4.3 Underwater Noise Assessment Highlights:

- The Project area is highly developed and existing underwater noise levels in the Fraser River, dominated by noise from vessels transiting the river, are relatively high.
- The proposed bridge will have a clear-span over the Fraser River and Deas Slough, minimizing instream works and the potential for underwater noise effects associated with construction.
- Sources of construction-related underwater noise such as driving piles along the edges of Deas Slough will be temporary in nature. Propagation of underwater noise from these sources can be mitigated effectively by scheduling such activities during periods of low tide when work can be completed under shallow water conditions or in the dry, thereby minimizing potential effects.
- Applying mitigation, including underwater noise monitoring and management during construction, will minimize the potential for Project-related changes in underwater noise conditions to affect fish or marine mammals.
- No post-construction residual effects or cumulative effects on underwater noise conditions are expected.

4.3 Underwater Noise

This section describes the existing conditions of underwater noise in the Fraser River South Arm, and Deas and Green Sloughs, and anticipated changes that may result from Project-related construction and operational activities. Underwater noise comprises one of the 'steps' along the pathway of effects of the Project, with fish and fish habitat and marine mammals being the ultimate receptors of Project-related effects. Underwater noise was therefore assessed as an intermediate component (IC) and information on estimated Project-related changes in underwater noise levels was used to support the assessment of Project-related effects on the following valued components (VCs): fish and fish habitat (**Section 4.4 Fish and Fish Habitat**) and marine mammals (**Section 4.6 Marine Mammals**).

4.3.1 Context and Boundaries

This section describes the context for assessment of Project-related effects on underwater noise in terms of Project setting, and defines the spatial, temporal, administrative and technical assessment boundaries. Rationale for selecting the assessment boundaries as defined is also provided.

4.3.1.1 Assessment Context

The Project includes on-shore installation of stone columns and driven piles, localized instream stone column and pile installation along the edges of Deas Slough to support the piers for the clear span over Deas Slough, restoration of Green Slough to its historic alignment, and removal of the four central segments of the Tunnel. Some of these activities have the potential to generate underwater noise that could affect marine mammals and fish in the Fraser River South Arm and Deas Slough. Therefore, predicting the anticipated change in underwater noise conditions during Project construction will support the assessment of Project-related effects on these valued components (VCs). Additional information on the selection of VCs, and the link between underwater noise and the VCs listed above is provided in **Section 3.1 Issues Scoping and Selection of Valued Components**.

4.3.1.2 Methodology

The assessment of underwater noise followed the general methodology described in **Section 3.0 Assessment Methodology**.

In early 2014, the Ministry initiated field and desktop studies to support planning and environmental assessment of the Project. The studies were designed to build on existing information and address known data gaps.

The objectives of the underwater noise studies were to:

- Measure background (ambient) underwater noise levels in areas that could potentially be affected by the Project to establish a baseline for evaluation of Project activities.
- Estimate areas where Tunnel decommissioning and construction activities might elevate underwater sound levels above the baseline.
- Estimate spatial zones where fish and marine mammals could potentially be affected by underwater noise generated by Project-related construction.

These objectives were addressed through completion of specific studies outlined in **Table 4.3-1**.

Table 4.3-1 Underwater Noise Studies to Support the Assessment

Study Name	Study Description
Field Survey	Existing levels of background (ambient) underwater noise were measured in the Fraser River South Arm and Deas Slough.
Modelling Study	Acoustic models were used to predict the noise footprint of Tunnel decommissioning and proposed bridge construction activities.

