

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Ocean Wave Energy Resource Assessment-
hotspots, exceedance-persistence, and predictability**

**A thesis presented in partial fulfilment of the
requirements for the degree of**

Master of Applied Science

in

Natural Resource Engineering

at Centre for Energy Research,

**Massey University, Palmerston North,
New Zealand.**

James Edward Frazerhurst

2007

Ocean Wave Energy Resource Assessment- hotspots, exceedance-persistence, and predictability



Figure A. (Title page). A breaking wave from the perspective of a surfer travelling inside (source: www.surfermag.com).

Abstract

Ocean wave energy conversion is evolving towards commercial viability. Succinct resource assessment is essential to the conversion of wave energy for grid supply electrical generation. The ability to differentiate potential wave energy locations by means of comprehensible evaluations is particularly useful to the commercial developers of wave energy power plants.

This report establishes an assessment of wave energy that provides an understanding of the resource in both spatial and temporal resolution. Three aspects of the wave resource are established; mapping of wave energy **hotspots** due to wave focusing, visualisation of the probability of wave energy **exceedance** and **persistence**, and calculation of the **predictability** of wave energy for a particular aspect of coast. These three assessments are explained with a review of the science surrounding the phenomena of wave creation and propagation, the development of wave energy converter devices, as well as visualisation and manipulation of wave resource assessments. The outputs of these assessment methodologies are comparable, uncomplicated, graphic representations of the resource.

Case studies for seven locations encircling New Zealand were investigated, in order to demonstrate the practicalities of the wave energy resource assessment methodology developed by this project.

This study modelled the transformation of several hundred combinations of wave height, period and direction from deep-water to shore. The different conditions were ranked in terms of probability of occurrence. Recombination of these iterations created hotspot maps. The locations examined in this study were then compared to other infrastructure for wave energy utilisation.

Historical wave data was processed to establish the probability of levels of wave energy being exceeded and persisting. This information establishes how often a potential wave energy plant might provide significant output and for how long this output might persist.

Collection of wave prediction data for aspects of New Zealand allowed the comparison of up to seven day forecasts with a “now forecast”. Assessment was then

made of the predictability of the climatic conditions creating waves for a location. The ability to be able to provide accurate forecasts of potential wave energy plants is of significant interest to generation companies in New Zealand in order to manage a diverse generation portfolio.

Key finding of this investigation:

- Waves and wave energy have significant variation of spatial, and temporal scales.
- Waves can be predicted for an aspect of coastline dependant upon the predictability of the climatic conditions of the wave generation location.
- Wave energy resource assessment is often presented as a single figure of averaged kilowatts per meter wave front that fails to adequately incorporate the temporal, spatial, and predictive aspects of the resource.
- A methodology was compiled to create “hotspot” (areas of intensified wave energy) mapping of a location utilising a wave transformation model. These maps can then be used to access spatial relationships to other digital information (electricity grid nodal locations, marine protected areas, navigation requirements, etc).
- Processing of wave climate data utilising Matlab© script developed by ASR Ltd identified the probability of wave energy being exceeded and persisting for a given location.
- Forecasts of wave characteristics are published on the Internet. Calculation of error between a “now forecast” and the previous day’s forecast for today (up to six days out), can give an assessment of the predictability of an aspect of a location provided the wave forecast model utilises significant climatic variables.
- Case studies of wave energy resource assessment (using the developed hotspot, exceedance persistence, and predictability methods) for seven locations encircling New Zealand, identified three classes of wave resource; exceptional (Southland), good (Otago, Taranaki, Auckland, Hokianga), and poor (Canterbury, Wellington).

Acknowledgements

Much of the inspiration and desire for science and the “new” direction my life has taken is attributed to my good friend Dr Shaw Mead. Thanks to you and I look forward to many years of long period barrels at outsidess.

Thanks to my supervisor, Professor Ralph Sims, your energy and enthusiasm is contagious, I feel privileged to have had you associated with my studies and development.

Inspiration and guidance from my good friend Dr Tim Haggitt has also been instrumental in my maturing respect for science and the scientific method.

