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VESSEL WAKE WASH ANALYSIS

BURNCO Aggregate Project, Howe Sound, BC

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REPORT

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Golder Associates

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1.0 INTRODUCTION

Vessel wake effects on the coastal environment have received considerable attention due to the observed as well as perceived impacts along shorelines. It is widely accepted that heavy ship traffic has the potential to cause environmental damage in narrow waterways and in the vicinity of sensitive areas such as wetlands or naturally low-energy coasts where hydrodynamic forcing generated by vessels can cause rapid changes in the coastal profile near the waterline (Kelpsaite et al. 2009; Kofoed-Hansen et al. 1999). Sediment transport rates and patterns can be altered by even a small increase in hydrodynamic loads. Waves of all types can also change the nature of benthic habitats by altering factors such as sediment grain size distribution and nutrient availability (Curtiss et al. 2009).

Howe Sound contains a number of major vessel routes for passenger and bulk cargo transport as well as a number of popular pleasure craft destinations. The Ramillies, Thornbrough and Queen Charlotte Channels have historically been and continue to be used for transporting passengers and cargo across Howe Sound and to other locations across the world. The busiest of these is the Queen Charlotte Channel which is adjacent to a BC Ferries terminal in Horsehoe Bay. Daily ferries depart from Horseshoe Bay across Georgia Strait to Nanaimo, across Howe Sound to Langdale and across Queen Charlotte Channel to Bowen Island. Daily ferries also depart Langdale for Horseshoe Bay and across Thornbrough Channel to Gambier and Keats Islands. Port Mellon, located at the southwestern end of the Thornbrough channel, is home to the Howe Sound Pulp and Paper Mill which ships pulp and paper products through Thornbrough Channel to locations around the world. Farther to the north and east lies Woodfibre, the source of a pulp mill until it was shut down in 2006, and Squamish Harbour, an actively used harbour for pleasure craft and commercial vessels. Several other parts of Howe Sound are popular destinations for pleasure craft, most notably Ekins Point which is used by the Thunderbird Yacht Club, and Plumper Cove Marine Park on Keats Island (BC MoE 1980; INNAV 2013). There are a wide variety of commercial and pleasure vessels which may pass through Howe Sound. These vessels create wake wash with different wave characteristics which depend on several factors: vessel speed, vessel shape and dimensions, displacement of water and navigation depth.

The purpose of this report is to estimate the wake wash energy at the shoreline generated by the proposed Project-related vessels; the analysis will be used to prepare an assessment of wake effects. Project-related vessels include a water taxi that will transport people to/from the Project site, a barge that will transport aggregate material and a tug that will pull/push the BURNCO aggregate barge to/from the loading facility. Two navigation routes shown in Figure 1 are being considered for the wake wash analysis of these three vessels: Thornbrough Channel (Route 1) and Ramillies Channel and Queen Charlotte Channel (Route 2). Although, the water taxi is planned to only operate on Route 1 between Gibsons and the Project site, the wake wash from the water taxi is analyzed along routes 1 and 2 for completeness and comparative purposes. A wind wave analysis was performed to compare the energy produced by potential worst case storm events in the area to the wake wash energy generated by proposed Project vessels.

