Stantec

Noise Technical Data Report

October 30, 2019

Prepared for:

Broadway Subway Project
Ministry of Transportation and Infrastructure

Prepared by:

Stantec Consulting Ltd.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Executive Summary

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (the Project) to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). The scope of the Project includes a 5.7 km tunnelled alignment (the Alignment), with six stations, running between the existing VCC-Clark Station and the western terminus at Arbutus and Broadway.

Construction of the tunnel and underground stations for the Project is anticipated to result in changes in noise conditions, relative to existing noise conditions in the Project area. During the operational phase of the Project, noise conditions in some areas (i.e., between VCC-Clark Station and the portal adjacent to Great Northern Way) may also change where the Project includes a short section of elevated track.

To support Project planning and procurement, the Project team has undertaken a review of potential noise effects associated with the construction and operation of the Project. This Technical Data Report (TDR) describes field studies, and noise predictive modelling, undertaken to assess potential changes in noise conditions during construction and operation of the Project and includes:

- Review of applicable regulatory noise thresholds
- Methods for determining existing noise conditions in the Review Area
- Results of a noise monitoring program to quantify the existing conditions
- Predictive noise modelling for construction and operation case

As a result of noise studies undertaken, it is anticipated that elevated noise levels may occur during the construction phase but will remain below noise thresholds associated with the City of Vancouver noise By-law No. 6555 (City of Vancouver 2016).

During the operational phase of the Project, elevated noise levels are anticipated to occur adjacent to the elevated portion of the alignment between VCC Clark Station and the portal adjacent to Great Northern Way. When comparing predicted noise levels at nine locations during operation, against the United States Federal Transportation Administration Transit Noise guideline (US FTA 2006), seven noise sensitive receptors fall into the “moderate” impact level, and two noise sensitive receptors fall into the “severe” impact category. Noise mitigation measures are recommended at these two locations.

Abbreviations

BC	British Columbia
dB	linear decibel level
dBA	A-weighted decibel level
FTA	Federal Transit Administration
hp	horse power
hr	hour
ISO	International Organization for Standardization
lb	pound
L_d	daytime equivalent sound level
L_{dn}	daytime and nighttime equivalent sound level
L_{eq}	equivalent sound level
L_n	nighttime equivalent sound level
L_{max}	maximum sound level
m	meter
m^3	cubic meter
MoTI	Ministry of Transportation and Infrastructure

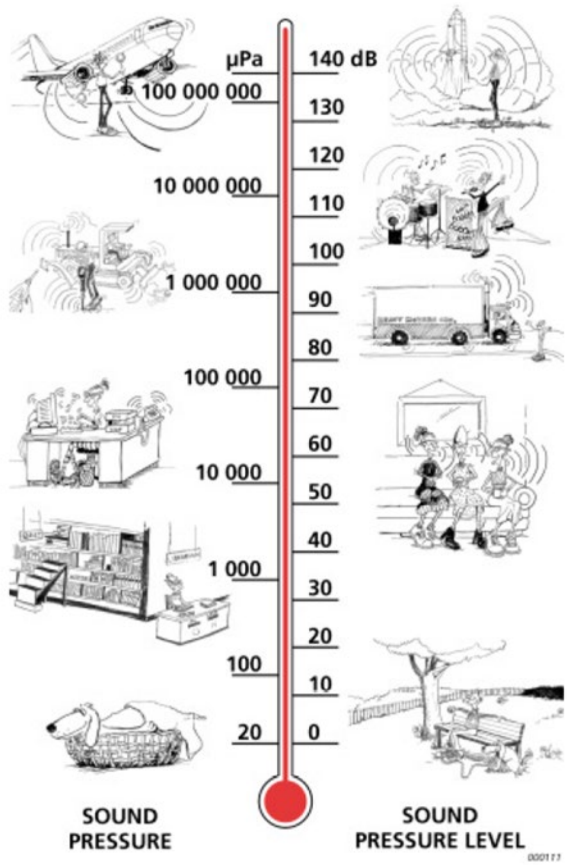
the Project	Broadway Subway Project
US	United States
UTM	Universal Transverse Mercator
SEL	Sound Exposure Level

