource inside the 100 meter depth contour, as this is where development of wave farms is likely to occur, at least using many of the WEC technologies currently under development.

Completing this additional work will provide a better estimate of the *developable* potential. It will also help PIER determine what role to play in the development of this technology.

Benefits to California

California has set aggressive goals for renewable energy development and greenhouse gas reductions. Wave energy conversion is an emerging technology that can potentially help meet these goals. More generally, deployment of wave energy technology would further diversify California's electricity generation mix, which will help meet the state's energy needs and address energy price volatility.

Table of Contents

Acknowledgements i
Abstract ii
Preface iii
Executive Summary iv
Table of Contents xi
List of Figures xiv
List of Tables xvii
1.0 Introduction 1
1.1. Background and Overview 1
1.2. Project Objectives and Overall Approach 1
1.3. Report Organization 2
2.0 Project Approach 4
2.1. Wave Energy Basics 4
2.2. Data Sources and Analytical Approach 8
2.2.1. Data Sources 8
2.2.2. Analytical Approach 9
3.0 Project Outcomes 14
3.1. Wave Statistical Database 14
3.1.1. Summary and Observations 14
3.1.2. Sample Detailed Results (cell 4) 17
3.2. Wave Energy Resource Assessment 21
3.2.1. Next Steps 24
3.3. Wave Energy Conversion (WEC) Technology 24
3.3.1. WEC Technology Design Considerations 24
3.3.2. WEC Development Status and Examples of WEC Devices 30
3.3.3. Next Steps 39
3.4. Current and Projected WEC Economics 39
3.4.1. Economic Base Case – Commercial-Scale WEC Plants 39
3.4.2. Impact of Wave Resource Density on Wave Farm Economics 42
3.4.3. Other Economic Considerations 43

3.4.4. Future Cost of Electricity 44
3.4.5. Conclusions and Next Steps 46
3.5. Wave Energy Environmental and Siting Considerations 46
3.5.1. Coastal Processes 47
3.5.2. Offshore Effects 48
3.5.3. Onshore Effects 49
3.5.4. Water Quality 50
3.5.5. Air Quality 50
3.5.6. Visual Resources 50
3.5.7. Space and/or Use Conflicts 50
3.5.8. Geology 51
3.5.9. Existing Information 51
3.5.10. Summary and Next Steps 52
3.6. Permitting and Regulatory Issues 52
3.6.1. Ocean Jurisdictions 52
3.6.2. Summary and Next steps 55
3.7. Wave Energy Electricity Production Potential 55
3.7.1. Next Steps 59
4.0 Conclusions and Recommendations 61
4.1.1. Wave Resource Assessment 61
4.1.2. Wave Energy Conversion (WEC) Technology and Economics 61
4.1.3. Permitting and Regulatory Issues 63
4.1.4. Recommendations for Further Work 64
4.1.5. Benefits to California 65
5.0 References 66
6.0 Glossary of Terms and List of Acronyms 68
6.1. Glossary of Terms 68
6.2. List of Acronyms 68
Appendix A: Wave Characteristics by Cell 70
Appendix B: State and Federal Regulatory Agencies and Regulations Applicable to Wave Energy 110
Federal Agencies 111
Federal Regulations 113
State and Local Authorities 119

List of Figures

Figure 1. Location of 10 one-degree latitude cells used for analysis v

Figure 2. Summary of deep water wave characteristics (significant wave height and dominant wave period) vi

Figure 3. Wave particle travel 5

Figure 4. Example short-term variability in wave characteristics 6

Figure 5. Typical Wave Statistics Scatter Diagram 7

Figure 6. Location of 10 one-degree latitude cells used for analysis 10

Figure 7. Buoy Locations 13

Figure 8. Summary of wave characteristics 15

Figure 9. Map of California highlighting Point Conception 15

Figure 10. Example of seasonal variation in significant wave height (cell 7) 16

Figure 11. Example of inter-annual variability in significant wave height (cell 7) 16

Figure 12. Cell 4 bathymetry 18

Figure 13. Scatter plot of buoy NDBC 46028 for 1984-1998 and 2001 (cell 4) 18

Figure 14. Significant wave height data for NDBC 46028 (cell 4) 19

Figure 15. Wave height seasonal variability for buoy NDBC 46028 (cell 4) 19

Figure 16. Probability distribution of significant wave height for buoy NDBC 46028 (cell 4) 20

Figure 17. Probability distribution of energy period (T_e) for buoy NDBC 46028 (cell 4) 21

Figure 18. Cell 7's seasonal variation in wave energy flux for buoy NDBC 46028 22

Figure 19. Cell 7's probability distribution of wave energy flux for buoy NDBC 46028 22

Figure 20. Global distribution of offshore annual wave power (kW/m of wave crest) 23

Figure 21. Principle of Operation of an Overtopping Device 26

Figure 22. Principle of Operation of an Oscillating Water Column Device 27

Figure 23: Principle of Operation of a Point Absorber (buoy-type shown) 28

Figure 24: Principle of Operation of an Attenuator 29

Figure 25. Energy technology commercialization timeline 31

Figure 27. AWS Ocean Energy's Archemedes Wave Swing WEC 32

Figure 28. Energetech's oscillating water column WEC 34

Figure 29. Ocean Power Delivery's Pelamis attenuator WEC 36

Figure 30. Ocean Power Technology's Power Buoy WEC 38

Figure 31. Wave Dragon WEC (left: prototype testing, right: artists concept of commercial unit) 39

Figure 32. Levelized cost of electricity breakdown for a commercial scale WEC power plant 42

Figure 33. Projected LCOE for a commercial scale (213 unit) Pelamis wave farm at various locations in California 43

Figure 34. Learning curve effects for wind energy in the European Union, 1980–1995 44

Figure 35. Projected cost reduction of wave energy compared to wind equivalent installed capacity 45

Figure 36 - Primary maritime boundaries 53

Figure 37. Typical methodology for estimating market potential 56

Figure 38. Identification of Primary and Secondary Sites for Wave Farm Development 59

Figure 39. Cell 1 bathymetry 71

Figure 40. NDBC 46047 significant wave height seasonal variation 73

Figure 41. NDBC 46047 wave energy flux seasonal variation 73

Figure 42. NDBC 46047 wave energy flux exceedance distribution 74

Figure 43. Cell 2 bathymetry 75

Figure 44. NDBC 46045 significant wave height seasonal variation 78

Figure 45. NDBC 46045 wave energy flux seasonal variation 78

Figure 46. NDBC 46045 wave energy flux exceedance distribution 79

Figure 47. Cell 3 bathymetry 80

Figure 48. NDBC 46011 significant wave height seasonal variation 82

Figure 49. NDBC 46011 wave energy flux seasonal variation 82

Figure 50. NDBC 46011 wave energy flux exceedance distribution 83

Figure 51. Cell 4 bathymetry 84

Figure 52. NDBC 46028 significant wave height seasonal variation 85

Figure 53. NDBC 46028 wave energy flux seasonal variation 85

Figure 54. NDBC 46028 wave energy flux exceedance distribution 86
Figure 55. Cell 5 bathymetry 87
Figure 56. NDBC 46042 significant wave height seasonal variation 88
Figure 57. NDBC 46042 wave energy flux seasonal variation 89
Figure 58. NDBC 46042 wave energy flux exceedance distribution 89
Figure 59. Cell 6 bathymetry 90
Figure 60. NDBC 46026 significant wave height seasonal variation 93
Figure 61. NDBC 46026 wave energy flux seasonal variation 93
Figure 62: NDBC 46026 wave energy flux exceedance distribution 94
Figure 63. Cell 7 bathymetry 95
Figure 64. NDBC 46014 significant wave height seasonal variation 97
Figure 65. NDBC 46014 wave energy flux seasonal variation 98
Figure 66. NDBC 46014 wave energy flux exceedance distribution 98
Figure 67. Cell 8 bathymetry 99
Figure 68. NDBC 46030 significant wave height seasonal variation 101
Figure 69. NDBC 46030 wave energy flux seasonal variation 102
Figure 70. NDBC 46030 wave energy flux exceedance distribution 102
Figure 71. Cell 9 bathymetry 103
Figure 72. NDBC 46022 significant wave height seasonal variation 105
Figure 73. NDBC 46022 wave energy flux seasonal variation 106
Figure 74: NDBC 46022 wave energy flux exceedance distribution 106
Figure 75. Cell 10 bathymetry 107
Figure 76. NDBC 46027 significant wave height seasonal variation 108
Figure 77. NDBC 46027 wave energy flux seasonal variation 108
Figure 78. NDBC 46027 wave energy flux exceedance distribution 109

List of Tables

Table 1. Deep water wave energy flux potentials for each cell vi

Table 2. Examples of WEC technologies in development (not a complete list) vii

Table 3. NDBC and CDIP data by analysis cell 11

Table 4. Wave energy flux estimates for each cell 23

Table 5. Wave Energy Conversion Technology Design Options 24

Table 6. Examples of WEC technologies in Development (not a complete list) 31

Table 8. AWS Ocean Energy's Archimedes Wave Swing WEC Characteristics 32

Table 9. Energetech WEC Characteristics 33

Table 10. Ocean Power Delivery's Pelamis WEC Characteristics 35

Table 11. Ocean Power Technology's PowerBuoy WEC characteristics 37

Table 12. Wave Dragon WEC characteristics 38

Table 13. Cost and Performance Assumptions for Two Commercial WEC Plants Deployed Off The Coast of San Francisco ($2004) 40

Table 14. California's *theoretical* deep water wave energy potential 57

Table 15: Examples of WEC technologies (not a complete list) 62

Table 16: Summary of recommendations for further work 64

Table 17. Annual CDIP Wave Statistics off cell 1 for 100 to 1,000 m Water Depth 71

Table 18. Scatter plot of NDBC Wave Statistics off cell 1 for 1,000+m water depth (NDBC 46047) 72

Table 19. Annual NDBC Wave Statistics off cell 2 for 100 to 1,000 m Water Depth 75

Table 20. Annual CDIP Wave Statistics off cell 2 for 100 to 1,000 m Water Depth 76

Table 21. Scatter plot of NDBC Wave Statistics for buoy NDBC 46045 77

Table 22. Annual NDBC Wave Statistics off cell 3 for 100 to 1,000 m Water Depth 80

Table 23. Scatter plot of NDBC Wave Statistics for buoy NDBC 46011 81

Table 24. Scatter plot of NDBC Wave Statistics for buoy NDBC 46028 84

Table 25. Annual CDIP Wave Statistics off cell 5 for 100 to 1,000 m Water Depth 87

Table 26. Scatter plot of NDBC Wave Statistics for buoy NDBC 46042 88

Table 27. Annual NDBC Wave Statistics off cell 6 for 100 to 1,000 m Water Depth..... 90
Table 28. Annual CDIP Wave Statistics off cell 6 for 100 to 1,000 m Water Depth..... 91
Table 29. Scatter plot of NDBC Wave Statistics for buoy NDBC 46026 92
Table 30. Annual NDBC Wave Statistics off cell 7 for 100 to 1,000 m Water Depth..... 95
Table 31 Annual NDBC Wave Statistics off cell 7 for 100 to 1,000 m Water Depth..... 96
Table 32. Scatter plot of NDBC Wave Statistics for buoy NDBC 46014 97
Table 33. Annual NDBC Wave Statistics off cell 8 for 100 to 1,000 m Water Depth..... 99
Table 34: Annual CDIP Wave Statistics off cell 8 for 100 to 1,000 m Water Depth..... 100
Table 35. Scatter plot of NDBC Wave Statistics for buoy NDBC 46030 101
Table 36. Annual NDBC Wave Statistics off cell 9 for 100 to 1,000 m Water Depth..... 103
Table 37. Annual CDIP Wave Statistics off cell 3 for 100 to 1,000 m Water Depth..... 104
Table 38. Scatter plot of NDBC Wave Statistics for buoy NDBC 46022 105
Table 39. Scatter plot of NDBC Wave Statistics for buoy NDBC 46027 107
Table 40. Selected Federal Regulations 116
Table 41. State and Local Agencies..... 119

1.0 Introduction

1.1. Background and Overview

The California Energy Commission's Public Interest Energy Research (PIER) program supports research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. Wave energy has been receiving increasing attention globally in the last several years, most notably in Europe. To help determine the appropriate role for PIER, the Energy Commission has funded research that was designed to characterize the wave energy resources off the coast of California, to estimate the electricity generation potential from wave energy, and to develop a greater understanding of various other aspects of wave energy development, such as economics, permitting and environmental issues.

The purpose of this report is to:

- Disseminate the results of PIER-funded research on ocean wave energy
- Establish the limitations of the findings to date
- Identify and prioritize research needs that will assist the Energy Commission in defining the appropriate role of wave energy within its renewable energy research portfolio

1.2. Project Objectives and Overall Approach

This report summarizes the PIER-funded research to assess the potential for ocean wave energy in California. The main focus was to characterize the resource and provide a reasonable estimate of the wave energy potential. In addition, technology, economics, and permitting requirements were assessed to provide a comprehensive picture of the potential for ocean wave energy in California. The types of potential environmental impacts were also assessed at a high level.

The main tasks of the PIER-funded research were:

- Compile a statistical database of wave characteristics based on buoy measurements and hindcast modeling. The database includes annual mean significant wave height, 20-year maximum significant wave height, and wave period. The information was compiled for ten one-degree latitude cells. Data on seasonal variations were also developed.
- Estimate the energy potentially available from ocean waves, expressed in kilowatts per meter of wave front (kW/m)
- Provide a preliminary estimate of the magnitude of electricity generation potential, given the technical, economic and environmental considerations, and the preferred locations for siting wave energy projects

- Identify factors impacting the development of ocean wave energy including information on permitting or regulatory requirements associated with deploying ocean wave energy devices.

To estimate the total primary deep water (depth >100 meters) wave energy resource, data sets from about 100 wave measurement stations were used to create a statistical database. In addition, a high-density digital bathymetry model was used to generate maps for the ten study areas.

Literature reviews and discussions with manufacturers were used to identify representative technology options. Shoreline technologies[3] were generally excluded from the review because a preliminary investigation showed that the potential for such technology in California was limited.

Economic analysis was conducted based on prior work supported by the Electric Power Research Institute (EPRI) for a commercial scale (100MW+) wave power plant. The plant configuration was specifically developed for a site near San Francisco. The economic analysis was extended to a total of 14 measurement stations with varying wave energy levels to assess the impact of wave energy levels of the cost of electricity. Learning curves were used to examine the long-term economic potential of wave power if it were to achieve a similar level of cumulative deployment as wind power enjoys today.

Environmental issues and permitting in California were assessed from literature reviews of similar projects, which includes offshore wind, offshore oil and gas and other projects. The assessment included California-specific environmental issues such as gray whale migration. A review of applicable laws and regulatory agencies involved in the permitting process is provided as well.

1.3. Report Organization

Following this Introduction, Section 2, *Project Approach*, begins with an overview of wave energy basics. It then provides a review of the analytical approach used to conduct the wave resources assessment. Section 3, *Project Outcomes*, summarizes the results of the analysis. This includes the deep water statistical data, estimates of the wave energy potential, a review of the commercial status and expected economics of wave energy conversion technology, and reviews of project development issues, such as permitting and environmental issues. Finally Section 3 also provides a preliminary estimate of the *theoretical* and *technical* electricity generation potential[4] from wave energy. The main conclusions from the research, along with a summary of

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[3] Shoreline technologies are those wave technologies that are built into the shoreline or a jetty.

[4] See the main text for definitions of *theoretical* and *technical* potential and other terms relevant

next steps are provided in Section 4, *Conclusions and Recommendations*. Appendix A includes details on the wave energy characteristics as summarized in Section 3. Appendix B includes details on federal and state regulatory bodies and relevant statutes.

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to assessing market potential.

2.0 Project Approach

This section describes the overall approach used in the analysis. In order to aid readers that may be less familiar with wave energy, this section first provides some general background on wave formation, propagation and characteristics.

2.1. Wave Energy Basics

Wind acting on ocean surfaces generates waves. Once ripples are created on the surface, a steep side forms against which the wind can push, and waves begin to grow and become better organized. In deep water, waves can travel for hundreds or thousands of miles without losing much energy. Because the relationship between winds and ocean waves is relatively well understood, and ocean waves traveling in deep water maintain their characteristics over long distances, sea states can be predicted accurately more than 48 hours in advance.[5]

In a well developed sea state, ocean waves can be described as an oscillatory system in which water particles travel in orbits (Figure 3). In deep water, ocean waves are minimally affected by water depth (left side of Figure 3). The diameter of the orbital paths of water particles under these waves decreases as depth increases, eventually shrinking to zero. As long as the depth is greater than about twice the wavelength, interaction with the seafloor is minimal. As depth decreases, ocean waves are increasingly influenced by interactions of the water particles with the ocean floor (middle and right side of Figure 3), and the orbits become elongated ellipses. This results in a loss of energy because of the friction of water particles on the ocean floor (NCSU, no date).

[5] NOAA's WAVEWATCH III model is an example of a 3rd generation wind-wave model allowing wave predictions more then 48 hours in advance (see http://polar.ncep.noaa.gov/waves/main_int.html).

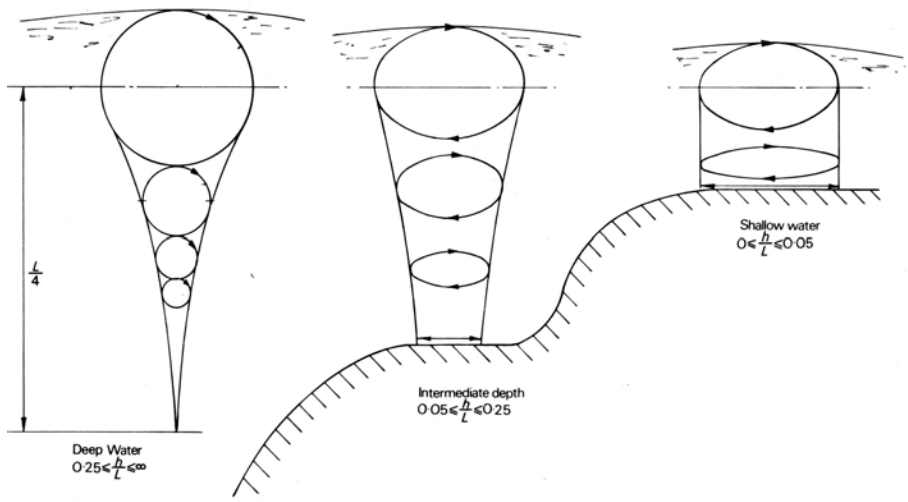


Figure 3. Wave particle travel

Source: EPRI

Ocean waves are a complex, strongly variable phenomenon. Real seas contain waves that vary considerably in height, period and direction at any given time. Figure 4 illustrates the potential short term variability of wave height at a given location. Items that affect wave conditions include wind duration, wind velocity, pressure, and temperature.

In the deep waters of the open ocean, waves propagate over distances on the order of a few hundred kilometers and maintain similar characteristics. This applies to large ocean basins, such as the Pacific Ocean. As waves approach the shore through waters of decreasing depth, waves are modified by a number of phenomena such as refraction and diffraction. As a result, the wave energy resource can vary significantly over distances of 1 km or less in shallow waters, depending on the local bathymetry. The energy level close to shore is usually significantly lower than offshore as energy is lost to bottom friction. In addition, wave crests tend to become parallel to the shoreline in shallow waters. The influence of the local bathymetry can also have a focusing effect on ocean waves, resulting in “hot-spots” that are favorable for near-shore or shoreline-based wave energy conversion (WEC) devices. As a result of the potentially significant variation in near-shore conditions, this report focuses on deep water conditions.

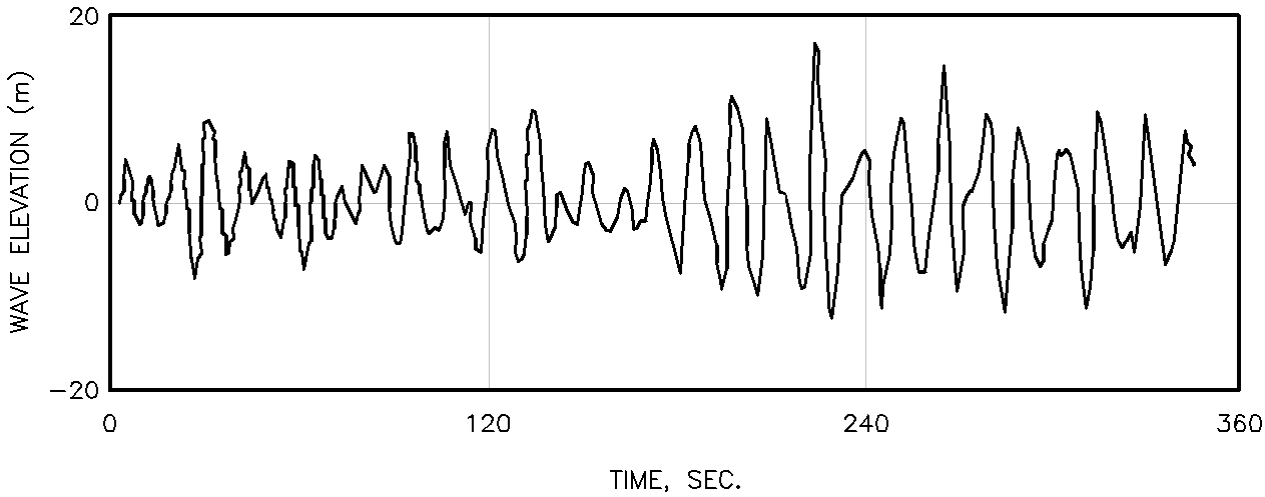


Figure 4. Example short-term variability in wave characteristics

Source: US Army Corps of Engineers

Despite significant overall variability, real seas can remain relatively constant over a period of a few hours. Sea states can therefore be described in terms spectral parameters. The spectral parameters typically used in the characterization of waves are the significant wave height [H_s], spectral peak period [T_P], mean period [T_z] (also called the zero-crossing period), energy period [T_e] and mean direction. The wave power level [P] (i.e., the flux of energy per unit length of wave crest), can be estimated from these parameters.[6] The variation in sea states during a period of time (e.g. month, season, or year) can be represented by a scatter diagram (Figure 5), which indicates how often a sea state with a particular combination of H_s and T_e occurs.

[6] See section 6.0 for definitions.

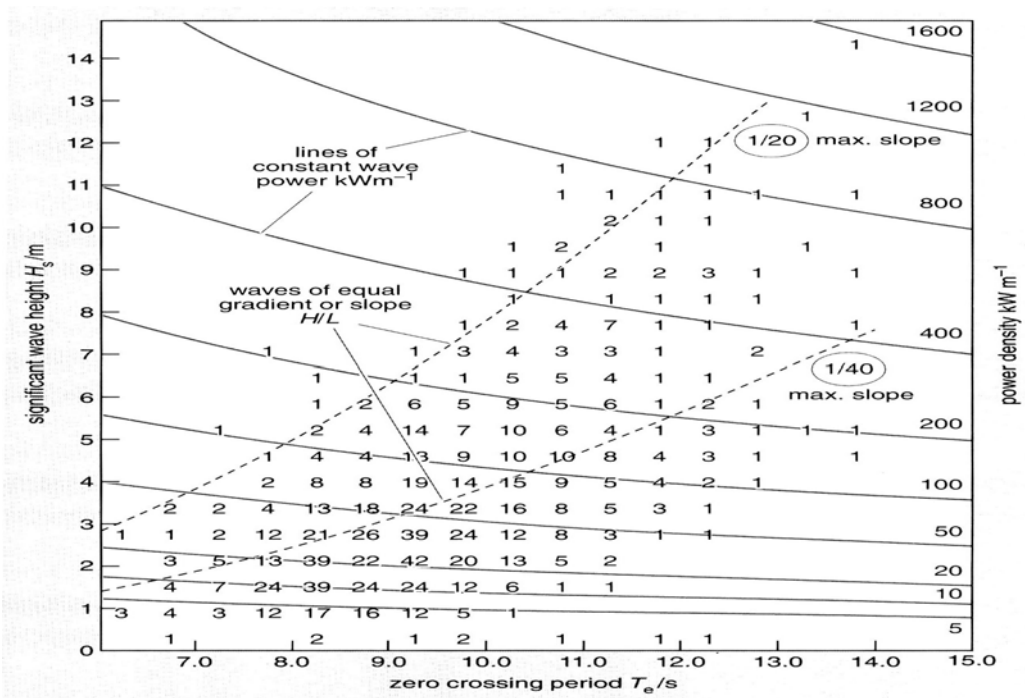


Figure 5. Typical Wave Statistics Scatter Diagram

Source: EPRI

Of the aforementioned statistics, height, period, and direction can be directly measured using a buoy. However, a wave's energy must be calculated using measured data. In deep water, the power level in each sea state can be approximated by (Hagerman 2001, Nielsen 2002):

$$P = 0.412\ H_s^2\ T_p \qquad \textbf{Equation 1}$$

If H_s is expressed in meters and T_p in seconds, P is given in kW/m of wave crest. The average wave power level, P_{ave}, during a period of time can be determined from a scatter diagram corresponding to the same time period by the following equation where, W_i is the number of times that sea states with power levels P_i occur:

$$P_{ave} = \Sigma P_i\ W_i\ /\ \Sigma W_i \qquad \textbf{Equation 2}$$

Note that this is a measure of the energy contained in the waves, not the energy extracted by a wave energy conversion device. Due to the strong seasonal and inter-annual variability of ocean waves, assessments of wave energy resources ideally should be based on long time series wave data – ten years or more. However, a five-year period is considered to be satisfactory, and even

assessments based on a shorter period (two or three years) may still provide valuable information.

2.2. Data Sources and Analytical Approach

2.2.1. Data Sources

The PIER-funded research to date relied on several sources of data. The first data source is from the Coastal Data Information Program (CDIP) at the Center for Coastal Studies, which is part of the Scripps Institute of Oceanography at the University of California at San Diego. The CDIP has deployed and maintains wave gauging stations at locations along the coasts of California, Oregon, Washington, Hawaii, Georgia, Minnesota, Virginia and North Carolina, of which about 60 are off the coast of California. Waves are measured in deep-water using buoys or pressure sensors attached to offshore oil platforms. This includes non-directional and directional buoys which also measure some basic directional properties of the wave field, such as mean wave direction and directional spread, as a function of wave frequency or period.

Close to shore, in water depths of 10 to 20 meters, pressure sensors mounted near the ocean floor measure wave conditions. These instruments measure pressure fluctuations associated with passing waves. These pressure time series can be converted to sea surface elevations and wave frequency spectra. This technique can also be used to measure directional information by placing four pressure sensors in a square.

The second data source is the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC). The NDBC provides hourly observations from a network of about 60 buoys and 60 Coastal Marine Automated-Network (C-MAN) stations. All stations measure wind speed, direction, and gust; barometric pressure; and air temperature. In addition, all buoy stations, and some C-MAN stations, measure sea surface temperature, wave heights, and periods. Data from 17 NDBC buoys were used in the analysis presented in this report.

The third data source was the Comprehensive Ocean-Atmosphere Data Set (COADS). This project is a cooperative effort between NOAA and the National Science Foundation. The COADS is derived primarily from ship observations between 1854 and 1995. The ships measured temperatures, humidity, winds, pressure, waves, and clouds. For this study, the data selected from COADS were observed wave heights, wave periods, and wave directions. However, a concern exists as to whether or not these data are reliable because ships do not typically sail in unfavorable conditions. Thus, this data set may not capture the full range of actual wave conditions. Other groups (e.g., Young et. al. 1995) have conducted research into the factors that account for bias in the COADS data, but because of these uncertainties, the wave energy potentials calculated for this report did not make use of the COADS data.

2.2.2. Analytical Approach

To assemble a comprehensive database of wave statistics, the California coastline was divided into 10 cells, as shown in Figure 6, with cell 1 starting in Southern California. Each cell measured 1 degree in latitude. All available NDBC and CDIP buoy data for each cell was collected (Table 3). Given the aforementioned uncertainty regarding COADS data, and the fact that buoys provide a consistent dataset, COADS was not used in this analysis.

The assembled data sets were divided into two groups according to water depth; deep water being defined as having a depth of 100 m or more and shallow water being less than 100 m. Since friction losses in deep water are negligible, it was assumed that a data from a single deep-water buoy would give a reasonable estimate of wave statistics over distances on a scale of 100 km or so. For this reason, a data set from a single deep water buoy was selected for each cell north of Point Conception and assumed to represent the wave climate of that cell and the corresponding statistics were likewise assumed to apply to the deep waters of that cell. The data were analyzed and assigned to bins according to wave height and wave period and were subsequently used to develop a scatter plot for the buoy for the particular time period of interest. Equations 1 and 2 were then applied to the scatter plot to develop an estimate of mean wave power density for the cell and time period of interest. For cells 1 and 2, data from multiple buoys were used to account for the complex behavior induced in the wave shadow of Point Conception and the Channel Islands. Figure 7 shows the locations of the buoys used in the analysis.

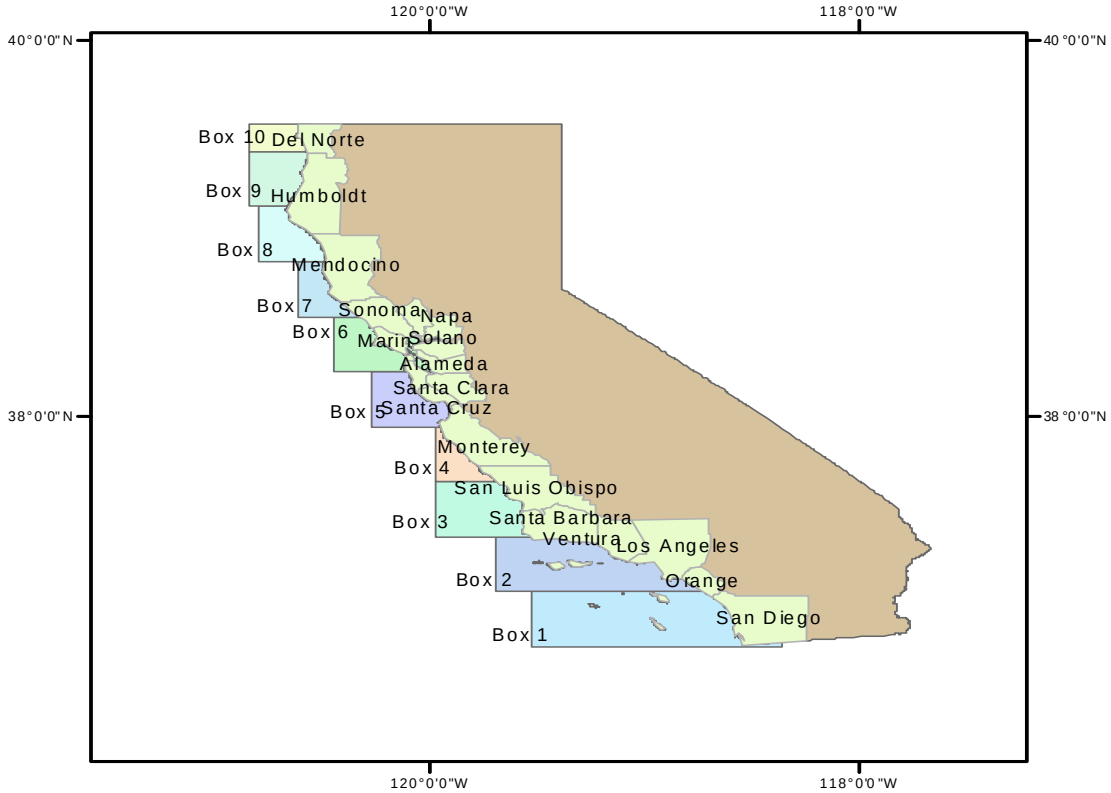


Figure 6. Location of 10 one-degree latitude cells used for analysis

Source: PIER

Table 3. NDBC and CDIP data by analysis cell

Measured Wave Data Sources for California Wave Statistics

Study Box	NDBC and CDIP Measurements										
	Station Number	Station Name	Latitude (deg N)	Longitude (deg W)	Depth (m)	Data Coverage	Calendar Years with 12 Months of Wave Data				
10	46027	St. Georges	41.85	124.38	60.0	1983-2001	1984-2001				
	0025	Crescent City S	41.74	124.18	9.1	9/1980-1/1983	1981-1982				
9	0112	Humboldt Bay Outer	40.95	124.43	248.7	4/1980-6/1981					
	0012	Humboldt Bay Inner	40.88	124.23	43.0	3/1980-9/1982					
	46022	Eel River	40.72	124.52	274.3	1982-2001	1982-1990	1992	1995-2001		
8	46030	Blunts Reef	40.42	124.53	82.3	1984-2001	1985-1998	2000-2001			
	0094	Cape Mendocino	40.29	124.74	325.6	3/1999-2/2000					
7	0030	Noyo	39.44	123.89	94.0	5/1981-6/1982					
	0031	Noyo Basin S	39.42	123.80	6.0	11/1981-6/1982					
	0032	Noyo Harbor H Dock	39.42	123.80	6.0	10/1981-6/1983					
	46014	Pt. Arena	39.22	123.97	264.9	1981-2001	1981-2001				
	ptac1	Point Arena	38.96	123.74	31.1	1984-2001					
6	46013	Bodega Bay	38.23	123.33	122.5	1981-2001					
	0029	Point Reyes	37.95	123.47	548.6	12/1996-7/2002					
	0021	Stinson Beach	37.90	122.65	9.1	5/1980-7/1982	1981				
	0056	San Francisco Wharf 45	37.82	122.42	13.4	3/1986-10/1989	1987-1988				
	0041	San Francisco	37.81	122.43	7.6	12/1982-6/1984	1983				
	0040	San Francisco Alioto's	37.81	122.42	7.0	3/1986-10/1989	1987-1988				
	0065	Hyde St, San Francisco	37.81	122.42	12.1	9/1988-12/1989	1989				
	46026	San Francisco	37.75	122.82	52.1	1982-2001	1983-1986	1991-1998	2000-2001		
	0023	Pacifica	37.63	122.50	10.0	8/1980-12/1982	1981-1982				
	0062	Montara	37.55	122.52	15.5	12/1986-3/1992	1987-1989				
	0047	Farallon	37.51	122.87	102.4	1/1982-10/1995	1982	1987	1991		
5	46012	Half Moon Bay	37.45	122.70	87.8	1980-2001	1981-1999	2001			
	0007	Capitola Pier	36.97	121.95	6.1	12/1977-11/1979					
	0008	Santa Cruz Pier	36.96	122.02	8.4	1/1978-7/1981	1978-1979				
	0006	Santa Cruz Harbor	36.95	122.00	13.1	10/1977-9/2001	1978	1981-1983	1987	1989	1992-2000
	0018	Seacliff	36.95	121.92	8.2	8/1978-5/1980					
	0044	N Monterey Bay	36.95	122.42	318.1	10/1979-4/1988	1982-1983				
	0108	Santa Cruz Offshore	36.89	122.07	60.9	6/1978-8/1981	1980				
	0009	Moss Landing	36.81	121.79	6.1	2/1978-9/1979					
	46042	Monterey	36.75	122.42	1920.0	1877-2001	1998-2001				
	0061	Marina	36.70	121.82	15.0	12/1986-10/1995	1987-1993				
	0010	Monterey Harbor	36.60	121.89	13.4	2/1978-7/1982	1980				
4	46028	Cape San Martin	35.74	121.89	1111.9	1983-2001	1984-1998	2001			
3	0076	Diablo Canyon	35.21	120.86	22.9	6/1983-7/2002	1985-1986	1989	1992-1994	1997-2002	
	46062	Point San Luis	35.10	121.00	379.0	1997-2001	1998-2001				
	46011	Santa Maria	34.88	128.87	185.9	1980-2001					
	46023	Pt. Arguello	34.71	120.97	384.1	1982-2001	1982-1995	1998-2001			
	0120	Point Arguello Harbor Outer	34.57	120.63	5.8	5/1978-9/1979					
	0019	Point Arguello Harbor Inner	34.57	120.63	2.5	5/1978-4/1980	1979				
2	0119	Point Arguello	34.49	120.72	83.0	5/1978-9/1986					
	0063	Harvest Platform	34.47	120.68	204.0	1/1987-4/1999	1987-1995	1997-1998			
	0071	Harvest	34.46	120.78	548.6	12/1995-7/2002	1999-2002				
	0011	Point Conception	34.45	120.43	16.8	6/1979-12/1979					
	0048	Point Conception Offshore	34.42	120.42	201.2	8/1978-12/1979					
	0017	Santa Barbara	34.40	119.69	7.6	10/1979-1/1983	1980-1982				
	0107	Goleta Point	34.33	119.80	182.6	6/2002-7/2002					
	0090	Montecito	34.33	119.64	61.0	10/1995-2/1996					
	46054	Santa Barbara W	34.27	120.45	447.1	1994-2001					
	46063	Point Conception	34.25	120.66	598.0	1998-2001					
	46053	Santa Barbara	34.24	119.85	417.0	1994-2001					
	0081	Ventura	34.18	119.48	53.0	1/1995-3/1995					
	0111	Anacapa Passage	34.17	119.43	109.7	6/2002-7/2002					
	0005	Channel Islands	34.17	119.24	6.1	1/1977-9/1983	1977	1979-1982			
	0038	Point Mugu	34.09	119.11	45.7	10/1982-7/1983					
	0141	Port Hueneme	34.09	119.17	38.0	3/1991-4/1991					
	0088	Santa Cruz Island W	34.07	119.83	55.0	10/1995-12/1995					
	0089	Santa Cruz Island E	34.06	119.58	55.0	10/1995-11/1995					
	0087	Santa Rosa Island	34.04	120.09	35.0	10/1985-12/1995					
	0105	Malibu	34.02	118.68	20.0	6/2002-10/002					
	0103	Topanga Nearshore	34.02	118.58	20.0	10/2001-1/2002					
	0102	Point Dume	33.98	119.00	365.0	6/2001-7/2002	2002				
	0110	Santa Cruz Island	33.97	119.64	73.2	3/1984-11/1985					
	0080	Santa Cruz Canyon	33.92	119.73	320.0	9/1986-6/1989	1988				
	0104	Hermosa Nearshore	33.86	118.42	20.0	1/2002-6/2002					
	0028	Santa Monica Bay	33.85	118.63	365.8	3/1981-7/2002	2001-2002				
	46045	Redondo Beach	33.84	118.45	147.9	1991-1999					

1	0101	Torrey Pines Inner	32.93	117.27	20.0	4/2001-7/2002	2002			
	0113	Scripps Canyon N	32.88	117.27	35.0	9/2002-11/2002				
	0115	Scripps Canyon NE	32.88	117.26	30.0	9/2002-12/2002				
	0114	Scripps Canyon NW	32.87	117.26	35.0	9/2002-11/2002				
	0116	Scripps Canyon S	32.87	117.26	28.0	9/2002-12/2002				
	0073	Scripps Pier	32.87	117.26	6.8	5/1976-7/2002	1977-1978	1980	1987	1989-2002
	0046	Point La Jolla Wind	32.86	117.35	182.9	10/2001-7/2002	2002			
	0095	Point La Jolla	32.85	117.35	179.8	7/1999-7/2002	2000-2002			
	0016	Mariners Basin	32.77	117.25	6.1	8/1978-7/1981	1979			
	0015	Quivira Basin	32.76	117.24	6.7	4/1978-7/1981				
	0022	Mission Bay Channel Entran	32.76	117.26	6.7	7/1980-10/1980				
	0014	Mission Bany Entrance	32.76	117.27	11.9	8/1978-7/1995	1981-1982	1987-1988		
	0002	Ocean Beach Pier	32.75	117.26	6.7	4/1976-10/1979	1997			
	0093	Mission Bay	32.75	117.37	122.5	2/1981-8/1998	1987-1990	1992	1994	
	0074	San Diego Channel Entranc	32.66	117.23	13.2	2/1993-3/2001				
	0091	Point Loma	32.63	117.44	180.0	11/1995-7/2002				
	0086	Silver Strand	32.59	117.14	6.7	7/1979-9/1979				
	0055	Imperial Beach N	32.58	117.14	10.2	1/1988-12/1996	1990-1996			
	0001	Imperial Beach	32.58	117.14	6.1	12/1975-3/1978	1977			
	46047	Tanner Banks	32.43	119.53	1393.5	1991-1993	1992	2000-2001		
	Stations in **Red** are operated by Scripps' CDIP and **Blue** by NOAA's NDBC.						Less Than 100 m not processed			
	White stations processed in conglomerate.					Light blue stations processed individually.				