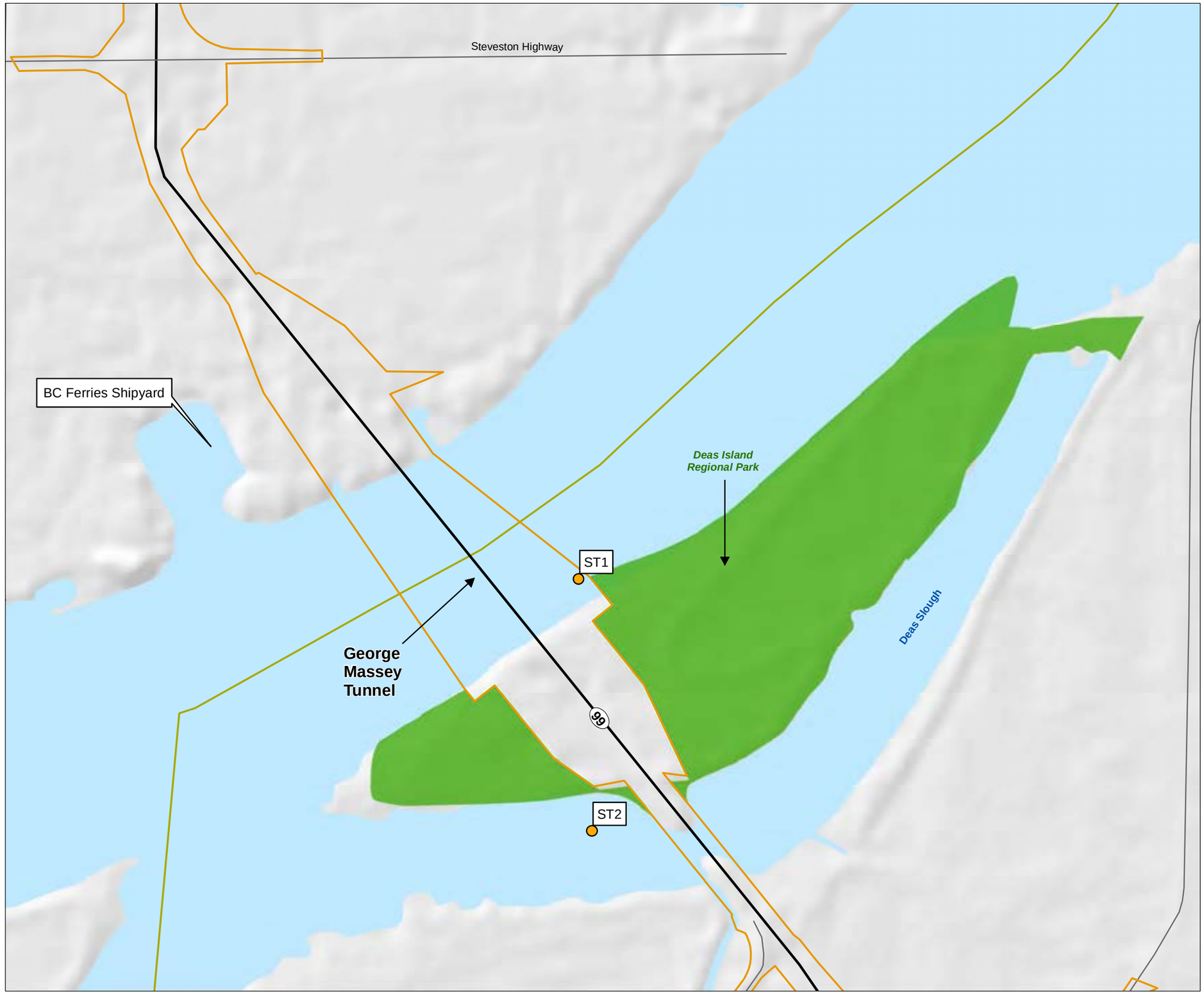
4.3.1.3 Assessment Boundaries

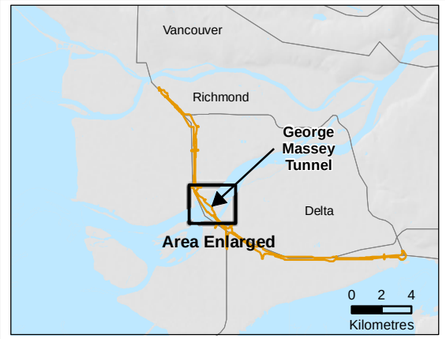
The assessment boundaries for underwater noise are defined below.

Spatial Boundaries

The assessment area includes those areas of the Fraser River South Arm, Deas Slough and Green Slough where noise generated by Project construction activities could potentially exceed background noise levels. Determination of the spatial extent of this zone is informed by the results of underwater sampling and modelling. The predicted extent of areas where potential Project-related change in underwater noise levels could influence receptor VCs (fish and marine mammals), based on results of modelling, is discussed in **Section 4.3.3**.

Underwater noise sampling at two locations, one in the Fraser River South Arm (ST1) and the other in Deas Slough (ST2) as shown on **Figure 4.3-1**, was undertaken to determine baseline noise levels in the identified zone. The sampling sites were selected based on proposed locations of Project-related activities that are likely to generate underwater sound that exceeds existing background ambient noise levels. Sampling stations were located near the banks of the river, off the main traffic routes, to prevent possible damage to instruments by passing vessels. Riverbed bathymetry of both the Fraser River South Arm and Deas Slough is fairly uniform close to the Tunnel construction site; therefore mean sound levels are not expected to vary substantially across the channels.





Legend

- Underwater Noise Sampling Location
- Project Alignment
- Municipal Boundaries
- Waterbody
- Highway
- Arterial/Collector Road

SOURCES

Parks and Protected Lands, First Nations Reserves from GeoBC, United States basemap data courtesy of USGS. Burns Bog courtesy of The Corporation of Delta and based on the Metro Vancouver Burns Bog Ecological Conservancy Area Management Plan - May 2007, all other data courtesy of Canvec - GeoGratis.

N

1:10,000

0 100 200 300 400 500

Metres

GEORGE MASSEY TUNNEL
REPLACEMENT PROJECT

UNDERWATER NOISE
SAMPLING LOCATIONS

Figure 4.3-1	13/05/2016

George Massey Tunnel Replacement Project | BC JOBS PLAN | B.C. on the Move

Path: O:\217-299\285\077\03\mxd\Underwater_Noise\EA\Fig4-3-1_285_077_03_EA_UW-Samples_160503_FINAL.mxd

Temporal Boundaries

Temporal boundaries for the assessment of Project-related effects on underwater noise were established based on the potential for the construction phase of the Project to interact with and have an effect on underwater noise. As discussed in **Section 3.1 Issues Scoping and Selection of Valued Components**, the construction phase of the Project includes components and activities that could interact with and affect underwater noise; therefore, the following temporal boundaries were defined for underwater noise assessment:

- Existing conditions
- Construction phase (including decommissioning of the Tunnel)
- Operations phase (including maintenance)

Temporal characteristics of the Project phases are discussed in **Section 1.1 Description of Proposed Project**.

Administrative Boundaries

No political, economic, or social constraints that could impose limitations on the assessment of potential Project-related effects on underwater noise have been identified; therefore, no administrative boundaries are defined.

Technical Boundaries

Due to logistical considerations, underwater noise sampling locations were placed away from the marine traffic routes, closer to the riverbanks. This is not expected to influence the baseline measurements, since mean ambient noise levels are not expected to vary substantially across the width of the channel at either of the sampling locations.

4.3.2 Existing Conditions

This section provides an overview of the methodology for collecting baseline data, and describes the existing underwater noise conditions within the assessment area. An overview of the regulatory context for management of underwater noise as relevant to the Project is also provided. A brief overview of acoustic fundamentals and terminology that is relevant to the discussion of underwater noise is presented below.

Acoustic Fundamentals and Terminology

The terms noise level and sound level refer to sound pressure level (SPL)[1]. As sound volume increases, there is a logarithmic increase in noise level. Therefore, to adequately express the very large range of pressure fluctuations, SPL is expressed on a logarithmic scale in decibels (dB), where an increase in sound energy by a factor of 10 corresponds to a 10 dB increase in sound level.

Several acoustic metrics are typically used to characterize the SPL of underwater sounds. These metrics, which may be presented in the form of graphs, tables, or maps, include root mean square (rms) SPL, peak SPL, and Sound Exposure Level (SEL).