Glossary

A-weighting	A frequency weighting scale, which corrects the sound pressure levels in individual frequency bands according to human ear sensitivities. The scale is based upon the fact that the region of highest sensitivity for the average ear is between 2,000 and 4,000 Hz. Sound levels are measured on a logarithmic scale in decibels, dB. The universal measure for environmental sound is the A–weighted sound level, dBA.
Airborne Sound	Sound that reaches the point of interest by propagation through air.
Bands (octave, 1/3 octave)	A series of electronic filters separate sound into discrete frequency bands, making it possible to know how sound energy is distributed as a function of frequency. Each octave band has a center frequency that is double the center frequency of the octave band preceding it.
Day-night equivalent sound level	The day-night equivalent sound level (Ldn) is a 24-hour time-averaged Leq, describing a receiver's cumulative noise exposure from all events over a full day. The Ldn includes a +10 decibel adjustment during the nighttime as a penalty for sounds occurring during the night period to account for greater nighttime sensitivity to noise.
Daytime	Defined as the hours from 07:00 AM to 10:00 PM.
dB—Decibel	The logarithmic units associated with sound pressure level, sound power level, or acceleration level. See sound pressure level, for example.
dBA—Decibel, A-Weighted	The logarithmic units associated with a sound pressure level, where the sound pressure signal has been filtered using a frequency weighting that mimics the response of the human ear to quiet sound levels. The resultant sound pressure level is therefore representative of the subjective response of the human ear. A-weighted sound pressure levels are denoted by the suffix 'A' (i.e., dBA), and the term pressure is normally omitted from the description (i.e., sound level or noise level).

Decibel Addition	In acoustics, due to the logarithmic nature of the decibel scale, two or more sound pressure levels (denoted as SPL1, SPL2 … SPLn) are added as follows: SPL1 + SPL2 + …SPLn = 10 log (10 (SPL1/10) + 10(SPL2/10) + …+ 10(SPLn/10)) As an example: 0 dB + 0 dB = 3 dB 50 dB + 50 dB = 53 dB 50 dB + 47 dB = 52 dB 50 dB + 40 dB = 50 dB
Frequency	The number of times per second that the sine wave of sound or of a vibrating object repeats itself. Now expressed in hertz (Hz), formerly in cycles per second (cps).
Nighttime	Defined as the hours from 10:00 PM to 07:00 AM.
Noise	Noise is considered unwanted sound
Receptor	Stationary position at which noise levels are assessed

Typical Sound Pressure
Levels Examples
(Bruel and Kjaer, 2000)