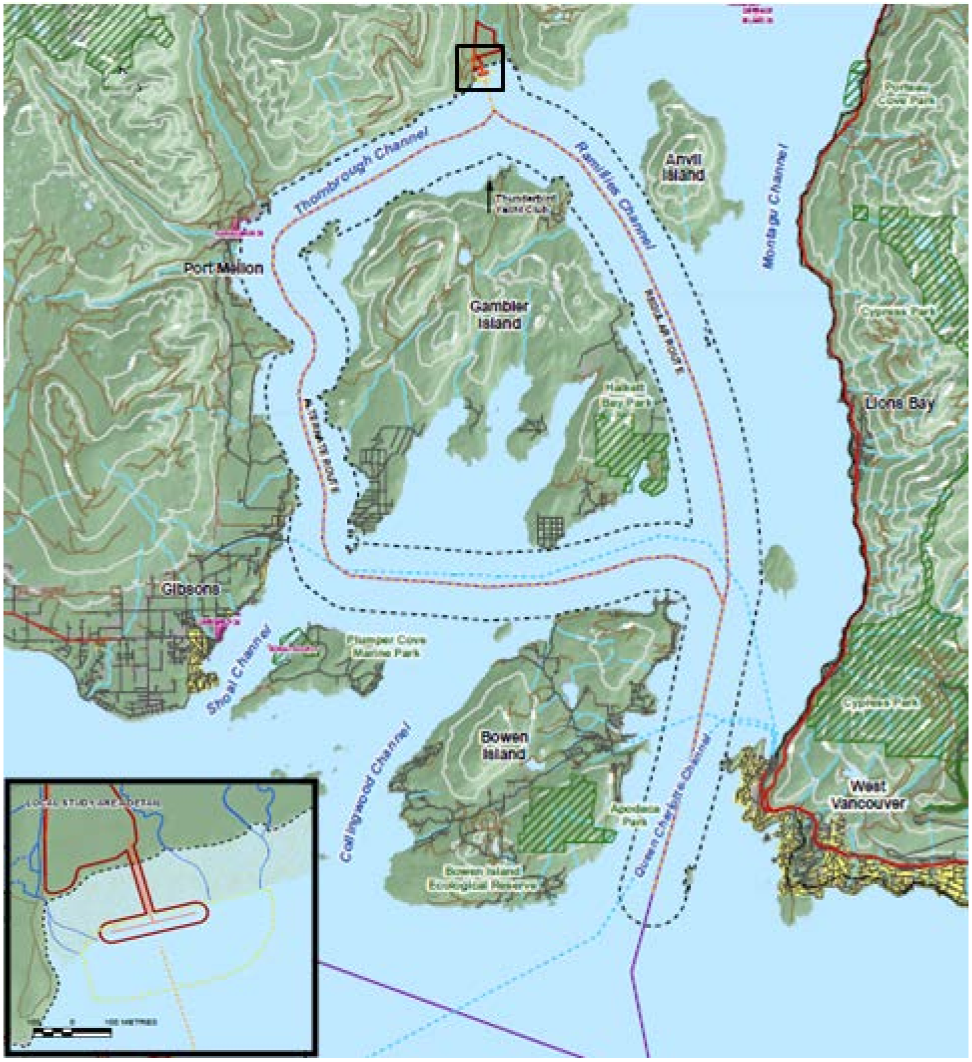

Figure 1: Map showing the Project area and the navigation channels.

2.0 BACKGROUND

Howe Sound extends from its northern most point at Squamish River to the southwest where the mouth of the fjord meets Georgia Strait. Tides within Howe Sound are mixed semi-diurnal with a mean range of 3.2 5 meters (m) between tidal highs and a maximum range of 5 m. Howe Sound is not a truly confined waterway in that it is subject to strong winds during winter. Winds are generally high frequency and northerly though there are areas which are sheltered by nearby topography and where winds speeds are lower.

Thornbrough channel is located on the western end of Howe Sound and extends between McNab Creek in the north to Langdale in the south. There are a number of streams and riparian areas along the west shore of the channel. The northern section of the channel is largely undeveloped except for a small, low-sloping open area around Seaside Park and a small low-sloping estuary at McNab Creek. The rest of the northern section of Thornbrough channel generally contains steep slopes and is heavily forested. An existing log boom occupies part of the channel and the remains of a log sort lie within the subtidal area to the southwest of McNab Creek.

The southern section of Thornbrough channel contains a more developed shoreline with the Langdale Ferry terminal, which is an actively used port for BC Ferries departures to Horseshoe Bay. The western shoreline is mostly low-sloping and developed while the eastern shoreline on Gambier Island is steep and heavily forested.

Ramillies channel runs between Gambier and Anvil Islands and connects the northern end of Thornbrough channel with the northern end of the Queen Charlotte channel. The western shoreline of Ramillies channel contains one large riparian area which extends down into a wetland within Douglas Bay on Gambier Island. Much of the rest of the western shoreline along with the eastern shoreline is steep and rocky and consists of dense herbaceous forests with little or no development.

Queen Charlotte channel connects the eastern edge of Howe Sound with the much larger Georgia Strait. The channel contains a significant amount of developed shoreline with the Horseshoe Bay Ferry terminal on the eastern shore and the Bowen Island Ferry terminal across from it on the western shoreline. A few riparian areas exist in Snug Cove and Apodaca Cove. The entrance to Queen Charlotte channel from the Georgia Strait contains patches of undeveloped forest land along both the eastern and western shorelines. Slopes are generally moderate throughout the channel except in a few coves and where the ferry terminals are located where slopes are shallower.

3.0 METHODS

An empirical model developed by Kriebel and Seelig (2005) improved from a model developed by Sorensen and Weggel (1984) was used to calculate the following wake wash parameters from each vessel: characteristic wave height, characteristic wave period, and wave energy. A data review of existing vessel information was performed to obtain the vessel characteristics (Table 1) for input to the model.

Table 1: Characteristics of Vessel Types.

