Discovery Passage, B.C., Canada - Tidal Energy Demonstration Project
Campbell River Fishing Pier

Revision 2.01

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Prepared for:

The City of Campbell River, Campbell River, BC

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Table of Contents

List of Figures

Index of Tables

1. SUMMARY

1.1. INTRODUCTION & STUDY BACKGROUND

This report examines the feasibility of a Tidal Energy Demonstration Project at the Discovery Fishing Pier in Campbell River, British Columbia. The feasibility was evaluated primarily on the characteristics of the physical ocean environment and the current state of the art in tidal stream energy conversion technologies.

Campbell River is situated in the southern portion of Discovery Passage within the Discovery Islands, just north of the Straight of Georgia. Oscillating differences in tidal height between the Straight of Georgia and Johnstone Straight (north of the Discovery Islands) drive large volumes of water though the various passages of the island group and in narrows creating some of the fastest tidal current velocities in the world. Campbell River is not situated at a narrows, but rather close to where Discovery Passage meets the Straight of Georgia. Still, currents adjacent the City of Campbell River are impressive and worthy of study.

The initial concept for the Tidal Energy Demonstration Project was a combination of grid connected power project, tidal technology demonstration and public relations tool. In this concept a tidal energy unit is installed on or near the fishing pier, connected to the grid via above-water lines and sell power to BC Hydro. An informational display on the Pier would help inform and educate the public about tidal energy and visitors could watch the turbine operate nearby.

In April of 2010 Triton Consultants Ltd completed Phase 1 of the Tidal Energy Demonstration Feasibility Study. This phase focused on providing preliminary estimates of tidal currents near the Discovery Pier. A two-dimensional computational tidal model developed by Triton was used to make current estimates. In this phase the model was validated only to water-level measurements in Campbell River. The results of Phase 1 showed moderate currents at the Discovery Pier, with speeds up to 2.1m/s. A preliminary wave analysis suggested that significant wave heights in the order of 2 to 3m occur at the Pier on a regular basis. Waves of this size could severely damage a tidal energy installation and so a detailed wave analysis was a required component of any further research.

In December 2010 the City of Campbell River elected to continue with the current stage of the project (Phase 2 and 3). This stage of the project is aimed at refining the tidal current estimates produced in Phase 1 of the Project, estimating potential hazards (particularly extreme waves), identifying suitable tidal energy technologies and assessing potential environmental impacts.

1.2. STUDY RESULTS

The tidal model initially used in Phase 1 of the project was refined and validated to water level and current measurements throughout the Discovery Islands Region. Using the upgraded model the maximum spring tide currents were found to range from 1.25m/s between the Pier and the breakwater to 2.57m/s 300m east of the Pier. Much stronger mid-channel currents neighbouring the Pier reach up to 3.7m/s and are the most energetic in the Discovery Passage south of Seymour Narrows.

A detailed wave model was constructed for this study. The model extends south past Texada Island and north to Seymour Narrows, encompassing all of the Northern Straight of Georgia. The model was calibrated to measurements made at Cape Mudge and Sentry Shoal. Statistical analysis of wind data from the Sisters Islet Weather Station was used to estimate the largest storm expected over a 200 year time period. The 200 year wind conditions were then used to drive the wave model. The results give an expected maximum significant wave height at the Discovery Pier of about 2.3m. Tidal energy devices are usually situated in sheltered areas; 2.3m waves would pose a risk of failure to the proposed turbine installation. It would be important that the selected turbine developer carry out appropriate engineering analysis to ensure that their device could withstand these extreme waves.

A preliminary environmental scoping for this project was completed by Ecofish Research Ltd for the area close to the Pier. While field-work identified several species of interest, this "scoping-level assessment did not find biological features of obvious sensitivity to the Project... it is plausible that its ecological impacts would be minor." Additional field research would be required following the location and site specific design of the turbine, support structure and auxiliary equipment (cabling, mooring, etc) in order to prepare an Environmental Impact Assessment, a key component of the Development Plan that would be needed to more the Project forward. An official permitting framework for tidal energy installations has yet to be released by the British Columbia government, but a best estimate of the process has been provided based on the related wind farm and run-of-river permitting processes.

A tidal turbine technology assessment was performed to identify the state of the art for small, low energy applications such as the Discovery Fishing Pier. Of the many companies developing tidal energy technologies, only a few are geared towards small installations. Of those only New Energy Corporation has reached the stage of commercialization (and even then only for freshwater installations). A better fit for this this project might be a technology developer looking to demonstrate their technology as the costs and risk of the project might be shared between the developer and the City (e.g Mavi Innovations Inc.)

Base case indicative total project cost was estimated at $1.4 million, including a 20% contingency, but excluding any allowances for subsidies, research grants and in-kind services that may be available to the City of Campbell River and the turbine device developer. In the Base Case development the permanent turbine is located close to the Discovery Fishing Pier (50 m east) for public viewing with power transmitted to shore by underwater cable but not connected to the BC Hydro grid because the cost is not justified by the turbine power output (tidal currents too small). If the turbine is only installed on a temporary basis with no power cable to shore (Option 1) then the indicative total project cost reduces to about $1.1 million.

Even allowing for electricity subsidy programs such as the feed-in-tariff program presently under consideration by the BC Ministry of Energy, locating a turbine near the Discovery Pier for the purpose of generating power is not economically feasible. The tidal currents are not large enough for production of large amounts of electricity. Further from shore (500-1100m), beyond the primary focus of this report, are more energetic sites with maximum current speeds ranging from 2.9-3.7m/s. At these sites a turbine may produce enough electricity to be economically attractive. Unfortunately a site further into Discovery Passage will likely garner more scrutiny from Transport Canada and environmental agencies.

1.3. THE WAY FORWARD

A staged development of the Project might be considered by the City. This scenario is a variation on the initial concept for this project termed the "base case" above. As in the base case, first the turbine would be deployed near the Pier where the turbine would be well within view of the Pier for viewing by the public. The marginal currents at this location, though not appropriate for economical energy generation, would afford the developer time to work out any bugs with the equipment. The low power generated at this location would not justify grid connection. All power generated could be dissipated by heating sea-water. All turbine telemetry including water velocity, turbine power and video of the operating turbine could be transmitted wirelessly to an information station on the Pier to supplement the public education component of the Project. (Option 1)

Upon successful demonstration of the turbine near the Pier, it could be relocated to a more energetic site further into the Passage (Option 1a). At this point grid connecting the device may be justified. The public education component of the project could be retained by situating fixed binoculars on the Pier and/or installing underwater cameras and continuing to operate the interactive information station. The cost for this relocation of the turbine to a more energetic current regime east of the Discovery Fishing Pier cannot be reasonably estimated at this time because of permitting and technical uncertainties. However for initial budgeting purposes a cost of $500K to $750K could be used. The total indicative cost of the Staged Project Development (Option 1 + Option 1a) would be in the order of $1.6M to $1.85M excluding any allowances from subsidies, research grants and in-kind services that may be available to the City of Campbell River and the turbine device developer.

Based on the technical analyses completed for this study, the installation of a demonstration tidal turbine near or adjacent to the Fishing Pier in Discovery Passage for the purpose of generating power is not economically feasible. To be more specific, it is not expected that revenues from the sale of electricity over the lifetime of the project will be greater than the sum of the initial and ongoing costs of the Project. The value of electricity produced, even with a possible British Columbia feed-in-tariff of $0.25 cents/kWhr falls far short of the indicative project costs – only 25% in the best case scenario. Despite its poor economics, there are, however, some very good reasons to continue with this project including: exposure for the City as a location for the development of renewable energy technologies, development of support industries for tidal technologies within Campbell River, education of the public and support for Campbell River's “sustainable community” initiatives.

If the Project were to move forward it would undoubtedly benefit from using the “Community Project Model” approach. In a Community Project the risk and the benefits of the project are shared among a number of interested stakeholders, who in this case could include the City, the turbine developer, the local industry, BC Hydro and the general public. In-kind contribution from these stakeholders might make up a significant portion of the costs and the Project may benefit from funding opportunities, such as Government grants and research funding that are only available through specific stakeholders. Government grants and research funding alone might make up to 50% of the Project cost. With these considerations in mind the Project might become attractive enough to pursue, but it is difficult to postulate what sort of agreements a community project might yield until detailed discussions between stakeholders are initiated.

1.4. LONG-TERM STUDY BENEFITS

This study has shown that there are world-class tidal current energy resources in Discovery Passage and the wider Discovery Islands. Although a small scale tidal demonstration project at the Campbell River Fishing Pier may not be economically feasible for the purpose of generating power, there are numerous higher energy sites within the Discovery Islands including the mid-channel area adjacent the City of Campbell River where economical power generation might be feasible.

The high energy currents in the region combined with the close proximity of the electrical grid will continue to draw the interest of private tidal energy developers. Some of these developers may be interested in sites outside of Campbell River but may still engage companies within the City to provide some of the industrial services required for large-scale tidal projects; others may target sites in the mid-channel region adjacent the City or other nearby sites.

Phase 2 and 3 of this study has yielded, in addition to information and data specific to the Discovery Fishing Pier Site, several valuable transferable assets which may help in the planning of future tidal projects in the Campbell River area. The tidal modelling refined for this study has been validated throughout the Discovery Islands Region and the wave model has been validated in the Northern Straight of Georgia. Based on these modelling studies, Triton could readily provide the City of Campbell River with detailed GIS mapping of tidal current velocities, kinetic energy and maximum wave heights which would serve as a guide for future large scale commercial tidal energy projects and as a planning tool for the City. In particular, these current, tidal energy and wave maps could be an invaluable tool for the City's Economic Development Department as it encourages tidal project developers and manufacturing companies to consider Campbell River as “the place to go” for tidal developments.

2. PROJECT BACKGROUND

In July 2009, the City of Campbell River issued a Request for Proposals from qualified consultants for a feasibility study of a Tidal Energy Demonstration Project at the City's Discovery Fishing Pier. The proposed project would investigate the feasibility of locating a demonstration tidal turbine at the Discovery Fishing Pier. Ideally the turbine would be fully connected to the nearby electricity grid.

This project is motivated not only by the City of Campbell River's desire to become more environmentally responsible, but also a desire to foster the development of an emerging industry in the region. The various passages in the Discovery Islands are home to some of the strongest tidal currents in the world. If tidal energy development were to commence in the region, Campbell River would benefit as the most likely city to provide the various industrial and commercial services that the turbine installations would require.

The site at the Discovery Fishing Pier was selected as much for its prominent location within the City as for its high-energy currents. With the high accessibility of the location, residents and tourist alike might be able to observe the generating station and learn about energy capture from tidal stream energy capture devices. It also ties in well with the adjacent Maritime Heritage Centre.

The City is hoping to partner with a tidal turbine developer wishing to showcase their technology and gain experience in the ocean environment, thereby sharing the cost and sharing the risk of the installation.

2.1. TRITON CONSULTANTS QUALIFICATIONS

Triton Consultants are Canada's most experienced Ocean Energy consultancy firm having been directly involved in the field for more than 20 years. Our special interest is in both wave and tidal stream renewable energy and the firm maintains an in-house suite of possibly the most advanced wave and tidal modelling software in the world. Recent projects have included a detailed tidal resource assessment in SW Korea, site selection work for Clean Current System's planned 1 MW tidal turbine installation in Minas Passage, Bay of Fundy and advanced wave modelling work with UVic for the West Coast Wave Collaboration Project (NRCan WCWC project)

In British Columbia, Triton completed a detailed evaluation of tidal energy sites in Discovery Passage for Lunar Energy (UK) in early 2008, and provided site selection, current measurement and tidal modeling support for the Race Rocks tidal demonstration projects near Victoria. The latter was the first operational in-stream tidal power project in Canada and the second in the world. Triton were the authors of BC Hydro's British Columbia tidal resource assessment (2002) and co-authors, with NRC, of Canada's Ocean Energy Atlas. Detailed description of all these projects, along with a selection of reports to download can be found on Triton's web site www.triton.ca.

Mr. Michael Tarbotton M.Sc, P.Eng, president and founder of Triton was Project Leader for this study. Mr. Tarbotton was a founding director of OREG (Canada's Ocean Renewable Energy Group) and he has presented numerous papers at OREG conferences and international ocean energy gatherings as far a-field as NewZealand. Mr. Tarbotton is a Canadian member of the IEA TC114 committees developing standards for wave and tidal energy resources.

Roy A. Walters, PhD, directed the setup and and execution of the Tidal model. Dr. Roy Walters formally of the National Institute for Water and Atmospheric Research of New Zealand and US Geological Service and now a consultant with Triton Consultants is an internationally recognized expert in ocean modelling. Dr. Walters is the developer of the River and Coastal Model (RiCOM). Triton makes extensive use of the RiCOM model in its tidal, river and tsunami engineering studies.

Clayton Hiles MASc, EIT was the lead investigator in the wave modelling component of this project, provided tidal modelling support and conducted data analysis. Mr. Hiles completed his Masters research at the University of Victoria in the field of resource assessment for ocean energy industry. He was the first researcher to join the West Coast Wave Collaboration Project and continues that work as a member of the Triton Team.

Triton's wave and tidal modelling work is not restricted to marine energy. The company has over 25 years developed an expertise in metocean analysis (wind, wave, currents) for new Port Site selection and marine transport analyses – often green-field sites. Many of the modelling tools developed for marine energy analysis have been used for the port site selection projects (& visa versa). Projects of interest include Chuckchi Sea Port development (DMT), Pebble Copper in the Gulf of Alaska, Beaufort Sea Gas Development and Bathurst Inlet Port access study.

3. INTRODUCTION

In July 2009, the City of Campbell River issued a Request for Proposals from qualified consultants for a feasibility study of a Tidal Energy Demonstration Project at the City's Discovery Fishing Pier. Triton Consultants Ltd were awarded the work February 17th, 2010. The work was divided into three Phases and only Phase 1 was given approval to proceed by the City with Phase 2 and 3 postponed until funding was available.

Phase 1 of the feasibility study was completed in April 2010. The majority of the Phase 1 work centred on determining the probable tidal current resources near the Fishing Pier using a two dimensional tidal model grid previously developed by Triton Consultants. The model extends from near Savary Island in Georgia Strait to central Johnstone Strait in the north and encompasses all the high-energy tidal passages in the Discovery Islands region. Triton refined this model grid in the area of the Fishing Pier to provide improved tidal current detail in this specific area of interest.

Detailed wave analysis was not included in phase 1 of the feasibility study but it became clear as the work proceeded, that for a floating tidal turbine device, waves from south east storms could be a major design concern. Triton therefore decided that the City needed to know, at an early stage, the likely magnitude of waves at the site. A preliminary parametric wave hind-cast was conducted for the period 1992 to 2007 and presented in the Phase 1 report.

In December 2010 funds became available to continue with the current stage of the project (Phase 2 and 3). This stage of the project was aimed at refining the current velocity estimates produced in Phase 1 of the Project, estimating potential hazards (particularly extreme waves), identifying suitable tidal energy technologies and assessing potential environmental impacts.

The report contains the following sections:

Section 4. - Tides and Currents
Section 5. - Extreme Waves
Section 6.- Assessment of Environmental Impacts
Section 7. - Assessment of Turbine Technologies
Section 8. - Turbine Placement and Expected Operation
Section 9. - A Community Project
Section 10. - Conclusions and Recommendations

Section 4. provides an assessment of the currents at the Discovery Pier. Section 5. covers the construction, validation and use of a wave model to estimate extreme waves at the Discovery Pier. Section 6. assesses the potential environmental impacts of the project and outlines the likely permitting and environmental studies required to move the project forward. Section 7. provides background information on the history of tidal turbine technologies, assess the current state of the industry and identifies several technologies which may be appropriate for installation at the Discovery Pier. Section 8. estimates the power output from two turbines under consideration, makes judgement on certain aspects of the project and recommends a configuration for the installation including placement of the turbine. Section 9. discusses how the Project might benefit from the "Community Project" organizational model. Finally, Section 10. presents concluding remarks and recommendations.

4. TIDES AND CURRENTS

4.1. INTRODUCTION

This section describes the development of a detailed finite element hydrodynamic model of the Discovery Islands Region extending from near Savary Island in Georgia Strait to central Johnstone Strait in the north and encompasses all the high-energy tidal passages in the Discovery Islands region. This model grid, which has 132,000 nodes and 252,000 triangular elements in the horizontal, was developed in-house by Triton Consultants over many months prior to the start of the Campbell River Tidal Demonstration feasibility study.

Triton refined this model grid in the area of the Fishing Pier to provide improved tidal current detail for the project in this specific area of interest. The model grid is relatively coarse in the wide straits and passages but graduates to much finer detail in narrow passages such as Seymour Narrows, Discovery Passage and Surge Narrows.

The time-stepping hydrodynamic tide and current model, RiCOM, used for this project is described below in Section 4.1.1. A more detail description of the models and recent applications can be found in Walters (2005).

4.1.1 Unstructured Finite Element Model RiCOM

The River and Coastal Model (RICOM) was developed by Dr. Roy Walters formally of the National Institute for Water and Atmospheric Research of New Zealand and US Geological Service who is now a consultant with Triton Consultants. RICOM was developed to solve some of the longstanding problems with finite element methods – namely lack of local mass conservation and problems with stability and/or accuracy with advection-dominated flows.

RiCOM's solution to these issues inherent in conventional finite element modelling allows a uniform approach to modelling both river and coastal systems, either in a coupled or uncoupled manner. RICOM solves the primitive hydrodynamic equations with a semi-implicit time-stepping scheme that is unconditionally stable with respect to time-step size which allows the time-step size to be controlled by the physics of the specific problem under consideration rather than by numerical constraints. Secondly, the model uses a semi-Lagrangian approximation for advection that is accurate, stable, and robust which yields accurate results without oscillations for high speed flows such as occur over weirs, in flow constrictions, and tidal rapids. Finally, the model uses a finite element spatial approximation that gives considerable flexibility in designing the computational grid. The particular elements that are chosen have no spurious modes so that the solution is free of grid-scale oscillations. Because of the design of the algorithm, wetting and drying capabilities are built in and do not require any special attention. In addition, the model conserves mass both locally and globally which is an important property when dealing with solute and particulate transport, especially when the transport equations are in a finite volume form.

The model has been used in tidal and boundary layer problems and a variety of trans-critical flow problems including two- and three-dimensional circulation problems and tsunami run-up calculations. A cohesive/non-cohesive sediment transport module has recently been added.

RiCOM is formulated from the Reynolds-averaged Navier-Stokes equations that are time averaged over turbulent time scales. The governing equations are derived using the Boussinesq approximation and by introducing a rotating frame of reference. The equations are spatially averaged to derive double-averaged equations which allow sub-grid spatial effects (turbines, vegetation, bottom roughness, etc) to be included in a rigorous manner. It is derived using a finite element approximation in space and a finite difference approximation in time. For more detail on the technical details of the model please see Walters (2005).

Triton have applied RiCOM successfully to a number of recent projects including storm surge estimates for the southern Beaufort Sea (Canada) and tidal dynamics in the Fraser River (B.C.), Cook Inlet Alaska, South West Korea and the Bay of Fundy in eastern Canada. The last project, which is ongoing, include the determination and location of tidal current resources for two large ocean energy developments.

For the Campbell River Project, the RiCOM model was used to investigate the general tidal dynamics of the Discovery Islands Region with detailed analyses and validation of tides and tidal currents throughout the Discovery Islands.

4.2. MODEL DEVELOPMENT

4.2.1 General procedures

The RiCOM model uses the same unstructured, triangular computational grid (or mesh) for either 2D or 3D calculation. Only 2D (depth averaged) computations were performed for this feasibility study. Full 3D computations can be readily performed if necessary, but were not included in this stage of the project as suitable measurements of the velocity profile were available.

The model bathymetric grid was initially developed from the CHS (Canadian Hydrographic Service) vector ENC (Electronic Navigation Chart) charts, using Triton’s in-house software which includes grid building program Trigrid2 (an advancement of public domain program Trigrid) and a program to convert vector ENC’s to shoreline, bathymetric contours and spot soundings for bathymetric grid construction.

Model grid building proceeded in three stages. a) Build a bathymetric TIN (Triangulated Irregular Network) from the ENC charts, b) Construct a model computational grid using the advancing front technique from the shoreline and c) Re-depth the model computational grid using the bathymetric TIN. Note: the advancing front techniques used to construct the computation grid, produces an exceptionally well-ordered grid with near equilateral triangles, which greatly improves the accuracy and efficiency of the hydrodynamic model calculations.

4.2.2 Tidal Model Boundary Conditions

The RiCOM tidal model was “driven” along the Georgia Strait and Johnstone Strait boundaries with sea surface elevations derived from 7 tidal constituents specifically semi-diurnal (twice daily) constituents M2, S2, N2, and diurnal constituents (once daily) K1, O1, P1, plus estimated mean water level (Z0) at both boundaries. These 7 constituents account for a large majority of the tidal signal. Note that there are more than 150 tidal constituents resulting from the relative position and orientation of the earth, moon and sun system. Most of these constituents make only a minor contribution to tide height or currents at any one point on the earth.

Triton would like to thank Dr. Michael Foreman at the Institute of Ocean Sciences IOS), Pat Bay, BC for providing the currently most accurate boundary constituent data for the Discovery Islands model. IOS and Triton are presently working together to improve the accuracy of this data and this new data will be used to drive the model once it is available.

Figure 4.1 shows the extent of the tidal model with model bathymetry (in metres). Figure 4.2 shows the model detail near Cape Mudge including the un-structured model computational grid and bathymetry. Figure 4.3 shows the model detail in Discovery Passage at Campbell River including the computational grid and bathymetry. Note the density of grid triangles at the Fishing Pier.

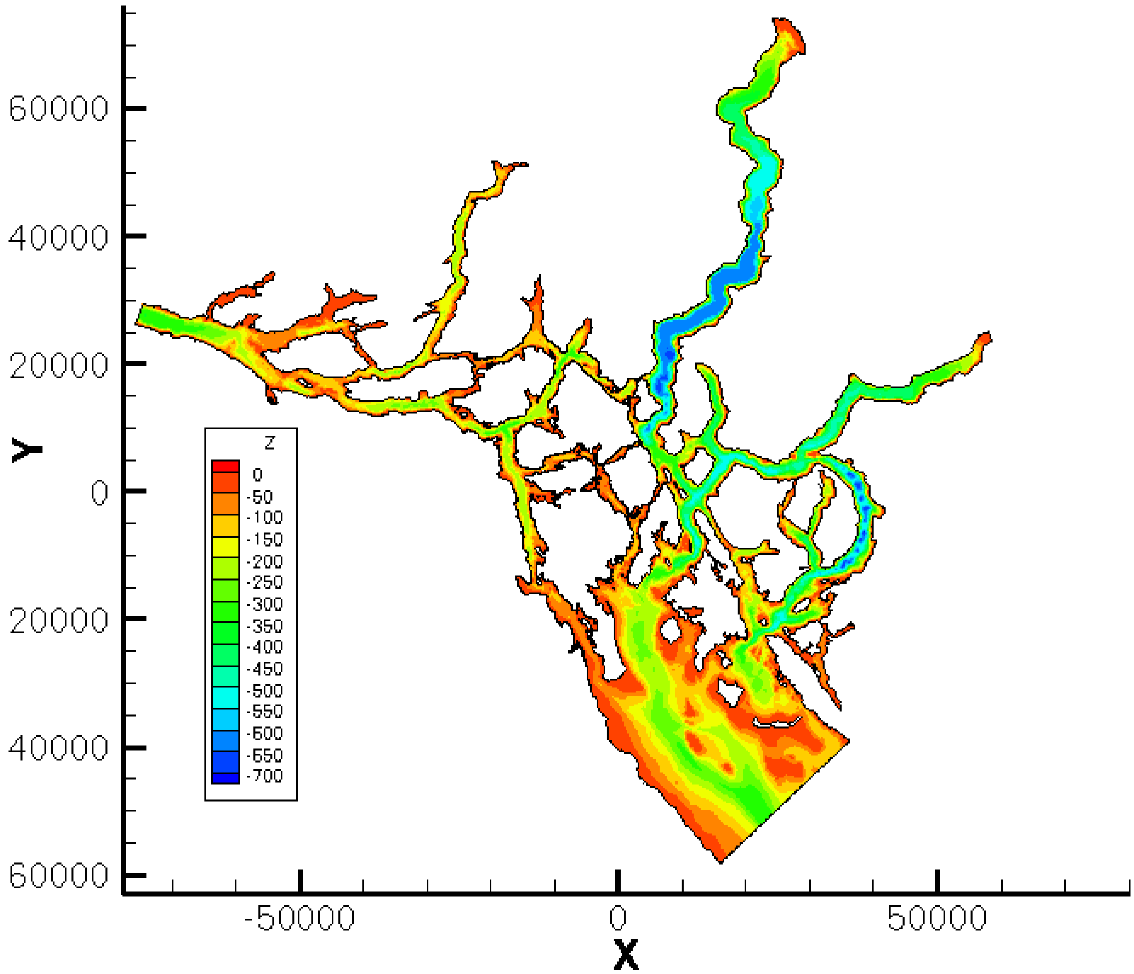

Figure 4.1: Tidal model domain and depth contours in metres.

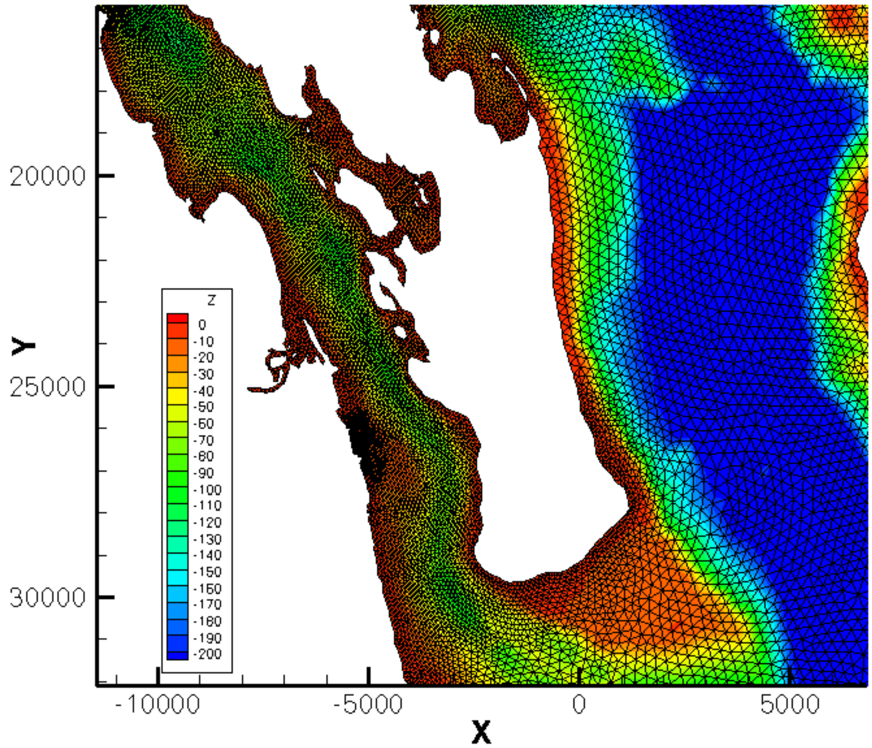

Figure 4.2: Tidal model detail Cape Mudge - depth contours and model grid

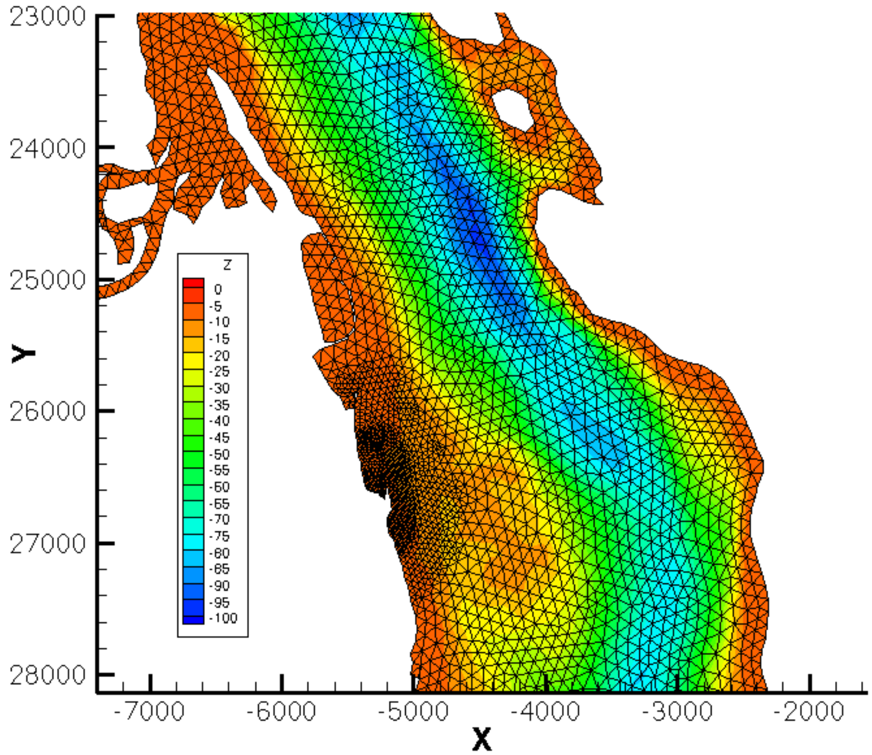

Figure 4.3: Tidal Model Detail at Fishing Pier- Model Grid and Depth Contours.

4.2.3 Model Operation

Once a satisfactory model grid and boundary conditions were developed the tidal model was run for specific dates of interest. However, the model had to be "spun-up" for a few days to make sure that initial condition errors had dissipated and results were accurate.

As with all advanced hydrodynamic models like RiCOM model computer run-times are long. The Discovery Region tidal model maybe the largest model yet run anywhere with 132,000 nodes. Run times for this model, in 2D mode, on a top end quad-core desktop computer are roughly 30 times real time. In other words 30 days of real time take approximately 1 day on the computer.

In 2D mode the model calculates water level and depth averaged current velocity at every node/element in the model domain at each time step. As the model time steps was roughly 20 sec (real time) the volumes of data can become overwhelming. To get over this problem water level and current data are recorded at specific points of interest such as Campbell River (CHS) Tide Station and at the Fishing Pier at each computational time step; this same data was recorded for every point in the model at 30 min intervals providing a regional view of tide height and current data and the ability to show animations of tidal dynamics over time.

In Phase 1 of this project, preliminary model verification was established by comparing tide heights calculated for the Campbell River tide Station (CHS 8074). Verification to measured tide height (water level) is standard practice for hydrodynamic models. Water currents can have significant local variability on the order of metres. This local variability makes verification to current measurements difficult.

In the current project phase water-level verification is carried using a number of different data sources including water level harmonics from past Canadian Hydrographic Service tidal measurement stations. Additionally modelled currents are compared to measurements at fixed ADCP deployments and boat-based ADCP measurements made specifically for this project.

4.3. MEASUREMENTS

Measurements are necessary for calibration and validation of the tidal model. Typically water level measurements are used for tidal model validation. Current measurements can be used for supplemental validation, but their significant spatial variability (on the order of metres) makes it difficult to match measurements to model results.

For this project Triton has obtained a number of different measured data-sets for locations around the Discovery Islands.

4.3.1 Boat-based water level and current survey

Triton subcontracted Ecofish Research to perform boat based ADCP measurements over the area of possible turbine deployment locations around the Campbell River Fishing Pier. Acoustic Doppler Current Profilers measure the water speed and direction at discrete locations in the water column from the sea floor to the sea surface. In this way the water velocity profile can be obtained. The velocity profile is very important for tidal installations as there can be a significant difference in water speed at the sea floor compared to the sea surface.

On May 13-14, 2011 Ecofish performed the boat based measurements. Triton Engineer Clayton Hiles was on-hand to supervise the work. The May 13th work consisted mostly of moored measurements near the pier. May 14th measurements consisted of roving surveys of the area around the Pier and a transect of all of Discovery Passage (approximately from the Pier to the Cape Mudge Village on Quadra Island). The moored measurements are used to validate the tidal model and the roving surveys give a detailed image of the spatial variability of the water currents near the pier. The transect of Discovery Passage is used to validate the performance of the tidal model over a wider area.

Figure 4.4: Photo of Ecofish Research technicians taking current measurements inside the Campbell River Fishing Pier. The orange catamaran is the Teledyne River Ray ADCP which is being towed from the boat using a boom. Ecofish staff Ian Murphy is piloting the boat and Andrew Cline (obscured to left) is monitoring the measurements.

4.3.2 Water level time-series and harmonics

Triton obtained water level harmonic constituents for Canadian Hydrographic Service Tidal gauges throughout the Discovery Islands. This data consists of an amplitude and phase for each tidal component at each of the stations. Figure 4.5 shows each of the Tidal Stations plotted on satellite imagery of the Discovery Islands.

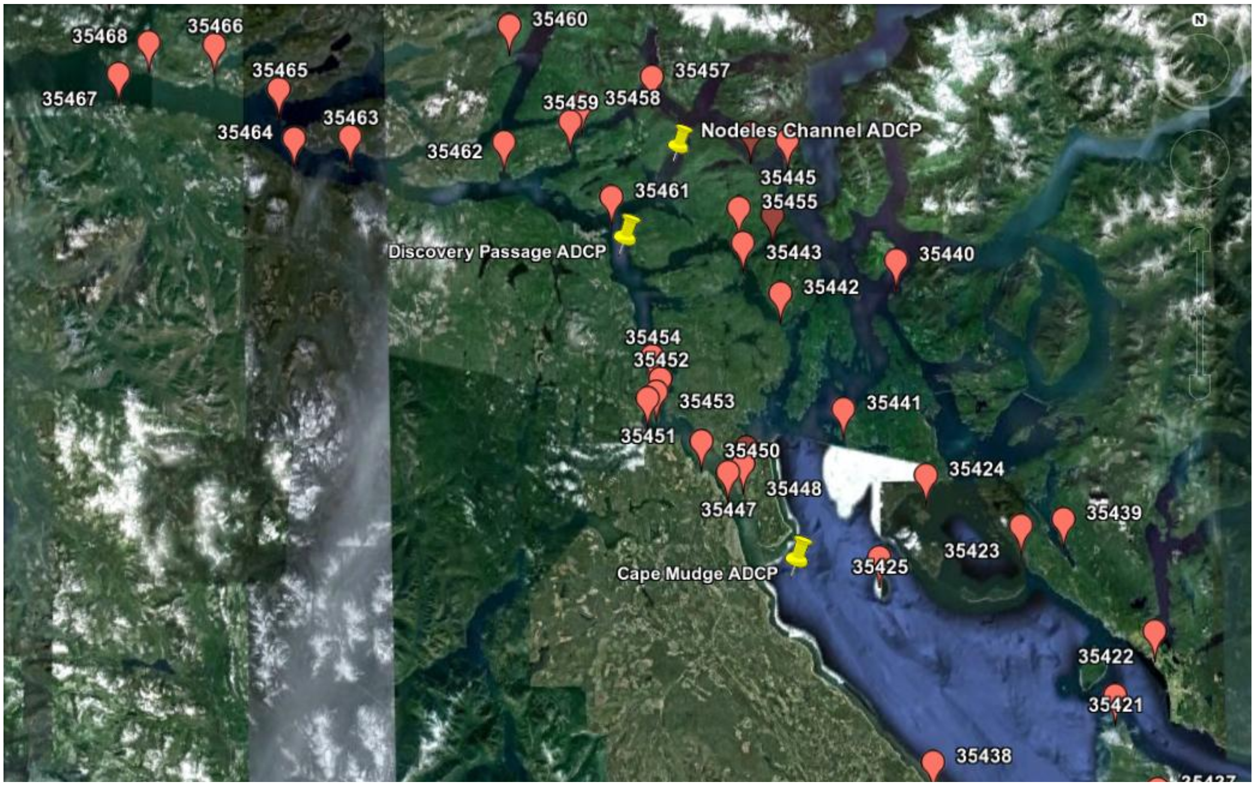

Figure 4.5: Satellite imagery of the Discovery Islands. Balloons show Canadian Hydrogaphic Service Tidal Stations, tacks show locations of IOS ADCP deployments.

The data from each gauge is presented and compared to the model results in Section 4.5. Though this data is used for validation purposes, in some cases the measurement quality must be considered. This data-set represents a collection of measurement made over approximately the last 50 years. Only the Campbell River Tidal Station is still active, the other stations were deployed temporarily over varying lengths of time, likely using a variety of measurement equipment. The measurement duration and the analysis methods used constrain how many tidal constituents can be identified. Technically there are over 150 tidal constituents, but in most cases 6 to 8 carry nearly all of the tidal signal.

As mentioned, the Campbell River Tidal gauge is still active. Triton has obtained time-series water level measurements from this station over relevant time periods.

4.3.3 Long deployment current measurements

Triton also obtained ADCP current measurements for locations near Cape Mudge, Chatham Point and Nodales Channel from the Institute of Ocean Sciences (IOS) (see Figure 4.5). Triton wishes to acknowledge Dr. Mike Forman for providing this data. The ADCPs were deployed on the ocean floor on fixed moorings from September 18th, 2009 to April 29th, 2010. The measurements were commissioned by a group led by Dr. Forman, who are studying circulation patterns in the Discovery Islands (Forman et al., 2011). The data from the current measurements is presented and compared to the model results in Section 4.5.

4.4. FLOW CHARACTERISTICS IN SOUTH DISCOVERY PASSAGE

There are a few characteristics of the tidal flow in Southern Discovery Passage that are worthy of discussion before the model validation is addressed. In Discovery Passage the tide flows north on the ebb and south on the flood. In subsequent sections of this report where current speed has been assigned a sign, the ebb tide is signed positive and the flood tide negative.

As indicated in Figure 4.6, two eddies are generated during the ebb tide. The larger on west side of Quadra Island is important for this work. This eddy restricts the flow of water to the west and central portions of Discovery Passage and results in an increase in current speed at the Discovery Pier during the ebb tide.

During the flood tide a large eddy develops off Cape Mudge and spins off southward into the Northern Straight of Georgia. The development and progression of the eddy is shown in Figures 4.7a-d. While this eddy has minimal impact of the currents at the Discovery Pier, it does effect the currents at one of the moored IOS current meters. Additionally this eddy effects the waves entering Discovery Passage from the south (see Section 5.). Another eddy, visible in the upper left corner of Figures 4.7a-d, constricts the flow in Southern Discovery Passage during the flood which in turn increases current speeds in eastern portion of the Passage adjacent Cape Mudge.

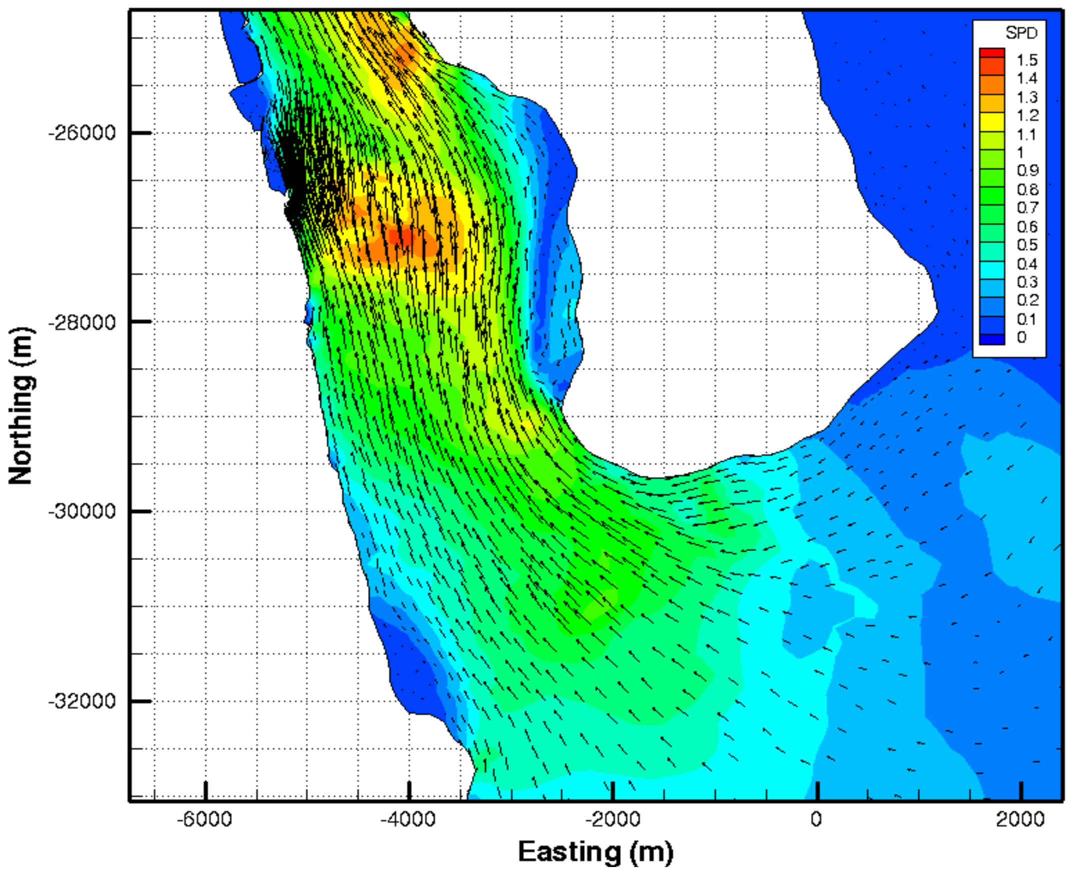

Figure 4.6: Current flow during the ebb tide at the southern entrance to Discovery Passage. Colour contours give current speed, quivers give direction. Red ovals give the location of eddies.

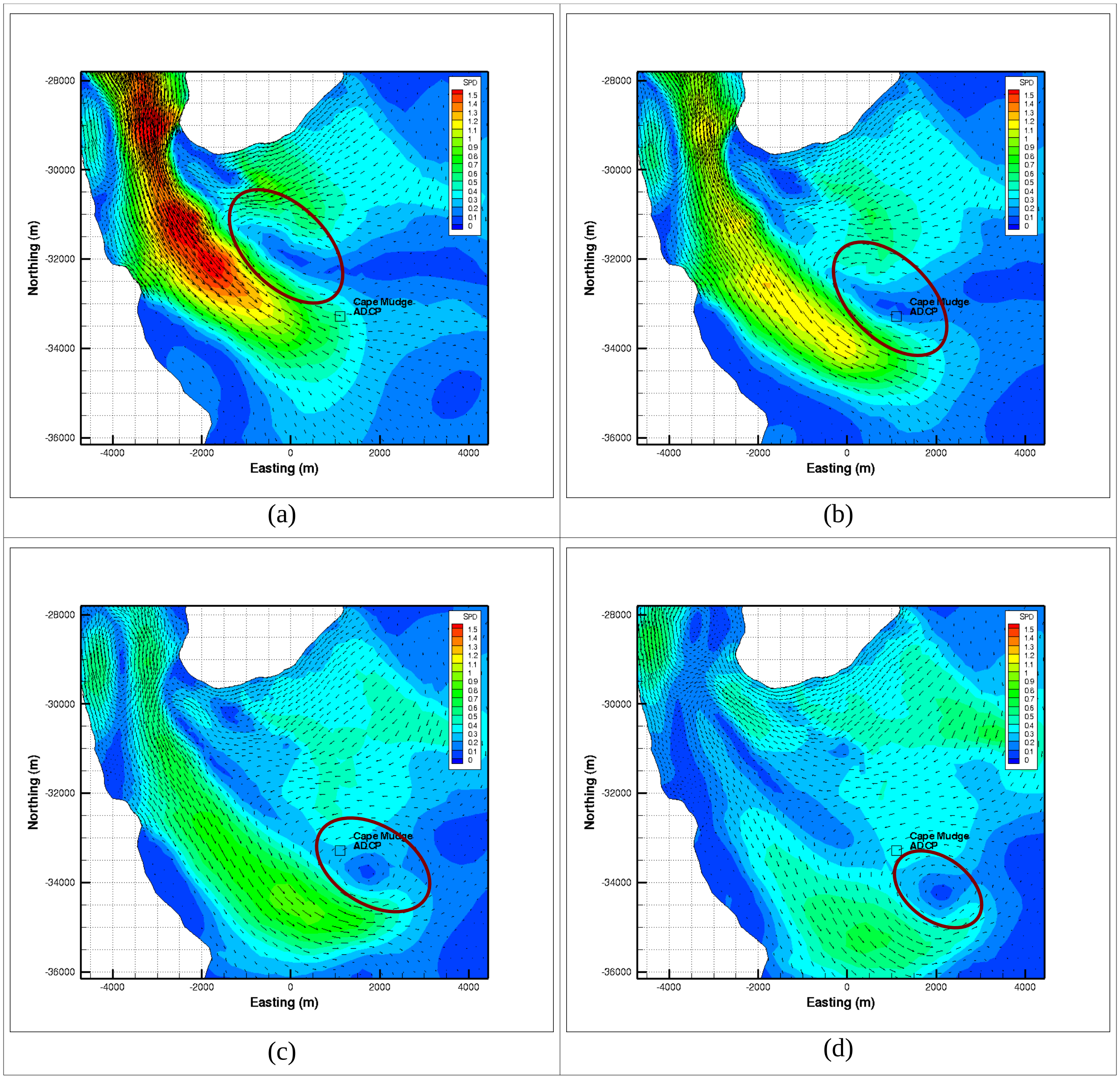

Figure 4.7: Development and progression of an eddy off Cape Mudge during the flood tide. Colour contours give current speed, quivers give direction. Red oval indicates eddy.