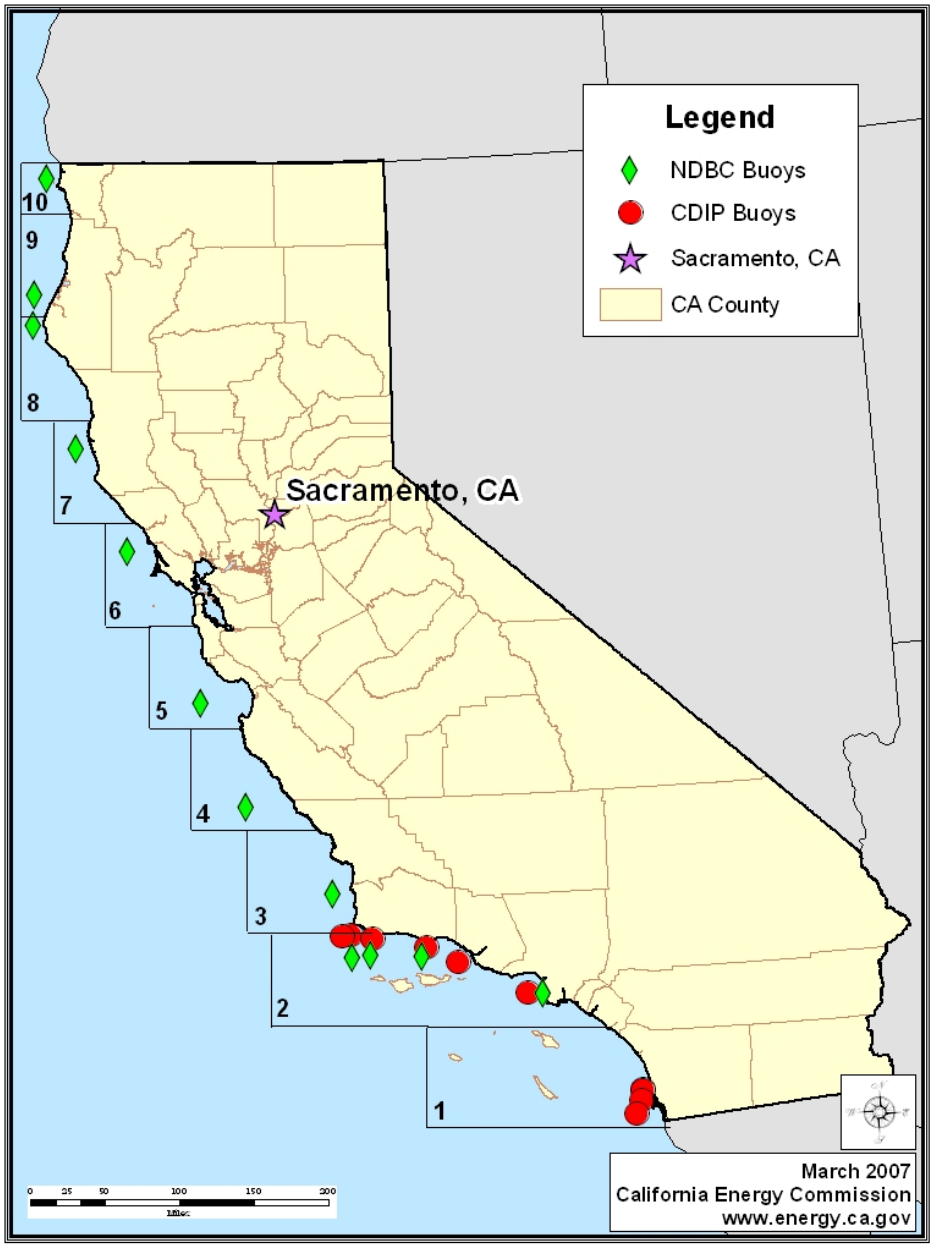


Figure 7. Buoy Locations

Source: PIER

3.0 Project Outcomes

3.1. Wave Statistical Database

3.1.1. Summary and Observations

Figure 8 provides a summary of deep water wave statistics for each cell. It illustrates a clear distinction in the wave climate north and south of Point Conception (see Figure 9 for the location of Point Conception). North of Point Conception mean significant wave heights (H_s) are about 2.0-2.5 meters, whereas south of Point Conception, H_s is only 1-2 meters. The mean dominant wave period does not vary significantly at about 11-12 seconds. A possible explanation for the distinct wave climates is as follows. Most of the wave energy incident upon California's shoreline originates from storms in the Northern Pacific Ocean. Point Conception divides California into two distinct near-shore wave climates. Southern California's lower energy wave climate can be attributed mainly to the abrupt change of the coastline to a south-west facing coastline south of Point Conception and the shadowing effects of the Channel Islands located off the Santa Barbara County coast. Northern California has no such shadowing effects and, as a result, has higher energy levels.

Not captured by Figure 8 are directional characteristics. North of Point Conception, the dominant wave direction is from the northwest for the April-October time period, shifting to a more westerly approach during the November through March period. There is considerably more variation south of Point Conception, where dominant direction was highly dependent on the particular buoy analyzed.

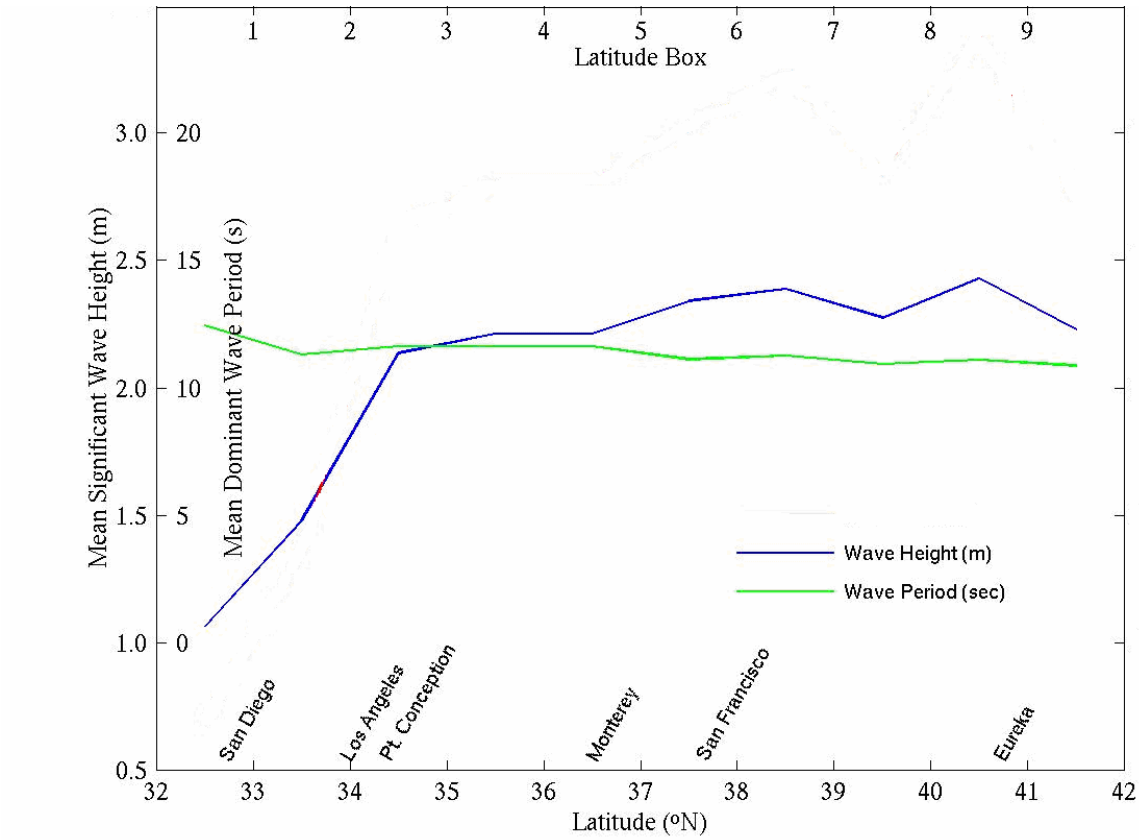


Figure 8. Summary of wave characteristics

Figure 9. Map of California highlighting Point Conception

Two other important observations can be made with respect to the variability of the wave resource. The first is on seasonal variability, as shown in Figure 10, which shows that wave heights are typically higher in the winter and lower in the summer and fall. This corresponds to

the stormy winter season and a calmer summer and fall. The second is on inter-annual variability, as shown in Figure 11 (for cell 7 as an example), which shows large variations from year to year, particularly for the maximum wave height, but also for the mean.

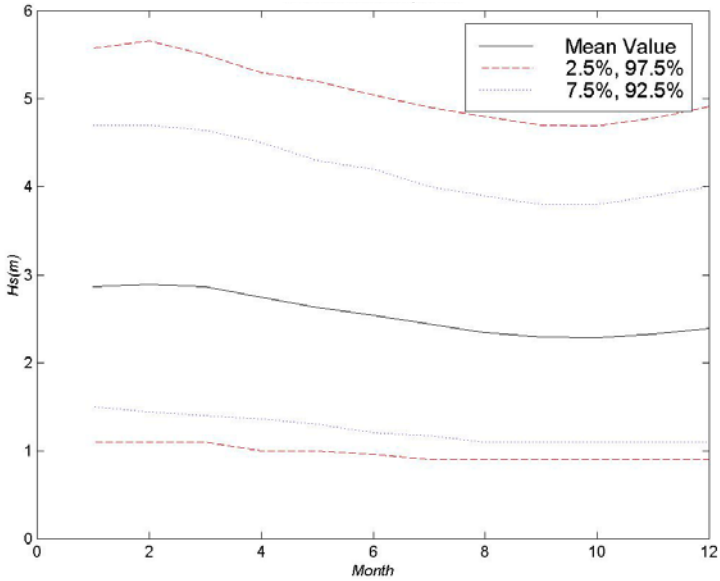


Figure 10. Example of seasonal variation in significant wave height (cell 7)

Source: PIER

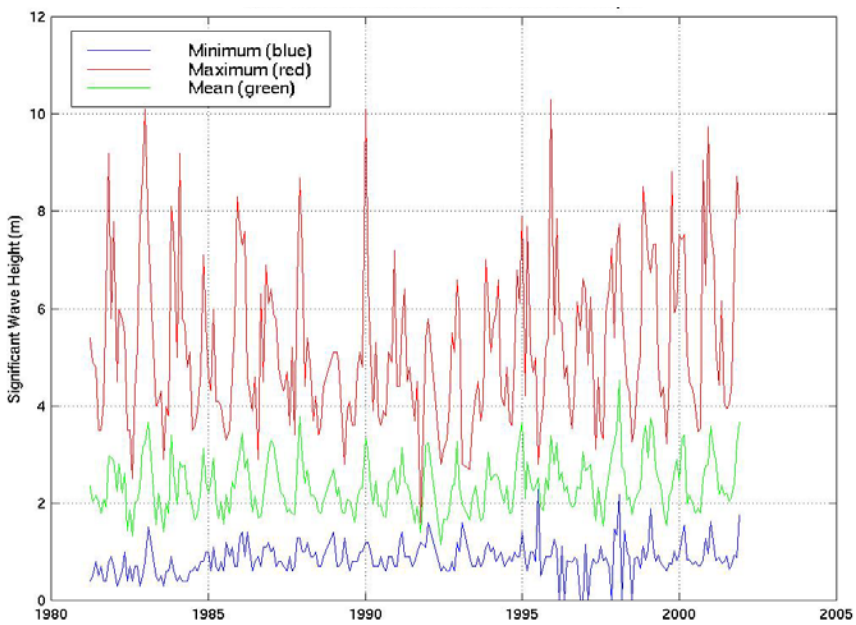


Figure 11. Example of inter-annual variability in significant wave height (cell 7)

Source: PIER

The maximum significant wave height is a critical wave parameter that will have both economic and safety impacts on wave farms. Extreme waves can snap moorings and have a destructive impact on wave energy conversion devices. Since it only takes one wave to do this, wave farm developers must take the maximum wave height statistics into account. Professor Dick Seymour of the Scripps Institute of Oceanography (Seymour 2003) states that a good "rule of thumb" is to take the largest measured significant wave height from a buoy measurement and multiply it by a factor of two. This factor of two accounts for the fact that measurement buoys measure incident waves over a 1-3 hour period and then analyze the time series to come up with statistical parameters such as the significant wave height. Thus, an individual large wave might not be recorded. Time series data show that significant wave heights of 10 to 11 meters occur every few years in California, which suggests that for design considerations, one should assume that extreme wave heights of 20 to 22 meters are possible.[7]

3.1.2. Sample Detailed Results (cell 4)[8]

The results for buoy NDBC 46028 of cell 4 are presented in Figure 12 through Figure 17 below. Appendix A contains similar information for all ten cells. Figure 12 shows cell 4's bathymetry. Note that water depths greater than 100 meters can be found within about 5-10 miles of shore. Figure 13 provides a scatter plot of significant wave height (H_s) and the spectral peak period (T_p). H_s of 1.5-2.5 meters is common, with a T_p of 8-10 seconds. Figure 14 shows the minimum, maximum and mean values for H_s over a nearly 20-year period. Figure 15 converts this into monthly data and shows the values of H_s between which there is an 85% and 95% probability of H_s occurring. The overall probability distributions of H_s and T_e are then given in Figure 16 and Figure 17 respectively.

---

[7] H_s is defined as the average height of the highest one third of waves recorded in a given monitoring period. Therefore, actual maximum wave heights are, by definition, larger than H_s.

[8] Cell 4 is used as an example only.

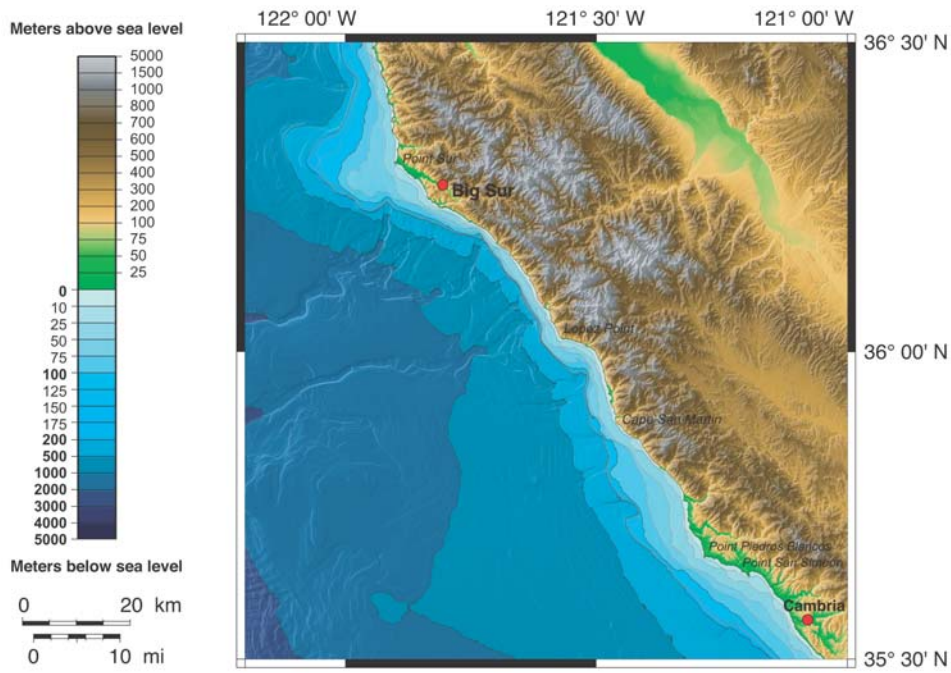


Figure 12. Cell 4 bathymetry

Source: PIER

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	0	0	1	4	1	3	5	2	0	0	**17**
1.0 - 1.5	0	1	8	10	41	15	18	31	21	3	0	**149**
1.5 - 2.0	0	0	26	24	75	31	33	32	24	4	0	**249**
2.0 - 2.5	0	0	16	41	61	27	34	28	16	5	1	**229**
2.5 - 3.0	0	0	2	27	39	16	27	27	12	4	0	**155**
3.0 - 3.5	0	0	0	9	22	10	17	22	9	3	0	**92**
3.5 - 4.0	0	0	0	2	10	5	8	17	7	2	0	**52**
4.0 - 4.5	0	0	0	0	4	3	4	9	6	1	0	**28**
4.5 - 5.0	0	0	0	0	2	2	2	4	4	1	0	**15**
5.0 - 5.5	0	0	0	0	1	1	1	2	2	0	0	**7**
5.5 - 7.0	0	0	0	0	0	1	1	1	3	0	0	**6**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**1**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**1**	**53**	**115**	**260**	**112**	**149**	**179**	**104**	**24**	**2**	**1000**

Figure 13. Scatter plot of buoy NDBC 46028 for 1984-1998 and 2001 (cell 4)

Source: PIER

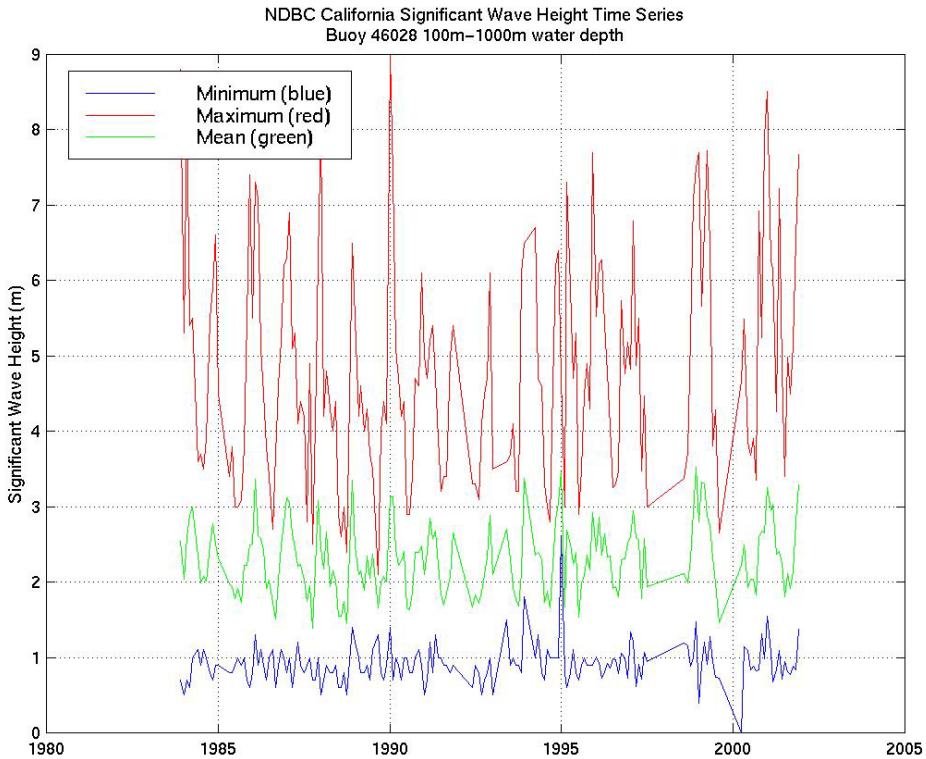


Figure 14. Significant wave height data for NDBC 46028 (cell 4)

Source: PIER

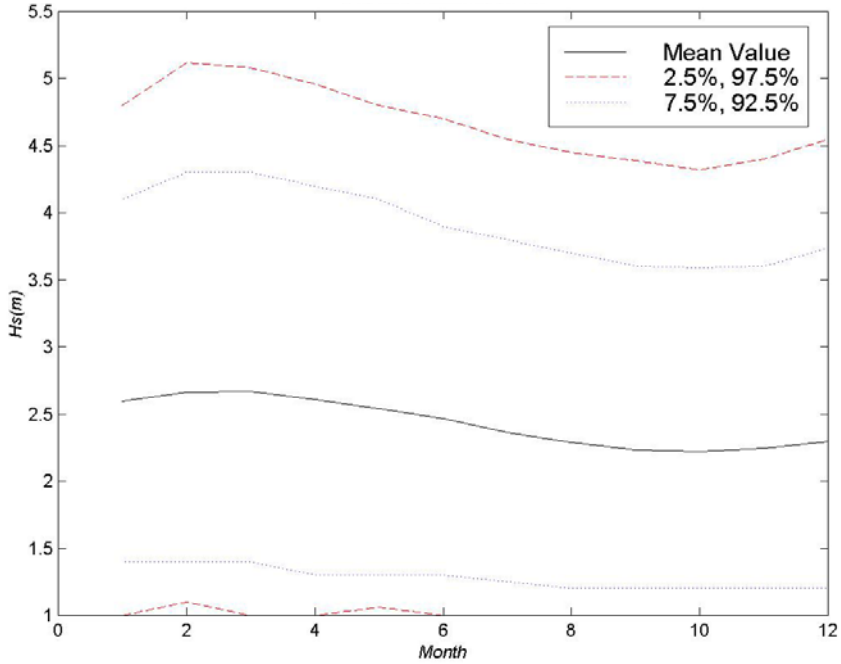


Figure 15. Wave height seasonal variability for buoy NDBC 46028 (cell 4)

Source: PIER

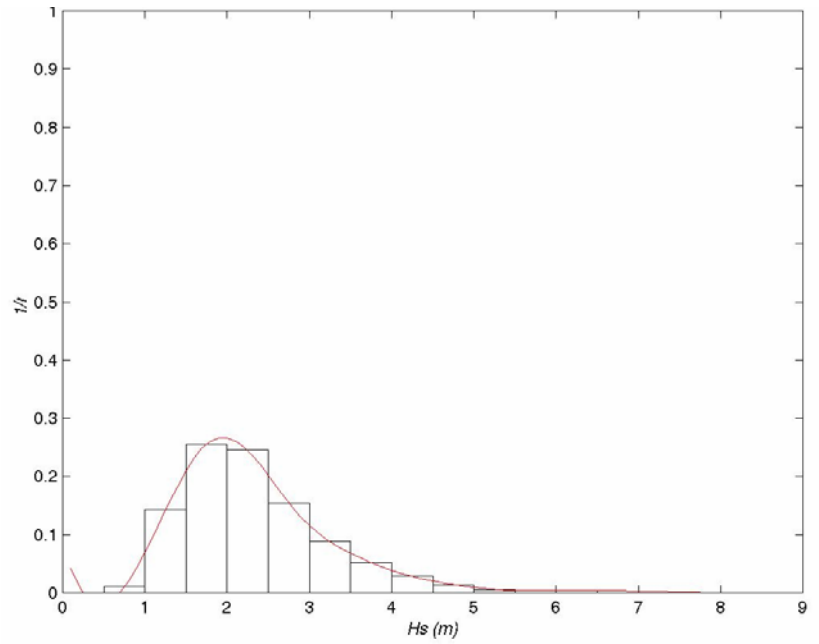


Figure 16. Probability distribution of significant wave height for buoy NDBC 46028 (cell 4)

Source: PIER

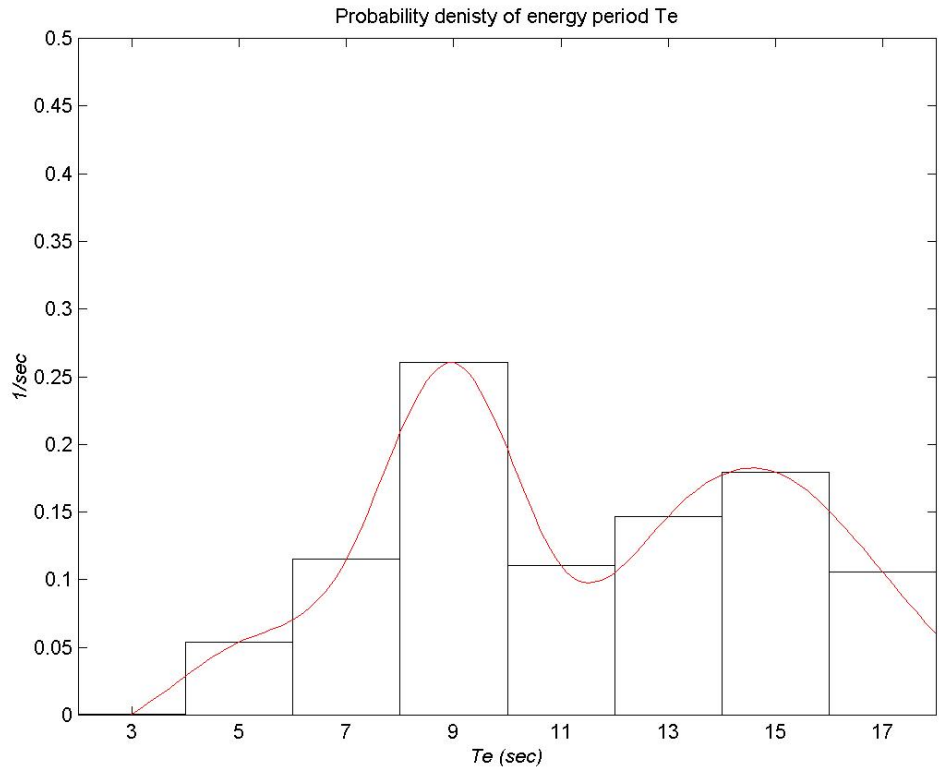


Figure 17. Probability distribution of energy period (T_e) for buoy NDBC 46028 (cell 4)
Source: PIER

3.2. Wave Energy Resource Assessment

After assembling the wave characteristics data as discussed in Section 2.2.2, Equations 1 and 2 were applied to that data to estimate the wave energy potential at the representative buoy(s) in each cell. The resulting potentials are given in Table 4 along with the corresponding buoy used in the analysis. North of Point Conception (cells 3 through 10), wave energy potential was estimated to range from 26 to 34 kW/m. South of Point Conception (cells 1 and 2) wave energy potential was found to be much lower at about 7-13 kW/m, primarily due to the blockage of northwesterly swells by Point Conception and the Channel Islands. Figure 18 and Figure 19 illustrate the seasonal variation and exceedance distribution respectively of calculated wave energy potential for NDBC 46028 located in cell 4. Similar figures for each cell and representative buoy combination can be found in Appendix A.

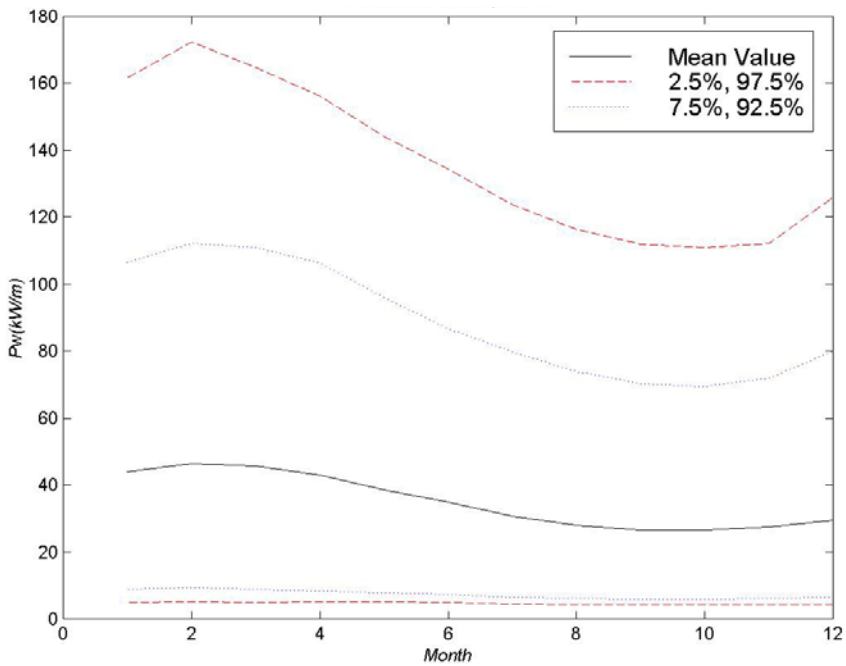


Figure 18. Cell 7's seasonal variation in wave energy flux for buoy NDBC 46028

Source: PIER

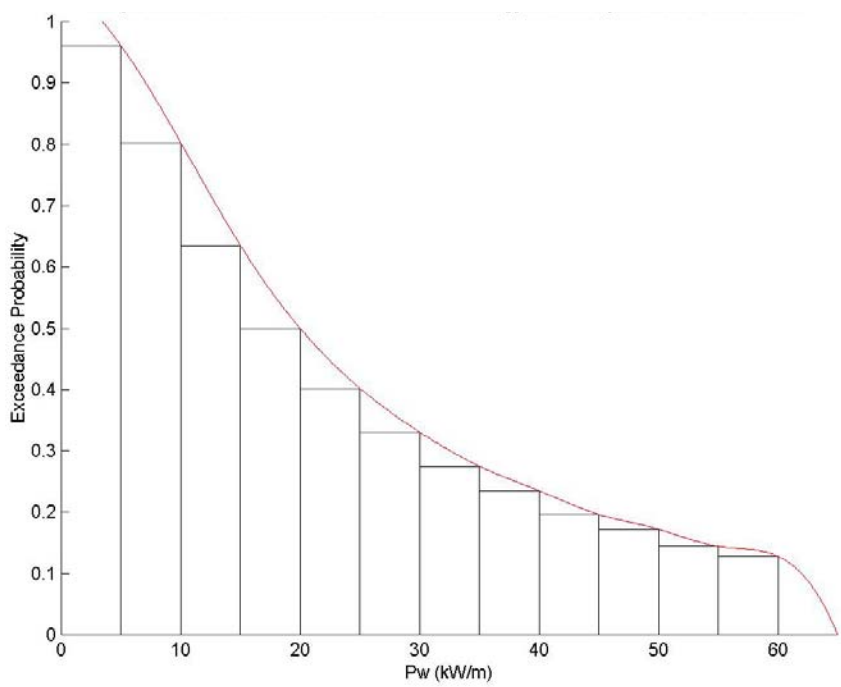


Figure 19. Cell 7's probability distribution of wave energy flux for buoy NDBC 46028

Source: PIER

Table 4. Wave energy flux estimates for each cell

Cell	Buoys Used	Wave Energy Flux (kW/m)
1	Multiple[9]	7
2	Multiple[9]	13
3	NDBC 46011	26
4	NDBC 46028	30
5	NDBC 46042	30
6	NDBC 46013	30
7	NDBC 46014	32
8	NDBC 46030	29
9	NDBC 46022	34
10	NDBC 46027	27

Source: PIER

California's wave resources can be considered moderate relative to the range that exists globally (Figure 20). In general, waves are most energetic between 40-60 degrees latitude in both hemispheres where shores are exposed to strong prevailing winds.

Figure 20. Global distribution of offshore annual wave power (kW/m of wave crest)

[9] The values for cells 1 and 2 are near shore data east of the Channel Islands. Wave energy flux values are expected to be higher (~30 kW/m) west of the Channel Islands.

Source: IEA (2003)

3.2.1. Next Steps

The analysis to date provides a good indication of the wave resources off the coast of California. Additional work is needed to:

- Validate and improve upon the results by comparing them to other studies and to incorporating data from the Comprehensive Ocean & Atmospheric Data Set COADS) maintained by NOAA and National Science Foundation's National Center for Atmospheric Research Specifically, the COADS data provides a longer timeframe with which to evaluate long-term trends. Examples of other studies of California's wave climate include the Wave Information Studies by the U.S. Army Corps of Engineers (U.S. Army Corps), the Pacific Ocean Reanalysis Wind 50-year time series by Graham and Diaz in 2001 (Graham 2001), and the World Wide Wave Atlas published by Fugro Oceanor AS (Oceanor). Another equally important step would be to assess the statistical significance of the CDIP and NDBC buoy data used in terms of data quality, span, and quantity. After validating the data's statistical significance, wave roses should be used to present wave characteristics.
- Develop an estimate of the likely range of the wave energy resource in each analysis cell based on data from multiple buoys and on the above additional analysis.
- Analyze and understand seasonal and inter-annual variability and its potential significance.
- Better understand the wave energy resource inside the 100 meter depth contour, as this is where some development of wave farms is likely to occur, at least using some of the WEC technologies currently under development.

3.3. Wave Energy Conversion (WEC) Technology

3.3.1. WEC Technology Design Considerations

WEC devices under development are highly varied in their designs. Nevertheless, WEC technologies can be broadly classified according to four basic characteristics (Table 5). Following a basic description of these characteristics, Section 3.3.2 provides brief descriptions of several technologies to illustrate how different WEC devices combine these design characteristics. That section also briefly reviews WEC technology development status.

Table 5. Wave Energy Conversion Technology Design Options

Design Element	Type	Description

Placement/ Location	Shoreline	Built into the shoreline cliff of jetty – least energetic regime
	Near shore	Between 10-25 meter depth
	Offshore	40+ meter depth – most energetic regime
Mooring	Fixed	Tightly tethered or secured (mounted) to ocean floor or shoreline
	Moving	Free floating, tethered only to prevent drifting (slack moored)
Wave Capture	Overtopping	Intakes water into a basin as wave breaks over the structure. Water is then let out through a turbine
	Oscillating water column	An enclosed moving column of water, resulting from wave surges, pushes air through an air turbine
	Point absorber	A floating structure that can absorb wave energy in all directions
	Attenuators	Exploits horizontal wave motion to drive a pump-like generator (e.g., hydraulic ram)
Power Take Off	Direct-acting	Reciprocating linear generator power take off systems
	Hydro turbines	Hydro turbines turn a generator - typically those designed for low head applications (Kaplan turbines)
	Pneumatic turbines	An enclosed moving column of water pushes air through a turbine
	Hydraulic systems	A hydraulic piston that pressurized hydraulic fluid that in turn drives an electric generator

Placement/Location

Shoreline Devices: Shoreline devices are built directly into a shoreline cliff or jetty and do not require moorings and underwater electrical cables. Access to the device for operations & maintenance (O&M) is also simpler. In general, the wave climate is least energetic at the shoreline, but this can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or diffraction. Some shoreline devices can also collect and focus wave energy as part of their design.

Near Shore Devices: Near shore devices are structures situated in shallow waters (typically 10 to 25 m water depth). They can be tethered or fixed to the seafloor. Placement at these depths provides access to greater wave energy than shoreline devices while limiting the distances to shore, which helps to manage interconnection costs and access to conduct O&M.

Offshore Devices: Offshore devices are situated in deeper water, with typical depths of more than 40 meters. Wave energy is greatest at these depths. Several different configurations have been deployed worldwide at commercial or near-commercial scale, with others are still in the development stage. Given the depths, these devices are typically free floating and slack-moored by cable instead of being fixed to the seafloor. If the devices are modular and free floating, O&M can also be accomplished by towing the devices back to shore.

Mooring

Fixed: The structure remains stationary to form the reference frame and it is the relative movement of the water that is used to do useful work. The devices can either be floating (using inertia and tethers to remain stationary) or fixed to the sea bed with a solid foundation.

Moving: These are devices which move in response to wave action to do useful mechanical work. They can be free floating and slackly tethered to the seafloor, or can have a portion that is fixed or tightly moored to the seafloor, with a separate section that moves relative to the fixed portion (e.g., as a piston moved inside a cylinder).

Wave Capture

Wave capture describes how the energy in the wave is captured. This is separate from how that energy is subsequently converted to useful work, which is described below under "power take off".

Overtopping Devices: An overtopping device uses a ramp, up which waves can run and overtop into a basin located behind it (Figure 21). This creates a reservoir at an elevated height relative to the ocean. The basin then empties back into the ocean, driving a low-head hydro turbine (the power take off device). An overtopping device can be fixed mounted to the shoreline or a jetty, or be deployed freely floating, but in the latter case, must remain stable relative to the ocean floor. Overtopping devices can use concentrators to focus the wave energy over the device. They are typically considered for shoreline or near-shore deployment.

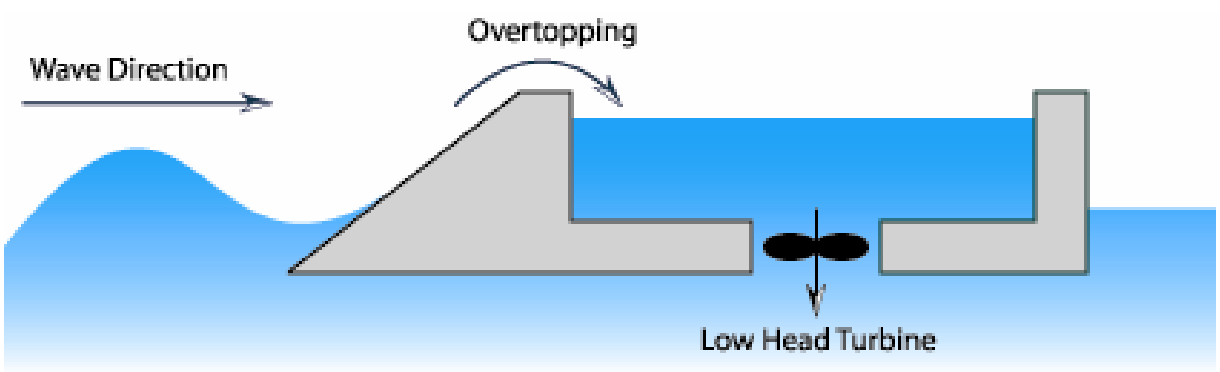
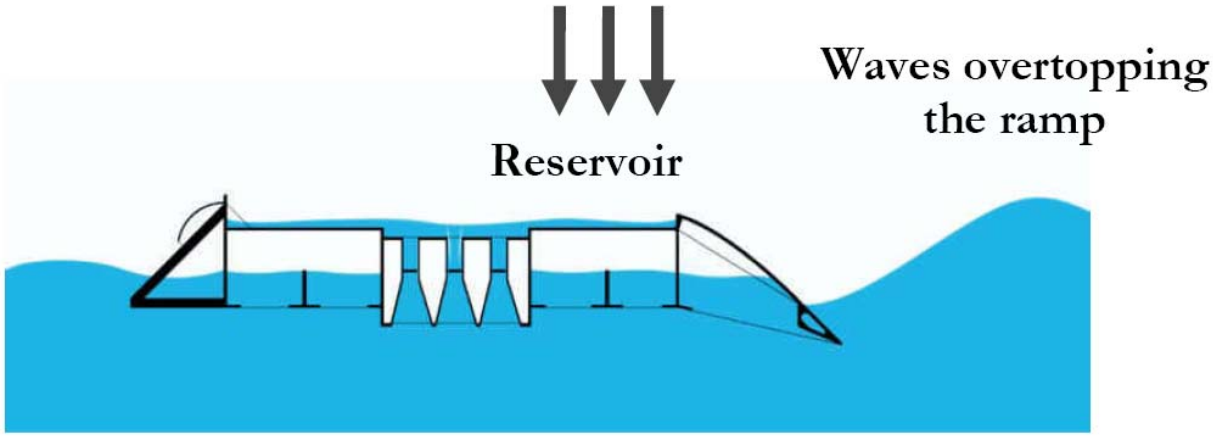


Figure 21. Principle of Operation of an Overtopping Device
Source: EPRI



Oscillating Water Column: An oscillating water column (OWC) uses an enclosed column of water as a piston to pump air (Figure 22). Incoming waves push the column of water up into the device, which in turn displaces the air. These structures can float, be fixed to the seabed, or mounted on the shoreline. An OWC device uses an air turbine to convert air flow into rotational energy that is then used to turn a generator. As with overtopping devices, OWCs can use concentrators to focus the wave energy into the device. Also, these devices are best deployed as shoreline or near-shore WECs, since they must remain stationary relative to the seafloor.

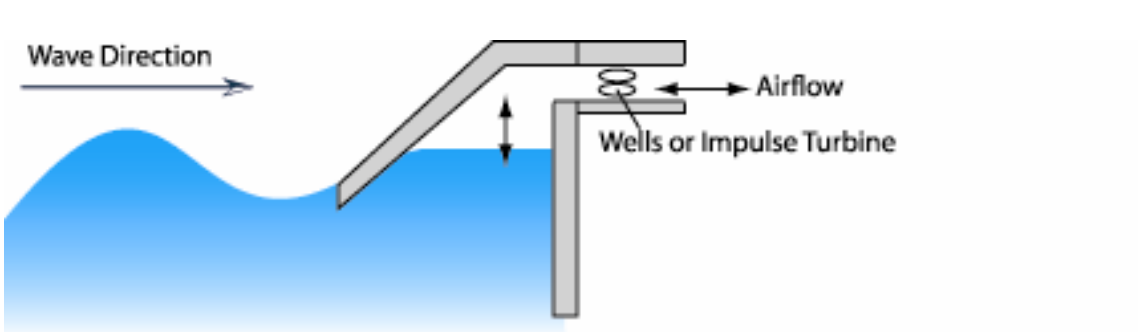


Figure 22. Principle of Operation of an Oscillating Water Column Device
Source: EPRI

Point Absorbers: Point absorbers are floating structures that can absorb waver energy in all directions, for example, a buoy-type structure that captures vertical wave motion (Figure 23). They may be designed to resonate so as to maximize energy extraction. They are comprised of a free-floating component that moves with the rising and falling waves. Point absorbers can float on or below the surface. In the case of a submerged device, the change in hydrostatic pressure above the WEC causes the unit to move up and down. The bottom part of the WEC is anchored

securely to the seafloor to form a stable reference frame – the linear motion between the two components is then converted to useful work. Individual devices have a relatively small footprint and so these devices can in theory be deployed in large arrays similar to offshore wind farms.