Vessel Type	Vessel Length (m)	Entrance Length (m)	Draught (m)	Vessel Speed (kt)	Block Coefficient Cb
Water Taxi	8.5	2.8	1.5	30.0	0.54
Tug Boat	26	8.7	4.0	6.0	0.50
Barge	80	10.0	5.5	6.0	0.95

Notes:
m = Meters
Kt = Knots
Cb = The ratio of the immersed volume of a vessel to the product of its immersed draft, length, and beam

The wake parameters, H_m and T, derived from Kriebel and Seelig (2005), are used to estimate wave energy, E, and wave energy flux, *P*, in equations (1) and (2), respectively.

$$P = ECg \qquad (1)$$

using the wave energy equation,

$$E = \frac{1}{16}\rho g H_{m0} \qquad (2)$$

and the group velocity $Cg = \frac{\lambda}{T}$, where λ is the wave length.

The annual energy flux was estimated conservatively by assuming the characteristic wave height, H_m was constant for the duration of the wave train. The wave energy generated by each vessel during one round trip per day (two transits along route) for the number of vessel operation days shown in Table 2 was used to compute the annual energy flux for the three vessel types at the extraction points selected along the shorelines and then interpolated to define a continuous line of energy flux. The magnitude of the energy flux can be used in further steps to estimate the potential of erosion along the shorelines. Locations of extraction points for the two navigation routes are shown in Figure 2.

Table 2: Vessel Movements during Operations.

Vessel Type	Operation days per year	Total # of trips per year
Water Taxi	260	520
Tug Boat	190	380
Barge	190	380

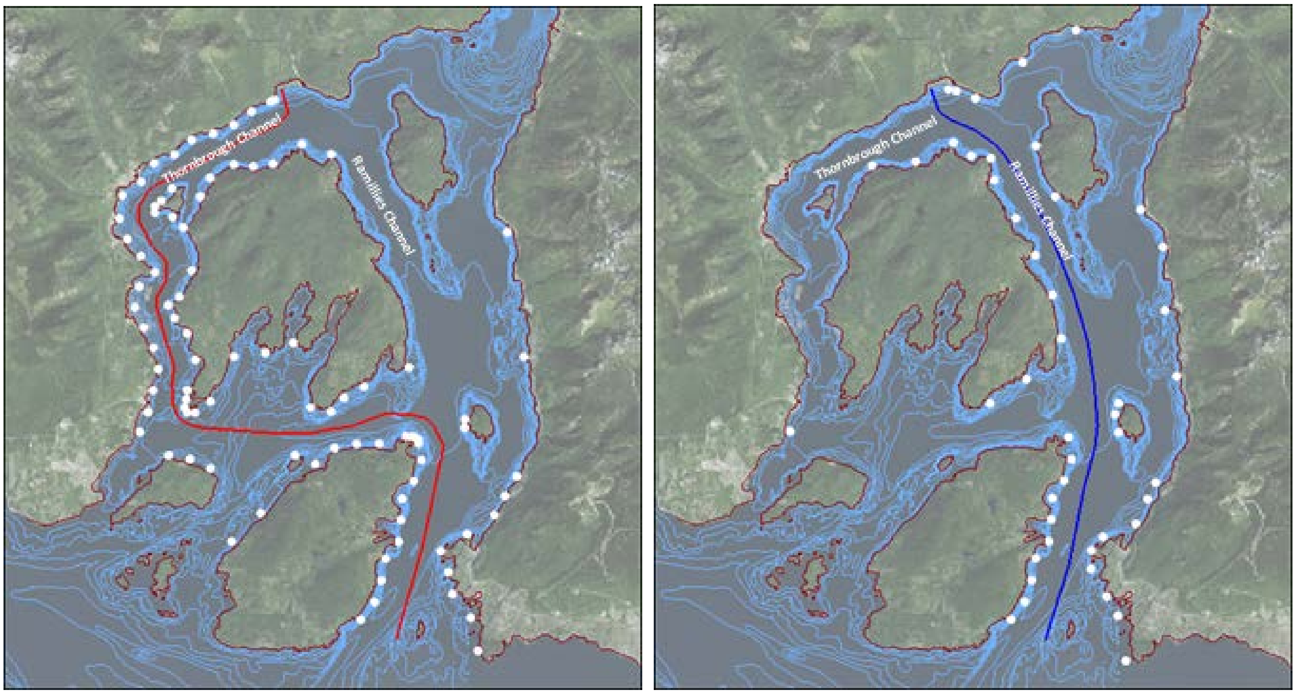

Figure 2: Extraction points along the shorelines for route 1 (left) and route 2 (right).