Thanks to directors of ASR Ltd, Dr Kerry Black, Dr Joseph Mathew and past director Dr Peter McComb, Thanks also to the former staff member Dr Dave Johnson. Thanks also to Dr Richard Gorman of NIWA and Chris Jewell of Mighty River Power Ltd.

Sorry to my friends and extended family that I have harangued with my passion for this topic. Your support and encouragement has been invaluable.

Love and thanks to my parents Chris and Mary Anne , brother Mark and his wife Ange , sister Sarah and husband Steve, for their support and guidance.

Much love and thanks to my wife Jennifer and daughter Kaia

Table of contents

ABSTRACT	- 3 -
ACKNOWLEDGEMENTS	- 5 -
TABLE OF CONTENTS	- 6 -
TABLE OF FIGURES	- 10 -
TABLE OF TABLES	- 14 -
1 INTRODUCTION	- 15 -
1.1 PROBLEM IDENTIFICATION	- 16 -
1.2 RESEARCH AIM	- 16 -
1.3 OBJECTIVES	- 16 -
2 IDENTIFICATION OF PARAMETERS AND PRINCIPALS	- 18 -
2.1 WAVES.....	- 18 -
2.1.1 WAVE CREATION AND DEEP WATER PROPAGATION	- 18 -
2.1.1.1 SUMMARY OF WAVE CREATION AND DEEP WATER PROPAGATION	- 27 -
2.1.2 WAVE TRANSFORMATION	- 28 -
2.1.2.1 SHOALING, REFRACTION AND DIFFRACTION	- 28 -
2.1.2.2 DISSIPATION DUE TO FRICTION AND PERCOLATION	- 31 -
2.1.2.3 BREAKING	- 33 -
2.1.2.4 GROWTH DUE TO THE WIND AND WAVE-WAVE INTERACTIONS.....	- 34 -
2.1.2.5 WAVE-CURRENT INTERACTION.....	- 34 -
2.1.2.6 SUMMARY OF WAVE TRANSFORMATION	- 35 -
2.1.3 OBSERVATION AND PREDICTION	- 35 -
2.1.3.1 MEASUREMENT.....	- 36 -
2.1.3.2 FIRST AND SECOND GENERATION WAVE PREDICTION MODELS.....	- 38 -
2.1.3.3 THIRD GENERATION WAVE PREDICTION MODELS.....	- 39 -
2.1.3.4 TRANSFORMATION MODELS	- 39 -
2.1.3.5 SUMMARY OF OBSERVATION AND PREDICTION.....	- 41 -
2.2 WAVE ENERGY RESOURCE ASSESSMENT METHODOLOGIES	- 41 -
2.2.1 TIME-AVERAGE WAVE ENERGY EVALUATION.....	- 42 -
2.2.1.1 SUMMARY OF TIME-AVERAGE WAVE ENERGY EVALUATION.	- 44 -
2.2.2 JOINT PROBABILITY TABLES	- 44 -
2.2.2.1 SUMMARY OF JOINT PROBABILITY TABLES	- 45 -
2.2.3 SPATIAL WAVE EVALUATION	- 45 -
	- 6 -