The time-average sound pressure (expressed as rms SPL) quantifies the average pressure in a given time window of noise. The maximum instantaneous sound pressure is expressed as peak SPL. The total sound exposure, expressed as SEL, measures the total sound energy contained in one or more sound pulses.

4.3.2.1 Baseline Data Collection

To measure baseline underwater noise levels prior to any Project construction activities, an Autonomous Multichannel Acoustic Recorder (AMAR; JASCO Applied Sciences) was deployed in the Fraser River South Arm channel (ST1; **Figure 4.3-1**) and in Deas Slough (ST2; **Figure 4.3-1**) from May 9 to 11, 2014. The AMAR was precisely calibrated to accurately measure noise levels continuously for 48 hours over the frequency range of 10 to 64 kHz. The objective of measuring baseline noise levels was to provide a quantitative description of underwater ambient noise in the Project Area.

4.3.2.2 Regulatory Context

There are no regulatory thresholds for the management of underwater noise in Canada. Thresholds for marine mammals and fish recommended by the U.S. National Marine Fisheries Service (NMFS) and DFO have been adopted for this Project. These recommended thresholds are described below.

[1] SPL is equal to 10 times the logarithm of the square of the sound pressure, in units of Pascals, divided by the square of a standard reference sound pressure.

Auditory Injury Thresholds

Beyond certain thresholds, underwater noise has the potential to injure marine mammals and fish. Auditory injury thresholds, or the levels at which injury to hearing organs can occur, are provided in **Table 4.3-2** and **Table 4.3-3** and discussed in the following.

Based on a review of data on hearing, and physiological and behavioural responses of marine mammals to anthropogenic sound, Southall et al. (2007) proposed species-specific mathematical functions (referred to as M-weighting functions) to filter sounds so as to reduce the parts of the frequency spectrum that the species of interest do not hear well (**Table 4.3-2**). Harbour seals, Steller sea lions, and California sea lions, all of which are pinnipeds, are the main species of concern in the assessment area. The M-weighting function specific to pinnipeds has been applied in this analysis. Southall et al. (2007) recommended dual thresholds for auditory injury based on peak SPL and M-weighted 24-hour SEL (i.e., the total sound exposure level for animals exposed to sounds generated in a 24-hour period).

The U.S. National Marine Fisheries Service (NMFS) has applied an auditory injury threshold for pinnipeds based on the rms SPL of a single pulse (**Table 4.3-2**).

Table 4.3-2 Auditory Injury Thresholds for Pulsed Sounds from the U.S. National Marine Fisheries Service (NMFS) and Southall et al. (2007) for Pinnipeds in Water

NMFS Level A Take Threshold rms SPL (dB re 1 µPa)	Southall et al. (2007) Peak SPL Threshold (dB re 1 µPa)	Southall et al. (2007) M-weighted 24-Hour SEL Threshold (dB re 1 μPa^2s)
190	218	186

Note: dB re 1 µPa = Units for decibels for underwater noise

Table 4.3-3 summarizes the Interim Criteria for Injury to Fish from Pile Driving Activities (AIP) developed by the U.S. Fisheries Hydroacoustic Working Group (FHWG 2008) and Fisheries and Oceans Canada (DFO) (B.C. MPDCA 2003).

Table 4.3-3 FHWG (2008) and DFO (B.C. MPDCA 2003) Auditory Injury Thresholds for Fish

Reference	Peak SPL (dB re 1 µPa)	SEL (dB re 1 μPa^2s)
FHWG (2008) fish ≥2 g	206	187
FHWG (2008) fish <2 g	206	183
DFO (2003) fish	210	-

Behavioural Disturbance Criteria

For marine mammals, the area of potential disturbance is often taken as the zone where underwater noise levels exceed 120 dB rms SPL (NOAA 2015, Southall 2007). Behavioural disturbance, however, is complex and depends on factors such as exposure duration, noise source type, habituation, and exposure context.

Underwater noise does not have the potential to cause behavioural effects when it falls below the background ambient noise level.

4.3.2.3 Existing Conditions

Characterization of existing conditions of underwater noise within the study area is based on the results of the underwater acoustic field measurements. The ambient measurements from acoustic recordings show that shipping traffic is the dominant source of variability in the data above 100 Hz frequency band in the Fraser River South Arm (**Appendix A**, **Figure 1**) and above 1,000 Hz in Deas Slough (**Appendix A**, **Figure 2**).

Constant machinery noise, possibly originating from shore, is present in the background of the recordings. For both monitoring locations, a small number of relatively high-amplitude noise events (e.g., passing vessels) contribute most of the sound energy. Intermittent low-frequency (less than 50 Hz) noise was observed at both recording locations during two six-hour periods. The source of this low frequency noise could not be identified.

Distributions of the total SPL measured over a wide frequency range (broadband sound levels) in the Fraser River South Arm and in Deas Slough are presented in **Table 4.3-4**. Ambient measurements in the Fraser River South Arm exceed 120 dB re 1 µPa[2], 20% of the time. The higher sound levels are primarily due to larger vessels, such as tugs and container ships, transiting the river. Ambient measurements in Deas Slough are substantially lower than in the main channel because vessel traffic in the slough consists primarily of smaller, slow-moving boats transiting to and from the marinas.

Table 4.3-4 Existing Distribution of the Broadband Sound Levels Measured in the Fraser River South Arm and Deas Slough

Sampling Location	5% Exceedance Level (dB re 1 µPa)	Median Level (dB re 1 µPa)	95% Exceedance Level (dB re 1 µPa)
Fraser River South Arm	126.6	108.7	93.6
Deas Slough	99.3	91.9	82.4

[2] dB re 1 µPa is the standard unit of decibel measurement for underwater noise.

4.3.3 Potential Effects

This section provides a summary of anticipated changes to underwater noise related to the construction and operation of the Project. It also describes the methodology used to assess potential Project-related effects.

4.3.3.1 Project Interactions

A preliminary review of the potential effects of Project interactions on underwater noise, intended to focus the assessment on those interactions of greatest importance, is presented below. Interactions rated as having no effect are not considered further in the assessment.