4.5. CALIBRATION AND VALIDATION

A 37 day model run starting March 25, 2010 (0:00 hrs UTC) was used to validate the tidal model. Note all dates and times are UTC which is 8 hrs ahead of PST.

The model is run for a period greater than 33 days so that the most important tidal constituents can be deciphered from the results. A tidal constituent is a sinusoidal component of the tidal water level signal, identified by its frequency and fully defined with an amplitude and phase. The amplitude and phase of a tidal constituent may be identified by harmonic analysis of a water level time series given that the constituent frequency is provided and the record is of sufficient length. If all significant tidal constituents can be identified accurately, then the tidal water level signal can be predicted for any time period. This is the method used by the Canadian Hydrographic Service to generate the Canadian Tide Tables.

Harmonic analysis may be used on tidal currents, but the results are significantly less reliable. While the tidal wave is distinctly harmonic, the induced currents at a given location may not be. For example, the eddy generated north of Cape Mudge on the ebb tide does not exist in that location during the flood. Consequently, the waters directly North of Cape Mudge flow South most of the time and are not well described by harmonic tidal constituents.

It is important to note that the model results presented in this section are only a small fraction of the tide height and current information presently available from the model. The model can be run for any time period either past or future and if more detail is required for any specific location, the model computational grid can be refined and the model re-run.

4.5.1 Harmonic Verification to Tide Gauges

The first verification carried out was to compare water level harmonics. Table 4.1 compares measured and modelled constituents K1 and M2, the most significant in this area. The number in the constituents name roughly indicates its frequency in cycles per day. The ID numbers of each station correspond to the tags in Figure 4.5. More constituents are compared in Appendix A.

As in Foreman (2011), D is the difference between the measured and modelled constituents in the complex plane:

$$D=\sqrt{(\zeta_{obs}\cdot\cos(\theta_{obs})-\zeta_{mod}\cdot\cos(\theta_{mod}))^2+(\zeta_{obs}\cdot\sin(\theta_{obs})-\zeta_{mod}\cdot\sin(\theta_{mod}))^2} \tag{4.1}$$

Where ζ is the constituent amplitude and θ is the constituent phase. The subscript *obs* indicates the parameter is derived from measurements, *mod* indicates that the parameter is derived from the model.

Generally there is good correlation of K1 and M2 at all tide gauges. The most notable exception is Surge Narrows and to a lesser extent Seymour narrows. At these locations there is a large phase difference. This difference occurs because the high velocity of the tidal flow in these areas causes significant turbulence. Turbulence effectively increases the viscosity of the fluid in these regions, acting as additional drag on the flow. RiCOM as it is implemented for this project does not model turbulence in detail and therefore differences in phase arise where turbulence is significant. RiCOM can model turbulence in more detail, but the modelling procedure is significantly more complicated and time consuming. Given that the effected areas are away from Campbell River, the additional effort of turbulence modelling was not justified.

The tide gauges closest to the Discovery Pier are Campbell River, Gowlland Harbour, Quathiaski Cove and Duncan Bay. For K1 agreement is good at all stations. For M2 the agreement at Campbell River is good, but the 3 other stations the difference is slightly larger. This may be because the measurement record length at these stations is only 29 days, not long enough to differentiate some of the tidal constituents.

Table 4.1 shows that the model is generally quite skilled at calculating water-level. The following section will assess the model's skill a calculating tidal currents.

ID	Name	K1 Gage Amp	K1 Gage Phase	K1 Model Amp	K1 Model Phase	K1 D	M2 Gage Amp	M2 Gage Phase	M2 Model Amp	M2 Model Phase	M2 D
35423	LUND'	0.89	288	0.90	287.6	0.01	1.02	35	1.04	35.2	0.02
35424	TWIN ISLETS'	0.90	288	0.90	287.8	0.00	1.01	35	1.05	35.5	0.03
35425	MITTLENATCH ISLAND'	0.86	289	0.89	286.7	0.05	0.99	35	1.03	33.9	0.05
35439	OKEOVER INLET'	0.70	304	0.89	292.3	0.25	1.03	41	1.07	41.4	0.04
35440	REDONDA BAY'	0.88	289	0.91	287.9	0.03	1.00	39	1.05	36.0	0.07
35441	WHALETOWN BAY'	0.93	288	0.90	286.9	0.04	1.01	35	1.04	34.7	0.03
35442	SURGE NARROWS'	0.91	287	0.78	282.8	0.15	0.98	35	0.75	11.8	0.41
35443	OCTOPUS ISLANDS'	0.78	285	0.77	282.8	0.04	0.73	5	0.72	8.9	0.05
35444	FLORENCE COVE'	0.89	292	0.90	288.2	0.07	0.98	36	1.01	36.1	0.03
35445	BIG BAY'	0.83	284	0.83	285.0	0.02	0.75	15	0.78	15.8	0.03
35446	WADDINGTON HARBOUR'	0.93	290	0.91	288.1	0.04	1.01	38	1.06	37.0	0.06
35447	*CAMPBELL RIVER'*	*0.85*	*284*	*0.84*	*285.6*	*0.02*	*0.83*	*20*	*0.81*	*23.9*	*0.07*
35448	*QUATHIASKI COVE'*	*0.81*	*288*	*0.84*	*285.7*	*0.05*	*0.77*	*19*	*0.82*	*25.9*	*0.11*
35449	*GOWLLAND HARBOUR'*	*0.77*	*284*	*0.83*	*286.4*	*0.06*	*0.66*	*7*	*0.70*	*21.9*	*0.18*
35450	*DUNCAN BAY'*	*0.78*	*287*	*0.82*	*285.5*	*0.04*	*0.62*	*9*	*0.68*	*17.7*	*0.11*
35451	BLOEDEL'	0.72	284	0.77	282.2	0.06	0.62	348	0.62	357.8	0.11
35452	SEYMOUR NARROWS'	0.69	272	0.70	275.1	0.04	0.95	320	0.77	326.3	0.20
35453	NYMPHE COVE'	0.70	282	0.77	282.5	0.07	0.88	347	0.61	359.7	0.32
35454	BROWN BAY'	0.67	275	0.67	272.5	0.02	0.92	316	0.86	316.4	0.06
35455	OWEN BAY'	0.68	273	0.68	275.0	0.03	0.85	320	0.76	323.1	0.10
35456	MERMAID BAY'	0.71	280	0.74	279.4	0.03	0.72	339	0.68	344.6	0.08
35457	SHOAL BAY'	0.69	272	0.65	272.0	0.04	0.88	308	0.83	308.1	0.05
35458	CORDERO ISLANDS'	0.63	270	0.64	270.9	0.01	0.85	305	0.84	302.4	0.04
35459	BLIND CHANNEL'	0.62	268	0.62	268.4	0.00	0.94	299	0.92	297.8	0.03
35460	SIDNEY BAY'	0.62	268	0.59	265.7	0.04	1.02	285	1.01	284.7	0.01
35461	CHATHAM POINT'	0.65	271	0.65	272.7	0.03	0.90	305	0.80	308.1	0.11
35462	KNOX BAY'	0.60	267	0.62	268.7	0.02	0.93	291	0.90	294.8	0.07
35463	BILLYGOAT BAY'	0.59	266	0.59	265.6	0.01	1.00	283	0.98	280.5	0.05
35464	KELSEY BAY'	0.56	262	0.57	260.7	0.01	1.16	276	1.13	274.4	0.04
35465	YORKE ISLAND'	0.56	260	0.56	260.4	0.00	1.17	272	1.14	271.7	0.04

Table 4.1: Comparison of measured and modelled tidal constituents K1 and M2. Amplitude (Amp) and difference (D) are in units of meters, phase is in units of degrees.

4.5.2 Time-series Verification to Moored ADCP measurements

Modelled tidal current were verified qualitatively to the three long-term ADCP moorings at Cape Mudge, Seymour Narrows and Nodeles Channel. The ADCP data is “binned” so that at each measurement includes the water velocity at discrete depths in the water column. Physical limitations mean the water velocity cannot be measured at the sea floor or the sea surface. The ADCP data was depth averaged by assuming the current speed to be zero at the ocean floor and equal to the shallowest bin at the sea surface. The current velocity was then integrated over the water column and divided by the depth to arrive at a depth-averaged value.

In Figures 4.8-4.9 the depth averaged eastward (u) and northward (v) components of the velocity measurements are compared to the model estimates for sites at Cape Mudge, Seymour Narrows and Nodales Channel respectively.

At the Cape Mudge ADCP (Figures 4.8) the model represents the larger eastward component of the velocity fairly well despite the irregularity of the of the signal. The northward component is well represented over the majority of the tidal cycle, but two sharp spikes in velocity (one negative, one positive) corresponding to a passing eddy is significantly under-predicted by the model.

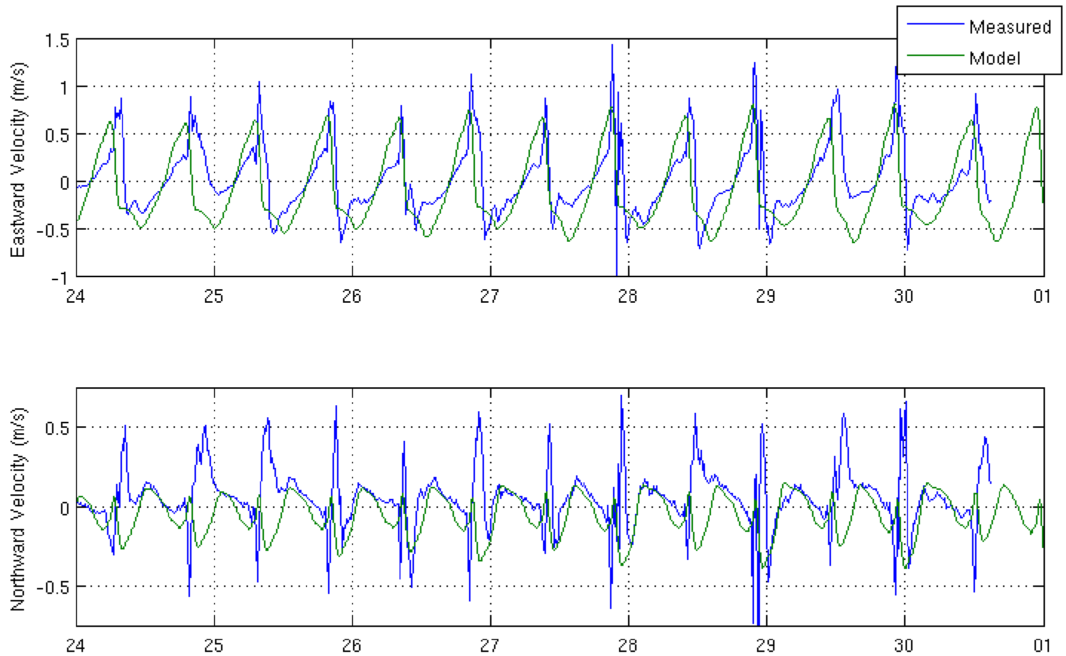

Figure 4.8: Comparison of north and east velocity components at Cape Mudge moored ADCP.

The currents at the Seymour Narrows and Nodales Channel ADCP's are less complex than those at the Cape Mudge ADCP.

At the Seymour ADCP (Figures 4.10) the model represents the larger northward component of the velocity very well during the ebb but underestimates the northward velocity on the flood. The eastward component of the velocity is very small, but still the model provides fairly good estimates. A spike in current speed occurs as the tide changes from ebb to flood due to a passing eddy. The model shows this spike with every tide change, but the measured data shows the spike occurring with less regularity. The reason for this difference is current not understood.

At the Nodales Channel ADCP (Figures 4.9) the current velocity small and very regular in both the northward and eastward components. The model shows excellent skill in estimating current velocity at this location.

In general the model does a good job at estimating the actual depth-averaged currents, especially where the flow is not complex and near sinusoidal in nature. Where the flow gets complex, such as when eddies or jets are present, the model has more difficultly making accurate estimates but still tends to capture the general form of the tidal current signal.

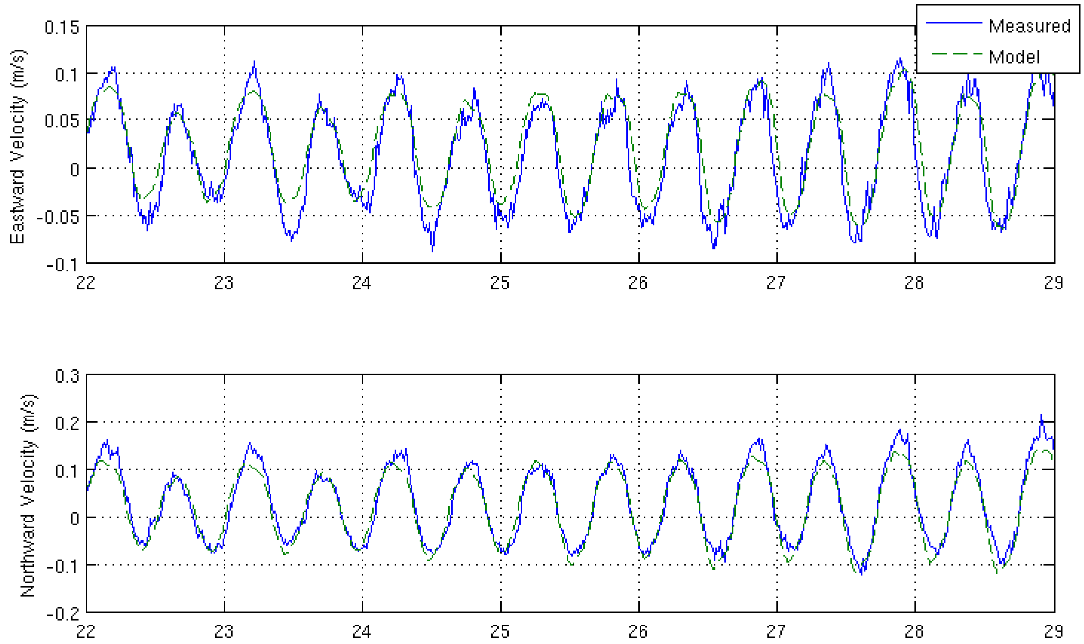

Figure 4.9: Comparison of north and east velocity components at the Nodeles Channel moored ADCP.

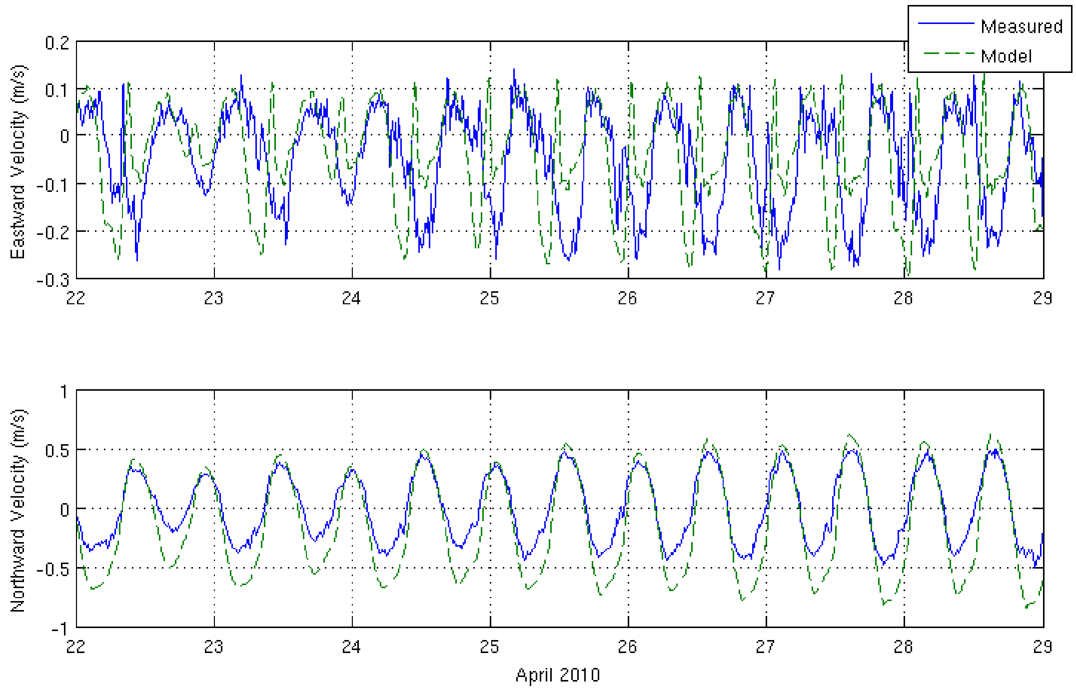

Figure 4.10: Comparison of north and east velocity components at the Seymour Narrows moored ADCP.

4.5.3 Time-series current verification to ADCP measurements

Boat-based ADCP current measurements commissioned for this study were used to verify the tidal model current estimates in the region of the Discovery Pier. The measurements are roving surveys of the region. They were generally completed in under one hour and so give a snapshot of the spatial distribution of currents around the Pier. It is crucial that the model be able to reproduce the spatial distribution of currents, as current distribution will be a primary factor affecting the siting of the proposed tidal turbine.

Figures 4.11-4.14 show plots of current speed tracks over Google Earth imagery and line plots of current speed over survey time. In the line plots the measured data was averaged over 30 second intervals. Modelled data was interpolated in both time and geographic space to correspond to the time and location of the measurements. Note that in Discovery Passage the tide flows northward on the ebb and southward on the flood.

May 14 - Survey on flood tide

Figure 4.11 below shows a current survey made during the flood tide (April 14, 18:00UTC). Measurements started between the Pier and the breakwater, moved northward, then at the north end of the Pier continued east and south. Note the significant gradient in current speed moving north-east from the breakwater, past the Pier towards the centre of Discovery Passage.

Figure 4.12 shows a time series comparison of the eastward (u) and northward (v) components of the measured and modelled current velocity for the flood tide current survey of April 14, 18:00UTC (see Figure 4.11). Though the model slightly underestimates the magnitude of the northward velocity component, its skill in estimating current velocity is in this case very good.

May 14 – Survey on ebb tide

Figure 4.13 below shows a current survey made during the ebb tide (April 15, 00:00UTC). Measurements started to the south of the Pier and continued northward, then the area in between the Pier and the breakwater was surveyed. Note that though there is significant variability in current speed over the region surveyed, that variability is much different than that observed during the flood. Current speeds are slower and more uniform east of the Pier than what occurs during the flood. Close to the Pier currents slow significantly and were nearly zero west of the Pier. Those performing the current measurement observed a clear separation of the flow speed regimes near the Pier, both visually and by the motor power required to overcome the current.

Figure 4.14 shows a time series comparison of the eastward (u) and northward (v) components of the measured and modelled current velocity for the ebb tide current survey of April 15, 00:00UTC (see Figure 4.13). The model provides excellent estimates of the eastward velocity component. The model provides good estimates of the northward velocity component as well, especially away from the Pier. Close to the Pier the model overestimates the northward velocity component. The Pier structure acts as drag on the water flow, slowing the flow. But, because the Pier is not resolved within the model neither is this additional drag, which is likely cause of the differences between the model and measurement in the northward velocity component shown in Figure 4.14.

Additional Surveys

Two additional surveys were conducted, one during slack tide, the other a transect of Discovery Passage. The results from these surveys are included in Appendix C. Overall the model has good skill in estimating currents in the region near the Discovery Pier.

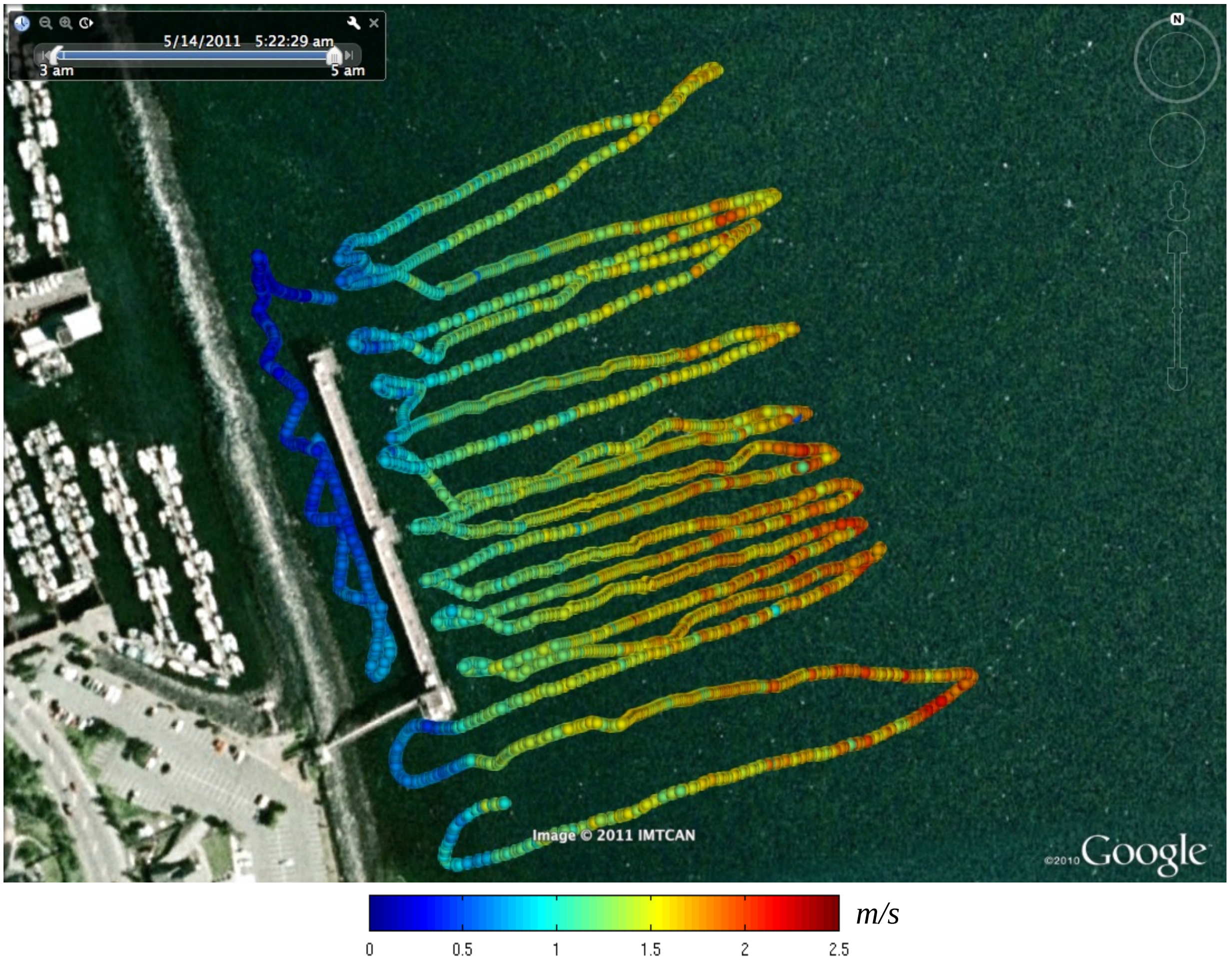

Figure 4.11: Current velocity survey during flood tide April 14, 18:00UTC. Coloured dots indicate depth averaged current speed.

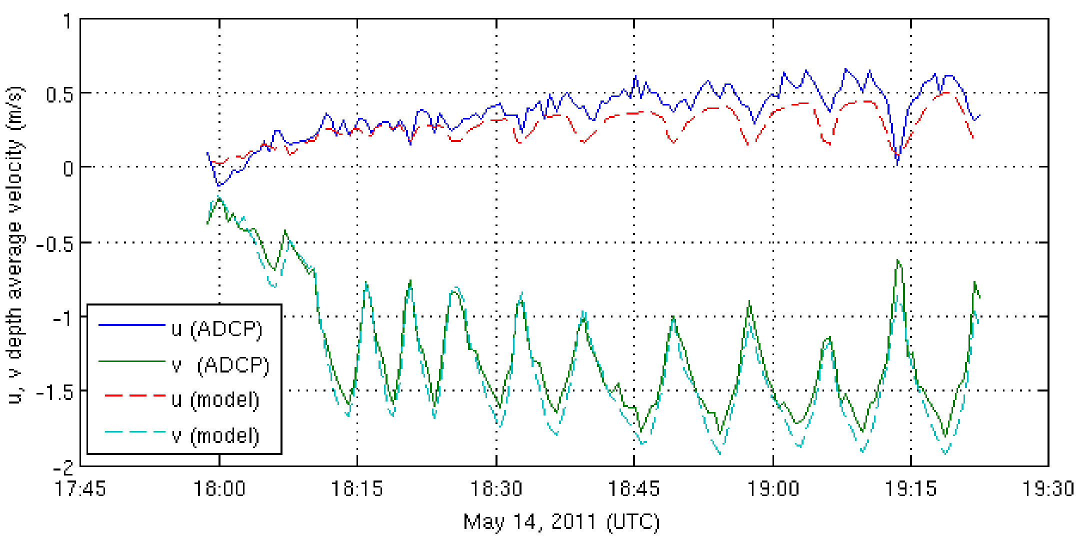

Figure 4.12: Time-series plot of measured and modelled u and v current velocity components for the survey of April 14, 18:00UTC.

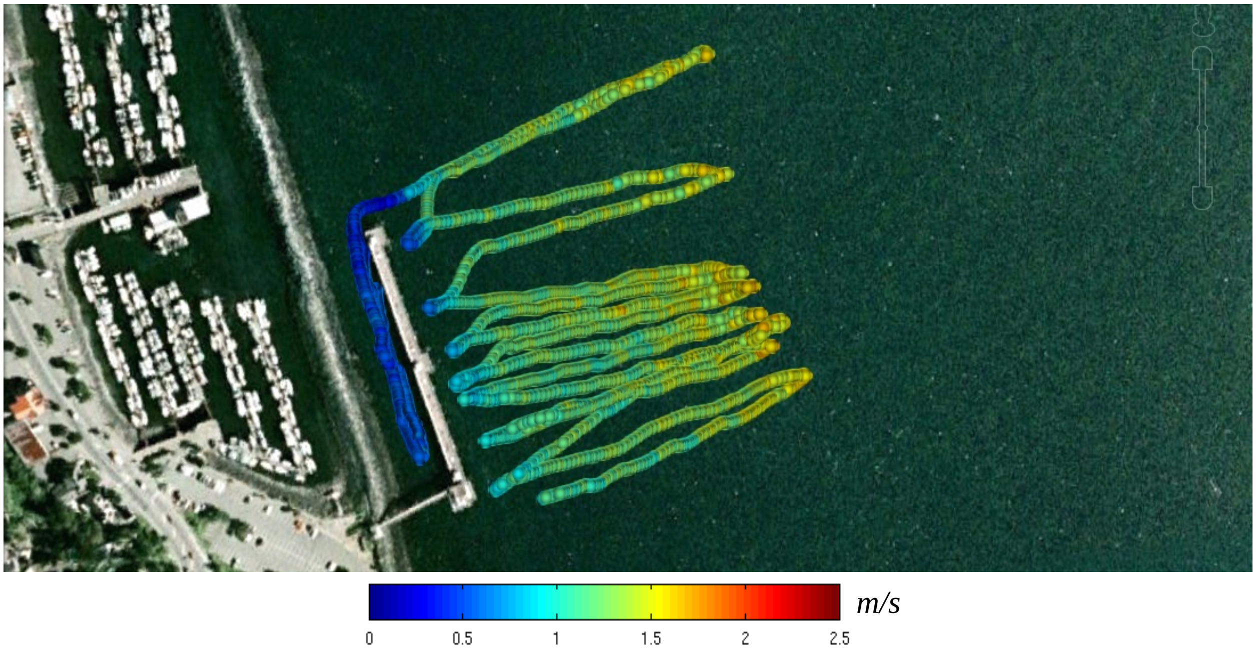

Figure 4.13: Current velocity survey during ebb tide April 15, 00:00UTC. Coloured dots indicate depth averaged current speed.

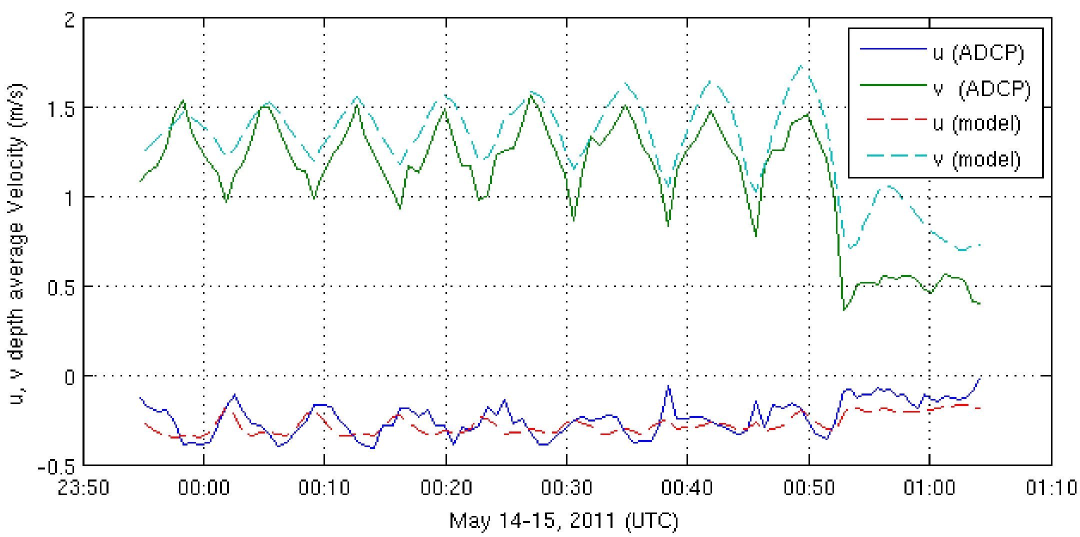

Figure 4.14: Time-series plot of measured and modelled u and v current velocity components for the survey of April 15, 00:00UTC.

4.5.4 Impact of Missing Constituents

The tidal model is forced with seven harmonic constituents (Z0, M2, N2, S2, K1, O1, P1) at the southern and northern boundaries. The primary tidal constituents L2 and K2 and constituents with periods greater than one day were not included because the source time-series data from which the boundary constituents were derived were not of long enough duration to resolve these constituents.

Shallow water constituents, which arise from the interaction of primary constituents, are generated within the model, but only those for which the primary constituents are available. This means that any shallow water constituents arising from interactions involving L2 or K2 are not modelled. This section assesses the impact of these missing constituents on current estimates.

Depth averaged current data from the Seymour Narrows bottom-moored ADCP was used as a test case. The Cape Mudge ADCP data was not used because the large eddy which passes by, obscuring the harmonic nature of the current signal and consequently making meaningful harmonic analysis difficult. At the Seymour ADCP there are no significant eddies and the tide ebbs and floods conveniently in the north-south direction. A plot of the depth averaged velocity at the Seymour ADCP is given in Figure 4.10.

Because we are working with measured time-series data, all tidal constituents will be present within that data. But, because the data is of limited duration, and because the amplitude of some components of the signal will be on the same order as signal noise only some of those constituents will be resolvable by harmonic analysis. The data was analyzed using the tidal analysis package *T_Tide (*Pawlowicz et al., 2002). From the 8 month data-set, 60 of the standard 70 tidal constituents could be resolved.

The tidal current signal was then recreated for 18.6 years (a full tidal epoch) using all 60 resolvable harmonic constituents. Additionally the tidal current signal was recreated over the same period using only those constituents used as boundary conditions in the model and the shallow water constituents that arise from them. A comparison of the recreated tidal current signals is given in Figure 4.15.

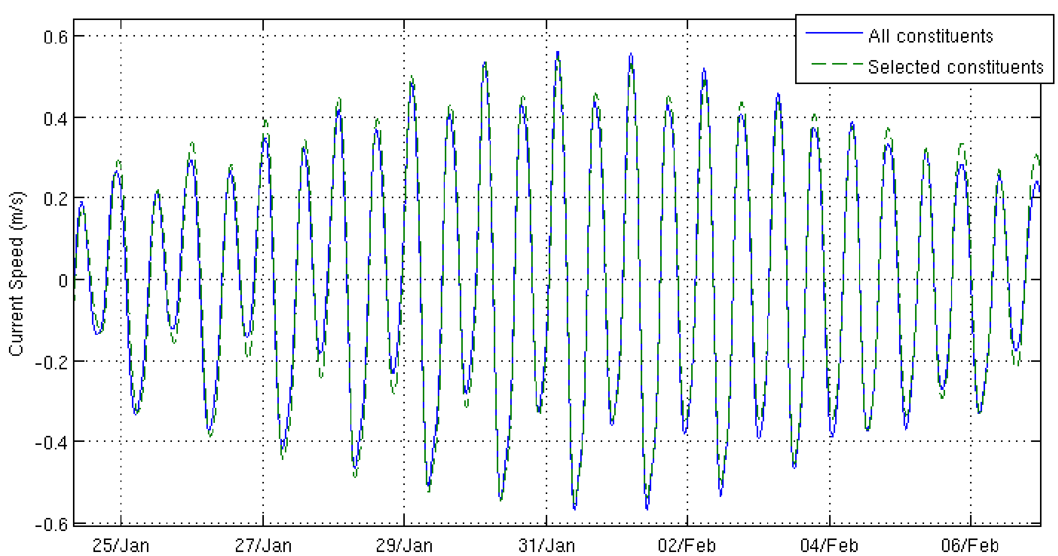

Figure 4.15: Comparison of time-series current data recreated from harmonic constituents at Seymour ADCP location. Positive values indicate ebb, negative values flood.

The mean and maximum current speed value from each signal as well as the average difference between the signals and the maximum difference between the signal are given in Table 4.2 . All stats are computed based on the absolute value of the current speed.

The average and maximum current speed for the selected constituent signal are slightly less than the one which contains all resolvable constituents with ratios of 0.99 and 0.96 receptively. It is important that the difference in maximum speed (4%) be accounted for when calculating design loads for the proposed turbine.

The maximum difference between the reconstructed signals was 0.15m/s, but on average the difference between the signal is zero. This maximum difference is of little consequence because it does not coincide with peak tidal flow.

This analysis of current measurements made by moored ADCP in Seymour Narrows shows that on average the constituents not included in the tidal model have only a very small impact on current estimates. On the other hand, the neglected constituents do cause under-estimation of the maximum current speed by 4% and this should be accounted for when calculating design loads on the proposed turbine.

	All Constituents	Selected Constituents	Ratio
Included Constituents	SSA MSM MM MSF MF ALP1 2Q1 SIG1Q1 RHO1O1 TAU1 BET1 NO1 CHI1 P1 K1 PHI1 THE1 J1 SO1 OO1 UPS1 OQ2 EPS2 2N2 MU2 N2 NU2 M2 MKS2 LDA2 L2 S2 K2 MSN2 ETA2 MO3 M3 SO3 MK3 SK3 MN4 M4 SN4 MS4 MK4 S4 SK4 2MK5 2SK5 2MN6 M6 2MS6 2MK6 2SM6 MSK6 3MK7 M8	O1 P1 K1 SO1 N2 M2 S2 MSN2 MO3 SO3 MK3 SK3 MN4 M4 SN4 MS4 S4 2MK5 2SK5 2MN6 M6 2MS6 2SM6 3MK7 M8	25/59
Ave. Speed (m/s)	0.241	0.238	0.99
Max. Speed (m/s)	0.610	0.585	0.96
Mean Diff (m/s)	0.00		NA
Max Diff (m/s)	0.15		NA

Table 4.2: Mean and maximum current speeds at Seymour ADCP derived from all resolvable harmonic constituents and those harmonic constituents which were included in the tidal model.

4.6. RESULTS – CURRENTS AT THE DISCOVERY PIER

The following section discusses the currents at and near the Discovery Pier based on the model results and the ADCP measurements. A second 36 day model run was conducted for December 2010 in order to capture the largest currents during the year (spring tide). Figure 4.16 shows a contour plot of average current speed throughout Southern Discovery Passage.

Average current speeds are largest in the centre of the Passage just south South of the Discovery Pier. Currents are fastest there because of the way that the water flow is funnelled by geography, bathymetry and eddies on both the flood and ebb tides. From this Figure it is evident that the region around the Discovery Pier is actually one of the most energetic near-shore sites within the City of Campbell River.

Figure 4.17 shows the average current speed in more detail around the Discovery Pier as well as reference stations N1-N6 which will be used to investigate the current characteristic around the Pier in more detail. These stations were selected to represent a range on acceptable deployment locations for the proposed turbine.

Figures 4.18 and 4.19 show the maximum current speed and average kinetic power density respectively. The maximum current speed is important as a design condition for the turbine, but in this case is unlikely to pose any constraints as the maximum current speeds are still relatively low.

Kinetic power density is an indicator of the energy in the tidal flow per unit of front facing area. While this metric cannot accurately indicate the total extractable energy in a tidal channel, it is a good indicator of the ambient energy density for small tidal projects such as the one currently under consideration. The kinetic power density is calculated as:

$$KPD = 1/2 \rho U^3 \tag{4.2}$$

Where ρ is the density of seawater ($1025 kg/m^3$), U is the current speed (m/s) and KED is in units of W/m^2.

The U^3 term in equation means that power density is very sensitive to current speed. Observing Figure 4.19 one can see that kinetic power density increases very quickly travelling east from the Pier. This gradient in energy would normally dictate that the turbine be sited as far into the centre of the Passage as possible in order to maximize energy capture. However, the Fishing Pier Tidal Demonstration Project has broader objectives than just generating power , including being a showcase for tidal energy, with a significant public education component. It is clearly desirable that visitors to the Pier are able to observe the turbine in operation from the Pier itself. Thus the closer the turbine is to the Pier the better, even when the tidal energy capture is quite small.

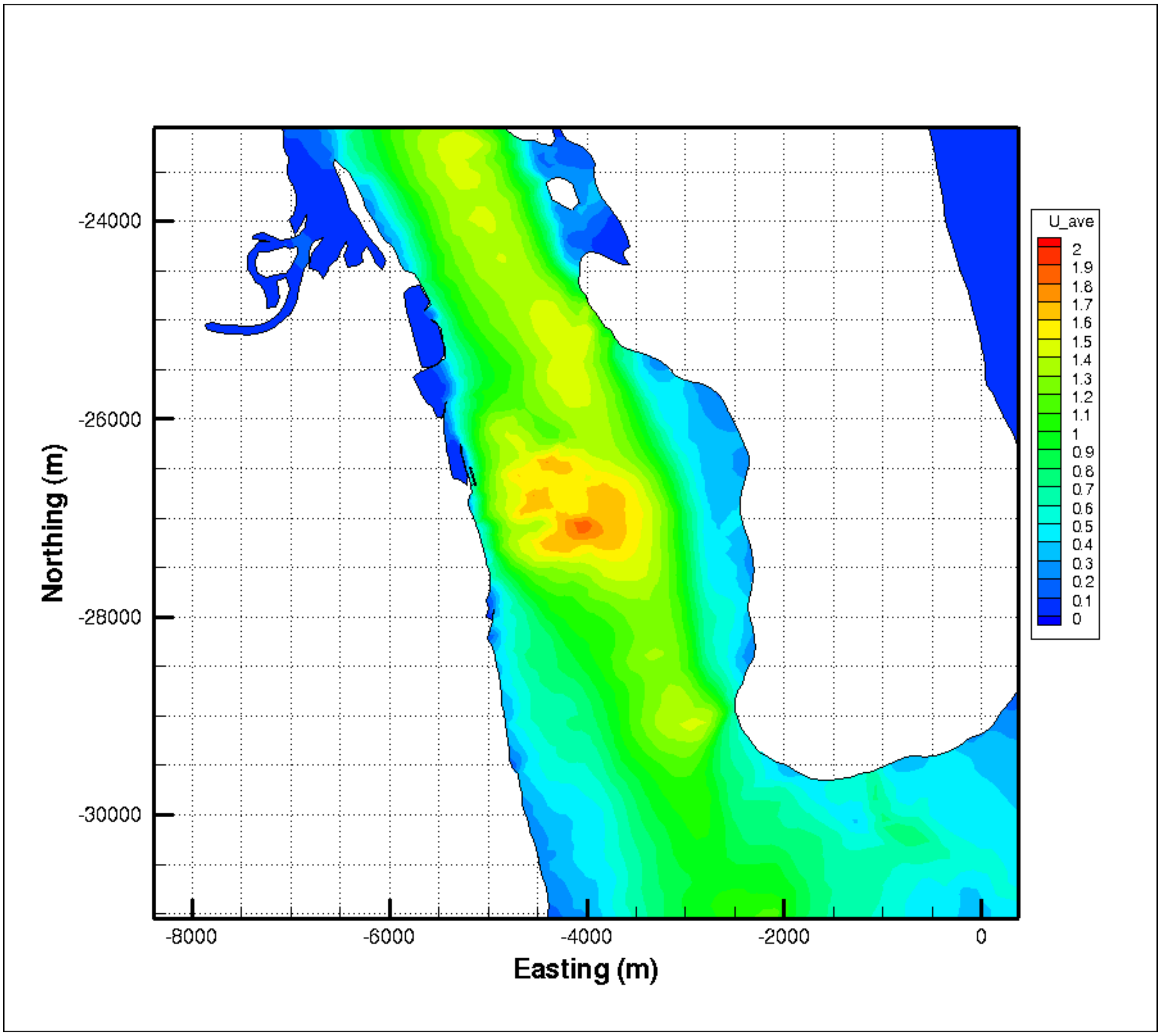

Figure 4.16: Average current speed in Southern Discovery Passage (Dec, 2010).

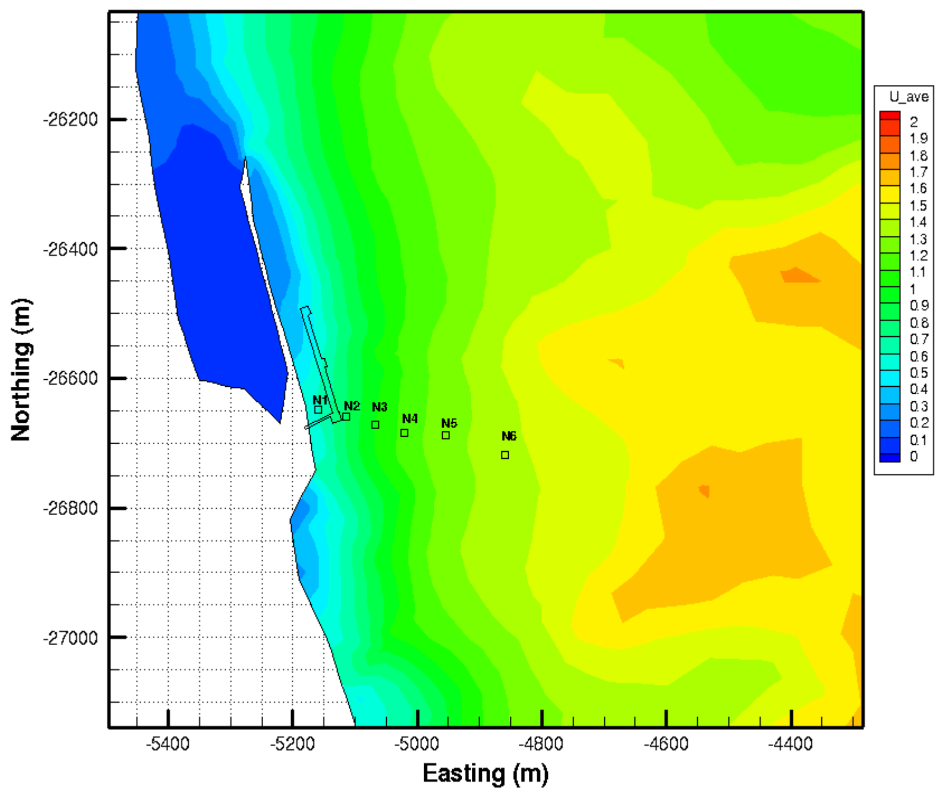

Figure 4.17: Average Current speed around the Discovery Pier (Dec, 2010).