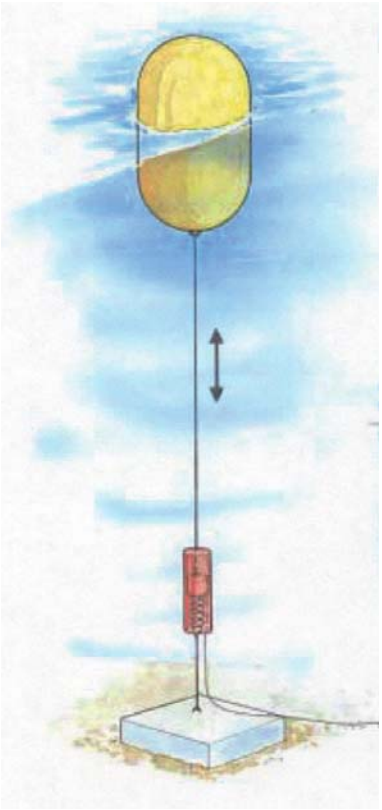


Figure 23: Principle of Operation of a Point Absorber (buoy-type shown)
Source: EPRI

Attenuators: Attenuators are similar to point absorbers in that they are free-floating and move with the ocean waves. They differ in that they lie parallel to the predominant wave direction and absorb wave energy progressively along their length (Figure 24). They are also slack-moored to the seafloor to allow them to move with ocean waves and to pivot to line up with the wave direction. The wave energy is captured by the movement of hinges that link adjacent floating segments.

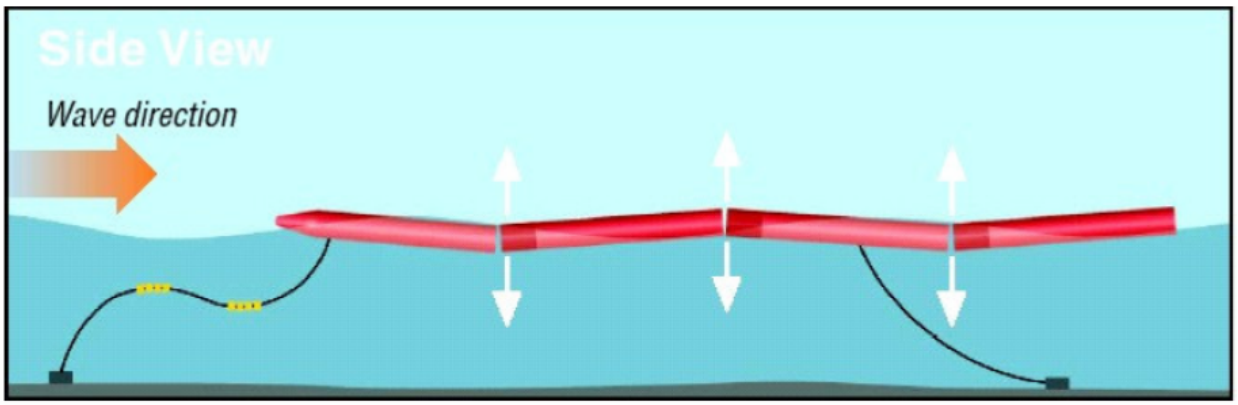


Figure 24: Principle of Operation of an Attenuator
Source: EPRI

Power Take-Off

A key challenge for WEC technologies is converting the relatively slow, highly variable oscillating motion of ocean waves into the fast rotational motion typically required for a generator. At the same time, the system should have some means of smoothing power output over multiple wave crests. This may include a means of storing some amount of energy. The output of a number of devices can also be manifolded together to smooth output. There are four principal forms of power take-off devices:

Direct Acting: Linear direct induction generators are being evaluated for wave power conversion (EPRI 2004a). Because these devices eliminate a conversion step (wave motion to rotational motion) they have the potential to simplify WEC design, reduce maintenance, and potentially increase power conversion efficiency.

Hydro turbines: Low-head hydro turbines (Kaplan turbines) are used in overtopping devices and are based on available technology from the hydropower industry. Efficiency levels are generally high and the adaptation of low-head turbines using variable speed power conversion systems allow for variable power output and optimized control over the flow rate. In at least one point absorber system, a high-head Pelton turbine design has been used.[10]

Pneumatic (air) turbines: Oscillating water column devices use air turbines to convert airflow into electricity. The most well-known development in this area has been the Wells turbine, which converts the bi-directional flow of the air in an oscillating water column into a unidirectional output using symmetrical aerofoil blades. The Wells turbine has fixed blades and has proven to be a reliable and simple conversion mechanism. The maximum efficiency of the turbine could be as high as 80% (Kimball 2003). However, As operating conditions vary from

[10] See http://finavera.com/en/wavetech/animation.

the design optimum, the efficiency decreases. Because of the variable nature of ocean waves, it can be expected that the air turbine will operate most of the time under partial load conditions, which results in average efficiencies of between 25% and 40%. To solve the issue of inherently low power conversion efficiency, some developers have come up with alternative configurations using variable pitch turbine designs to optimize power output and have also added active valves to be able to better tune the system to the incident wave power levels and optimize overall device performance.[11]

Hydraulic Systems: Most of the buoy-based and attenuator systems feature a hydraulic power conversion system. In such a system, piston rams convert the motion of the absorber device into hydraulic pressure, which in turn drives a generator. Accumulators can be used to smooth the power output and increase the power quality of a given device. The advantage of hydraulic power conversion systems is that the components are readily available and are widely used in the offshore oil & gas industry. A typical hydraulic conversion train uses volumetric displacement pumps, which convert the slow movement of an absorber system first into hydraulic pressure and then into electricity using a standard generator.

3.3.2. WEC Development Status and Examples of WEC Devices

The past few years have seen an increase in development activity for wave energy systems, most notably in Europe. Several demonstration projects have been installed and initial commercial deployment, with projects in the 2-3 MW range have begun. This section highlights some of these technologies and projects as a means of characterizing WEC development status and the application of the various WEC design features. It is not meant to be an exhaustive assessment, as there are a large number of technologies in development. Broadly speaking the status of energy technologies can be divided up into five stages, as shown in Figure 25. These stages are used to characterize the status of the WEC technologies listed in Table 6 and described in more detail below.

[11] For example, see http://www.energetech.com.au/

R&D	Demonstration			Market Entry	Market Penetration	Market Maturity
	Initial System Prototypes	Refined Prototypes	Commercial Prototypes			
• Research on component technologies • General assessment of market needs • Assess general magnitude of economics	• Integrate component technologies • Initial system prototype for debugging	• Ongoing development to reduce costs or for other needed improvements • "Technology" (systems) demonstrations • Some small-scale "commercial" demonstrations	• Commercial demonstration • Full size system in commercial operating environment • Communicate program results to early adopters/ selected niches	• Commercial orders • Early movers or niche segments • Product reputation is initially established • Business concept implemented • Market support usually needed to address high cost production	• Follow-up orders based on need and product reputation • Broad(er) market penetration • Infrastructure developed • Full-scale manufacturing	• Roll-out of new models, upgrades • Increased scale drives down costs and results in learning
10+ years	4 - 8 years			1 - 3 years	10 - 20 years	Ongoing

Note: times are approximate – actual time in a given stage can vary significantly.

Figure 25. Energy technology commercialization timeline

Source: Navigant Consulting, Inc.

Table 6. Examples of WEC technologies in Development (not a complete list)

WEC Name	Company	Website
Archimedes Wave Swing	AWS Ocean Energy	www.waveswing.com
Energetech OWC	Energetech	www.energetech.com.au
Pelamis	Ocean Power Delivery	www.oceanpd.com
PowerBuoy	Ocean Power Technologies	oceanpowertechnologies.com
Wave Dragon	Wave Dragon	www.wavedragon.net

AWS Ocean Energy's Archimedes Wave Swing

The Archimedes Wave Swing is a bottom standing completely submerged point absorber with a linear direct generator to convert the oscillatory motion into electricity. The device consists of a large air-filled cylinder which is submerged beneath the waves. As a wave crest approaches, the water pressure on the top of the cylinder increases and the upper part or 'floater' compresses the air within the cylinder to balance the pressures. The reverse happens as the wave trough passes and the cylinder expands. The relative movement between the floater and the fixed lower part or 'basement' is converted directly to electricity using a linear generator. First-generation machines will be rated at over 1MW and have a load factor in excess of 35%. The complete system has been tested at full-scale via a pilot plant that is installed off the coast of Portugal. Engineering of the pre-commercial demonstrator is now ongoing.

In October 2004, the AWS pilot plant, with a rated capacity of 2MW, exported power to the electricity grid in Portugal for the first time. The unit achieved a total peak power of around 1.5

MW. In April 2006, AWS Ocean Energy raised £2 million in equity funding from the investment group RAB Capital (AWS 2006). The new funding will be used scale up operations and design a full-scale demonstration unit in 2007 for commissioning in 2008. The updated Mark Two design will build on the results of the testing off the coast of Portugal.

Table 7. AWS Ocean Energy's Archimedes Wave Swing WEC Characteristics

Weight/Dimensions	7x9.5 meters Mark I prototype
Rated Power	2 MW
Placement/Location	Near-shore to offshore
Mooring	Fixed: solid structure on ocean floor
Wave Capture	Fully-submerged point absorber
Power Take Off	Linear direct induction generator
Apparent Development Status	**Refined/Commercial Prototype:** Commercial unit is in design based on successful prototype tests

Figure 26. AWS Ocean Energy's Archimedes Wave Swing WEC

Source: AWS Ocean Energy

Energetech

Energetech is developing an oscillating water column that can be deployed in water depths of up to 50 meters. The device features a parabolic focusing wall, which is used to focus waves into the oscillating water column. A key feature of the device is the two-way, variable-pitch blade air turbine, which raises the average conversion efficiency from roughly 30% to 60% compared to a fixed pitch blade designs. The device is mounted on a number of legs (piles) and is held in place by a tethering system. A full-scale device was deployed in October 2005, at Port Kembla, Australia. Testing has been ongoing since then. (Energetech 2006)

Table 8. Energetech WEC Characteristics

Weight/Dimensions	36x35 meters, 485 tons
Rated Power	1-2 MW
Placement/Location	Shoreline to 50 meters
Mooring	Fixed: stands on legs with taught tethers to hold in place[12]
Wave Capture	Oscillating water column with parabolic focusing wall
Power Take Off	2-way variable pitch air turbine (Denniss-Auld turbine)
Apparent Development Status	**Commercial Prototype:** Full-scale unit installed in November 2005 in Port Kembla, Australia

[12] The Port Kembla prototype was fixed. Future units will be slack moored floating units with heave plates.

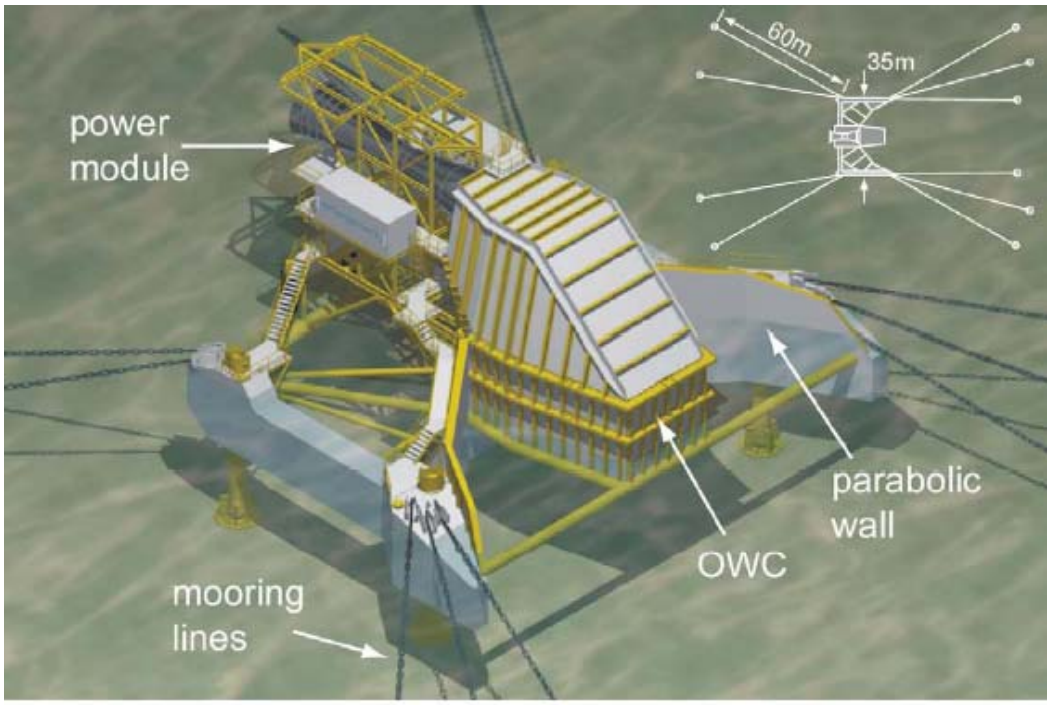


Figure 27. Energetech's oscillating water column WEC

Source: Energetech

Ocean Power Delivery

The Pelamis is a semi-submerged attenuator. Its articulated structure is composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity. Power from all the joints is fed down a single umbilical cable to a junction on the sea bed. Several devices can be connected together and linked to shore through a single undersea cable.

A novel joint configuration is used to induce a tunable, cross-coupled resonant response, which increases power capture in low wave height conditions. Control of the restraint applied to the joints allows this resonant response to be 'turned-up' in small seas where capture efficiency must be maximized or 'turned-down' to limit loads and motions in survival conditions. The machine is held in position by a mooring system comprised of a combination of floats and

weights which prevent the mooring cables becoming taut. It maintains enough restraint to keep the Pelamis positioned but allows the machine to swing head on to oncoming waves.

The 750 kW full-scale P1A unit is 120m long and 3.5 m in diameter and contains four sections and three power conversion modules, each rated at 250kW. A full-scale, grid-connected, pre-production prototype was built and deployed in October 2004, at the European Marine Energy Test Center in Orkney, Scotland. Ocean Power Delivery is currently building the first commercial plant in Portugal, consisting on three units (2.25 MW) and has announced a second plant for Orkney, consisting of four units (3 MW) (Ocean Power Delivery, 2006)

Table 9. Ocean Power Delivery's Pelamis WEC Characteristics

Weight/Dimensions	120x3.5 meters
Rated Power	750 kW (P1A unit)
Placement/Location	Offshore (nominally 50m)
Mooring	Floating: slack-moored
Wave Capture	Linear attenuator
Power Take Off	Hydraulic rams with accumulators
Apparent Development Status	**Market Entry:** 3-unit (2.25 MW) commercial plant being installed in Póvoa de Varim, Portugal, for summer 2007 operation, and 4-unit (3 MW) project announced for Orkney, Scotland

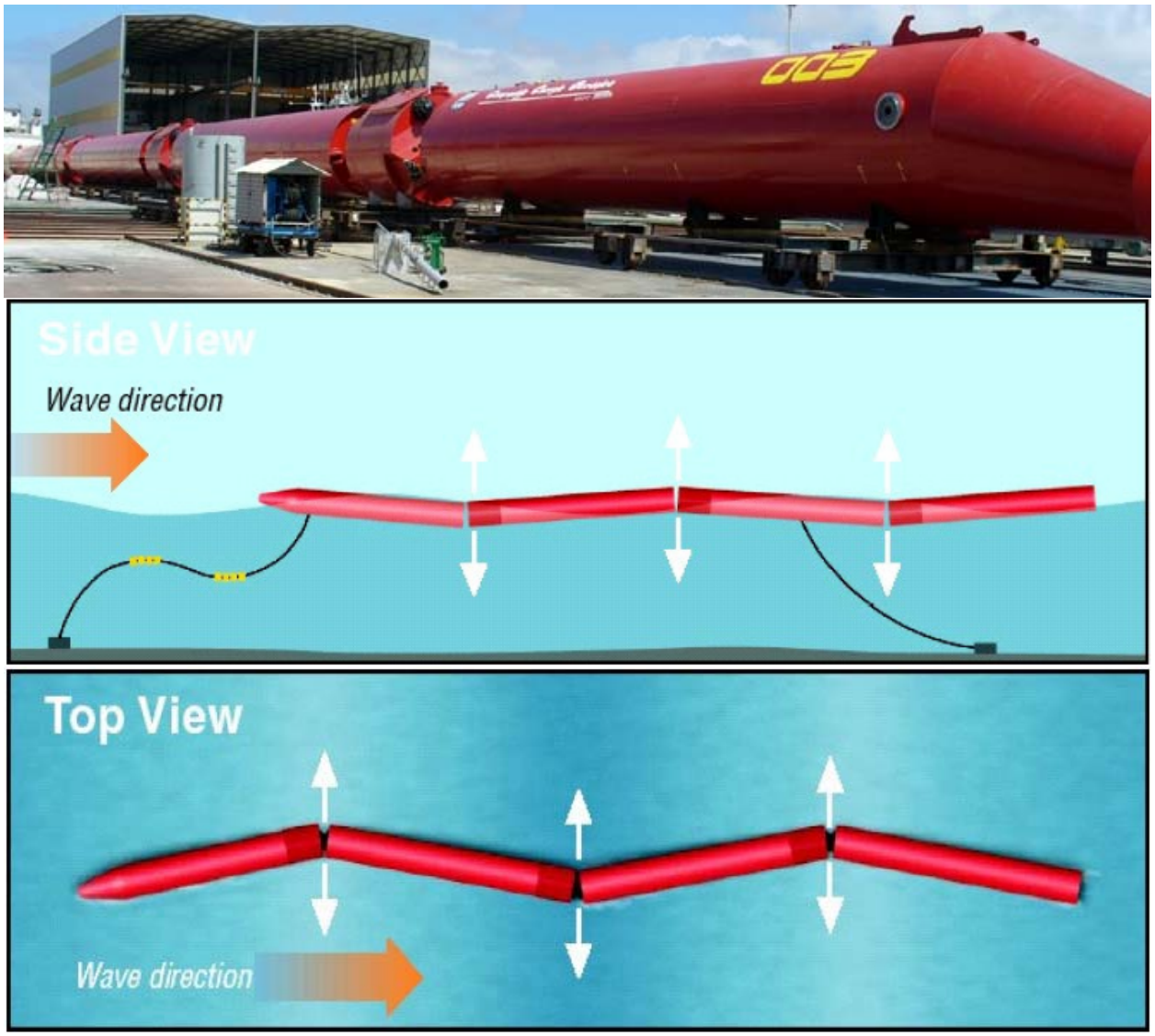


Figure 28. Ocean Power Delivery's Pelamis attenuator WEC

Source: EPRI 2004a; Ocean Power Delivery website

Ocean Power Technologies PowerBuoy

The PowerBuoy being developed by Ocean Power Technologies consists of a 5m diameter buoy. The buoy is mounted on a long tubular structure that is used to provide reaction mass to the system. The system is loosely moored directly to the seabed. The current individual demonstration units are rated at 40 kW. The power take off device converts the mechanical stroking created by the movement of the unit caused by ocean waves into rotational mechanical energy, which, in turn, drives the electrical generator. The control system uses sensors and an onboard computer to continuously monitor the height, frequency and shape of the waves interacting with the PowerBuoy system. The control system collects data from the sensors and uses proprietary algorithms to electrically adjust the performance of the PowerBuoy system in

real-time and on a wave-by-wave basis. By making these electrical adjustments automatically, the PowerBuoy system is able to maximize the amount of electricity generated from each wave. In the event of storm waves larger than 13 feet, the control system automatically locks down the PowerBuoy system and electricity generation is suspended. When the wave heights return to a normal operating range of 13 feet or less, the control system automatically unlocks the PowerBuoy system and electricity generation and transmission recommences. This safety feature prevents the PowerBuoy system from being damaged by the increased amount of energy in storm waves.

The 40kW PowerBuoy system has a diameter of 12 feet near the surface, and is 52 feet long, with approximately 13 feet of the PowerBuoy system protruding above the surface. Larger PowerBuoy systems are expected to be slightly longer and have a larger diameter. For example, a 500kW PowerBuoy system, once developed and manufactured, is expected to have a maximum diameter of approximately 42 feet and be approximately 62 feet long with approximately 18 feet protruding above the ocean surface (Ocean Power Technology, 2007).

Table 10. Ocean Power Technology's PowerBuoy WEC characteristics

Weight/Dimensions	Approx 4x17 meters (prototype); 14x20 meters (planned)
Rated Power	40 kW (prototype); 500 kW (planned)
Placement/Location	Near shore to offshore
Mooring	Floating (slack moored)
Wave Capture	Floating point absorber
Power Take Off	Oil-filled hydraulics
Apparent Development Status	**Initial System Prototype**

Figure 29. Ocean Power Technology's Power Buoy WEC

Source: Ocean Power Technology

Wave Dragon

The Wave Dragon is a floating, slack-moored, overtopping device. It consists of two wave reflectors focusing the waves towards a ramp. Behind the ramp there is a large reservoir where the water that runs up the ramp is collected and temporarily stored. The water leaves the reservoir through low-head hydro turbines that utilize the head between the level of the reservoir and the sea level. The main components of a Wave Dragon are: the main body with a doubly curved ramp made of reinforced concrete and/or steel; two wave reflectors (steel and/or reinforced concrete), the mooring system; and the low-head hydro turbines connected to permanent magnet generators.

The first prototype connected to the grid is currently deployed in Nissum Bredning, Denmark. Long-term testing is being carried out to determine system performance, including availability and power production in different sea states. The company is targeting multi-MW commercial demonstrations for sometime in 2007 (Wave Dragon, 2007)

Table 11. Wave Dragon WEC characteristics

Weight/Dimensions	53x33 meters, 237 tons (prototype); up to 390x220 meters, 55,000 tons (proposed commercial units)
Rated Power	20 kW (prototype); 4-11 MW (proposed commercial units)
Placement/Location	offshore (commercial units)
Mooring	Floating (slack-moored)
Wave Capture	Overtopping with wave reflectors

Power Take Off	Low-head hydro turbines with permanent magnet generators
Apparent Development Status	**Initial System Prototype**

Figure 30. Wave Dragon WEC (left: prototype testing, right: artists concept of commercial unit)
Source: Wave Dragon

3.3.3. Next Steps

In order to better understand the potential for different WEC designs in California, additional work needs to be done to assess the suitability and performance of WECs for the California wave climate. Note that several devices have active controls to optimize performance in real time. Also, physical size of major elements may need to be optimized for the California wave climate.

3.4. Current and Projected WEC Economics

As en emerging technology, wave energy does not have a commercial track record to aid in estimating project economics. In this section, capital and operating costs are estimated for commercial-scale plants based on current technology. Cost reductions from learning curve effects are then are applied to estimate long-term economics. The analysis presented below is derived from work sponsored by the Electric Power Research Institute (EPRI 2004b; EPRI 2004c) that examined in detail two wave farms with the same annual output – one based on the Energetech OWC and the second on OPD's Pelamis.

3.4.1. Economic Base Case – Commercial-Scale WEC Plants

Limited data are available to date on cost, performance and economics of wave power plants. As described in Section 3.3, some WEC technologies are just now entering the first stages of commercial deployment at plants scales of 2-3 MW. This is considerably smaller than the

expected sizes of commercial wave farms, which may be 100 MW or more. In 2004, EPRI carried out a study to assess the economics and performance of a commercial wave power plant producing 300,000MWh (~100-150 MW) per year (EPRI 2004b, EPRI 2004c). The wave energy available at the assumed deployment site (off San Francisco) was about 21 kW/m, which is lower than some of the more energetic regimes in Northern California.

Table 12 summarizes the WEC plant cost and performance assumptions as given in the EPRI reports, and the resulting levelized cost of electricity (LCOE). These assumptions are for commercial scale plants with costs extrapolated from pilot scale estimates also made by the authors of the EPRI studies, i.e., they are not meant to represent mature technology costs that could be expected from further development and deployment of the technology over time. Two technologies were chosen: the Energetech oscillating water column (OWC) and Ocean Power Delivery's Pelamis. Uncertainties in the cost estimates were reported to be +35% / -25%. Performance predictions were made using the wave resource data derived from the San Francisco buoy NDBC 46026, which is located about 24km west (seaward) of San Francisco.

Table 12. Cost and Performance Assumptions for Two Commercial WEC Plants Deployed Off The Coast of San Francisco ($2004)

	OPD Pelamis	Energetech OWC
Wave Farm Specifications		
Wave Power Density at Site	21 kW/m	21 kW/m
Number of WEC Devices	213	152
Rated Capacity per device	500kW	1,000kW
Annual Output per Device	1,407 MWh/year	1,973 MWh/yr
Annual Output at busbar	299,691 MWh/yr	299,896 MWh/yr
Installed Cost Assumptions		
Absorber Structure	$52M	$76M
Power Conversion System	$133M	$67M
Mooring	$25M	$20M
Balance of Station	$52M	$54M
Total Installed Cost	$262M	$217M
Construction Financing	$17M	$22M
Total Plant Investment	**$279M**	**$241M**
Total Installed Cost ($/kW)	**$2,620/kW**	**$1,607/kW**
Operations & Maintenance (O&M)		
Insurance	$2.6M	$1.9M
Parts	$5.2M	$4.3M
Operations	$5.2M	$4.3M
Total Annual O&M	**$13M**	**$10.6M**
10-year refit	$28.7M	$15.7M

Financial Assumptions		
Project Economic Life	20 years	20 years
Fixed Charge Rate (Real $)[13]	6.9%	6.9%
Levelized Cost of Electricity ($2004)	**11.2 ¢/kWh**	**9.8 ¢/kWh**

The economic analysis shows an LCOE in the range of 10-11 ¢/kWh, with incentives. Figure 31 shows a breakdown of the LCOE by cost element for the Pelamis case. Nearly 50% of the LCOE is associated with the annual O&M and the 10-year refit. As technology matures and reliability increases, it is expected that these costs will decrease. By comparison, O&M costs for modern land-based wind farms are 1 ¢/kWh or less.

[13] This the fixed charge rate reported in the EPRI studies. Utility economic assumptions were used. The fixed charge rate is reported to include the impacts of federal and state tax incentives similar to those currently available for wind power. These include the federal production tax credit (PTC, [1.8 ¢/kWh for 10 years when the analysis was conducted]), 5-year accelerated depreciation, and a 6% state investment tax credit. The EPRI study also appears to have included the 10% federal investment tax credit (ITC), although it is currently not possible to claim both the ITC and the PTC. Thus, the fixed charge rate used above may be low. A higher fixed charge rate would result in a higher cost of electricity. Additional details on the methodology are available in the EPRI studies.

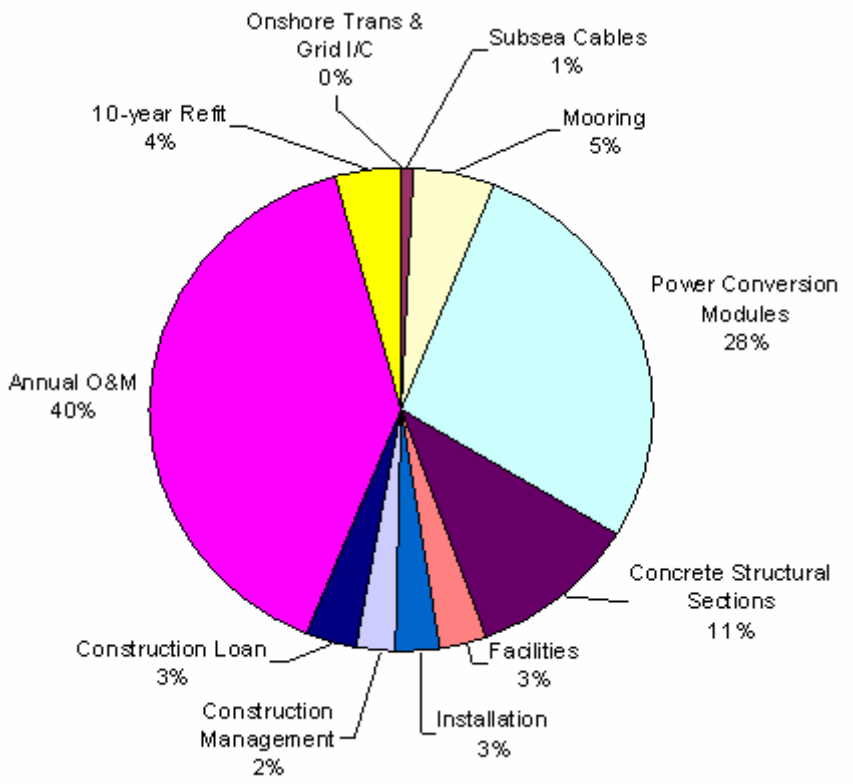


Figure 31. Levelized cost of electricity breakdown for a commercial scale WEC power plant

Source: EPRI

3.4.2. Impact of Wave Resource Density on Wave Farm Economics

As with other renewable energy conversion technologies, the economics of ocean wave energy will depend on the quality of the resource. In order to evaluate the impact of the power level on the cost of electricity, the same analysis methodology used to estimate the above costs was applied to 14 different measurement locations along the California coast. Wave data from CDIP and NOAA stations in Northern California located in various water depths were used for the analysis. In each case, the analysis included a re-evaluation of the WEC performance to optimize it for that particular wave climate. All other cost parameters were left the same. Figure 32 shows the results of the analysis. As expected, the LCOE decreases with higher wave power densities, approaching 7 ¢/kWh for the given financial assumptions.

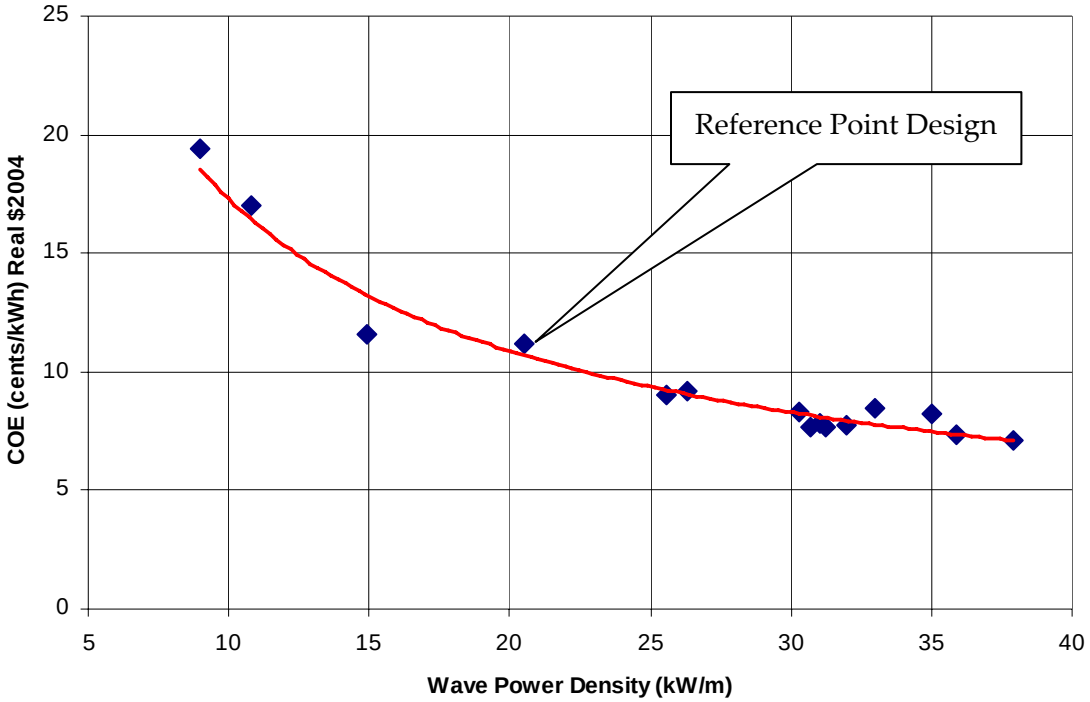


Figure 32. Projected LCOE for a commercial scale (213 unit) Pelamis wave farm at various locations in California.

3.4.3. Other Economic Considerations

The foregoing economic analysis was for a large-scale commercial plant using today's technology. Initial deployment of the technology will occur at a much smaller scale, as evidenced by the two commercial projects using the Pelamis described in Section 3.3.2. Obviously, smaller plants will produce electricity at higher cost, due to both manufacturing economics of scale and the fact that several cost elements are, to a large degree, fixed costs, such as grid interconnection and project development/permitting. Nevertheless, these initial projects are important and necessary to validate performance in a commercial setting and to demonstrate that environmental impacts are in line with expectations and are acceptable.

The deployment of relatively unproven technologies also entails greater risks for investors, which is typically reflected in a higher cost of capital – higher than the assumed costs used in the analysis presented above. This further raises the cost of electricity. For example if the 6.9% real fixed charge rate used to develop the above estimates was instead 10%, the estimated LCOE for the Pelamis and the OWC wave farms would be about 15¢/kWh and 12¢/kWh, respectively. At a fixed charge rate of 15%, the LCOEs would be about 19¢/kWh and 16¢/kWh, respectively.

3.4.4. Future Cost of Electricity

Conversely, it can be expected that if wave power is successfully commercialized and deployed more broadly, learning curve effects will help to drive down the cost of electricity below the levels shown here. Applying learning curves to the above costs provides an indication of the long-term economics of a particular technology. Learn curves describe a relatively simple, quantitative relationship between cost and the cumulative production or use of a technology. There is substantial empirical support for such a cost-experience relationship from various industries, including energy technology (EPRI 2004b, EPRI 2004c).

Cost reduction goes hand-in-hand with cumulative production experience and follows a logarithmic relationship such that for each doubling of the cumulative production volume, there is a corresponding percentage drop in cost. Related industries such as wind, photovoltaics and ship-building have shown *progress ratios* between 78% and 85% (i.e., for every cumulative doubling of production costs drop by 15% to 22%). In Europe, the levelized cost of energy from wind power has followed a progress ratio of about 82% (see Figure 33).

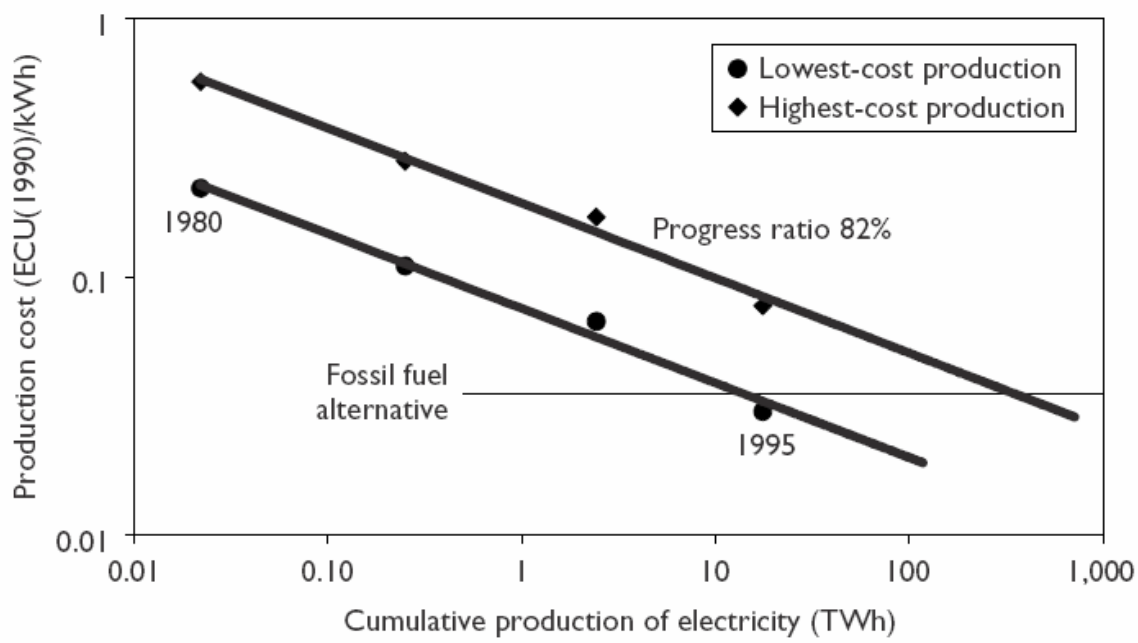
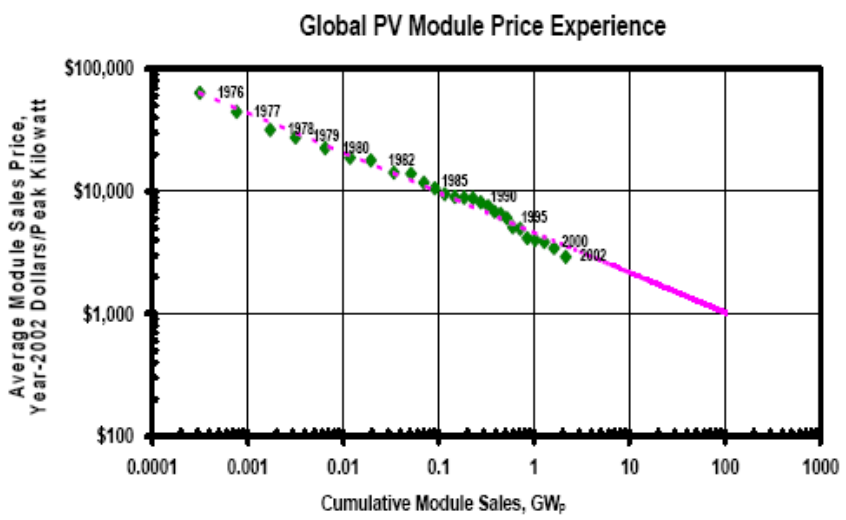


Figure 33. Learning curve effects for wind energy in the European Union, 1980–1995

Source: EPRI



Assuming wave power costs reductions follow a similar path to wind power, the result of applying an 82% progress ratio to wave power is shown in Figure 34, using the above costs for the commercial-scale plant as a starting point. It shows that wave energy should follow a similar trajectory as wind power. The upper and lower bound for wave energy is based on the present uncertainty in cost predictions for wave power plants.

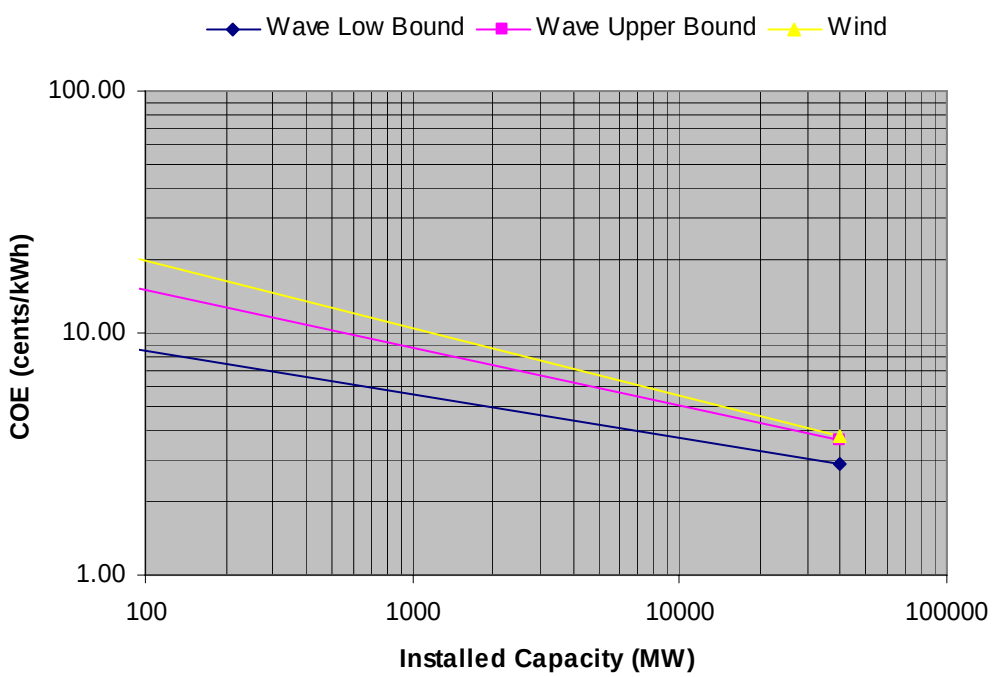


Figure 34. Projected cost reduction of wave energy compared to wind equivalent installed capacity, assuming similar learning curve effects

Source: EPRI

3.4.5. Conclusions and Next Steps

The economic analysis shows a levelized cost of electricity (LCOE) in the range of 10-11 ¢/kWh, assuming incentives similar to those currently available for wind power are available to wave power result in an effective real fixed charge rate of 6.9%. When a range of wave resource values is considered (from 8-38 kW/m) the LCOE ranges from about 7-20 ¢/kWh for the same financial assumptions.