Wind data recorded in Howe Sound at Pam Rocks Marine Weather Station (Latitude: 49°29'16.460" N, Longitude: 123°17'56.092" W) were analyzed for extreme wind events that would have the potential to generate the largest wave energy across the channels and along the shoreline. The hourly data recorded at Pam Rocks over an 18-year interval (1994 to 2012) was obtained from Environment Canada (2014) for this analysis.

The wave climate in the vicinity of the study site was estimated with the use of a nested version of the SWAN (acronym for Simulating Waves Nearshore) model (Booij et al. 1999). The innermost model spatial resolution, shown in Figure 3b was 100 m and the large grid shown in Figure 3a had a resolution of 250 m. Initial model simulations were conducted to estimate wave heights generated by the largest wind event at Pam Rocks recorded from the north and south to identify the worst case scenario for wind-wave generated energy in Howe Sound. The model results showed that winds from the north generate very small wave heights (less than 0.5 m) across the Channels due to the sheltering by local topography and short fetch. However, model simulations executed using a wind event from the south predicted wave heights ranging from 0.6 to 1.8 m across the Channels. Therefore the wind events from the south were further analyzed for a worst case scenario. The wind data were filtered for southerly wind direction ranging from 160˚ to 200˚ True North. A Peak Over Threshold (POT) analysis was performed on the filtered data using a threshold wind speed of 12 meters per second (m/s) and storm duration > 4 hours. The threshold value of 12 m/s represents the typical annual maximum wind speed in Howe Sound. A total of 55 wind storm events, during the 18.3 year wind record were identified and all 55 events were simulated to predict wave height using SWAN. The SWAN model allows the use of wind grids as the forcing mechanism for wave prediction. Wind grids were built and the wind vectors were aligned in the direction of the Channels inside the Navigation Routes for each scenario to simulate local topographic steering of wind direction and develop more realistic estimates of wave height.

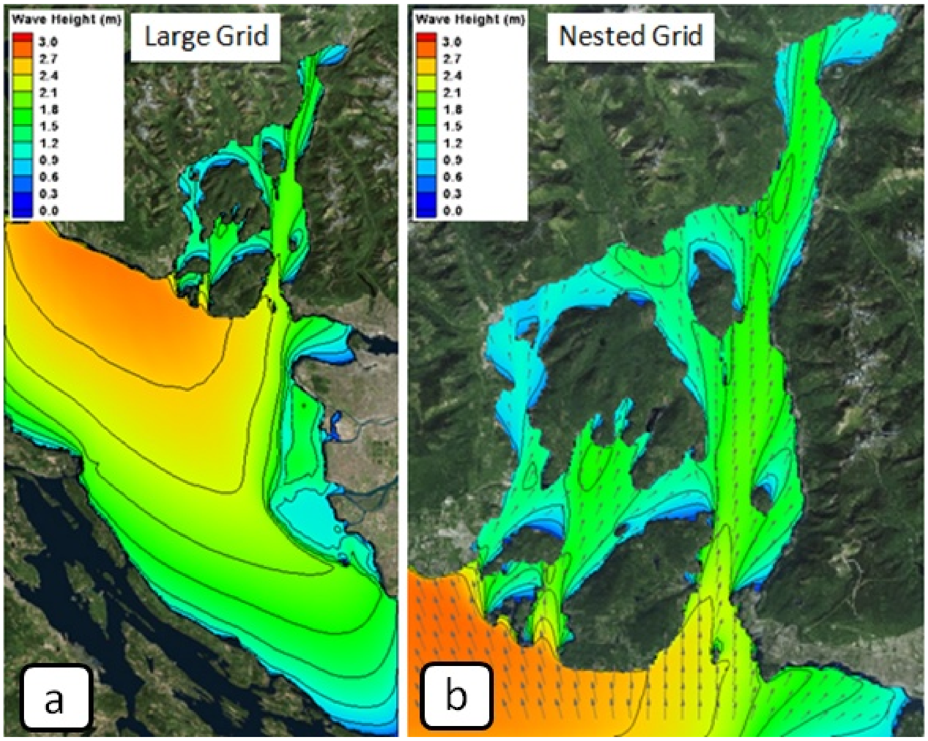

Figure 3: Wave height for a) large and b) nested grids extracted from SWAN output for a southerly wind event (wind speed: 19 m/s; wind direction 190˚).

Wind-wave energy and wind-wave energy flux were computed using equations (1) and (2) after extracting the wave parameters from SWAN for the 55 wind events. The average annual energy flux from wind-wave events was calculated by summing the wind-wave energy from the 55 events at each extraction point and dividing by the length of the data record (18 years). The annual energy flux generated by the vessel wake wash was then compared to the estimate of annual wind-wave energy flux. Figure 4 shows a flow diagram of the steps used to calcualte the energy flux for wake wash and wind-waves.