Construction: Key Project-related construction activities with the potential to interact with underwater noise include the following:

- On shore ground improvements and pile driving for the new bridge piers.
- Localized in-stream ground improvement and pile installation for the clear span over Deas Slough.
- Removal of the four central Tunnel segments.
- Transportation of Tunnel segments for offsite recycling.

Operation: As the new bridge will have a clear span across the Fraser River South Arm, Project activities (including routine maintenance) are expected to have minimal influence on underwater noise.

An overview of potential interactions between Project activities and underwater noise during the construction and operation of Project components is provided in **Appendix B**.

4.3.3.2 Potential Effects

Project effects on underwater noise were assessed by modelling the expected underwater noise levels generated by Project activities. An overview of the underwater acoustic modelling that was completed is presented in this section. Further detail, including construction activities selected for modelling and the rationale for the selection, assumptions made regarding construction scenarios, equipment types, and source noise levels are provided in the technical volume, **Underwater Noise Modelling Study** included under **Section 16.3**.

The Marine Operations Noise Model was used to estimate the underwater sound levels associated with the following Project activities:

- Scenario 1: Pile driving along the edge of Deas Slough
- Scenario 2: Vibratory installation of piles along the edge of Deas Slough
- Scenario 3: Vibrodensification along the edge of Deas Slough
- Scenario 4: Cutter suction dredging to remove sediment overlying the Tunnel
- Scenario 5: Tug and barge activity when Tunnel segments are being removed
- Scenario 6: Simultaneous removal of sediment and riprap, and tug and barge activity during Tunnel removal

The results of the Marine Operations Noise Model were used to generate visual maps of peak SPL, rms SPL, and SEL for each of the six scenarios. The reported sound levels were applied as the maximum levels over all depths that were modelled.

Potential Effects

Human-generated noise, referred to as anthropogenic noise, is commonly categorized as pulsed or non-pulsed sounds. Pulsed sounds are brief (less than few seconds) and intermittent, with rapid changes of sound pressure (e.g. an impact-hammer strike). Non-pulsed sounds are characterized by gradual changes in sound pressure over time (e.g., marine vessels transiting and a vibratory pile driver in operation).

Effects from Pulsed Noise Sources

The highest level of pulsed noise is anticipated to be generated by pile driving along the edge of Deas Slough. Results of underwater noise modelling of the scenario involving 100 minutes (3,500 blows) of impact pile-driving along the edge of Deas Slough indicate that the potential extent of acoustic injury zone (defined by the two FHWG SEL threshold criteria, FHWG 2008) associated with this activity will be within 700 m for fish weighing less than two grams, and approximately 600 m for fish weighing two grams or more. Modelling results also indicate that underwater noise levels generated by the modelled scenario would be lower than the thresholds recommended for preventing auditory injury in pinnipeds, as per Southall et al. (2007), beyond 600 m from the source. These predictions are considered conservative because in arriving at them, the model assumes that the receiver (i.e., fish or marine mammal) is stationary for the duration of the sound exposure. Avoidance behaviour by marine mammals and fish would lessen their overall sound exposure and thus reduce the duration of time they would spend in the injury zone for impact pile-driving.

The modelling scenario assumed pile driving along the edge of Deas Slough through a maximum water depth of five metres, which corresponds to a high tide. Much of the actual Project-related construction along the edge of Deas Slough would occur under lower water conditions or in the dry with low tide. As such, actual underwater noise levels generated by pulsed sources associated with Project construction are expected to be lower than the values predicted through modelling.

Effects of Non-Pulsed Noise Sources

Of the non-pulsed noise sources modelled, cutter suction dredging was found to generate the highest levels of underwater noise. The extent within which the behavioural disturbance threshold for marine mammals (120 dB re 1 µPa SPL zone) was reached was smallest (0.44 km) for tug and barge activities associated with crane lift of the Tunnel segments. Noise generated by tug and barge traffic associated with the Project was found similar to existing ambient noise levels in the Fraser River South Arm, where the behavioural disturbance threshold for marine mammals is exceeded 20% of the time, primarily due to larger vessels such as tugs and container ships transiting in the river. Of the non-pulsed noise sources modelled, a combination of cutter suction dredging, rip rap removal, and tug and barge operations was found to create the largest zone (3.45 km) where the behavioural disturbance threshold for mammals is exceeded.

Although vibratory pile driving was identified as the source of highest level of non-pulsed noise, modelling results indicated that noise from this activity was concentrated at low frequencies (< 200 Hz), which dissipate rapidly in the shallow sediments of Deas Slough, confining the zone where the marine mammal behavioural disturbance threshold is reached to a relatively small (0.6 km) extent within Deas Slough.

Sound is strongly attenuated in shallow water such at Deas Slough because of increased bottom loss due to absorption of sound energy by sediments. Furthermore, bottom loss is enhanced by soft sediments such as silt and clay, which are more absorptive than harder materials like sand and gravel. As a result, noise from construction activities is expected to attenuate more rapidly with distance in Deas Slough than in the Fraser River South Arm. In Deas Slough, sound propagation is further restricted by Deas Island and the surrounding riverbank.

4.3.4 Mitigation Measures

A hierarchical approach, based on avoidance of potential effects followed by minimization or reduction of unavoidable effects, was used in identifying strategies to mitigate potential Project-related effects on underwater noise.

Measures to avoid potential effects have been/will be incorporated into project considerations such as site and route selection, scheduling, design, and construction and operation procedures and practices. Where potential effects cannot be avoided through project considerations, standard mitigation measures, best management practices (BMP), and construction and operational environmental management plans (EMPs) will be implemented to minimize potential Project-related effects or reduce them to acceptable levels. These measures are described in general terms below.

4.3.4.1 Avoidance

The new bridge will span the Fraser River from bank to bank without the need for any permanent works below the high water level. This approach has been taken to avoid, as much as possible, Project-related effects on the river and sloughs, including generation of underwater noise during construction and operation. Similarly, a clear span is proposed over Deas Slough as well.