Initially, one can expect LCOEs to be significantly higher than these values for two basic reasons. First, The deployment of relatively unproven technologies entails greater risks for investors, which is typically reflected in a higher cost of capital. Second, initial deployments of the technology will likely involve much smaller wave farms. Thus, it is not unreasonable to expect that if California is chosen for early commercial projects, that the LCOE for these projects will exceed 15¢/kWh, and possibly 20¢/kWh. However, the purpose of these early projects may be to demonstrate the technology and document WEC performance (including environmental impacts) and the LCOE may therefore be less important than other aspects of such projects.

Conversely, it can be expected that if wave power is successfully commercialized and deployed more broadly, that this will drive down the cost of electricity below these levels. There is substantial empirical support for such "learning curve" effects, and it is reasonable to expect that wave energy, like wind power and solar power, has opportunities for reaping the benefits of manufacturing economies of scale and technology improvements.

A wide variety of WEC technologies are being pursued by different developers, and there is as yet no consensus about which technology will ultimately be the most cost competitive. It is also unclear which technology will prove to be best suited for the US west coast. The US west coast in general and California in particular has its own bathymetry, wave climate and infrastructure constraints which might be better suited to some devices than others. Further research and analysis is needed to identify those technologies that will be best suited to the California wave climate, and that will also meet expectations in terms of environmental impact and other siting constraints.

Thus, a useful next step would be to conduct additional technology assessment specific to California. It would also then be useful to conduct economics analysis using a range of financing assumptions, and to break out the impact of incentives since at present, wave energy is not eligible for the incentives applied in the EPRI analysis.

3.5. Wave Energy Environmental and Siting Considerations

The construction, operation, and decommissioning of structures in the water and on land have the potential to affect terrestrial and marine environmental resources. Each WEC project will have unique effects on the environment, depending on two things: the design of the device (including the size of the array), and the specific environmental characteristics of the project site. In California, every potential project is required to undergo a project-specific environmental review (see Section 3.6 below).

This section presents a preliminary review of the types of potential environmental impacts of wave energy devices off the coast of California. More analysis is needed to assess impacts of specific WEC designs at specific sites. For example, Pacific Gas & Electric has taken some initial steps to evaluate the potential for a wave energy project off the coast of Mendocino and Humboldt counties (PG&E 2007). More recently, Finavera Renewables announced that they had received a FERC Preliminary Permit, valid for three years, to allow them to conduct various studies, including analysis of oceanographic conditions, commercial and recreational activities and other impacts potentially associated with its proposed 100MW wave power project in Coos County, Oregon (Finavera 2007). These studies should begin to shed light on the specific impacts that can be expected from a real project. EPRI has also conducted some work in this area (EPRI 2006).

Impacts may occur during the construction/installation phase of a wave energy project and during operations. During the construction phase, impacts could come from:

- Directional drilling through the shoreline
- Cable burial on the ocean floor
- Set down of anchors or installation of other permanent structures into the seafloor
- Drilling into the seabed for heavy-uplift anchors
- Cable laying and other operational activities
- Additional onshore transmission facilities to connect to the nearest grid interconnection point

Once the wave farm is installed, the main impacts are expected to result from increased operational activity to maintain the devices, as well as the direct impacts of the devices themselves. The sections below outline some of the potential effects. Potential environmental and siting issues posed by wave-energy devices include:

- Coastal processes
- Ocean effects
- Onshore effects
- Water quality
- Air quality
- Visual resources
- Use conflicts
- Geology

3.5.1. Coastal Processes

The purpose of a wave-energy device is to remove energy from ocean waves and convert that energy into electricity. Reducing the wave energy available to coastal processes could result in

changes to sediment transport patterns, beach nourishment, coastal erosion, and other coastal processes. Depending on the design of the project, WEC structures could act as breakwaters or jetties. Reduced wave energy levels could also increase the competitive advantage of faster growing algae and kelp species over wave-resistant species (e.g. giant kelp over bull kelp, fleshy algae over coralline algae).

3.5.2. Offshore Effects

Sensitive habitats

Areas of hard bottom, kelp forests, and eelgrass beds are all highly productive, sensitive habitats that are found in the near-shore environment. These habitats are afforded special protection under several state and federal environmental laws. Offshore structures and pipelines running to shore have the potential to affect these habitats by physically displacing or destroying areas of these habitats. Moorings, foundations and sub-sea cables can affect the seabed, particularly during installation.

Sensitive species

Marine mammals and species listed as threatened or endangered with federal or state governments are provided special protection under the Marine Mammal Protection Act and federal and state Endangered Species Acts. Many of these species make use of the offshore and near-shore environment, and structures placed in these environments have the potential to adversely affect these species.

Noise

Anthropogenic noise in the marine environment can be introduced by construction activities, such as pile driving, and decommissioning activities, such as the detonation of explosives. Normal WEC operation will also produce noise. Underwater noise of certain levels and frequencies can injure or kill marine mammals, birds, and fish, and potentially disrupt normal patterns of behavior.

Migration

Gray whales migrate annually along the coast of California from their feeding grounds in the Arctic Sea to their calving grounds in the coastal lagoons of Baja California. The annual migration occurs from November to May, and whales can be sighted from the surf zone up to two nautical miles offshore. Large offshore WEC arrays could interfere with this migration pattern. Other species may also be affected.

Shading

Structures at or near the ocean surface have the potential to interfere with the highly productive micro-layer and upper reaches of the water column, by restricting the amount of sunlight available to primary producers. A reduction in primary food production can have ripple effects throughout the local ecosystem.

Entrainment and impingement

Structures that pump seawater are likely to entrain plankton, larvae, and other small organisms. Intake pipes can impinge, or trap, larger animals such as fish and invertebrates.

Electromagnetic Fields

The artificial magnetic and electric fields (associated with submarine electric cables) can interfere with orientation in migrating animals, and with the feeding mechanisms of elasmobranchs (group of fishes which includes the sharks, rays, and skates). At the present time, the significance or scale of these impacts is not well understood.

Incidental use of structures

Depending on the design of the WEC structures, marine mammals such as sea lions and seals could use them as haul-out areas, and marine birds will likely use them for roosting or nesting. Wave energy structures could affect these animals, and conversely, these animals could affect the structures. Certain devices or measures (e.g., barriers, hazing, etc.) may prevent animals from using the structures; however these devices can be harmful to marine fauna.

Any solid structure placed in the water has the potential to act as a fish attractor, which in turn can attract fish predators, ultimately changing the local marine ecosystem and adversely affecting fish populations. Regulators are especially concerned about the effects on managed fish populations and essential fish habitat.

3.5.3. Onshore Effects

Components of a wave-energy facility that must be located onshore have the potential to affect vulnerable elements of the terrestrial environment. This includes shoreline WEC devices, road access, and equipment used to interconnect to the grid. Potential onshore impacts include disruption of sensitive species and habitats such as wetlands, coastal dunes, and riparian corridors. In addition to biological resources, onshore elements of a project could adversely affect cultural resources, agricultural land, traffic, the viewshed, recreation, and the public's access to the shore. Public safety issues related to geology, accidents, and intentional acts of destruction are also potential concerns.

3.5.4. Water Quality

Water quality can be affected in a variety of ways by structures place in the ocean. Increases in turbidity can smother benthic organisms and filter-feeding marine biota, and can be caused by construction/decommissioning activities and by ongoing operations. Anti-fouling products used to treat structures placed in the marine environment can leach toxic contaminants such as copper and tin. Hydrocarbon-based lubricants, such as grease and oil, can be toxic if released accidentally into the marine environment. Vessels used in the construction, maintenance, and decommissioning of offshore structures can, in the event of a collision, accidentally release diesel fuel and oil.

3.5.5. Air Quality

Many areas of coastal California are out of compliance with state and/or federal air quality standards. Air emissions can be created by vessels and diesel-powered equipment used during construction, operation, and decommissioning of a project.

3.5.6. Visual Resources

Many areas of coastal California are well-known for their scenic attributes, and the beauty of highly scenic areas is protected under local and state laws. A large-scale offshore industrial facility has the potential to disrupt the scenic beauty of California's coastline. Offshore wave energy conversion (WEC) devices generally have low profiles, but adverse visual impacts can be exacerbated by navigational markings required by the Coast Guard, such as signs and warning lights. Land-based collection, switching stations, and transmission lines could also create visual impacts.

3.5.7. Space and/or Use Conflicts

Commercially-viable build-out of some wave-energy devices could involve arrays covering large areas, and any WEC project could present a hazard to shipping. A large array of wave energy devices could potentially impose an exclusion zone on commercial fishing. The physical presence of structures in the water could also affect recreational boaters. Additionally, any device designed to remove wave energy from the near-shore environment has the potential to affect recreational surfers in the area. Other uses of the marine environment that would be incompatible with the presence of a wave-energy device include commercial shipping (i.e., shipping lanes), military exercises, and scientific research. California is currently exploring the possibility of expanding its system of designated marine protected areas (MPA); existing and newly created MPAs would not be appropriate locations for wave energy projects.

Near-shore and shoreline devices could interfere with fish farming, whereas offshore devices could interfere with fisheries areas such as for salmon and herring.

3.5.8. Geology

California is seismically active, and the offshore area is no exception. Projects must be designed to withstand forces associated with seismicity, liquefaction, and tsunamis. A site-specific geotechnical analysis is generally required for the installation of offshore structures.

If sub-sea power or communications cables are required between the offshore array and an onshore facility, the shore landing of these cables can affect sensitive surf zone and beach habitats. Recently, Horizontal Directional Drilling (HDD) and Horizontal Directional Boring (HDB) have increasingly been used to install cable conduit from an onshore landing to offshore waters. These methods cause fewer adverse environmental impacts compared to the more traditional trenching method; however, these methods have the potential to release drilling mud into the ocean, especially if the local geological formation is prone to fracture.

3.5.9. Existing Information

To date, there is limited data available specifically on the environmental impacts of wave energy conversion devices. Some studies in Europe are beginning to examine environmental impacts and to document the results of demonstration projects. We refer the reader to Section E of the Wave Energy Thematic Network at www.waveenergy.net. In the United States, EPRI has published several reports on wave energy conversion, available for download at www.epri.com/oceanenergy.[14] The recently formed Ocean Renewable Energy Coalition (www.oceanrenewable.com) also has resources on this topic.

In 2003, the Department of the Navy prepared an Environmental Assessment under the National Environmental Policy Act (NEPA) for the proposed installation and testing of a wave energy project at Marine Corps Base Hawaii (MCBH) Kane'ohe Bay. The proposed project involved the phased installation and operational testing of up to six WEC buoys off the North Beach at MCBH Kane'ohe Bay for a period up to five years. Each buoy was expected to produce an average of 20 kW of power, with a peak output of 40 kW. The WEC buoys would be anchored in about 100 feet of water at a distance from shore of approximately 3,900 feet. The power would be transmitted to shore by means of an armored and shielded undersea power cable connected to a land transmission cable. The land cable would be routed to the existing MCBH Kane'ohe Bay electrical grid system.

In the Environmental Assessment, the Navy identified the following areas for analysis under NEPA: shoreline physiography, oceanographic conditions (i.e., coastal processes), marine biological resources, terrestrial biological resources, land and marine resource use compatibility, cultural resources, infrastructure, recreation, public safety, and visual resources.

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[14] California's environment and environmental regulatory structure are different from those of other states and other countries. Therefore, care should be taken when applying the information in these reports to projects proposed for California.

3.5.10. Summary and Next Steps

Environmental impacts from wave energy conversion devices will be site- and technology-specific. Structures associated with wave energy will have environmental impacts similar to other structures placed offshore, but there will also be impacts unique to wave energy devices. Each project proposed for California will need to undergo a project-specific environmental review under the regulatory structure described in more detail in the following section.

Although there is an existing body of knowledge regarding the impacts of offshore structures and activities, additional work is needed to better understand the expected impacts of actual WEC technologies under development, and in the most likely areas of deployment in California.

3.6. Permitting and Regulatory Issues

The environmental permitting process for projects located offshore California is complex, involving a variety of federal, state and local jurisdictions. This section outlines the permitting framework as it is expected to apply to wave energy projects in California. It is expected that wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny. Early involvement of stakeholders and regulatory agencies will help identify areas of concern, so that environmental issues can be addressed during the siting and design phase of the project.

3.6.1. Ocean Jurisdictions

The zones establishing national sovereignty over sea, airspace and economic resources is complex, with overlapping legal authorities and agency responsibilities.[15] The United Nations Convention on the Law of the Sea[16] establishes the sovereignty of a coastal nation over its territorial seas (out to 12 nautical miles[17]) and defines exploitation rights in the Exclusive Economic Zone (out to 200 nautical miles). As shown in the figure below, in the United States the boundary between state and federal jurisdiction is located three nautical miles from the coastline. States have jurisdictional authority over and title to submerged lands out to three nautical miles offshore. Beyond the three-mile limit, the federal government is the primary jurisdictional authority, with the right to manage and develop resources in the seabed, including oil, gas, and all other minerals. Coastal states retain some approval authority over some projects in federal waters, as is discussed below.

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[15] See http://www.oceancommission.gov/documents/prepub_report/primer.pdf

[16] UNCLOS contains a legal framework covering navigation, maritime boundaries, fisheries, the marine environmental, etc. Since 1994, 138 nations have joined this Convention.

[17] One nautical mile is 1,852 meters (approximately 6,076 feet), or about 1.15 statute miles.

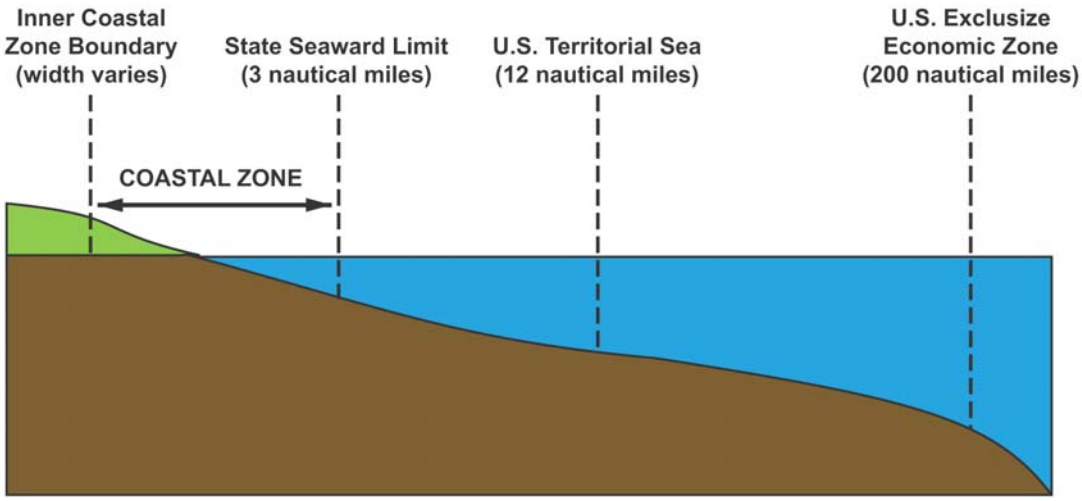

Figure 35 - Primary maritime boundaries

Wave energy devices may be located completely in state waters (i.e., all project elements located within three nautical miles of shore), or in both State and federal waters, with elements of the project located both beyond and within the three-mile limit (e.g.., an array located 5 miles offshore, with sub-sea transmission cables running to an onshore transmission facility). The location of a particular project determines which regulatory authorities apply and which approvals are required, as outlined below. For projects located completely within state waters, required approvals are expected to include:

- Project-specific environmental review under the National Environmental Policy Act (NEPA – for federal agencies) and the California Environmental Quality Act (CEQA – for state agencies)
- A license from the Federal Energy Regulatory Commission (FERC)
- A license from the US Coast Guard
- A permit from the Army Corps of Engineers under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act
- Possible federal consultation with National Oceanic & Atmospheric Administration (NOAA) Fisheries and/or the US Fish and Wildlife Service under the federal Endangered Species Act, the Magnuson-Stevens Fishery Conservation Act, and/or the Marine Mammal Protection Act
- A General Lease from the California State Lands Commission
- A Coastal Development Permit from the California Coastal Commission
- An Authority to Construct and a Permit to Operate from the regional Air Pollution Control District

- A 401 Certification, and possibly an National Pollutant Discharge Elimination System (NPDES) permit and Waste Discharge Requirements from the Regional Water Quality Control Board and/or the State Water Board
- Possible state consultation with the California Department of Fish and Game under the California Endangered Species Act
- Local approvals for those aspects of the project which are located onshore

For a project located both in state and federal waters, required approvals could include:

- Project-specific environmental review under NEPA (for federal agencies) and CEQA (for State agencies)
- A lease from the Minerals Management Service (for those elements in federal waters)
- A license from the Federal Energy Regulatory Commission
- A license from the US Coast Guard
- A permit from the Army Corps of Engineers under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act
- An Authority to Construct and a Permit to Operate for air emissions from the federal Environmental Protection Agency
- An NPDES permit for wastewater discharge from the federal Environmental Protection Agency
- Possible federal consultation with NOAA Fisheries and/or the US Fish and Wildlife service under the federal Endangered Species Act, the Magnuson-Stevens Fishery Conservation Act, and/or the Marine Mammal Protection Act
- A General Lease from the California State Lands Commission (for those elements in State waters)
- From the California Coastal Commission, a federal consistency certification for those elements of the project in federal waters, and a coastal development permit for those elements of the project in State waters
- A 401 Certification from the Regional Water Quality Control Board and/or the State Water Board
- Possible State consultation with the California Department of Fish and Game under the California Endangered Species Act
- Local approvals for those aspects of the project which are located onshore.

This list is not comprehensive. Depending on the location of the facility, additional regulatory review may be required, for example, if the project is located in a National Marine Sanctuary, or if it may disturb cultural resources. Conversely, a small pilot project located wholly in state

waters may not require, for example, a license from FERC, and other aspects of the environmental review process may not be as demanding.

The federal and state agencies listed above, and their respective legislative authorities, are discussed in more in Appendix B.

3.6.2. Summary and Next steps

Environmental and permitting issues are expected to be major considerations for wave energy projects, and more work needs to be done to fully understand them. As it relates to the PIER-funded research, more work is necessary to develop a realistic assessment of the permitting timeline and likelihood that a wave energy project will meet all the requirements. Understanding the preferred order in which to apply for all the permits would also be beneficial. Pacific Gas & Electric has taken some initial steps to evaluate the potential for a wave energy project off the coast of Mendocino and Humboldt counties. This study should begin to shed light on the specific impacts that can be expected from a real project. To the extent that this information is shared, it will benefit future potential projects.

3.7. Wave Energy Electricity Production Potential

Estimation of wave energy electricity generation potential requires not only knowledge about the resource, but also of the constraints on developing that resource and on the competitive economics. Figure 36 outlines a general approach for estimating market potential. It begins with a broad assessment of the resource and successively screens out components that (i) are not likely to be developed for technical (e.g., siting constraints due to environmental concerns, device spacing within and spacing between wave farms) and (ii) economic reasons (e.g., wave resource quality, distance to shore, access to onshore transmission). One can then apply a market penetration methodology to estimate how quickly the market may develop.

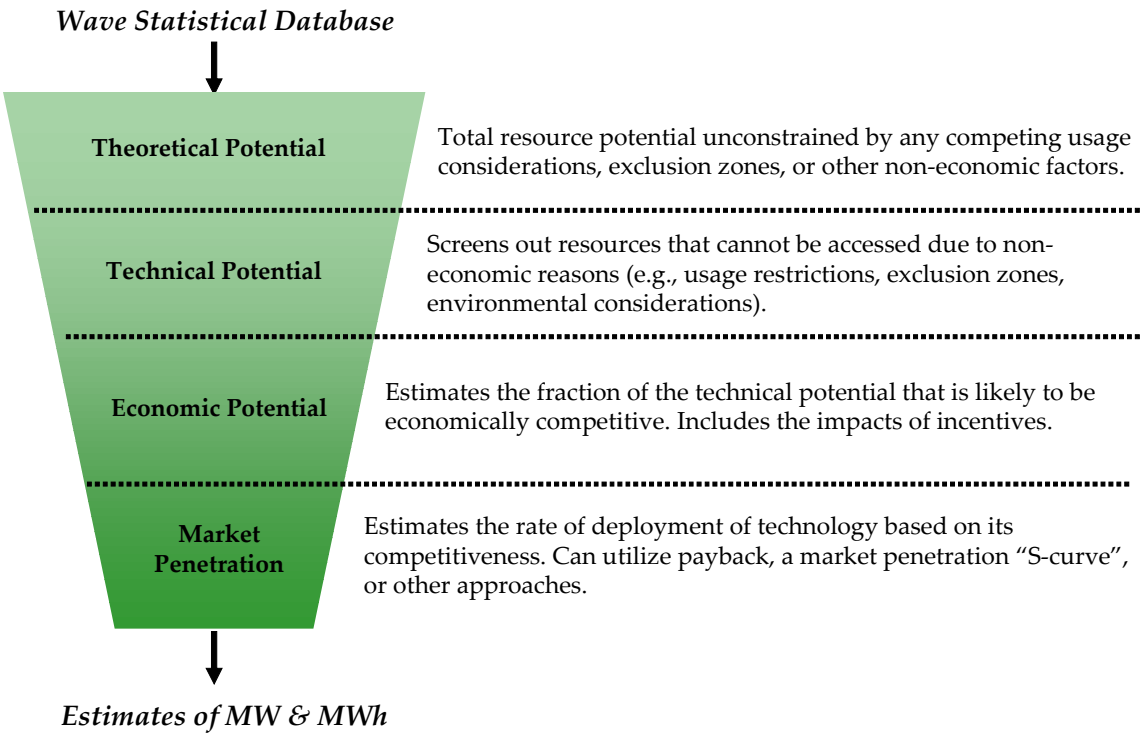

Figure 36. Typical methodology for estimating market potential

Source: Navigant Consulting, Inc.

Based on the wave energy resource assessment work done to date, it is possible to provide a preliminary estimate of the *theoretical potential*, which is summarized in Table 13. Table 13 was generated assuming the wave power densities in Table 4 extend across the whole cell. For cells 1 and 2, Table 13 uses buoy data from west of the Channel Islands, where the wave resource is more energetic than east of the Channel Islands. It is important to note that the estimate of theoretical potential does not factor in technical or economic constraints, nor is it the expected output from wave farms. Rather, it is a measure of the energy contained in the waves themselves. It is expected that after completing additional analysis recommended in the report, (e.g., of the constraints on development, such as the inability to develop projects in marine sanctuaries), the *technical potential* may be significantly smaller than the theoretical potential, possible by at an order of magnitude or more. Further analysis of the economics will also be necessary to estimate the potential contributions of wave energy to the California resource mix. It is also important to note that the data presented here are based on deep water (>100 meters) wave statistics, yet some WECs currently in development are designed to operate in shallower water where the wave resource is likely to be less energetic.

To estimate the theoretical potential, California's 1,250 km coastline was divided into two categories: primary and secondary sites (see Figure 37). Primary sites were defined as locations with the following attributes: reasonable permitting process (expected), good wave conditions and water depths greater than 50 meters within 10 miles of the coast. Secondary sites were

defined as locations for which it is expected to be difficult to obtain permits (e.g., marine sanctuaries) or sites that have to be located further offshore because of wave shadowing effects (e.g., Channel Islands in Southern California). Secondary sites would likely be developed only in the longer term, if at all, due to their higher costs and permitting constraints. Grid interconnection constraints were not evaluated as part of this study, but are expected to present further limitations as to where wave power plants could be located. In particular access to the transmission system is limited in parts of northern California where some of the better wave resources are located.

Table 13. California's *theoretical* deep water wave energy potential[18]

Cell	Landmark	Wave Power Density (kW/m)	Primary Sites Length (km)	Secondary Sites Length (km)	Primary Sites Power (MW)	Secondary Sites Power (MW)
1	San Diego[19]	32	0	162	0	5,184
2	Los Angeles[19]	32	35	104	1,120	3,328
3	Santa Barbara	26	127	0	3,302	0
4	Monterey	30	0	127	0	3,810
5	Santa Cruz	30	0	127	0	3,810
6	San Francisco	30	104	18	3,120	540
7	Sonoma	32	127	0	4,064	0
8	Mendocino	29	130	0	3,770	0
9	Humboldt	34	116	0	3,944	0
10	Del Norte	27	81	0	2,187	0
	Total		**720**	**538**	**21,507**	**16,672**

Source: PIER

In order to maintain a high capacity factor, which has a key impact on economics, wave energy conversion devices are tuned to the lower summer wave energy climate and, realistically, only a portion of the total available energy will be extracted. Furthermore, taking into account the need for shipping channels, other exclusions and inter-device spacing, the fraction of the theoretical potential that may be exploitable could be in the range of 15-30%, depending on the technology used. For the purpose of this study, a factor of 20% is used. The resulting preliminary estimate of *technical potential* is:

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[18] This initial estimate is based on a simple multiplication of the linear coastline with the estimated wave energy levels in each cell.

[19] Wave power estimates are for west of the Channel Islands. East of the Channel Islands, the resource is about 1/3 – 1/4 these values.

Primary Sites:	4,301 MW
Secondary Sites	3,334 MW
Total	7,635 MW

Technologies deployed or currently under development have capacity factors in the range of 40-60%. For the purpose of this study, a 50% capacity factor is used. The resulting energy produced per year is:

Primary sites	18,840 GWh
Secondary Sites	14,604 GWh
Total	33,444 GWh

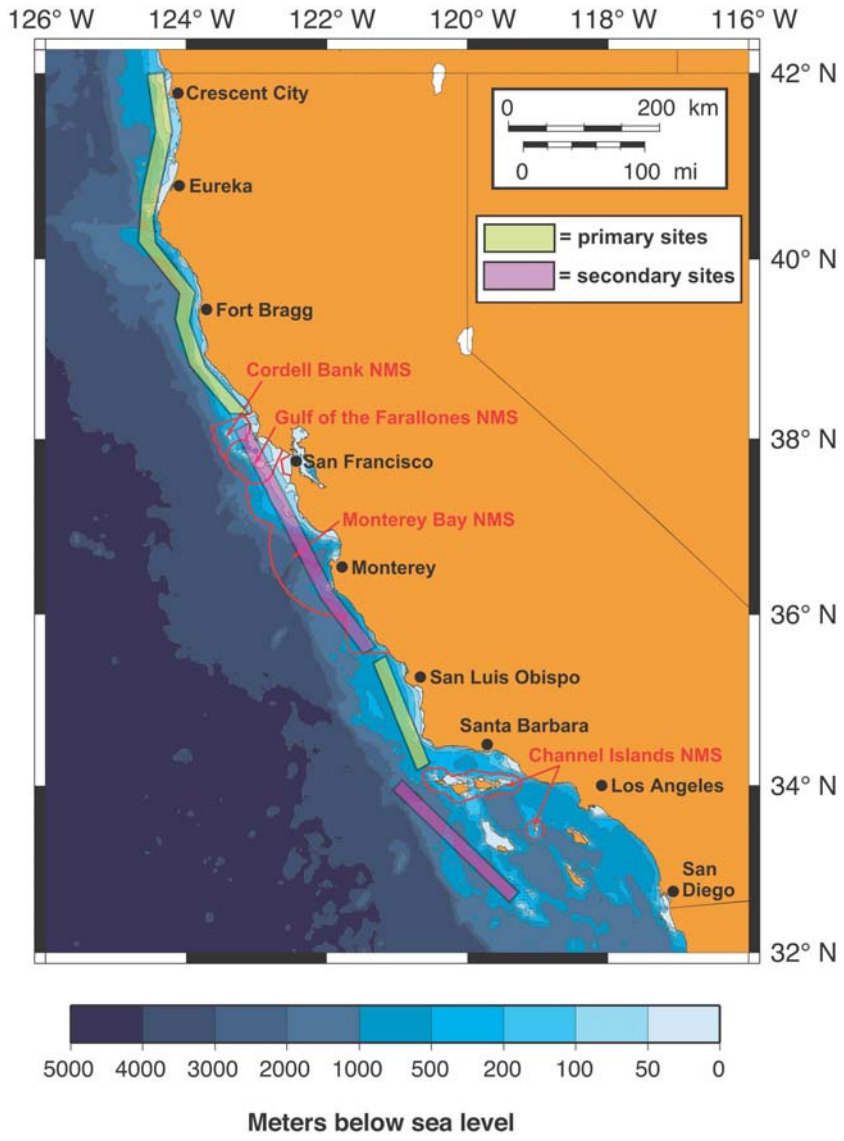

Figure 37. Identification of Primary and Secondary Sites for Wave Farm Development.
Source: PIER.

3.7.1. Next Steps

The following steps are considered necessary to develop a refined estimate of the potential for wave energy in California:

- Conduct a Geographical Information System (GIS) survey to screen out locations for reasons such as shipping lanes, marine sanctuaries, and other exclusions. This analysis should also include an assessment of the location of on-shore facilities needed, including electric transmission, shipyards, and ports.

- For the remaining area, conduct a more detailed assessment of wave farm deployment, including device spacing, inter-farm spacing, and device performance
- Refine the economic analysis and conduct a basic market penetration analysis

4.0 Conclusions and Recommendations

4.1.1. Wave Resource Assessment

A database of deep water wave characteristics has been assembled from buoy data using representative buoys in ten different regions off the California coast. The wave resources north of Point Conception are estimated to be between 26-34 kW/m. This represents a potentially attractive wave climate and in many cases is found within a few miles of shore due to the favorable bathymetry of the waters of the California coast. However, in many areas, one challenge may be finding good sites for wave farms that are also close to onshore transmission lines.

South of Point Conception, wave energy is estimated to be lower (7-13 kW/m) because of the blockage of swells by Point Conception and the Channel Islands. In order to access more energetic waves south of Point Conception, it would be necessary to go farther offshore, which would increase the cost of wave projects, all else equal.

The estimated wave energy resource, when combined with the large size of the California coastline, implies a *theoretical potential* of more than 38 GW. Of this, a preliminary estimate of the *technical potential* is 20% of this amount, or about 8 GW. These estimates should be viewed as preliminary as not enough is yet known about constraints to the development of wave energy in California to provide a realistic estimate of how much of this could actually be developed. For example, sensitive marine habitat, other exclusions, and access to the transmission grid are expected to have a significant impact on the amount of the wave resource that is technically and economically viable. For smaller projects in may be possible to interconnect to the sub-transmission or distribution grid, which may facilitate siting. It is also important to note that the estimates presented here are based on deep water (>100 meters) wave statistics, yet most WECs currently in development are designed to operate in shallower water where the wave resource is likely to be less energetic.

4.1.2. Wave Energy Conversion (WEC) Technology and Economics

Wave energy conversion designs and technologies were profiled, along with some of the companies developing them (Table 14) . In general, the most advanced WEC technologies are just now entering initial commercial deployment, in projects that are 2-3 MW in size (representing the deployment of 1-4 devices). Most WEC technologies are still in the prototype stage. Of the devices reviewed, the Pelamis from Ocean Power Delivery appears to be the most mature, followed by the Energetech Oscillating Water Column (OWC), but is important to note that developments are occurring on a regular basis, and the reader is advised to seek out other data sources for the latest developments.

Table 14: Examples of WEC technologies (not a complete list)

Company & WEC Name	Device Type & Size	Commercial Status (Q1 2007)
AWS Ocean Energy Archimedes Wave Swing	Submerged point absorber, 2 MW	Refined/Commercial prototype
Energetech OWC	Oscillating water column, 1-2 MW	Commercial prototype
Ocean Power Delivery Pelamis	Floating, Hinged attenuator, 750 kW	Market entry (3-4 unit "farms")
Ocean Power Technologies PowerBuoy	Floating point absorber, 40 kW	Initial system prototype
Wave Dragon	Floating overtopping, 20 kW	Initial system prototype

As an emerging technology, wave energy does not have a commercial track record to aid in estimating project economics. In 2004, EPRI published detailed economic analysis of two hypothetical wave farms in the 100-150 MW range, one based on the Pelamis, the other on the Energetech OWC, to be sited of the coast of San Francisco with a wave resource of 21 kW/m. The studies' assumptions were for commercial scale plants with costs extrapolated from pilot scale estimates, i.e., they were not meant to represent mature technology cost levels that could be expected from further development and deployment of the technology over time. Uncertainties in the cost estimates were reported to be +35% / -25%.

The economic analyses showed a levelized cost of electricity (LCOE) in the range of 10-11 ¢/kWh, assuming incentives similar to those currently available for wind power would be available to wave power.[20] When a range of wave resource values is considered (from 8-38 kW/m) the LCOE ranges from about 7-20 ¢/kWh for the same financial assumptions.

Initially, one can expect LCOEs to be significantly higher than these values for two basic reasons. First, the deployment of relatively unproven technologies entails greater risks for investors, which is typically reflected in a higher cost of capital. For example if the 6.9% real fixed charge rate used to develop the above estimates was instead 10%, then the Energy Commission estimates that LCOE for the Pelamis and the OWC would be about 15¢/kWh and 12¢/kWh, respectively. At a fixed charge rate of 15%, the LCOEs are about 19¢/kWh and 16¢/kWh, respectively. Second, initial deployments of the technology will likely involve much smaller wave farms. Thus, it is not unreasonable to expect that if California is chosen for early commercial projects, that the LCOE for these projects will exceed 15¢/kWh, and possibly 20¢/kWh. With that said, however, the LCOE associated with early projects is not necessarily an important metric, as these projects will provide valuable information on WEC performance, including environmental impacts.

[20] The net effect of incentives was expressed in the EPRI reports in the real fixed charge rate used in the analysis, which was 6.9%.

Conversely, it can be expected that if wave power is successfully commercialized and deployed more broadly, that this will drive down the cost of electricity below these levels. There is substantial empirical support for such "learning curve" effects, and it is reasonable to expect that wave energy, like wind power and solar power, has opportunities for reaping the benefits of manufacturing economies of scale.

4.1.3. Permitting and Regulatory Issues

The likely environmental impacts for WEC technologies were reviewed at a high level, along with a review of the necessary permits that would need to be obtained for development.

The construction, operation, and decommissioning of structures in the water and on land have the potential to affect terrestrial and marine environmental resources. The most significant impacts may actually occur during the construction/installation phase of a wave energy project. During this phase, impacts could come from:

- Directional drilling through the shoreline
- Cable burial on the ocean floor
- Set down of anchors or installation of other permanent structures into the seafloor
- Drilling into the seabed for heavy-uplift anchors
- Cable laying and other operational activities
- Additional onshore transmission to connect to the nearest grid interconnection point

Once the wave farm is installed, the main impacts are expected to result from increased operational activity to maintain the facility, as well as the direct impacts of the WECs themselves. Potential environmental and siting issues posed by wave-energy devices include:

- Coastal processes
- Ocean effects
- Onshore effects
- Water quality
- Air quality
- Visual resources
- Use conflicts
- Geology

These all need to be better understood to fully assess the potential for wave energy in California. Pacific Gas & Electric has taken some initial steps to evaluate the potential for a wave

energy project off the coast of Mendocino and Humboldt counties. This study should begin to shed light on the specific impacts that can be expected from a real project.

The environmental permitting process for projects located offshore California is complex, involving a variety of federal, state and local jurisdictions. It is expected that wave energy projects proposed for offshore California will be subject to a high level of public and regulatory scrutiny. Wave energy devices may be located completely in State waters, or more likely, in both State and federal waters

4.1.4. Recommendations for Further Work

The goal of the PIER-funded research to date has been to characterize the wave energy potential and the suitability of wave energy in California. The results to date suggests that much of the California coast has good wave energy potential, and that over the long term, the economics could be attractive. However, a range of environmental and other factors have also been identified that could limit deployment of wave energy technology. Thus, more research is needed to characterize the *developable* potential. This will aid PIER in determining its role and the specific areas of research to support. Table 15 provides a summary of the recommendations contained throughout this report. These recommendations are focused on improving the quality of the data and addressing the very important question of how much of the resource may be ultimately be developable given the range of constraints that must be considered.

Table 15: Summary of recommendations for further work

Wave Resource Assessment	Validate and improve upon the results by comparing them to other studies and incorporating data from the COADS dataset
	Assess the statistical significance of the CDIP and NDBC buoy data used (data quality, span, and quantity)
	Develop wave roses to present wave characteristics
	Develop an estimate of the likely range of the wave energy resource in each analysis cell based on data from multiple buoys and on the above additional analysis. This should include processing the data is such as way as to facilitate analysis of WEC devices. This should also leverage additional work in the public domain.
	Analyze and understand seasonal and inter-annual variability and its potential significance
	Develop estimates of the wav resource within the 100 meter contour (shallow water)
Wave Energy Conversion Technologies and Economics	Assess the suitability and performance of WECs for the California wave climate
	Conduct additional economic analysis specific to California, and using a range of financing assumptions. It would also be useful to break out the impact of incentives since at present, wave energy is not eligible for the incentives applied in the EPRI analysis.

	Given the continual developments in the field, monitor progress on significant prototype development and commercial deployment
	Additional work is needed to better understand the expected impacts of actual WEC technologies under development, and in the most likely areas of deployment in California. This may eventually need to include field work and deployment of WEC devices to monitor and measure actual impacts.
Environmental and Permitting Issues	More work is necessary to develop a realistic assessment of the permitting timeline and likelihood that a wave energy project will meet all the requirements. Understanding the preferred order in which to apply for all the permits would also be beneficial.
	Conduct a Geographical Information System (GIS) survey to screen out locations for reasons such as shipping lanes, nature sanctuaries, and other exclusions. This analysis will also include an assessment of the location on shore facilities needed, including electric transmission, shipyards, and ports
Electricity Generation Potential	For the remaining area, conduct a more detailed assessment of wave farm deployment, including device spacing, inter-farm spacing, and device performance
	Refine the economic analysis and conduct a basic market penetration analysis

4.1.5. Benefits to California

California has set aggressive goals for renewable energy development and greenhouse gas reductions. Wave energy conversion is an emerging technology that can potentially help meet these goals. The deployment of wave energy technology would also further diversify California's electricity generation mix, which will help meet the state's energy needs and address energy price volatility.

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6.0 Glossary of Terms and List of Acronyms

6.1. Glossary of Terms

Bathymetry: The measurement of the depth of bodies of water, particularly of oceans and seas.

Benthic: of, relating to, or occurring at the bottom of a body of water.

Significant Wave Height (Hs): The significant wave height is a commonly used statistical measure for the wave height, and closely corresponds to what a trained observer would consider to be the mean wave height. It is defined as the average height of the highest one third of waves recorded in a given monitoring period.

Dominant wave period (Tpeak or Tp): Tp, also called peak wave period, is the reciprocal of the center frequency of the frequency band that has the largest energy. Dominant wave period corresponds to the period of the larger waves that occurred during the measurement time period (http://www.cefas.co.uk/science/glossary.htm_

Average wave period (Tz): The average or mean wave period. Also called the zero-crossing wave period (http://www.cefas.co.uk/science/glossary.htm)

Energy Period (Te): The energy period is defined as the period of a simple sinusoidal wave with the same energy as the real sea (http://www.carbontrust.co.uk/technology/technologyaccelerator/ME_guide2.htm).