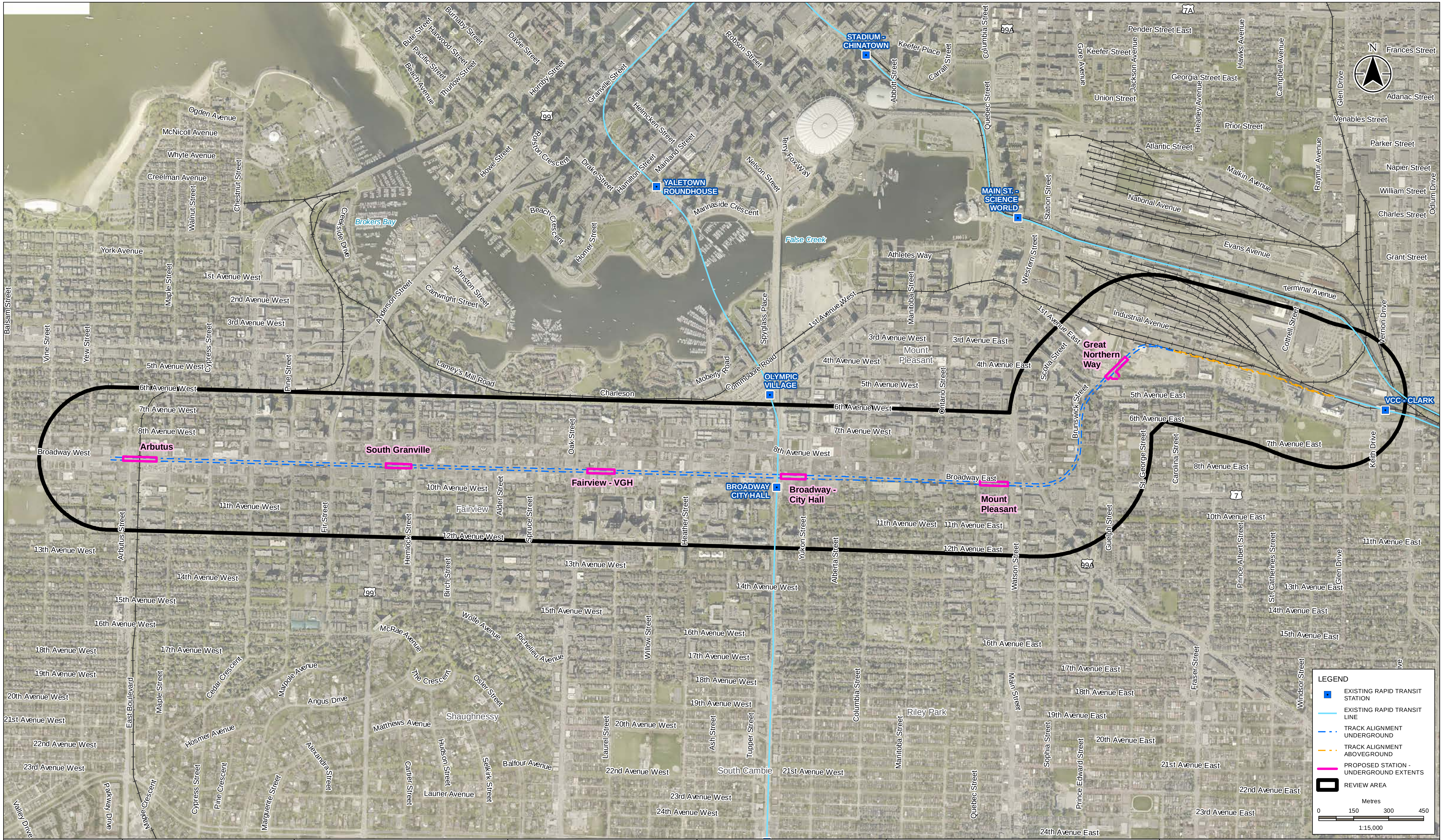


1.0 INTRODUCTION

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (the Project) to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). The scope of the Project includes a 5.7 km tunnelled alignment (the Alignment), with six stations, running between the existing VCC-Clark Station and the western terminus at Arbutus and Broadway.

This TDR presents the following information:

- Noise Review Area (Section 2.0)
- Summary of applicable regulatory requirements (Section 3.0)
- Existing noise conditions for representative sensitive noise receptors within the Review Area (Section 4.0)
- Noise modelling methods and details (Section 5.0)
- Noise modelling results (Section 6.0)
- Summary (Section 7.0)



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING		REVISIONS			
DWG No.	DESCRIPTION	DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

NOISE MONITORING OVERVIEW MAP

SCALE 1:15,000 | DATE 17-11-29 | CONTRACT NO. | SUB CONSULTANT PROJECT NO. 115814099

SHEET NO. FIGURE 1 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

S:\1232\projects\115814099\gis\figures\reports\technical_data_report_final\noise\fig_1_EN-NO-001.mxd Revised: 2020-01-28 By: tcardinal