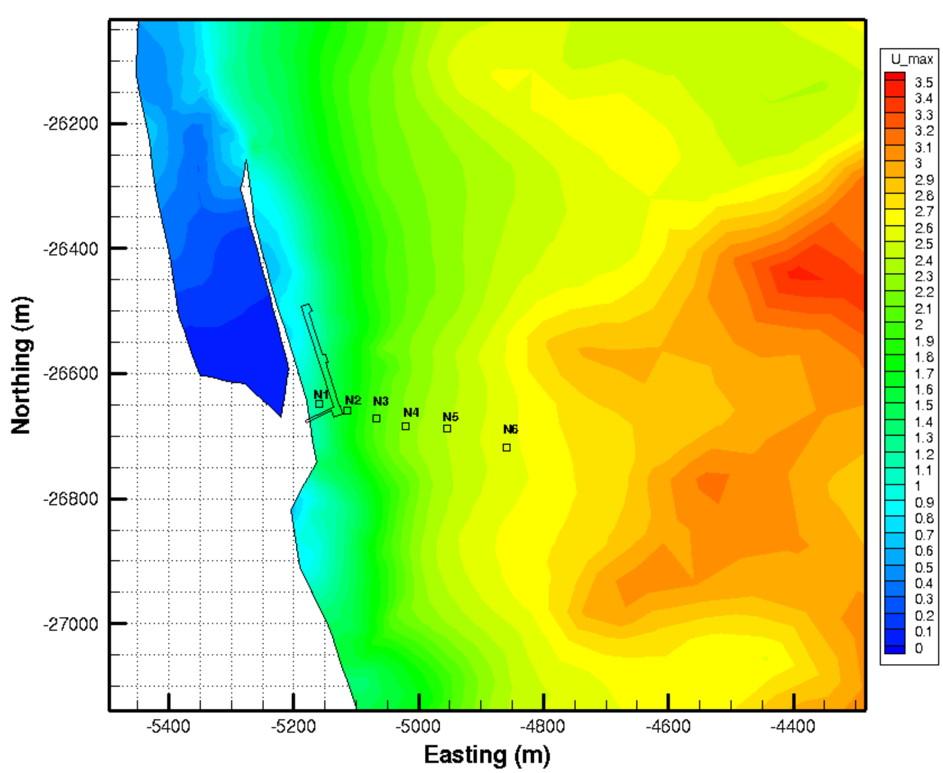

Figure 4.18: Maximum current speed around the Discovery Pier (Dec, 2010).

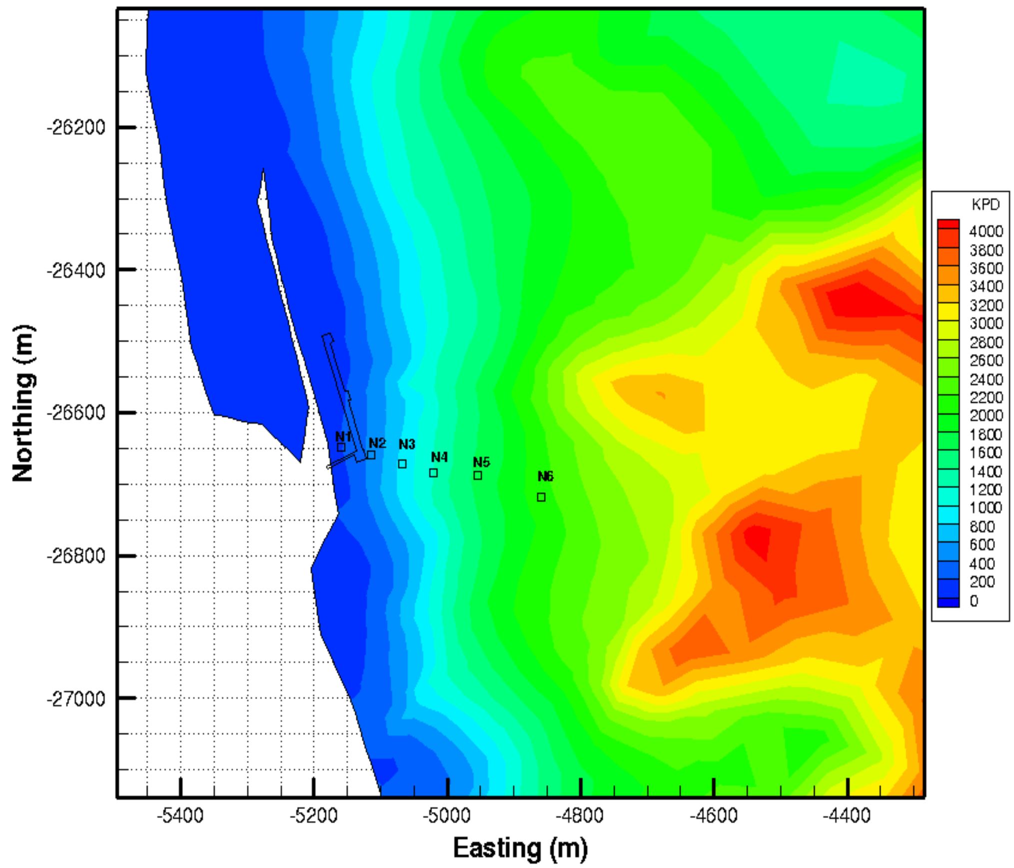

Figure 4.19: Average kinetic power density around the Discovery Pier (Dec, 2010).

Figures 4.20 and 4.21 show the current speed at stations N1 through N6. From these plots it is obvious that current speed increases dramatically travelling eastward from the Pier. Table 4.3 summarizes the average and maximum current speed and average kinetic power density at each station. Also given is the distance of each station from N1.

The current speeds at N1-N2 are too slow for effective operation of any tidal turbine that Triton is aware of. The current speed at N3 may be sufficient for some low speed turbines such as one model produced by New Energy Ltd. The current speeds at N5 and N6 are still marginal, but achieve the the minimum speeds required by most turbine developers.

Siting the turbine will be a delicate balance of meeting the minimum operating current of the turbine and meeting the visibility conditions that make the turbine useful as an educational and promotional tool and balancing with transportation corridor restrictions and movement of marine mammals and aquatic species.

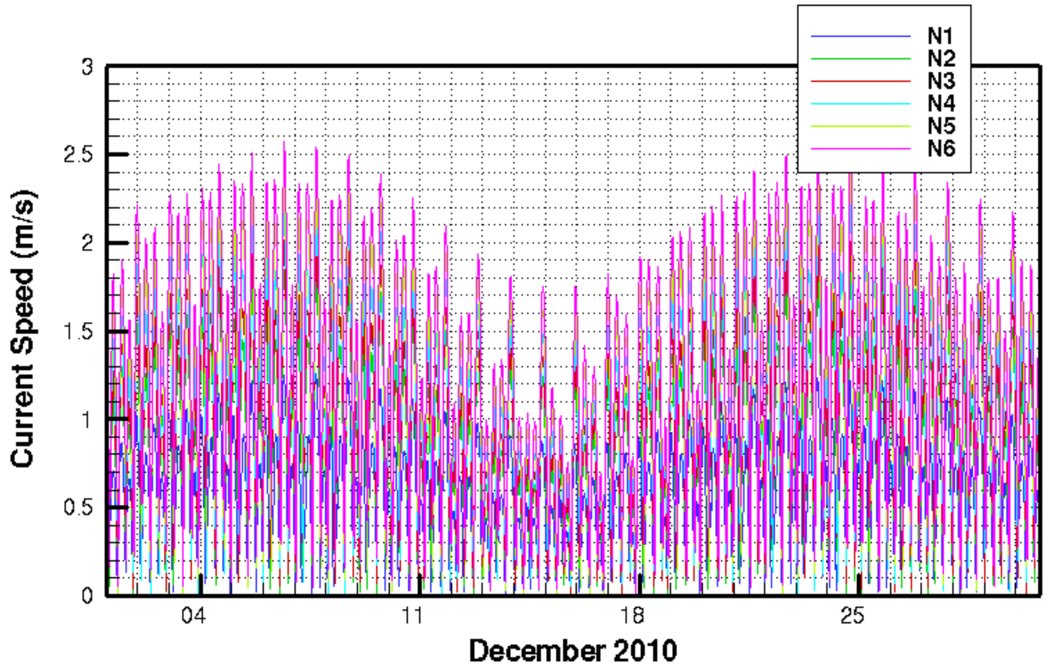

Figure 4.20: Current speed at transect locations (Dec, 2010).

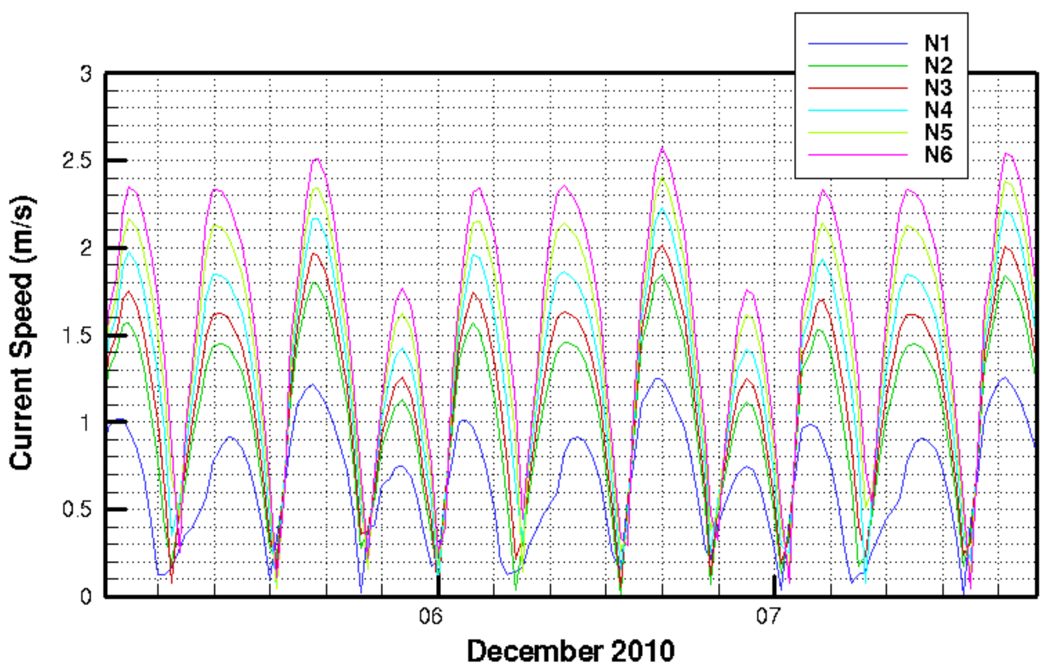

Figure 4.21: Current speed at transect locations (Dec 5th-8th, 2010).

	U_ave (m/s)	U_max (m/s)	KPD_ave (W/m^2)	Distance (m)
N1	0.60	1.25	189	0
N2	0.80	1.66	445	46
N3	1.00	2.01	857	93
N4	1.13	2.23	1208	143
N5	1.26	2.40	1653	208
N6	1.37	2.57	2119	308

Table 4.3: Average current speed, maximum current speed, average kinetic power density and distance from N1 for December 2010 tidal model run.

4.6.1 Vertical Structure of Currents near Discovery pier

The vertical structure of currents (or *current profile*) around the Discovery Pier is of interest for two reasons. The first is so that the turbine can be positioned in the water column to take advantage of the fastest current speeds. The second is so that the differential loading (varying current speed over the diameter of the rotor) can be understood. These points will be of specific interest to the turbine designer/developer.

The current profile was recorded with each ADCP measurement made around the Discovery Pier. The measurements made while the boat was moored are most convenient for analyzing the velocity profile. Figure 4.22 below shows the three locations where moored ADCP measurements, the data/time (UTC) and the tide state during the measurements. These locations were selected as estimates of where the proposed turbine might be sited.

Figure 4.22: Locations of moored ADCP measurements (May13-14, 2011).

Plots of depth average current speed and selected current profiles at each ADCP are provided in Appendix B. Figure 4.23 below shows the average normalized profiles for the flood (circle) and ebb (triangle) moored measurements. Bin-depth is normalized by water depth and current speed is normalized by the depth-averaged current speed. The data in Figure 4.23 were attained by averaging all the normalized profiles in the measurement set. The slack tide measurement is not included in this plot because the velocity profile is not well developed during the slack tide.

The profiles shown in Figure 4.23 for the flood and ebb are well formed except for an outlier near the surface that was presumably caused by the hull of the boat from which the measurements were being taken. The profiles are nearly identical. A best fit of the data is given in red. This is useful for estimating current velocity throughout the water column based on depth-averaged data.

The formula used for the best fit of the current speed profiles is:

$$U_z / U_0 = \alpha \cdot (Z / Z_0)^{\beta} \tag{4.3}$$

Where U_z is the current speed at a specific distance from the sea bottom, U_0 is the depth-averaged speed, Z is the distance of U_z, Z_0 is the total depth and α and β are fitting parameters. A least squares analysis identified α and β as 1.08 and 1/5 respectively.

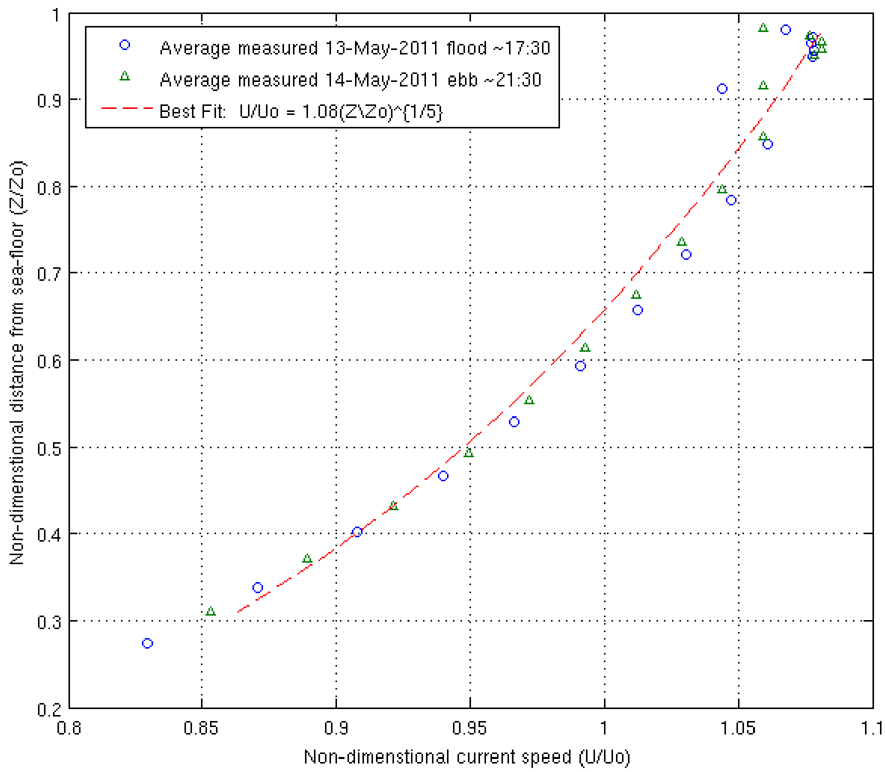

Figure 4.23: Average current profile on the ebb and flood tides at sites near the Discovery Pier.

4.7. CONCLUSIONS

Triton has developed a detailed tidal model of the area stretching from the Northern Straight of Georgia to Johnston Straight, including the Discovery Islands and Discovery Passage. The model has been successfully validated to harmonic tidal constituents at 30 different tide gauges, qualitatively compared to long term current measurements at Cape Mudge, Seymour Narrows and Nodales Channel, and validated in detail to current measurements made specially for this project around the Discovery Pier. Given the successful validation of the model throughout the Discovery Islands, the results may be applicable not just to the Discovery Pier Project but also other future projects in the region.

The model shows that Discovery Pier location is one of most energetic near-shore tidal sites within the City of Campbell River. Despite this, the current speeds at this location are marginal for economic extraction of tidal energy. Normally peak current speeds of approximately 2.5m/s or 5knots are assumed to be necessary for energy extraction. The model results and measurements made around the Discovery Pier show that there is a significant gradient in current speed traversing east from the Pier. Just between the breakwater and the Pier there is a maximum current speed of 1.25m/s, 300m from the Pier there is a maximum current speed of 2.57m/s. The current speeds for economic energy extraction do exist, but 300m away from the Pier. This compromises a major goal of the project, to show case tidal technology by having it visible from the Discovery Pier.

In addition to the siting considerations just mentioned, the exposure of the device to large waves from the Straight of Georgia must be considered, as waves will be larger the further the device is sited from shore.. Extreme waves is the topic of the following Section of this report.

5. *EXTREME WAVES*

For design purposes it is important to estimate the largest loads that a structure is likely to endure over its lifetime. For the proposed tidal installation forces resulting from wave impacts may be the most significant. In Phase 1 of the feasibility study report a preliminary study of waves in Campbell River region was performed. A simple wind-based hind-cast using Triton's WaveHind software was used to estimate conditions at the entrance to Discovery Passage. The results showed that waves greater than 2 meters are to be expected often and that waves greater than 3m occur about once a year. WaveHind is designed for use over open fetches and does not take into account refraction and shoaling and therefore could not be used to estimate wave conditions at the Campbell River Pier.

In the present phase of the feasibility study a SWAN (Simulating WAves Near-shore) wave model has been constructed to better assess the wave environment at the Discovery Pier. The SWAN software is able to account for refraction and shoaling when calculating wave conditions, and is therefore appropriate for calculating wave conditions inside Discovery Passage near Campbell River. SWAN is more accurate than the WaveHind program used previously, but it also more complicated to set-up and takes much longer to run.

SWAN is open-source wave modelling software which uses user supplied wind and wave boundary conditions, digital bathymetry and a user-created computational grid to determine the transformation of surface waves in water of arbitrary depth. The model provides spectral descriptions of the waves at discrete locations – the node points of the computational grid. The governing equation of the SWAN model is the discrete spectral action balance equation which is derived from conservation of energy. SWAN has been specifically developed for near-shore wave modelling and is normally capable of modelling all the important physical processes that occur as waves approach shore including refraction, diffraction, wave-current interaction and the development of waves due to local winds within the modelled domain. Some of these phenomena are intrinsic to the discrete equations including refraction - the bending of the wave fronts toward shallower water. Other physical phenomena are incorporated by inclusion of source and sink terms in the governing equation as is the case for wave diffraction effects.

The model, shown in Figure 5.1, spans the Northern Straight of Georgia from south of Texada Island to Discovery Passage north of Campbell River. The model is driven by surface winds measured at the Sisters Island Weather Station (off Lasqueti Island). The great extent of the grid in the south-easterly direction is so that the wind can act over the entirety of the available fetch. The southern boundary of the domain is imposed with a wave boundary condition sourced from the Halibut Bank wave buoy. Current data is supplied by the tidal model discussed in Section 4.

This part of the report covers the construction, testing and operation of the wave model as well as the extreme wave analysis. The extreme wave analysis was used to find the largest significant wave expected at the Discovery Pier in 200 years (the "200 year storm"). Later this value is used to guide the siting and design of the proposed turbine installation. Wind conditions were estimated by a statistical analysis of 17 years of wind data for the region. The 200 year storm was simulated by scaling up the winds of a large storm which occurred April 2-3, 2010. The model was driven with the scaled winds, measured wave boundary conditions and modelled tidal currents. For comparison a statistical and parametric method are used to estimate the 200 year wave height at Sentry Shoal. The results are given in Section 5.6.3.

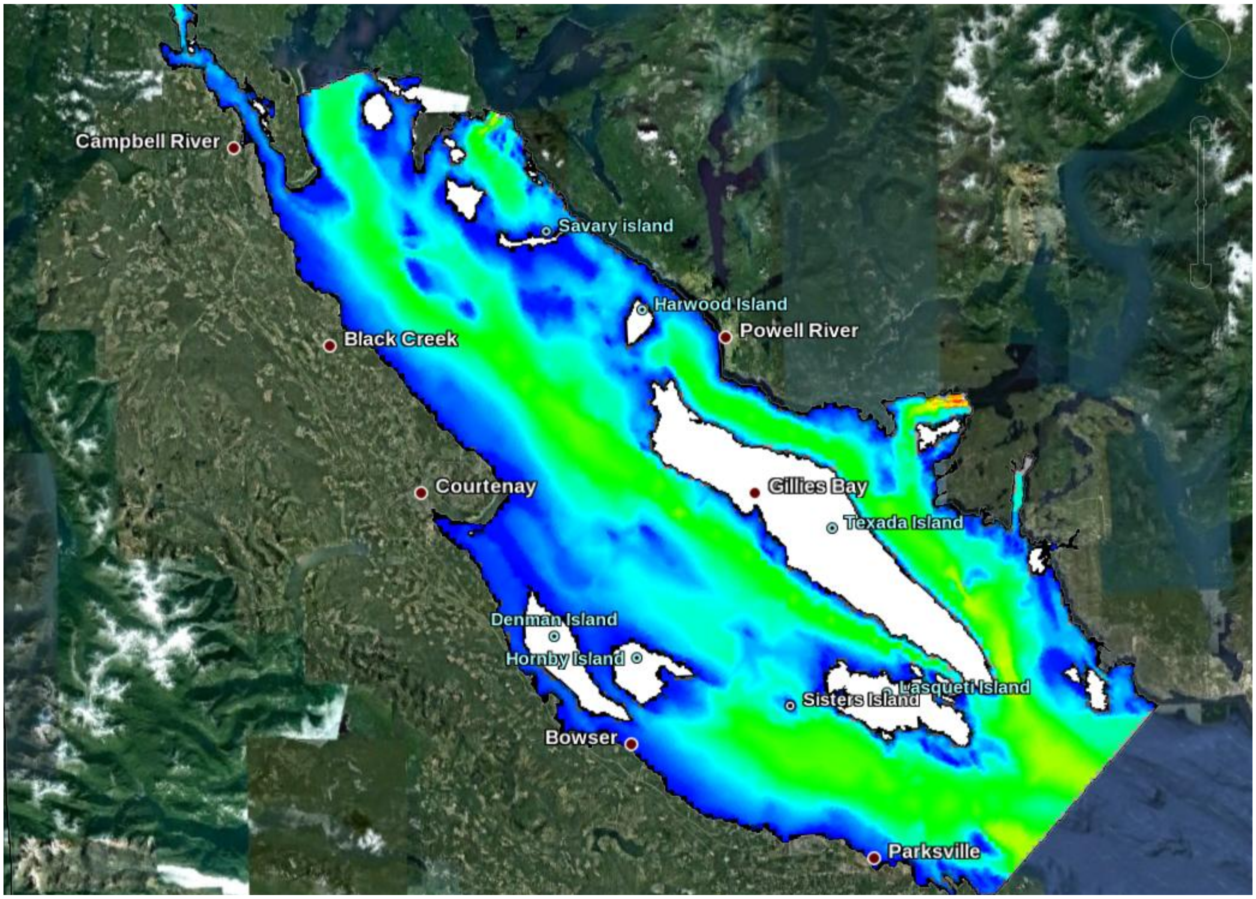

Figure 5.1: Bathymetric contours of the wave model plotted over Google Earth satellite imagery.

5.1. MODEL DEVELOPMENT

5.1.1 Computational Grid

A computational grid different than the one used for tidal flow modelling was developed for the wave model. The different grid was necessitated due to the differing physical processes important in wave modelling. Waves are generated as wind blows over long stretches of open water, therefore it is important that the wave model include all sections of open-water adjacent to Campbell River. Because the Discovery Islands block the propagation of most waves generated to the north of Campbell River, the model does not need to extend far in that direction. On the other-hand the Northern Straight of Georgia is a wide open channel perfect for the development and propagation of waves. The southern boundary of the model was selected south of Texada and Lasqueti Islands because little wave energy will get past those islands from the south and because a wave buoy at Halibut Bank provides a convenient wave boundary condition.

The unstructured grid was constructed based on bathymetric data from electronic navigation charts of the area. The grid was created in TriGrid2 using the "advancing-front" generation technique. The grid contains 91014 nodes and 175684 elements ranging in size from 20 to 550m. This is a large number of elements for the size of the geographic area covered, but is required to maintain the accuracy of computations over the very complex geography of the area which includes rapid changes in bathymetry and many islands and rocky outcroppings. Where necessary the grid was further resolved to maintain local accuracy. The grid is too dense to be plotted in its entirety, Figure 5.2 shows the area around Cape Mudge.

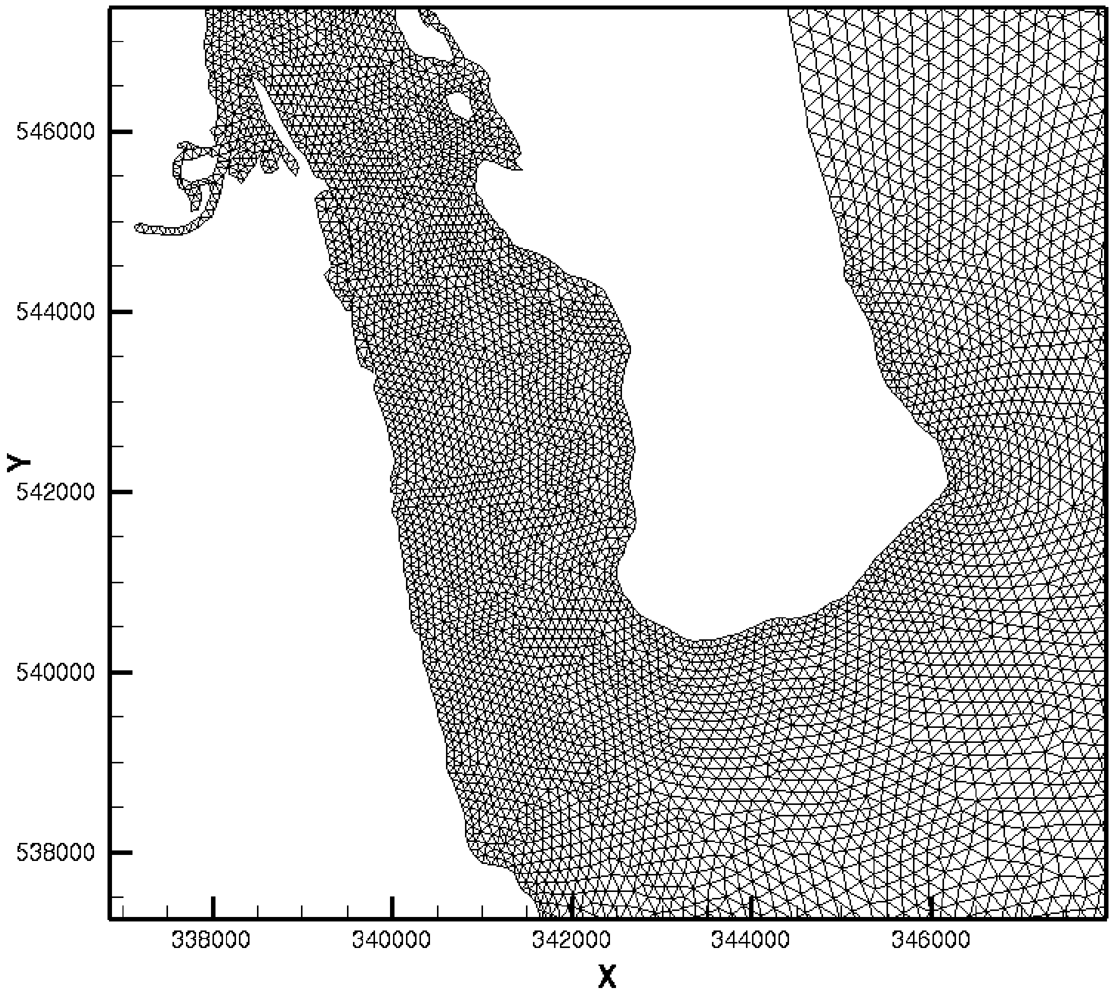

Figure 5.2: Close-up of computational wave grid around Cape Mudge

5.1.2 Boundary Conditions

The model is driven over the entire domain by local winds as measured at the Sisters Island Light Station and on the southern boundary by waves as measured by the Halibut Bank Wave buoy. These measured data are discussed in detail in the following section.

Currents are also applied in the northern portion of the wave model. To minimize computational effort, currents in areas outside Discovery Passage were assumed to be zero. To remove discontinuity in the current field a transition zone 10km in radius was applied south of Cape Mudge. Currents were scaled so that those 10km and further away were zero, and those from 10 km to 0 km varied quadratically from zero to their full value.

5.2. MEASUREMENTS

Measurement were used both to drive the model and to validate its operation. This section discusses the wave and wind measurements used in this study.

5.2.1 Measured wind data

Because of geographic isolation, waves in the Straight of Georgia are primarily generated by local winds. For this reason local winds were used as the primary driver of the wave model. An archive of wind data measured at the Sisters Island Light Station was obtained from Meteorological Services of Canada. This station is ideal for measurement of over-sea winds as it is located away from any major landmasses and provides a stable measurement platform (unlike floating buoys which move around). Data coverage is also better at the land based station (>89%) compared to the Sentry Shoal buoy (85%).

The archive contains three distinct sub-sets: the first is hourly average wind velocity data (1975 through 1992), the second is 2 minute average wind velocity sampled every 15 minutes (1992 through 1994) and finally, 2 minute average wind velocity sampled every hour (1994 to present). Because of the sampling differences, the data could not be assembled into a single large data-set. Hourly average wind speeds are the most appropriate for input into the wave model, therefore it is this data sub-set that is used where possible, specifically where statistical analysis is performed to estimate extreme winds.

Table 5.1: Averaging window, sampling period and data coverage of wind data-sets from the Sisters Island Light Station.

Date Range	Averaging Window	Sampling Period	Coverage
1975-1992	1hr	1hr	90.05%
1992-1994	2min	15min	89.06%
1994-2011	2min	1hr	96.09%

Shown in Figure 5.3 below is a wind rose produced the 1975-1992 data. Note that direction in the rose is non-meteorological, meaning direction is referenced to where the winds are headed. As expected the strongest and most frequent winds are aligned with the Straight of Georgia, with the most powerful winds directed up the Straight. It is these winds that will be most critical in creating large waves at the entrance to Discovery Passage.

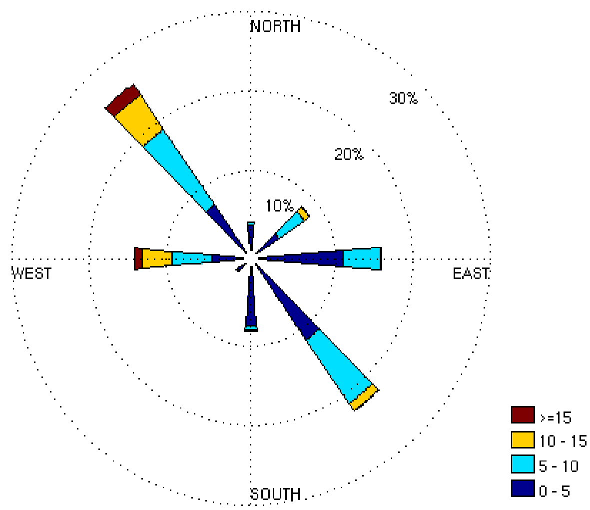

Figure 5.3: Wind rose of 1hr average wind data from 1975-1992 at the Sisters Island Light Station. Note that direction in the rose is non-meteorological, direction is referenced to where the winds are headed.

Table 5.2 shows the distribution of wind speed occurrences by month. Large wind speeds occur most frequently in the fall and winter months. In the summer months wind speeds tend to be lower, but there are still a significant number of occurrences above 14m/s.

Table 5.2: Bi variate distribution of wind speed with month.

Wind Speed (m/s)		**Month**												**Total**
From	**To**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Events**
0	2	1870	1912	2061	1935	1827	1980	2221	2622	2379	2417	1356	1433	24013
2	4	2810	2281	2856	3058	2913	2995	3023	3535	2677	2813	2444	2542	33947
4	6	1476	1263	1851	1879	1892	2287	2357	2496	1722	1622	1459	1574	21878
6	8	1135	1023	1377	1394	1489	1907	1849	1720	1143	1167	1162	1255	16621
8	10	1213	1106	1274	1301	1254	1500	1178	927	746	1096	1370	1489	14454
10	12	1085	877	882	692	682	503	352	371	391	682	1137	1172	8826
12	14	600	444	453	272	186	182	132	128	163	402	685	701	4348
14	16	492	266	275	138	124	57	35	63	84	290	358	459	2641
16	18	269	232	171	80	30	11	9	29	35	132	263	347	1608
18	20	66	79	52	19	11	1	0	0	3	23	108	101	463
20	22	14	15	12	8	1	0	0	0	0	4	41	54	149
22	24	2	1	0	0	0	0	0	0	0	0	8	12	23
24	26	0	0	1	1	0	0	0	0	0	0	2	0	4

Table 5.3 shows the bivariate distribution of wind speed with direction. This table uses the same data-set as the previous two figures, but ignores the few records with wind direction of zero degrees. This table shows that most occurrences of wind speed over 14m/s and all occurrences of wind speeds over 20m/s fall into the 90 and 140 degree direction bins. This confirms again that the most powerful winds come from the South-East and travel North-West up the Straight of Georgia.

Table 5.3: Bi-variate distribution of wind speed with direction.

Wind Speed (m/s)		Wind Direction (degrees, meteorological)								Total
From	To	50	90	140	180	230	270	320	360	Events
0	2	1100	2039	2056	2125	1769	4716	4189	5908	23902
2	4	438	2766	5921	1966	2214	8097	8966	3467	33835
4	6	46	2031	5763	281	1582	4919	6620	597	21839
6	8	32	2314	5303	88	1790	2053	4760	271	16611
8	10	24	2968	5332	32	2208	742	2942	202	14450
10	12	14	2768	3811	15	910	123	1064	117	8822
12	14	4	1643	2224	4	142	14	281	30	4342
14	16	0	997	1478	3	34	0	116	9	2637
16	18	0	571	975	0	13	0	47	2	1608
18	20	0	146	310	0	0	0	7	0	463
20	22	0	38	111	0	0	0	0	0	149
22	24	0	4	19	0	0	0	0	0	23
24	26	0	0	4	0	0	0	0	0	4
	Total	1658	18285	33307	4514	10662	20664	28992	10603	128685

5.2.2 Measured wave data

Measured wave data from the Halibut Bank buoy were used, along with wind forcing, to drive the wave model. Measured wave data from the Sentry Shoal and Cape Mudge buoys was used to validate the wave model. The location of the buoys is indicated in Table 5.4 and Figure 5.4.

Table 5.4: Wave measurement buoy locations

Buoy	ID	Location
Cape Mudge	MEDS336	49.998°N, -125.195°
Sentry Shoal	C46131	49.91°N, -124.99°
Halibut Bank	C46146	49.34°N, -123.73°

The Sentry Shoal and Halibut Bank buoys are permanently moored ODAS (Ocean Data Acquisition System) type buoys operated by Environment Canada. The ODAS buoys are quite large and serve as a platform to measure a number of properties of the ocean and atmosphere, but most importantly waves and wind. The buoys measure the non-directional wave spectrum and the statistical wave parameters significant wave height (Hs), peak period (Tp) and peak direction (θp). These statistical parameters represent the dominant wave height, wave period and wave direction in the sea. The Sentry Shoal and Halibut Bank buoys cannot measure wave direction.

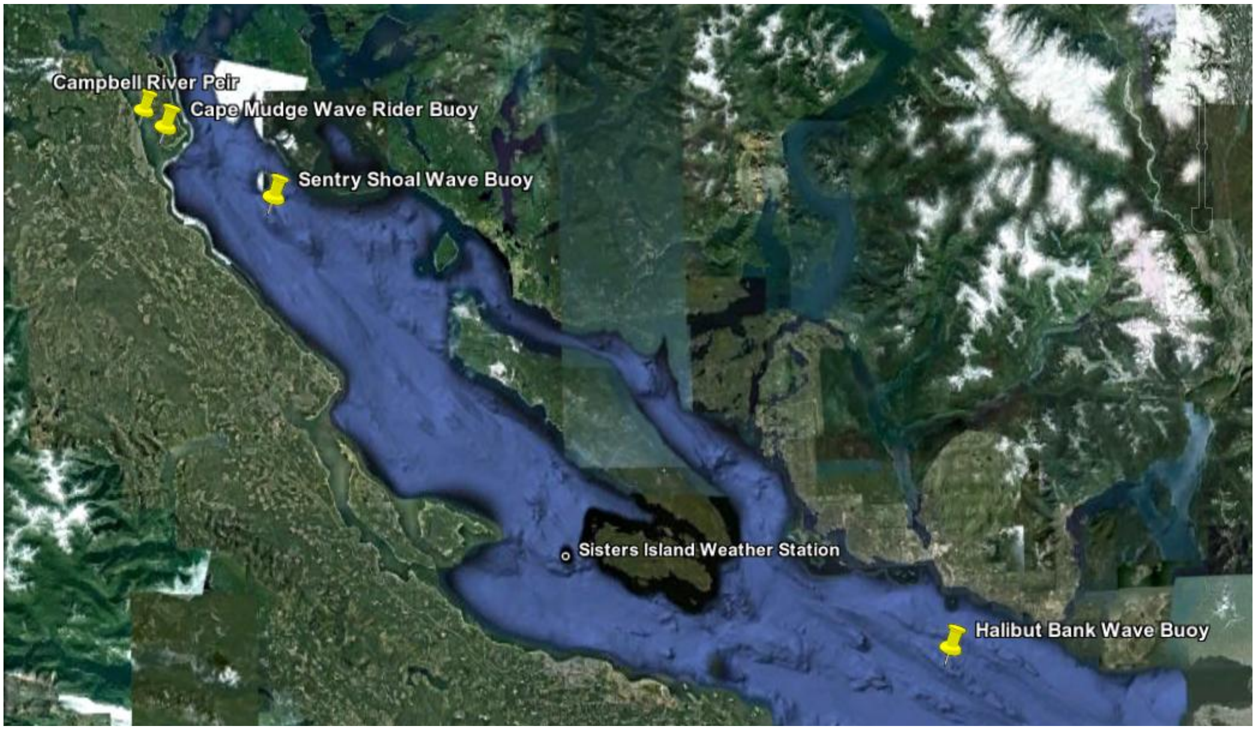

Figure 5.4: Location of the Cape Mudge, Sentry Shoal and Halibut Bank buoys in relation to Campbell River.

In the data-sets that Triton obtained from Integrated Science Data Management for the Sentry and Halibut boy there are two entries for significant wave height, one simply labelled "Characteristic significant wave height" and the other labelled "Characteristic significant wave height (reported by the buoy)". Interestingly, at both buoys the former entry contains obviously erroneous data over large periods of time, while the latter appears to report correct data over most of the same periods. It was due to this discrepancy that in Phase 1 Triton deemed the Sentry Shoal buoy data unreliable. Further analysis has shown that the wave height "reported by the buoy" is generally reasonable, and will be used in conjunction with quality assurance procedures as a means of validating the SWAN wave model.

The Cape Mudge buoy was a Wave Rider type buoy temporarily deployed in 1997. Wave Rider buoys are comparably small, spherical buoys about 1m in diameter that are often capable of measuring full directional wave spectra (as was the case with the Cape Mudge buoy).

The exact deployment location of the Cape Mudge buoy is uncertain as the coordinates quoted in the data file locates the buoy on land very close to the Cape Mudge Light Station. Environment Canada was questioned on the matter, but was unable to produce a more accurate location for the buoy. The location was quoted to three decimal degrees (as indicated in Table 5.4), if the accuracy of the location is assumed to be +/-0.001° the buoy may be located in water only about 60m from shore in about 4m of water. This very shallow water depth will significantly transform the waves indecent on the buoy, making it a difficult model calibration target.

5.3. CALIBRATION AND VALIDATION

Calibration and validation to local measurements is required to ensure the accuracy of the modelled results. Data from the Sentry Shoal and Cape Mudge measurement buoys, discussed in the previous section, were used to assess the accuracy of the wave model. A detailed account of the calibration process is provided in Appendix D.

5.4. EFFECT OF CURRENTS

To explore the effect of currents on waves in Discovery Passage, a model run was performed using a constant driving wind speed and direction of 20m/s and 140 degrees (nautical). The currents calculated for April 2010 were applied to the model. With this setup, the only force causing the waves to vary in time is the currents. Figure 5.5 shows the significant wave height and current speed at the Discovery Pier. The current have been signed so that positive values correspond to the ebb tide and negative values correspond to the flood (Discovery Passage ebbs north and floods south). It is evident in Figure 5.5 that significant wave height at the Discovery Pier fluctuates with the tidal stage, with waves ranging from 1.44m to 1.67m. The largest waves occur during the peak of the ebb flow, the smallest occur just after the peak of the flood flow.

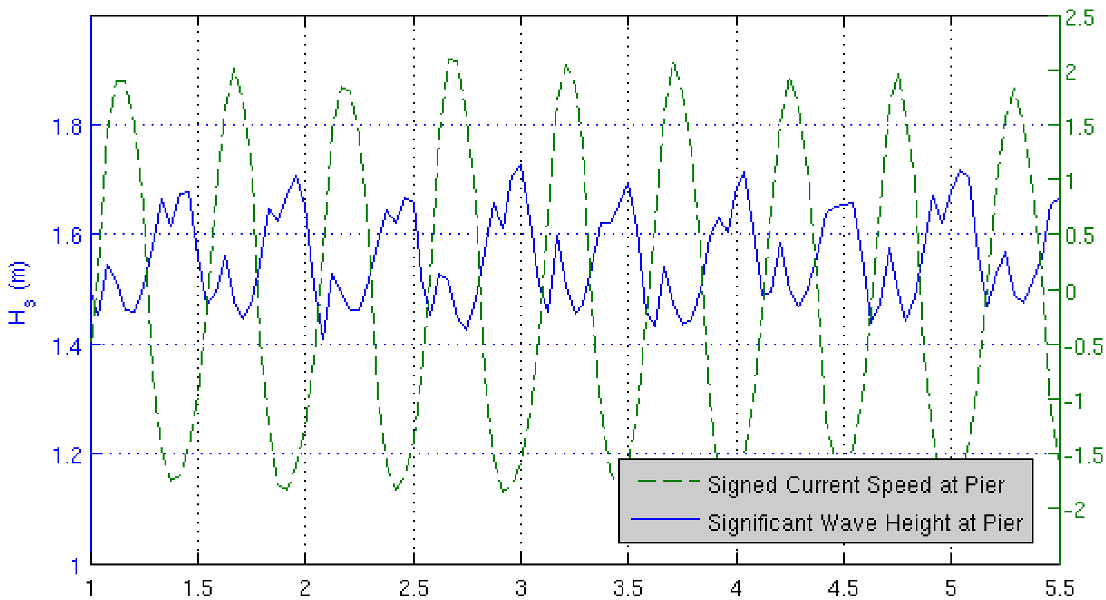

Figure 5.5: Significant wave height and current speed at the Discovery Pier. Current speed has been signed so that the northward ebb is positive and the southward flood is negative.

Figure 5.6 shows contour of significant wave height during different stages of the tidal cycle. Again, the only force modifying the wave heights in time is the current velocity.