Peak Wave direction: the mean direction at Tp (http://www.cefas.co.uk/science/glossary.htm)

6.2. List of Acronyms

CDIP: Coastal Data Information Project

CEQA: California Environmental Quality Act

COADS: Comprehensive Ocean-Atmosphere Data Set

EPRI: Electric Power Research Institute

FERC: Federal Energy Regulatory Commission

GIS: Geographical Information System

HDB: Horizontal Directional Boring

HDD: Horizontal Directional Drilling

ITC: Investment Tax Credit

LCOE: Levelized Cost of Energy

MCBH: Marine Corps Base Hawaii

MPA: Marine Protected Area

NDBC: National Buoy Data Center

NEPA: National Environmental Policy Act

NOAA: National Ocean and Atmospheric Administration

NPDES: National Pollutant Discharge Elimination System

O&M: Operation and Maintenance

OWC: Oscillating Water Column

PTC: Production Tax Credit

PIER: Public Interest Energy Research

RD&D: Research Development and Demonstration

WEC: Wave Energy Conversion

Appendix A: Wave Characteristics by Cell

Cell 1: San Diego County

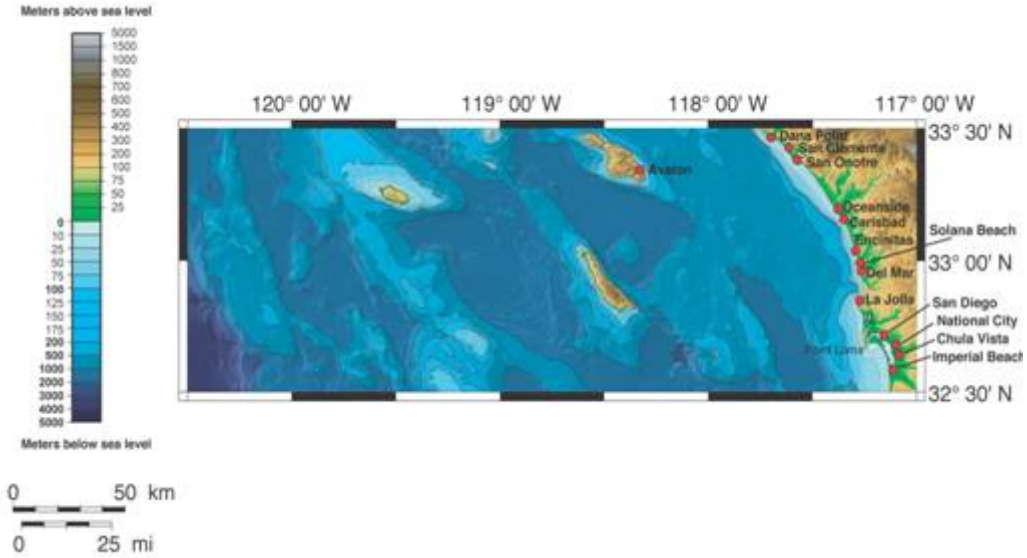

Figure 38. Cell 1 bathymetry

Table 16. Annual CDIP Wave Statistics off cell 1 for 100 to 1,000 m Water Depth.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WAVE (m)												
No. of Observations:	1,176	1,521	537	0	2,464	2,093	2,442	2,778	2,516	2,829	2,435	2,774
Minimum	0.45	0.44	0.54	0.00	0.38	0.41	0.40	0.42	0.43	0.37	0.38	0.32
Maximum	7.56	4.48	4.78	0.00	3.37	3.87	3.93	6.64	6.26	6.94	4.15	3.06
Median	1.04	0.92	1.53	0.00	0.90	0.86	0.99	0.94	0.89	0.96	0.94	0.97
Mean	1.12	1.05	1.66	0.00	0.97	0.95	1.10	1.03	0.96	1.05	1.09	1.06
STD	0.50	0.46	0.75	0.00	0.36	0.38	0.45	0.44	0.37	0.46	0.51	0.40
Variance	0.25	0.21	0.57	0.00	0.13	0.14	0.20	0.19	0.14	0.21	0.26	0.16
PERIOD (sec)												
No. of Observations:	1,176	1,521	537	0	2,464	2,093	2,442	2,778	2,516	2,829	2,435	2,774
Minimum	4.13	4.74	4.92	0.00	4.00	3.88	4.13	4.20	3.82	4.00	4.34	3.94
Maximum	25.60	25.60	21.33	0.00	18.29	18.29	19.69	19.69	28.44	28.44	19.69	19.69
Median	12.80	12.80	12.80	0.00	12.80	11.64	12.80	12.80	12.80	12.80	12.80	12.80
Mean	11.86	11.77	12.68	0.00	11.73	11.48	11.90	12.55	12.60	12.04	12.21	12.19
STD	2.68	2.55	2.07	0.00	2.47	2.67	2.72	2.73	2.97	3.09	2.84	2.79
Variance	7.16	6.49	4.28	0.00	6.13	7.13	7.40	7.46	8.85	9.56	8.08	7.76
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Long Term Avg. Yrs.
WAVE (m)											
No. of Observations:	852	2,782	1,661	6,492	23,491	28,591	23,797	34,680	58,663	35,686	21
Minimum	0.48	0.46	0.12	0.44	0.33	0.40	0.38	0.37	0.30	0.31	0.39
Maximum	2.75	3.36	6.00	6.28	3.70	4.68	4.73	4.49	3.86	4.10	4.71
Median	1.05	1.01	1.08	1.10	0.99	1.12	1.02	0.96	0.93	0.89	1.00
Mean	1.09	1.11	1.29	1.19	1.07	1.27	1.09	1.04	1.01	0.97	1.10
STD	0.31	0.39	0.69	0.40	0.41	0.55	0.41	0.38	0.36	0.37	0.44
Variance	0.10	0.15	0.48	0.16	0.16	0.30	0.17	0.14	0.13	0.14	0.21
PERIOD (sec)											
No. of Observations:	852	2,782	1,661	6,492	23,491	28,591	23,797	34,680	58,663	35,686	21
Minimum	4.74	3.51	4.20	3.24	2.78	3.23	3.12	2.70	2.38	2.27	3.73
Maximum	21.33	18.29	28.44	25.60	20.00	22.22	22.22	22.22	22.22	20.00	22.25
Median	13.47	12.80	12.80	12.80	12.80	14.29	14.29	13.33	13.33	12.50	12.95
Mean	13.28	12.16	12.37	12.20	12.24	12.87	12.87	12.69	12.60	11.74	12.29
STD	2.77	2.87	3.06	3.62	3.25	3.72	3.77	3.71	3.74	3.63	3.03
Variance	7.65	8.23	9.36	13.13	10.54	13.86	14.23	13.74	13.99	13.15	9.44
DIRECTION (deg)											
No. of Observations:	0	0	117	4,597	18,479	26,362	23,797	34,680	58,663	35,686	8
Minimum	0.00	0.00	175.00	172.00	0.00	155.00	145.00	12.00	4.00	3.00	83.25
Maximum	0.00	0.00	296.00	308.00	356.00	317.00	359.00	318.00	315.00	346.00	326.88
Mean	0.00	0.00	257.02	233.29	234.85	234.28	231.65	233.64	232.61	243.96	237.66

Table 17. Scatter plot of NDBC Wave Statistics off cell 1 for 1,000+m water depth (NDBC 46047)

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	0	0	0	3	1	2	2	1	0	0	**10**
1.0 - 1.5	0	0	7	8	33	16	21	34	22	3	0	**143**
1.5 - 2.0	0	0	13	31	51	30	36	50	38	6	0	**256**
2.0 - 2.5	0	0	2	40	56	26	39	42	31	10	0	**245**
2.5 - 3.0	0	0	0	20	36	11	24	34	20	8	1	**154**
3.0 - 3.5	0	0	0	6	19	5	12	24	17	5	1	**88**
3.5 - 4.0	0	0	0	2	11	3	7	16	11	2	0	**52**
4.0 - 4.5	0	0	0	0	5	2	4	9	7	1	0	**28**
4.5 - 5.0	0	0	0	0	2	1	2	4	4	1	0	**14**
5.0 - 5.5	0	0	0	0	1	0	1	2	2	0	0	**6**
5.5 - 7.0	0	0	0	0	0	0	0	1	2	0	0	**4**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**0**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**0**	**23**	**106**	**217**	**95**	**147**	**218**	**156**	**36**	**2**	**1000**

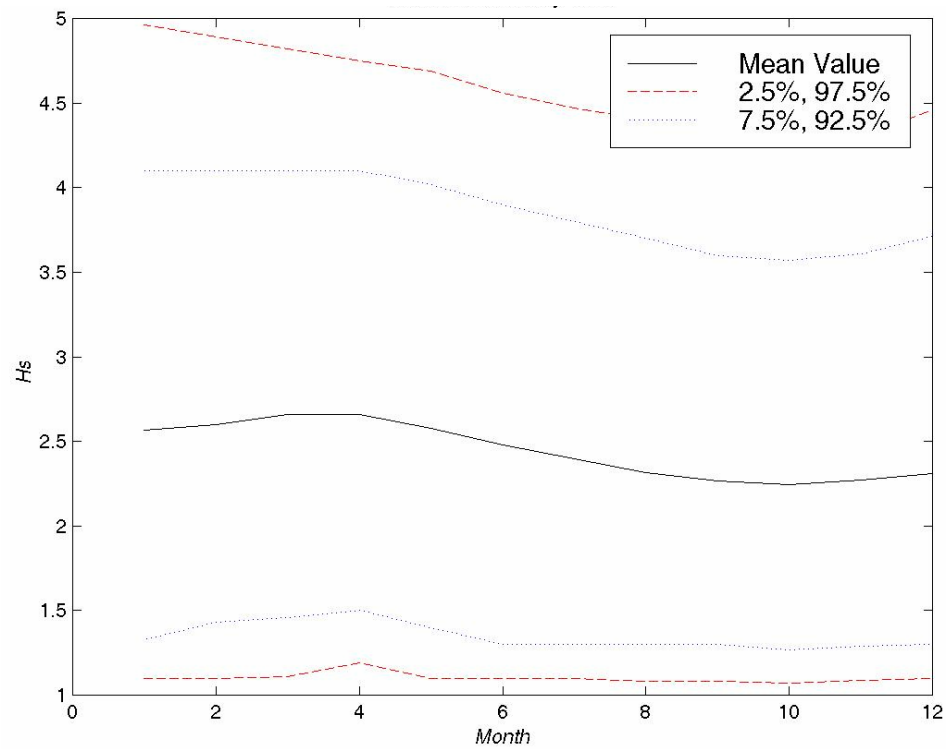

Figure 39. NDBC 46047 significant wave height seasonal variation

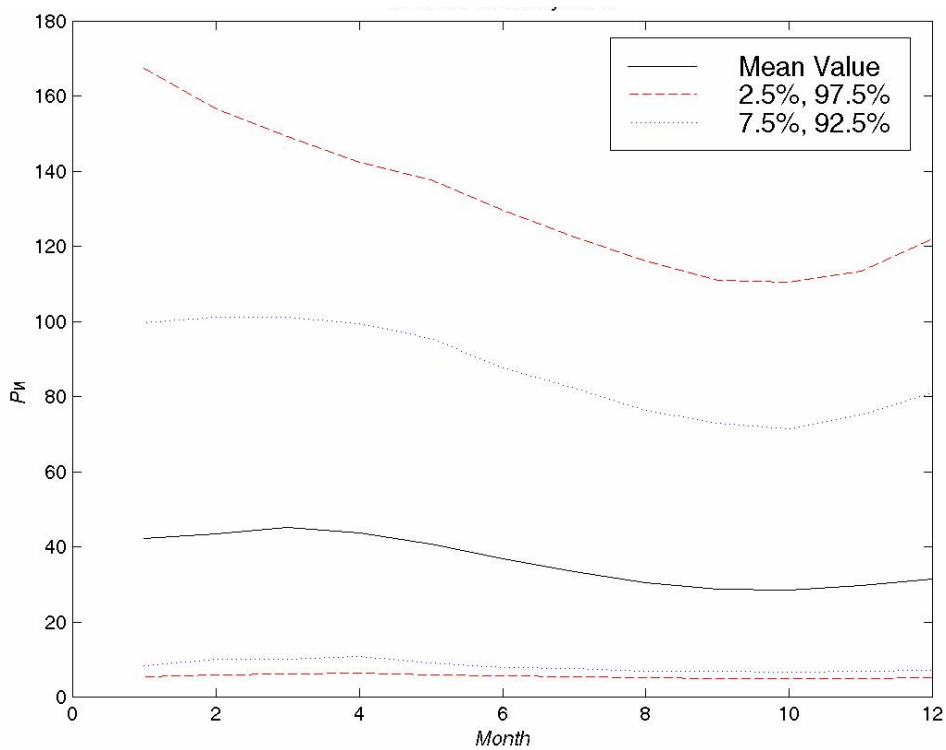

Figure 40. NDBC 46047 wave energy flux seasonal variation

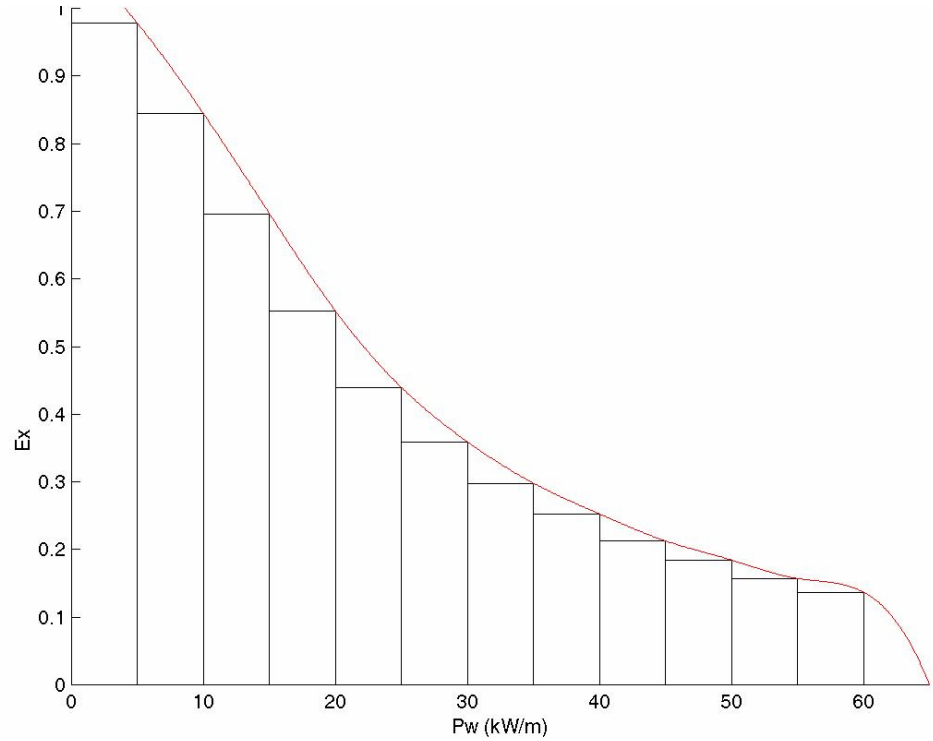

Figure 41. NDBC 46047 wave energy flux exceedance distribution

Cell 2: Orange, Los Angeles, Ventura, and Southern Santa Barbara Counties

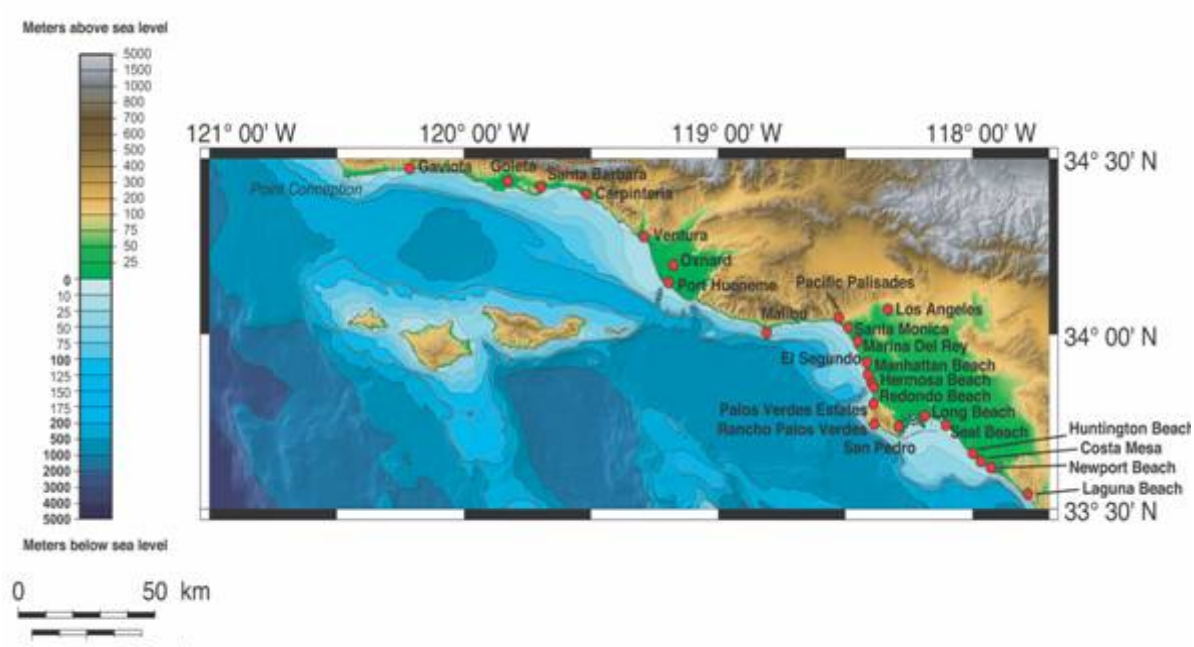

Figure 42. Cell 2 bathymetry

Table 18. Annual NDBC Wave Statistics off cell 2 for 100 to 1,000 m Water Depth

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WAVE (m)												
No. of Observations:	4,537	8,496	7,992	8,335	8,077	7,819	8,729	5,221	8,377	15,634	11,690	14,765
Minimum	0.20	0.10	0.30	0.40	0.30	0.30	0.40	0.40	0.40	0.30	0.00	0.10
Maximum	4.40	6.80	4.00	4.50	6.30	7.20	8.00	3.10	3.90	4.70	3.30	4.20
Median	1.00	1.20	1.20	1.10	0.90	1.00	1.00	1.00	1.10	0.90	1.00	1.00
Mean	1.13	1.39	1.29	1.20	1.06	1.15	1.08	1.08	1.14	1.00	1.09	1.05
STD	0.59	0.78	0.55	0.47	0.54	0.49	0.50	0.38	0.41	0.48	0.45	0.48
Variance	0.34	0.61	0.30	0.22	0.29	0.24	0.25	0.14	0.17	0.23	0.20	0.23
PERIOD (sec)												
No. of Observations:	4,537	8,496	7,992	8,335	8,077	7,819	8,729	5,221	8,377	15,634	11,690	14,765
Minimum	2.30	2.30	2.70	2.90	3.60	2.90	3.60	3.10	2.60	2.50	0.00	2.80
Maximum	99.00	99.00	99.00	99.00	99.00	25.00	99.00	99.00	25.00	25.00	20.00	25.00
Median	7.70	9.10	9.10	11.10	12.50	14.30	12.50	12.50	11.10	12.50	12.50	12.50
Mean	8.23	9.61	9.95	10.66	12.02	12.43	12.34	12.44	10.82	11.49	11.72	11.77
STD	5.24	5.85	3.92	3.90	4.17	3.91	4.24	5.79	4.08	3.78	3.61	3.77
Variance	27.41	34.17	15.35	15.21	17.37	15.28	17.98	33.57	16.63	14.32	13.00	14.24
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	8,632	11,688	14,765
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	349.00	355.00	344.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	238.59	243.22	241.95

	1994	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)									
No. of Observations:	28,433	32,200	34,036	21,407	34,238	35,031	34,394	32,180	20
Minimum	0.10	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.18
Maximum	5.50	7.60	4.97	5.15	7.15	8.50	6.96	7.95	5.71
Median	1.20	1.10	1.14	1.26	1.44	1.55	1.54	1.51	1.16
Mean	1.34	1.38	1.30	1.48	1.66	1.77	1.73	1.76	1.30
STD	0.67	0.80	0.62	0.76	0.90	0.89	0.85	0.93	0.63
Variance	0.44	0.64	0.38	0.57	0.80	0.80	0.72	0.87	0.42
PERIOD (sec)									
No. of Observations:	28,433	32,200	34,036	21,407	34,238	35,031	34,394	32,180	20
Minimum	2.80	2.60	2.63	0.00	0.00	0.00	0.00	0.00	1.97
Maximum	25.00	25.00	99.00	25.00	99.00	99.00	25.00	25.00	61.75
Median	11.10	11.10	11.11	11.11	12.50	12.50	12.50	12.50	11.59
Mean	10.76	11.12	11.14	11.18	11.87	11.78	11.69	11.75	11.24
STD	3.56	3.59	3.70	3.64	4.19	4.11	3.92	3.78	4.14
Variance	12.67	12.86	13.71	13.25	17.59	16.85	15.36	14.31	17.56
DIRECTION (deg)									
No. of Observations:	27,573	24,487	9,453	4,392	0	0	0	0	7
Minimum	0.00	20.00	18.00	5.00	0.00	0.00	0.00	0.00	6.71
Maximum	357.00	350.00	357.00	356.00	0.00	0.00	0.00	0.00	352.57
Mean	266.63	264.64	241.54	249.15	0.00	0.00	0.00	0.00	249.39

Table 19. Annual CDIP Wave Statistics off cell 2 for 100 to 1,000 m Water Depth

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WAVE (m)													
No. of Observations:	189	290	194	1,507	338	0	0	0	310	2,411	2,950	2,837	2,845
Minimum	0.67	0.71	0.69	0.34	0.34	0.00	0.00	0.00	0.57	0.66	0.51	0.51	0.53
Maximum	7.21	4.86	5.97	3.06	2.38	0.00	0.00	0.00	2.86	7.22	9.21	4.58	5.01
Median	1.38	1.62	2.71	0.89	0.82	0.00	0.00	0.00	1.26	1.79	1.67	1.50	1.55
Mean	1.65	1.80	2.79	0.95	0.94	0.00	0.00	0.00	1.35	2.03	1.84	1.60	1.72
STD	1.05	0.66	0.97	0.36	0.42	0.00	0.00	0.00	0.45	0.98	0.79	0.55	0.71
Variance	1.11	0.44	0.95	0.13	0.18	0.00	0.00	0.00	0.20	0.95	0.62	0.31	0.51
PERIOD (sec)													
No. of Observations:	189	290	194	1,507	338	0	0	0	310	2,411	2,950	2,837	2,845
Minimum	2.91	4.74	6.10	4.00	3.46	0.00	0.00	0.00	4.57	4.65	5.02	4.92	5.12
Maximum	25.60	16.00	18.29	21.33	18.29	0.00	0.00	0.00	16.00	36.57	19.69	19.69	19.69
Median	9.14	9.85	11.64	11.64	11.64	0.00	0.00	0.00	9.14	12.19	11.64	11.64	11.13
Mean	10.23	10.17	11.22	11.14	11.41	0.00	0.00	0.00	9.69	12.20	11.43	11.32	11.01
STD	3.77	2.63	2.18	3.12	3.19	0.00	0.00	0.00	2.75	2.96	2.72	2.98	2.78
Variance	14.22	6.91	4.76	9.72	10.18	0.00	0.00	0.00	7.57	8.78	7.38	8.90	7.73
DIRECTION (deg)													
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Long Term Avg. Yrs.
WAVE (m)													
No. of Observations:	2,834	2,679	2,638	2,650	5,416	5,715	7,559	34,908	35,843	47,679	61,197	38,383	22
Minimum	0.47	0.49	0.70	0.78	0.45	0.60	0.55	0.37	0.21	0.36	0.29	0.33	0.51
Maximum	5.17	4.96	5.02	6.06	6.82	6.66	6.16	6.70	6.57	6.66	7.23	6.08	5.75
Median	1.64	1.65	1.96	1.94	1.72	2.16	1.93	1.57	1.42	1.17	1.06	0.98	1.56
Mean	1.81	1.76	2.11	2.07	1.93	2.29	2.05	1.74	1.70	1.45	1.36	1.24	1.74
STD	0.78	0.75	0.81	0.78	1.03	0.86	0.83	0.91	0.95	0.82	0.81	0.71	0.77
Variance	0.61	0.56	0.66	0.61	1.06	0.74	0.68	0.83	0.90	0.67	0.66	0.50	0.63
PERIOD (sec)													
No. of Observations:	2,834	2,679	2,638	2,650	5,416	5,715	7,559	34,908	35,843	47,679	61,197	38,383	22
Minimum	5.02	5.12	5.12	5.12	3.85	3.45	5.12	2.56	2.22	2.70	2.38	2.04	4.10
Maximum	21.33	19.69	19.69	19.69	22.22	20.00	19.69	22.22	25.00	22.22	22.22	22.22	21.24
Median	11.13	11.64	11.64	11.13	12.19	12.50	11.13	10.24	11.11	11.76	11.76	10.00	11.18
Mean	11.27	11.43	11.55	11.05	11.88	12.26	10.87	11.03	11.26	11.39	11.24	10.40	11.16
STD	2.87	2.83	2.78	2.76	3.18	2.63	2.86	3.64	3.76	3.97	3.96	3.75	3.09
Variance	8.22	8.04	7.73	7.61	10.09	6.93	8.18	13.26	14.16	15.80	15.71	14.06	9.81
DIRECTION (deg)													
No. of Observations:	0	330	1,855	1,852	4,577	4,822	5,351	28,290	33,820	47,679	61,197	38,383	11
Minimum	0.00	192.00	152.00	151.00	125.00	111.00	150.00	87.00	59.00	4.00	1.00	1.00	93.91
Maximum	0.00	326.00	330.00	330.00	330.00	329.00	330.00	344.00	357.00	360.00	360.00	360.00	341.45
Mean	0.00	294.15	282.43	290.61	278.82	284.82	281.58	276.17	276.18	266.54	259.07	263.18	277.59

Table 20. Scatter plot of NDBC Wave Statistics for buoy NDBC 46045

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	2	1	2	2	4	4	9	12	4	0	0	**40**
0.5 - 1.0	0	11	64	76	65	39	76	157	87	12	0	**588**
1.0 - 1.5	0	1	28	72	42	23	34	43	23	5	0	**273**
1.5 - 2.0	0	0	4	23	12	6	10	14	2	1	0	**72**
2.0 - 2.5	0	0	1	9	4	2	3	3	0	0	0	**20**
2.5 - 3.0	0	0	0	2	1	0	0	1	0	0	0	**5**
3.0 - 3.5	0	0	0	0	1	0	0	0	0	0	0	**1**
3.5 - 4.0	0	0	0	0	0	0	0	0	0	0	0	**0**
4.0 - 4.5	0	0	0	0	0	0	0	0	0	0	0	**0**
4.5 - 5.0	0	0	0	0	0	0	0	0	0	0	0	**0**
5.0 - 5.5	0	0	0	0	0	0	0	0	0	0	0	**0**
5.5 - 7.0	0	0	0	0	0	0	0	0	0	0	0	**0**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**0**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**2**	**13**	**98**	**185**	**128**	**75**	**133**	**230**	**118**	**18**	**1**	**1000**

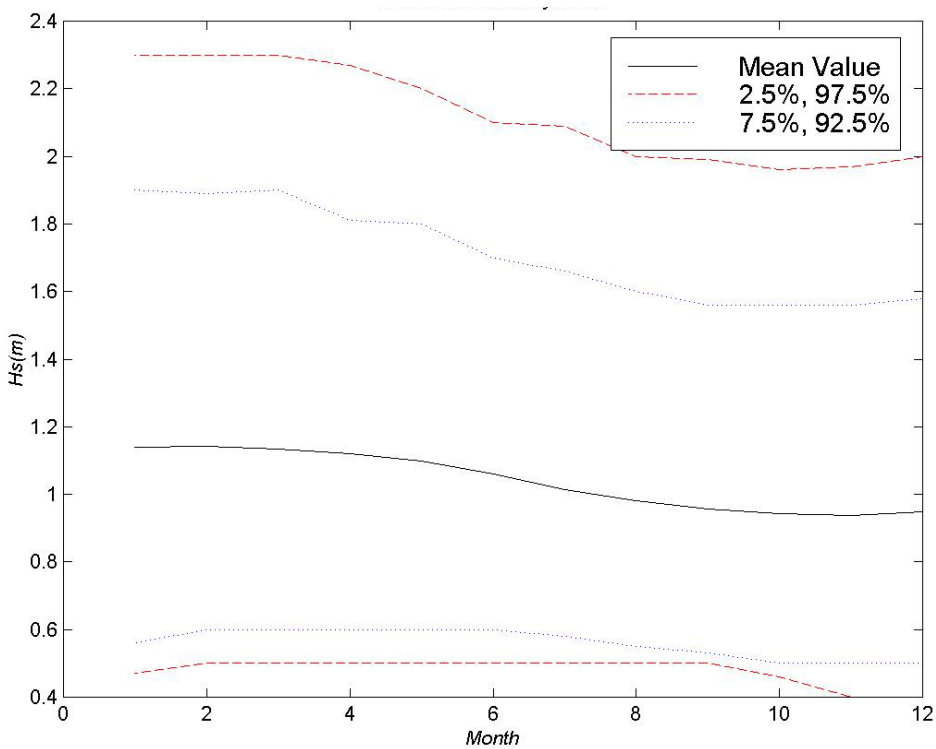

Figure 43. NDBC 46045 significant wave height seasonal variation

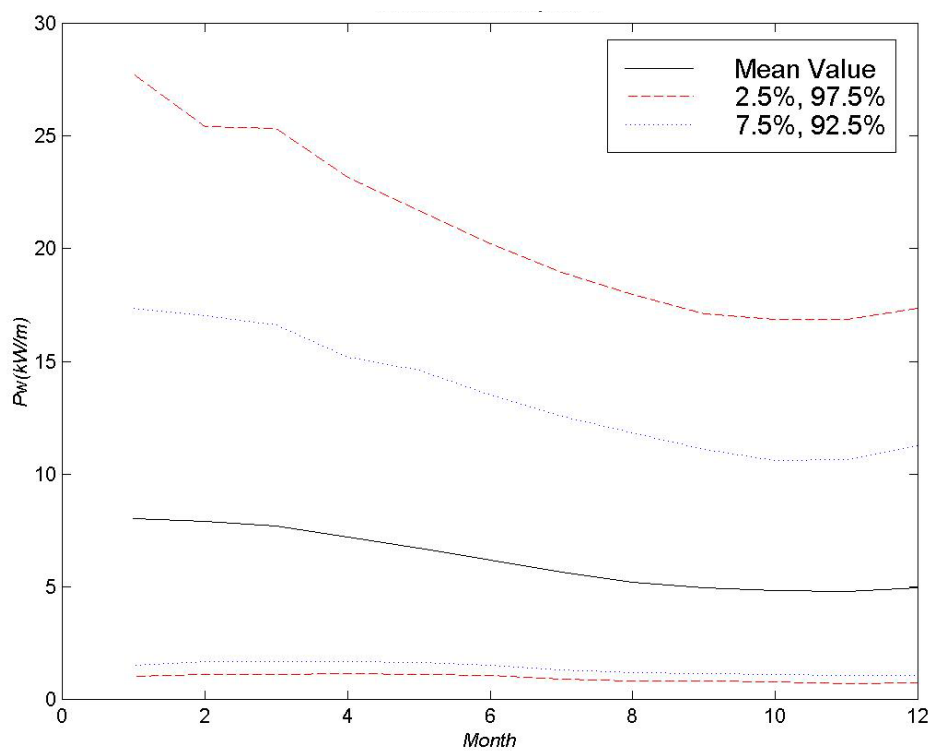

Figure 44. NDBC 46045 wave energy flux seasonal variation

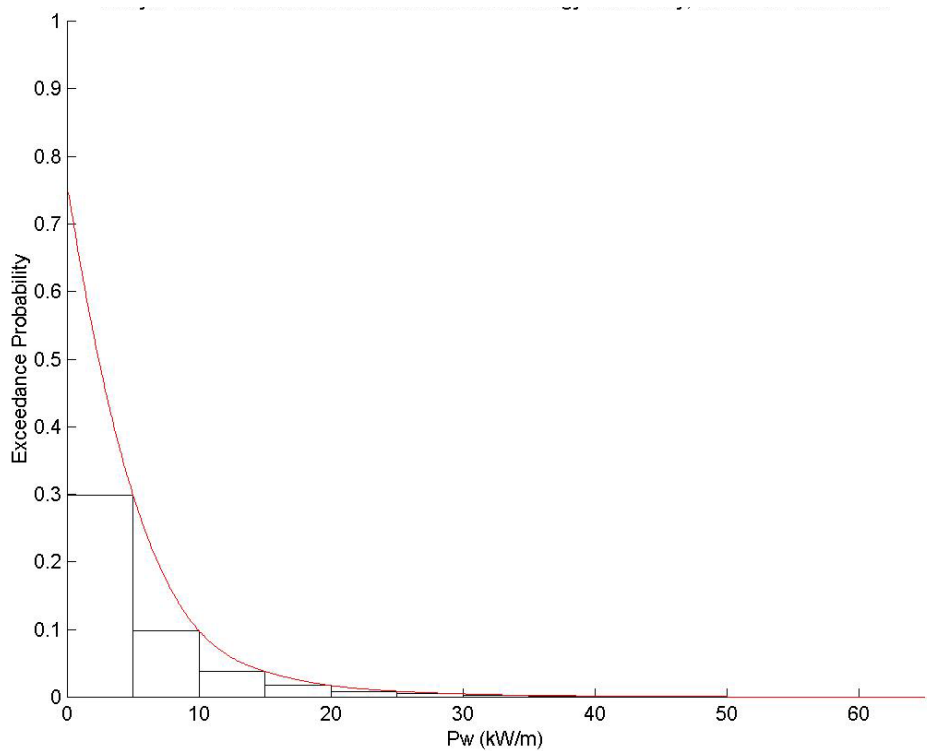

Figure 45. NDBC 46045 wave energy flux exceedance distribution

Cell 3: Northern Santa Barbara and Southern San Luis Obispo Counties

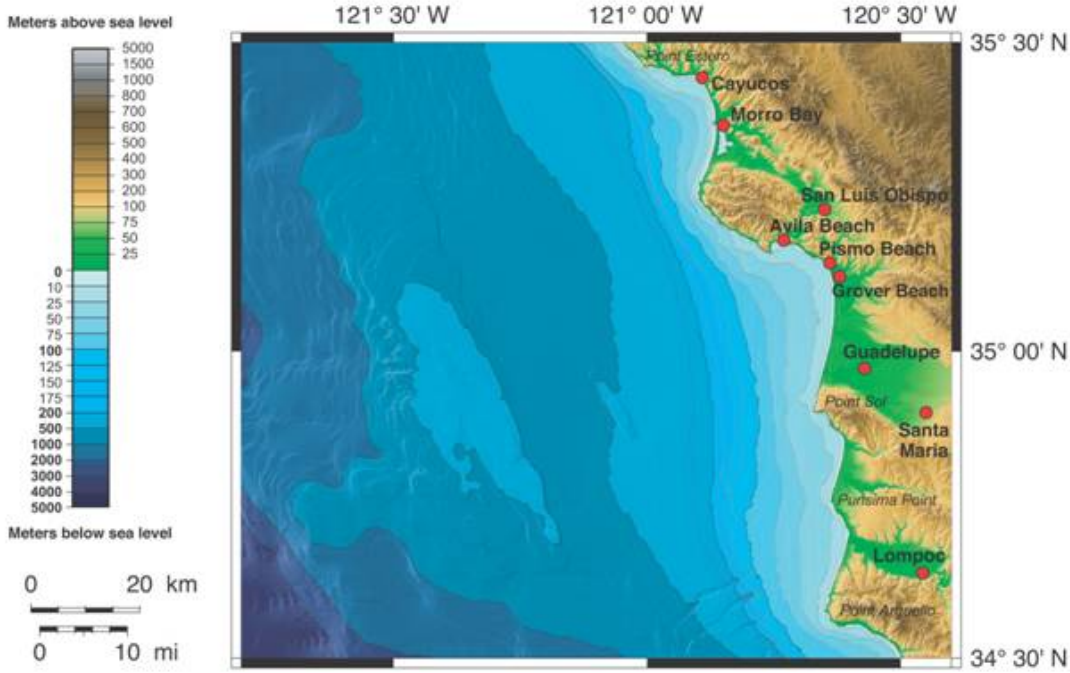

Figure 46. Cell 3 bathymetry

Table 21. Annual NDBC Wave Statistics off cell 3 for 100 to 1,000 m Water Depth

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
WAVE (m)												
No. of Observations:	2,025	7,909	13,426	14,314	12,331	15,548	15,288	11,301	14,148	15,410	12,749	15,307
Minimum	0.50	0.40	0.30	0.20	0.30	0.50	0.40	0.60	0.60	0.60	0.60	0.50
Maximum	5.20	7.10	8.00	8.20	7.30	8.00	8.10	6.40	9.20	5.50	6.00	8.00
Median	1.90	1.90	1.80	2.00	2.20	1.80	1.90	1.80	1.80	1.80	1.80	1.90
Mean	1.89	2.03	2.01	2.23	2.40	2.00	2.12	2.02	2.03	1.89	1.93	2.11
STD	0.78	0.91	1.00	1.07	1.00	0.81	0.93	0.89	0.81	0.64	0.72	0.85
Variance	0.61	0.82	1.00	1.15	1.00	0.65	0.86	0.79	0.65	0.41	0.52	0.72
PERIOD (sec)												
No. of Observations:	2,026	7,909	13,426	14,314	12,331	15,548	15,288	11,301	14,148	15,410	12,749	15,307
Minimum	0.00	3.40	2.40	2.30	3.70	2.90	3.00	4.00	3.20	3.40	3.40	3.60
Maximum	20.00	20.00	99.00	99.00	99.00	99.00	99.00	25.00	25.00	99.00	99.00	25.00
Median	12.50	10.00	10.00	10.00	11.10	11.10	11.10	12.50	11.10	11.10	11.10	11.10
Mean	11.93	10.52	10.19	10.81	11.49	11.64	11.73	11.97	11.62	11.49	10.92	11.54
STD	2.52	2.96	3.99	5.17	4.36	3.66	3.69	3.48	3.20	3.72	3.37	3.50
Variance	6.33	8.79	15.90	26.74	18.98	13.40	13.62	12.11	10.24	13.83	11.33	12.28
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)											
No. of Observations:	13,655	7,565	7,291	15,763	8,189	17,386	25,573	23,974	23,540	26,074	22
Minimum	0.60	0.80	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.34
Maximum	5.80	5.70	6.10	7.00	5.73	7.10	8.15	7.45	8.10	7.68	7.08
Median	1.90	2.10	1.90	1.90	1.91	1.98	2.11	2.08	1.99	2.06	1.93
Mean	1.98	2.21	2.10	2.16	2.04	2.15	2.43	2.23	2.13	2.24	2.11
STD	0.74	0.81	0.92	0.97	0.78	0.90	1.08	0.98	0.87	0.96	0.88
Variance	0.55	0.66	0.85	0.94	0.61	0.80	1.17	0.97	0.76	0.91	0.79
PERIOD (sec)											
No. of Observations:	13,655	7,565	7,291	15,763	8,189	17,386	25,573	23,974	23,540	26,074	22
Minimum	3.80	4.00	0.00	3.30	0.00	0.00	0.00	0.00	0.00	0.00	2.11
Maximum	25.00	25.00	25.00	25.00	25.00	25.00	25.00	99.00	25.00	25.00	51.45
Median	11.10	11.10	10.00	11.10	12.50	11.11	12.50	12.50	12.50	12.50	11.35
Mean	11.36	11.77	10.64	11.61	11.83	11.72	12.46	12.16	12.06	12.07	11.52
STD	3.38	3.38	3.65	3.40	3.27	3.40	3.52	3.73	3.67	3.49	3.57
Variance	11.43	11.44	13.34	11.55	10.72	11.55	12.39	13.90	13.45	12.15	12.97
DIRECTION (deg)											
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 22. Scatter plot of NDBC Wave Statistics for buoy NDBC 46011

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	1	0	0	0	0	0	0	1	1	0	0	**4**
0.5 - 1.0	0	1	3	4	16	5	6	10	4	0	0	**48**
1.0 - 1.5	0	0	17	27	76	26	27	35	23	3	0	**234**
1.5 - 2.0	0	0	13	52	81	33	37	30	19	4	0	**269**
2.0 - 2.5	0	0	2	39	50	25	34	27	13	4	0	**194**
2.5 - 3.0	0	0	0	12	27	13	23	23	9	3	0	**111**
3.0 - 3.5	0	0	0	2	14	6	11	20	9	2	0	**65**
3.5 - 4.0	0	0	0	0	6	3	6	13	7	1	0	**36**
4.0 - 4.5	0	0	0	0	2	2	3	6	5	1	0	**20**
4.5 - 5.0	0	0	0	0	1	1	1	3	3	1	0	**10**
5.0 - 5.5	0	0	0	0	0	0	1	1	2	0	0	**5**
5.5 - 7.0	0	0	0	0	0	0	0	1	3	0	0	**5**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**0**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**1**	**1**	**35**	**137**	**273**	**115**	**149**	**170**	**97**	**20**	**1**	**1000**