Propagation of underwater noise from activities such as driving piles along the edges of Deas Slough, which are the primary sources of Project-related underwater noise, can be mitigated effectively by avoiding undertaking them in water. Scheduling such activities during periods of low tide, when work can be completed under shallow water conditions or in the dry, is expected to minimize potential effects on underwater noise.

4.3.4.2 Minimization

In instances where avoidance of underwater noise propagation cannot be achieved through scheduling, environmental protection measures will be implemented to avoid or minimize the effect of Project-related change in underwater noise conditions on receptors (fish and marine mammals). These measures, which will involve monitoring and mitigation of underwater noise, will be outlined in a Marine Mammal Management Plan included under the Construction Environmental Management Plan (CEMP) for the Project as described in **Section 12.0 Management Plans**.

The Marine Mammal Management Plan will include a description of standard best practices and mitigation measures that will be implemented to minimize the effects of underwater noise generated during marine-based construction activities. Mitigation and monitoring measures for underwater noise described in the plan will include, but will not be limited to:

- Limited use of engines and propellers on stationary vessels, whenever possible.
- Maintaining consistent navigation courses and speeds.
- Conducting land-based pile driving whenever possible.
- Conducting activities with the potential to generate underwater noise as efficiently as possible.
- Avoiding unnecessary idling of marine-based equipment.
- Implementation of marine mammal monitoring during activities anticipated to generate underwater noise, including an underwater noise monitoring program.
- Underwater noise monitoring conducted during Project construction activities that have the potential to generate underwater sound levels that may exceed auditory thresholds that can cause physical injury to fish or marine mammals.

Underwater noise monitoring will be conducted using a hydrophone at the onset of pile driving activities to confirm the results of this assessment and ensure underwater noise levels do not exceed auditory injury thresholds as described in **Section 4.3.2.2**. If warranted by the results of monitoring, additional mitigation measures (e.g., bubble curtains or sound-damping sleeves) will be deployed.

Measures identified above are standard best practices proven to be effective in managing underwater noise levels during in- or near-water construction. Specific mitigation measures such as deployment of bubble curtains and sound-damping sleeves are proven techniques shown to reduce underwater pile driving sound levels by 10 dB or more (ICF Jones and Stokes, and Illingworth and Rodkin Inc. 2009).

4.3.5 Residual Effects

As discussed in **Section 4.3.3.1**, the new bridge will have a clear span across the Fraser River South Arm and Deas Slough, and post-construction activities (including routine maintenance) are expected to have minimal influence on underwater noise. Therefore, no residual adverse effects on underwater noise are expected post construction.

Implementation of mitigation measures during pile driving, as discussed in **Section 4.3.4**, including construction scheduling that allows noise-generating activities to be undertaken in shallow water or in the dry, are expected to avoid or minimize the potential to generate pulsed sounds at levels capable of inducing auditory injury in marine mammals and fish.

In-water construction activities, specifically those associated with Tunnel decommissioning, are expected to generate temporary, localized increases in non-pulsed noise levels during Project construction. Implementation of mitigation measures discussed in **Section 4.3.4** are expected to minimize the potential to generate underwater noise levels above the baseline condition.

Unavoidable temporary construction-related effects on underwater noise are categorized as follows, and characterized below in terms of the direction, magnitude, extent, duration, frequency, reversibility, and likelihood of the effect:

- Residual effect #1: Effects from pulsed noise sources (e.g. impact pile driving)
- Residual effect #2: Effects from non-pulsed noise sources (e.g. removal of Tunnel segments and overlying material)

Definitions for ratings applied to residual effects criteria, developed with specific reference to underwater noise, are presented in **Table 4.3-5**. Summary of criteria ratings for the potential residual effects is provided in **Table 4.3-6** and **Table 4.3-5**. Context for the characterization of the residual effect, i.e. sensitivity/resilience of underwater noise conditions to potential Project-related effects, based on existing conditions, is also provided. Given the close link between Potential Project-related changes in underwater noise conditions and effects on receptor VCs–i.e. fish and fish habitat, and marine mammals–characterization of residual effects is presented in the context of their influence on receptor VCs. Specifically, the magnitude of potential residual effects is discussed in terms of potential for increase in underwater noise levels to cause behavioural disturbance or auditory injury in fish or marine mammals.

Table 4.3-5 Criteria Used to Characterize Residual Effects on Underwater Noise

Criteria	Description	Definition of Rating	
Direction	Overall nature of the residual effect	Adverse	Negative effect as a result of the Project.
		Positive	Beneficial effect as a result of the Project.
		Neutral	Neutral effect as a result of the Project.
Magnitude	Intensity of the effect relative to natural or baseline conditions	Negligible	No measurable change in underwater noise level
		Low	A measurable change within natural variability, and not expected to affect receptor VCs (i.e. fish and marine mammals)
		Moderate	A measurable change outside the range of natural variability, but not expected to result in substantive effects on receptor VCs.
		High	A measurable change outside the range of natural variability and potentially harmful to receptor VCs.
Extent	Geographic extent / distribution of the residual effect	Site	Effect is restricted to the immediate Project alignment.
		Local	Effect is restricted to the LAA.
		Regional	Effect extends beyond the LAA
Duration	Length of time over which the residual effect is expected to persist	Short term	Effect occurs for a limited period during Project construction and does not persist beyond several hours at a time.
		Moderate term	Effect persists over a period of days to weeks during construction.
		Long term	Effect persists beyond construction phase, or Change is permanent.

Criteria	Description	Definition of Rating	
Frequency	Nature of the occurrence of the residual effect (e.g., how often the stressor affects the IC)	Rare	Effect occurs for a limited number of times during Project construction or operation.
		Uncommon	Effect occurs intermittently during Project construction or operation.
		Frequent	Effect occurs frequently during Project construction or operation.
		Continuous	Effect occurs continuously during Project construction or operation.
Reversibility	Potential for the effect to be reversed or naturally return to baseline level after the disturbance has ceased (or after a period of time after the disturbance has ceased)	Reversible	Baseline conditions will be naturally restored after disturbance has ceased.
		Irreversible	Baseline conditions will not be naturally restored after disturbance has ceased.
		Change	Effect may fluctuate between positive and adverse for the duration of the disturbance.
Likelihood	Likelihood that the residual effect may occur	Low	Likelihood of residual effect is less than 10%.
		Moderate	Likelihood of residual effect is between 10% and 25%.
		High	Likelihood of residual effect is greater than 25%.