During the ebb flow, when currents are directed northward, and large waves are mostly confined to the South-West of Discovery Passage. Current speeds are greatest in the centre of the Passage. The waves are moving in the same direction as the currents; this tends to increase refraction towards shore where wave energy is dissipated due to wave breaking. This trend continues as the tide turns to slack, with slightly larger waves penetrating the entrance to the passage with the slow in currents

During the flood flow, currents are directed southward and large waves are able to penetrate far into the Passage. Again currents are largest in the centre of the Passage, but in this case are moving south. Because the waves are moving in the opposite direction of the current the waves tend to refract towards the centre of the Passage where currents are greatest. This concentrates wave energy in the centre of the channel, away from shore. Because the waves tend away from the shoreline they are less likely to break, therefore more wave energy is conserved as the waves move up the Passage. This weakens as the the tide turns to slack, but is still visible in the centre of the channel in Figure 5.6d where significant currents persist.

Clearly, the tidal stage will effect the impact of the 200 year storm on the Discovery Pier.

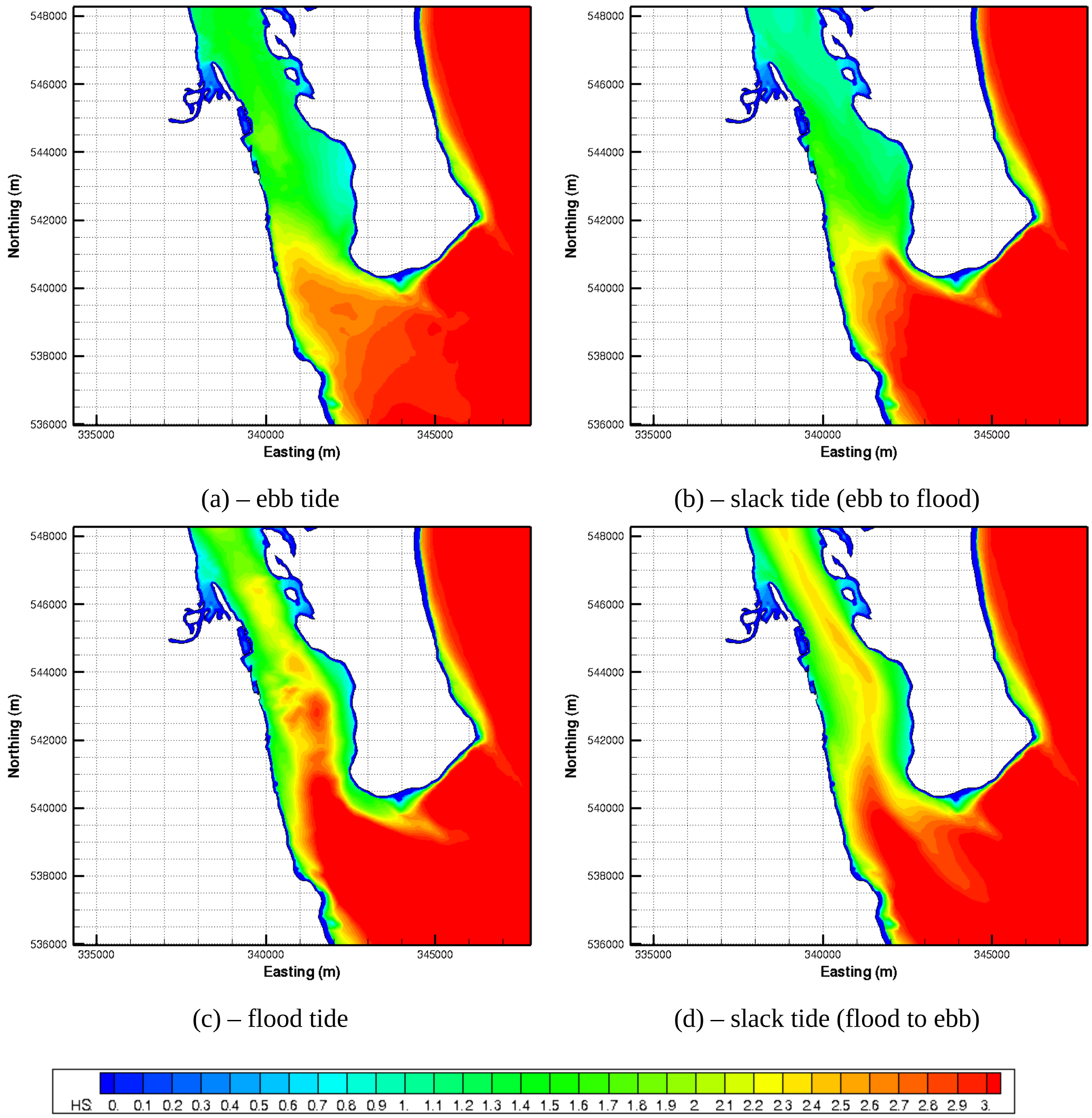

Figure 5.6: Wave height in Discovery Passage as modified by tidal currents. Constant wind speed and direction of 20m/s and 140 degrees (nautical) drive the model. Modelled currents were sourced from the April 2010 run of the tidal model.

5.5. EXTREME WIND ANALYSIS

The isolated nature of the Strait of Georgia means that nearly all wave energy is generated locally by local winds. So, to estimate extreme waves first extreme winds are estimated.

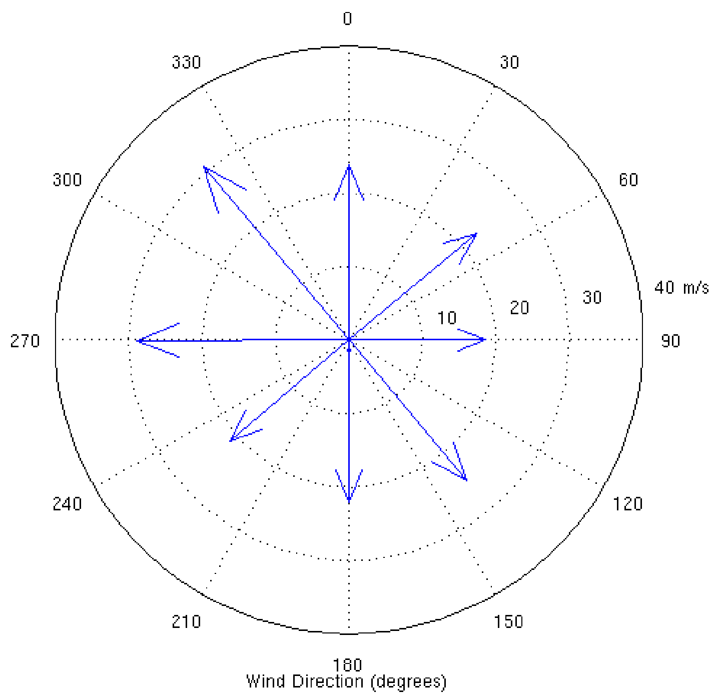

Figure 5.7: A polar plot showing the largest expected wind speed in eight compass direction.

Extreme wind event analysis was performed based on historical archives of wind data measured at the Sisters Island Lighthouse (see Section 5.2.1). The wind data was binned into 8 compass directions. The annual maximum approach (Holthuijsen, 2007) was used to estimate the maximum wind velocity expected in each of those directions. The annual maximum approach takes the largest wind speed values from each year and uses them to fit a to a probability distribution (in this case the Gumbel). From the fitted Gumbel distribution the expected maximum wind speed can be calculated for any return period. These calculations were performed in the Matlab computing environment using the WAFO Toolbox (Brodtkorb et al., 2000). It is typical engineering practice to estimate the largest loads expected in the lifetime of the product and use these values to guide design. The waves which will load the proposed tidal installation are the results of local winds, therefor the largest expected wind event in the estimated lifetime of the installation (~20 years) was sought. Because the tidal installation at the Campbell River Pier would be particularly susceptible to catastrophic failure, a factor of safety of 10 was added so that, effectively, the largest winds in 200 years were sought. Figure 5.7 shows the direction and magnitude of the largest wind speed expected in 200 years in each of the principle direction; Table 5.5 gives the same information numerically.

Table 5.5: Maximum expected wind speed from each compass direction.

Direction	50	90	140	180	230	270	320	360
Wind Speed (m/s)	21.3	28.9	30.9	23.9	22.8	18.6	24.9	22.1

The largest expected wind speed is 31m/s coming from 140 degrees. To model this 200 year wind in the SWAN wave model a large storm in recorded in April 2010 was scaled up so that the peak value matched 31m/s. The unscaled wind speed and direction during the entire month of the storm is shown in Figure 5.8. The storm occurs April 2-3; notice that the wind direction during this time is constant at roughly 140°. The tidal model, discussed in detail in Section 4., was used to generated currents for the period of the April storm, which were then applied in the SWAN wave model.

A detail of the scaled and unscaled wind speed during the storm is given in Figure 5.9.

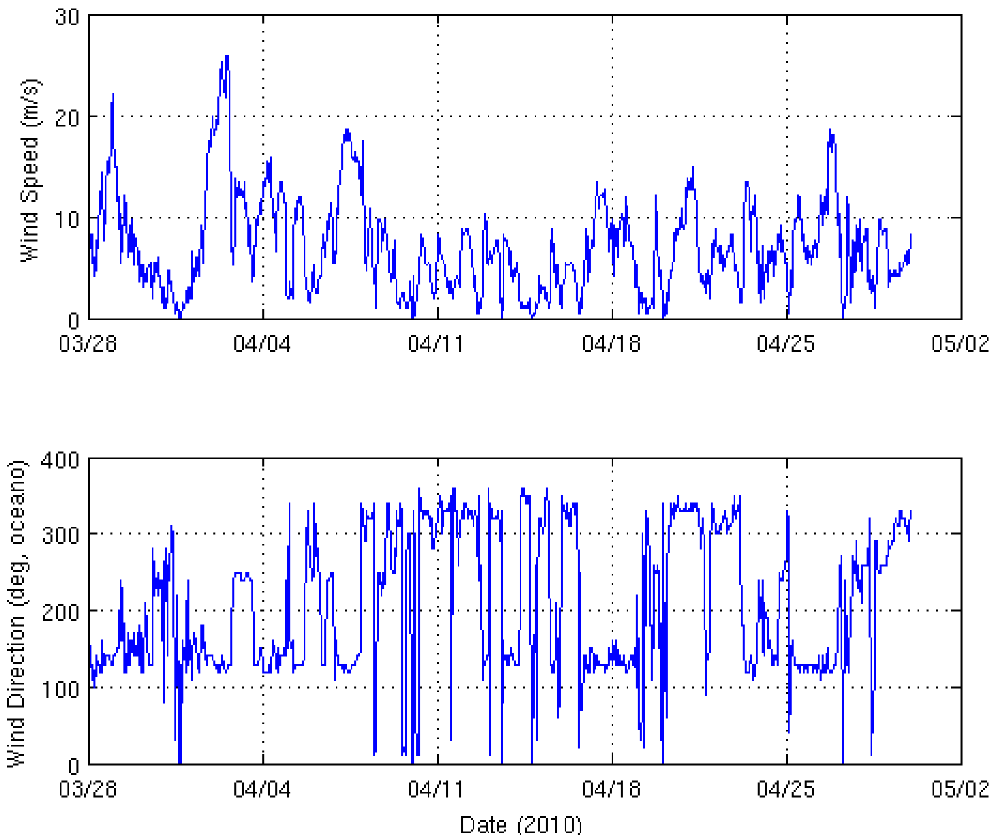

Figure 5.8: Wind speed and direction measured at the Sisters Island Light Station, April 2010.

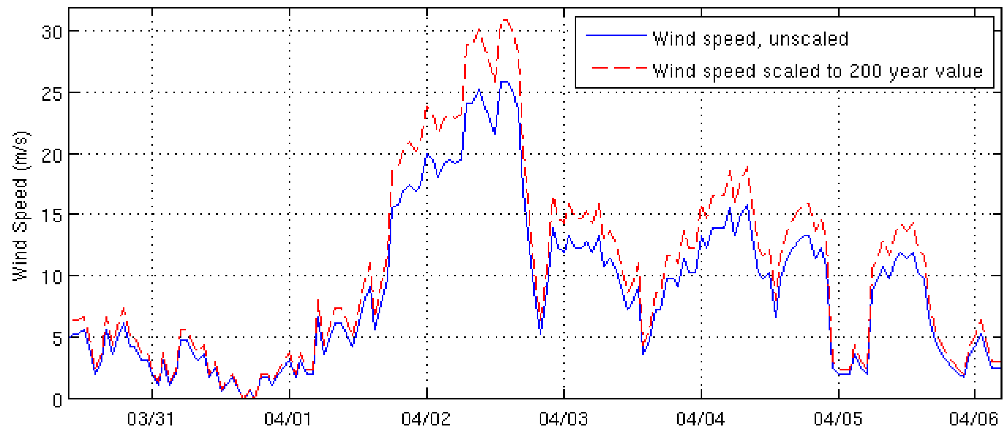

Figure 5.9: Detail of winds measured at the Sisters Island Light Station during a storm in early April 2010. Dashed line indicates that a scaling factor has been applied to the measured winds so that the peak of the storm corresponds to the largest wind speed expected in 200 years.

DURATION

In addition to wind speed, storm duration is an important factor in determining the resultant wave height. Here a storm is defined a wind event with speed greater than 20m/s which is sustained for 3 hours or more. Storm duration is the length of time that wind speed remains above 20m/s. The longer that high winds blow over the ocean, the more energy is transferred to the air to the water and results in larger waves. The duration of the 200 year storm (synthesized from the April 2010 storm) is 21 hours with a peak wind speed of 30.9 m/s.

Figure 5.10 shows a scatter plot of storm duration vs. peak wind speed for every storm measured by the Sisters Island Light Station since 1975. There is no clear relationship between peak storm wind speed and duration. It is noted that the longest measured storm duration is 14 hours. The duration of the synthesized 200 year storm, at 21 hours, is well in excess of any storm measured in the last 35 years. This indicates that the duration of the 200 year storm is likely over estimated, but since this scenario contributes to worst case wave conditions, it is retained.

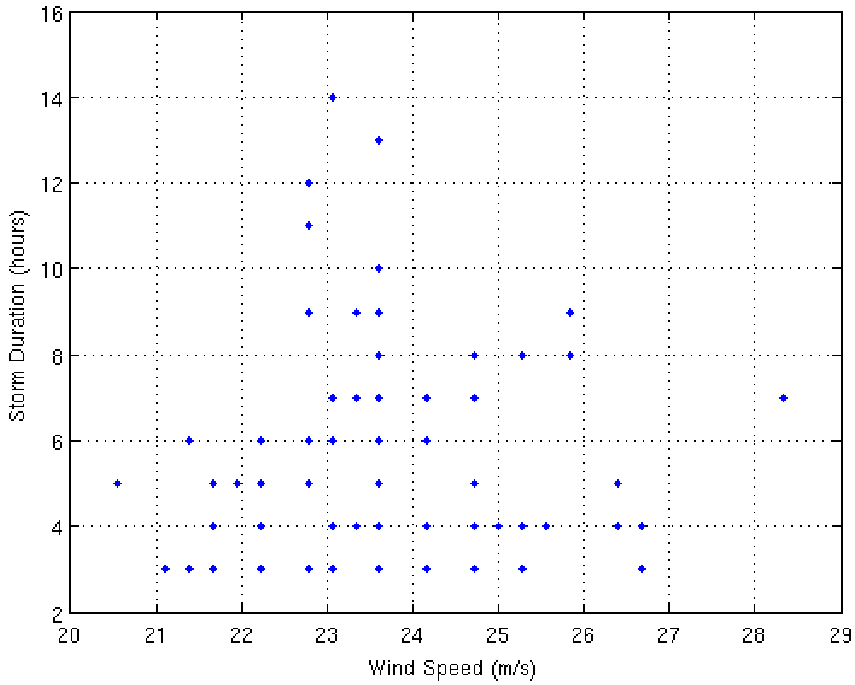

Figure 5.10: Storm duration vs. peak wind speed for every storm measured by the Sisters Island Light Station since 1975

5.6. EXTREME WAVE ANALYSIS

In this section the waves resulting from the 200 year storm are estimated. A simple parametric and statistical methods are discussed first. Because of the simplicity of these methods, they cannot be used to predict extreme waves in the physically complex region inside Discovery Passage, but are applicable in the more open waters of the Strait of Georgia South of Cape Mudge.

The setup and operation of the SWAN wave model for the 200 year storm is then discussed. Because of the sophistication of the model, its results are generally applicable.

5.6.1 A Parametric Model

Empirical formulas, such as the following from the US Army Corps of Engineers Shore Protection Manual allow significant wave height and peak period to be estimated based on the wind speed (U_A) and fetch (F):

$$H_s = 1.616\text{E-}2 \cdot U_A \cdot F^{1/2}$$ (significant wave height)

$$T_p = 6.238\text{E-}1 (U_A F)^{1/3}$$ (peak period)

$$t = 8.93\text{E-}1 \left(\frac{F^2}{U_A}\right)^{1/3}$$ (required storm duration)

Wind speed is usually taken 10m form the ocean surface, fetch is the length of open water over which the wind blows.

For the 200 year wind conditions calculated in Section 5.5. these parameters apply to Sentry Shoal :

$U_A = 31m/s$ (200 year wind speed)

$F_{sentry} = 65km$ (Fetch SE from Sentry Shoal to Lasquiti Island)

$F_{CM} = 80km$ (Fetch SE from Cape Mudge to Lasquiti Island)

Applying the equations the following estimates are calculated:

Sentry Shoal:

H_s = 4.03m

T_m = 7.9seconds

t = 4.6 hours

Cape Mudge:

H_s = 4.48m

T_m = 8.4seconds

t = 5.3 hours

5.6.2 Statistical Models

Extreme waves may also be calculated using statistical methods based on the waves that have been measured at a location over a long period of time. The *annual maximum approach* (discussed in Section 5.5.) was used to find the largest significant wave height expect at the Sentry Buoy in 200 years. There is approximately 18 years of data available form the Sentry Shoal buoy. Some erroneous data was found in the Sentry Shoal wave data set and removed, most notably from October 1998 to May 1999.

A number of probability distributions were tested including the Generalized Extreme Value, the generalized gamma, the generalized Pareto, the Gumbell, log-normal, the normal and the Weibull distributions. The 200 year significant wave height estimates ranged from 3.8 to 4.6m, with the Gumbell producing the largest waves estimate. Given that 4.6m is the most conservative estimate it was used to calibrate the SWAN model.

5.6.3 SWAN Extreme Wave Model

The SWAN wave model validated earlier was used to estimate extreme waves at the Campbell River pier based on extreme winds.

<u>**VERIFICATION**</u>

The model was driven by the winds of the April 2-3, 2010 storm scaled up to the 200 year wind speed value. Since the scaled winds speeds used in the simulation are hypothetical, the results cannot be validated to measurements. So, as further verification of the model, it was first run for the April 2-3 storm without scaling of the winds. In Figure 5.11 the wave height results are compared to those measured at the Sentry Shoal buoy. The model shows skill in estimating wave heights throughout the April 2-3 storm and estimates the peak significant wave of the storm exactly.

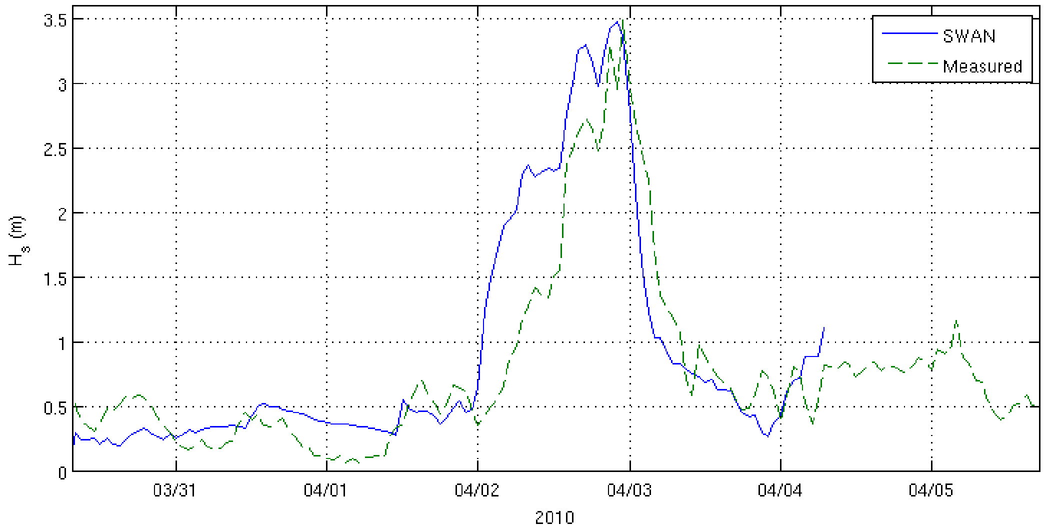

Figure 5.11: Significant wave height measured at the Sentry Shoal buoy and significant wave height predicted by SWAN at Sentry Shoal based on 200 year winds.

DISCUSSION

Having gathered further confidence in the skill of the model, it was run for the April 2-3 storm with scaled winds to simulate the 200 year storm. The significant wave height results of the modelled 200 year storm at Sentry Shoat are give in Figure 5.12. Notice that at the peak of the storm the wave height is 4.6m, equal to the largest extreme wave height estimates made using the statistical methods and somewhat larger than the estimates made by the parametric equations.

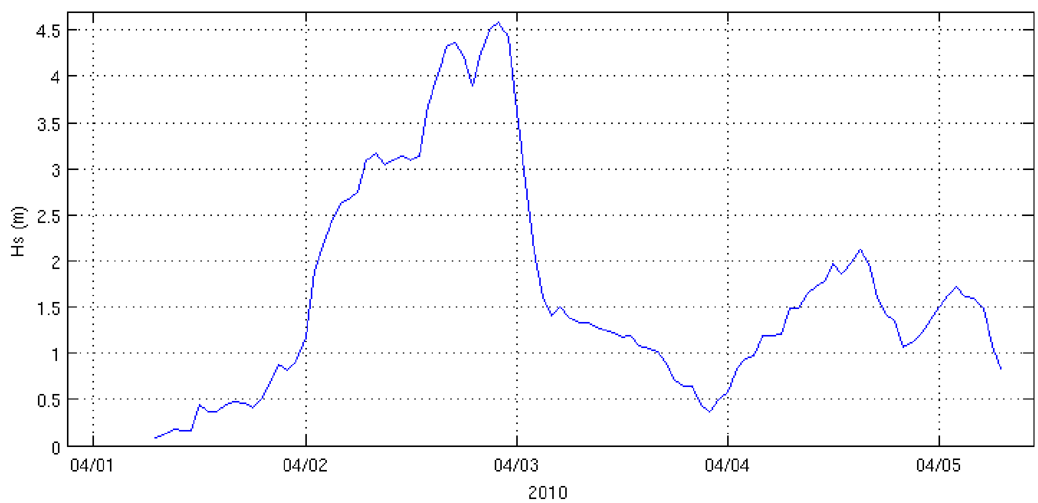

Figure 5.12: Significant wave height modelled at Sentry Shoal during the 200 year storm.

Figure 5.13 shows the distribution of significant wave height throughout the Northern Straight of Georgia during the peak of the scaled April 2010 storm. Wave height declines significantly as waves enter the mouth of Discovery Passage. This occurs in part due to bottom friction, but more significantly due to refraction. Refraction causes waves to turn toward shallower water, in this case, effectively deflecting waves toward shore where they dissipate due to breaking. The waves have dissipated significantly by the time that they reach the region of interest near the Discovery Pier.

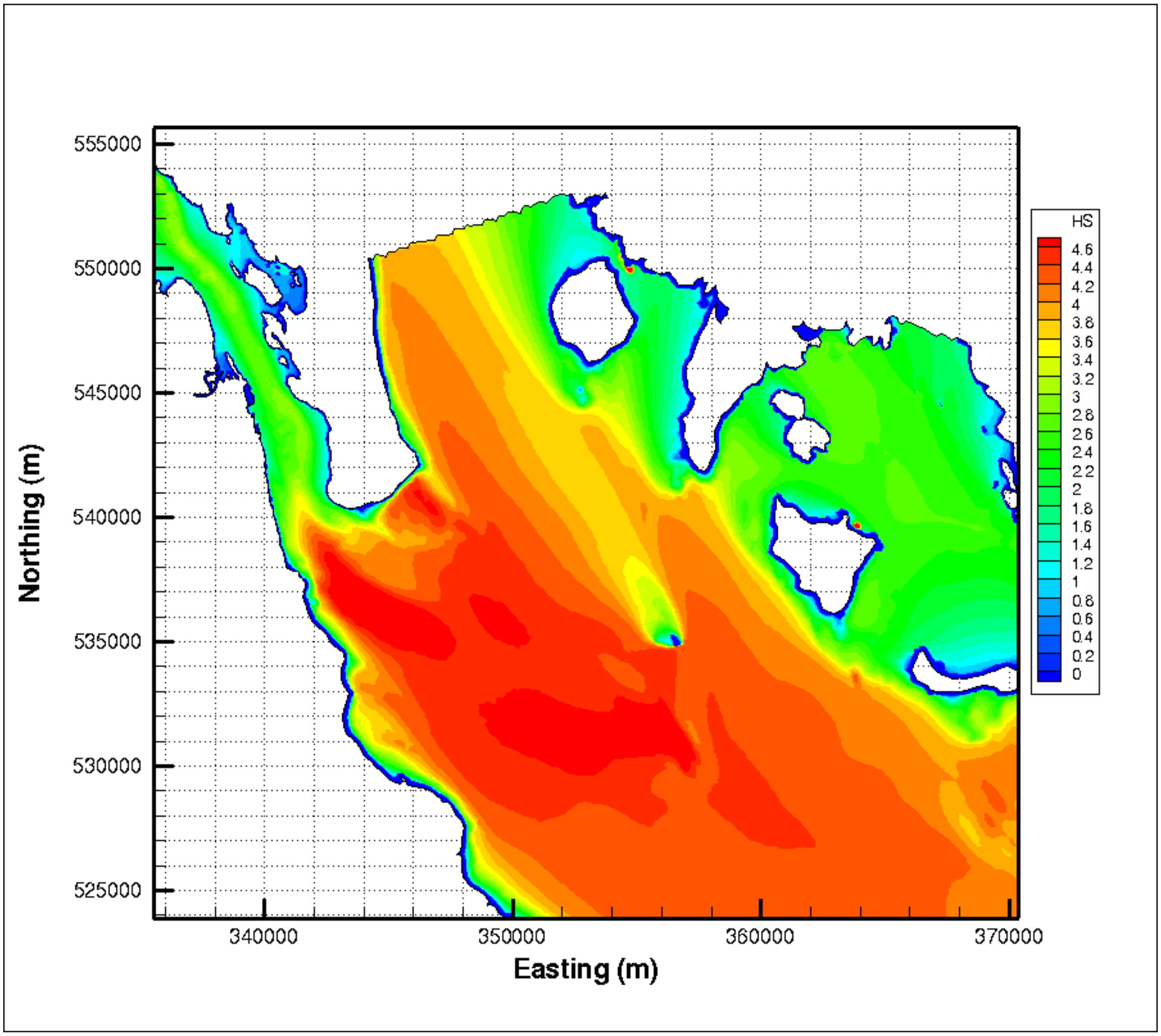

Figure 5.13: Significant wave height in Northern Straight of Georgia (02-Apr-2010 22:00:00UTC wind scaled to 200 year extreme).

The site, located in approximately 12m of water, just east of the Discovery Pier shown in Figures 5.14 and 5.15. These figures show the spatial variability of significant wave height near the peak of the 200 year storm. The significant wave height at the Pier is given in Figure 5.16. The maximum significant wave height calculated at this location was 2.3m, occurring at 02-Apr-2010 17:00:00UTC, five hours before the peak wave height at Sentry Shoal. This time differential occurs because of a combination of tidal flow and wind direction. The peak wave period at the Pier is shown in Figure 5.17. The peak wave period coinciding with the maximum wave height was 5 seconds. Together these parameters indicate the worst wave conditions to be expected at the Discovery Pier over a 200 year period. In fact, these extreme conditions has spatial variability.

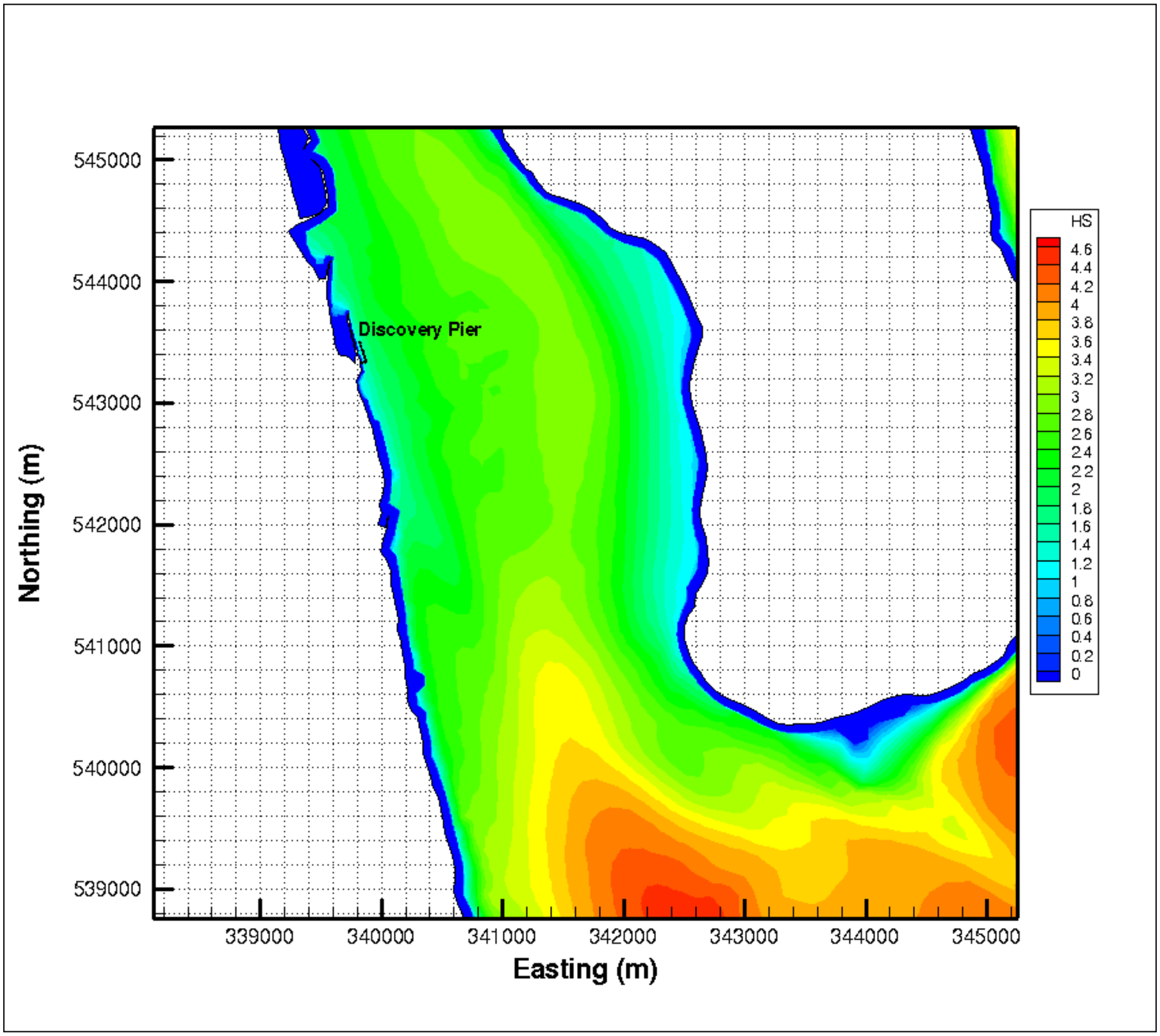

Figure 5.14: Significant wave height around Campbell River (02-Apr-2010 22:00:00UTC wind scaled to 200 year extreme).

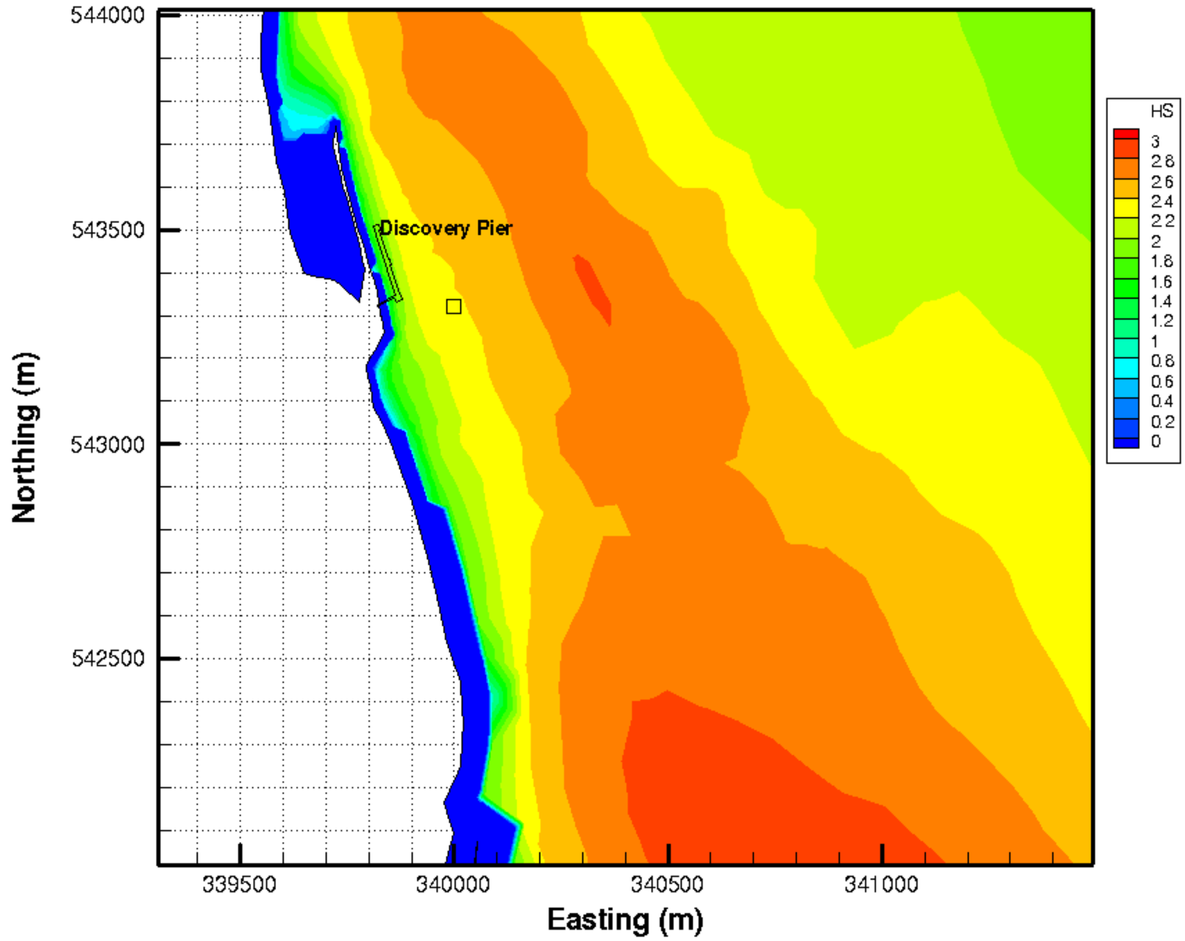

Figure 5.15: Significant wave height around Campbell River (02-Apr-2010 17:00:00UTC wind scaled to 200 year extreme).

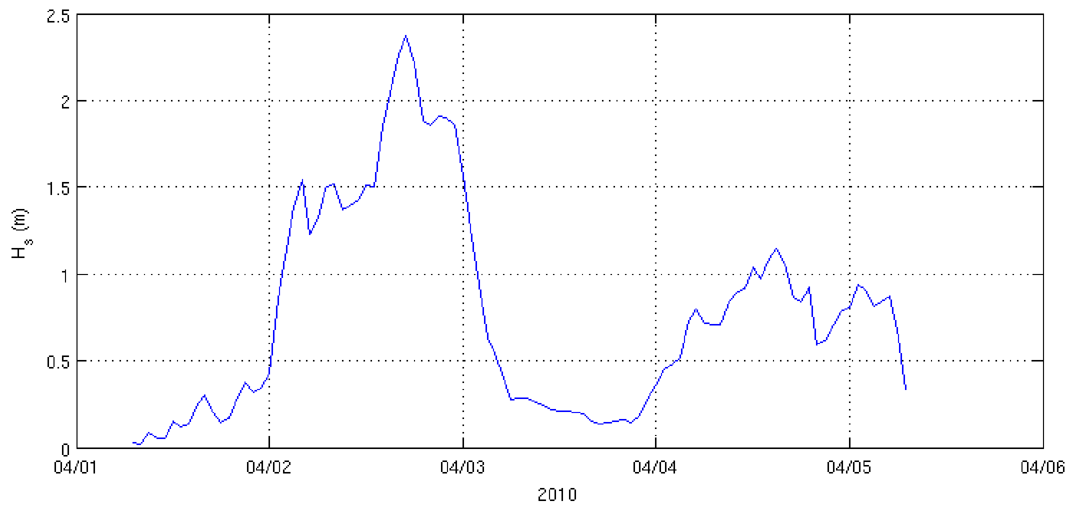

Figure 5.16: Significant wave height at Discovery Pier (April 2010, wind scaled to 200 year extreme).

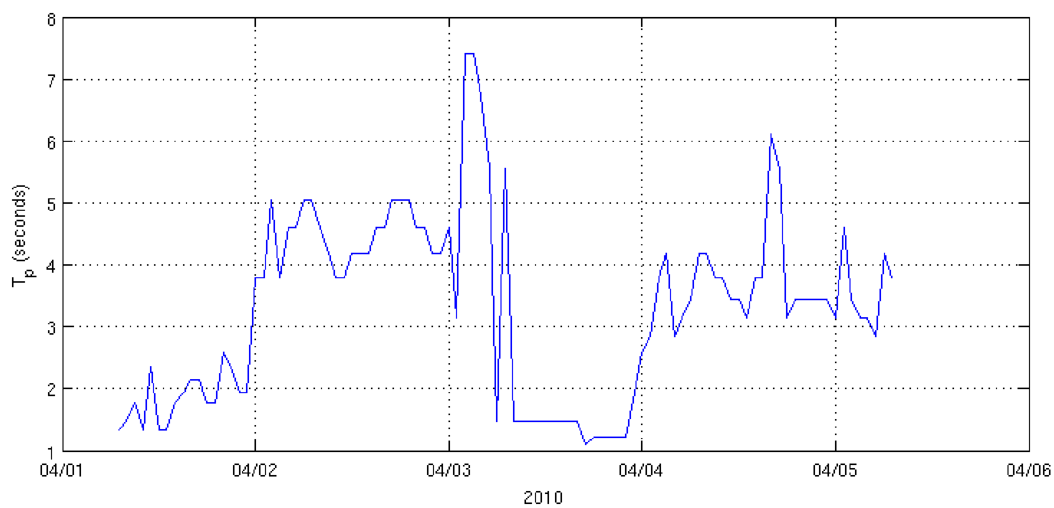

Figure 5.17: Peak wave period at the Discovery Pier (April 2010, wind scaled to 200 year extreme).

Figure 5.18 shows the maximum significant wave height achieved at any point during the 200 year storm and locations N1-6 as discussed in Section 4. The maximum significant wave height for N1-N6 is given in Table 5.6. From N6 to N3 the wave height varies from 2.51m to 2.29m . The analysis indicates that the waves must start to break around N2 as the maximum wave height there is reduced to 2.05m. The spatial gradient in maximum wave height observed here is not as large as gradient in maximum current speed observed in Section 4. Therefore, staying close to the Pier does not protect a turbine from large waves.

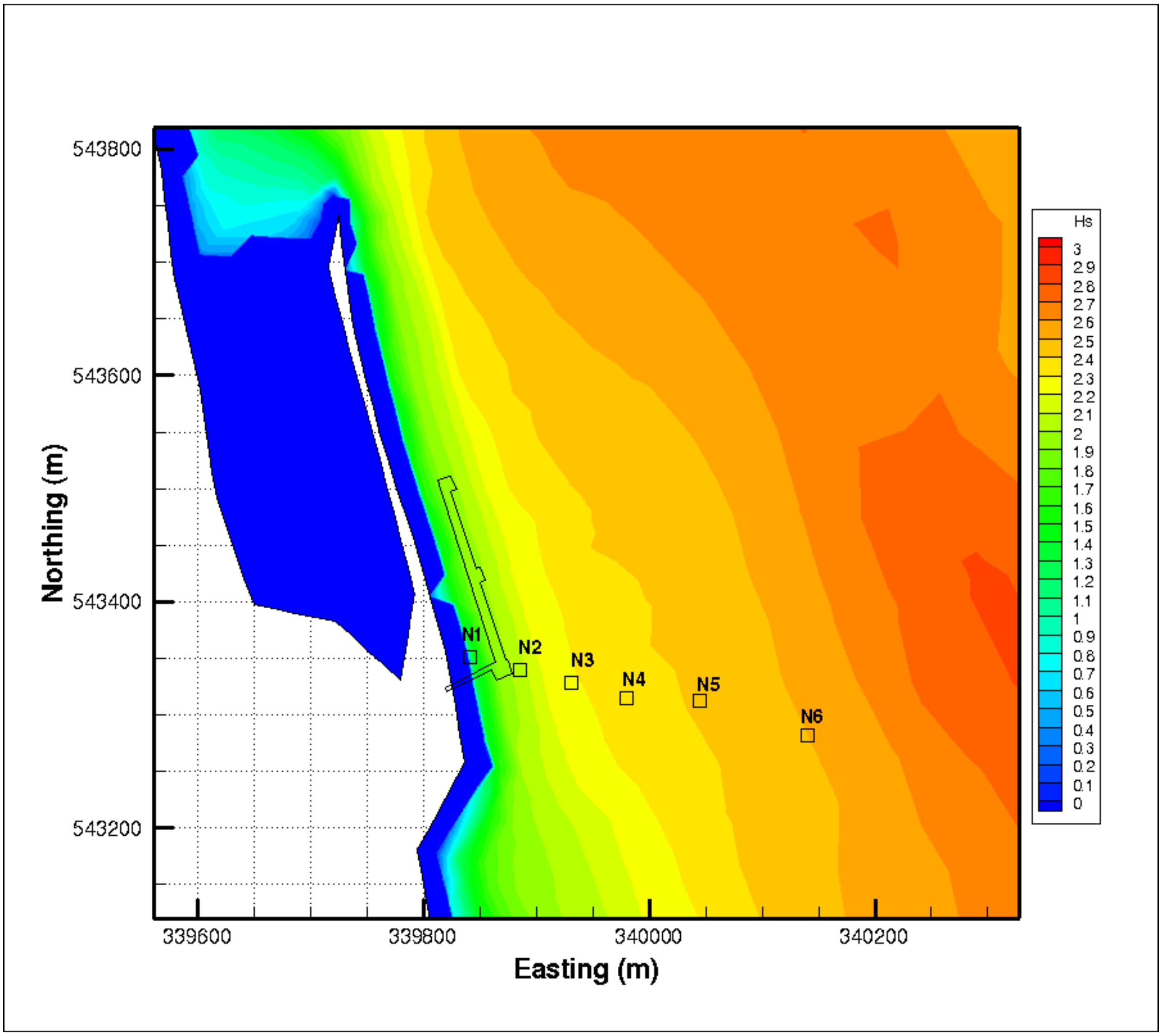

Figure 5.18: Maximum significant wave heights achieved during 200 year storm.

	Hs_max (m)	Distance (m)
N1	1.30	0
N2	2.05	46
N3	2.29	93
N4	2.34	143
N5	2.41	208
N6	2.51	308

Table 5.6: Maximum wave height and distance from N1 for 200 year storm.

5.7. CONCLUSIONS

Triton has developed a complex wave model based on the SWAN software. This model has been calibrated to measurements made by the Sentry Shoal and Cape Mudge wave buoys. An extreme wind analysis was used to attain boundary conditions representing the largest storm in 200 years. The model was used to estimate the waves produced by this 200 year storm. Given that the model vas verified at Cape Mudge and Sentry Shoal it is applicable throughout the region and so the extreme wave estimates may be useful for guiding other projects in the region.

The largest significant wave height calculated at the Discovery Pier (at location shown on Figure 4.20) during the storm was approximately 2.3m at 5 seconds peak period. This maximum wave height corresponds to the peak of the south going flood tide. At the peak of the ebb tide the wave height is lower but the wave period increases to about 7.5 sec.