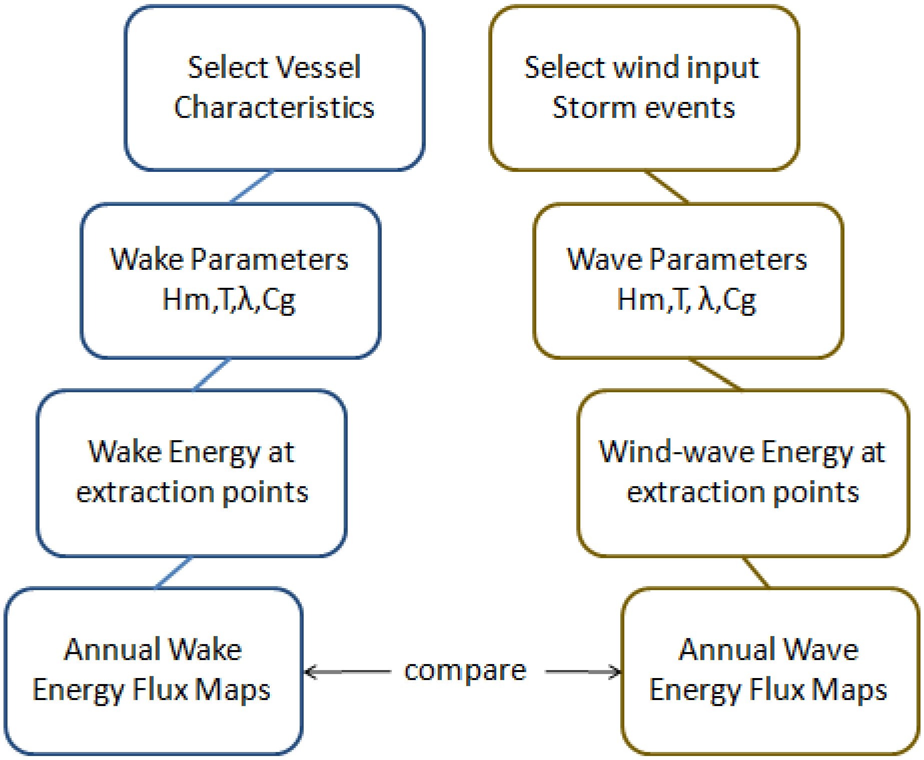

Figure 4: Diagram of the methods used for the analysis of wake wash (left column) and wind-waves (right column).

4.0 ANALYSIS

The cumulative annual wave energy flux and the spatial distribution of the annual wave energy flux for wind-waves and wake wash were compared to determine the potential for impacts to community resources and shoreline habitats.

4.1 Wave Energy Analysis

Wind-wave energy within the Project area varies based on the exposure of the shoreline to southerly wind events. The wake wash generated by a moving vessel also varies spatially based on the local water depth that influences the transformation of the wakes as they travel to the shore (local water depth refers to the depths that have effect on the wakes while they travel to the shoreline away from the navigation depth, also defined as the depth along the navigation line). The spatial distribution at the shorelines along routes 1 and 2 of the cumulative annual wind-wave energy and cumulative annual wake wash energy for the water taxi are presented in Figure 5 for route 1 and Figure 7 for route 2. The spatial distribution of the wake wash cumulative annual energy for the tug and barge is similar to the water taxi, however the magnitude of the energy is sufficiently small that it cannot be presented on the same scale as the wave energy from the wind-waves and water taxi. The cumulative annual energy flux calculations indicate that the wake wash energy produced by the tug and barge is less than 1% of the total energy. Wind-wave energy is largest along the shorelines of Queen Charlotte Channel (red to yellow colors) because it is open to the longest southerly fetch across the Georgia Strait. Annual wind-wave energy is lower in magnitude, but still substantial (light green to light blue) along the east side of Montagu Channel and the south end of Gambier Island (Figure 5). Wave energy generated by the water taxi does not vary significantly within the Project area as compared to the spatial distribution of wind-wave energy (the maximum on the color bar scale). The cumulative annual wave energy flux generated by the tug and barge was several times smaller than the water taxi and therefore has inappreciable influence on sediment transport or changes to shoreline habitats. Table 3 summarizes the maximum cumulative annual wave energy flux at the shoreline along each route for the three vessels types and southerly wind-waves. Extraction points were defined at equal intervals along the shorelines of the vessel routes for collocated output from the wind wave model (extraction points) and for calculation of wake wave parameters. This was to facilitate a direct comparison between wind wave energy and wake wave energy at representative locations along each route. The maximum cumulative energy flux is defined as the highest value obtained among the extracted points after summing the energy flux of the trips for each vessel or wind-wave events during a year. The wind-wave energy is nearly three times the magnitude of the maximum wake wash energy from the water taxi and nearly 40,000 times the energy generated by the tug boat. The maximum annual wind-wave energy flux calculated within the Project is 30,058,000 kilowatts per meter per year (kW/m/year).