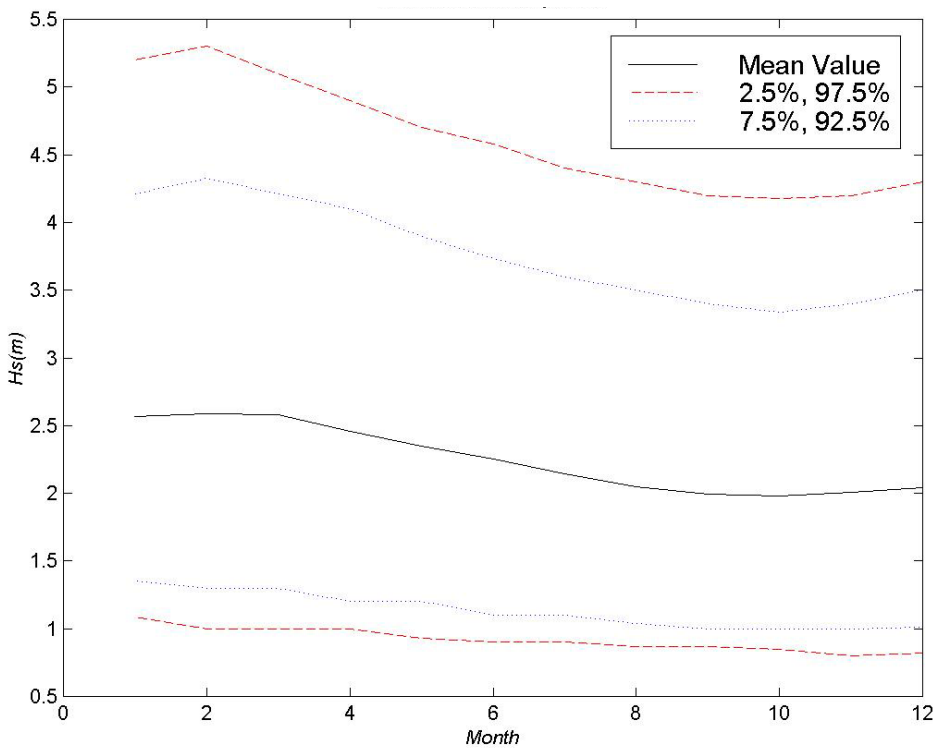

Figure 47. NDBC 46011 significant wave height seasonal variation

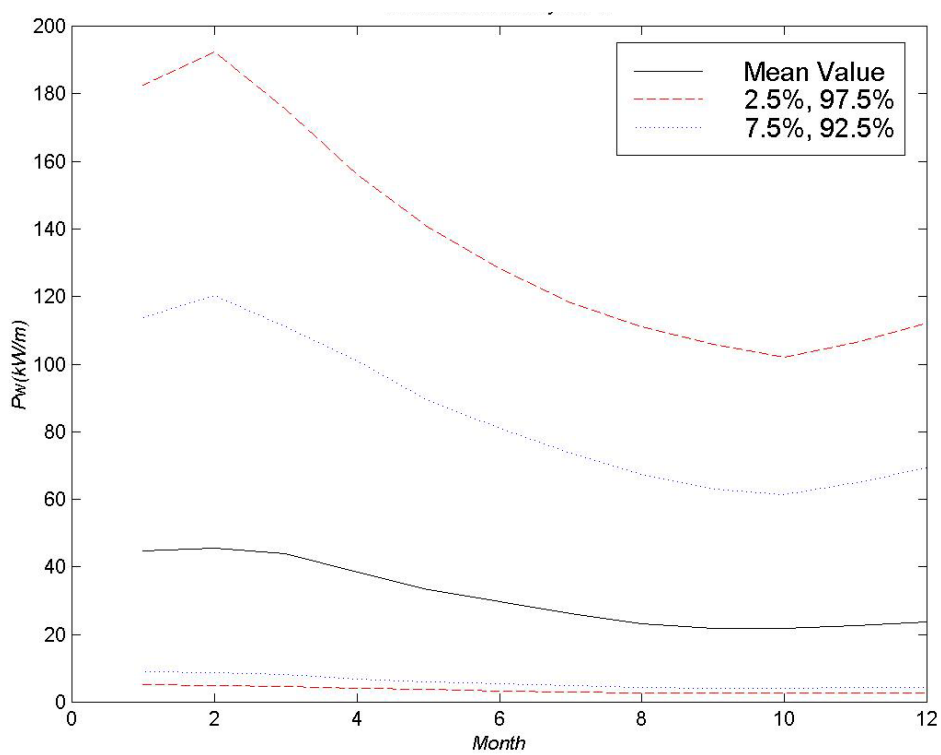

Figure 48. NDBC 46011 wave energy flux seasonal variation

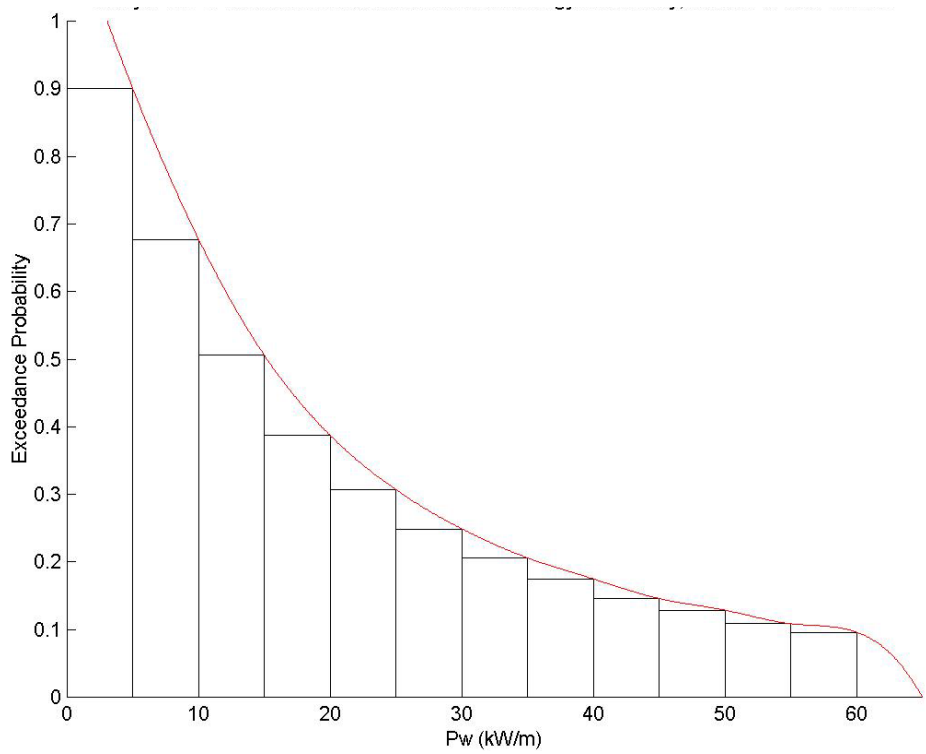

Figure 49. NDBC 46011 wave energy flux exceedance distribution

Cell 4: Northern San Luis Obispo and Southern Monterey Counties

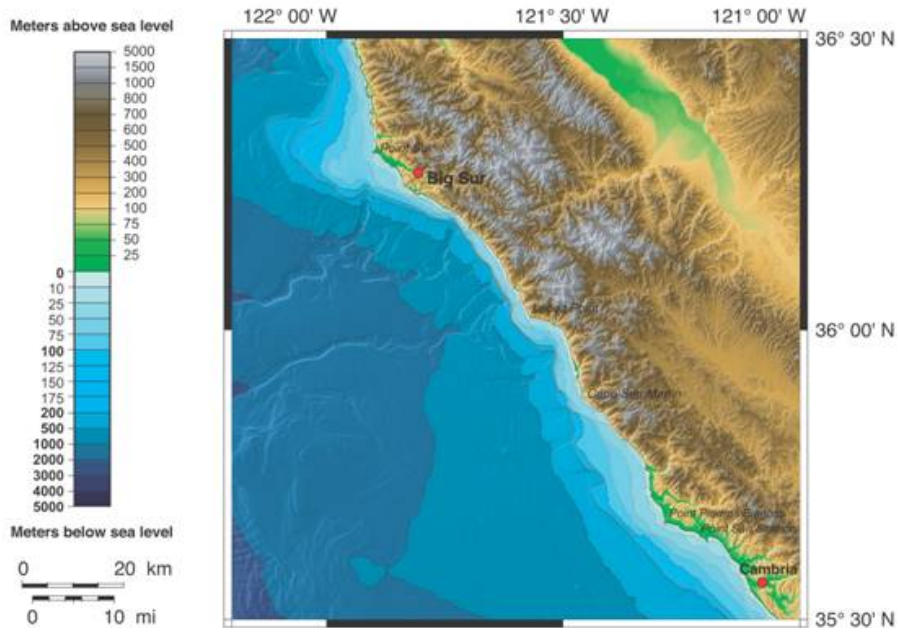

Figure 50. Cell 4 bathymetry

Table 23. Scatter plot of NDBC Wave Statistics for buoy NDBC 46028

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	0	0	1	4	1	3	5	2	0	0	**17**
1.0 - 1.5	0	1	8	10	41	15	18	31	21	3	0	**149**
1.5 - 2.0	0	0	26	24	75	31	33	32	24	4	0	**249**
2.0 - 2.5	0	0	16	41	61	27	34	28	16	5	1	**229**
2.5 - 3.0	0	0	2	27	39	16	27	27	12	4	0	**155**
3.0 - 3.5	0	0	0	9	22	10	17	22	9	3	0	**92**
3.5 - 4.0	0	0	0	2	10	5	8	17	7	2	0	**52**
4.0 - 4.5	0	0	0	0	4	3	4	9	6	1	0	**28**
4.5 - 5.0	0	0	0	0	2	2	2	4	4	1	0	**15**
5.0 - 5.5	0	0	0	0	1	1	1	2	2	0	0	**7**
5.5 - 7.0	0	0	0	0	0	1	1	1	3	0	0	**6**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**1**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**1**	**53**	**115**	**260**	**112**	**149**	**179**	**104**	**24**	**2**	**1000**

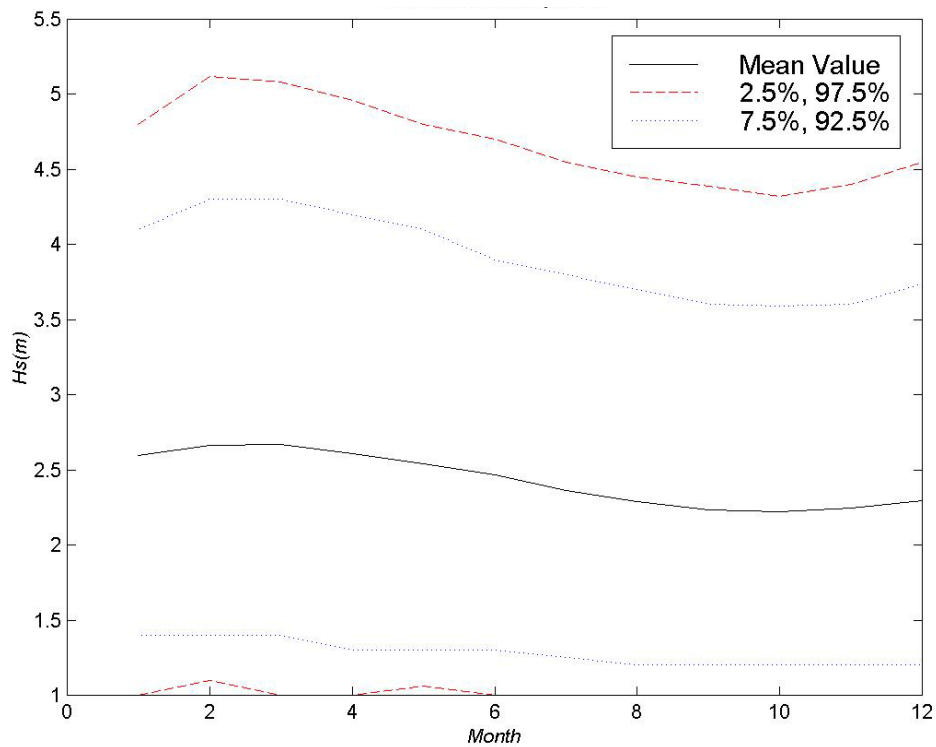

Figure 51. NDBC 46028 significant wave height seasonal variation

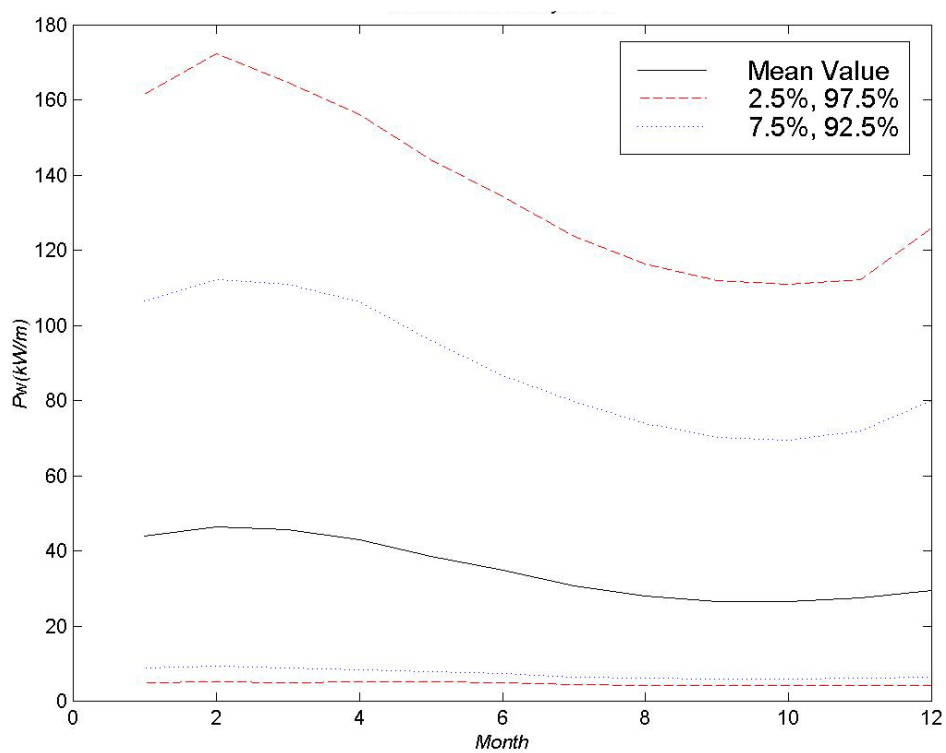

Figure 52. NDBC 46028 wave energy flux seasonal variation

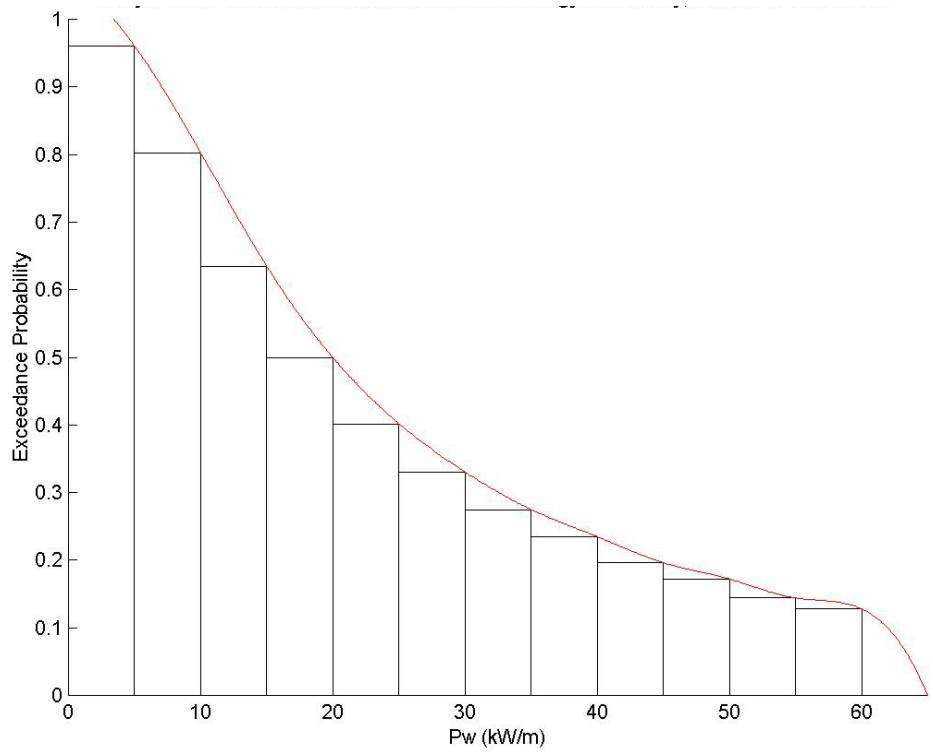

Figure 53. NDBC 46028 wave energy flux exceedance distribution

Cell 5: Northern Monterey and Southern San Mateo Counties

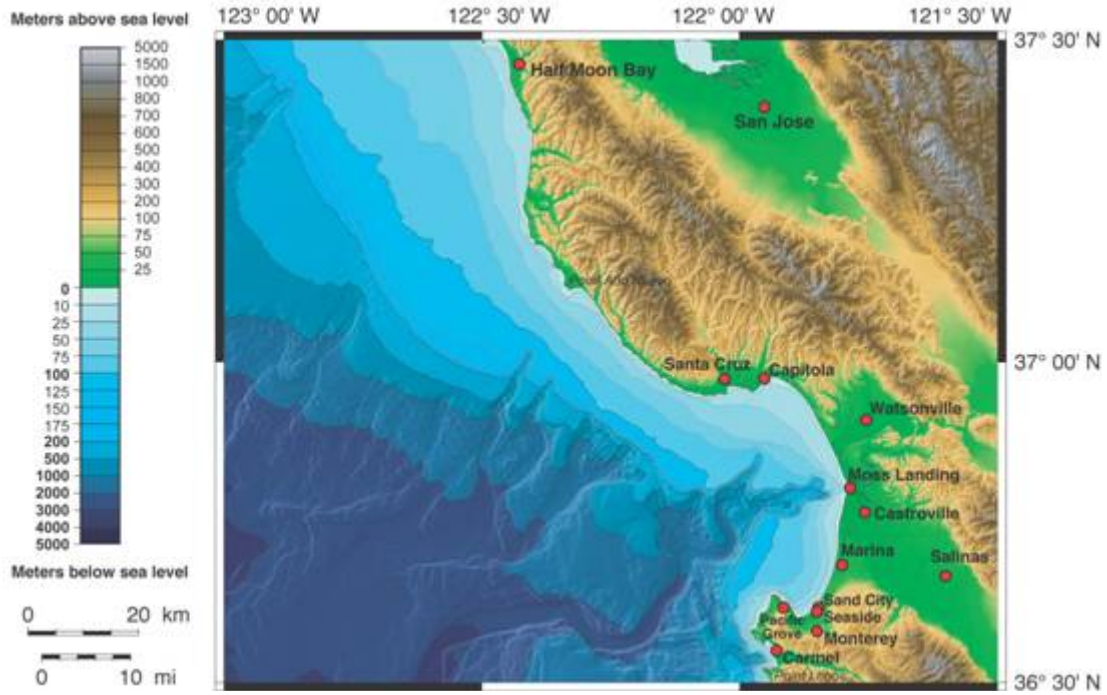

Figure 54. Cell 5 bathymetry

Table 24. Annual CDIP Wave Statistics off cell 5 for 100 to 1,000 m Water Depth

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Long Term Avg. Yrs.
WAVE (m)											
No. of Observations:	111	0	114	0	0	0	0	0	1,788	450	4
Minimum	0.76	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.06	0.19	0.45
Maximum	7.44	0.00	6.49	0.00	0.00	0.00	0.00	0.00	7.32	7.35	7.15
Median	2.52	0.00	2.09	0.00	0.00	0.00	0.00	0.00	1.67	2.19	2.12
Mean	3.11	0.00	2.17	0.00	0.00	0.00	0.00	0.00	1.94	2.30	2.38
STD	1.86	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.92	0.87	1.13
Variance	3.46	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.85	0.76	1.45
PERIOD (sec)											
No. of Observations:	111	0	114	0	0	0	0	0	1,788	450	4
Minimum	4.57	0.00	6.10	0.00	0.00	0.00	0.00	0.00	3.66	5.82	5.04
Maximum	25.60	0.00	25.60	0.00	0.00	0.00	0.00	0.00	19.69	23.27	23.54
Median	11.64	0.00	10.67	0.00	0.00	0.00	0.00	0.00	11.64	12.80	11.69
Mean	14.21	0.00	10.80	0.00	0.00	0.00	0.00	0.00	11.52	12.73	12.31
STD	5.88	0.00	2.94	0.00	0.00	0.00	0.00	0.00	2.77	2.28	3.47
Variance	34.54	0.00	8.63	0.00	0.00	0.00	0.00	0.00	7.66	5.21	14.01
DIRECTION (deg)											
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 25. Scatter plot of NDBC Wave Statistics for buoy NDBC 46042

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	0	1	2	6	2	5	7	2	0	0	**24**
1.0 - 1.5	0	0	8	21	53	17	25	41	19	2	0	**187**
1.5 - 2.0	0	0	8	43	83	34	36	36	22	3	0	**265**
2.0 - 2.5	0	0	2	20	70	31	38	27	15	4	0	**208**
2.5 - 3.0	0	0	0	7	39	17	29	27	11	3	0	**134**
3.0 - 3.5	0	0	0	3	18	10	19	22	9	2	0	**82**
3.5 - 4.0	0	0	0	1	10	5	10	16	6	1	0	**50**
4.0 - 4.5	0	0	0	0	4	3	5	9	5	1	0	**27**
4.5 - 5.0	0	0	0	0	1	1	2	5	3	1	0	**13**
5.0 - 5.5	0	0	0	0	0	1	1	2	2	0	0	**6**
5.5 - 7.0	0	0	0	0	0	0	1	1	2	0	0	**5**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**1**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**1**	**20**	**97**	**285**	**121**	**171**	**193**	**94**	**18**	**0**	**1000**

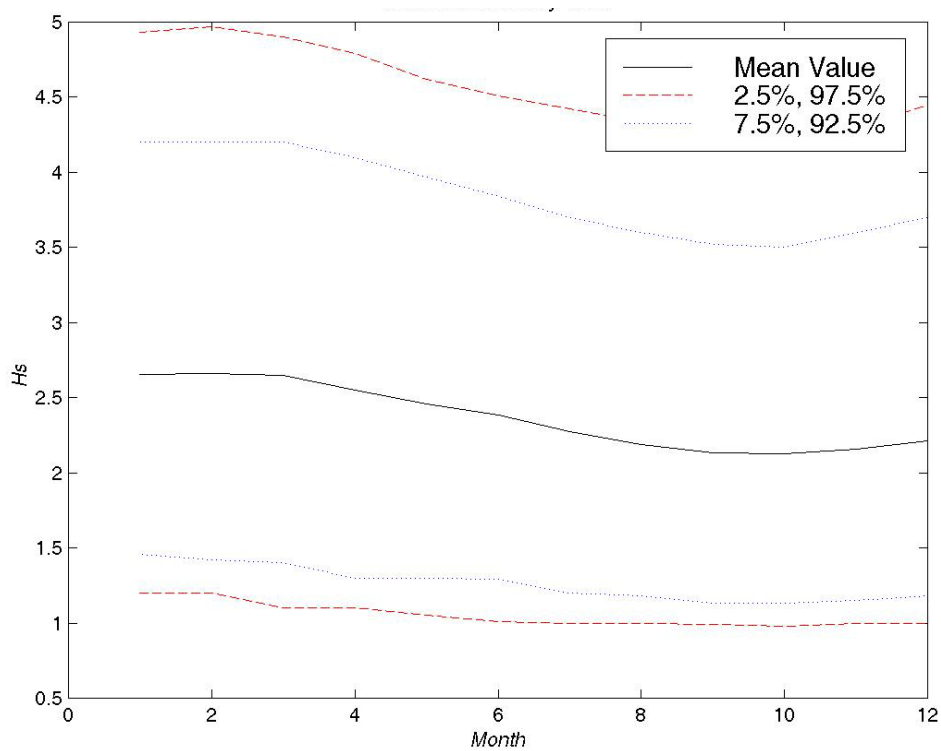

Figure 55. NDBC 46042 significant wave height seasonal variation

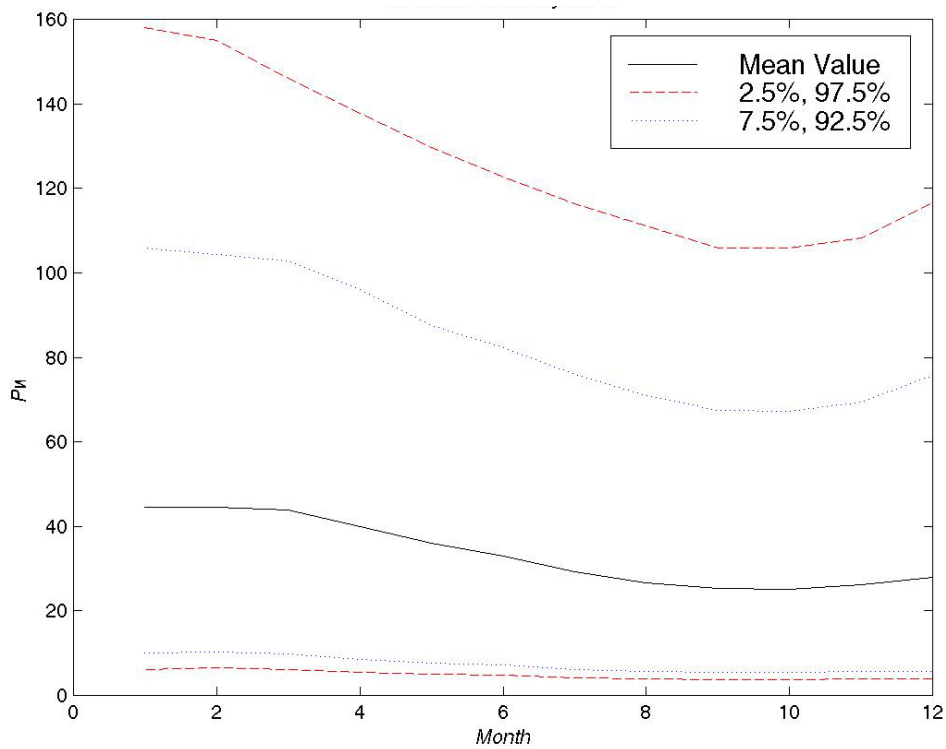

Figure 56. NDBC 46042 wave energy flux seasonal variation

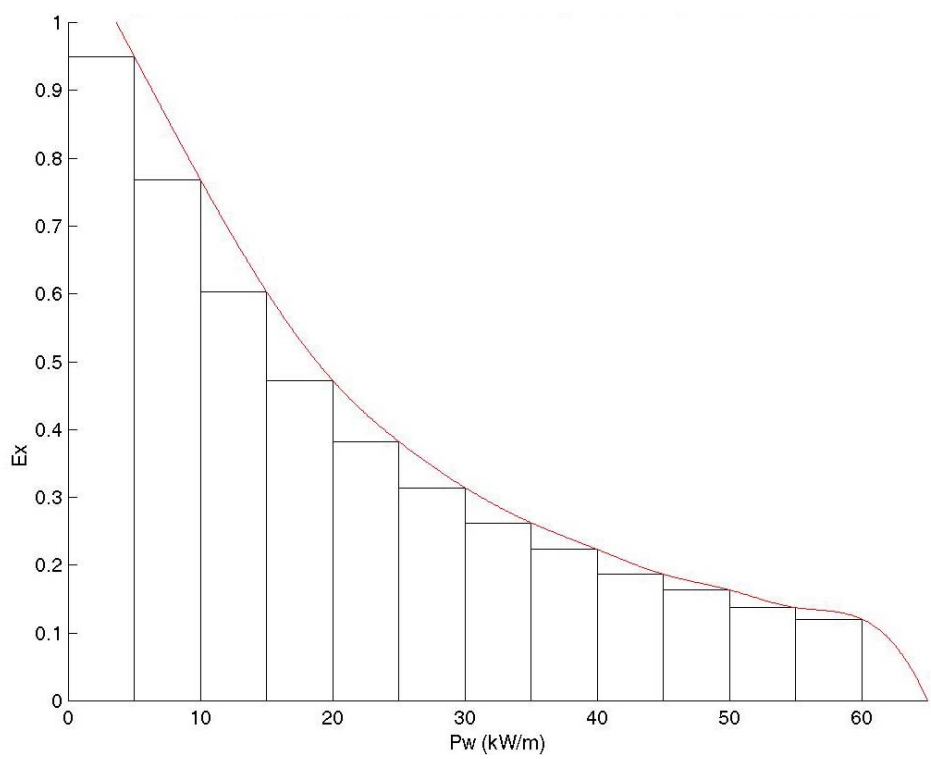

Figure 57. NDBC 46042 wave energy flux exceedance distribution

Cell 6: San Mateo, San Francisco, Marin and Southern Sonoma Counties

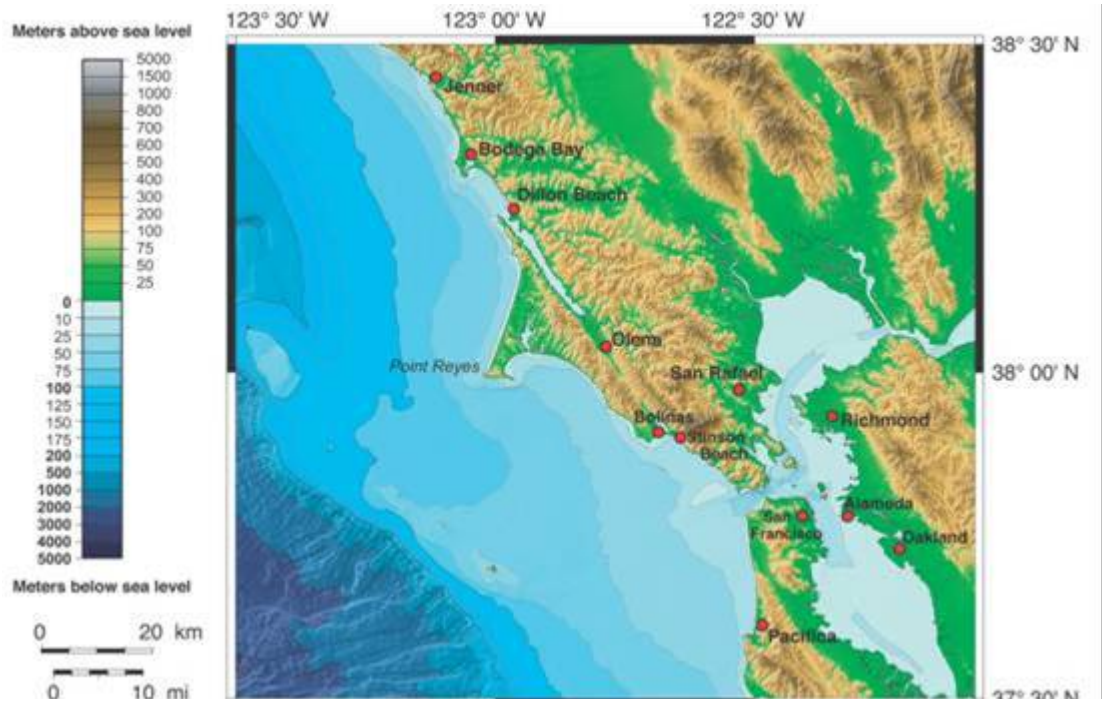

Figure 58. Cell 6 bathymetry

Table 26. Annual NDBC Wave Statistics off cell 6 for 100 to 1,000 m Water Depth

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WAVE (m)												
No. of Observations:	4,952	8,357	7,551	8,326	8,378	3,427	7,564	6,933	5,249	7,805	8,712	6,137
Minimum	0.30	0.20	0.30	0.40	0.60	0.60	0.50	0.30	0.60	0.60	0.50	0.40
Maximum	6.60	7.10	8.40	7.30	8.70	7.00	6.20	7.00	5.10	7.80	5.80	6.20
Median	2.00	1.80	2.10	2.30	2.00	2.00	2.00	1.90	1.90	2.00	2.00	2.10
Mean	2.06	1.93	2.34	2.44	2.10	2.18	2.19	2.09	2.02	2.17	2.17	2.19
STD	0.86	1.00	1.10	1.02	0.84	0.89	0.92	0.85	0.69	0.87	0.88	0.93
Variance	0.74	1.00	1.21	1.04	0.70	0.80	0.85	0.73	0.48	0.76	0.77	0.86
PERIOD (sec)												
No. of Observations:	4,952	8,357	7,551	8,326	8,378	3,427	7,564	6,933	5,249	7,805	8,712	6,137
Minimum	3.20	2.90	2.90	3.10	3.40	4.30	3.60	3.80	3.60	3.10	4.00	3.60
Maximum	99.00	99.00	99.00	99.00	99.00	99.00	25.00	99.00	25.00	25.00	25.00	25.00
Median	9.10	10.00	10.00	10.00	11.10	12.50	12.50	11.10	11.10	11.10	11.10	11.10
Mean	9.51	10.11	10.19	10.72	11.15	12.58	11.77	11.12	11.31	11.27	11.56	11.46
STD	2.88	3.69	4.60	3.55	3.68	3.66	3.39	3.38	3.56	3.21	3.34	3.27
Variance	8.29	13.59	21.11	12.62	13.51	13.39	11.48	11.44	12.64	10.33	11.14	10.72
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1993	1994	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)										
No. of Observations:	8,530	8,503	8,684	8,220	2,215	6,520	8,287	8,534	8,299	21
Minimum	0.60	0.70	0.60	0.72	0.60	0.71	0.62	0.63	0.62	0.53
Maximum	6.70	6.80	8.80	6.43	6.13	7.66	8.28	7.82	8.11	7.14
Median	2.20	2.20	2.00	2.11	2.59	2.21	2.38	2.17	2.31	2.11
Mean	2.32	2.32	2.27	2.26	2.61	2.39	2.52	2.33	2.46	2.26
STD	0.92	0.88	1.07	0.87	0.83	0.98	1.07	1.01	1.02	0.93
Variance	0.85	0.78	1.15	0.75	0.69	0.96	1.14	1.03	1.04	0.87
PERIOD (sec)										
No. of Observations:	8,530	8,503	8,684	8,220	2,215	6,520	8,287	8,534	8,299	21
Minimum	3.80	3.70	3.60	3.70	3.45	4.00	3.03	3.70	3.85	3.54
Maximum	25.00	20.00	25.00	25.00	25.00	25.00	99.00	25.00	25.00	52.95
Median	11.10	11.10	11.10	11.11	12.50	11.11	11.11	11.11	11.11	11.05
Mean	11.60	11.40	11.39	11.29	12.56	11.17	11.72	11.76	11.22	11.28
STD	3.39	3.21	3.31	3.28	2.86	3.34	4.07	3.57	3.45	3.46
Variance	11.46	10.32	10.98	10.78	8.17	11.19	16.56	12.78	11.93	12.12
DIRECTION (deg)										
No. of Observations:	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table 27. Annual CDIP Wave Statistics off cell 6 for 100 to 1,000 m Water Depth

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WAVE (m)												
No. of Observations:	1,831	191	0	0	970	2,239	1,659	1,070	2,090	2,208	1,306	1,830
Minimum	0.59	0.81	0.00	0.00	0.58	0.58	0.47	0.61	0.53	0.54	0.08	0.64
Maximum	5.98	8.97	0.00	0.00	4.68	6.98	6.80	6.16	4.02	4.85	6.61	5.95
Median	1.55	2.24	0.00	0.00	1.65	1.90	1.94	1.74	1.56	1.67	1.86	1.79
Mean	1.76	2.64	0.00	0.00	1.85	2.11	2.11	1.85	1.67	1.83	2.25	1.93
STD	0.79	1.38	0.00	0.00	0.72	0.95	0.94	0.77	0.63	0.75	1.33	0.76
Variance	0.63	1.92	0.00	0.00	0.52	0.90	0.88	0.60	0.39	0.56	1.77	0.58
PERIOD (sec)												
No. of Observations:	1,831	191	0	0	970	2,239	1,659	1,070	2,090	2,208	1,306	1,830
Minimum	4.00	5.33	0.00	0.00	4.00	4.13	4.20	3.88	4.34	4.13	5.12	4.41
Maximum	18.29	16.00	0.00	0.00	18.29	18.29	25.60	28.44	19.69	21.33	28.44	28.44
Median	9.85	11.64	0.00	0.00	11.64	10.67	11.64	11.64	9.85	10.67	11.64	10.67
Mean	10.31	11.71	0.00	0.00	11.05	11.02	11.70	11.75	10.28	11.02	12.79	10.97
STD	2.63	1.89	0.00	0.00	2.75	2.60	2.90	3.15	2.65	2.89	5.36	3.28
Variance	6.90	3.57	0.00	0.00	7.56	6.78	8.42	9.94	7.02	8.37	28.72	10.74
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1994	1995	1996	1997	1998	1999	2000	2001	2002	Long Term Avg. Yrs.
WAVE (m)										
No. of Observations:	2,119	2,192	1,106	15,133	16,145	15,273	17,092	16,989	9,470	19
Minimum	0.68	0.47	0.78	0.57	0.74	0.60	0.70	0.62	0.65	0.59
Maximum	5.02	5.76	5.61	6.86	8.15	8.19	7.85	8.37	6.22	6.48
Median	1.78	1.69	2.96	2.28	2.47	2.53	2.32	2.47	2.39	2.04
Mean	1.89	1.93	2.72	2.45	2.72	2.64	2.45	2.63	2.52	2.21
STD	0.76	0.95	1.17	0.98	1.11	1.09	0.96	1.07	1.03	0.96
Variance	0.58	0.90	1.38	0.96	1.22	1.20	0.92	1.14	1.06	0.95
PERIOD (sec)										
No. of Observations:	2,119	2,192	1,106	15,133	16,145	15,273	17,092	16,989	9,470	19
Minimum	4.57	3.94	4.00	3.33	3.45	3.85	3.70	3.33	3.57	4.07
Maximum	28.44	23.27	20.00	22.22	22.22	25.00	22.22	22.22	20.00	22.55
Median	10.67	10.67	11.76	10.00	10.00	10.53	10.00	10.00	9.09	10.66
Mean	10.68	10.86	11.78	10.83	11.06	11.12	11.06	10.84	10.30	11.11
STD	2.79	2.86	2.90	3.24	3.53	3.49	3.47	3.40	3.11	3.10
Variance	7.80	8.17	8.39	10.49	12.43	12.16	12.02	11.56	9.64	10.04
DIRECTION (deg)										
No. of Observations:	0	0	1,106	15,133	16,145	15,273	17,092	16,989	9,470	7
Minimum	0.00	0.00	152.00	100.00	102.00	151.00	129.00	141.00	159.00	133.43
Maximum	0.00	0.00	335.00	351.00	351.00	356.00	351.00	345.00	359.00	349.71
Mean	0.00	0.00	283.81	294.35	300.68	302.69	300.40	303.26	304.15	298.48

Table 28. Scatter plot of NDBC Wave Statistics for buoy NDBC 46013

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	1	1	5	13	5	5	8	3	0	0	**41**
1.0 - 1.5	0	1	12	16	54	19	21	25	17	3	0	**168**
1.5 - 2.0	0	0	24	30	69	31	32	25	14	3	0	**228**
2.0 - 2.5	0	0	11	37	53	29	37	24	11	4	0	**206**
2.5 - 3.0	0	0	1	27	35	18	31	26	10	3	0	**151**
3.0 - 3.5	0	0	0	9	22	9	21	23	8	2	0	**94**
3.5 - 4.0	0	0	0	2	11	5	11	17	6	1	0	**53**
4.0 - 4.5	0	0	0	0	5	3	5	10	5	1	0	**29**
4.5 - 5.0	0	0	0	0	2	1	2	5	3	0	0	**13**
5.0 - 5.5	0	0	0	0	1	0	1	2	2	0	0	**6**
5.5 - 7.0	0	0	0	0	0	0	1	1	2	0	0	**4**
7.0 - 9.0	0	0	0	0	0	0	0	0	0	0	0	**0**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**2**	**49**	**126**	**265**	**120**	**167**	**166**	**81**	**17**	**0**	**1000**