4.3.5.1 Residual Effect #1: Effects from Pulsed Noise Sources

After implementing mitigation measures discussed in **Section 4.3.4**, potential impact pile driving along the edges of Deas Slough is not expected to expose fish or marine mammals to pulsed noise levels capable of inducing auditory injury. Nonetheless, residual pulsed noise at lower levels (including sediment-borne vibration) has the potential to temporarily cause behavioural disturbance and mask sounds used for foraging and communication of marine mammals and fish. **Table 4.3-6** presents a summary of the criteria ratings for this residual effect.

Table 4.3-6 Criteria Ratings for Construction-related Effects from Pulsed Noise Sources

Criteria	Criteria Rating	Rationale for Criteria Rating
Direction	Adverse	Noise-generating construction activities (specifically pile driving) near the shoreline have the potential to result in a temporary increase in underwater noise levels.
Magnitude	Moderate	Majority of noise-generating activities near the shoreline are expected to be undertaken in shallow water or in the dry. With monitoring and mitigation, the resulting changes will be below levels that injure fish or marine mammals.
Extent	Local	Spatial extent will be restricted to the LAA.
Duration	Short term	Effect will occur only during specific noise-generating construction activities undertaken in water, and is not expected to persist beyond the duration of such activities.
Frequency	Rare	Effect will occur only in the rare instance where undertaking a noise-generating activity in water cannot be avoided through management of the construction schedule.
Reversibility	Reversible	Underwater noise conditions will return to baseline conditions as soon as the contributing activity ceases.
Likelihood	Low	Noise-generating activities near the shoreline are expected to be undertaken in shallow water or in the dry, during low tides, minimizing the probability of a measurable change in underwater noise.

4.3.5.2 Residual Effect #2: Effects from Non-Pulsed Noise Sources

In-water activities associated with construction, including removal of Tunnel segments and overlying material, and vibrodensification, will add to underwater noise levels in the river. Noise from these activities has the potential to cause behavioural disturbance and mask sounds used for foraging and communication of marine mammals and fish. **Table 4.3-7** presents a summary of the criteria ratings for this temporary, construction-related residual effect.

Table 4.3-7 Criteria Ratings for Effects from Non-Pulsed Noise Sources

Criteria	Criteria Rating	Rationale for Criteria Rating
Direction	Adverse	Noise-generating construction activities in or immediately adjacent to water have the potential to result in a temporary increase in underwater noise levels.
Magnitude	Low to Moderate	Noise from construction activities are expected to be temporary and localized, and fall within the present range of sound levels generated by vessel traffic in the river.
Extent	Local	Spatial extent will be restricted to the LAA.
Duration	Short term	Effect will occur only during specific noise-generating construction activities undertaken in water, and is not expected to persist beyond the duration of such activities.
Frequency	Uncommon	Effect will occur only during specific noise-generating construction activities undertaken in water, including removal of Tunnel segments and overlying material, and vibrodensification
Reversibility	Reversible	Underwater noise conditions will return to baseline conditions as soon as the contributing activity ceases.
Likelihood	High	There is estimated to be a greater than 25% probability that a measurable change in underwater noise will occur during in-water construction and Tunnel decommissioning activities.

Context: The Fraser River South Arm is an active marine transportation corridor, and existing underwater noise levels in the Project area, dominated by noise from vessels transiting the river, are relatively high. Sensitivity of underwater noise conditions in the river to temporary, short-term changes resulting from in-water construction activities, including Tunnel decommissioning, is therefore considered to be low.

When examining the characteristics of residual effects of construction, including Tunnel removal, on underwater noise, it is important to appreciate that the characterization criteria as discussed above are applied to underwater noise as an IC. Characterization of potential effects of changes in underwater noise conditions on receptor VCs is included in the respective VC effects assessment sections (i.e. **Section 4.4 Fish and Fish Habitat** and **Section 4.6 Marine Mammals**).

4.3.6 Cumulative Effects Assessment

Where Project-related construction results in a temporary, short-term increase in underwater noise levels in the Fraser River South Arm, Deas Slough, or Green Slough, such changes are not anticipated to overlap spatially or temporally with other projects or activities and result in cumulative effects.

4.3.7 Follow-up Strategy

Underwater noise monitoring will be conducted using a hydrophone at the onset of pile driving activities to confirm the results of this assessment and ensure underwater noise levels do not exceed applicable auditory injury thresholds for marine mammals and fish.

No post-construction underwater noise monitoring or follow-up is proposed as no potential Project-related effects on underwater noise is anticipated after completion of construction.