Table 3: Maximum cumulative annual wave energy flux along the shoreline for the three vessels types and the southerly wind-waves.

Route	Wind Wave Energy kW/m/year	Water Taxi kW/m/year	Tug boat kW/m/year	Barge kW/m/year
1	1,324,000	388,000	16	4.0
2	3,578,000	358,000	6.2	4.0

The wave energy generated by the three vessels and wind-waves on an annual basis were cumulated to develop an estimate of total wave energy flux along the shorelines within the Project area. The wake wash energy from the water taxi and from the wind-waves were then computed as a percentage of the total wave energy flux at each extraction point along the shoreline for route 1 (Figure 6) and route 2 (Figure 8). Since the tug boat and barge generate less than 1% of the total energy at all shorelines along routes 1 and 2, the percent contribution from the tug and barge is not presented spatially. Red colors in Figure 6 (right) and Figure 8 (right) indicate nearly 100% of the total wave energy is contributed by wind-waves, which is most evident along the southerly exposed shorelines. Orange and yellow colors indicate wind-waves are also the dominant forcing mechanism contributing 80 to 90% of the total energy received on the shoreline. In Figure 6 (left) and Figure 8 (left) the blue color indicates the contribution of wave energy generated by the water taxi is very small in comparison to wind-waves. Along the narrower channels, which are more sheltered from wind-waves and wake wash increases because of shorter distances to the sailing line, the contribution of total energy from the water taxi increases. Along Route 1, the maximum contribution of the total energy from the water taxi is greatest along the narrower channels where the total cumulative annual wave energy is up to 25% of the total wave energy (Figure 6 left) and wind-waves remain the dominant contributing source of the wave energy in this area.

In general, wind-waves dominate the wave energy climate along the shorelines of route 2. The wave energy along the shorelines of route 1 varies spatially; vessel wake wash from the water taxi contributes up to 25% of the annual wave energy along portions of the Thornbrough channel shoreline.

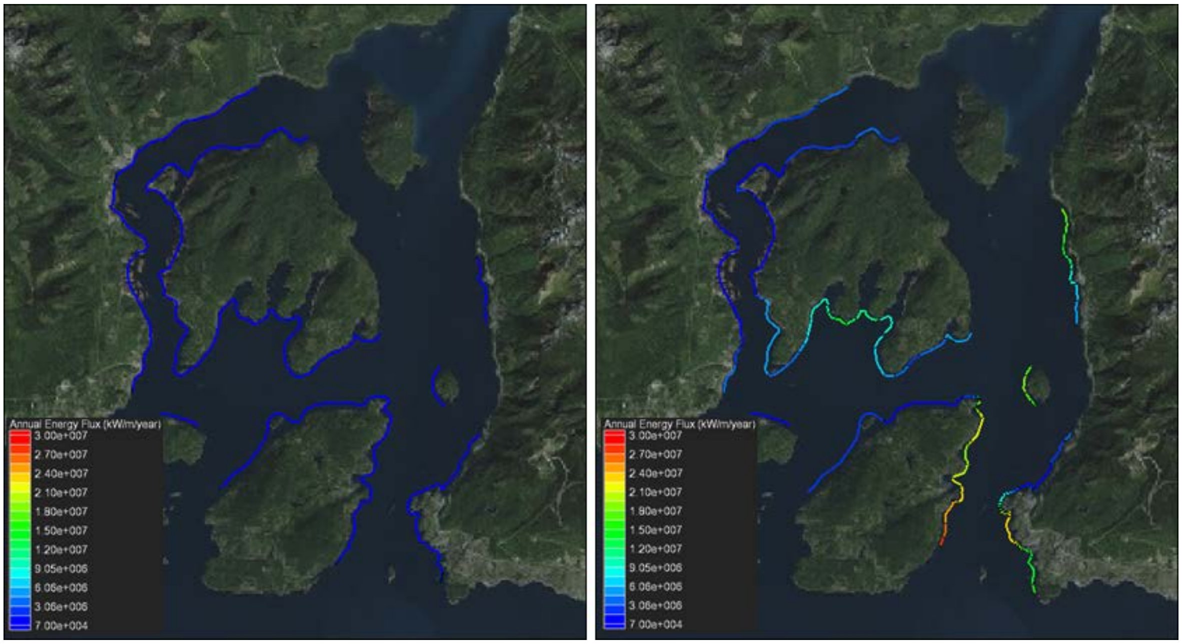

Figure 5: Annual energy flux for water taxi wake wash (left) and wind-waves (right) along route 1.