2.2.4	TEMPORAL WAVE EVALUATION	- 46 -
2.2.5	WAVE FORECASTING	- 48 -
2.2.6	SUMMARY OF SPATIAL, TEMPORAL WAVE EVALUATION AND WAVE FORECASTING.....	- 49 -
2.2.7	GEOGRAPHIC INFORMATION SYSTEMS (GIS).....	- 49 -
2.2.7.1	GIS ARCHITECTURE.....	- 51 -
2.2.7.2	GIS AND WAVE ENERGY ASSESSMENT.....	- 51 -
2.2.7.3	SUMMARY OF GIS.....	- 51 -
2.3	RENEWABLE ENERGY SYSTEMS	- 52 -
2.3.1	COMMON BENEFITS.....	- 52 -
2.3.1.1	SUSTAINABLE DEVELOPMENT, SUSTAINABLE ENERGY.....	- 52 -
2.3.1.2	AVOIDING CO ₂ EMISSIONS	- 54 -
2.3.1.3	DISTRIBUTED GENERATION.....	- 55 -
2.3.1.4	COST EFFECTIVENESS.....	- 55 -
2.3.2	COMMON BARRIERS.....	- 56 -
2.3.2.1	“NOT IN MY BACK YARD” (NIMBYISM).....	- 57 -
2.3.2.2	RESOURCE CONSENT IN NEW ZEALAND	- 57 -
2.3.2.3	GOVERNANCE.....	- 58 -
2.3.2.4	ECONOMIC RISK.....	- 58 -
3	WAVE ENERGY CONVERTER DEVICES	- 60 -
3.1.1	EXTREME WAVES AND SURVIVABILITY	- 61 -
3.1.2	A PLETHORA OF DEVICES	- 62 -
3.1.3	DEVICE DEVELOPMENT.....	- 64 -
3.1.4	THE CAPTURE WIDTH RATIO (CWR).....	- 66 -
3.1.5	DEVICES COMPARED FOR IMPLEMENTATION OF PILOT AND A COMMERCIAL WAVE POWER PLANT.	- 66 -
3.1.6	ENVIRONMENTAL IMPACTS.....	- 67 -
3.1.7	GRID CONNECTION	- 70 -
3.1.8	DEPLOYMENT.....	- 71 -
3.1.9	FUTURE DEVELOPMENTS.....	- 72 -
3.1.10	WAVE ENERGY CONVERTER DEVICES.....	- 72 -
3.1.11	SUMMARY OF WAVE ENERGY CONVERTER DEVICES	- 73 -
4	WAVE ENERGY ASSESSMENT OF NEW ZEALAND.....	- 75 -
4.1	WAVE CLIMATE –WAM TWENTY-YEAR HINDCAST MODEL.....	- 75 -
4.1.1	VALIDATION.....	- 75 -
4.1.2	WAVE PARAMETERS FROM THE SPECTRA OF A 3G WAM MODEL.....	- 77 -
4.1.3	SUMMARY OF WAVE CLIMATE	- 80 -

4.2	BATHYMETRIC DATA.....	- 80 -
4.2.1	DATA ACQUISITION METHOD.....	- 81 -
4.2.2	SUMMARY OF BATHYMETRY	- 85 -
4.3	WAVE FORECASTS	- 86 -
4.3.1	EXAMPLE DATA COLLECTION.....	- 89 -
4.3.2	WAVE CHARACTERISTICS DURING PERIOD OF STUDY.	- 93 -
4.3.3	SUMMARY OF WAVE FORECASTS.....	- 95 -
4.4	INFRASTRUCTURE	- 95 -
4.4.1	ENERGY DEMAND.....	- 95 -
4.4.2	TRANSMISSION	- 96 -
4.4.3	PORTS	- 101 -
4.4.4	SUMMARY OF INFRASTRUCTURE DATA.....	- 102 -
5	DATA ASSESSMENT	- 103 -
5.1	IDENTIFYING HOTSPOTS.....	- 103 -
5.1.1	WAVE TRANSFORMATION MODELLING	- 103 -
5.1.2	RECALCULATION OF ITERATIONS AND GEO-REGISTRATION...-	104 -
5.1.3	HOTSPOT INTERPRETATION.....	- 104 -
5.1.4	SUMMARY OF HOTSPOT IDENTIFICATION METHODOLOGY	- 105 -
5.2	EXCEEDANCE-PERSISTENCE.....	- 105 -
5.2.1	SUMMARY OF EXCEEDANCE-PERSISTENCE METHODOLOGY ..-	108 -
5.3	PREDICTABILITY	- 108 -
5.3.1	PREDICTABILITY CALCULATION.....	- 109 -
5.3.2	PREDICTABILITY INTERPRETATION	- 112 -
5.3.3	SUMMARY OF PREDICTIVE METHODOLOGY	- 114 -
6	NEW ZEALAND CASE STUDIES	- 115 -
6.1	HOTSPOTS	- 116 -
6.1.1	HOTSPOT MAPS.....	- 119 -
6.2	EXCEEDANCE-PERSISTENCE.....	- 128 -
6.3	PREDICTABILITY	- 137 -
6.4	WAVE ENERGY POSSIBILITIES	- 138 -
7	FUTURE DEVELOPMENTS	- 142 -
7.1	HOTSPOTS	- 142 -
7.1.1	BATHYMETRIC DATA.....	- 143 -
7.1.2	WAVE GENERATION AND PROPAGATION MODELLING	- 143 -
7.2	EXCEEDANCE-PERSISTENCE.....	- 144 -