The maximum significant wave height around the Pier has spatial variation, values range from 1.30m at N1 to 2.51m at N6. But, even at N3 the maximum wave height is 2.29m. Presumably the waves break somewhere between N3 and N1. Therefore, staying close to the Pier does not protect a turbine from large waves. Placement of the turbine will be discussed in more detail in Section 8. The following section discusses ecological implications of the Project and the regulatory process involved.

6. *ENVIRONMENTAL IMPACTS AND PERMITTING*

Ecofish Research Ltd was contracted to provide a preliminary environmental scoping and overview of possible regulatory requirements for the proposed Tidal Demonstration Project. Their report presents a general discussion of potential environmental effects for tidal power development, provides a description of the current regulatory framework for developing tidal power projects in British Columbia, and provides a preliminary scoping-level environmental review of the proposed tidal project. A summary follows, for the full report see Appendix E.

Potential environmental effects caused by tidal power development are well described in the literature. These include habitat loss caused by project footprints and habitat disruption caused by construction, installation, and maintenance activities. Potential changes in tidal flow patterns caused by project operation may affect nutrient transport, distribution of fish or invertebrate larva, and productivity by changing sediment resuspension patterns. Marine mammals, diving seabirds, and migratory fishes may be directly affected by collisions, entanglement with equipment, and noise generated by turbines and related infrastructure.

The operational policy for developing ocean energy projects in BC is still under development by the provincial government; however, the regulatory framework for permitting tidal power projects will generally follow the steps outlined in the BC IPP Guidebook. Phases in the provincial regulatory process include an investigative phase, application preparation and submission phase, project referral process and First Nation consultation phase, and a final authorizations phase. Federal screening under CEAA may be required if federal authorizations or permits are required for construction or operation of the proposed project. Construction or operation of tidal power project may require authorization under the Navigable Waters Protection Act, the Canadian Environmental Protection Act, or the Fisheries Act. There is some precedent for streamlining the permitting process by developing the project off of the grid, as in the case of the Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks; however, this would need to be investigated with the applicable regulatory agencies.

A preliminary scoping-level environmental review was conducted for the proposed tidal power project adjacent to the Discover Fishing Pier. This review included data obtained from online databases on shoreline characteristic, on the potential occurrences of species of conservation concern, and from the results of a site visit (May 11, 2011) in which subtidal habitats were described using images collected from an underwater camera. No biological features of obvious sensitivity to the Project were identified. The footprint caused by anchoring systems and subsea cables will result in habitat loss, though the magnitude of this effect cannot be determined prior to having a detailed Project design. Salmonid habitat in near-shore areas may be disrupted during the construction phase of the Project by sedimentation or noise, though any effects would be short-term. Given the small scale of the Project, it is unlikely to change to hydrodynamic flow. As such the proposed tidal Project is unlikely to adversely affect nutrient subsidies, larval and propagule dispersal, and waste removal for the local marine community, including rearing salmonids. Marine mammals, diving birds, and fish including pacific salmon may be at risk of collisions and entanglement with equipment, and noise generated by turbines or related infrastructure may induce avoidance behaviour.

It is likely that any installation at Campbell River, which encompasses an area of frequent boat traffic, would require federal permitting under the Navigable Waters Protection Act. It is also possible that the project would require a HADD, though this would need to be determined through an aquatic impact assessment. In either case a review under CEAA would be triggered and the project would be subject to a federal screening environment assessment once the complete design is determined. There is some precedent for stream-lining the regulatory processes if the installation is small, temporary and not grid connected. For more on the regulatory process and more detail on the possible CEAA triggers see Section 2.2 of Appendix E.

7. ASSESSMENT OF TURBINE TECHNOLOGIES

7.1. INTRODUCTION

The power potential of the ocean tides has been known for many centuries. Remains of a tidal mill (analogous to a water mill on a river) dating from the 8th century AD has recently been found in the UK but there is no doubt that tide mills were used throughout Europe and Asia since before recorded history.

The energy at any place in a tidal system is made up of a combination of potential energy associated with the height (head) of the tide and kinetic energy associated with flow speed. The total energy in the system cannot exceed the sum of the potential and kinetic energy minus losses such as bottom friction. Seymour Narrows is a good example of this process at work. The head difference (potential) between Johnstone Strait and Discovery Passage drives the exceptionally strong currents in Seymour Narrows and, in the future, flows through Canoe Pass for the tidal demonstration between Maude and Quadra Islands.

Tidal developments fall into two broad categories 1) Barrages or dams that principally exploit the tides' potential energy and 2) In-stream turbine farms that principally exploit the tides' kinetic energy or flow speed. Tidal barrages are similar in concept to conventional hydro dams with low head turbines (e.g La Rance Estuary France, Annapolis Royal, Nova Scotia). In-stream tidal turbines are conceptually similar to wind turbines but the depth of flow is limited compared to a wind turbine which have the whole atmosphere, but the power fluid (water) is 800 times as dense as air.

Barrages are limited to places where the tidal range is high (e.g. Bay of Fundy). However, in-stream tidal developments can be considered in any place where tidal currents exceed about 2 m/s. High currents can be created by flow constrictions (narrowing), tidal phasing (tide higher at one side of a tidal narrows creating current flow) and flow acceleration around a headland.

In recent years environmental and public concerns related to the long-term impacts and costs of hydro dams has constrained the development of tidal barrage systems, and encouraged the design of in-stream tidal turbines. In the last 10 years more than 80 individual company's in Canada, USA, Europe, Australia and elsewhere, have been set-up to research, design and develop in-stream tidal turbines. In Canada there are 6 or 7 companies actively engaged to in-stream tidal turbine research.

The Discovery Island's area of British Columbia has some of the most vigorous tidal flows in the world making the region one of the most attractive sites anywhere for in-stream tidal energy developments. Section 7.2 below provides a classification for in-stream tidal turbines and section 7.3. provides a listing of in-stream tidal device developers (& web sites) and the types of tidal devices under development.

7.2. IN-STREAM TIDAL TURBINE TECHNOLOGIES

In-steam tidal energy extraction devices can be divided into three broad technology categories:

- **Axial Flow Turbines**
- **Cross-Flow Turbines**
- **Oscillating Devices and other concepts**

7.2.1 Axial Flow Turbines

Axial flow turbines are conceptually similar to underwater wind turbines. The axis of the turbine is always horizontal and orientated in the direction of the current flow. This is the most common type of turbine being developed for tidal current energy extraction. Unlike wind turbines, a small number of axial flow designs have the rotor enclosed within a duct (e.g. Clean Current Turbines, Vancouver, B.C.) which accelerates the tidal flow through the turbine and increases power production. However, the largest number of turbines in this class are un-ducted (e.g. Marine Current Turbines, UK).

The axial turbine support structure can be floating, fixed (e.g. Pile) or gravity based. However, in most cases for large turbines, a gravity base has been selected to reduce interference with marine traffic

All the turbines (each approx. 1 MW) selected for the Bay of Fundy Minas Passage tidal demonstration project are axial flow turbines, two are ducted and two are un-ducted and all employ a gravity base support structure.

7.2.2 Cross-Flow Turbines

Cross-flow turbines are the second most important class of tidal energy device. These devices have turbine aerofoil blades mounted around the periphery of a rotor with their axes parallel to a central drive shaft. Rotor blades are orientated at right angles to the current flow but the central drive shaft can be horizontal or vertical. The early stage development of these cross-flow devices all had vertical drive shafts allowing the generator to be located above water for easy maintenance (e.g. BlueEnergy, New Energy). Recent developments of these turbines have been moving towards a horizontal driveshaft which allows the turbine unit to be either mounted on a floating structure, fixed (turbine fence) or on the seabed (e.g. Mavi, New Energy, ORPC).

The cross flow turbine support structure can be floating or on a sea-bed mounted gravity base. At the present time the majority of cross-flow unit designs are un-ducted. However the efficiency improvements of using a duct may foster development of more cross-flow turbines with an integrated duct. (e.g Mavi and Blue Energy).

Cross-flow turbines are also called Gorlov turbines which have helical blades and Darrius turbines which have straight or curved aerofoil blades. The rotors used by New Energy, Blue Energy and Mavi are also called Davis Turbines after the pioneering design and testing work done by Barry Davis at National Research Council (Canada) and field trials done 30 years ago.

7.2.3 Oscillating Devices and other concepts

Oscillating tidal devices have been developed and field tested in UK. The recent Pulse Tidal device currently being tested on the Humber Estuary (UK) has two large aerofoils attached to a large cranking mechanism (much like a steam engine) which transfers mechanical power to the surface for power generation and testing. In its final form this device will be fully submerged with power cabled to shore, with the two aerofoils providing counteracting forces which reduces the requirement for a large bottom support structure. The developers claim that this device can be installed in much shallower water than competing axial or cross-flow turbines. These oscillating devices are an interesting concept but only time will tell whether other developer will take up the idea.

In Australia, BioPower Systems have been developing a tidal stream device which uses an oscillating fin analogous to a fish fin. The concept has been developed in design and lab testing but as far as is known no device has been field tested. Another interesting concept which uses vortex induced vibrations in tidal flows is being developed in the USA (Vortex Hydro Energy).

Water Wheels have been have been used to harness tidal energy in tidal mills for centuries. Two companies are exploring this concept one in Canada (Water Wall) and one on Denmark (Tideng)

7.3. IN-STREAM TIDAL DEVICE DEVELOPERS

EMEC (European Marine Energy Centre, Scotland UK, http://www.emec.org.uk/tidal_developers.asp) includes a listing, on their web site, of the tidal device developers known to EMEC, their country base and simplified description of the device classification. This list is contributed by the developers themselves and includes companies that do not develop tidal devices or are at such early stage of development (e.g. just an idea, no theoretical basis) that it is not useful or informative to have them listed.

Triton have edited & corrected this list and added more accurate description of the device classification/design and the probable stage of their development based on a detailed review of the developers web sites. In this process the listing has been reduced from more than 80 developers to less than 50 companies that can be considered “serious contenders” in the tidal device field either currently or perhaps in the next 5 to 8 years.

The probable stage of development has been defined by a number classification as follows:

- 1. Theoretical
- 2. Design
- 3. Laboratory Testing
- 4. Field Testing
- 5. Demonstration
- 6. Commercial

Only two tidal device developers can be considered near commercial as of this date. New Energy Corp. (Canada) and Torcardo BV (Netherlands). Even Torcardo is questionable as a commercial turbine as the company only seems to supply the turbine itself not the support structure. New Energy Corp do indeed supply small floating “off-the-shelf” turbines which have been in small rivers or dam sites both in Canada and overseas.

Approximately 9 developers have reached the demonstration stage including Alstom/Clean Current(France/Canada) , Hammerfest Strom (Norway), Hydra (Norway), Marine Current Turbines(UK), Verdant Power (USA/Canada), ORPC (USA) and Pulse Tidal(UK). Marine Current Turbines were the first company to install a demonstration stage tidal device, followed closely by Clean Current Turbines at Race Rocks (B.C., Canada)

Table 7.1 below shows a world-wide listing of in-stream tidal developers and their device details

COMPANY	TECHNOLOGY	COUNTRY BASE	STAGE OF DEVELOPMENT	DEVICE TYPE	ROTOR AXIS	SUPPORT STRUCTURE	DUCTING
Cetus Energy	Cetus Turbine	Australia	3	Axial	Horizontal	Floating	No Ducting
Clean Current Power Systems	Clean Current Tidal Turbine	Canada	5	Axial	Horizontal	Gravity Base	Ducted
Alstom Hydro	Clean Current Tidal Turbine	France	5	Axial	Horizontal	Gravity Base	Ducted
Hydro-Gen	Hydro-gen	France	4	Axial	Horizontal	Floating	No Ducting
Voith Hydro	Hytide	Germany	4	Axial	Horizontal	Gravity Base	No Ducting
OpenHydro	Open Centre Turbine	Ireland	4	Axial	Horizontal	Gravity Base	Ducted
Tocardo BV	Tocardo Turbines	Netherlands	6	Axial	Horizontal	Gravity Base	No Ducting
Hammerfest Strom	Tidal Stream Turbine	Norway	5	Axial	Horizontal	Gravity Base	No Ducting
Hydra Tidal Energy Technology AS	Morild ©	Norway	5	Axial	Horizontal	Floating	No Ducting
Magallanes Renovables	Magallanes Project	Spain	2	Axial	Horizontal	Floating	No Ducting
Atlantis Resources Corp	AK-1000	UK	4	Axial	Horizontal	Gravity Base	No Ducting
Lunar Energy	Rotech Tidal Turbine	UK	3	Axial	Horizontal	Gravity Base	Ducted
Marine Current Turbines	Seagen, Seaflow	UK	5	Axial	Horizontal	Fixed	No Ducting
Nautricity Ltd	CoRMaT	UK	3	Axial	Horizontal	Moored	No Ducting
Ocean Flow Energy	Evopod	UK	4	Axial	Horizontal	Floating	No Ducting
SMD Hydrovision	TiDEL	UK	3	Axial	Horizontal	Floating	No Ducting
Swanturbines Ltd.	Swan Turbine	UK	4	Axial	Horizontal	Gravity Base	No Ducting
Tidal Energy Ltd	Delta Stream	UK	3	Axial	Horizontal	Gravity Base	No Ducting
Tidal Generation Limited	Deep-gen	UK	4	Axial	Horizontal	Gravity Base	No Ducting
TidalStream	TidalStream Triton Platform	UK	4	Axial	Horizontal	Moored	No Ducting
Aquantis Inc	C-Plane	USA	2	Axial	Horizontal	Moored	No Ducting
Bourne Energy	CurrentStar / TidalStar / OceanStar	USA	2	Axial	Horizontal	Floating	No Ducting
Verdant Power	Various	USA	5	Axial	Horizontal	Fixed	No Ducting
Tidal Energy Pty Ltd	DHV Turbine	Australia	4	Cross-flow	Vertical	Fixed	Ducted
Blue Energy	Blue Energy Ocean Turbine	Canada	3	Cross-flow	Vertical	Floating	Ducted
Mavi Innovations Inc	Mavi Mi2	Canada	3	Cross-flow	Horizontal	Floating	Ducted
New Energy Corp	EnCurrent Vertical Axis Hydro Turbine	Canada	6	Cross-flow	Vertical	Floating	No Ducting
Atlantisstrom	Atlantisstrom	Germany	3	Cross-flow	Horizontal	Moored	No Ducting
Ponte di Archimede	Kobold Turbine / Enermar	Italy	5	Cross-flow	Vertical	Floating	No Ducting
Bluewater	BlueTec	Netherlands	3	Cross-flow	Vertical	Floating	No Ducting
Ecofys	Wave Rotor	Netherlands	4	Cross-flow	Vertical	Floating	No Ducting
Norwegian Ocean Power	The Pulsus Turbine	Norway	2	Cross-flow	Vertical	Gravity Base	No Ducting
Current Power AB	Current Power	Sweden	2	Cross-flow	Vertical	Gravity Base	No Ducting
Aquascientific	Aquascientific Turbine	UK	3	Cross-flow	Horizontal	Moored	No Ducting
Kepler Energy	THAWT	UK	2	Cross-flow	Horizontal	Gravity Base	No Ducting
Neptune Renewable Energy Ltd	Proteus	UK	3	Cross-flow	Vertical	Floating	Ducted
Hydrokinetic Laboratory	HyPEG	USA	2	Cross-flow	Vertical	Gravity Base	No Ducting
Natural Currents	Red Hawk	USA	2	Cross-flow	Vertical	Floating	No Ducting
Ocean Renewable Power Company	OCGen	USA	4	Cross-flow	Horizontal	Gravity Base	No Ducting
Pulse Tidal	Pulse-Stream	UK	5	Hydrofoils		Fixed	

Table 7.1: In-Stream Tidal Developers, Stage of Development & Device Characteristics

At the present time only 5 companies are developing in-stream tidal turbines in Canada. These 5 developers are shown in Table 7.2 below.

COMPANY	TECHNOLOGY	COUNTRY BASE	STAGE OF DEVELOPMENT	DEVICE TYPE	ROTOR AXIS	SUPPORT STRUCTURE	DUCTING
Blue Energy	Blue Energy Ocean Turbine	Canada	3	Cross-flow	Vertical	Floating	Ducted
Clean Current Power Systems	Clean Current Tidal Turbine	Canada	5	Axial	Horizontal	Gravity Base	Ducted
Mavi Innovations Inc	Mavi Mi2	Canada	3	Cross-flow	Horizontal	Floating	Ducted
New Energy Corp	EnCurrent Vertical Axis Hydro Turbine	Canada	6	Cross-flow	Vertical	Floating	No Ducting
Water Wall Turbine	WWTurbine	Canada	2	Water Wheel	Horizontal	Fixed	

Table 7.2: In-stream Tidal Device Developers in Canada, Stage of Development and Device Characteristics

At this feasibility stage of the Campbell River Fishing Pier tidal demonstration project only Canadian companies have been considered as candidates for the primary project sponsors and developers. In general, only Canadian based firms can qualify for Federal and Provincial support in the form of grants and tax credits for research and development. This government support could contribute as much as 50% of the total project cost for a technology demonstration project like that proposed by the City of Campbell River.

As the Campbell River tidal project develops in the future, it may be possible to consider non-Canadian tidal device developers who open up offices in Canada (e.g. Verdant Power). However Canadian Government support will not likely be as generous for these foreign developers because the tidal devices were developed outside Canada.

Blue Energy

Triton attempted to contact Blue Energy by phone and email (Jon Ellison Exec VP) but was unable to leave any messages because mail boxes were full. This may be a temporary situation but as Blue Energy could not be reached to see if they were interested in the Campbell River project they were eliminated from further consideration for the time being.

Clean Current Turbines

Russell Stothers (COO) was contacted at an early stage in the feasibility study to see if his company were interested in contributing to the Tidal Demonstration study. Clean Current have the most advanced axial turbines in Canada and play on the world stage. They were the second company in the world to have an operational demonstration turbine at Race Rocks, SW of Victoria (B.C.). Russell regretted that their turbine was not really suitable for the water depths near the Fishing Pier, but that Clean Current would be very interested to talk to the City of Campbell River when larger scale turbine installations were being planned for deeper waters in Discovery Passage.

Mavi Innovations Inc.

Mavi have been developing the Mi2 Tidal power System, a floating cross-flow turbine rated at 50 kW (@ 3 m/s) designed for installation at energetic tidal flow sites and aimed towards providing green power to remote communities and coastal lodges. The turbine is ducted and was tested at NRC's Institute for Ocean Technology large towing tank at Memorial University in St. John's Newfoundland. CFD modelling of the turbine and floating hull have established the efficiency of the device and the ability of the floating hull and moorings to withstand waves in the order of 2 m (significant). The turbine rotor is now supported on a submerged horizontal drive shaft with the aim of mounting the device or multiple devices on the seabed in the near future.

Mavi (Voytek Klaptocz, Technical Director) has been extremely helpful in providing Triton with details of their turbine designs and discussing the specific metocean constraints (currents and waves) at the Fishing Pier Tidal Demonstration site. Mavi have provided us with a detailed discussion document on their turbine and floating hull concept and indicative costing for the Tidal Demonstration project (see Appendix F.).

New Energy Corp.

New Energy Corp was established in Calgary (AB) in 2003. The company develops and manufactures in-stream floating cross-flow turbines ranging from 5 kW to 250 kW rated capacity (the ENCurrent product line). The knowledge gained from testing of these smaller turbines, at numerous locations in Canada (also Alaska and India), are leading to scaling up of the basic design to turbines rated at 125 kW and 250 kW. New Energy are the technology lead on the Canoe Pass Tidal Commercialization Project which involves installing two 250 kW ENCurrent turbines in the small passage between Maude Island and Quadra Island, near Campbell River. The project is at the final approvals stage.

The ENCurrent turbine design is an un-ducted vertical axis cross-flow turbine with the generator mounted above water. New Energy were the first company in the world (and still maybe the only company) to manufacture in-stream turbines for commercial sale. All of the ENCurrent devices to-date have been installed in sheltered river or dam tailrace locations. Though New Energy does not yet provide a product suited to an exposed marine environment, it is not thought likely that there are insurmountable technical reasons why New Energy's present turbine offerings could not be upgraded for the task, once the required design work and testing have been completed.

Clayton Bear, New Energy CEO and CTO was contacted by phone and in person to discuss the Campbell River Tidal Demonstration Project. New Energy are very keen to work with the City on this project but the company staff are currently very busy on other projects across Canada and were not able to provide any new design effort on the specific requirements (wave exposure, mooring) that will be needed at the Campbell River Fishing Pier site. However, Clayton was very informative on the potentials for Government research and development funding and provided information on the “list price” for a standard sheltered water (river) ENCurrent device and floating hull. The data sheet for New Energy's ENC-025L-F4 turbine is provided in Appendix G.

Water Wall Turbine

Water Wall Turbine is a company based in Vancouver (BC) who have been developing a water wheel like device for extracting energy from tidal or river currents. The web site provides limited information on the device but it is presumed that installation in a narrow tidal channel would be the best application. In addition the device has a very large frontal area which would attract large wave loads at the Campbell River site. This technology should be given some consideration during the next stage of the Demonstration Project.

7.4. INDICATIVE COST ESTIMATE

7.4.1 Base Case Indicative Cost Estimate (Permanent Installation close to Fishing Pier)

Table 7.3 shows an indicative project cost estimate for a a permanent demonstration tidal turbine located at N3 (51 m east of the Discovery Fishing Pier) with the turbine connected to shore by an underwater power cable. The costs for Item 1 Turbine, Hull & Power System (except the underwater cable) were provided by Mavi Innovations Inc based on the Mi2 system (see Appendix F.). New Energy did provide a cost estimate, but it was not received in time to be properly reviewed by Triton staff for inclusion in this report. The Mavi's 50kW Mi2 turbine and hull designs are capable of working in the long term current and wave conditions at this N3 site, although the average power generated will be less than 3 kW with a maximum power (during peak spring-tide flow) of just over 15 kW (see Table 8.2).

Item	Description	Cost ($CDN)	Sub-Total ($CDN)	% of Total
1	**Turbine, Hull & Power System**			
1.1	Turbine Module	130,000		
1.2	Power Take-off	140,000		
1.3	Floating Hull	160,000		
1.4	Mooring System	80,000		
1.5	Instrumentation	40,000		
1.6	Underwater Cable	50,000		
	Sub-Total		600,000	43.67%
2	**Freight, Assembly & Installation**			
2.1	Freight	25,000		
2.2	Site Assembly	30,000		
2.3	Anchor Installation	15,000		
2.4	Underwater Cable Laying	20,000		
2.5	Install Unit at Location	15,000		
2.6	Fishing Pier Public Info System	30,000		
	Sub-Total		135,000	9.83%
3	**Project Planning & Design**			
3.1	Project Planning & Scheduling	50,000		
3.2	Site Specific Engineering Design	100,000		
	Sub-Total		150,000	10.92%
4	**Environmental Permitting & Public Meetings**			
4.1	Navigable Waters Protection Act	50,000		
4.2	Biological & Other Studies	150,000		
4.3	Public Meetings	30,000		
4.4	Permitting Management	30,000		
	Sub-Total		260,000	18.92%
	TOTAL without Contingency		1,145,000	
	Contingency (20%)		229,000	16.67%

Table 7.3: Indicative Project Cost Estimate for a Permanent Demonstration Tidal Turbine located at N3 (51 m east of Fishing Pier)

The costs for Items 2 (Freight, Assembly & Installation), Item 3 (Project Planning & Design) and Item 4 (Environmental Permitting, & Public Meetings) were estimated by Triton Consultants Ltd. These costs have broad confidence limits because demonstration tidal projects have a very limited history and the planning and regulatory requirements have not yet been established by the Federal or Provincial Governments.

The cost estimates do not include 1) the on-shore cost of interconnection to the BC Hydro grid (say $40K), 2) the cost of on-going environmental studies at the site (could be in excess of $100K) or 3) the cost of monitoring the turbine facility and the performance of the turbine while it is on station (could be $25K/year).

The costs have NOT been reduced to allow for Government subsidies and research grants which may be available to the project developer. These subsides and grants could reduce the total demonstration project cost by between 20% and 30% although these cost reductions are specific to the developer selected for the work.

7.4.2 Option 1 Indicative Cost Estimate (Temporary Installation close to Fishing Pier)

The power production of a turbine installed close to the Fishing Pier at N3 is quite small. There are strong arguments to suggest that connecting this unit to shore by power cable are un-economic (high project cost/ low power production) and that such an installation might not receive strong Public support.

However, one option to reduce the total project cost might be to make the turbine installation only temporary (6 to 12 months) and not to connect the turbine to shore by underwater cable. In this scenario the turbine developer would be able to test out the turbine at an easily accessible location close to shore prior to a permanent installation nearer the centre of Discovery Channel where tidal currents are sufficient to generate useful and more economic power.

The cost savings for this Option 1 compared to the Base Case could be $100K for cable etc in Items 1 and 2 (Turbine and Installation), $50K in Item 3 (Project Planning and Design) and $100K in Item 4 (Environmental/Permitting) for a potential total savings of $300K including a 20% contingency. The total project cost could reduce from $1.4 million for the Base Case shown on Table 7.3 to about $1.1 million for Option 1.

Option 1 is the first phase of a "**Staged Development"** discussed in more detail in Section 8.3.

8. TURBINE PLACEMENT AND EXPECTED OPERATION

Using the currents estimates made in Section 4. and the turbine performance curves (Appendix F. and Appendix G.) the power production from each tidal turbine was calculated. The turbine performance curves give the power output for a given current speed. All that is needed to estimate power output is the the current speed. In this case a time-series of current speeds were obtained from the December 2010 tidal model run. Figures 8.1 and 8.2 show the expected average and maximum power output for the 50kW Mavi Mi2 turbine and the 25kW New Energy EnCurrent turbine at sites N1-N6 (see Section 4.6.). The average power output of each turbine is very close. At the sites further from shore (N5, N6) the Mavi turbine has a slight performance edge, as it is designed for higher current speeds. Table 8.1 below gives the estimated yearly energy output of each turbine based on the average power output of December2010.

Location	New Energy EnCurrent Turbine (kWhr/year)	Mavi Innovations Mi2 Turbine (kWhr/year)
N1	7,250	7,250
N2	57,970	61,380
N3	81,670	87,030
N4	118,600	125,460
N5	163,530	173,030
N6	210,380	222,480

Table 8.1: Estimated yearly output from the Mavi Mi2 turbine and the New Energy EnCurrent turbine.

The maximum power output from each device is very close for sites N1-N5, but the New Energy turbine deviates for N6 as it reaches it maximum rated power of 25kW. There is a significant increase in power production traversing outwards from N1 to N6, but still only a fraction of the turbines' rated power.

The present value of the electricity generated by the turbine may be estimated using the yearly energy output (Table 8.1) and estimated values of discount rate and energy purchase price. Using the Mavi turbine at N6, and assumed discount rate of 8% and energy sale price of $0.06/kWhr, the present value of the electricity generated over the 20 year lifetime of the tidal turbine is $34,000. Obviously this will not cover the capital and maintenance costs of the Project.

The British Columbia Ministry of Energy intends to recommend the introduction of a Feed-in-Tariff Regulation to support British Columbia's clean energy objectives. This regulation would require BC Hydro to establish a feed-in-tariff incentive program (BC Ministry of Energy, 2010). “These policies are designed to encourage the development of renewable generation through energy contracts, guaranteed access to the grid and payment of rates that would enable generators to recover their costs over a reasonable period of time.” (BC Hydro, 2011) The energy purchase prices associated with this program are yet to be announced. Nova Scotia is implementing a similar feed-in-tariff program. The Nova Scotia program is still under consideration, but drafts of the program have set energy purchase prices to be $0.78/kWhr. This would be the largest feed-in-tariff for tidal power in the world if it goes through.

Using $0.78/kWhr in the previous calculation, the present value of the electricity generated over the turbine's lifetime jumps to $448,000. While this is still not be sufficient to cover the total project costs, it goes far towards that goal. However, a more likely estimate of the BC Hydro feed-in-tariff is $0.25/kWhr; at this price the present value of the electricity generated by the turbine is $143,000. Section 9. discusses how the costs of the project might be shared between the City, the turbine developer and other interested parties (Campbell River fabrication industry?). It also outlines a number of funding programs for which this project may be eligible.

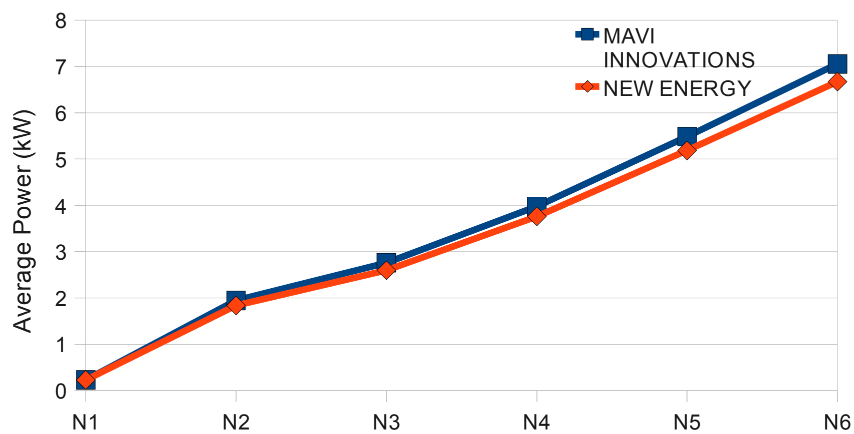

Figure 8.1: Average power produced by the Mavi Innovations' Mi2 Turbine and New Energy's ENC-025L-F4 turbine at sites N1-N6 (December 2010 model run).

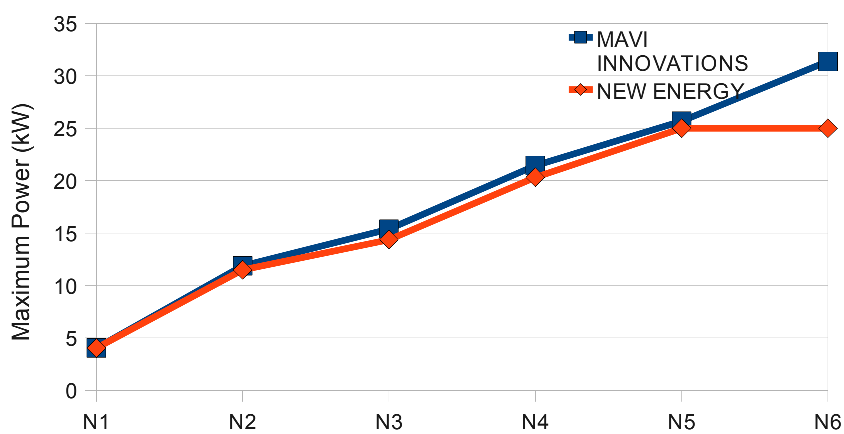

Figure 8.2: Average power produced by the Mavi Innovation's Mi2 Turbine and New Energy's ENC-025L-F4 turbine at sites N1-N6.

8.1. ALTERNATIVE SITES

As directed by the City of Campbell River, this study has focused on the area immediately surrounding the Discovery Fishing Pier. If this constraint can be relaxed there are several locations away from the Pier that are considerably more energetic. Figure 8.3 shows locations N1-N10 over colour contours of kinetic power density and contour lines of depth. A wider view is given in Figure 8.4. Locations N7-N10 are not close to the Pier, but are centred on "hot-spots" of tidal kinetic energy. These sites may be of interest if the City would consider an adjustment or staged approach to the Project.

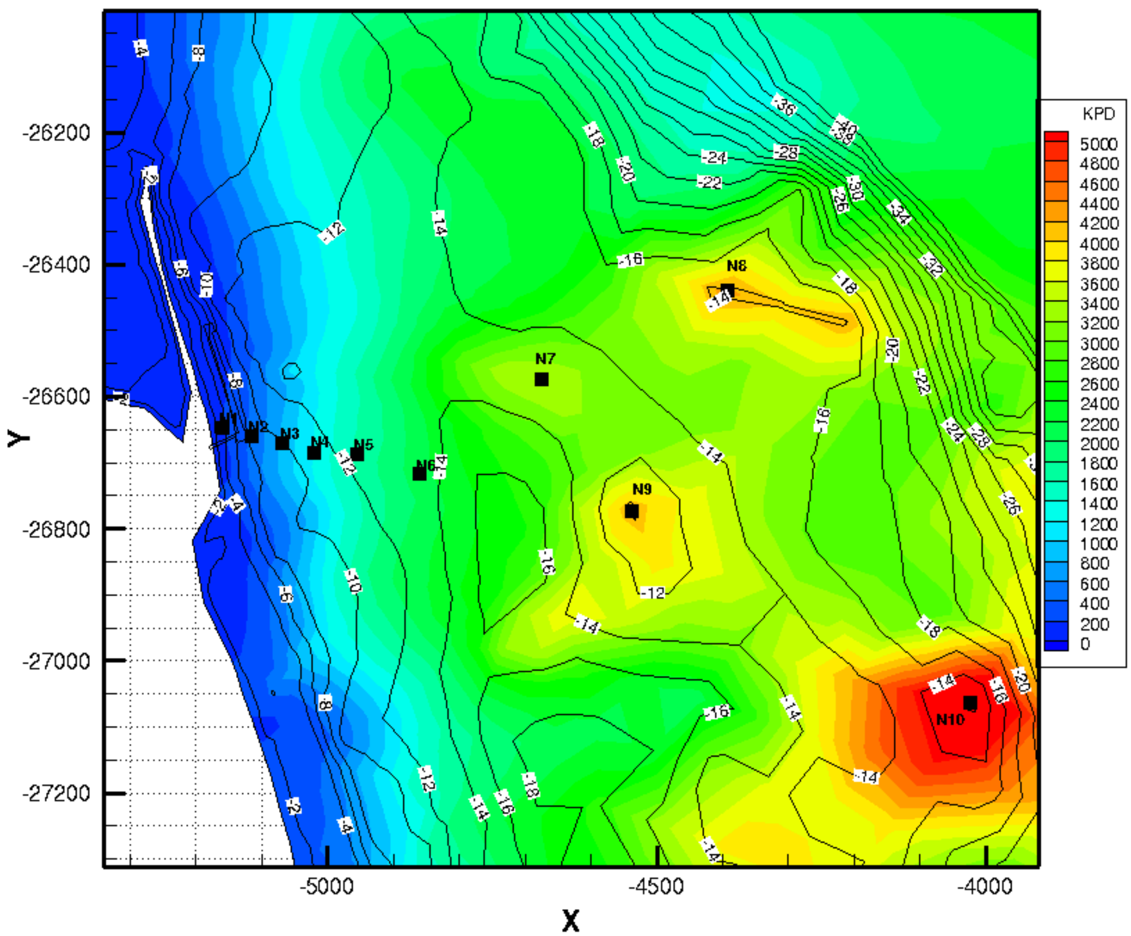

Figure 8.3: Location of sites N1-N10 over colour contours of average kinetic power density and contour lines of depth.

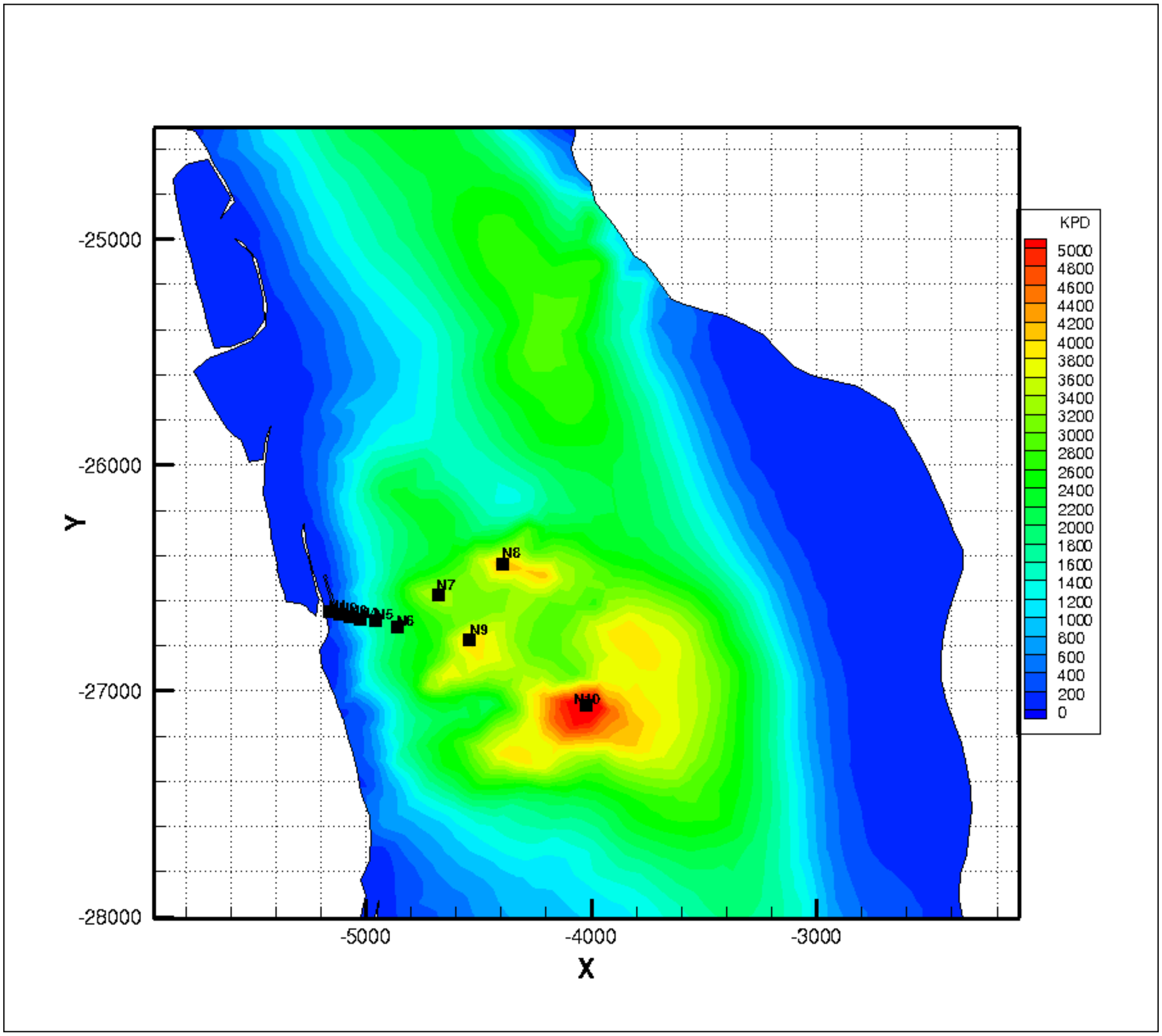

Figure 8.4: Location of sites N1-N10 over colour contours of average kinetic power density (wide view).

8.2. SUMMARY OF SITE CHARACTERISTICS

Summarized in Table 8.2 is the location, wave, current and power statistics at locations N1-N10. Depths are measured to mean sea level, distance to the Pier is measured to the South-East corner of the Pier. Maximum wave heights are based on the 200 year storm described in Section 5.6.3, currents speeds are based on the December 2010 tidal model run described in Section 4.6. Power output is estimated based on the currents of the December 2010 model run and the power curves of the New Energy and Mavi turbines. The present value of the power generated over the lifetime of the turbine is based on an estimated lifetime of 20 years, a discount rate of 8% and an energy purchase price of $0.25/kWhr.

			Wave Height	Current Speed		Power (New Energy Corp)			Power (Mavi Innovations)		
	Depth (m)	Distance to Pier (m)	Max (m)	Mean (m/s)	Max (m/s)	Mean (kW)	Max (kW)	Pres. Val. ($)	Mean (kW)	Max (kW)	Pres. Val. ($)
N1	3.5	42	1.30	0.57	1.25	0.23	4.03	5,000	0.23	4.04	5,000
N2	9.5	27	2.05	0.86	1.84	1.84	11.49	40,000	1.95	11.86	42,000
N3	9.8	51	2.29	0.95	2.01	2.60	14.36	56,000	2.76	15.37	59,000
N4	11.0	101	2.34	1.08	2.23	3.76	20.32	81,000	3.98	21.44	86,000
N5	12.5	166	2.41	1.20	2.40	5.18	25.00	111,000	5.49	25.66	118,000
N6	13	265	2.51	1.30	2.57	6.67	25.00	143,000	7.05	31.37	152,000
N7	12.8	452	2.79	1.52	2.92	9.76	25.00	210,000	11.31	46.87	243,000
N8	13.8	759	2.75	1.63	3.42	10.97	25.00	236,000	13.70	50.00	295,000
N9	9.9	593	2.76	1.62	3.12	10.89	25.00	234,000	13.59	50.00	292,000
N10	11.7	1170	2.81	1.80	3.66	12.67	25.00	273,000	17.88	50.00	384,000

Table 8.2: Summary of location, wave, current and power stats at locations N1-N10. Note that the present value of the power generated over the lifetime of the turbine is based on an estimated lifetime of 20 years, a discount rate of 8% and an energy purchase price of $0.25/kWhr.

Note that at the more energetic sites the New Energy ENC-025L-R4 turbine reaches maximum rated capacity. At these sites a different New Energy turbine (ENC-025-R4), designed for higher current speeds may be more appropriate.

8.3. A STAGED DEVELOPMENT

A staged tidal turbine installation scenario could be considered for the Campbell River Tidal Demonstration Project . Firstly the turbine would be deployed near the Pier around the N3 site (Option 1 Section 7.4.2). At this location the turbine would be well within view of the Pier for viewing by the public. The marginal currents at this location, though not appropriate for economical energy generation, would afford the developer time to work out any bugs with the equipment. As the deployment would be temporary there would be no reason to connect the turbine to shore. Power generated could be dissipated by heating sea-water and all turbine telemetry including water velocity and turbine power could be transmitted wirelessly to a information station on the Pier for consumption by the public. Obtaining permitting is expected to be simplified by the fact that the deployment would be temporary.

This initial stage of the Project would allow all stakeholders time to gain experience working together and with the various regulatory process that must be navigated.

After completing a successful demonstration deployment near the Pier of 6 to 12 months, the turbine would be moved further out into the Passage (N7-10) where currents are more energetic. At these more energetic locations sufficient power could be generated to justify grid connection and sale of the produced power. Observation from the Pier may still be facilitated by proving fixed binoculars for public use. The information station mentioned before would continue to operate and could include several above and under-water video views of the turbine in operation.

The specific placement of the turbine would likely require detailed guidance from Transport Canada to minimize impact on boat and other marine traffic. In the Passage the turbine may still be mounted to a floating structure, or instead mounted to the sea floor. Mounting to the sea-floor would significantly reduce wave loads, but could reduce current speeds. Either way, marker buoys will be required to mark the area as a no-go zone for boats in order to avoid collisions and entanglement of fishing gear.

Cabling costs may also dictate placement of the turbine. At present the costs associated with cable purchase and placement have not been fully assembled. Cable laying services may be provided by Island Tug and Barge, but the cost of the cable itself is unknown. The industry is highly specialized and the purchase of such a small length of cable (compared to large companies like BC Hydro) is unusual. This is complicated by the fact that neither of the considered turbine manufactures have a marine cable specified for their devices. Triton gratefully acknowledges that staff at Mavi Innovations are currently working to clarify this issue.

Because it would be temporary and not grid connected, the initial deployment (Option 1) of the turbine near the Pier is not expected to trigger detailed environmental assessment (as was the case for Clean Currents turbine at Race Rocks). The preliminary environmental assessment provided by Ecofish and summarized in Section 6. covers this area completely. The sites away from the Pier are not covered by the Ecofish study, but as they are of similar depth and geography to those closer to shore it is expected they will have similar biology. Depending on how the Project proceeds a more detailed environmental review may be triggered by the long-term placement of the tidal turbine. The possible permitting process is explored in detail in Section 6.

The economic feasibility of this project for the purpose of power generation is dependant on the feed-in-tariff program currently under development by the BC Ministry of Energy and BC Hydro. The tariff has been estimated at $0.25/kWh for illustrative purposes only. Triton has no inside knowledge of the tariff to be set by BC Hydro and provides this estimate based only on industry indicators and intuition.