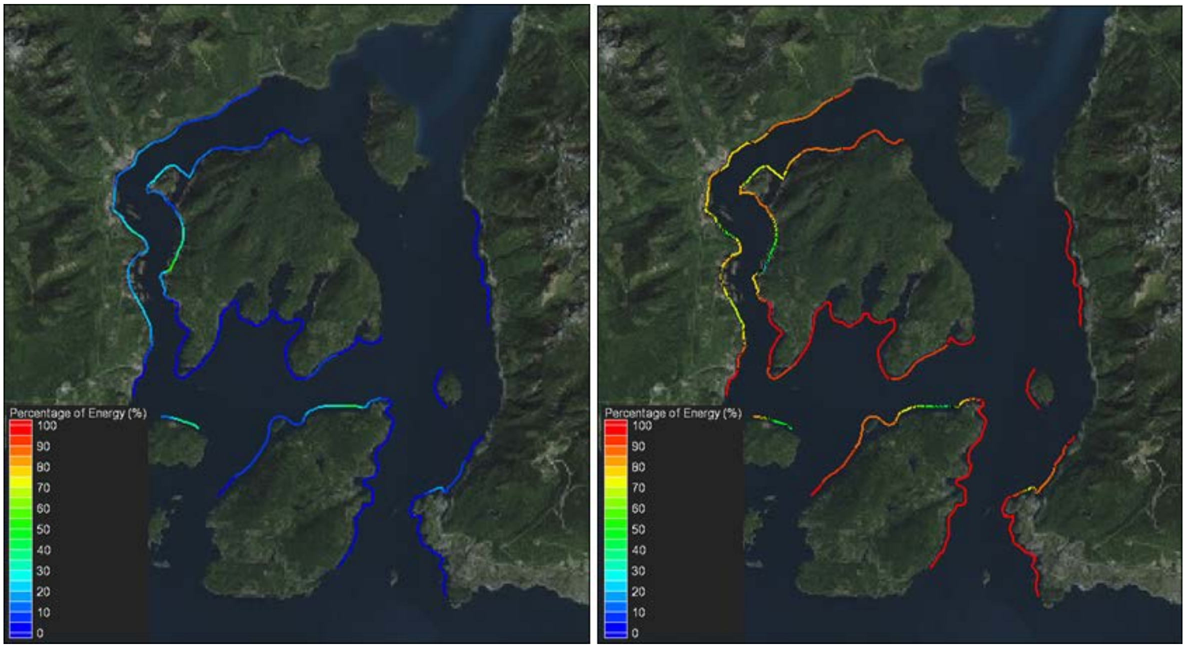

Figure 6: Contribution of annual energy flux percentage for water taxi wake wash (left) and wind-waves (right) along route 1.