7.3	PREDICTABILITY	- 145 -
8	SUMMARY AND CONCLUSIONS.....	- 146 -
8.1	KEY FINDINGS OF THIS INVESTIGATION:.....	- 146 -
9	REFERENCES	- 149 -
10	APPENDIX A, SEASONAL EXCEEDANCE-PERSISTENCE	- 154 -
10.1	HOKIANGA.....	- 154 -
10.2	AUCKLAND	- 156 -
10.3	TARANAKI	- 158 -
10.4	WELLINGTON	- 160 -
10.5	CANTERBURY	- 162 -
10.6	OTAGO.....	- 164 -
10.7	SOUTHLAND.....	- 166 -

Table of figures

Figure A. (Title page). A breaking wave from the perspective of a surfer travelling inside (source: www.surfermag.com).....	3 -
Figure 2.1. Waves grow in height first at a linear rate (a straight line), then exponentially (a rising curve), and finally reach saturation when growth is limited (a horizontal line) (Source: Butt and Russell, 2002).....	19 -
Figure 2.2. Exponential wave growth. Turbulent eddies, (shown as clockwise rotating red “squiggles”) increase in size at the same time as wave height. The eddies and waves are inextricably linked creating a positive feed back loop of both wave height and eddy size (Source: Butt and Russell, 2002)..	20 -
Figure 2.3. Generation of irregular waves (a sea) by a storm (wind to ocean energy transfer), the propagation of regular swell waves across the ocean (energy-transfer agent), and shoaling and final breaking of wave on the shore (energy dissipation as heat, sound and kinetic sediment transportation) (Source: Komar 1998).....	21 -
Figure 2.4. Energy density of waves and the period (T) of the waves is a common method of describing the wave spectrum. During the processes of wave generation (a sea), propagation (as swell), and shallow water seabed interaction (surf) (Source: Komar 1998).....	22 -
Figure 2.5. Individual waves in a wave group travel at twice the velocity of the group and move through from the front to the back (demonstrated by the red wave), and appear to an observer to be “born” at the back and “die” at the front. (Source: Butt and Russell, 2002).....	24 -
Figure 2.6. Wave half life (time required for wave height to decrease by one half) according to decay in wave height (H) and internal friction (Source: Keulegan 1950 in Komar, 1998).....	26 -
Figure 2.7. Wave refraction and an aerial photograph of the refraction process. C_{∞} and C are the offshore and shoreward phase velocities. α_{∞} is the offshore angle of approach, α the shoreward angle of approach S_{∞} and S are the spacing of wave orthogonals offshore and shoreward respectively. The increase in length from S_{∞} to S shows a divergence of energy per metre of wave front. (Source: Frazerhurst and Mead 2003, Komar, 1998).....	30 -
Figure 2.8. Wave transformation across bathymetric features. Left hand side shows a canyon with subsequent diverging wave orthogonals. Right hand side shows ridge (or shoal) with subsequent concentration (or focus) of wave orthogonals (Source: United States Army Corps of Engineers, 2002).....	30 -
Figure 2.9. Water particle displacements from mean position for shallow-water, and deepwater. (Source: United States Army Corps of Engineers, 2002).....	32 -
Figure 2.10. Local fluid velocities and accelerations during wave propagation (Source: United States Army Corps of Engineers, 2002).....	32 -
Figure 2.11. Simple classification of breaker types, and right hand side with wave rider’s perspective with vortex length (l), width (w) and angle (θ). H is the estimated wave height. (Source: Mead, 2003)...	34 -
Figure 2.12. Schematic diagram of several types of wave measurement systems (Source: Brooks, 2004).....	37 -
Figure 2.13. Approximate global wave distribution of time-average wave power in kW/m. (Source: Brooks, 2003).....	42 -
Figure 2.14. Idealised wave heights for North and East aspect coastlines of Oahu Hawaii , USA. Average wave height is less for the North Shore than adjacent East Side notwithstanding large seasonal swells. (Idealised example from James Frazerhurst’s personal observation).....	47 -
Figure 2.15. Contour map and perspective visualisation output of GIS Wind Farmer (Source: Garrad Hassan, 2005).....	50 -