9. *A COMMUNITY TIDAL PROJECT*

This study has established that a tidal demonstration project at the Discovery Fishing Pier for the purpose of generating power is not economically feasible. To be more specific, it is not expected that revenues from the sale of electricity over the lifetime of the project will be greater than the sum of the initial and ongoing costs of the Project. Despite its poor economics, there are, however, some very good reasons to continue with this project including: exposure for the City as a location for the development of renewable energy technologies, development of support industries for tidal technologies within Campbell River, education of the public and support for Campbell River's “sustainable community” initiatives.

If the City of Campbell River decided to move forward with this Project, it would undoubtedly benefit from using the “Community Project Model” approach. In a Community Project the risk and the benefits of the project are shared among a number of interested stakeholders, who in this case could include the City, the turbine developer, the local industry (e.g fabrication, marine construction, cable laying), BC Hydro and the general public. In-kind contribution from these stakeholders might make up a significant portion of the costs, and the Project may benefit from funding opportunities, such as Government grants and research funding, that are only available through specific stakeholders. With these considerations in mind the Project might become attractive enough to pursue, but it is difficult to postulate what sort of agreements a community project might yield until detailed discussions between stakeholders are initiated.

It is absolutely critical, at an early stage of the Community Project planning to involve the developer of the selected tidal turbine technology. By selecting a technology developer at the “demonstration” stage the City would likely find that the developer would be willing to provide support for a significant portion of the turbine cost with in-kind contributions. At the demonstration stage the technology developer is motivated by the need to demonstrate the successful operation of their turbine within the marine environment and to establish the commercial viability their technology.

By partnering with the technology developer the City may have to make concessions on some aspects of the Project design including deployment location and duration but will gain potential access to a number of funding opportunities including:

- Scientific Research and Experimental Development (SR&ED) Tax Incentive Program
- The Innovative Clean Energy Fund
- Western Economic Diversification Funding
- Sustainable Development Technology Canada Funding

Triton would be able to assist the City in contacting any of the technology developers discussed in this report to initiate discussions on the opportunities for moving forward with a Community project approach.

It will also be important to involve BC Hydro, at they are the ones that will facilitate connection to the electrical grid and ultimately purchase any power produced.

The are navigational and environmental concerns surrounding this Project that will no-doubt draw considerable attention from Transport Canada, the Department of Fisheries and Oceans and Provincial and Federal environmental regulatory agencies. This report has speculated at the level of scrutiny that each of the proposed turbine placement options would garner and the associated cost. But, given the lack of precedent for tidal demonstration projects these estimates have a high margin of uncertainty. The Community Project planners must therefore work with these permitting agencies from the start and be prepared to share Project information both informally and formally throughout the process to both guide the agencies in their deliberations and move the Project forward as quickly as possible.

10. CONCLUSION

10.1. STUDY RESULTS

The tidal model initially used in Phase 1 of the project was refined and validated to water level and current measurements throughout the Discovery Islands Region. Using the upgraded model the maximum spring tide currents were found to range from 1.25m/s between the Pier and the breakwater to 2.57m/s 300m east of the Pier. Much stronger mid-channel currents neighbouring the Pier reach up to 3.7m/s and are the most energetic in the Discovery Passage south of Seymour Narrows.

A detailed wave model was constructed for this study. The model extends south past Texada Island and north to Seymour Narrows, encompassing all of the Northern Straight of Georgia. The model was calibrated to measurements made at Cape Mudge and Sentry Shoal. Statistical analysis of wind data from the Sisters Islet Weather Station was used to estimate the largest storm expected over a 200 year time period. The 200 year wind conditions were then used to drive the wave model. The results give an expected maximum significant wave height at the Discovery Pier of about 2.3m. Tidal energy devices are usually situated in sheltered areas; 2.3m waves would pose a risk of failure to the proposed turbine installation. It would be important that the selected turbine developer carry out appropriate engineering analysis to ensure that their device could withstand these extreme waves.

A preliminary environmental scoping for this project was completed by Ecofish Research Ltd for the area close to the Pier. While field-work identified several species of interest, this “scoping-level assessment did not find biological features of obvious sensitivity to the Project... it is plausible that its ecological impacts would be minor.” Additional field research would be required following the location and site specific design of the turbine, support structure and auxiliary equipment (cabling, mooring, etc) in order to prepare an Environmental Impact Assessment, a key component of the Development Plan that would be needed to more the Project forward. An official permitting framework for tidal energy installations has yet to be released by the British Columbia government, but a best estimate of the process has been provided based on the related wind farm and run-of-river permitting processes.

A tidal turbine technology assessment was performed to identify the state of the art for small, low energy applications such as the Discovery Fishing Pier. Of the many companies developing tidal energy technologies, only a few are geared towards small installations. Of those only New Energy Corporation has reached the stage of commercialization (and even then only for freshwater installations). A better fit for this this project might be a technology developer looking to demonstrate their technology as the costs and risk of the project might be shared between the developer and the City (e.g Mavi Innovations Inc.)

Base case indicative total project cost was estimated at $1.4 million, including a 20% contingency, but excluding any allowances for subsidies, research grants and in-kind services that may be available to the City of Campbell River and the turbine device developer. In the Base Case development the permanent turbine is located close to the Discovery Fishing Pier (50 m east) for public viewing with power transmitted to shore by underwater cable but not connected to the BC Hydro grid because the cost is not justified by the turbine power output (tidal currents too small). If the turbine is only installed on a temporary basis with no power cable to shore (Option 1) then the indicative total project cost reduces to about $1.1 million.

Even allowing for electricity subsidy programs such as the feed-in-tariff program presently under consideration by the BC Ministry of Energy, locating a turbine near the Discovery Pier for the purpose of generating power is not economically feasible. The tidal currents are not large enough for production of large amounts of electricity. Further from shore (500-1100m), beyond the primary focus of this report, are more energetic sites with maximum current speeds ranging from 2.9-3.7m/s. At these sites a turbine may produce enough electricity to be economically attractive. Unfortunately a site further into Discovery Passage will likely garner more scrutiny from Transport Canada and environmental agencies.

10.2. THE WAY FORWARD

A staged development of the Project might be considered by the City. This scenario is a variation on the initial concept for this project termed the "base case" above. As in the base case, first the turbine would be deployed near the Pier where the turbine would be well within view of the Pier for viewing by the public. The marginal currents at this location, though not appropriate for economical energy generation, would afford the developer time to work out any bugs with the equipment. The low power generated at this location would not justify grid connection. All power generated could be dissipated by heating sea-water. All turbine telemetry including water velocity, turbine power and video of the operating turbine could be transmitted wirelessly to an information station on the Pier to supplement the public education component of the Project. (Option 1)

Upon successful demonstration of the turbine near the Pier, it could be relocated to a more energetic site further into the Passage (Option 1a). At this point grid connecting the device may be justified. The public education component of the project could be retained by situating fixed binoculars on the Pier and/or installing underwater cameras and continuing to operate the interactive information station. The cost for this relocation of the turbine to a more energetic current regime east of the Discovery Fishing Pier cannot be reasonably estimated at this time because of permitting and technical uncertainties. However for initial budgeting purposes a cost of $500K to $750K could be used. The total indicative cost of the Staged Project Development (Option 1 + Option 1a) would be in the order of $1.6M to $1.85M excluding any allowances from subsidies, research grants and in-kind services that may be available to the City of Campbell River and the turbine device developer.

Based on the technical analyses completed for this study, the installation of a demonstration tidal turbine near or adjacent to the Fishing Pier in Discovery Passage for the purpose of generating power is not economically feasible. To be more specific, it is not expected that revenues from the sale of electricity over the lifetime of the project will be greater than the sum of the initial and ongoing costs of the Project. The value of electricity produced, even with a possible British Columbia feed-in-tariff of $0.25 cents/kWhr falls far short of the indicative project costs – only 25% in the best case scenario. Despite its poor economics, there are, however, some very good reasons to continue with this project including: exposure for the City as a location for the development of renewable energy technologies, development of support industries for tidal technologies within Campbell River, education of the public and support for Campbell River's “sustainable community” initiatives.

If the Project were to move forward it would undoubtedly benefit from using the “Community Project Model” approach. In a Community Project the risk and the benefits of the project are shared among a number of interested stakeholders, who in this case could include the City, the turbine developer, the local industry, BC Hydro and the general public. In-kind contribution from these stakeholders might make up a significant portion of the costs and the Project may benefit from funding opportunities, such as Government grants and research funding that are only available through specific stakeholders. Government grants and research funding alone might make up to 50% of the Project cost. With these considerations in mind the Project might become attractive enough to pursue, but it is difficult to postulate what sort of agreements a community project might yield until detailed discussions between stakeholders are initiated.

10.3. LONG-TERM STUDY BENEFITS

This study has shown that there are world-class tidal current energy resources in Discovery Passage and the wider Discovery Islands. Although a small scale tidal demonstration project at the Campbell River Fishing Pier may not be economically feasible for the purpose of generating power, there are numerous higher energy sites within the Discovery Islands including the mid-channel area adjacent the City of Campbell River where economical power generation might be feasible.

The high energy currents in the region combined with the close proximity of the electrical grid will continue to draw the interest of private tidal energy developers. Some of these developers may be interested in sites outside of Campbell River but may still engage companies within the City to provide some of the industrial services required for large-scale tidal projects; others may target sites in the mid-channel region adjacent the City or other nearby sites.

Phase 2 and 3 of this study has yielded, in addition to information and data specific to the Discovery Fishing Pier Site, several valuable transferable assets which may help in the planning of future tidal projects in the Campbell River area. The tidal modelling refined for this study has been validated throughout the Discovery Islands Region and the wave model has been validated in the Northern Straight of Georgia. Based on these modelling studies, Triton could readily provide the City of Campbell River with detailed GIS mapping of tidal current velocities, kinetic energy and maximum wave heights which would serve as a guide for future large scale commercial tidal energy projects and as a planning tool for the City. In particular, these current, tidal energy and wave maps could be an invaluable tool for the City's Economic Development Department as it encourages tidal project developers and manufacturing companies to consider Campbell River as “the place to go” for tidal developments.

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Appendix A.
Comparison of Water Level Harmonics

				Measured Harmonics Amp. (m)					RiCOM Harmonics Amp. (m)					Difference (m)				
ID	Lat	Long		S2	M2	N2	K1	O1	S2	M2	N2	K1	O1	S2	M2	N2	K1	O1
35423	49.9809	-124.7668	LUND'	0.25	1.02	0.21	0.89	0.50	0.25	1.04	0.23	0.90	0.49	0.00	0.02	0.02	0.01	-0.01
35424	50.0358	-124.9216	TWIN ISLETS'	0.26	1.01	0.22	0.90	0.49	0.25	1.05	0.23	0.90	0.49	-0.01	0.03	0.01	0.00	0.00
35425	49.9500	-125.0000	MITTLENATCH ISLAND'	0.25	0.99	0.22	0.86	0.48	0.25	1.03	0.23	0.89	0.49	0.00	0.05	0.01	0.03	0.01
35439	49.9870	-124.6969	OKEOVER INLET'	0.29	1.03	0.21	0.70	0.51	0.24	1.07	0.24	0.89	0.48	-0.05	0.04	0.03	0.19	-0.03
35440	50.2628	-124.9649	REDONDA BAY'	0.23	1.00	0.23	0.88	0.49	0.25	1.05	0.23	0.91	0.49	0.02	0.05	0.00	0.03	0.00
35441	50.1067	-125.0556	WHALETOWN BAY'	0.25	1.01	0.21	0.93	0.51	0.25	1.04	0.23	0.90	0.49	0.00	0.03	0.02	-0.03	-0.02
35442	50.2297	-125.1565	SURGE NARROWS'	0.25	0.98	0.19	0.91	0.48	0.18	0.75	0.16	0.78	0.42	-0.07	-0.23	-0.03	-0.14	-0.05
35443	50.2833	-125.2170	OCTOPUS ISLANDS'	0.17	0.73	0.16	0.78	0.45	0.18	0.72	0.16	0.77	0.42	0.00	-0.01	-0.01	-0.01	-0.03
35444	50.3124	-125.1677	FLORENCE COVE'	0.22	0.98	0.24	0.89	0.50	0.24	1.01	0.23	0.90	0.49	0.02	0.03	-0.02	0.01	-0.01
35445	50.3915	-125.1415	BIG BAY'	0.19	0.75	0.16	0.83	0.47	0.18	0.78	0.17	0.83	0.47	-0.01	0.02	0.01	0.00	0.00
35446	50.9154	-124.8291	WADDINGTON HARBOUR'	0.26	1.01	0.23	0.93	0.51	0.26	1.06	0.24	0.91	0.50	-0.01	0.05	0.01	-0.01	-0.02
35447	50.0420	-125.2466	CAMPBELL RIVER'	0.21	0.83	0.17	0.85	0.50	0.19	0.81	0.18	0.84	0.47	-0.02	-0.02	0.01	-0.01	-0.03
35448	50.0508	-125.2214	QUATHIASKI COVE'	0.20	0.77	0.17	0.81	0.48	0.19	0.82	0.18	0.84	0.47	0.00	0.06	0.01	0.03	-0.01
35449	50.0677	-125.2160	GOWLLAND HARBOUR'	0.16	0.66	0.13	0.77	0.43	0.16	0.70	0.15	0.83	0.46	0.00	0.04	0.02	0.05	0.02
35450	50.0748	-125.2895	DUNCAN BAY'	0.16	0.62	0.14	0.78	0.46	0.16	0.68	0.15	0.82	0.45	0.00	0.06	0.01	0.04	-0.01
35451	50.1206	-125.3772	BLOEDEL'	0.17	0.62	0.13	0.72	0.41	0.16	0.62	0.13	0.77	0.43	-0.01	0.00	0.01	0.05	0.02
35452	50.1412	-125.3559	SEYMOUR NARROWS'	0.30	0.95	0.20	0.69	0.41	0.25	0.77	0.18	0.70	0.41	-0.05	-0.17	-0.03	0.01	-0.01
35453	50.1273	-125.3628	NYMPHE COVE'	0.18	0.88	0.18	0.70	0.43	0.16	0.61	0.13	0.77	0.43	-0.03	-0.27	-0.05	0.07	0.00
35454	50.1652	-125.3689	BROWN BAY'	0.31	0.92	0.19	0.67	0.38	0.28	0.86	0.19	0.67	0.38	-0.03	-0.06	0.00	0.00	0.01
35455	50.3202	-125.2232	OWEN BAY'	0.28	0.85	0.18	0.68	0.38	0.24	0.76	0.17	0.68	0.38	-0.03	-0.09	-0.01	0.01	0.00
35456	50.3993	-125.2021	MERMAID BAY'	0.21	0.72	0.14	0.71	0.40	0.19	0.68	0.15	0.74	0.42	-0.02	-0.04	0.00	0.03	0.02
35457	50.4599	-125.3645	SHOAL BAY'	0.30	0.88	0.19	0.69	0.38	0.27	0.83	0.18	0.65	0.37	-0.03	-0.05	-0.01	-0.04	-0.01
35458	50.4315	-125.4808	CORDERO ISLANDS'	0.29	0.85	0.19	0.63	0.37	0.28	0.84	0.19	0.64	0.37	-0.01	-0.01	0.00	0.01	0.00
35459	50.4136	-125.5007	BLIND CHANNEL'	0.34	0.94	0.19	0.62	0.37	0.31	0.92	0.21	0.62	0.36	-0.03	-0.03	0.02	0.00	0.00
35460	50.5158	-125.6003	SIDNEY BAY'	0.33	1.02	0.17	0.62	0.35	0.34	1.01	0.23	0.59	0.35	0.02	-0.01	0.06	-0.03	-0.01
35461	50.3333	-125.4330	CHATHAM POINT'	0.29	0.90	0.20	0.65	0.37	0.27	0.80	0.18	0.65	0.37	-0.03	-0.10	-0.01	0.00	0.00
35462	50.3922	-125.6104	KNOX BAY'	0.31	0.93	0.18	0.60	0.35	0.30	0.90	0.20	0.62	0.36	0.00	-0.02	0.02	0.02	0.01
35463	50.3994	-125.8652	BILLYGOAT BAY'	0.30	1.00	0.22	0.59	0.35	0.33	0.98	0.22	0.59	0.35	0.03	-0.02	0.01	0.00	0.00
35464	50.3973	-125.9581	KELSEY BAY'	0.39	1.16	0.24	0.56	0.33	0.38	1.13	0.25	0.57	0.34	-0.01	-0.03	0.01	0.01	0.01
35465	50.4500	-125.9830	YORKE ISLAND'	0.39	1.17	0.26	0.56	0.32	0.38	1.14	0.26	0.56	0.33	0.00	-0.04	0.00	0.00	0.01

ID	Lat	Long		Measured Harmonic Phase (°) S2	M2	N2	K1	O1	RiCOM Harmonic Phase (°) S2	M2	N2	K1	O1	Difference (°) S2	M2	N2	K1	O1
35423	49.9809	-124.7668	LUND'	62	35	5	288	265	64	35	12	288	265	2	0	7	0	0
35424	50.0358	-124.9216	TWIN ISLETS'	65	35	9	288	264	64	35	13	288	265	-1	0	4	0	1
35425	49.9500	-125.0000	MITTLENATCH ISLAND'	66	35	10	289	268	63	34	11	287	264	-3	-1	2	-3	-4
35439	49.9870	-124.6969	OKEOVER INLET'	71	41	21	304	267	72	41	20	292	268	1	1	-1	-12	1
35440	50.2628	-124.9649	REDONDA BAY'	70	39	12	289	266	65	36	13	288	265	-5	-3	2	-1	0
35441	50.1067	-125.0556	WHALETOWN BAY'	64	35	8	288	266	64	35	12	287	264	0	0	5	-1	-1
35442	50.2297	-125.1565	SURGE NARROWS'	64	35	360	287	268	28	12	348	283	259	-36	-23	-11	-5	-9
35443	50.2833	-125.2170	OCTOPUS ISLANDS'	22	5	342	285	261	24	9	346	283	259	2	4	4	-3	-2
35444	50.3124	-125.1677	FLORENCE COVE'	60	36	13	292	267	65	36	14	288	265	5	0	1	-4	-1
35445	50.3915	-125.1415	BIG BAY'	35	15	346	284	262	36	16	352	285	264	1	1	6	2	1
35446	50.9154	-124.8291	WADDINGTON HARBOUR'	68	38	14	290	266	66	37	14	288	265	-2	-1	1	-2	0
35447	50.0420	-125.2466	CAMPBELL RIVER'	43	20	351	284	263	47	24	1	286	263	4	4	-350	1	0
35448	50.0508	-125.2214	QUATHIASKI COVE'	42	19	351	288	263	49	26	3	286	263	7	7	-348	-3	0
35449	50.0677	-125.2160	GOWLLAND HARBOUR'	37	7	341	284	264	43	22	360	286	262	6	15	19	2	-1
35450	50.0748	-125.2895	DUNCAN BAY'	26	9	340	287	265	38	18	356	286	262	12	9	17	-2	-3
35451	50.1206	-125.3772	BLOEDEL'	11	348	331	284	260	12	358	335	282	258	1	10	5	-2	-1
35452	50.1412	-125.3559	SEYMOUR NARROWS'	340	320	291	272	255	341	326	296	275	254	1	6	6	3	0
35453	50.1273	-125.3628	NYMPHE COVE'	9	347	288	282	260	14	360	338	282	259	5	13	50	0	-1
35454	50.1652	-125.3689	BROWN BAY'	333	316	287	275	259	333	316	288	272	251	1	0	1	-2	-8
35455	50.3202	-125.2232	OWEN BAY'	340	320	291	273	251	338	323	297	275	252	-1	3	6	2	1
35456	50.3993	-125.2021	MERMAID BAY'	359	339	310	280	260	357	345	320	279	258	-2	6	11	-1	-2
35457	50.4599	-125.3645	SHOAL BAY'	330	308	286	272	251	327	308	283	272	251	-3	0	-2	0	1
35458	50.4315	-125.4808	CORDERO ISLANDS'	335	305	285	270	252	322	302	278	271	251	-13	-3	-7	1	-1
35459	50.4136	-125.5007	BLIND CHANNEL'	322	299	283	268	249	319	298	272	268	249	-3	-1	-10	0	0
35460	50.5158	-125.6003	SIDNEY BAY'	311	285	263	268	244	309	285	261	266	246	-2	0	-2	-3	3
35461	50.3333	-125.4330	CHATHAM POINT'	327	305	276	271	249	327	308	283	273	251	0	3	7	2	2
35462	50.3922	-125.6104	KNOX BAY'	314	291	266	267	241	317	295	270	269	248	3	4	5	1	8
35463	50.3994	-125.8652	BILLYGOAT BAY'	309	283	257	266	250	306	281	257	266	247	-3	-2	1	-1	-3
35464	50.3973	-125.9581	KELSEY BAY'	305	276	248	262	242	301	274	251	261	243	-5	-1	3	-1	1
35465	50.4500	-125.9830	YORKE ISLAND'	301	272	248	260	241	299	272	248	260	242	-2	0	0	0	1

Appendix B.
Comparison of Discovery Pier current surveys and model results

May 13, Survey on flood-to-slack tide

Figure B.1 below shows a current survey made during the end of the flood when the tide was nearing slack (April 13, 20:00UTC). Measurements started to the south of the Pier and continued northward, then the area in between the Pier and the breakwater was surveyed. Note the missing portion of track at the south end of the Pier where measurements failed to be recorded.

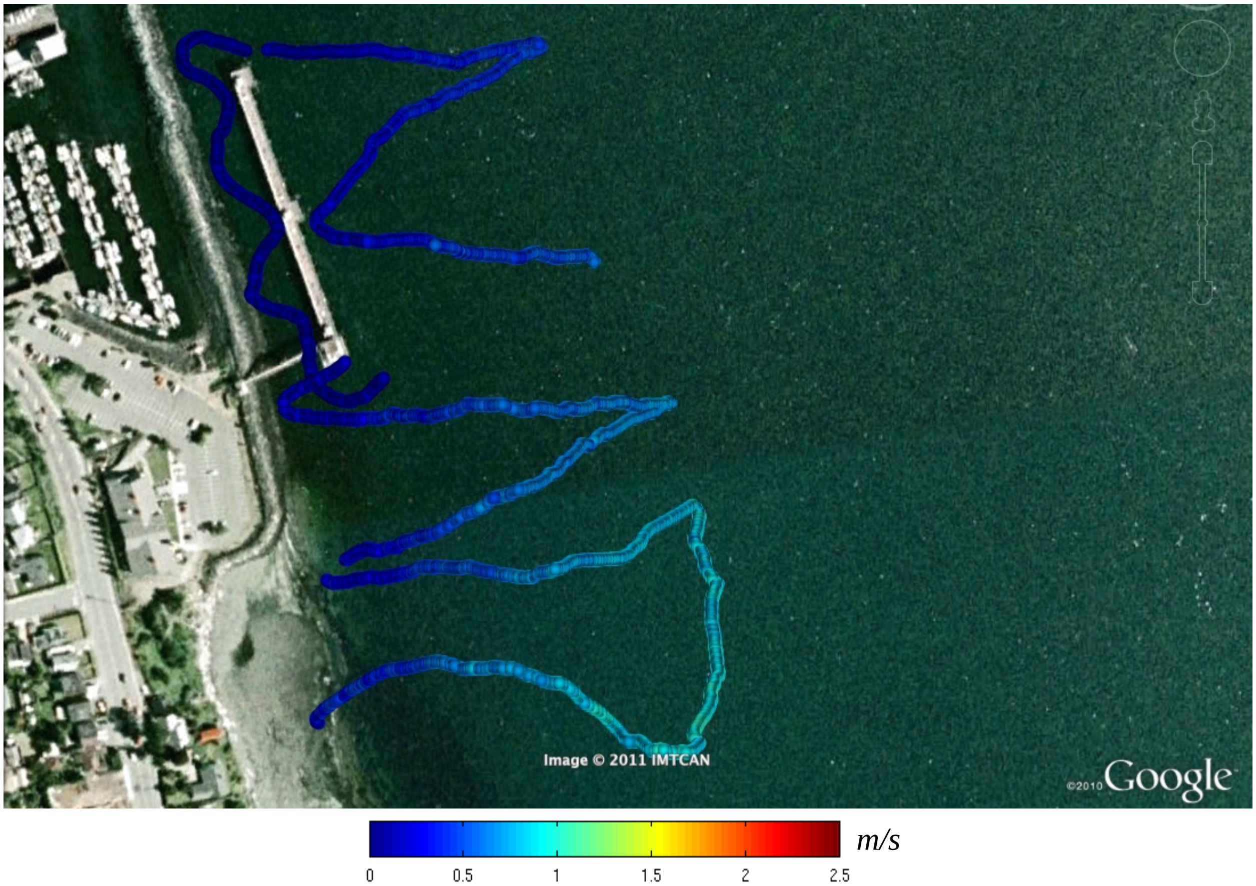


Figure B.1: Current velocity survey at slack tide April 13, 20:00UTC. Coloured dots indicate depth averaged current speed.

Figure B.2 shows a time series comparison of the eastward (u) and northward (v) components of the measured and modelled current velocity for the slack tide current survey of April 13, 20:00UTC (see Figure B.1). The model tends to overestimate the magnitude of the northward component of the velocity vector and underestimate the magnitude of the eastward component by a small margin. In general the model shows excellent skill in estimating the current velocity

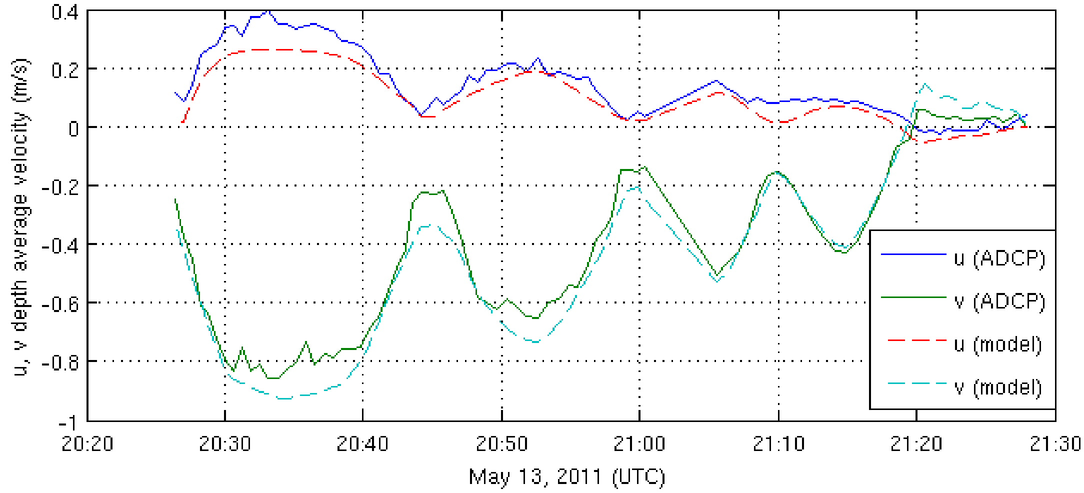


Figure B.2: Time-series plot of measured and modelled u and v current velocity components for the survey of April 13, 20:00UTC.

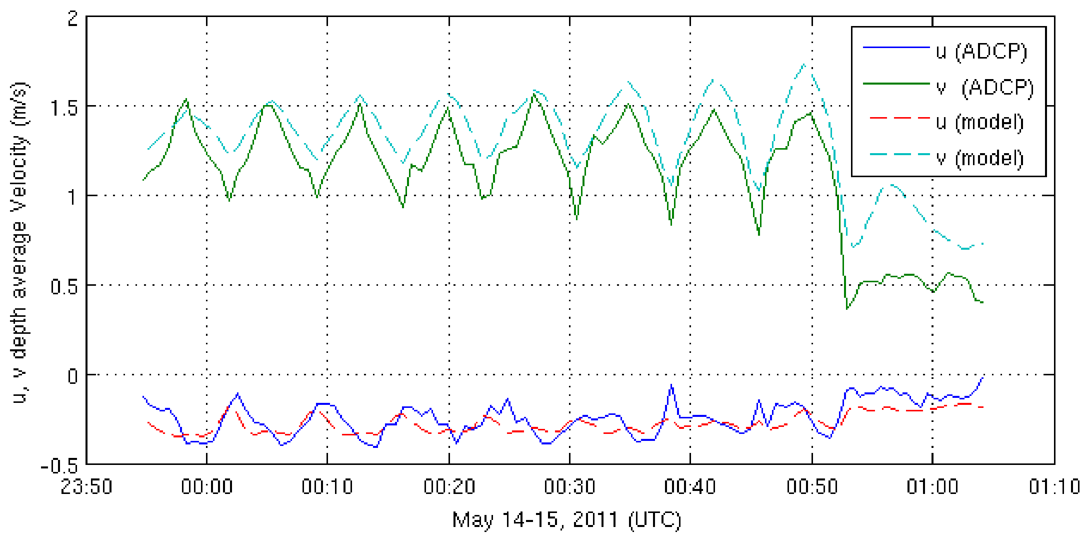
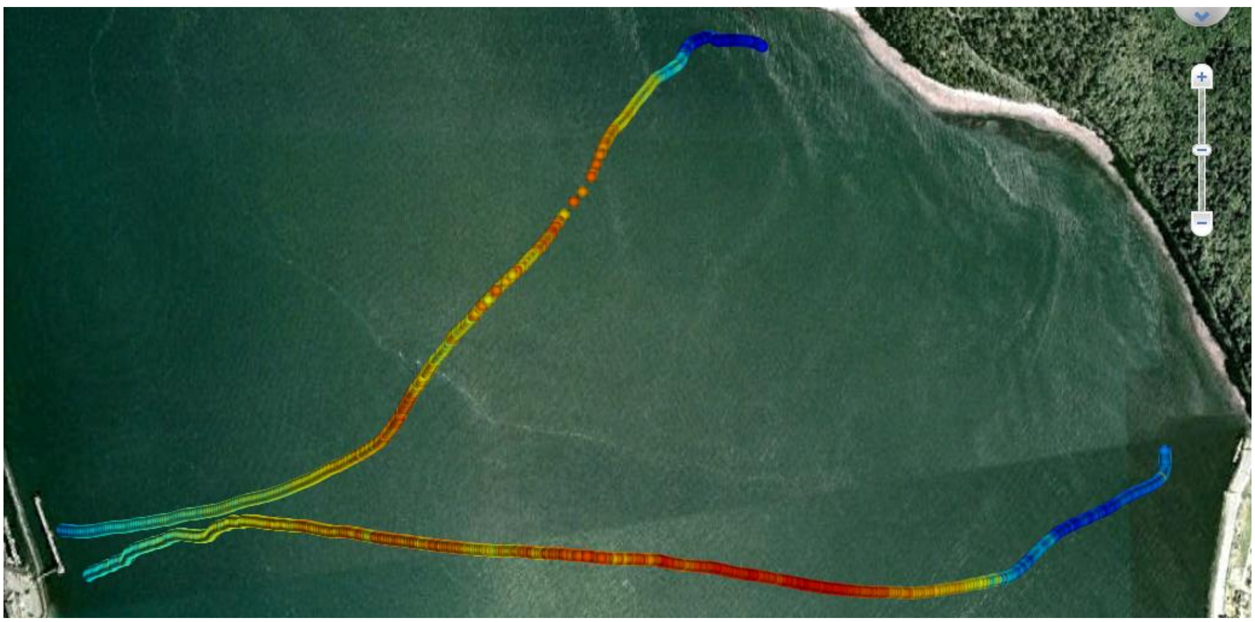


Figure B.3: Time-series plot of measured and modelled u and v current velocity components for the survey of April 15, 00:00UTC.

May 14, Transect of Discovery Passage

Figure B.4 shows a current speed transect of Discovery Passage conducted May 14, 2011 19:00UTC on the flood tide. Note that no measurements were taken between approximately 19:53 and 20:10 as the boat was motored up the coast on the east side of Discovery Passage. As expected, current speeds increase substantially in the centre of the Passage and peak in the deepest portion of the Passage. Figure B.6 shows the water depth of the transect. A very large eddy forms on the east side of the Passage close to Quadra Island. To those taking measurements the eddy was plainly visible as variations in water surface texture. Accompanying the eddy were large boils where sub-surface waters were forced upwards. The eddy is well reproduced in the model.

Figure B.5 shows a time series comparison of the eastward (u) and northward (v) components of the measured and modelled current velocity during the transect. Note that the Teledyne River Ray ADCP used to perform the current measurements is capable of profiling only the top 40m of the water column. Where the water depth was greater than 40m, the measurements only capture the faster moving upper portion of the water column. It is only where water depth is greater than 40m that the modelled current velocity deviates significantly from the measured value, otherwise the model reproduces the current velocity with good skill.



m/s

Figure B.4: Satellite image of Discovery Passage transect with indicators of current speed. Discovery Passage current velocity transect April 14, 19:00UTC. Coloured dots indicate depth averaged current speed.

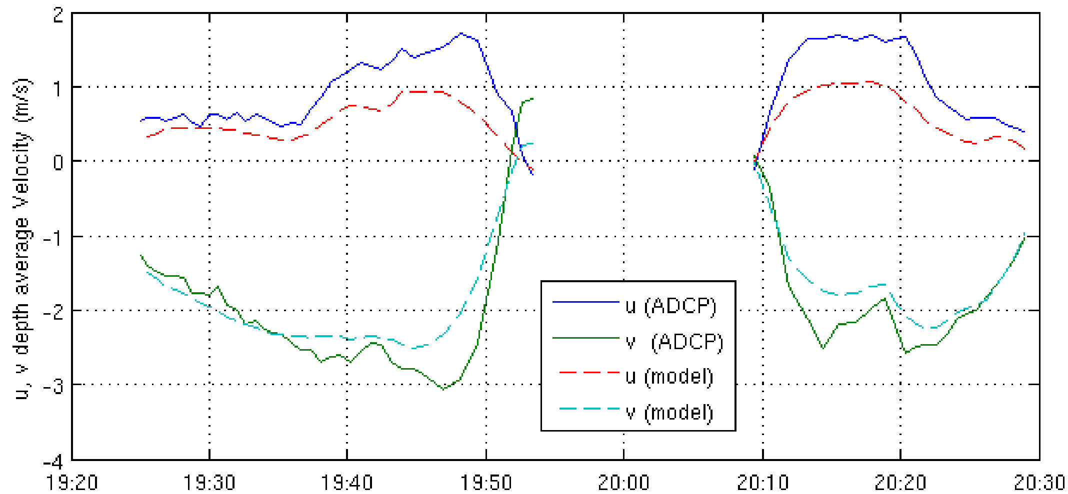


Figure B.5: Comparison of measured and modelled data for Discovery Passage transect of May 14, 2011 19:00UTC

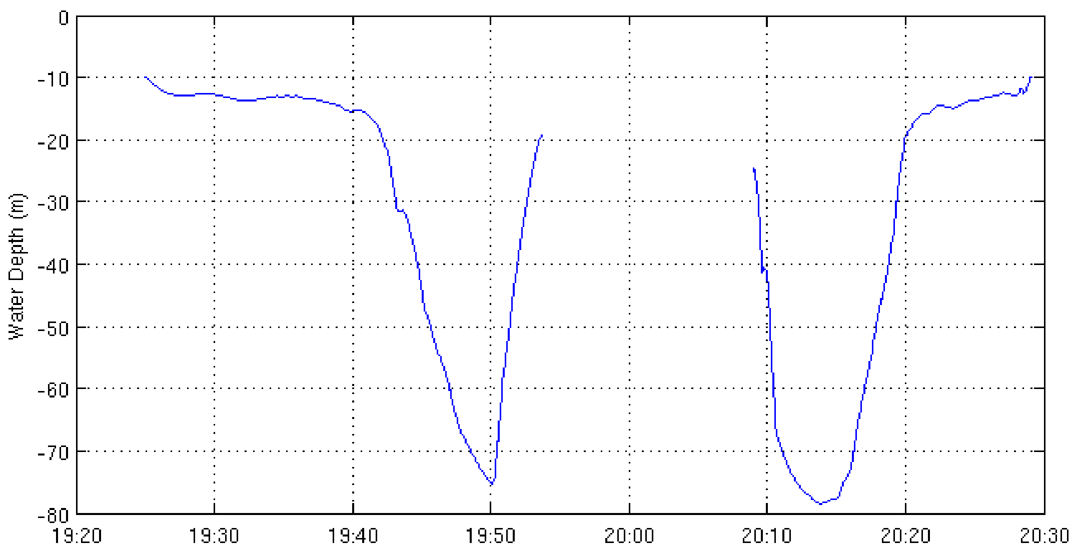


Figure B.6: Water depth during the May 14, 2011 19:00UTC transect of Discovery Passage.

Appendix C.
Current profiles at moored ADCP measurements near Discovery Pier

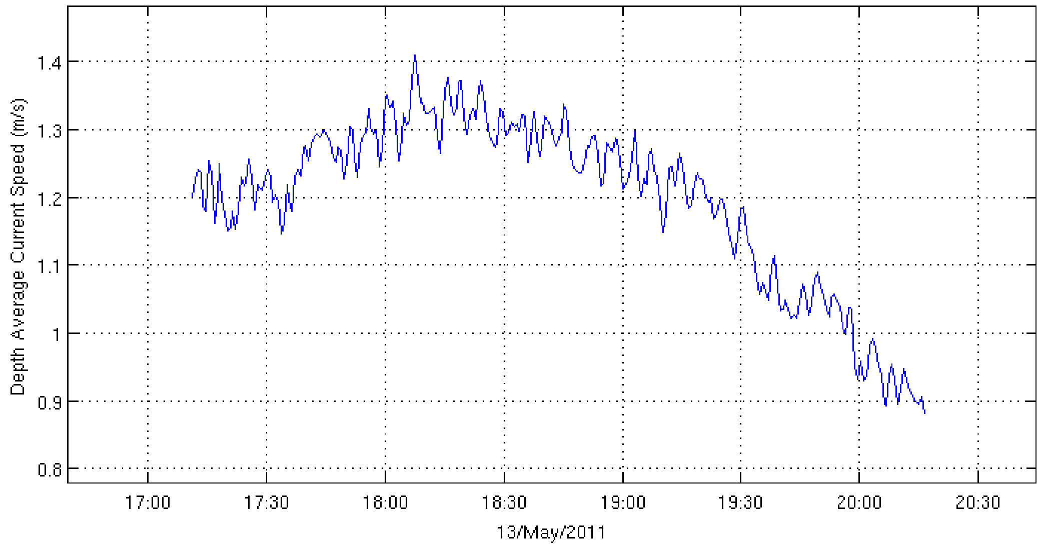


Figure C.1: Depth averaged current speed during flood May 13, 2011 (UTC).

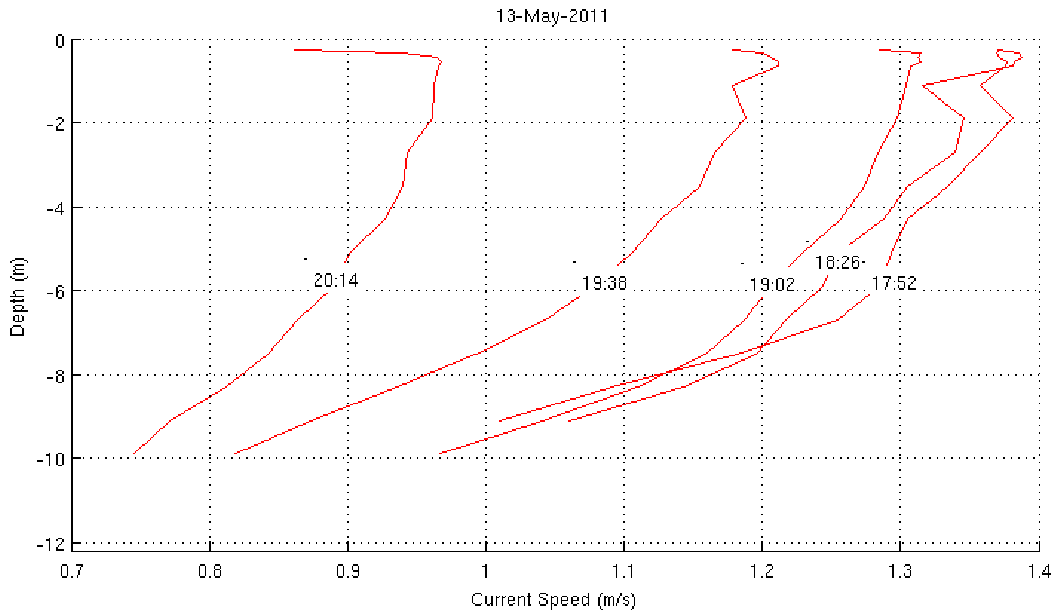


Figure C.2: Selected current profiles on flood tide May 13, 2011 (UTC).

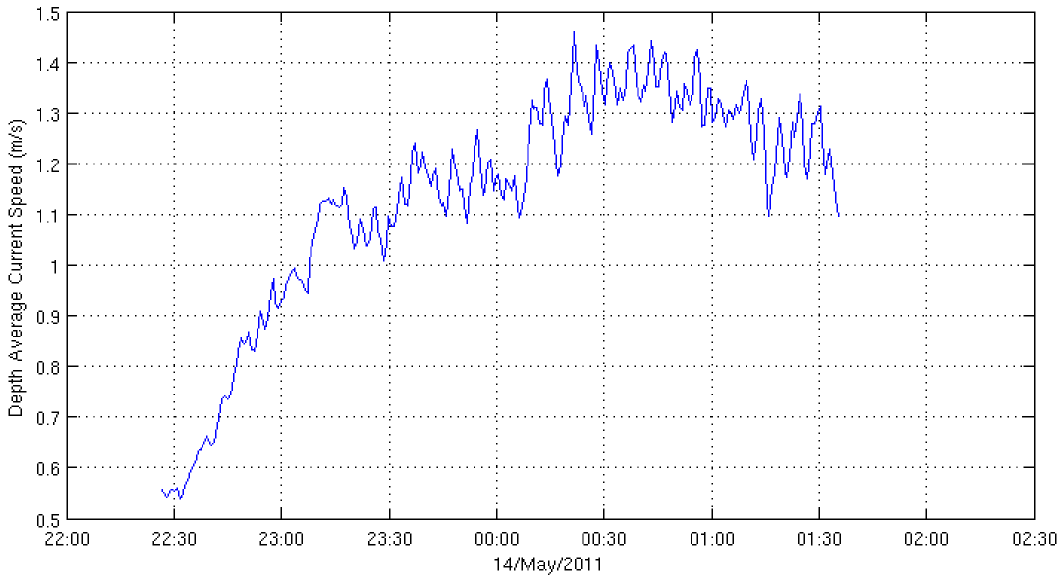


Figure C.3: Depth average current speed during ebb tide May 13-14, 2011 (UTC).

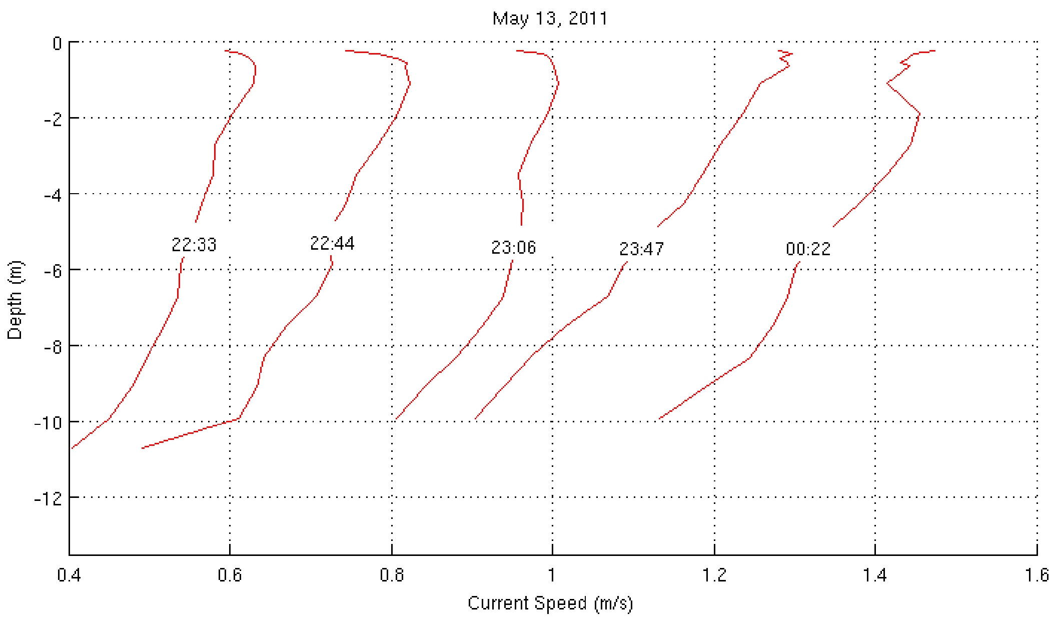


Figure C.4: Selected current profiles on ebb tide May 13-14, 2011 (UTC).