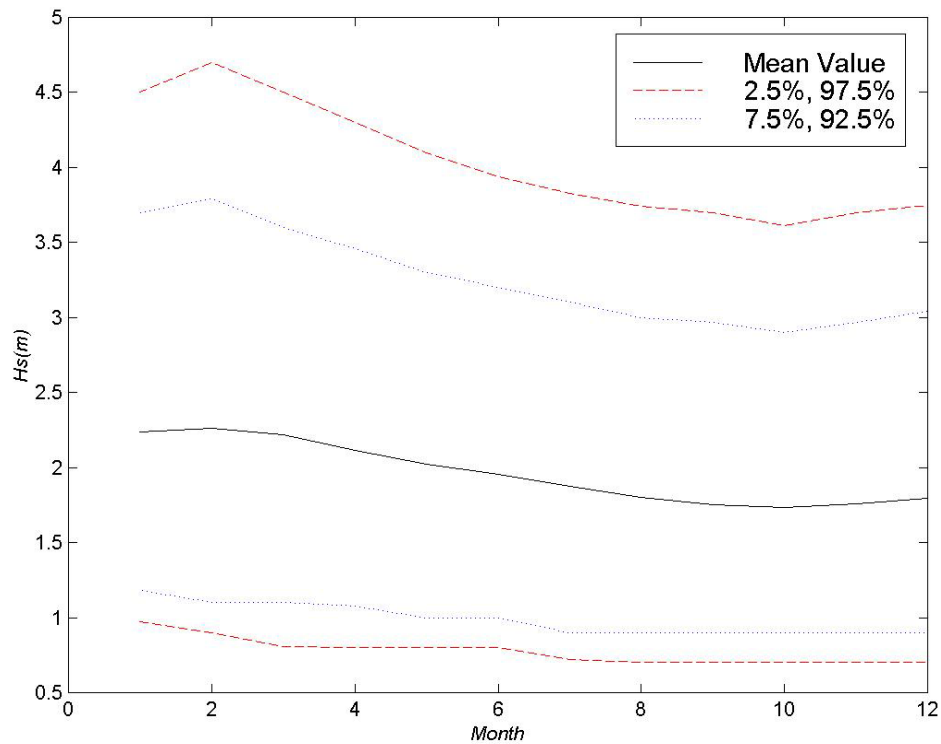

Figure 59. NDBC 46013 significant wave height seasonal variation

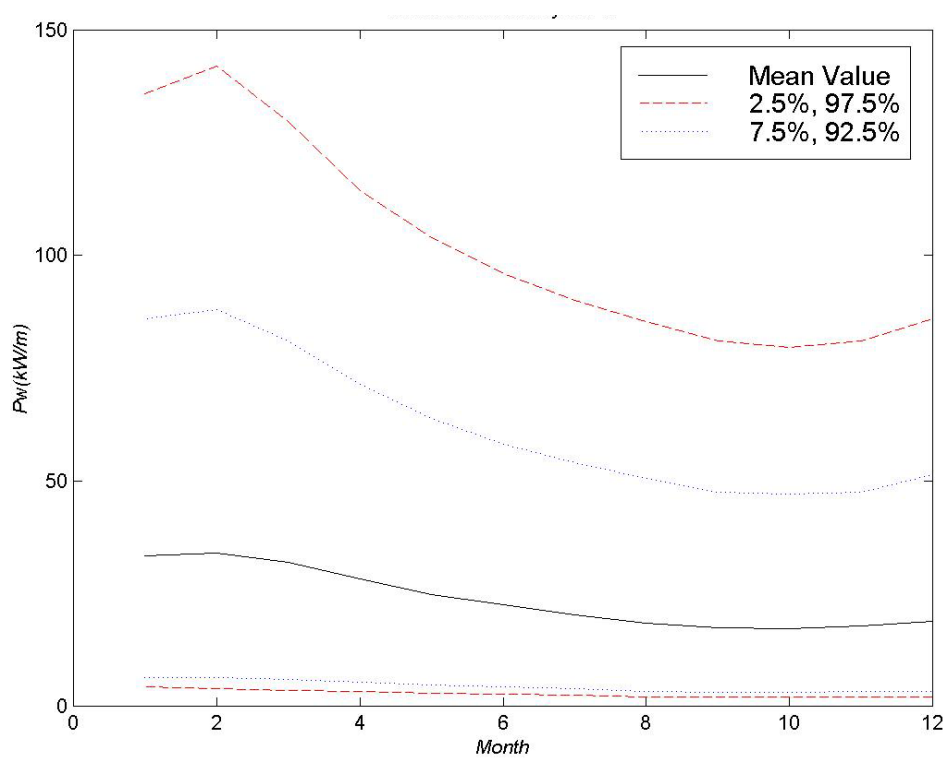

Figure 60. NDBC 46013 wave energy flux seasonal variation

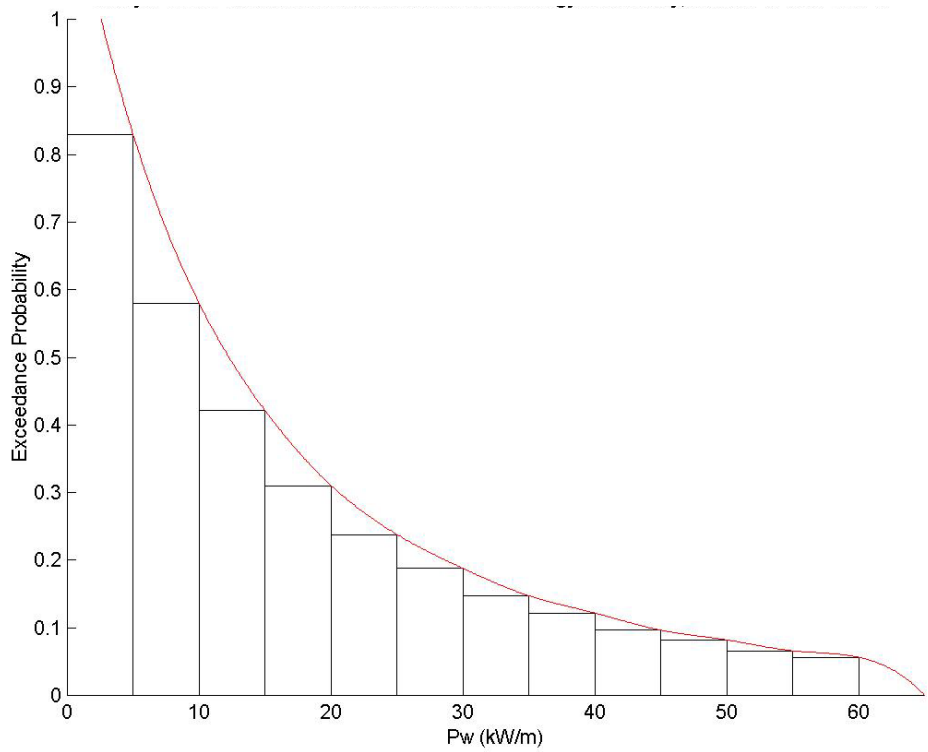

Figure 61: NDBC 46013 wave energy flux exceedance distribution

Cell 7: Northern Sonoma and Southern Mendocino Counties

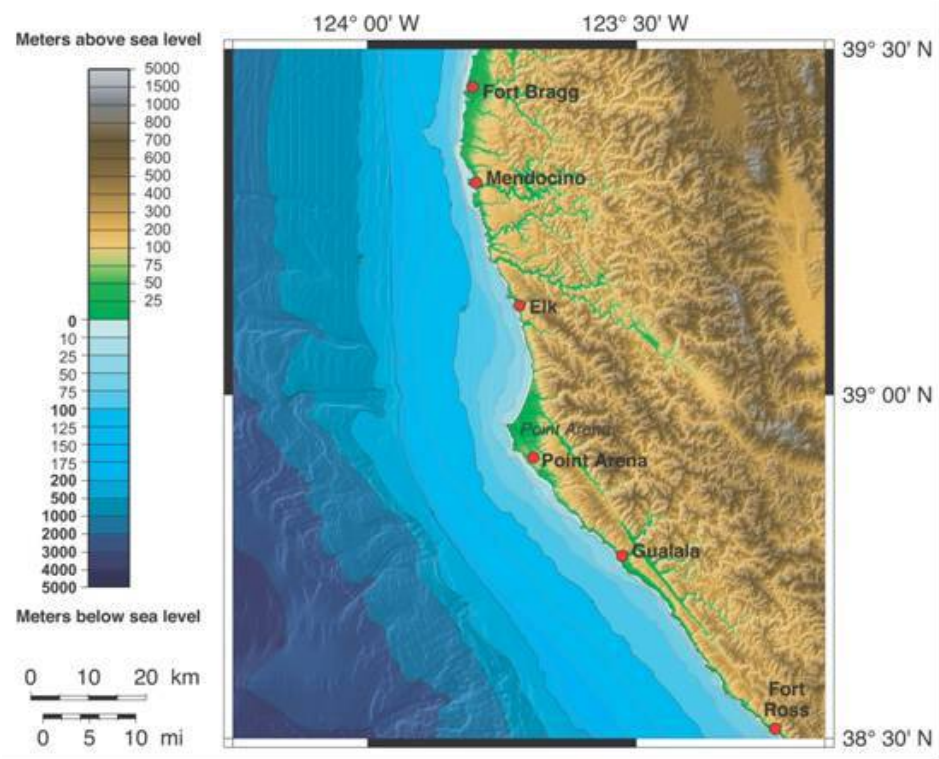

Figure 62. Cell 7 bathymetry

Table 29. Annual NDBC Wave Statistics off cell 7 for 100 to 1,000 m Water Depth

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
WAVE (m)												
No. of Observations:	5,462	8,284	6,061	8,678	7,860	7,282	8,563	6,464	7,363	8,201	6,848	4,592
Minimum	0.40	0.30	0.30	0.40	0.60	0.60	0.60	0.70	0.60	0.60	0.70	0.60
Maximum	9.20	8.70	10.10	9.20	8.30	7.70	8.70	7.20	5.10	10.10	6.40	6.60
Median	2.20	2.00	2.10	2.20	2.10	2.20	2.30	2.10	2.00	2.20	2.10	2.00
Mean	2.30	2.24	2.35	2.33	2.21	2.45	2.50	2.24	2.09	2.31	2.29	2.23
STD	1.05	1.18	1.27	1.04	0.91	1.10	1.10	0.85	0.77	0.98	0.91	1.06
Variance	1.11	1.39	1.60	1.08	0.83	1.21	1.22	0.72	0.59	0.96	0.82	1.12
PERIOD (sec)												
No. of Observations:	5,462	8,284	6,061	8,678	7,860	7,282	8,563	6,464	7,363	8,201	6,848	4,592
Minimum	3.10	3.60	3.10	2.80	3.80	4.00	2.90	3.80	3.70	3.10	4.30	4.00
Maximum	99.00	99.00	99.00	99.00	99.00	25.00	25.00	99.00	99.00	25.00	25.00	25.00
Median	10.00	10.00	10.00	11.10	11.10	11.10	12.50	11.10	11.10	11.10	11.10	11.10
Mean	10.07	10.35	10.63	10.84	11.57	11.68	11.96	11.36	11.10	10.90	11.23	10.97
STD	4.15	4.56	5.01	3.76	3.53	3.67	3.44	3.72	3.63	3.35	3.44	3.25
Variance	17.25	20.79	25.12	14.15	12.48	13.44	11.81	13.83	13.14	11.25	11.82	10.56
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	4,219
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	345.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	298.43

	1993	1994	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)										
No. of Observations:	6,007	8,557	7,470	8,872	8,655	8,604	8,503	8,645	8,685	21
Minimum	0.70	0.70	0.50	0.00	0.00	0.00	0.60	0.72	0.64	0.49
Maximum	7.00	6.80	10.30	7.85	7.23	8.52	8.83	9.74	8.72	8.20
Median	2.00	2.30	2.30	2.29	2.29	2.42	2.42	2.24	2.51	2.20
Mean	2.17	2.42	2.53	2.44	2.40	2.72	2.60	2.41	2.66	2.38
STD	0.87	0.93	1.16	0.97	0.99	1.22	1.14	1.07	1.09	1.03
Variance	0.75	0.87	1.34	0.95	0.97	1.50	1.30	1.14	1.19	1.08
PERIOD (sec)										
No. of Observations:	6,007	8,557	7,470	8,872	8,655	8,604	8,503	8,645	8,685	21
Minimum	3.40	3.80	4.30	0.00	0.00	0.00	4.35	3.70	4.17	3.14
Maximum	25.00	20.00	25.00	20.00	25.00	99.00	99.00	99.00	25.00	59.76
Median	10.00	11.10	11.10	11.11	11.11	11.11	11.11	11.11	11.11	10.96
Mean	10.90	11.31	11.76	11.36	11.49	11.62	11.50	11.73	11.32	11.22
STD	3.35	3.25	3.18	3.26	3.26	3.65	3.79	3.99	3.53	3.66
Variance	11.25	10.57	10.14	10.64	10.62	13.33	14.33	15.89	12.48	13.57
DIRECTION (deg)										
No. of Observations:	737	0	0	0	0	0	0	0	0	2
Minimum	145.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.50
Maximum	338.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	341.50
Mean	279.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	288.79

Table 30 Annual NDBC Wave Statistics off cell 7 for 100 to 1,000 m Water Depth

	1981	1982	Long Term Avg. Yrs.
WAVE (m)			
No. of Observations:	251	451	2
Minimum	0.64	0.69	0.67
Maximum	3.15	5.85	4.50
Median	1.71	2.39	2.05
Mean	1.74	2.42	2.08
STD	0.51	0.93	0.72
Variance	0.26	0.87	0.57
PERIOD (sec)			
No. of Observations:	251	451	2
Minimum	4.92	5.33	5.13
Maximum	16.00	18.29	17.15
Median	7.53	10.67	9.10
Mean	8.23	10.29	9.26
STD	2.24	2.40	2.32
Variance	5.00	5.78	5.39
DIRECTION (deg)			
No. of Observations:	0	0	0
Minimum	0.00	0.00	0.00
Maximum	0.00	0.00	0.00
Mean	0.00	0.00	0.00

Table 31. Scatter plot of NDBC Wave Statistics for buoy NDBC 46014

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**1**
0.5 - 1.0	0	0	2	6	11	3	4	7	3	0	0	**36**
1.0 - 1.5	0	0	13	20	49	15	16	21	15	2	0	**151**
1.5 - 2.0	0	0	14	40	62	26	27	21	12	3	0	**206**
2.0 - 2.5	0	0	3	51	51	27	32	23	10	4	1	**202**
2.5 - 3.0	0	0	0	30	39	20	29	24	10	4	0	**157**
3.0 - 3.5	0	0	0	10	26	10	22	23	9	3	0	**105**
3.5 - 4.0	0	0	0	2	13	6	13	18	8	2	0	**62**
4.0 - 4.5	0	0	0	0	5	3	7	13	6	1	0	**36**
4.5 - 5.0	0	0	0	0	2	2	3	8	4	1	0	**20**
5.0 - 5.5	0	0	0	0	1	1	1	4	4	1	0	**11**
5.5 - 7.0	0	0	0	0	0	0	1	3	5	1	0	**11**
7.0 - 9.0	0	0	0	0	0	0	0	0	1	0	0	**2**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**0**	**33**	**161**	**259**	**113**	**157**	**165**	**87**	**22**	**2**	**1000**

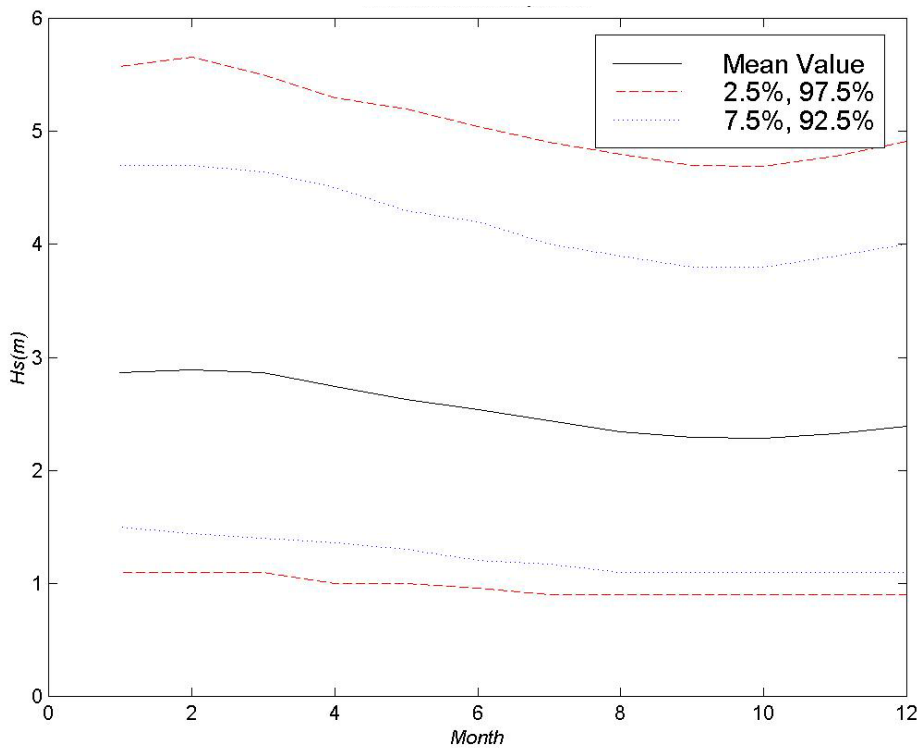

Figure 63. NDBC 46014 significant wave height seasonal variation

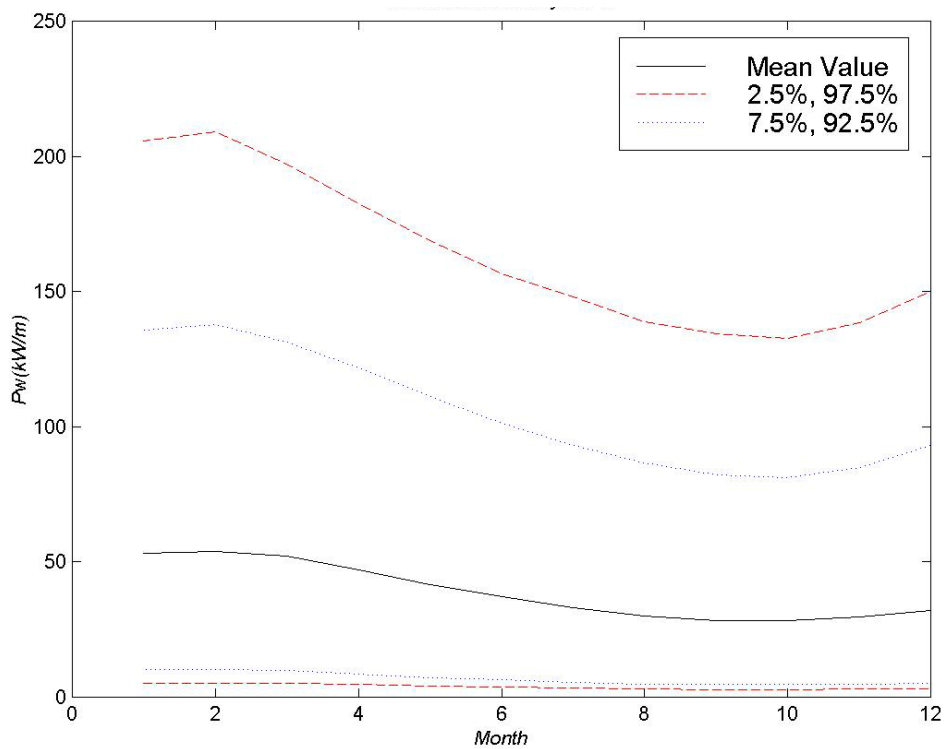

Figure 64. NDBC 46014 wave energy flux seasonal variation

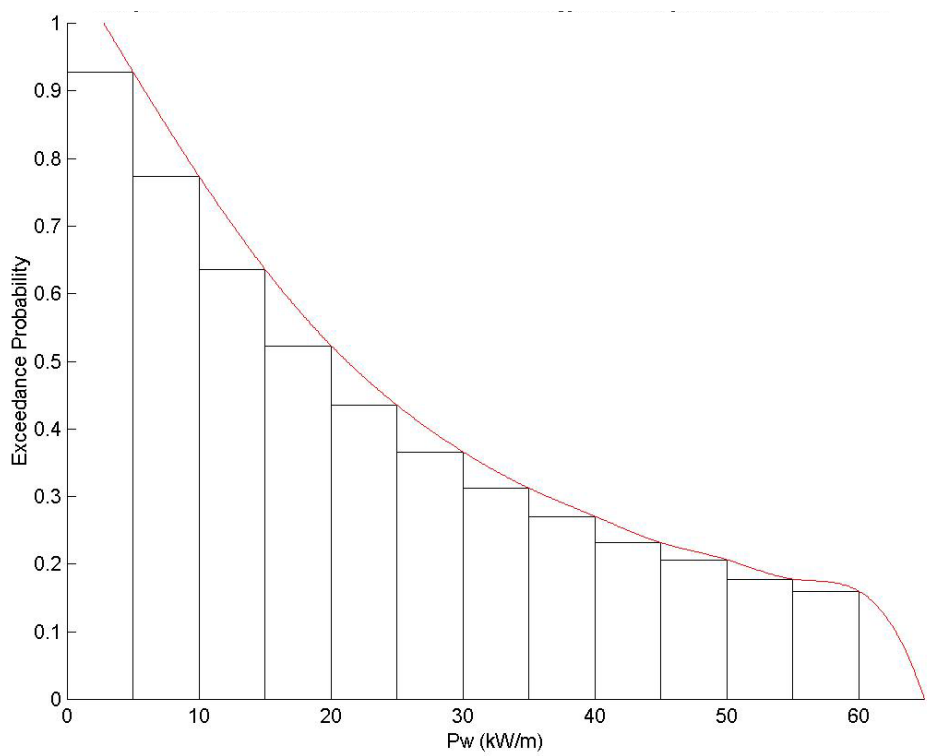

Figure 65. NDBC 46014 wave energy flux exceedance distribution

Cell 8: Northern Mendocino and Southern Humboldt Counties

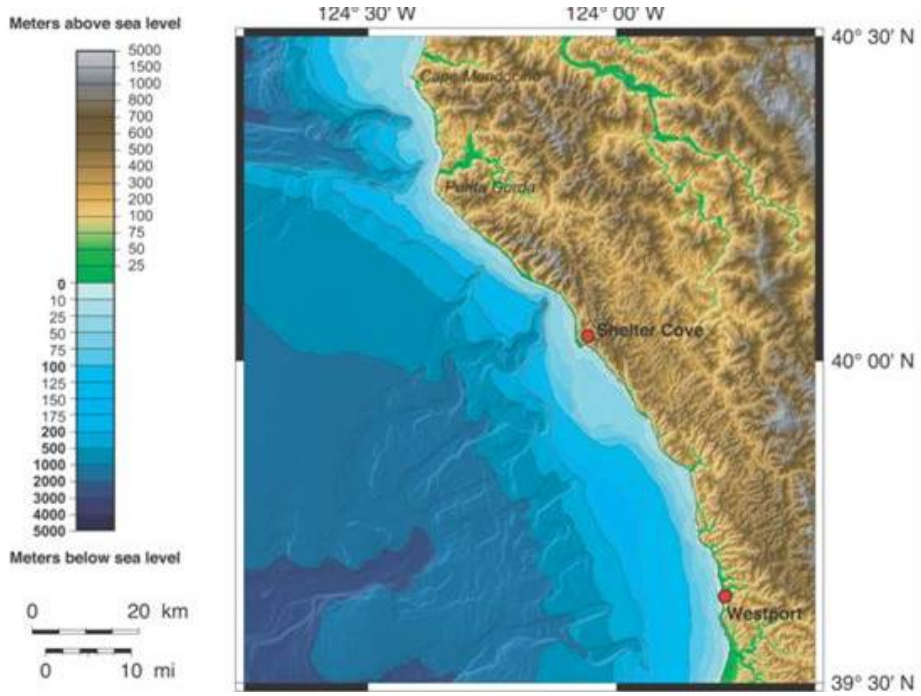

Figure 66. Cell 8 bathymetry

Table 32. Annual NDBC Wave Statistics off cell 8 for 100 to 1,000 m Water Depth

	1988	1989	1990	1991	1992	1993	1994
WAVE (m)							
No. of Observations:	6,046	8,670	7,832	5,337	1,946	8,307	5,607
Minimum	0.60	0.60	0.60	0.70	0.00	0.00	0.70
Maximum	8.80	5.40	11.40	6.10	5.40	6.50	7.60
Median	2.10	1.90	2.00	1.90	2.00	1.70	2.30
Mean	2.25	1.98	2.20	2.06	2.11	1.92	2.40
STD	0.98	0.74	1.01	0.80	1.01	0.92	0.99
Variance	0.97	0.55	1.01	0.65	1.03	0.85	0.97
PERIOD (sec)							
No. of Observations:	6,046	8,670	7,832	5,337	1,946	8,307	5,607
Minimum	3.40	3.60	3.20	3.30	0.00	0.00	4.20
Maximum	99.00	25.00	99.00	25.00	20.00	25.00	25.00
Median	10.00	10.00	10.00	9.10	11.10	10.00	12.50
Mean	10.64	10.35	10.53	10.17	11.15	11.07	12.06
STD	7.17	3.02	3.17	2.96	3.08	3.32	2.96
Variance	51.45	9.13	10.03	8.73	9.48	11.04	8.74
DIRECTION (deg)							
No. of Observations:	0	0	0	0	1,946	8,307	5,606
Minimum	0.00	0.00	0.00	0.00	146.00	9.00	78.00
Maximum	0.00	0.00	0.00	0.00	356.00	358.00	355.00
Mean	0.00	0.00	0.00	0.00	294.52	286.07	289.22

	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)								
No. of Observations:	8,622	8,824	6,901	4,232	2,397	8,645	8,609	14
Minimum	0.50	0.64	0.78	0.70	0.65	0.69	0.60	0.55
Maximum	9.40	6.44	6.66	9.58	9.31	9.39	9.53	7.97
Median	2.20	2.15	2.01	2.20	2.54	2.14	2.41	2.11
Mean	2.35	2.31	2.15	2.42	2.64	2.35	2.56	2.26
STD	1.09	0.94	0.88	1.13	1.11	1.03	1.13	0.98
Variance	1.20	0.88	0.78	1.28	1.23	1.05	1.28	0.98
PERIOD (sec)								
No. of Observations:	8,622	8,824	6,901	4,232	2,397	8,645	8,609	14
Minimum	4.00	3.70	3.12	4.17	4.17	3.85	3.13	3.13
Maximum	20.00	20.00	25.00	25.00	25.00	25.00	25.00	34.50
Median	11.10	10.00	11.11	10.00	12.50	11.11	11.11	10.69
Mean	10.99	10.81	10.98	10.90	12.42	11.50	11.12	11.05
STD	2.77	2.87	2.96	3.44	3.02	3.53	3.31	3.40
Variance	7.65	8.26	8.79	11.80	9.11	12.45	10.95	12.69
DIRECTION (deg)								
No. of Observations:	8,619	8,824	6,901	0	0	0	0	6
Minimum	45.00	0.00	137.00	0.00	0.00	0.00	0.00	69.17
Maximum	355.00	358.00	358.00	0.00	0.00	0.00	0.00	356.67
Mean	290.21	291.11	288.54	0.00	0.00	0.00	0.00	289.94

Table 33: Annual CDIP Wave Statistics off cell 8 for 100 to 1,000 m Water Depth.

	1999	2000	Long Term Avg. Yrs.
WAVE (m)			
No. of Observations:	9,691	1,597	2
Minimum	0.70	1.03	0.87
Maximum	9.42	7.18	8.30
Median	2.15	2.66	2.41
Mean	2.40	2.93	2.67
STD	1.13	1.13	1.13
Variance	1.29	1.28	1.28
PERIOD (sec)			
No. of Observations:	9,691	1,597	2
Minimum	3.23	4.35	3.79
Maximum	22.22	22.22	22.22
Median	9.09	12.50	10.80
Mean	10.32	12.39	11.35
STD	3.06	4.00	3.53
Variance	9.38	16.00	12.69
DIRECTION (deg)			
No. of Observations:	9,691	1,597	2
Minimum	4.00	146.00	75.00
Maximum	359.00	350.00	354.50
Mean	303.37	265.58	284.47

Table 34. Scatter plot of NDBC Wave Statistics for buoy NDBC 46030

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**1**
0.5 - 1.0	0	0	2	11	11	3	4	7	4	1	0	**43**
1.0 - 1.5	0	1	10	45	61	15	17	20	17	2	0	**189**
1.5 - 2.0	0	0	5	54	76	28	25	18	10	2	0	**219**
2.0 - 2.5	0	0	2	32	71	33	31	18	8	3	0	**198**
2.5 - 3.0	0	0	0	10	53	22	29	19	8	3	0	**145**
3.0 - 3.5	0	0	0	3	27	12	22	18	7	2	0	**91**
3.5 - 4.0	0	0	0	2	12	6	13	14	6	1	0	**53**
4.0 - 4.5	0	0	0	0	5	3	6	10	4	1	0	**29**
4.5 - 5.0	0	0	0	0	2	1	3	6	2	0	0	**14**
5.0 - 5.5	0	0	0	0	1	0	1	3	2	0	0	**7**
5.5 - 7.0	0	0	0	0	0	0	1	3	2	0	0	**7**
7.0 - 9.0	0	0	0	0	0	0	0	0	1	0	0	**1**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**1**	**19**	**159**	**320**	**126**	**153**	**135**	**70**	**16**	**1**	**1000**

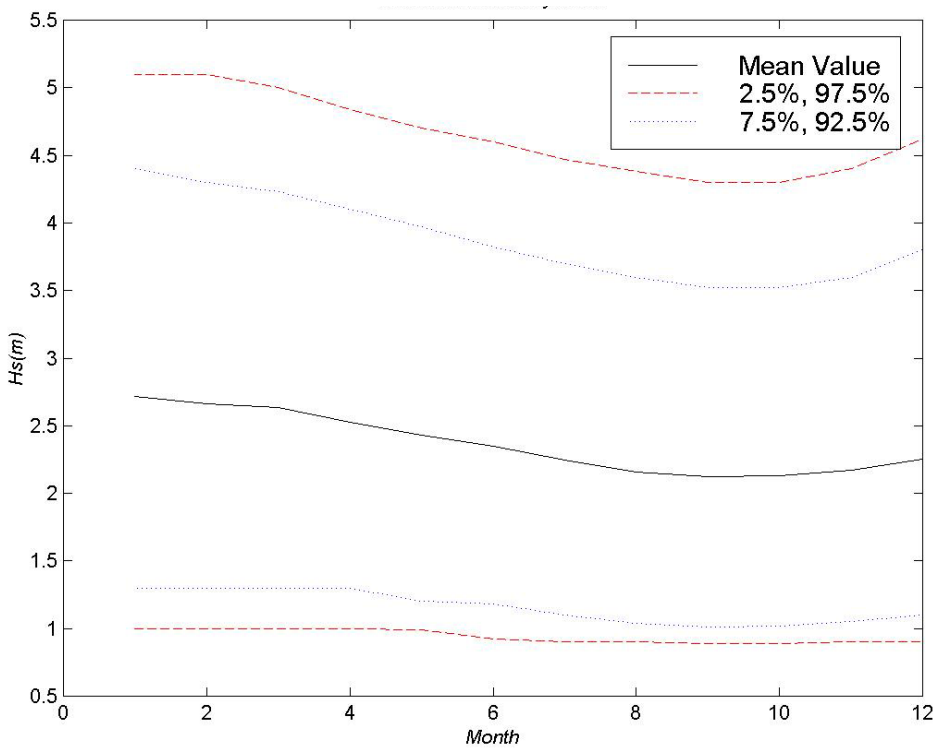

Figure 67. NDBC 46030 significant wave height seasonal variation

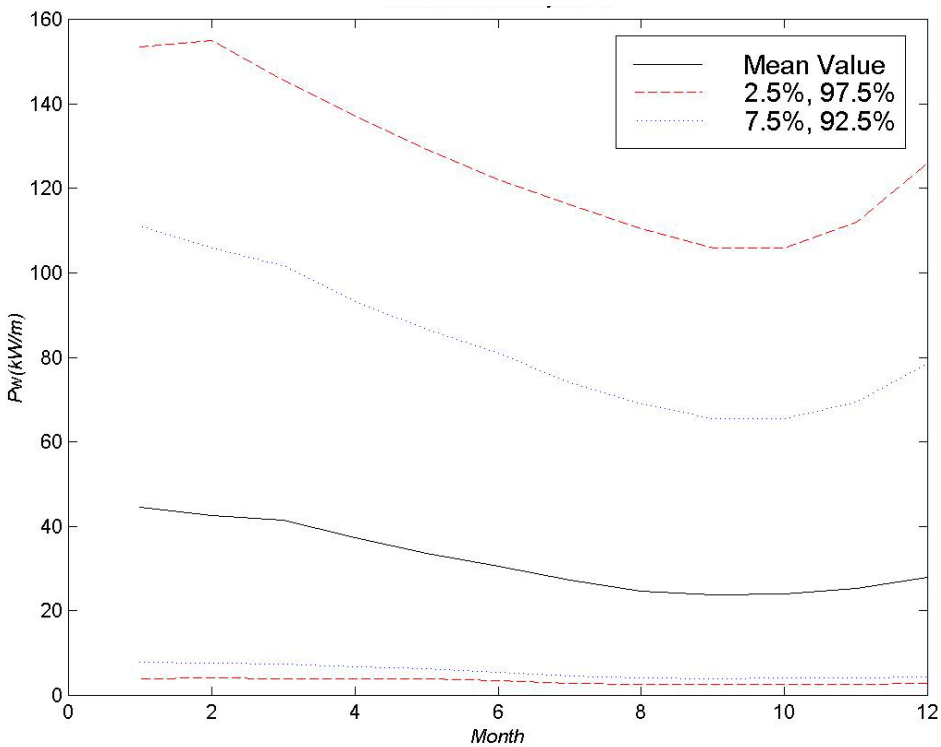

Figure 68. NDBC 46030 wave energy flux seasonal variation

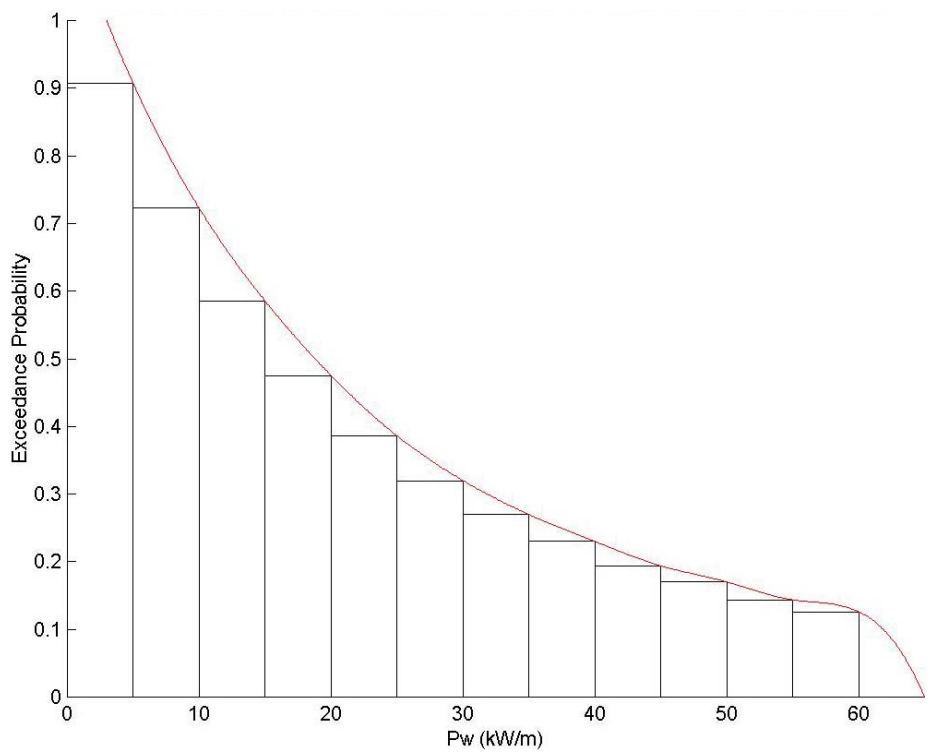

Figure 69. NDBC 46030 wave energy flux exceedance distribution

Cell 9: Northern Humboldt County

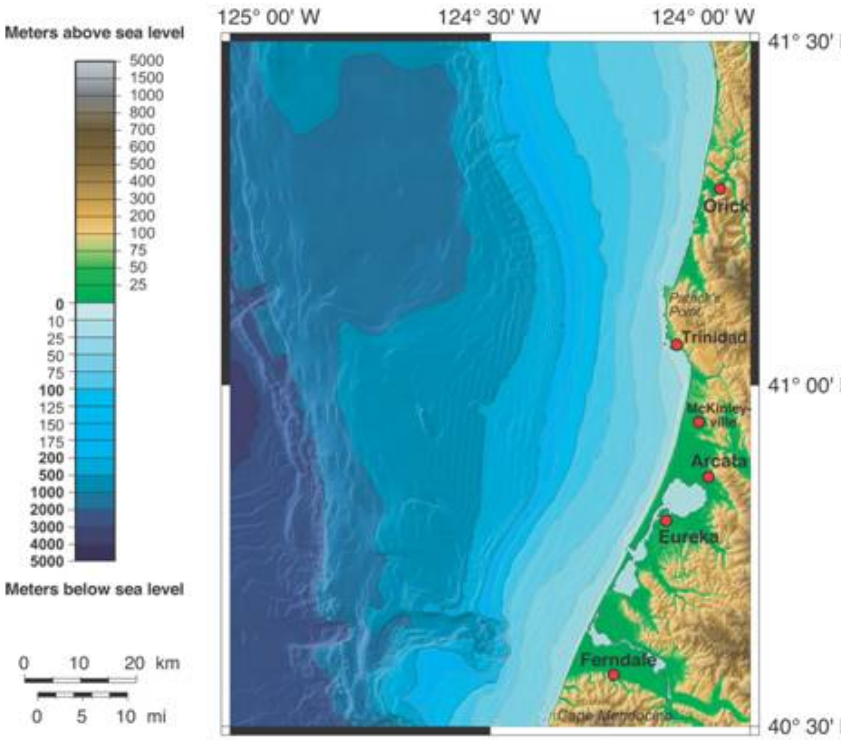

Figure 70. Cell 9 bathymetry

Table 35. Annual NDBC Wave Statistics off cell 9 for 100 to 1,000 m Water Depth

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
WAVE (m)												
No. of Observations:	7,846	8,590	5,799	8,680	7,318	5,822	6,418	8,634	4,689	7,535	8,600	6,863
Minimum	0.40	0.40	0.30	0.50	0.50	0.50	0.60	0.50	0.60	0.60	0.40	0.60
Maximum	8.30	8.80	12.00	8.60	8.10	9.80	10.00	5.90	10.40	6.70	7.60	7.40
Median	2.10	2.20	2.30	2.20	2.20	2.20	2.20	2.10	2.70	2.20	2.20	2.00
Mean	2.33	2.51	2.42	2.29	2.45	2.43	2.41	2.16	2.86	2.36	2.33	2.21
STD	1.22	1.31	1.19	0.99	1.10	1.16	1.06	0.84	1.22	1.02	0.97	1.03
Variance	1.49	1.71	1.41	0.98	1.21	1.35	1.13	0.71	1.49	1.03	0.95	1.05
PERIOD (sec)												
No. of Observations:	7,846	8,590	5,799	8,680	7,318	5,822	6,418	8,634	4,689	7,535	8,600	6,863
Minimum	2.90	3.60	3.60	4.00	3.40	3.80	3.60	3.10	3.40	4.30	4.20	4.00
Maximum	99.00	99.00	99.00	99.00	99.00	20.00	99.00	25.00	99.00	99.00	25.00	25.00
Median	10.00	10.00	10.00	11.10	10.00	10.00	11.10	10.00	12.50	11.10	10.00	11.10
Mean	10.15	10.82	10.77	11.12	10.95	10.85	11.05	10.72	11.86	11.18	10.97	11.09
STD	3.42	4.16	3.60	3.74	3.57	3.00	3.55	3.15	3.22	3.90	3.12	3.27
Variance	11.71	17.28	12.94	13.96	12.76	9.01	12.63	9.89	10.37	15.25	9.71	10.70
DIRECTION (deg)												
No. of Observations:	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	1994	1995	1996	1997	1998	1999	2000	2001	Long Term Avg. Yrs.
WAVE (m)									
No. of Observations:	6,485	7,955	3,316	8,486	5,986	7,619	5,490	8,644	20
Minimum	0.60	0.50	0.54	0.00	0.00	0.00	0.57	0.54	0.43
Maximum	8.60	9.50	7.43	9.52	8.83	10.67	9.07	9.04	8.81
Median	2.20	2.30	2.53	2.24	2.61	2.46	1.94	2.36	2.26
Mean	2.36	2.49	2.68	2.37	2.95	2.71	2.16	2.53	2.45
STD	1.12	1.18	1.05	1.05	1.47	1.35	1.02	1.18	1.13
Variance	1.26	1.40	1.10	1.10	2.15	1.82	1.05	1.39	1.29
PERIOD (sec)									
No. of Observations:	6,485	7,955	3,316	8,486	5,986	7,619	5,490	8,644	20
Minimum	3.40	3.70	3.12	0.00	0.00	0.00	4.17	3.85	3.11
Maximum	25.00	25.00	20.00	25.00	99.00	25.00	25.00	25.00	57.80
Median	10.00	11.10	12.50	11.11	12.50	11.11	10.00	11.11	10.82
Mean	10.79	11.35	11.92	11.42	11.88	11.63	10.99	11.30	11.14
STD	3.01	3.09	3.06	3.26	3.87	3.35	3.46	3.40	3.41
Variance	9.06	9.56	9.38	10.64	15.01	11.22	11.99	11.57	11.73
DIRECTION (deg)									
No. of Observations:	0	0	0	0	0	0	0	0	0
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 36. Annual CDIP Wave Statistics off cell 3 for 100 to 1,000 m Water Depth