Figure 2.16. Cost (\$/kW) of renewable energy technology with cumulative production capacity (MW) and the involvement of government funding to realise commercial equality. (Source: Electric Power Research Institute, 2004b).....- 59 -

Figure 3.1. Classification of ocean wave energy conversion processes based on mode of energy absorption (pitch, heave, surge or combined modes), type of absorber (A), and type of reaction point (B). (Source: Hagerman 1995 in Brooke 2003)- 64 -

Figure 4.1. Position of wave buoys (+) used for comparison with the Hindcast model. Shaded squares indicate dry cells in the 1.125°x 1.125° New Zealand regional grid, while grid cells from which hindcast output spectra were interpolated are marked (*). (Source: Gorman *et al*, 2003b)- 76 -

Figure 4.2. Significant wave height (Hs) at a wave buoy site near Foveaux Strait (Fig. 4.1) show as time series data simulated by the wave model and as measured by the buoy. (Source: Gorman *et al*, 2003b)- 76 -

Figure 4.3. Significant wave height (Hs) at a wave buoy site near Foveaux Strait (Fig. 4.1) as simulated by the wave model and as measured by the buoy, show as regression, with the line of best fit and equivalence lines shown by solid and dashed lines respectively. (Gorman *et al*, 2003b).....- 77 -

Figure 4.4. The components of spectral density $F(f, \Theta)$ at the prediction point P, for propagation direction Θ_1 . As an example this uses an up fetch spectrum at E, interpolated from hindcast spectra at cells A and C. For propagation direction Θ_2 , the fetch to the coast (PG) was used to compute a fetched-limited spectral density (Gorman *et al*, 2003b).- 79 -

Figure 4.5. The use of multibeam survey to determine the bathymetry of a site. Swathes are made across the ocean floor as the vessel makes passes (black lines). Location of vessel is kept in check with real time kinetic global positioning systems (RTK-GPS)(Source www.niwa.cri.nz).- 81 -

Figure 4.6. Screen capture of the geo-processing of navigation chart NZ42 Sample shows Northland Peninsular, North Island.- 82 -

Figure 4.7. Screen capture of the digitising of geo-registered navigation charts using MapInfo Professional GIS. X, Y, Z data was collected with X, Y being NZMG northing and easting, and Z being the ocean depths. Sample shows Hokianga Harbour and adjacent coastline.....- 83 -

Figure 4.8. Screen capture of Surfer© (Golden software 1996). X, Y, Z data (in red) converted into a grid using Surfer grid creation capabilities. Data was rotated according to convention of wave transformation model. The land has been blanked. The grid will now be trimmed of locations lacking in X, Y, Z data. Sample shows Hokianga Harbour and adjacent coastline.- 84 -

Figure 4.9. Screen capture of the plotting of the modified bathymetry data for the wave transformation model in the 3DD suite of hydrodynamic models. Sample shows Hokianga Harbour and adjacent coastline extending to the continental shelf (>200m depth).....- 85 -

Figure 4.10. Screen capture of buoyweather.com site. Wave characteristics are viewed across the middle of this web page by way of a bar graph in crimson for a particular location at a particular date, in this case 37° S 173.75° E on 4/21/04 .As this is a United States of America based site the dates are shown as MM/DD/YY and wave heights are in feet. Peak wave heights, significant wave heights, average period, and direction are provided at six hourly intervals. (Source: www.buoyweather.com)....- 87 -