4.3.8 References

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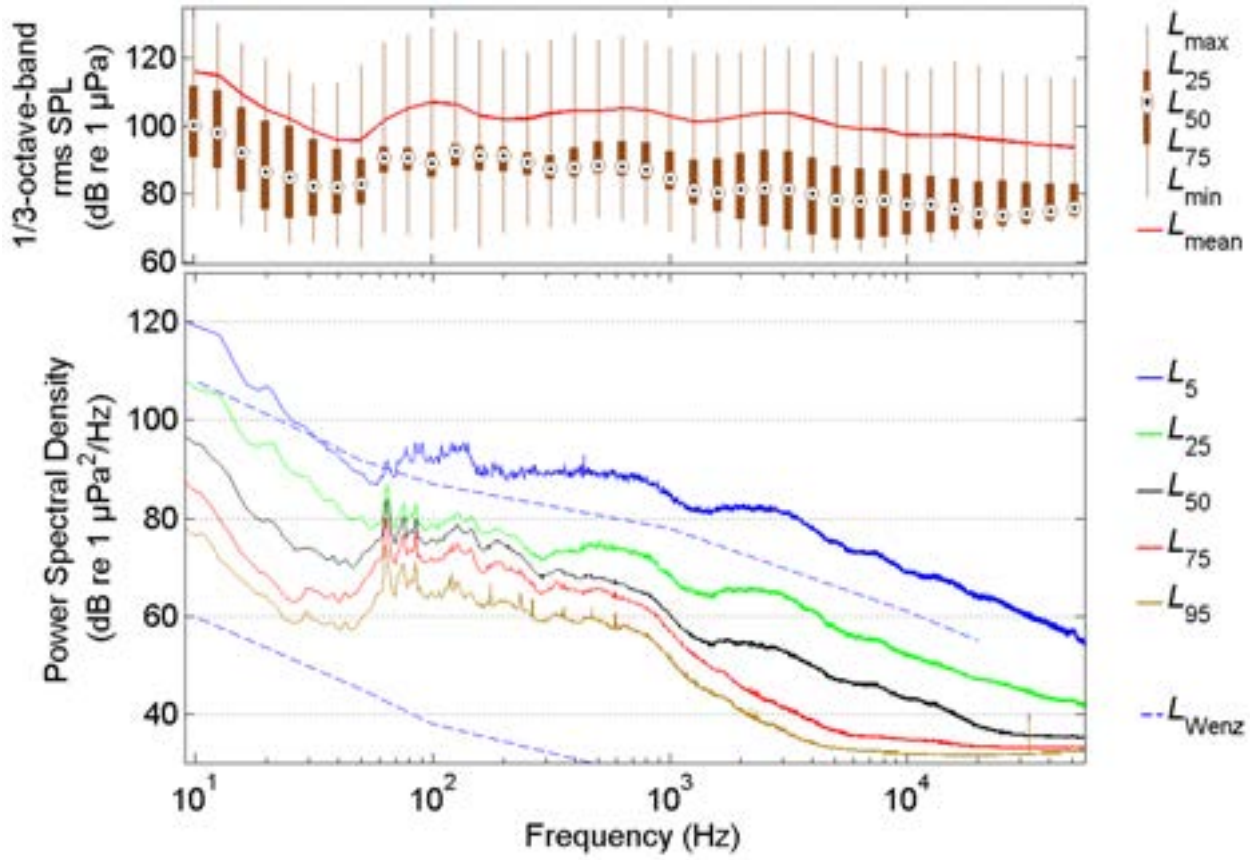
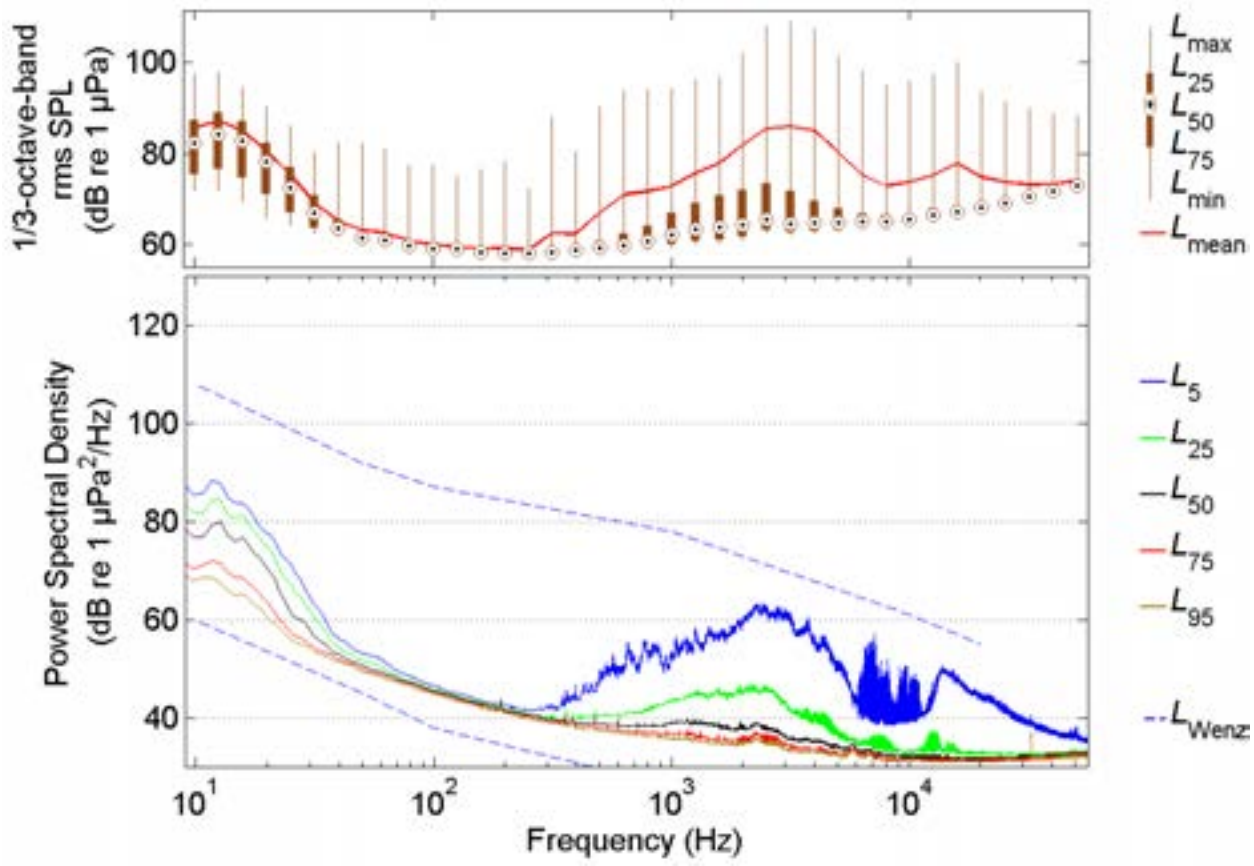
APPENDIX A

Statistical Distribution of Ambient Noise Measured in the Fraser River South Arm and Deas Slough



Notes: Top: The boxes indicate the first (25%), second (50%), and third (75%) quartiles. The red line indicates the linear mean. Bottom: The *Nth* percentile corresponds to the sound level that was exceeded by *N*% of the data.