	1980	1981	Long Term Avg. Yrs.
WAVE (m)			
No. of Observations:	25	315	1
Minimum	1.52	0.67	0.67
Maximum	6.76	6.80	6.80
Median	3.10	2.38	2.38
Mean	3.65	2.51	2.51
STD	1.55	1.19	1.19
Variance	2.40	1.41	1.41
PERIOD (sec)			
No. of Observations:	25	315	1
Minimum	10.67	6.40	6.40
Maximum	25.60	18.29	18.29
Median	11.64	10.67	10.67
Mean	14.10	11.13	11.13
STD	4.84	2.20	2.20
Variance	23.41	4.82	4.82
DIRECTION (deg)			
No. of Observations:	0	0	0
Minimum	0.00	0.00	0.00
Maximum	0.00	0.00	0.00
Mean	0.00	0.00	0.00

Table 37. Scatter plot of NDBC Wave Statistics for buoy NDBC 46022

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	1	0	0	0	0	0	0	0	0	0	0	**1**
0.5 - 1.0	0	0	3	13	14	4	4	6	5	1	0	**49**
1.0 - 1.5	0	0	11	37	60	15	14	13	8	1	0	**160**
1.5 - 2.0	0	0	6	46	65	25	22	15	7	2	0	**189**
2.0 - 2.5	0	0	2	32	56	29	30	19	8	3	0	**179**
2.5 - 3.0	0	0	0	14	46	23	30	21	9	3	0	**147**
3.0 - 3.5	0	0	0	5	33	13	24	20	8	3	0	**106**
3.5 - 4.0	0	0	0	2	17	7	16	18	7	2	0	**70**
4.0 - 4.5	0	0	0	0	8	4	9	14	6	1	0	**43**
4.5 - 5.0	0	0	0	0	3	2	5	10	5	1	0	**26**
5.0 - 5.5	0	0	0	0	1	1	2	6	4	1	0	**15**
5.5 - 7.0	0	0	0	0	0	0	1	5	5	1	0	**14**
7.0 - 9.0	0	0	0	0	0	0	0	1	2	0	0	**3**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**1**	**1**	**23**	**149**	**305**	**123**	**157**	**147**	**75**	**19**	**2**	**1000**

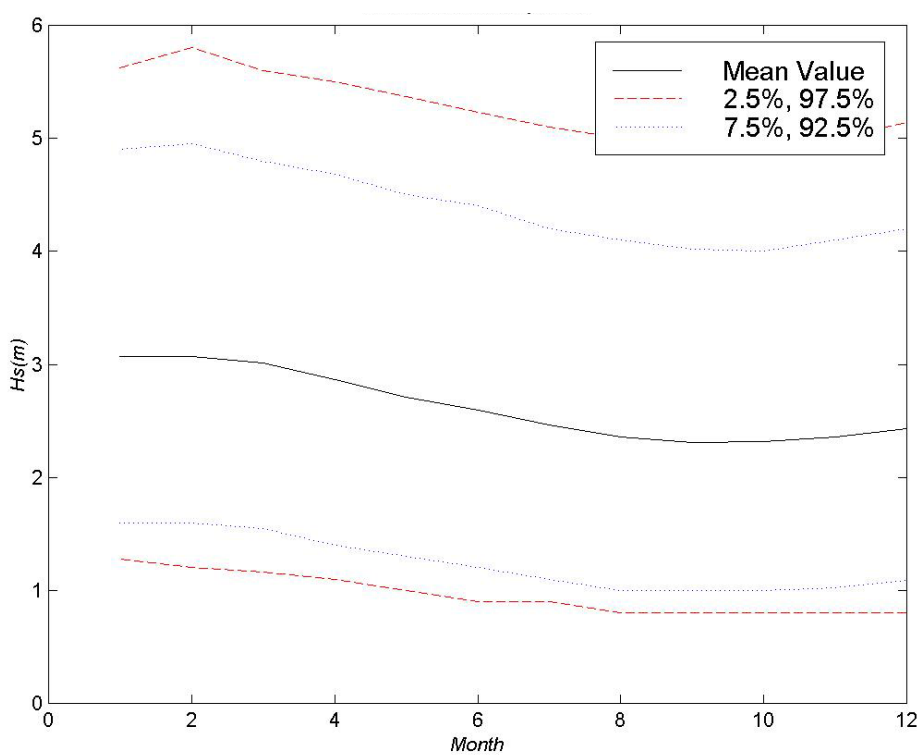

Figure 71. NDBC 46022 significant wave height seasonal variation

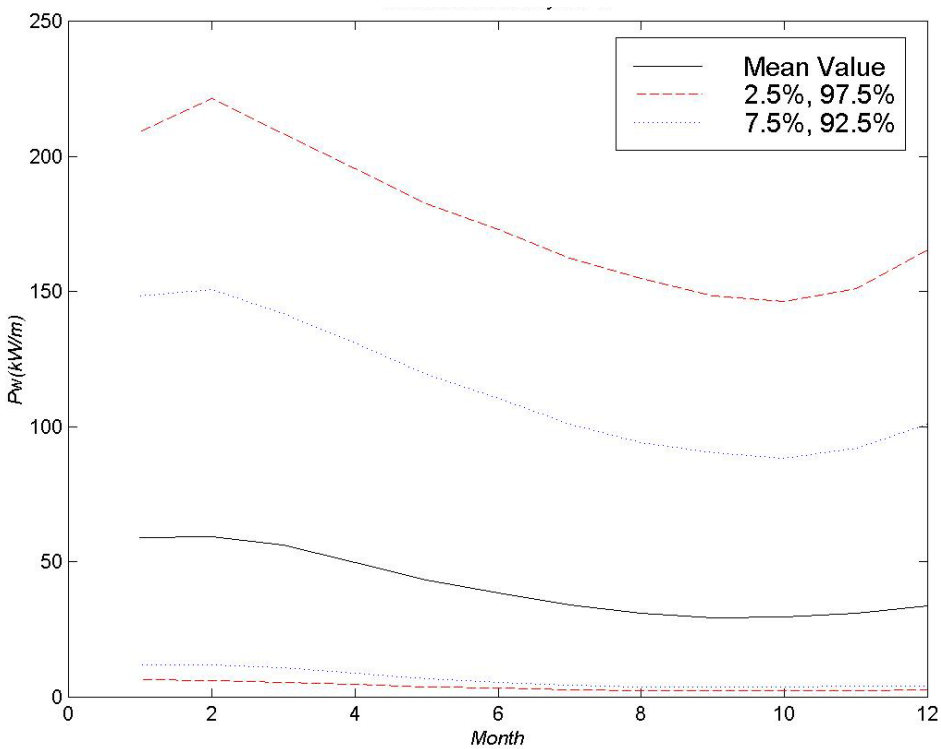

Figure 72. NDBC 46022 wave energy flux seasonal variation

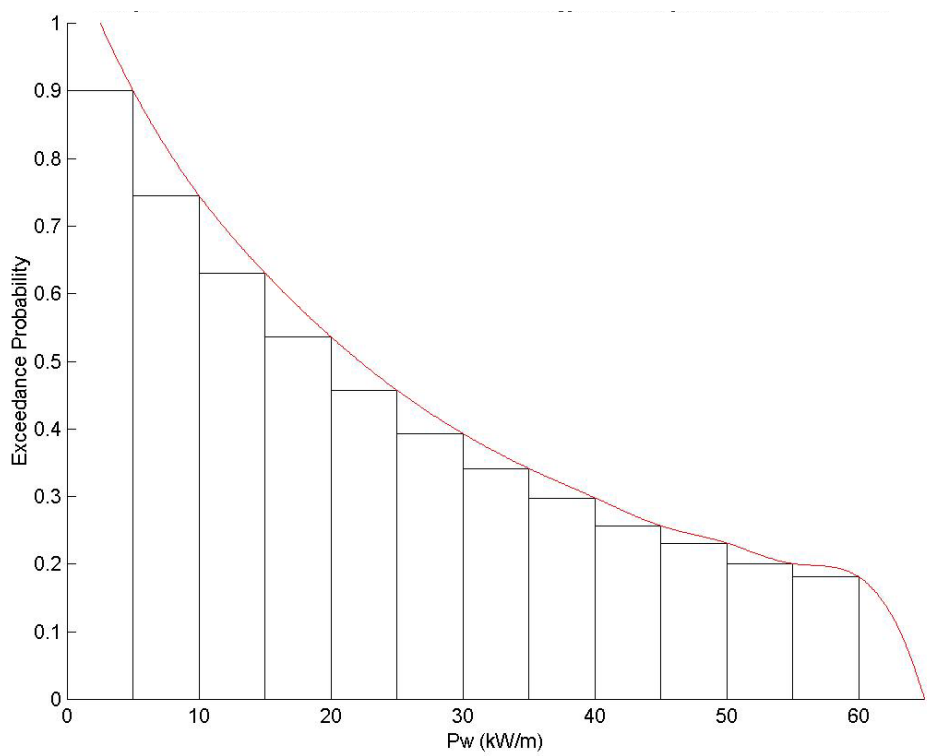

Figure 73: NDBC 46022 wave energy flux exceedance distribution

Cell 10: Del Norte County

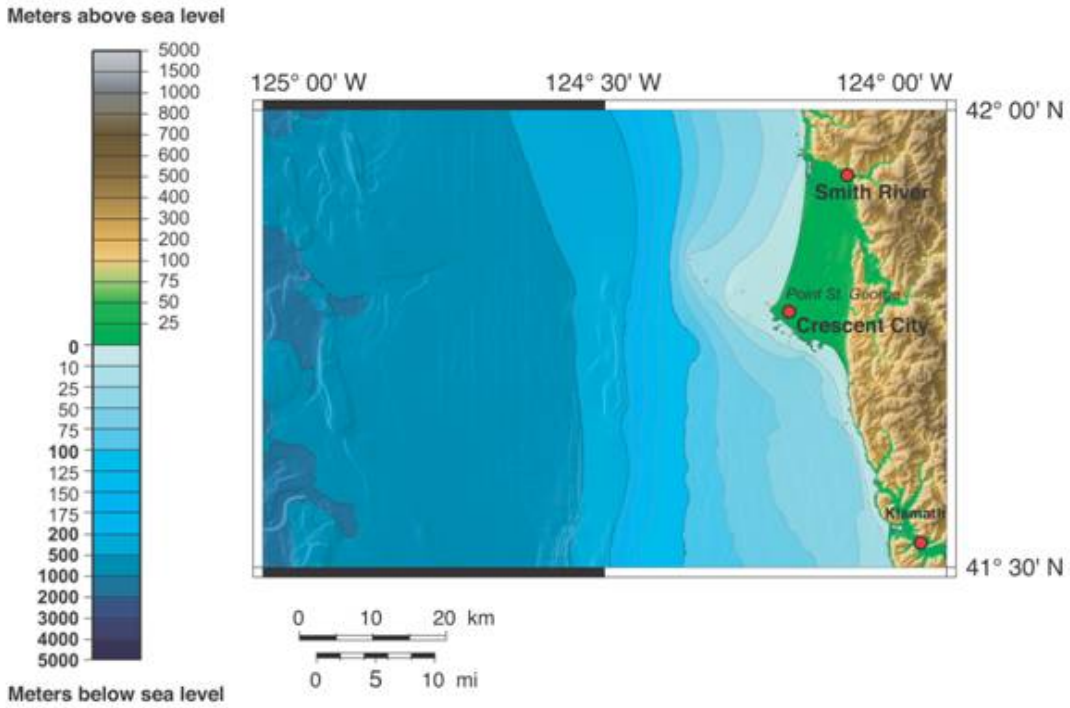

Figure 74. Cell 10 bathymetry

Table 38. Scatter plot of NDBC Wave Statistics for buoy NDBC 46027

Hs (m) \ Tp (sec)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20+	**Total**
0.0 - 0.5	0	0	0	0	0	0	0	0	0	0	0	**0**
0.5 - 1.0	0	0	3	16	16	4	4	6	5	1	0	**54**
1.0 - 1.5	0	0	11	40	65	18	15	12	8	2	0	**172**
1.5 - 2.0	0	0	10	46	72	31	26	16	8	2	0	**212**
2.0 - 2.5	0	0	5	43	54	37	34	21	9	3	0	**207**
2.5 - 3.0	0	0	1	27	32	25	32	20	9	3	0	**148**
3.0 - 3.5	0	0	0	11	17	14	22	17	8	2	0	**91**
3.5 - 4.0	0	0	0	3	9	6	14	15	6	1	0	**54**
4.0 - 4.5	0	0	0	1	4	3	7	10	4	1	0	**29**
4.5 - 5.0	0	0	0	0	1	1	3	6	3	1	0	**15**
5.0 - 5.5	0	0	0	0	0	0	1	3	2	0	0	**8**
5.5 - 7.0	0	0	0	0	0	0	1	3	3	0	0	**8**
7.0 - 9.0	0	0	0	0	0	0	0	0	1	0	0	**1**
9.0 - 11.0	0	0	0	0	0	0	0	0	0	0	0	**0**
Total	**0**	**1**	**30**	**186**	**271**	**139**	**160**	**131**	**66**	**17**	**1**	**1000**

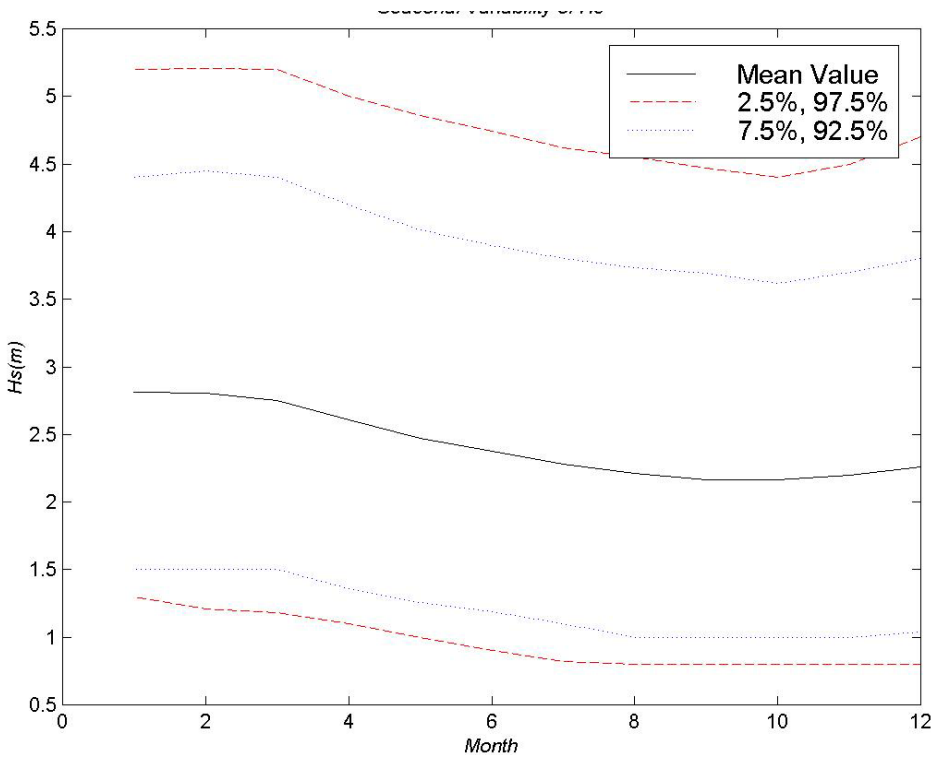

Figure 75. NDBC 46027 significant wave height seasonal variation

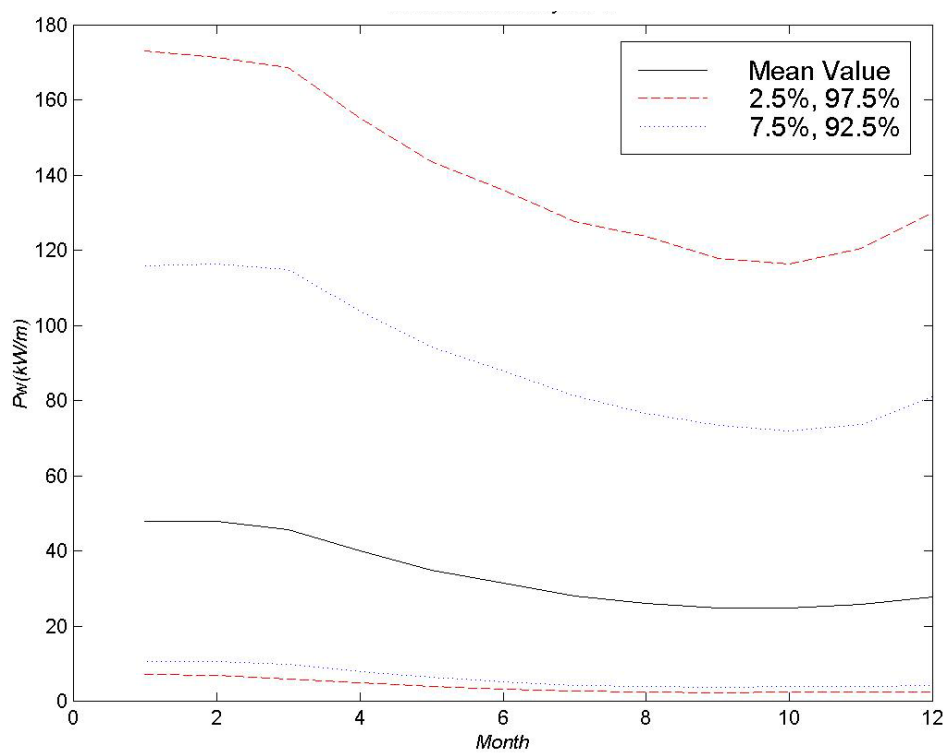

Figure 76. NDBC 46027 wave energy flux seasonal variation

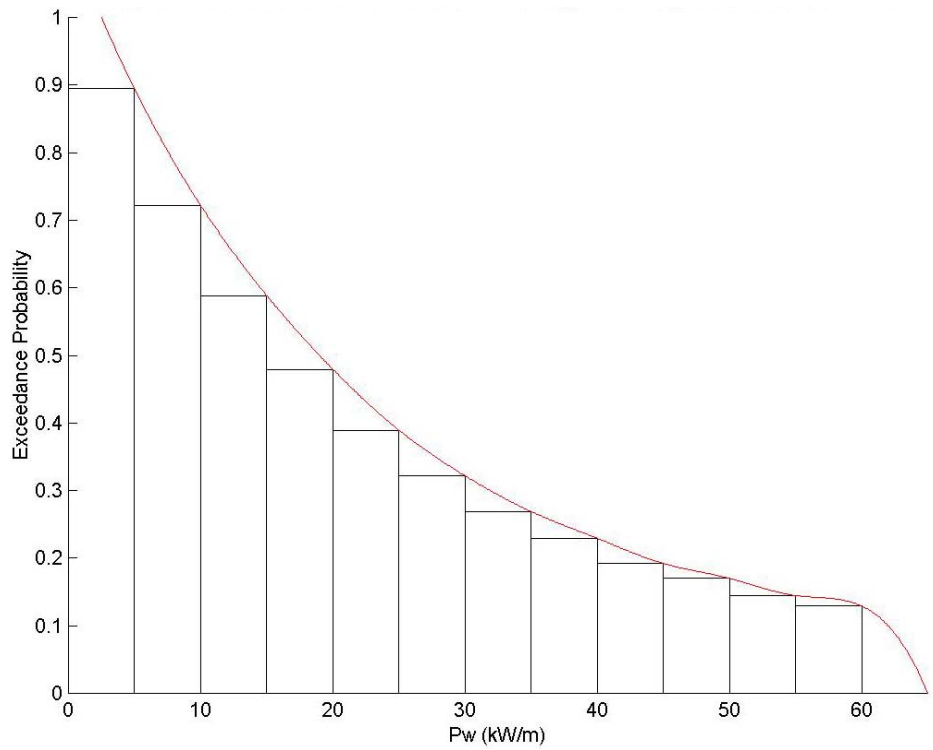

Figure 77. NDBC 46027 wave energy flux exceedance distribution

Appendix B: State and Federal Regulatory Agencies and Regulations Applicable to Wave Energy

Federal Agencies[21]

Minerals Management Service

With the passage of the Energy Policy Act of 2005 (EPAct), Public Law 109-58 (H.R. 6), the Minerals Management Service (MMS), a bureau of the U.S. Department of the Interior, was assigned jurisdiction over Renewable Energy and Alternate Use Program projects, such as wind, wave, ocean current, solar, hydrogen generation, and projects that make alternative use of existing oil and natural gas platforms in federal waters. A new program within MMS has been established to oversee these operations on the U.S. Outer Continental Shelf. At the time of this writing, MMS is preparing a programmatic environmental impact statement that will focus on generic impacts from each industry sector based on global knowledge, and identify key issues that subsequent, site-specific assessments will consider. The programmatic EIS will focus on the environmental, cultural, and socioeconomic impacts associated with establishing a national alternative energy program and rules.

As part of this EIS, three study areas for the State of California were defined. Maps of these areas, showing jurisdictional boundaries can be downloaded from http://ocsenergy.anl.gov/. A draft EIS and draft rules are scheduled to be published February 2007 and final rules in the late summer of 2007. MMS will coordinate with other agencies in the permitting of offshore renewable energy projects. At the time of this writing, it is not certain how this new program for ocean energy developments will affect the licensing and permitting process for offshore wave power plants. For further information on the EIS and rulemaking process please visit http://ocsenergy.anl.gov/.

Federal Energy Regulatory Commission

Pursuant to the Federal Powers Act[22], FERC is an independent agency regulating interstate transmission of natural gas, oil, and electricity and hydropower projects. FERC also has regulatory authority over the terms and rates for power supply contracts from a wave power project to a local utility.[23] FERC issues licenses for private hydropower development on

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[21] Much of the legal information in this section is courtesy of the documentation and analysis from the landmark Ocean Energy Resources website from the Law Offices of Carolyn Elefant. See http://www.his.com/~israel/loce/ocean.html

[22] "….it shall be unlawful for any person….for the purpose of developing electric power, to construct, operate or maintain any dam…reservoir, power house or other works…across navigable e waters of the US or upon any part of public lands or reservations of the US…except in accordance with a license….[issued by FERC].

[23] In most cases, small developers obtain certification as a "qualifying facility" (QF) or "exempt wholesale generator (EWG) to avoid regulation as a utility or in some cases, obtain more favorable rate treatment. FERC also has jurisdiction over sales by a developer to a utility which are known as "wholesale sales." In

navigable waterways, federal lands, and commerce clause waterways. The hydropower licensing process includes consulting with a wide range of stakeholders, identifying environmental issues through a scoping process and preparing an environmental assessment of the project under NEPA (see below). Licenses are issued by Commission Order. This traditional licensing process takes several years to complete and the license is issued for thirty to fifty years.

In 2003, FERC determined through a first-time legal interpretation that the AquaEnergy Group demonstration project in the State of Washington falls under the jurisdiction of the Federal Powers Act.[24] FERC determined that a wave energy buoy is a hydropower project, with a "power house" that uses water to generate electric power. If such a device generates electricity that will be sold onto the grid, the project falls under the licensing authority of FERC. This determination is legally murky, raising questions about whether the definition of "navigable waterways" extends to coastal waters up to 12 nm from shore, and whether the determination is consistent with the State Lands Act and the Outer Continental Shelf Lands Act. As a result of this decision, it is likely that wave energy devices will be subject to FERC's licensing authority.

U.S. Army Corps of Engineers

Under Section 404 of the Clean Water Act, the discharge of dredged or fill material into waters of the United States requires a permit from the USACE. The Corps also has permitting authority under Section 10 of the Rivers and Harbors Act[25], which requires a permit for the placement of structures altering or obstructing navigable waters outside of State limits. Wave energy projects that involve the placement of structures in the water will almost certainly require a permit from the Corps.

Federal Consultation Agencies

Under the federal Endangered Species Act and the Magnuson-Stevens Fisheries Conservation Act, a federal agency such as MMS, FERC or the Corps may be required to formally consult

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most cases, wholesale rates established in a contract between the supplier and purchaser and are then submitted for review to FERC to ensure that rates are "just and reasonable." Retail sales, i.e., sales directly to the end user are regulated by the state utility commissions. Interconnection with the utility means that the demo project has to get in the queue with all other new users of the lines. (Reference: Law Office of Carolyn Elefant).

[24] See http://www.ferc.gov/legal/court-cases/pend-case.asp and scroll down to the AquaEnergy Group.

[25] See 43 U.S.C. section 403: "It shall not be lawful to build or commence the building of any wharf, pier…or other infrastructure in any port, roadstead…or other water of the US except on plans recommended by the Chief of Engineers and authorization by the Secretary of the Army."

with NOAA Fisheries and/or the USFWS, if a proposed project under that agency's regulatory authority has the potential to adversely affect listed species, designated critical habitat, or essential fish habitat. The agency may also consult with NOAA Fisheries regarding marine mammal concerns under the Marine Mammal Protection Act. NOAA Fisheries will become involved in a wave project if it is located within a protected area such as a National Marine Sanctuary. National Marine Sanctuaries often transcend federal and State jurisdictional boundaries and may extend to the seafloor and subsoil resources (see "Marine Protection, Research and Sanctuaries Act"). There are four National Marine Sanctuaries along the California coast: Cordell Bank, Gulf of the Farallones, Monterey Bay, and Channel Islands.

U.S. Environmental Protection Agency

The US EPA is responsible for issuing wastewater discharge permits, called National Pollution Discharge Elimination System (NPDES) permits, under the Clean Water Act for projects in federal waters. This agency also regulates air quality in coordination with the State, and may issue an Authority to Construct or Permits to Operate for projects located in federal waters.

U.S. Coast Guard

The U.S. Coast Guard regulates maritime security, and requires that structures in the water be appropriately marked so they don't become a hazard to navigation. The Coast Guard is also involved in oil spill prevention and response efforts.

Federal Regulations

There are over forty principle statutes addressing potential environmental impacts at the federal level,[26] but only a handful are directly relevant to wave power jurisdictions.[27] A description of the most important and relevant statutes, and a more extensive table of applicable federal regulations, is presented below. The primary federal regulations applicable to a specific wave power project will be different depending on design and location of the project. Because wave power is a nascent industry in California and the United States, this list will almost certainly change in the future.

National Environmental Policy Act (NEPA)

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[26] For a brief summary of specific laws see: http://www.csc.noaa.gov/opis/html/legal.htm#BNDs

[27] Ocean Thermal Energy Conversion Ac (42 U.S.C. sec. 9101); Coastal Zone Management Act (CZMA)

NEPA requires that the environmental consequences of a proposed project must be considered before a federal agency makes a discretionary decision to license, permit or otherwise allow a project to go forward. Some small-scale projects qualify as "categorical exemptions," requiring very little environmental review. Most wave power projects, however, will require either an Environmental Assessment, in which the agency finds that the project will not cause significant adverse impacts to the environment, or, for large-scale projects with significant adverse effects, an Environmental Impact Statement. The EIS process generally requires coordination among multiple agencies and stakeholder groups, a public comment period, and formal certification by the agency.

Relevance: Every wave power project requiring authorization from a federal agency will be required to undergo a project-specific environmental review under NEPA. For large projects, the NEPA process is often conducted in coordination with the State-level CEQA process (see below), with a federal agency leading the NEPA review and a State agency as the CEQA lead.

River and Harbors Act

Section 10 of this Act prohibits the obstruction or alteration of navigable waters of the United States without a permit from the United States Army Corps of Engineers (USACE). For the purpose of this regulation, "navigable waters of the United States" include the U.S. Territorial Sea as defined prior to 1988 (i.e., extending three nautical miles seaward from the shoreline). Limited authorities extend across the outer continental shelf for artificial islands, installations and other devices.

Relevance: Any wave power project sited in "navigable waters of the United States" that will involve the construction and placement of floating and/or fixed structures, laying of power transmission lines, dredging, or any other activity that obstructs or alters the seabed and overlying waters will need to obtain a "Section 10 Permit" from the USACE.

Clean Water Act

Section 404 of the Clean Water act prohibits the discharge of dredged or fill material into waters of the United States without a permit from the USACE. For the purpose of this regulation, "waters of the United States" include the U.S. Territorial Sea as defined prior to 1988 (i.e., extending three nautical miles seaward from the shoreline). The term "dredged material" means material that is excavated or dredged from waters of the United States. The term "fill material" means any material used for the primary purpose of replacing an aquatic area with dry land or of changing the bottom elevation of a water body. The term "discharge of fill material" means the addition of fill material into waters of the United States (e.g., riprap, seawalls, breakwaters, artificial islands, etc.). The placement of pilings may or may not constitute discharge of fill material (refer to Section 323.2).

Section 401 of the Clean Water Act gives certification authority to State governments over activities that may result in discharge into their navigable waters – i.e., before any federal

permit or license can be issued for any activity which may result in discharge, certification must be obtained from the government of the State in which the discharge will occur. In California, the State Water Resources Control Board (SWRCB) and the Regional Water Quality Control Boards (RWQCBs) are responsible for taking certification actions for activities subject to any permit issued by a federal agency.

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) Permit Program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete conveyances such as pipes or man-made ditches.

Relevance: A wave power project that discharges dredged or fill material into waters of the United States requires a Section 404 permit from the USACE. The Regional Water Quality Control Board must certify the Corps' Section 404 permit with a Section 401 certification. Any discharge of wastewater from a point source must be covered under an NPDES permit, issued by the US EPA in federal waters and by the Regional Water Quality Control Board in State waters. In some cases, the State Water Resources Control Board will issue either the 401 certification or the NPDES permit, or both.

Clean Air Act

The Clean Air Act establishes primary and secondary ambient air quality standards designed to protect public health and welfare. Stationary sources in federal waters are regulated by the US EPA, and in State waters by the regional Air Pollution Control District (APCD). Mobile sources, such as marine vessels, trucks, and automobiles, are regulated by the California Air Resources Board (CARB).

Relevance: The construction, modification, or operation of a wave energy facility that may emit pollutants into the atmosphere must first obtain an Authority to Construct and/or a Permit to Operate from the US EPA or the local APCD. Mobile sources of air emissions such as marine vessels may be required to meet exhaust emission standards set by CARB.

Title 33 -- Navigation and Navigable Waters

Under these regulations, the District Commanders of the United States Coast Guard have the authority to determine whether an obstruction in the navigable waters of the United States is a hazard to navigation and, if so, what markings (lights, fog signals, etc.) must be placed on or near the obstruction for the protection of navigation.

Relevance: The District Commander responsible for California (District 11) will need to authorize any wave power project and determine the necessary marking requirements. The authorization process will be coordinated with the Corps' permitting process.

Coastal Zone Management Act

The California Coastal Commission[28] has federal consistency review authority pursuant to the federal Coastal Zone Management Act (CZMA). For most projects that require a federal license or permit, the Commission must review the project and certify that it is consistent with the California Coastal Management Plan, of which the substantial policy component is the Chapter 3 resource policies of the Coastal Act. A project that can reasonably be expected to affect the coastal zone, such as a project that requires a permit from the Army Corps of Engineers for the placement of fill, is subject to federal consistency review under the CZMA. The Coastal Commission must determine that a proposed project is consistent with the California Coastal Management Plan before the federal agency can issue its license or permit.

Relevance: If the project occurs wholly within State waters (or other areas where the Commission has retained coastal development permit jurisdiction), the Commission's permit review satisfies federal consistency requirements. If a project is wholly or in part in federal waters, a separate federal consistency review would most likely be required.

Endangered Species Act/Fish and Wildlife Coordination Act

Section 7 of the Endangered Species Act directs all federal agencies to consult with the USFWS and NOAA Fisheries, to ensure that the actions they authorize, fund, or carry out do not jeopardize listed species or destroy or adversely modify critical habitat. The Fish and Wildlife Coordination Act provides that whenever an activity is planned to modify waters by a department or agency of the United States, that entity shall first consult with the USFWS, NOAA Fisheries, and with the State agency exercising administration over the fish and wildlife resources.

Relevance: Depending on the exact nature and degree of environmental impacts a wave power project has the potential to cause, the USFWS and/or NOAA Fisheries may be informally or formally consulted during the federal permitting process.

Table 39. Selected Federal Regulations

Legislative Authority	Major Program/Permit	Lead Agency
Federal Power Act	Issues license for any type of electric power generation within/or on navigable waters; interconnection is parallel process	FERC

[28] The CZMA is administered by the California Coastal Commission for areas offshore the coastline of the Pacific Ocean, and by the San Francisco Bay Conservation and Development Commission for waters of San Francisco Bay and contiguous areas.

Legislative Authority	Major Program/Permit	Lead Agency
Rivers and Harbors Act - Section 10	Regulates all structures and work in navigable water of the U.S. Extended out to 200 nm under the OCSLA for fixed structures/artificial islands	U.S. Army Corps of Engineers (District Office)
National Environmental Policy Act (NEPA)	Requires an environmental review for all major federal actions that may significantly affect the quality of the human environment	Lead agency varies depending on project Council on Environmental Quality
Coastal Zone Management Act	Jurisdictional rights to states to review activities that may affect the state's coastal resources	California Coastal Commission
Navigation and Navigable Waters	Navigation aid permit (markings and lighting)	U.S. Coast Guard
Clean Water Act, Section 404	Regulates discharge of dredged or fill material into waters of the United States	U.S. Army Corps of Engineers (District Office)
Clean Water Act, NPDES program	Regulates discharges of pollutants into the waters of the United States	U.S. Environmental Protection Agency
Clean Air Act	Establishes primary and secondary ambient air quality standards	U.S. Environmental Protection Agency
Migratory Bird Treaty Act	No "taking" or harming of birds determination	U.S. Fish and Wildlife Service Migratory Bird Conservation Commission
National Historic Preservation Act	Consultation on the protection of historic resources — places, properties, shipwrecks	Department of the Interior State Historic Preservation Offices
Magnuson-Stevens Fishery Conservation & Management Act	Conserves & manages fish stocks to a 200-mile fishery conservation zone & designates essential fish habitat	National Marine Fisheries Service (NOAA Fisheries)
National Marine Sanctuary Act (Title III)	Designates marine protected areas	National Ocean Service (within NOAA)
Endangered Species Act	Consultation on action that may jeopardize threatened & endangered (listed) species or adversely modify critical habitat. May require the preparation of a Biological Assessment	U.S. Fish & Wildlife Service National Marine Fisheries Service (NOAA Fisheries)

Legislative Authority	Major Program/Permit	Lead Agency
Marine Mammal Protection Act	Prohibits or strictly limits the direct of indirect taking or harassment of Marine Mammals (Permits may be sought for "incidental take")	National Marine Fisheries Service (NOAA Fisheries)
Submerged Lands Act	Grants states a title for public lands/natural resources held in trust by the government	Minerals Management Service
Outer Continental Shelf Lands Act	Manages the OCS with leasing rights for minerals production. Also covers artificial islands, ,installations, and other devices located on the seabed	Minerals Management Service
Estuary Protection Act	Conserves estuarine areas	Fish and Wildlife Service

State and Local Authorities

Under most federal licensing and permitting regimes (e.g., FERC hydropower licensing, Section 404 permits), federal agencies must consult with the affected State, and in some cases require compliance with the State's laws and regulations. As with the federal regulatory process, the State permitting process will vary for each individual project depending on the location and design of the project. Onshore facilities will also likely require approvals from the local government (either City or County), possibly including a coastal development permit, a special use permit or a zoning change.

For the State of California, the key agencies involved in the permitting process are the State Lands Commission, the Coastal Commission, the regional Air Quality Management District, the regional Water Quality Control Board, and the Department of Fish and Game. The following table provides a short description of applicable California regulations:

Table 40. State and Local Agencies

STATE	State and local agencies	Any activity that has the potential to cause adverse effects to the human environment	CEQA assessment
	California State Lands Commission	Use of submerged/tidal lands or other public trust lands	General lease
	California Coastal Commission	Development within Coastal Zone (submerged/tidal lands or other public trust lands; lands not covered by certified LCP) Development that triggers a federal permit, that may affect coastal resources	Coastal development permit Federal consistency review
	California Air Resources Board Air Quality Management Districts	Any activity that may result in the production of air emissions	Authority to Construct Permit to Operate

	California State Water Resource Control Board Regional Water Quality Control Boards	Any activity which may result in discharge into State waters	Section 401 certification Waste discharge requirements
	California Department of Fish and Game	Any activity	Consultation under California Endangered Species Act
LOCAL	County/city governments	Development within Coastal Zone (where local government has a certified Local Coastal Plan)	Coastal development permit

California Environmental Quality Act (CEQA)

CEQA requires that the potential environmental effects of a proposed project be analyzed and disclosed, and that means to avoid or minimize those impacts be identified. As with NEPA, there are different levels of environmental review under CEQA, depending on the scale and location of the proposed project. An Initial Study and Negative Declaration is appropriate when an agency finds that the proposed project will not have significant adverse environmental effects, or if any adverse effects can be mitigated so that they are no longer significant after mitigation. An Environmental Impact Report is similar to an Environmental Impact Statement under NEPA – the EIR requires multiple agency and stakeholder coordination, and a public comment period. Unlike NEPA, CEQA specifically requires that a proposed project incorporate mitigation measures to avoid or substantially reduce significant environmental effects.

Relevance: A wave power project subject to State authority will be required to undergo an environmental analysis under CEQA.

Submerged Lands Act/California State Lands Act

The Submerged Lands Act grants coastal states title to offshore lands out to three nautical miles offshore, as well as the rights to the natural resources on or within those lands. The federal government relinquishes its claims to the lands and resources, but maintains the right to regulate offshore activities for national defense, international affairs, navigation, and commerce. The State Lands Commission has jurisdiction over all State-owned tide and submerged lands, including the tidal and submerged lands adjacent to the entire coast and offshore islands of the State from the mean high tide line to three nautical miles offshore.

Relevance: Any wave power project involving floating devices, seabed structures, and/or power transmission cables on State-owned tidal and submerged lands will require a General Lease from the State Lands Commission.

Coastal Zone Management Act/California Coastal Act

The California Coastal Act requires that any proposed project involving development in the coastal zone obtain a coastal development permit. The coastal zone extends from three nautical miles offshore to an onshore location that varies depending on location. On tidelands and submerged lands, the issuing agency for a coastal development permit is the California Coastal Commission, and the standard of review is the resource policies of Chapter 3 of the Coastal Act. For onshore development in areas where the local government has a certified Local Coastal Program, the issuing agency is the local government (either the City or the County), although the permit may be appealable to the Commission. The standard of review for a locally-issued CDP is the certified Local Coastal Program.

Relevance: Wave power projects located within the coastal zone will require a coastal development permit from the Coastal Commission and/or the appropriate local government agency.

Clean Water Act/California Porter-Cologne Water Quality Control Act

As discussed above, Section 401 of the Clean Water Act requires that the State certify a project subject to the Corps' Section 404 permit requirements. Under the Porter-Cologne Act, all parties proposing to discharge waste that could affect waters of the State must file a report of waste discharge with the appropriate Regional Board. The Regional Board will then issue or waive waste discharge requirements (WDRs). It is important to note that while Section 404 permits and 401 certifications are required when the activity results in fill or discharge directly below the ordinary high water line of waters of the United States, **any** activity that results or may result in a discharge that directly or indirectly impacts waters of the State or the beneficial uses of those waters are subject to WDRs. In practice, most Regional Boards rely on applications for 401 certification to determine whether WDRs are also required for a proposed project.

Relevance: Any wave power project involving the discharge of dredged or fill material in waters of the United States will require a Section 404 Permit from the USACE, and a Section 401 Certification (and possibly WDRs) from the SWRCB or the appropriate RWQCB.

The California Endangered Species Act (CA ESA)

This Act parallels the main provisions of the federal Endangered Species Act, and is administered by the California Department of Fish and Game (DFG). The CA ESA establishes a petitioning process for the listing of threatened or endangered species, and prohibits the

"taking" of listed species. During the CEQA process, State lead agencies consult with DFG to ensure that the proposed project is not likely to jeopardize the continued existence of any endangered or threatened species, or result in destruction or adverse modification of essential habitat.

Relevance: The California Department of Fish and Game consults on projects that have the potential to cause adverse effects to listed species.