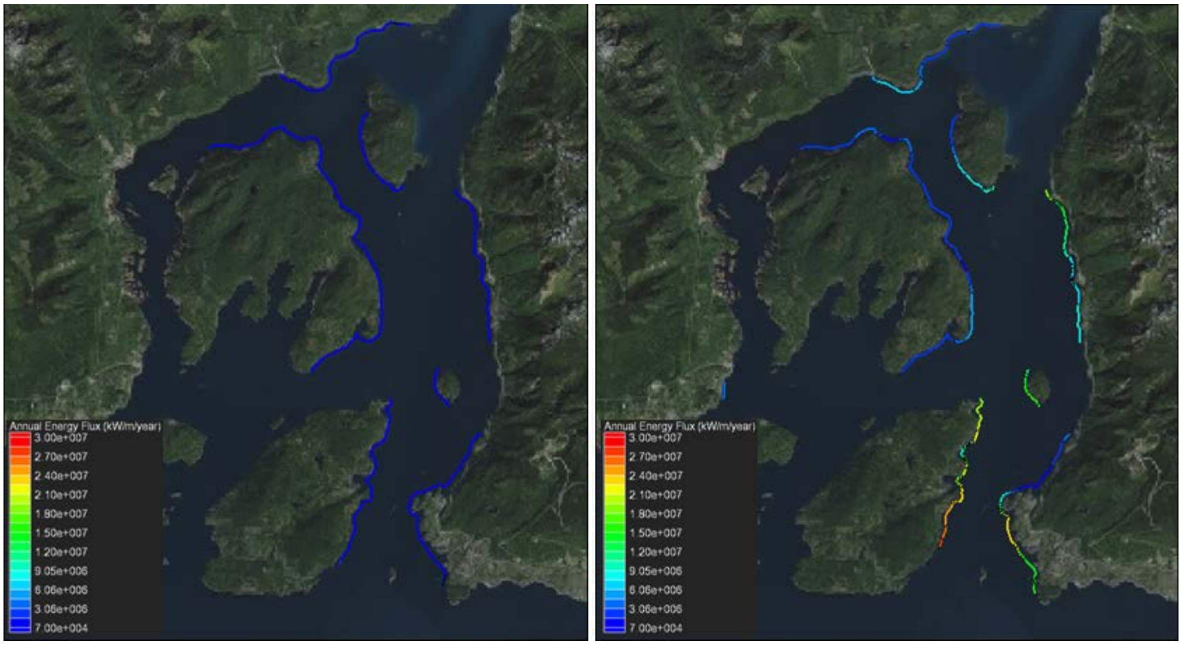

Figure 7: Annual energy flux for water taxi wake wash (left) and wind-waves (right) along route 2.

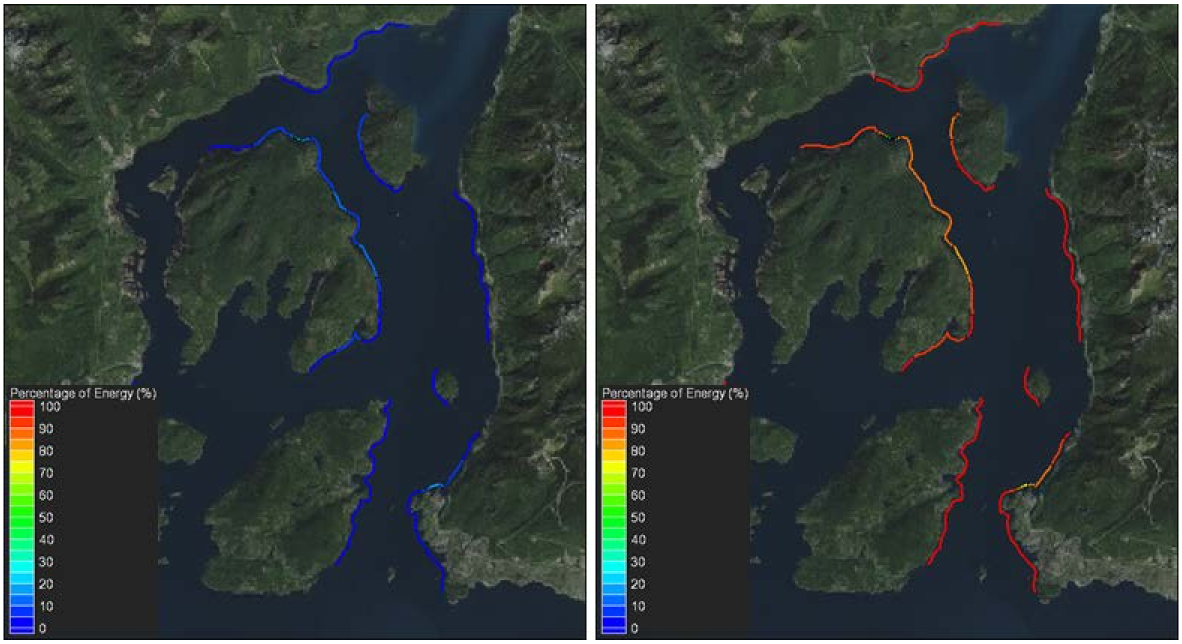

Figure 8. Contribution of annual energy flux percentage for water taxi wake wash (left) and wind waves (right) along route 2.

5.0 CONCLUSIONS

Wind events during winter months in Howe Sound typically generate wave forces which exceed those that may be generated by Project- related vessels along many of the shorelines of route 1 and all of the shorelines along route 2. The expected impact of vessel wake from the tug and barge operating in the Project area would contribute less than 1% to the total wave energy along both routes. The cumulative energy generated by the water taxi is a dominant contributor to the annual wave energy flux along some shorelines of route 1through Thornborough Channel. In general, the magnitude of the wave energy generated by the water taxi, assuming 260 round trips per year, is about 75% less than the magnitude of the wind-wave energy along the shorelines of route 1. Given the amount of existing recreational and commercial vessel activity within Howe Sound, wake wash produced during vessel transits for the proposed Project are not anticipate to adversely affect community resources (*e.g.*, recreational areas, marinas, personal property).

6.0 CLOSURE

We trust the information contained in this report is sufficient to assess potential effects of vessel wake on community, marine, and other resources. Should you have any additional questions regarding the Project, please do not hesitate to contact the undersigned.

Report Signature Page

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