Figure 4.11. Excel spreadsheet for organizing e-mailed data for a single location. Significant wave heights (Hs) and wave periods (T) are shown but direction (Dir) was also collated. The yellow cells represent the first day of records, the blue the second day. This staggering of each 24 hour predictions allowed comparison for the same day on the same line. Hence line 28-31 shows the first full six days prediction and the “now forecast”.....- 89 -

Figure 4.12. Locations of the virtual buoy sites for this investigation represented in yellow (Source: www.buoyweather.com).....- 91 -

Figure 4.13a. The national electricity grid for New Zealand including the varying sizes of transmission lines, grid nodes, power stations, and sub stations (source: Transpower, 2005)- 97 -

Figure 4.13b. The national electricity grid for New Zealand including the varying sizes of transmission lines, grid nodes, power stations, and sub stations (source: Transpower, 2005)- 99 -

Figure 4.14. Locations of where new generation might more easily be connected to existing grid nodal points.- 100 -

Figure 5.1 . Front-end window of the ASR Ltd Exceedance-Persistence Matlab script.- 106 -

Figure 5.2. Screen capture of a portion of the Excel file for the probability output table of the ASR Matlab script. The increasing numbers on the left hand side represent kW/m of energy. These extend down to less than or equal to 100 kW/m. The numbers across the top of the table represent hours. These extend out to 240 hours. The three hour intervals correspond to the temporal resolution of the hindcast data. This figure only shows the corner of the full table as the full table is too large to be able to show details.- 107 -

Figure 5.3a. Exceedance-persistence example showing 100 different data lines for 0 to 100 kW/m energy calculations for a Hokianga location during winter (legend can be found at figure 5.10). The 0 kW/m line and 100 kW/m are indicated by the red text and arrows.- 108 -

Figure 5.3a. Legend for the exceedance-persistence charts. The values are for the wave energy calculated from the wave spectrum generated from the WAM hindcast and represent the exceedance of energy (hence \geq).- 108 -

Figure 5.4. Calculation of RNMSE, highlighted in yellow for the 1 to 6 day forecasts for a particular location.- 110 -

Figure 5.5. Comparison of the RNMSE as percentage for the significant wave height (H_s) for six locations around New Zealand.- 111 -

Figure 5.6. Comparison of the RNMSE as a percentage of the wave periods (T) for six locations around New Zealand.- 111 -

Figure 5.7. Comparison of the RNMSE as a percentage of the swell direction for six locations around New Zealand- 112 -

Figure 5.8. Swell heights from buoyweather.com predictions for SS NZ.....- 113 -

Figure 5.9. Swell heights from buoyweather.com predictions for NNE NZ- 114 -

Figure 6.1. Locations based on WAM hindcast data show the average wave energy (calculated from the spectral modelling).....- 116 -

Figure 6.2. A combination of all hotspot modelling on a continuous scale of wave heights from 0 kW/m (blue) to a maximum of 55kW/m (red). Hotspot modelling has used the general method of energy calculation (equation 2.6) and weighted average combining iterations of wave model WBEND.....- 118 -

Figure 6.3. Weighted average wave energy for coastline adjacent to Hokianga harbour derived from WAM 20 year wave hindcast and digitised bathymetry 200m x 200m cells. Note that the nearest grid node (Kaikohe) is not visible at this scale.- 120 -

Figure 6.4. Weighted average wave energy for coastline adjacent to Waitemata harbour derived from WAM 20 year wave hindcast and digitised bathymetry 300m x 300m cells.- 121 -

Figure 6.5. Weighted average wave energy for Taranaki coastline derived from WAM 20-year wave hindcast and digitised bathymetry 2000m x 2000m cells.....- 122 -

Figure 6.6. Weighted average wave energy for coastline adjacent to Wellington region from WAM 20 year wave hindcast and digitised bathymetry 500m x 500m cells.- 123 -

Figure 6.7. Weighted average wave energy for Canterbury coastline derived from WAM 20year wave hindcast and digitised bathymetry 2500m x 2500m cells.....- 124 -