Figure 1 **Station 1, Fraser River South Arm. Top: Statistics of 1/3-octave-band rms Sound Pressure Levels (1-minute average) over a 24-hour Recording Period. Bottom: Exceedance Percentiles of Ambient Noise Power Spectral Density Levels (1-minute Average) over the Recording Period.**



Notes: Top: The boxes indicate the first (25%), second (50%), and third (75%) quartiles. The red line indicates the linear mean. Bottom: The Nth percentile corresponds to the sound level that was exceeded by N% of the data.

Figure 2 **Station 2, Deas Slough. Top: Statistics of 1/3-octave Band rms Sound Pressure Levels (1-minute Average) over the 24-hour Recording Period. Bottom: Exceedance Percentiles of Ambient Noise Power Spectral Density Levels (1-minute Average) over the Recording Period.**

APPENDIX B

Overview of Potential Project Interactions with Underwater Noise

Table 1 Overview of Potential Project Interactions with Underwater Noise

Project Phase/ Component	Interaction Ranking	Project Works and Activities that Interact with the VC	Nature of Potential Interaction
Pre-Construction / Site Preparation			
Pre-Construction / Site Preparation	No interaction	• Surveying • Clearing and grubbing of vegetation within the existing Highway 99 ROW • Installing temporary drainage structures and diversions • Relocating utilities • Preloading for embankment and highway construction • Acquiring property for the Project	**Nature of interaction:** No interaction anticipated. **Rationale:** All activities to be land-based.
	No effect	• Restoration of Green Slough to its historic alignment • Installing temporary drainage structures and diversions • Conducting additional site investigations (i.e., a geotechnical drilling program)	**Nature of interaction:** Works and activities within or along the shores of the Fraser River South Arm, Deas Slough, and Green Slough. **Rationale:** Activities not expected to have an effect on underwater noise.
	Potential Effect	• Installing temporary bridges and barging facilities	**Nature of interaction**: Works and activities within or along the shores of the Fraser River South Arm. **Rationale**: If activities include in-river construction, some level of underwater noise may be generated.

Project Phase/ Component	Interaction Ranking	Project Works and Activities that Interact with the VC	Nature of Potential Interaction
Construction			
New bridge including approaches and ramp connections	No interaction	• Installing upland piers, including pile installation • Installing drainage structures/settling ponds • Constructing approach spans (concrete deck slab on steel or concrete girder) • Constructing bridge towers and installing support cables using land-based equipment • Installing retaining walls	**Nature of interaction:** No interaction anticipated. **Rationale:** All activities to be land-based.
	No effect	• Ground improvements associated with new bridge piers • Hoisting pre-assembled deck segments from barges in the river or land-based transport system	**Nature of interaction:** Activities with the potential to interact underwater noise. **Rationale:** Activities not expected to have an effect on underwater noise.
	Potential Effect	• Installing piers adjacent to Deas Slough and Green Slough, including pile installation	**Nature of interaction:** Localized ground improvements and pile installation at the edge of Deas Slough. **Rationale:** Noise could be propagated to water through sediment-borne vibration.

Project Phase/ Component	Interaction Ranking	Project Works and Activities that Interact with the VC	Nature of Potential Interaction
Highway 99 improvements, including interchange upgrades	No interaction	• Replacement of interchanges at Westminster Highway, Steveston Highway and Highway 17A • Replacement of over/underpasses at Cambie Road, Shell Road, Highway 91 Westbound Ramp, Blundell Road, Ladner Trunk Road and 112th Street • Highway widening from Bridgeport in Richmond to Highway 91 in Delta including construction of embankments, placing and compacting fill for road base, establishing improved drainage and paving	**Nature of interaction:** No interaction anticipated. **Rationale:** All activities to be land-based.
	No effect	• N/A	N/A
	Potential Effect	• N/A	N/A
Tunnel decommissioning	No interaction	• Backfilling of onshore portions of Tunnel approaches	**Nature of interaction:** No interaction anticipated. **Rationale:** All activities to be land-based.
	No effect	• Removing electrical/mechanical/utilities equipment from the Tunnel	**Nature of interaction:** Potential for interaction. **Rationale:** All activities are enclosed in the existing Tunnel and have low potential for noise.
	Potential Effect	• Removing of four Tunnel segments and associated scour protection • Transporting Tunnel elements for offsite recycling and operating support vessels for that activity	**Nature of interaction:** Dredging, tug and barge operations and removal of rip rap. **Potential Project-related effects include:** Disturbance to fish and mammals.

Project Phase/ Component	Interaction Ranking	Project Works and Activities that Interact with the VC	Nature of Potential Interaction
Decommissioning of Deas Slough Bridge	No interaction	• N/A	**Nature of interaction:** No interaction anticipated.
	No effect	• Removal of Deas Slough Bridge including substructures	**Nature of interaction:** Removal of bridge including substructures with limited instream activities and low potential for underwater noise generation. **Potential Project-related effects include:** none.
	Potential Effect	• N/A	N/A
Operation and Maintenance			
Highway 99 and interchanges	No interaction	• Operating reconfigured Highway 99 and interchanges • Highway 99 and interchange maintenance (drainage maintenance, winter maintenance, emergency maintenance, road cleaning, etc.)	**Nature of interaction:** No interaction anticipated. **Rationale:** Proposed activities will be land-based.
	No effect	• N/A	N/A
	Potential Effect	• N/A	N/A

Project Phase/ Component	Interaction Ranking	Project Works and Activities that Interact with the VC	Nature of Potential Interaction
New bridge	No interaction	• N/A	N/A
	No effect	• Operating the new bridge • Bridge maintenance (winter maintenance, emergency maintenance, structure maintenance, etc.)	**Nature of interaction:** No interaction anticipated. **Rationale:** Proposed activities will be land-based.
	Potential Effect	• N/A	N/A

"N/A" indicates that no Project works and/or activities are applicable to the category