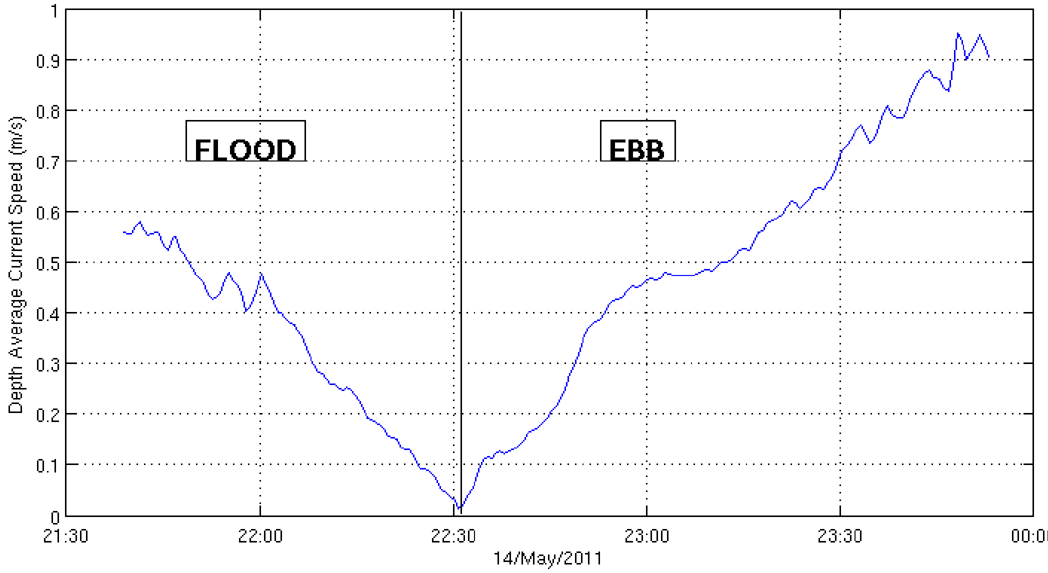


Figure C.5: Depth averaged current speed during slack tide (transition from flood to ebb) May 14, 2011 (UTC).

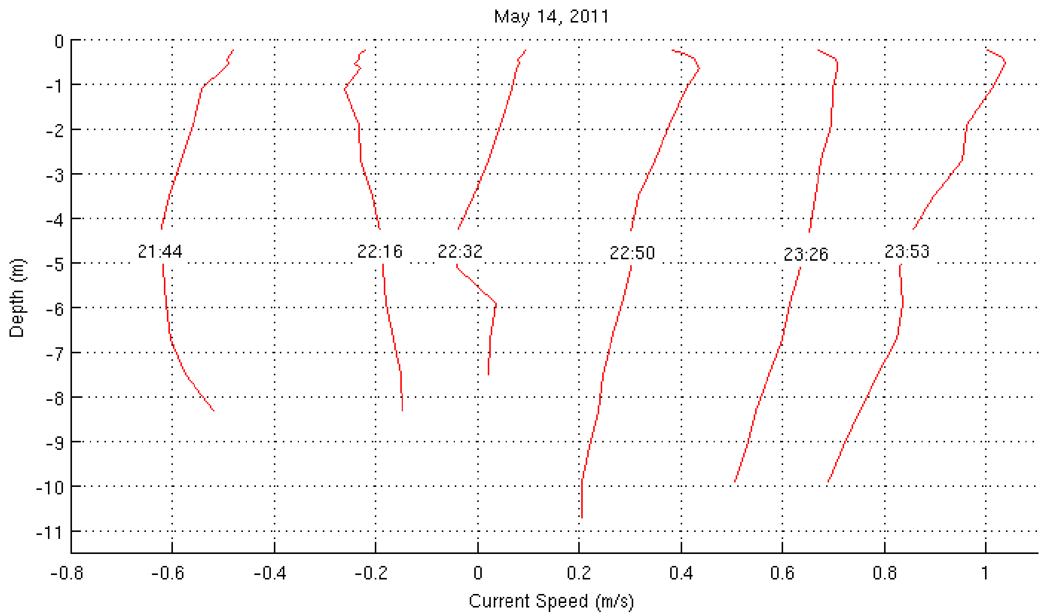


Figure C.6: Selected current profiles on slack tide May 14, 2011 (UTC). Here the current speed has been signed so that negative values correspond to the flood tide and positive values the ebb tide.

Appendix D.
Wave Model Calibration and Verification

October 1997 was selected as a validation period for the wave model. During this month data from the Cape Mudge Wave Rider buoy is available and quality assessment has shown the Sentry Shoal wave data to be reasonable during this period. The 2 minute average wind data (sampled every hour) available for this time period was approximated as hourly average in order to facilitate its use with the SWAN wave model. This approximation will tend to over estimate wind speeds by a small margin. The wind speed and direction data over the calibration period is given in Figure D.1.

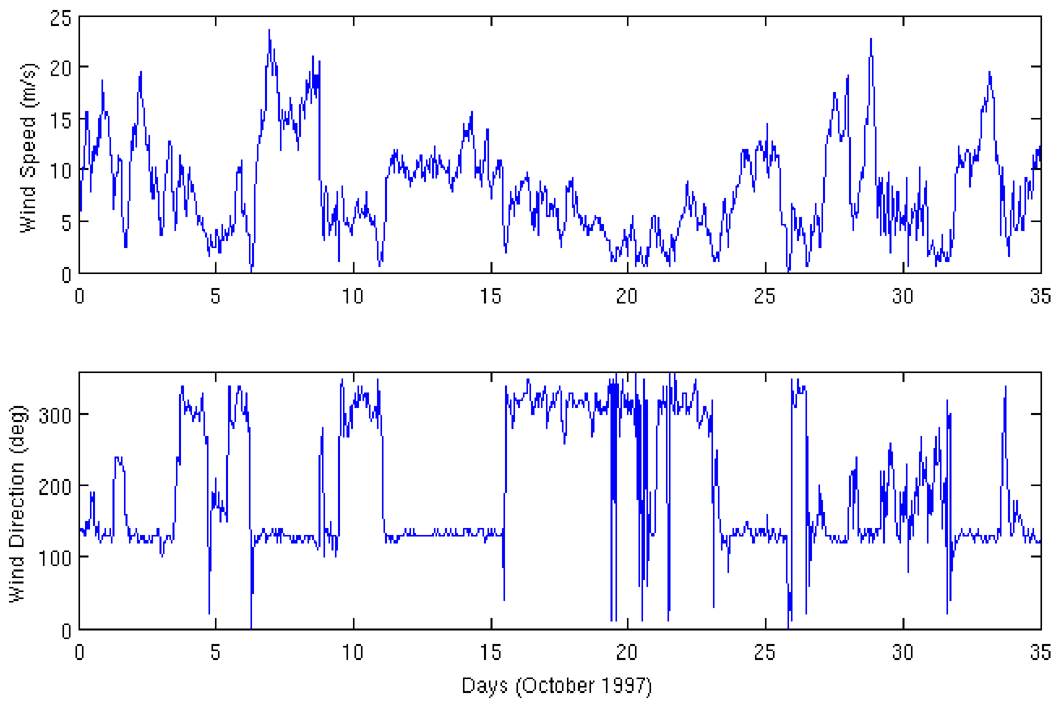


Figure D.1: Wind speed and direction during October 1997

SWAN optionally allows for wave calculations to be made using a number of different formations of the governing physics (e.g. wind generation of waves, wave breaking and bottom friction). In most cases these formulations are based on both analytical and empirical methods. As a consequence of being based in part on empirical methods, some formulations of the governing physics are more appropriate in certain situations. The default formulations in SWAN are tuned to perform well in situations where open-ocean waves are propagating from deep water towards an exposed shoreline. The presently considered case is markedly different; locally generated waves are propagating through shallow water and encountering a number of geographic obstacles which do no necessarily terminate the wave group.

During development of this model Triton experimented with a number of different formulations of the governing physics. The selected formulation were attained based on many calibration runs.

Version 40.81 of SWAN was used. Model physics parameters were configured as follows:

Table D.1: Physics control parameters used in SWAN model.

Run Mode	*Unstructured, non-stationary (max 20 iterations), 3rd generation*
Wave growth	*Komen 5E-5*
Breaking	*Enabled*
Friction	*Enabled*
Other Parameters	*All other parameters left as default*

A comparison of measurements of wave height and the wave model estimates at the Cape Mudge buoy over a thirty-three day period are given in Figure D.2. Agreement is typically quite good. SWAN tends to over estimate wave height at Sentry Shoal, but estimates at Cape Mudge have little bias.

Given that the Cape Mudge buoy was located within a few 10's of metres to shore the model's skill in estimating waves at this location is quite remarkable. Local bathymetry and depth induced wave breaking play a significant role in wave estimates and typically make it more difficult to make skillful estimates very near shore.

During calm periods the model tends to calculate larger wave heights than were measured. This discrepancy is in part due to the limitations of the measurement equipment. The Wave Rider buoy operates on the assumption that the buoy motion follows the same path as the water particles. This is in general a good assumption except for very calm seas. During calm seas the waves that are present may not be large enough to induce the buoy into motion and may break on the buoy's hull. Though the Sentry Buoy operates on a different principle, similar issues may be experienced.

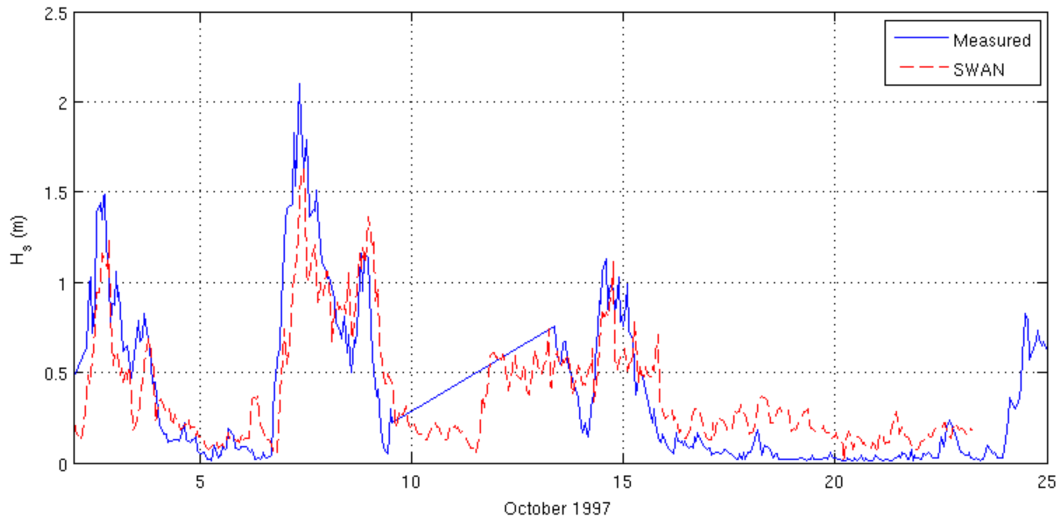


Figure D.2: Significant wave height measurements and SWAN estimates at the Cape Mudge buoy location.

A comparison of the measured and modelled wave height at the Sentry Shoal buoy is given in Figure 5.5. The modelled results compare very well to the measurements, but there is a positive bias of about 26cm. Most importantly for this work, the model is accurately predicting the waves during high seas with some positive bias. It is most important that high seas be modelled correctly, as the purpose of this wave model is to estimate design wave loads at the Discovery Pier.

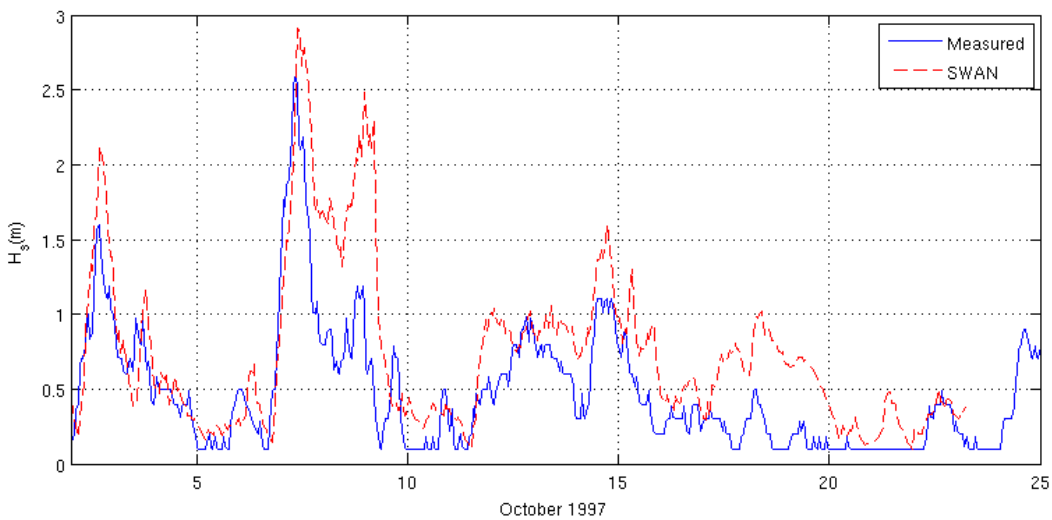


Figure D.3: Significant wave height measurements and SWAN estimates at the Sentry Shoal buoy location.

Figures D.4 and D.5 show the measured and modelled peak wave period at the Mudge buoy and Sentry buoy respectively. In both these figures erroneous wave period measurements are evident. Due to the fetch limitations on Straight of Georgia it is unlikely for waves with peak period larger than 12 seconds to be generated. These erroneous measurements generally occur during calm periods where, as already noted, the buoys measurement techniques may fail. Similarly, in the model low frequency energy due to numerical error may dominate the wave spectrum during calm periods and cause erroneous Tp estimates.

If the erroneous measurements and estimates are eliminated the modelled data compares quite well at the Mudge Buoy. The Sentry buoy has intermittent Tp measurements at predominately twice the the trending Tp. It is postulated that these measurements represent a sub-harmonic of the trending Tp, but it is unclear if these measurements are indicative of the wave environment or an artifact of the wave measurement method.

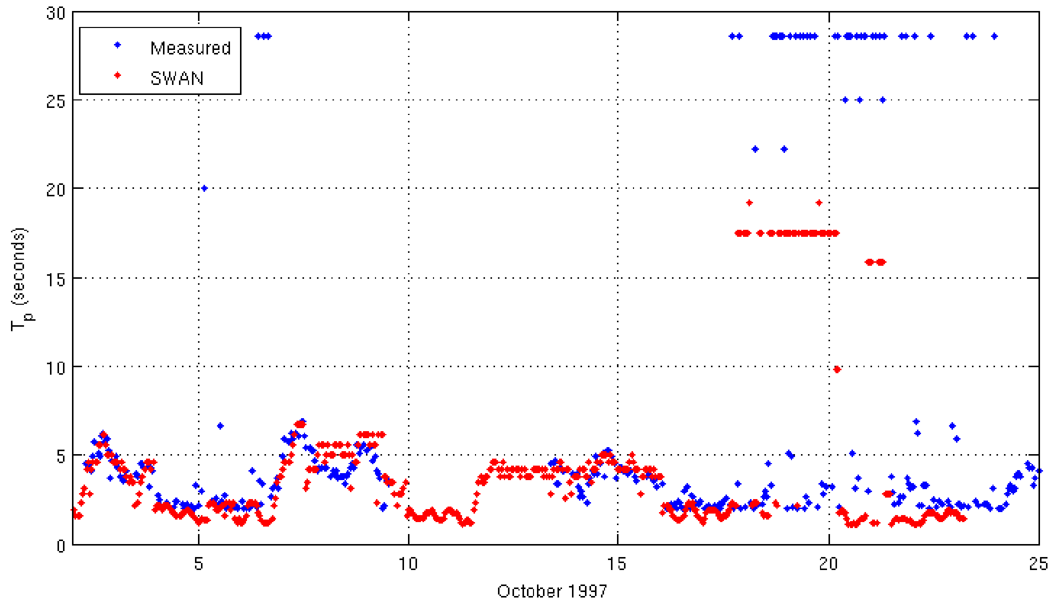


Figure D.4: Measured and modelled peak wave period at the Cape Mudge Wave buoy.

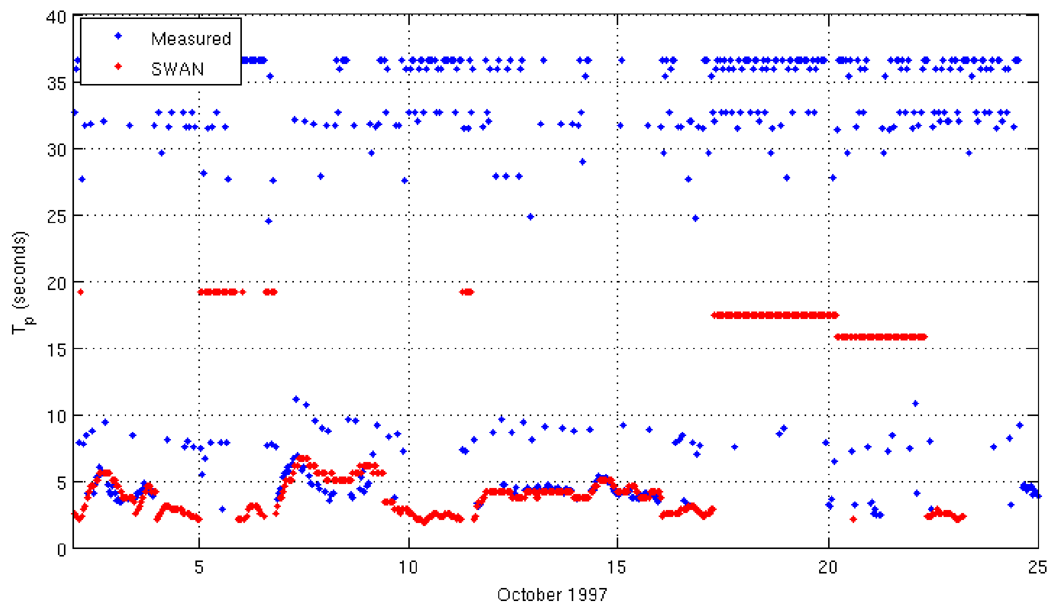


Figure D.5: Measured and modelled peak wave period at the Sentry Shoal Wave buoy.

Quantitative comparison of the measured and modelled wave data is given in Table D.2. *Mean measurement* is the mean measured value (in some cases with outliers removed), *bias* is the systematic offset between the modelled and measured value, *RMS error* is the root-mean-square difference between the modelled and measured value, *scatter index* is RMS error divided by the mean measured value, *correlation coefficient* is a quantitative measure of the correlation between the measured and modelled data (1 indicates perfect correlation).

Table D.2: Significant wave height and peak wave period validation statistics at the location of the Cape Mudge and Sentry Shoal wave buoys.

	Mudge Buoy Hs (m)	**Mudge Buoy Tp (sec)**	**Sentry Buoy Hs (m)**	**Sentry Buoy Tp (sec)**
Mean measurement.	0.37	3.46	0.37	5.21
Bias	0.03	-0.21	0.26	-1.29
RMS Error	0.22	1.13	0.32	2.51
Scatter Index	0.58	0.32	0.87	0.48
Correlation Coeff.	0.88	0.70	0.76	-0.49

Modelled significant wave height at the Mudge buoy compares very well to measurements in terms of bias and correlation coefficient. The scatter index is relatively large indicating that though the model on average makes accurate predictions, there is significant scatter around that average. In terms of Tp, the model again performs well at the Mudge buoy. Bias and scatter index are low and correlation is relatively high (it is more difficult to correctly correlate Tp than it is Hs).

Modelled significant wave height at the Sentry buoy compares well to measurements. There is a notable positive bias of 26cm and significant scatter. This positive bias may be a result of approximating the 2 minutes averaged wind data as one hour averaged (effectively overstating wind speed by a small margin). The correlation coefficient is quite high, indicating that though there is significant scatter in the data, on average the model accurately estimates the measured wave height. The measured Tp data from the Sentry Shoal buoy is quite poor and even with neglecting some erroneous portions of the data-set, it still does not compare well to the modelled peak wave period.

Appendix E.
Preliminary Environmental Scoping – Ecofish Research Ltd.

Campbell River Tidal Energy

Preliminary Environmental Scoping

FINAL




Prepared for:

The City of Campbell River
301 St. Ann's Road
Campbell River, BC
V9W 4C7

July 27, 2011

Prepared by:

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Certification:

Certified: stamped version on file

Deborah L. Lacroix, R. P. Bio. No. 2089

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Executive Summary

The City of Campbell River has proposed a small, single turbine, tidal power demonstration project to be located adjacent to the Discover Fishing Pier in downtown Campbell River. This report presents a general discussion of potential environmental effects for tidal power development, provides a description of the current regulatory framework for developing tidal power projects in British Columbia, and provides a preliminary scoping-level environmental review of the proposed tidal project.

Potential environmental effects caused by tidal power development are well described in the literature. These include habitat loss caused by project footprints and habitat disruption caused by construction, installation, and maintenance activities. Potential changes in tidal flow patterns caused by project operation may affect nutrient transport, distribution of fish or invertebrate larva, and productivity by changing sediment resuspension patterns. Marine mammals, diving seabirds, and migratory fishes may be directly affected by collisions, entanglement with equipment, and noise generated by turbines and related infrastructure.

The operational policy for developing ocean energy projects in BC is still under development by the provincial government; however, the regulatory framework for permitting tidal power projects will generally follow the steps outlined in the BC IPP Guidebook. Phases in the provincial regulatory process include an investigative phase, application preparation and submission phase, project referral process and First Nation consultation phase, and a final authorizations phase. Federal screening under CEAA may be required if federal authorizations or permits are required for construction or operation of the proposed project. Construction or operation of tidal power project may require authorization under the Navigable Waters Protection Act, the Canadian Environmental Protection Act, or the Fisheries Act. There is some precedent for streamlining the permitting process by developing the project off of the grid, as in the case of the Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks; however, this would need to be investigated with the applicable regulatory agencies.

A preliminary scoping-level environmental review was conducted for the proposed tidal power project adjacent to the Discover Fishing Pier. This review included data obtained from online databases on shoreline characteristic, on the potential occurrences of species of conservation concern, and from the results of a site visit (May 11, 2011) in which subtidal habitats were described using images collected from an underwater camera. No biological features of obvious sensitivity to the Project were identified. The footprint caused by anchoring systems and subsea cables will result in habitat loss, though the magnitude of this effect cannot be determined prior to having a detailed Project design. Salmonid habitat in near-shore areas may be disrupted during the construction phase of the Project by sedimentation or noise, though any effects would be short-term. Given the small scale of the Project, it is unlikely to change to hydrodynamic flow.

As such the proposed tidal Project is unlikely to adversely affect nutrient subsidies, larval and propagule dispersal, and waste removal for the local marine community, including rearing salmonids. Marine mammals, diving birds, and fish including pacific salmon may be at risk of collisions and entanglement with equipment, and noise generated by turbines or related infrastructure may induce avoidance behaviour.

It is likely that any installation at Campbell River, which encompasses an area of frequent boat traffic, would require federal permitting under the Navigable Waters Protection Act. It is also possible that the project would require a HADD, though this would need to be determined through an aquatic impact assessment. In either case a review under CEAA would be triggered and the project would be subject to a federal screening environment assessment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

The City of Campbell River has proposed a small-scale, single turbine, tidal power demonstration project to be located adjacent to the Discover Fishing Pier in downtown Campbell River. This report presents a general discussion of potential environmental effects expressed in the scientific literature for tidal power development and provides a description of the current regulatory framework for developing tidal power projects in British Columbia (BC).

This report also provides a preliminary scoping-level environmental review of the proposed tidal project, located adjacent to the Discovery Pier. The environmental review includes data obtained from online databases on shoreline characteristics and on the potential occurrences of species of conservation concern, and presents the results of a site visit in which subtidal habitat characteristics within the vicinity of the proposed tidal project were described using images collected from an underwater camera.

2. BACKGROUND REVIEW

Marine renewable energy holds both the potential benefits of reducing CO_2 emissions and mitigating climate change, and the potential costs to marine biodiversity ensuing from altered tidal and wave process and other disturbances (Boehlert and Gill 2010; Shields *et al.* 2011). These trade-offs may scale up in parallel. Large developments producing hundreds of MW will involve arrays of multiple turbines with the capacity to alter hydrodynamic flows over several kilometres or even at regional scales, while single-turbine developments producing only modest levels of electricity are likely to have only localized or minimal impacts (Boehlert and Gill 2010; Shields *et al.* 2011).

2.1. Potential effects of tidal energy projects on the environment

A growing number of publications caution about the potential effects of marine renewable energy projects on ecological communities (Boehlert and Gill 2010; Shields *et al.* 2011). Most of these concerns relate to major development proposals involving arrays of multiple turbines and other large infrastructure; they may not necessarily apply to small scale projects such as the proposed Campbell River Project. A comprehensive discussion of potential environmental effects from tidal power developments is provided in Polagye *et al.* (2010). Here we summarized potential effects from a general perspective; the potential relevance of these issues to the Campbell River Project is discussed in Section 3.3.

2.1.1. Potential Construction Effects

Construction and installation effects are likely temporary, with only the project footprint (turbine, anchors, and subsea cables) resulting in potentially permanent effects. Construction and installation effects can include destruction of habitat caused by placement of structures, disruption of habitat by sedimentation, noise, and increased activity, and potential mortality of sessile organisms and fish (Polagye *et al.* 2010). In addition, anchoring systems physically disturb benthic environments (Boehlert and Gill 2010). Construction can be timed to minimize effects, especially to migratory species of fish, birds, and mammals.

2.1.2. Potential Operational Effects

A set of biological concerns related to tidal energy devices have been associated with changes to hydrodynamic flow (Boehlert and Gill 2010; Shields *et al.* 2011). These concerns include reduced transport of nutrients and food particles by tidal currents, thereby decreasing the energetic and nutrient subsidies that fuel marine ecological communities. These subsidy reductions may directly affect the nutrient supply of basal and lower trophic organisms (e.g. algae and filter feeders), indirectly reducing the prey base of upper-level consumers, such as fish. Reduced tidal flows may also diminish the removal of biological waste products due to reduced flows (Boehlert and Gill 2010; Shields *et al.* 2011).

Many organisms rely on currents to disperse their larvae or propagules, and flow levels are a settlement cue for many kinds of larvae. Human-caused changes to tidal currents, therefore may affect dispersal and settlement patterns for some species (Shields *et al.* 2011). Rockfishes, for instance, produce live young that are dispersed by currents and that eventually settle in kelp communities where they undergo early juvenile development (Love *et al.* 2002); large tidal energy developments, therefore, could potentially alter their settlement and recruitment patterns.

Altered tidal flows may also change sediment resuspension patterns, which may indirectly reduce primary productivity by affecting the light environments available to phytoplankton. Sediment redistribution could also potentially smother sessile organisms that are adapted to hard substrates (Shields *et al.* 2011).

Another set of concerns involves the potential for tidal energy devices to affect marine mammals, diving seabirds, and migratory fishes. These concerns include collisions, entanglement with equipment, and noise generated by turbines and related infrastructure (Boehlert and Gill 2010). Marine mammals in particular may be affected by noise, as they are well-known to avoid areas associated with high levels of acoustic disturbance (Boehlert and Gill 2010). Similarly, crustacean larvae use reef noise as cues for orientation and settling from pelagic into benthic stages, which makes them vulnerable to changes in the acoustic environment (Boehlert and Gill 2010)

Large scale tidal projects, with multiple turbines, may also have the potential to create electro-magnetic fields resulting from electricity transmission. The electro-magnetic fields can potentially affect the ability of electro-magnetic sensitive species to locate prey and navigate (Boehlert and Gill 2010). Although elasmobranchs (sharks and their relatives) are likely to be particularly sensitive to electro-magnetic disturbance (Gill 2005), the combination of acoustic and electro-magnetic disturbances could potentially affect the ability to orient and navigate by migrating cetaceans and salmonids (Boehlert and Gill 2010).

Maintenance activities for tidal turbines are specific to design; however, we can assume that a variety of maintenance activities will be required periodically. Maintenance activities may include surfacing or removing the turbine, removal of fouling organisms, painting structures, repairing or welding damaged equipment, and lubrication of moving parts (Polagye *et al.* 2010). Potential effects will be similar to those during the construction phase; disruption of habitat by sedimentation, noise, and increased activity, and potential disturbance of marine life that may have colonized structures that are removed for maintenance. Maintenance can be timed to minimize effects, especially to migratory species of fish, birds, and mammals.

2.2. Regulatory Framework

2.2.1. Provincial Regulatory Process

Tidal energy is an emerging industry in BC and guidelines for regulating and permitting new projects are still evolving. An operational policy specific to the development on ocean energy projects in BC is still under development by the provincial government and is expected to be released to the public in the fall of 2011 (M. Porter, pers. comm., 2011). In the meantime, direction for permitting tidal power projects will generally follow the steps outlined in the BC IPP Guidebook (ILMB 2008). For projects greater than 50 MW a BC Environmental Assessment is required; however, the proposed Campbell River tidal project is well below this threshold. The steps that are currently required to permit a new tidal power project less than 50 MW are as follows[1]:

1. Investigative Phase: Proponent conducts pre-feasibility studies to determine project viability, assess potential environmental and social constraints and determine application

[1] http://www.agf.gov.bc.ca/clad/tenure_programs/programs/oceanenergy/index.html

http://www.em.gov.bc.ca/SiteCollectionDocuments/Ocean%20Energy%20Policy%20Directive%20June%2007.pdf requirements. The following permits are/may be required to conduct investigative studies[2]:

a. Land Act Section 14a Investigative Permit: This permit, typically issued for 2 years, authorizes initial investigations for determining siting of investigative technical equipment on Crown Land. The permit is issued under the BC Land Act. Upon receipt of the investigative permit application a file will be opened with the provincial government. The cost for an Investigative Permit is $560.

b. License of Occupation: If the proponent intends to place investigative technical equipment on Crown Land then a License of Occupation (LOC) is required in addition to the Investigative Permit. The LOC application must be submitted within 6 months of the commencement date of the investigative permit and will not be approved without a corresponding investigative permit. The cost of an application to temporarily install investigative equipment for data collection for tidal power is $560.

The application will also require a draft preliminary project description that defines technical aspects of the proposed project in sufficient detail to allow technical experts to determine the scope of studies and assessments required to meet legislative requirements. It is often in this phase of the regulatory process that the proponent determines if the project will trigger a federal review under the Canadian Environmental Assessment Act (CEAA) (see Section 2.2.2). It must also be noted that some Crown Land applications require advertising, security deposit, proof of insurance, and letter of consent.

The preliminary environmental scoping presented in Section 3 of this report is an example of an environmental pre-feasibility study. Based on the recommendations provided, it will be at the City of Campbell River's discretion to determine if (a) the project is feasible, (b) the project is not feasible, or (c) additional studies are required to determine feasibility. Additional feasibility studies may include, but are not limited to; social, economic, community, heritage, and technical.

2. Application Preparation and Submission Phase: Proponent prepares an application and notifies the BC Provincial Government (through Front Counter BC) of their intent to develop a project. For tidal power projects the application includes the following items:

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[2] http://www.agf.gov.bc.ca/clad/Documents/LPSB/Forms/app_form.pdf

http://www.agf.gov.bc.ca/clad/tenure_programs/programs/windpower/smp.pdf

a. Land Application Form[3]: A Land Act application will be required. The cost of the application is $3,696. It must also be noted that some Crown Land applications require advertising, security deposit, proof of insurance, and letter of consent.

b. Development Plan: A development plan and environmental impact assessment is required by the regulatory agencies to evaluate and approve the proposed project. The development plan includes the project description, location, and a detailed description of the impacts of all project phases, including the construction, operation, and decommissioning of the project. Information must be thorough and provide regulators with sufficient information to address legislated requirements. Information presented in the development plan must be substantiated through technical studies and conclusions must be based on scientific data and expert opinion. The following information is typical of development plans for Independent Power Production (IPP) projects:

    i. Detailed project description, including all components and phases of the project

    ii. Environmental impact assessment

    iii. Social/Heritage effects assessment

    iv. Information that addresses relevant legislation

    v. Construction plans and construction environmental management plan

    vi. Operational monitoring plan

    vii. Summary report

3. Project Referral Process and First Nation Consultation: Upon receipt of the application, Front Counter BC will forward the applications to applicable local, provincial and/or federal government agencies, First Nations, and third parties for consultation, review and approval. This stage also marks the initiation of a federal CEAA review if this is required (see Section 2.2.2).

4. Authorizations: At this stage provincial and federal agencies will provide tenures, authorizations, and permits. Once all authorizations have been received and permits are

[3] http://www.agf.gov.bc.ca/clad/Documents/LPSB/Forms/app_form.pdf

in place the proponent can commence work, ensuring that any tenure, authorization, or permit conditions are fulfilled.

2.2.2. Federal Regulatory Process and CEAA

The rationale for a project requiring federal screening under CEAA is as follows: Under section 5 of the Canadian Environmental Assessment Act, an environmental assessment is required because, for the purpose of enabling the project to be carried out in whole or in part, federal authorizations or permits are required for construction or operation of the proposed project. Generally, tidal power projects may require authorization under the Navigable Waters Protection Act, the Canadian Environmental Protection Act, or the Fisheries Act:

a. Navigable Waters Protection Act: Any project that is being built in, on, over, under, through or across a navigable waterway requires an approval under the NWPA. This, in turn, would trigger the requirement for an environmental assessment in accordance with CEAA if the work was considered a substantial interference with navigation. In addition, named works defined as a bridge, dam, boom or causeway require an approval under NWPA and trigger the requirement for an assessment in accordance with CEAA.

b. Canadian Environmental Protection Act: Any project that will dispose of substances in waters over which Canada exercises jurisdiction will require permits under Subsection 127(1) of the Canadian Environmental Protection Act. Permits issued under the act would trigger the requirement for an environmental assessment in accordance with CEAA.

c. Fisheries Act: Where adverse effects to fish habitat cannot be avoided through project relocation, redesign or mitigation, habitat compensation options may be required. This will require an authorization for a Harmful Alteration, Disruption or Destruction of Fish Habitat (HADD) under Section 35(2) of the Fisheries Act. If there is the potential for the destruction of fish by any other means than fishing an authorization will be required under Section 32 of the Fisheries Act. Authorizations under the Fisheries Act would trigger the requirement for an environmental assessment in accordance with CEAA.

The provincial and federal governments are working to harmonize the review and approval process of major projects, including tidal power projects. Accordingly, the process for review under CEAA is similar in many ways to the requirements that are required for a provincial development plan and in most cases the information provided to the provincial agencies can be used for the federal process. The additional information required under CEAA will depend on the type of environmental assessment. The CEAA has four types of environmental assessments: (1) screening (including class screening); (2) comprehensive study; (3) mediation; and (4) review panel. A small demonstration tidal project would likely only trigger a screening environmental assessment (see Section 2.2.3). The objective of a screening environmental assessment is to determine if the project is likely to cause significant adverse environmental effects. In addition to the items outline in the provincial Development Plan, the screening report requires assessment of cumulative environmental effects and the effect of the environment on the project.

2.2.3.Regulatory Case Studies

In 2006, a partnership between Encana, Clean Current Power Systems, and Pearson College established the Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks, southern Vancouver Island. As Race Rocks is located in an Ecological Reserve the lead provincial regulator that oversaw permitting and approvals for the project was BC Parks. Federal regulators involved included Fisheries and Oceans Canada and Transport Canada. Permitting was executed as an amendment to Pearson College's existing operations permit from BC Parks which has a mandate to assist in the demonstration of alternative energy technology. The project was exempt from legislative requirements typically applied to IPP developments because the project was not commercial, did not require connection to the grid, and because of its small scale required very little civil works. A review under CEAA was not required by the federal regulators; however, a habitat assessment was completed for the project area and the proponent was required to consult with local First Nations. Transport Canada required that the turbine be set at a depth that allowed a minimum of 5 m clearance below the surface of the water. The permitting and approval process was completed within seven months. Direct support of the project from BC Parks resulted in a condensed regulatory timeframe. The project was permitted to operate as a demonstration project until 2011, at which point the proponent can either remove the turbine or solicit permission to operate it at the site permanently (Sugarman *et al.* 2010).

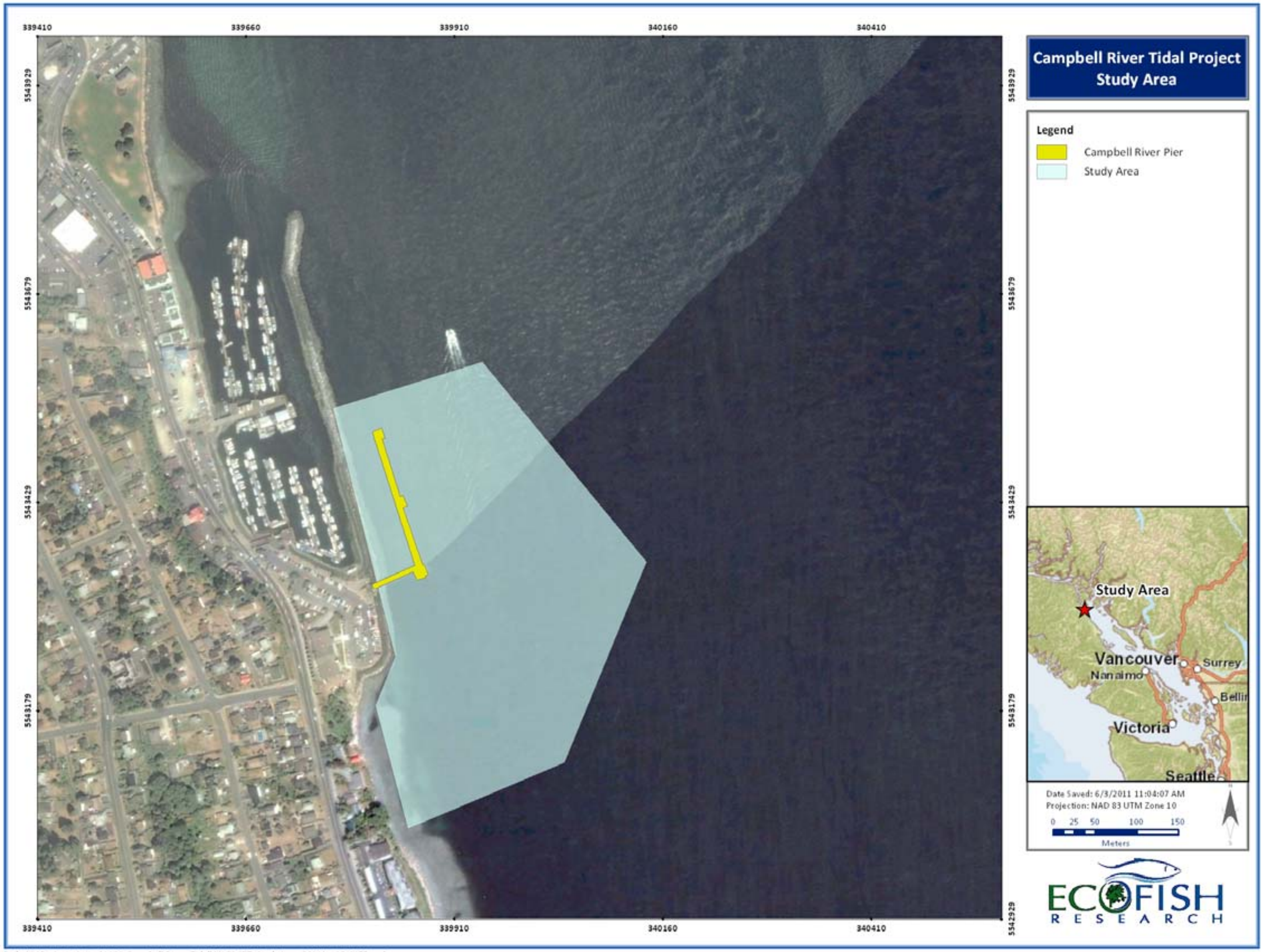
The only precedent for a tidal power project that has undergone a CEAA review in BC is The Canoe Pass Tidal Energy Project at Maud Island, which proposes two 250 kW suspended turbines. This project has triggered a screening under the CEAA with Transport Canada acting as the Federal Environmental Assessment Coordinator (Canadian Environmental Assessment Agency 2010). The Canoe Pass project initiated the CEAA review process in 2008 and is still in the approval and permitting phase. The Canoe Pass precedent, however, provides little guidance for gauging whether the smaller project proposed by the city of Campbell River would trigger a screening under CEAA.

3. CAMPBELL RIVER TIDAL PROJECT PRELIMINARY SCOPING-LEVEL ENVIRONMENTAL REVIEW

The City of Campbell River has proposed a tidal energy project in the vicinity of the Campbell River Fishing Pier. The proposed installation consists of a 25-50 kW floating turbine held by a 4-point anchor system. The study area (Figure 1) is characterized by human-made breakwater structures (i.e. riprap), the fishing pier, an intertidal zone, and subtidal habitats that are gently-sloping and shallow (maximum depth=13 m).

This section documents a preliminary scoping-level environmental review of the proposed development. It includes data obtained from online databases on shoreline characteristics and on the potential occurrences of species of conservation concern, and the results of a site visit in which subtidal habitats were described preliminarily using images collected from an underwater camera.

Figure 1. **The Campbell River Study Tidal Project study area.**

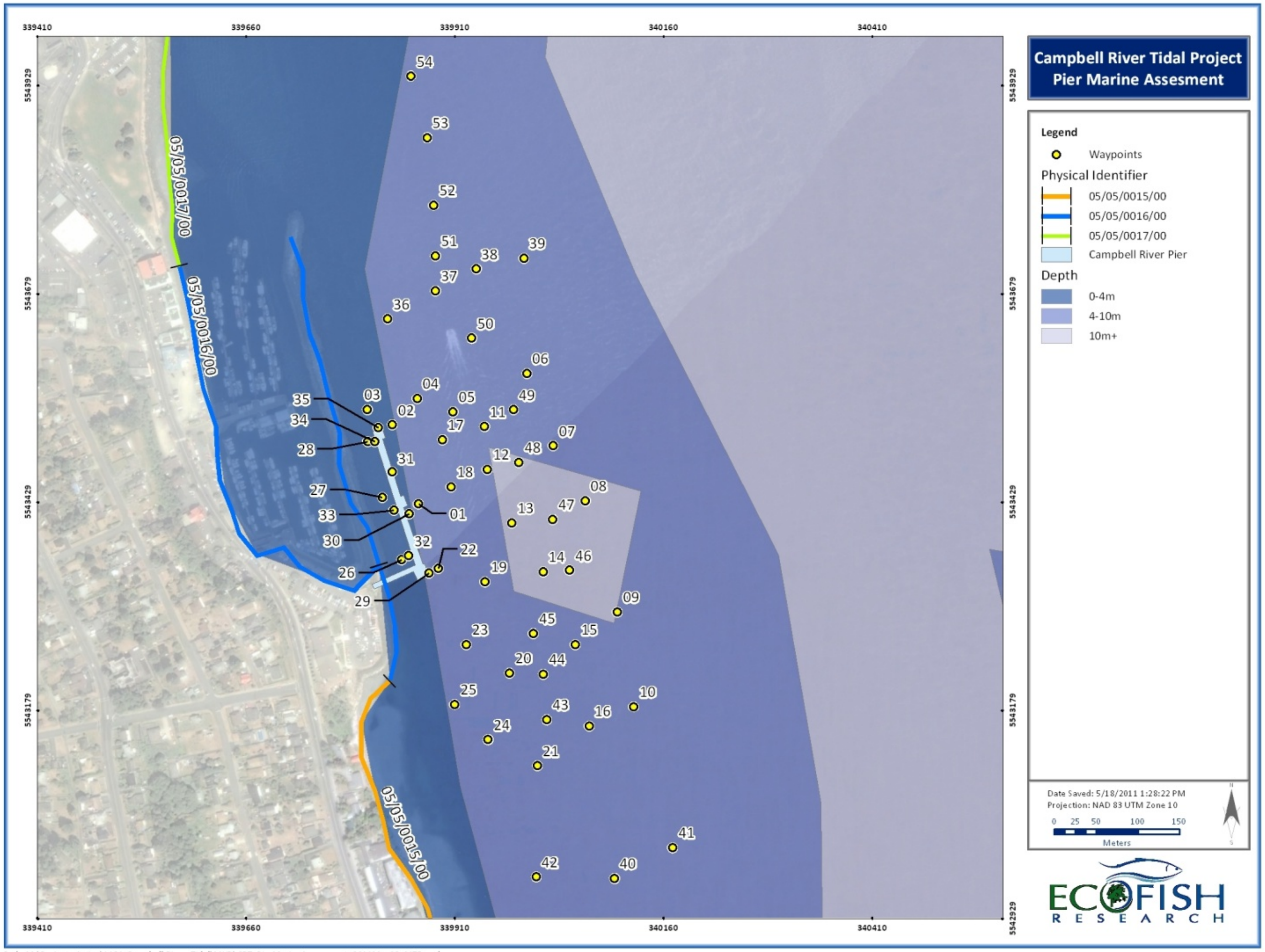


3.1. Methods

Online databases were used to collect biological information on species of conservation concern that may interact with the proposed development and on shoreline characteristics.