Figure 6.8. Weighted average wave energy for coastline adjacent to Otago harbour derived from WAM 20 year wave hindcast and digitised bathymetry 200m x 200m cells.- 125 -

Figure 6.9. Weighted average wave energy for coastline adjacent to Southland harbour derived from WAM 20 year wave hindcast and digitised bathymetry 3000m x 3000m cells.- 126 -

Figure 6.10. Legend for the exceedance-persistence charts. The values are for the wave energy calculated from the wave spectrum generated from the WAM hindcast and represent the exceedance of energy (hence \geq).- 128 -

(a) Great Barrier Island- 129 -

(b) Mahia.....- 129 -

(c) Wellington- 130 -

(d) Hokianga.....- 130 -

(e) Auckland.....- 131 -

(f) Cape Egmount.....- 131 -

(g) Greymouth.....- 132 -

(h) Banks Peninsular- 132 -

(i) Otago Peninsular- 133 -

(j) South West Cape- 133 -

Figure 6.11 (a-j). Comparison of ten day, annual, wave energy, exceedance-persistence charts for Great Barrier Island (a), Mahia (b), Wellington (c) Hokianga (d), Auckland’s West Coast (e), Cape Egmount (f), Greymouth (g), Banks Peninsular (h), Otago Peninsular (i) and South West Cape (j).....- 133 -

Figure 6.12. New Zealand coastline and exceedance-persistence diagrams representative of major coastline aspects.....- 135 -

Figure 6.13. Comparison of the probability of wave exceedance for a persistence of 3 hours.- 136 -

Figure 6.14. Comparison of the probability of wave exceedance for a persistence of 48 hours.- 136 -

Figure 6.15. Comparison of the probability of wave exceedance for a persistence of 96 hours.- 137 -

Figure 6.16. Wave height (metres), period (seconds) and direction (degrees) percentage root normalized mean square errors for 6 locations around New Zealand.- 138 -

Figure 7.1. The Distributed Integrated Ocean Prediction System (DIOPS). Interaction of several wave models (described here by domain objects) is a pattern that the mapping of hotspots should attempt to emulate beyond the “offshore” and “nearshore” models (WAM, and WBEND respectively) of the case studies.....- 144 -

Table of tables

Table 2.1. Joint probability table of significant wave height (Hs) and peak period (Tp) for Muriwai. Twenty-year hindcast providing the data. Probabilities are expressed as percentages with totals of each height bin and period bin on the bottom row and far right column respectively. This table represent 90.45 % of the total yearly wave conditions.	- 44 -
Table 2.2. Wave energy calculated from wave height and period from Table 2.1 above to show the kilowatt-hours per metre wave front, in each combination of wave height and period.....	- 45 -
Table 2.3. Comparison of wind energy turbines and relative (Sims, 2004)	- 56 -
Table 3.1. Environmental effects of wave energy converters (Source: Thorpe, 1992).	- 68 -
Table 3.2. Issues and impacts of offshore wave energy converters upon the environment (Source: Electric Power Research Institute 2004c).....	- 70 -
Table 4.1. buoyweather.com e-mail example of a seven day forecast. The swell (ft), period (sec), and surf direction (deg) columns are collated. From this table 7/28 6am, 12pm, 6pm and 7/29 12 am were deemed the now forecast.	- 88 -
Table 4.2. The resulting now forecast and six days of predictions for the significant height of a single location, after the accumulation of seven day’s data.....	- 90 -
Table 4.3. Average wave significant height (Hs), period (T) and direction (Dir) for now forecast sites and corresponding twenty-year hindcast locations. Data from buoyweather.com was converted from feet into metres for comparison. Great Barrier Island has been abbreviated to GBI.....	- 93 -
Table 4.4. Regional estimates of New Zealand’s national annual electricity energy usage. Estimates are based upon information collected for year up to end of March 2002. (Energy Efficiency Conservation Authority, 2005).....	- 96 -
Table 6.1. Hotspot map interpretations.	- 127 -
Table 6.2. Case study assessment summaries	- 139 -
Table 6.3. Summary of case study wave energy possibilities including preliminary anthropocentric considerations.....	- 139 -