Field work was conducted on 11 May, 2011, to describe subtidal habitats within the Project study area (Figure 1). A skiff was used as a platform from which a cable-attached video camera (Seaview model 650) was lowered to record images of benthic habitats and of organisms occupying the benthos or water column. Fifty three points were sampled by holding the skiff as stationary as possible (within the constraints of wind and current), lowering the camera to the bottom on a downrigger, and collecting 40-120 seconds of video imagery at the bottom. At each point, sampling of the water column occurred for 10-30 seconds during the lowering and recovery of the camera. The location of sampling points (Figure 2) was recorded with a handheld GPS (Garmin GPSMAP® 76CSx). Opportunistic wildlife observations were recorded at the surface while conducting video sampling.

Figure 2 **Locations of physical identifiers of the provincial Coastal Resources Information System from which shoreline descriptions were obtained (colour bands), and of GPS waypoints where subtidal habitats were video-sampled (numbers).**



Video analysis was conducted by a single observer who estimated the percent covers of different substrate and seaweed classes on the benthos and searched for images of fish and invertebrates at each sampling point. The percent cover estimates were obtained by examining both video footage and representative still images captured from video. The size of the area sampled at each point, however, is unknown and likely varied according to camera height above the substrate and camera movement due to current and boat drift.

Seaweeds were grouped into height classes but were not identified taxonomically. There are two caveats to these height estimates. First, there was no scale embedded in the video frames and the estimates, therefore, height estimates relied on the observer's prior familiarity with similar habitats as a scientific diver. Second, height estimates were specific to early May, when annual seaweeds are at an early growth stage. Also, video sampling precludes sifting through canopy layers, which may have lead to false negative data for non-canopy seaweeds.

The features for which percent cover was estimated are listed below:

1) Soft substrate: sand or other fine sediments (Figure 3).
2) Pebble and/or shell-covered substrate (Figure 4).
3) Non-canopy seaweeds: height <10 cm (Figure 3).
4) Low canopy bladed kelps: Heights 10-100 cm; includes, but is not limited to *Laminaria* spp. (Figure 5).
5) High canopy bladed kelps: Heights ≥100 cm; includes, but is not limited to, bull kelp (Figure 6).

Figure 3 Soft substrate and non-canopy seaweeds at Waypoint 2, 11 May 2011.

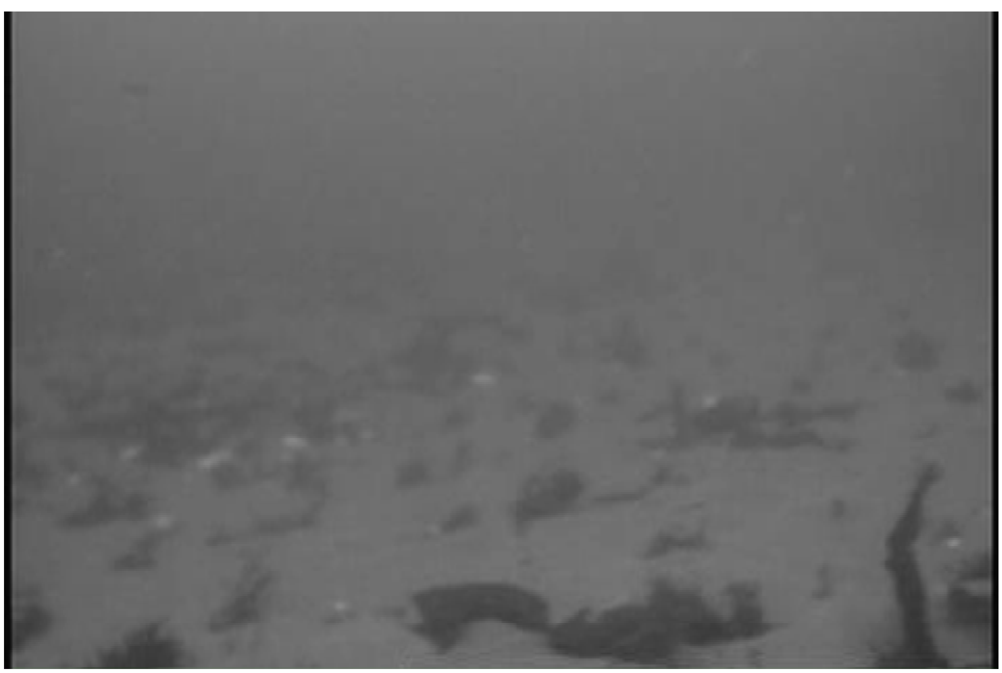


Figure 4 Pebble and/or shell-covered substrate mixed with seaweeds at Waypoint 18, 11 May 2011.

Figure 5 Low canopy bladed kelps at Waypoint 5, 11 May 2011

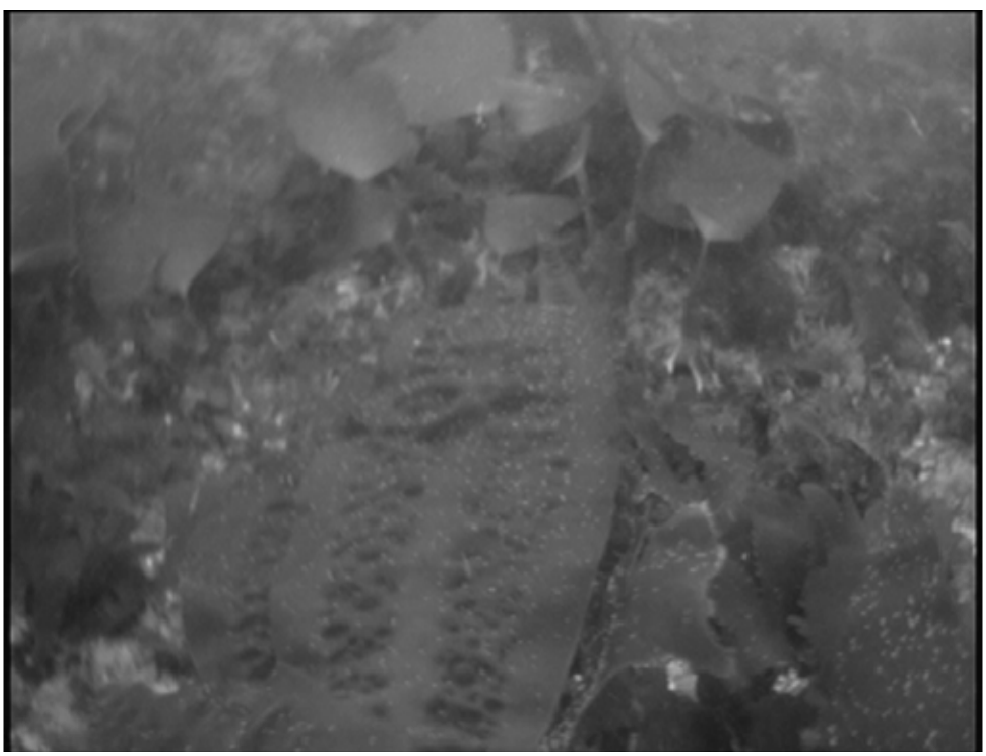
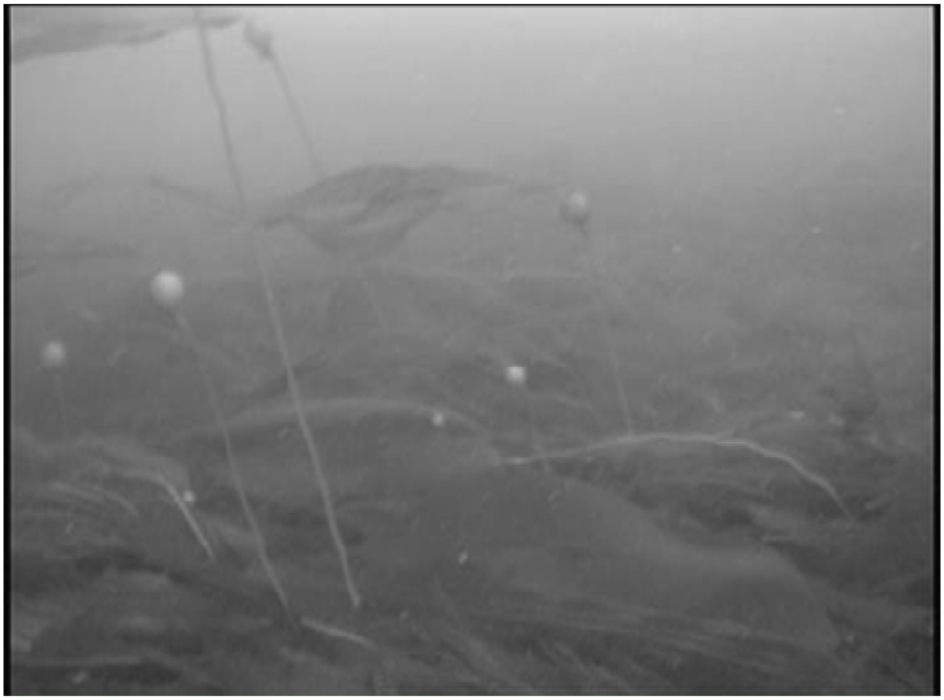
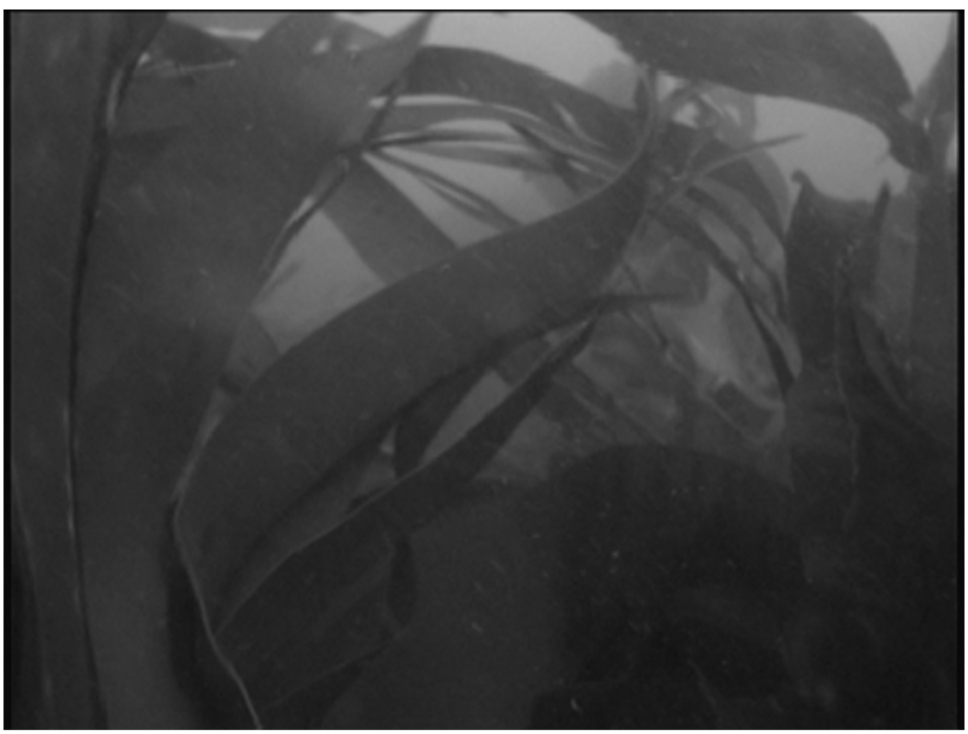


Figure 6 High canopy bladed kelps: a) bull kelp at Waypoint 51 and b) high canopy bladed kelps at Waypoint 21, 11 May 2011

A)



B)



3.2. Results

3.2.1. Species at Risk

We used the province's 'Species and Ecosystem Explorer' online search tool managed by the BC Conservation Data Centre (2011) to compile a preliminary list of provincially blue and red-listed species including those species federally listed under the *Species at Risk Act*. The BC Conservation Data Centre ranks and lists species using criteria established by NatureServe. Red-listed species are those that are deemed extirpated, endangered, or threatened within BC. Extirpated species no longer exist in BC but do occur elsewhere. Endangered species face imminent extinction or extirpation. Threatened species will likely become endangered if limiting factors are not reversed. Blue-listed species are not endangered or threatened, but are considered "of special concern" because of life history characteristics that make them more sensitive to human or natural disturbance.

Table 1 lists six marine mammals, three fish species, and six birds which occur in the study area (Boehlert and Gill 2010). The province does not provide a conservation status for many marine fishes, but the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) lists quillback rockfish (*Sebastes maliger*) as threatened, and this species likely occupies rocky habitats in the vicinity of Campbell River.

Table 1. Marine and estuarine species of conservation concern known to use the study area

English Name	Scientific Name	*COSEWIC designation	[§]BC List	**SARA	Habitat Type
Brant	*Branta bernicla*		Blue		estuarine; lacustrine; palustrine; riverine; terrestrial
Cutthroat Trout, *clarkii* subspecies	*Oncorhynchus clarkii clarkii*		Blue		estuarine; lacustrine; marine; terrestrial
Dolly Varden	*Salvelinus malma*		Blue		estuarine; lacustrine; marine; riverine
Double-crested Cormorant	*Phalacrocorax auritus*	Not at risk (May 1978)	Blue		estuarine; lacustrine; marine; palustrine; riverine; terrestrial
Great Blue Heron, *fannini* subspecies	*Ardea herodias fannini*	Special concern (May 2008)	Blue	Special concern (Feb 2010)	estuarine; lacustrine; palustrine; riverine; terrestrial
Green Sturgeon	*Acipenser medirostris*	Special concern (May 1987)	Red	Special concern (Aug 2006)	estuarine; marine; riverine
Harbour Porpoise	*Phocoena phocoena*	Special concern (Nov 2003)	Blue	Special concern (Jul 2005)	estuarine; marine
Humpback Whale	*Megaptera novaeangliae*	Special concern (May 2011)	Blue	Threatened (Jan 2005)	estuarine; marine
Killer Whale (Northeast Pacific Northern Resident Population)	*Orcinus orca* pop. 6	Threatened (Nov 2008)	Red	Threatened (Jun 2003)	estuarine; marine
Killer Whale (West Coast Transient Population)	*Orcinus orca* pop. 3	Threatened (Nov 2008)	Red	Threatened (Jun 2003)	estuarine; marine
Marbled Murrelet	*Brachyramphus marmoratus*	Threatened (Nov 2000)	Blue	Threatened (Jun 2003)	estuarine; lacustrine; marine; terrestrial
Northern Fur Seal	*Callorhinus ursinus*	Threatened (Nov 2010)	Red		estuarine; marine
Peregrine Falcon, *pealei* subspecies	*Falco peregrinus pealei*	Special concern (Apr 2007)	Blue	Special concern (Jun 2003)	estuarine; lacustrine; marine; riverine; terrestrial
Steller Sea Lion	*Eumetopias jubatus*	Special concern (Nov 2003)	Blue	Special concern (Jul 2005)	estuarine; marine
Tufted Puffin	*Fratercula cirrhata*		Blue		marine; terrestrial

*Committee on the Status of Endangered Wildlife in Canada; dates indicate time of last examination and change.

[§]**Blue** indicates indigenous species or subspecies of special concern (formerly Vulnerable) in British Columbia; **Red** includes indigenous species or subspecies that have been classed or are candidates for Extirpated, Endangered, or Threatened status in British Columbia.

**Federal Species at Risk Act status; dates indicate time of last examination and change.

3.2.2. Shoreline Community

Shoreline descriptions obtained from the provincial Coastal Resources Information System are the only biological data with adequate spatial resolution for the small size of the study area. According to these data, the shoreline is characterized by a narrow band (<1 m-wide) of splashzone *Verrucaria* (a complex of encrusting black lichen and blue green algae), patchy bull kelp (*Nereocystis luetkeana*), and a continuous band of barnacles, green algae, and bleached red algae (Figure 2).

3.2.3. Salmonid Habitat

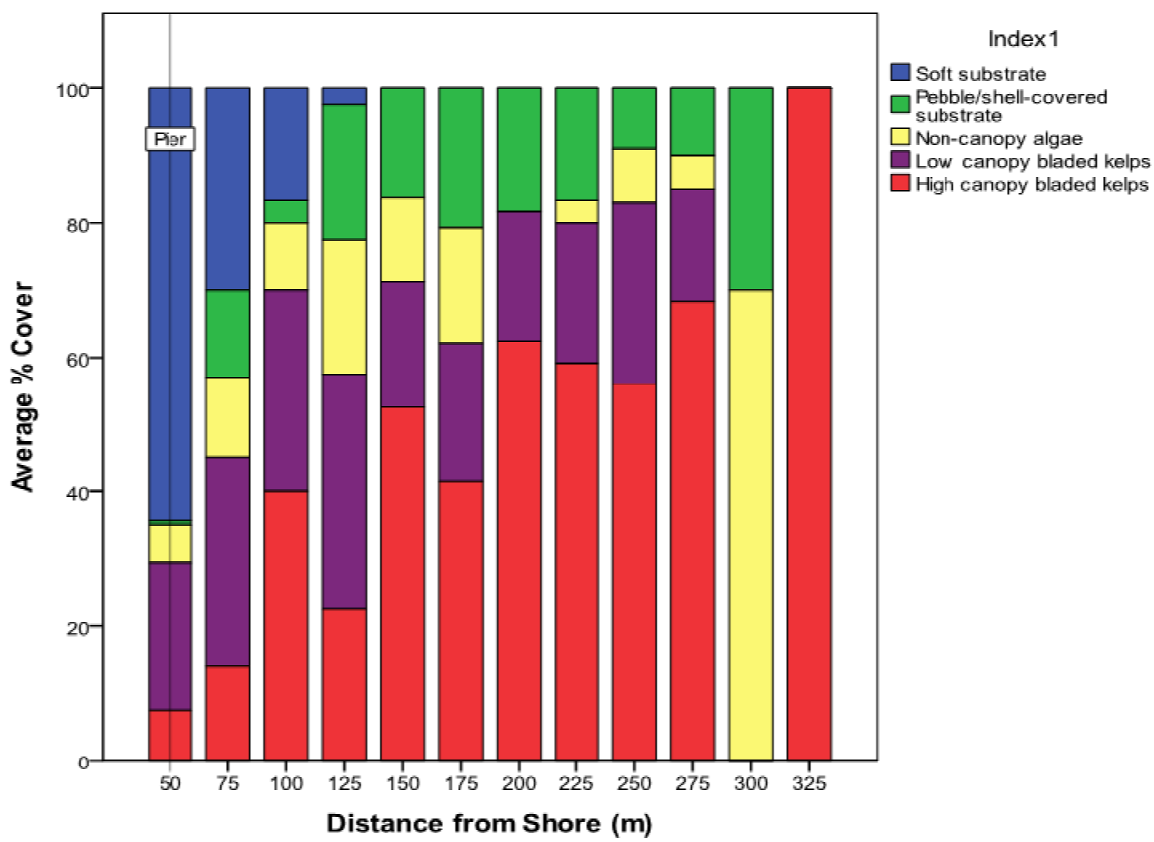
Georgia Strait is arguably the most important rearing area for juvenile Pacific salmon (*Oncorhynchus* spp.) on Canada's Pacific coast (Beamish *et al.* 2005) and is also an important migration route for Pacific salmon returning to local rivers as well as those migrating to rivers throughout BC and Washington State to spawn. Foreshore sampling for juvenile salmon was conducted between 1982 and 1986, prior to the construction of the Discovery Harbour Marina, located approximately 1 km north of the proposed Project. Catches included wild and hatchery chinook (*Oncorhynchus tsawytscha*) and coho (*Oncorhynchus kisutch*) juveniles from the Campbell River and Quinsam River and chum (*Oncorhynchus keta*) and pink (*Oncorhynchus gorbuscha*) juveniles of local origin as well as from the Fraser River and others river to the south (Bravender *et al.* 1999). Similar species likely rear in the foreshore areas adjacent to the proposed Project; however, this has not been confirmed by field sampling. Adult salmon migrate in close proximity to the Campbell River Discovery Pier during the salmon migration period (June to October) where they are targeted by anglers fishing from the pier. Small scale sea-pen rearing of pink salmon has resulted in high abundance of adult pink salmon congregating around the pier in some years (S. Anderson, pers. comm., 2011). Sea-pen rearing and release programs are sponsored by local groups and the Quinsam River Hatchery (BC Tyee Club Pinks for the Pier Program). Pens are located at the Hidden Harbour condominium complex marina, south of the Project area, and at the government dock adjacent to project area. Local Campbell River adult chinook salmon will also hold in the vicinity of the pier in some years, prior to migrating into the Campbell River to spawn (S. Anderson, pers. comm., 2011).

3.2.4. Subtidal Habitats

Video sampling did not record any fish or invertebrates on the benthos or water column. The absence of fish and mobile benthic invertebrates (e.g. crabs) probably represents a false negative. Mobile organisms likely fled prior to being recorded when disturbed by the approaching camera, which moved constantly due to boat drift and current. Large sessile invertebrates (e.g. *Pycnopodia* or other large seas stars), however, likely would have been recorded if they had been present. Smaller sessile invertebrates (e.g. scallops) likely were present but video resolution may have been inadequate to record them.

Within the immediate vicinity of the fishing pier the subtidal habitat is characterized mainly by soft substrate with relatively low percent cover of seaweeds. Most areas located farther from the fishing pier, which also were in relatively deeper water (Figure 7), were characterized by a high percent cover of bladed kelps, both canopy and non-canopy forming (Figure 7). Appendix 1 provides the raw numbers and additional information for these data.

Figure 7 Percent cover estimates of different substrate and seaweed classes obtained via point-sampling with a video camera in the area of the Campbell River Fishing Pier during 11 May, 2001.



3.2.5.Wildlife Observations

Wildlife observations are listed in Table 2. A Steller sea lion (non-bull), approximately 80 Brant, a belted kingfisher, and a juvenile bald eagle were observed opportunistically in the Project area during the site visit on 11 May, 2011. Both Brant and Steller sea lion are provincially blue-listed (special concern). The Steller sea lion is also federally listed under Schedule 1 of the *Species at Risk Act* as Special Concern (Table 1).

Table 2. Wildlife observed during the subtidal habitat field study on May 11, 2011.

Time	Taxon	Number seen	Location
8:47	Steller sea lion (non-bull)	1	Approx. 100 m SE of pier
9:22	brant geese	≈80	Vicinity of waypoint 7
10:52	belted kingfisher	1	Vicinity of waypoint 33
11:45	juvenile bald eagle	1	Vicinity of waypoint 50

3.3. Discussion

No biological features of obvious sensitivity to the Project were identified. We did not discover species of conservation concern with small home ranges or that are habitat specialists, habitat structures that are particularly rare or fragile. These findings should be interpreted in the limited context of the limited fieldwork that was conducted. One Steller sea lion and a gaggle of approximately 80 Brant geese were observed during the site visit. Both species are provincially blue listed. The Steller sea lion is also federally listed as Special Concern under Schedule 1 of the *Species at Risk Act*. Juvenile pacific salmon rear in the near-shore areas adjacent to the proposed Project and adult pacific salmon migrate through the proposed Project area.

Our biological assessment of study area is preliminary. Thus, the exact nature of the Projects potential impacts cannot be fully evaluated at this time. Nonetheless, given the small scale of the Project, it is unlikely to change hydrodynamic flow. As such the proposed tidal Project is unlikely to adversely affect nutrient subsidies, larval and propagule dispersal, and waste removal for the local marine community, including rearing salmonids (Boehlert and Gill 2010; Shields *et al.* 2011).

Marine mammals, diving birds, and fish including pacific salmon may be at risk of collisions and entanglement with equipment, and noise generated by turbines or related infrastructure may induce avoidance behaviour. Further study is needed to substantiate this possibility. Salmonid habitat in near-shore areas may be disrupted during the construction phase of the Project by sedimentation or noise, though any effects would be short-term. The footprint caused by anchoring systems and subsea cables will result in some habitat loss, however, this magnitude of this effect cannot be quantified without a detailed design.

The Project area lacks natural rocky reefs; structures associated with the Project are likely to increase habitat heterogeneity and attract fish. The possible attraction to artificial structures by large predatory fishes and by consumers of these fishes (e.g. sea lions) could potentially raise predation rates for migrating juvenile salmonids and other fishes (Boehlert and Gill 2010). Whether these effects will be ecologically substantial is difficult to evaluate because existing fishing pressure associated with local boat traffic and the fishing pier likely has altered the local abundance of predatory fishes.

4. SUMMARY AND RECOMMENDATIONS

Tidal power developments in BC, including the proposed demonstration project at Campbell River, are subject to provincial permitting requirements as outlined in Section 2.2.1.of this report. There is some precedent for streamlining the permitting process by developing the project off of the grid, as in the case of the Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks; however, this would need to be investigated with the applicable regulatory agencies. At the very least, it is likely that any installation at Campbell River, which encompasses an area of frequent boat traffic, would require federal permitting under the Navigable Waters Protection Act. It is also possible that the project would require a HADD, though this would need to be determined through an aquatic impact assessment which is completed as part of the development planning process. In either case a review under CEAA would be triggered and the project would be subject to a federal screening environment assessment.

The scope of this report was limited to environmental resources; however, social, economic, health, and heritage assessments will also be required as part of the provincial approval process. We recommend that the city be proactive in this regard and engage public stakeholders and First Nations very early on in the regulatory process.

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6. APPENDIX 1

Subtidal habitat description as percent cover for the individual waypoint sampled on May 11, 2011.

Time of day	Video clip	Waypoint	% soft substrate	% pebble-shell	% non-canopy	% low canopy	% high canopy
9:10	6	2	50	0	30	20	0
9:12	7	3	80	0	10	10	0
9:14	8	4	10	0	40	50	0
9:16	9	5	0	15	15	35	35
9:19	11	6	0	15	15	35	35
9:22	12	7	0	15	15	35	35
9:24	13	8	0	15	15	35	35
9:27	14	9	0	15	0	15	70
9:29	15	10	0	30	70	0	0
9:33	16	11	0	30	70	0	0
9:36	18	12	0	20	20	30	30
9:39	19	13	0	20	10	40	30
9:41	20	14	0	50	0	25	25
9:44	21	15	0	0	0	30	70
9:45	22	16	0	0	0	0	100
9:49	23	17	0	20	20	30	30
9:52	24	18	0	30	20	25	25
9:54	25	19	0	30	0	35	35
9:57	26	20	0	50	10	10	30
9:59	27	21	0	0	0	0	100
10:04	29	22	0	15	15	50	20
10:08	30	23	0	10	20	50	20
10:11	31	24	0	0	25	30	45
10:13	32	25	50	0	10	30	10
10:18	33	26	55	0	5	40	0
10:20	34	27	55	0	5	20	20
10:21	35	28	75	0	5	10	10
10:40	36	29	0	20	5	45	30
10:43	37	30	25	30	5	20	20
10:45	38	31	75	0	5	20	0
10:51	39	32	55	5	10	20	10

Time of day	Video clip	Waypoint	% soft substrate	% pebble-shell	% non-canopy	% low canopy	% high canopy
10:52	40	33	40	0	10	35	15
10:56	41	34	70	0	0	25	5
10:58	42	35	85	0	0	15	0
11:01	43	36	0	0	0	10	90
11:04	44	37	0	5	0	15	80
11:06	45	38	0	0	0	0	100
11:08	46	39	0	0	0	0	100
11:17	47	40	0	0	0	0	100
11:20	48	41	0	0	0	0	100
11:25	49	42	0	0	0	0	100
11:28	50	43	0	0	0	0	100
11:31	51	44	0	0	0	0	100
11:32	52	45	0	30	0	0	70
11:35	53	46	0	30	0	0	70
11:38	54	47	0	20	0	0	80
11:40	55	48	0	20	0	40	40
11:43	56	49	0	30	0	40	30
11:45	57	50	0	40	0	50	10
11:49	58	51	0	30	10	20	40
11:51	59	52	0	10	10	40	40
11:54	60	53	0	20	20	55	5
11:55	61	54	0	15	10	65	10

Appendix F.
MAVI Mi2 Tidal Power System – Technical Documentation

MAVI Mi2 TIDAL POWER SYSTEM

At the request of Triton Consultants, we (Mavi Innovations Inc.) put together an overview of the MAVI Mi2 tidal power system that is specifically designed for powering British Columbia's coastal communities.

Our baseline Mi2 ducted turbine has a 2m diameter cross-flow rotor and a rating of 50kW in 6 knot currents. The Mi2 module, comprising of the rotor, drivetrain and generator is designed to be fully submerged. The module can therefore be either secured to a floating platform, or deployed on the seabed using a gravity base.

For this project, it is anticipated that the Mi2 would be deployed in the floating configuration so that it is visible and accessible for showcasing/educational purposes. A floating system also allows for greater flexibility when determining the deployment location. For example, the turbine can initially be deployed close to shore for maximum visibility and to allow for stringing an above water power cable instead of running a cable along the seafloor. Once all the environmental and regulatory concerns are met, and the power production at the specific site is well defined, the turbine could be relocated further into the channel where the tidal flows are more vigorous. At that point, if a floating turbine is not feasible due to navigational constraints, the Mi2 turbine module could be mounted on a gravity base and fully submerged.

A summary of the principal features of the Mi2 Tidal Power System is provided below. We elected not to provide a 3D rendering of the Mi2 system for inclusion in this report in order to protect Mavi's intellectual property for competitive reasons (a PCT application was filed for Mavi's ducted turbine and a system patent is currently being developed). We would, however, welcome the opportunity to meet with representatives from the city to provide a complete product overview and discuss the specifics of the project on a more confidential basis.

Mavi was also requested to provide a cost estimate for the project. For preliminary budgetary purposes, the cost of a floating Mi2 Tidal Power System is estimated to be 550,000 CAD. This price is based on a 50kW direct drive permanent magnet generator configuration and includes the floating platform with overhead service crane, power take-off for gird connection, integrated log deflector, anchor and mooring harness, and basic instrumentation package with onboard power supply and remote monitoring. The cost of the cable and installation costs were not included in this estimate nor any significant margins. Fabrication costs are a significant percentage of the overall cost; Mavi will therefore have to obtain quotes from local fabrication shops to refine the cost estimate.

All structural, mechanical and electrical components of the Mi2 tidal system have been engineered to operate in currents up to 4m/s (~8 knots). In addition, the floating platform and mooring harness were designed to operate in the ocean environment and dynamically simulated in 2 meter waves (8s period) for a range of current speeds from 0 to 4m/s. It is important to note that many cost cutting measures can be introduced if the tidal resource at the deployment site is less energetic such as using a lower capacity generator for slower tidal flows (and lower capacity power electronics), lighter anchors and lower safety factors when designing structural components. Once a list of requirements (max. current speed, project duration, depth of deployment, wave/wind climate, navigational considerations, etc.) is provided for the project, Mavi's engineers will review the Mi2 design and will engage the local marine industry to obtain quotes on fabrication, assembly and deployment in order to submit a more refined project cost.

We, at Mavi, see this project as an ideal collaborative opportunity for showcasing our made in BC technology. We would like to work with a local academic institution to develop an informative display panel that shows turbine power production in real time, current direction, speed, etc. We have also incorporated a number of unique and signature features into the design to make for a more impressive showcasing display such as a log deflector that may also act as a navigational aid.

While we are prepared to provide a significant portion of the engineering and project development work on an in-kind basis, we would also like to explore other means of collaboratively raising the required funds for the project.

Throughout our technology development we have completed a variety of industrial research projects working with organizations including the Industrial Research Assistance Program (IRAP), Natural Resources Canada (NRCan), and the National Research Council Institute for Ocean Technology (NRC-IOT). We have a strong interest in continuing to develop relationships with government bodies, First Nations, and academic and industrial organizations. We are therefore keen to work with project proponents from Campbell River to develop a proposal suitable for attracting funding from the various government and community development programs.

Mi2 Product Specification

Mi2 Turbine Module

- 2 metre diameter cross-flow rotor housed inside MAVI Duct
- Permanent magnet direct drive generator rated at 50kW, 70 rpm in 6 knot current. See power curve provided in Figure 1 (gearbox and lower capacity generator optional);
- In-line mechanical brake for emergency braking
- In-line clutch for disconnect from generator (to protect generator from over-torque and emergency disconnect to allow for rapid rotor braking);
- Fully submerged design: can be deployed from Mavi's floating platform or on the seabed using a gravity base;
- Optional integrated rotor cage (please note that a rotor cage will result in performance decrease; the cage could be initially installed and subsequently removed depending on fish and marine mammal impact study);
- Designed to be grid connected, or interface with hybrid diesel battery system.

Floating Platform

- 12 m long, 7.5m beam catamaran structure with main working deck and auxiliary sliding maintenance deck;
- Overhead gantry crane for lowering/raising and servicing the turbine module (also used as mounting point for communications equipment, navigational lights and attachment point for routing above water power cable);

- Designed for good stability and seakeeping performance and low drag to minimize mooring requirements (dynamic motion and loads simulated in 2m, 8s period irregular waves at current speeds from 0 to 4m/s);
- Optional bi-directional integrated log deflector. Also designed to act as navigational aid.

Mooring System

- Mooring harness designed for current speeds up to 4m/s in Hs=2m, Ts=8s;
- Hybrid synthetic-chain mooring harness with integrated mooring floats to facilitate decoupling the Mi2 platform from the mooring lines;
- Mooring harness can maintain the system on station within a few metres with and without waves;
- The mooring harness will be fine tuned for the deployment site once the specifics of the installation are defined (current speed range and direction, depth, bottom composition, station-keeping requirements, wave spectrum and wind loading). Mavi will incorporate all site specific data into a dynamic simulation to ensure all performance requirements are met and calculate the station keeping performance. A subsea cable can also be included in the simulation.

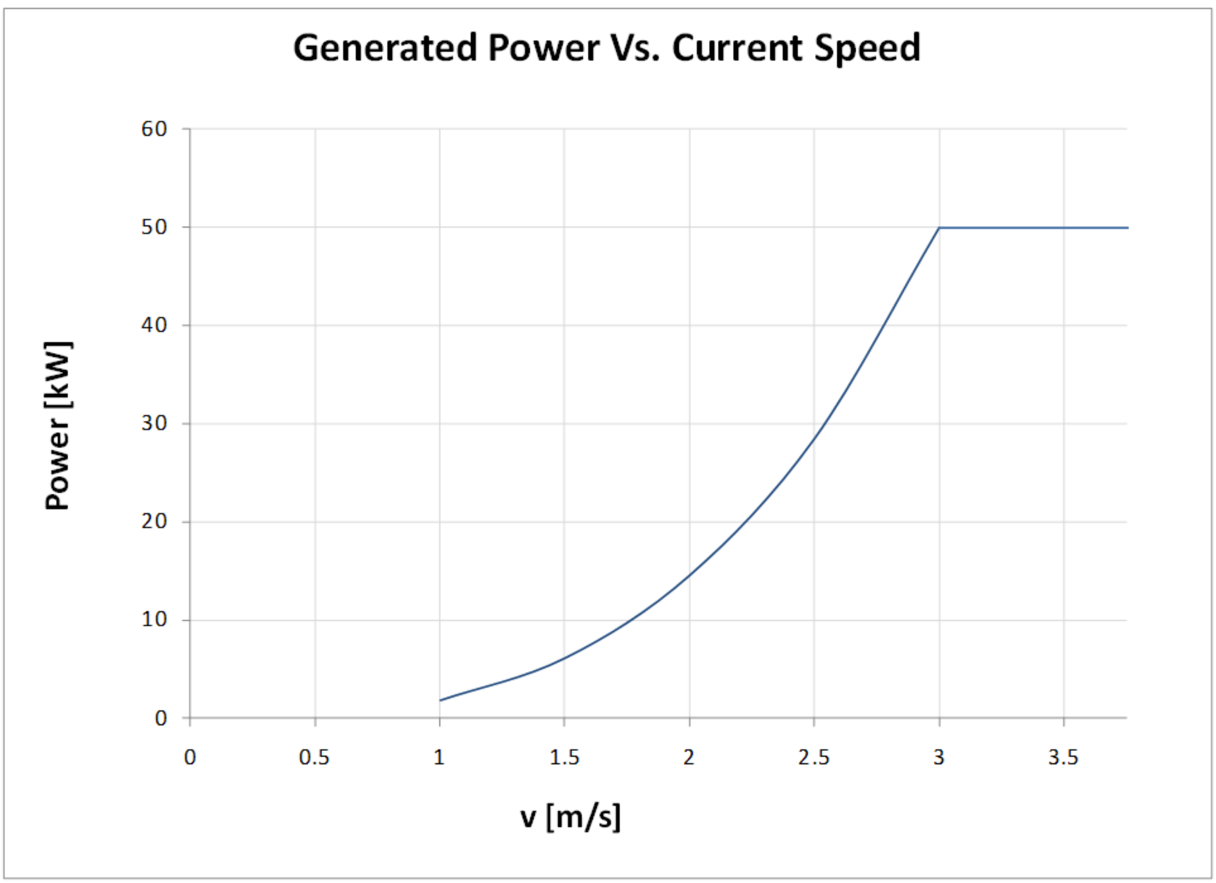


Figure 1: *Power vs. Current speed at output of PM generator (Please note that there will be additional electrical losses dependent on type of end connection. A value of 15% can be used for preliminary evaluation purposes.)*

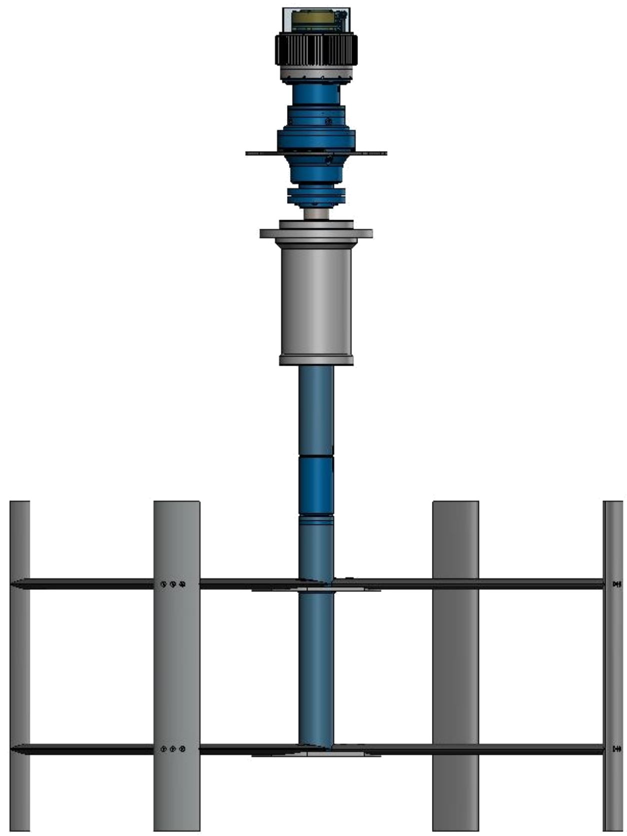
Appendix G.
New Energy ENC-025L-F4 – Technical Documentation

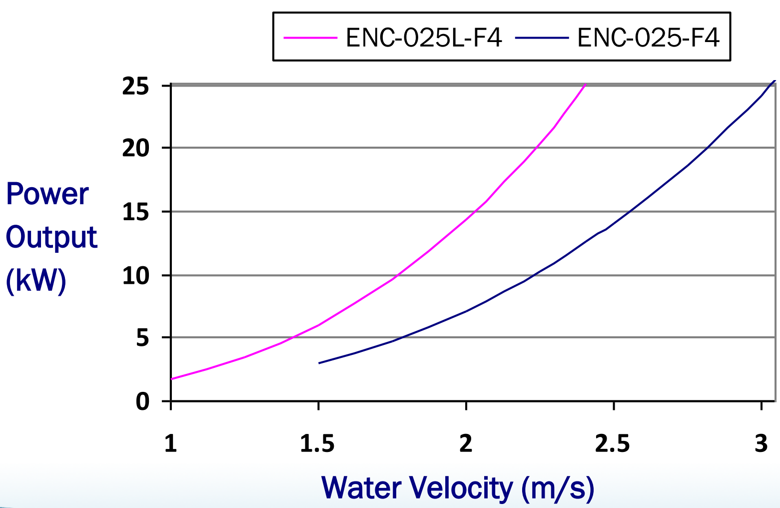
EnCurrent Hydro Turbines
25 kW Specification

New Energy Corporation Inc.

ENC-025-F4, ENC-025-R5, ENC-025L-R4
EnCurrent Features and Benefits

- Generates electricity with no greenhouse gas emissions.
- Harnesses the energy from moving water without the need for dams, barrages or penstocks.
- Minimal civil works required with installation.
- Low fish mortality rates due to slow rotational speed and open design.
- Grid connected or standalone operation.
- Permanent Magnet generator allows the turbine to run at peak performance in a wide range of water flows.
- Drive train and generator positioned above the waterline for system longevity and ease of maintenance.
- Safety brake for high water flow or low power conditions.
- Wetted materials made of aluminum or coated steel.


ENC-025-F4



EnCurrent Applications

- Installs easily into controlled waterways such as irrigation and engineered canals.
- ENC-025-F4 and ENC-025L-F4 optimized for installation in free flow applications.
- Installation on a floating platform for sites with widely varying water levels such as rivers.
- Multi-directional operation allows for installation into tidal currents. Tidal option available on request.
- ENC-025-R5 optimized for installation in restricted flow applications with up to 1.4 meters of head.

Sustainable Hydropower

New Energy Corporation Inc.

Characteristic	ENC-025-F4	ENC-025-R5	ENC-025L-F4
Maximum Power Output	25 kW	25 kW	25 kW
Water Velocity at Max Power	3 m/s	3 m/s*	2.4 m/s
Rotor speed at Max Power	40 RPM	33 RPM	22.4 RPM
Overall System Mass	1760 kg	1910 kg	2665 kg
Overall System Height	4.24 m	4.24 m	5.41 m
Rotor Diameter	3.40 m	3.40 m	4.83 m
Rotor Height	1.70 m	1.70 m	2.41 m
Number of Blades	4	5	4
Distance from top of rotor to:			
Center of Bottom Bearing	0.467 m	0.467 m	0.594
Mounting Surface	1.056 m	1.056 m	1.089 m
Gearbox Ratio	30.7:1	38.6:1	53.5:1
Generator Output	0—307 V	0—318 V	0—300 V

* For the ENC-025-R5 the water velocity is based on the ambient water velocity and head differential.

Power Plants with 25 kW Turbines

The 25 kW Turbines can be deployed in single or multiple unit power plants. In a multiple-unit configuration, a single power plant is capable of providing generating capacities of 500 kW or more.

Multiple-unit power plants can be deployed in rivers or tidal flows by or in man-made canals. Within rivers and tidal flows, the turbines can be deployed either in series or parallel within the flow. For man-made canals, the turbines can be installed in series throughout the canal, with the possibility of inducing a minimal amount of head differential upstream of each turbine. For more information on multiple-unit power plants, contact sales at New Energy.

http://www.newenergycorp.ca

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