2.0 REVIEW AREA

2.1 REGIONAL SETTING

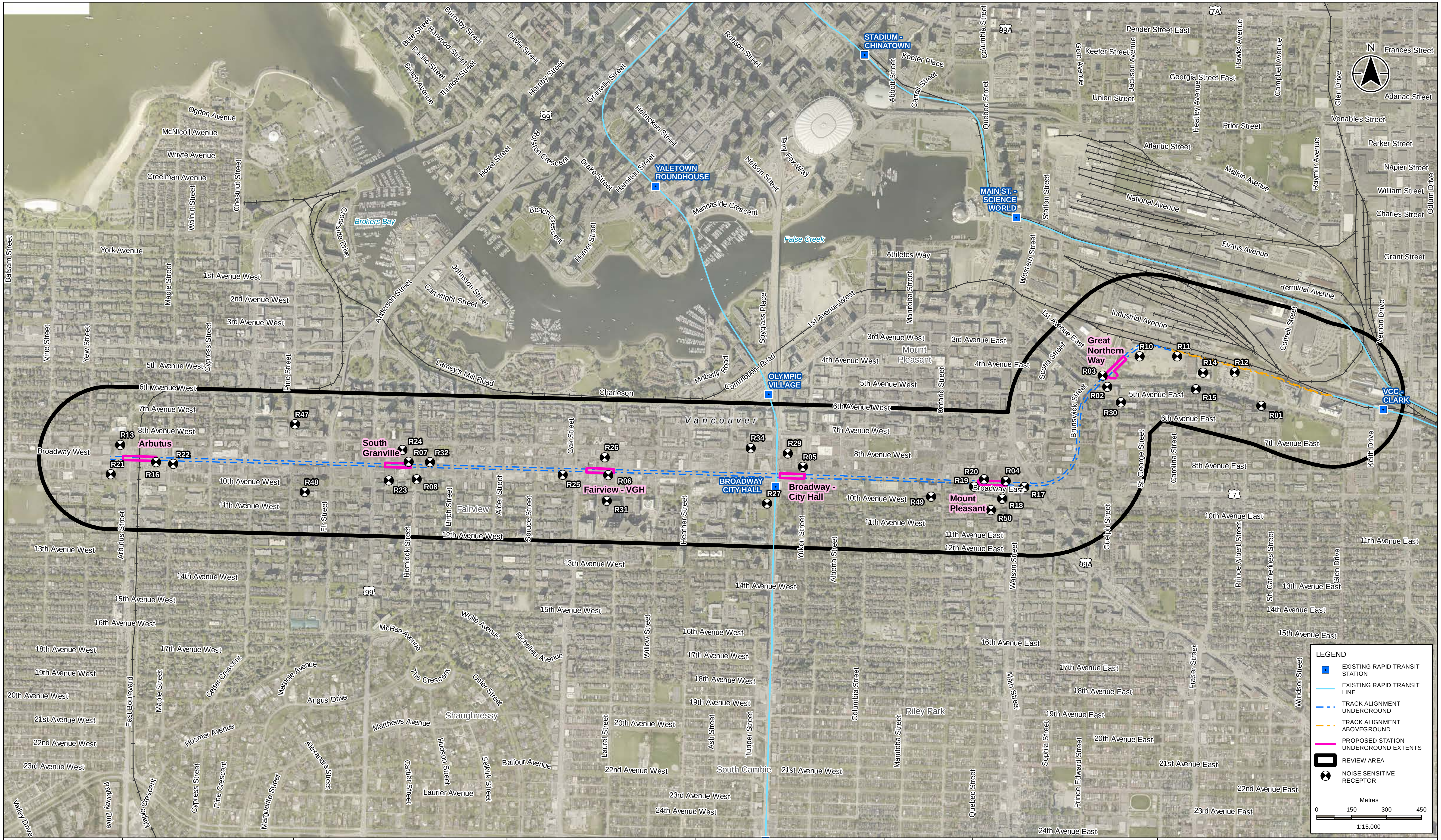
The Review Area is within Vancouver, British Columbia (BC), and extends along the Project alignment (the Alignment), from VCC-Clark Station, near Clark Street and Great Northern Way to the intersection of Arbutus Street and West Broadway Avenue. The Review Area is located within an urbanized part of Vancouver, which includes residential neighbourhoods, commercial businesses, industrial, medical and educational areas, major roadways, and a rail line.

2.2 NOISE SENSITIVE RECEPTORS

The review of noise effects focuses on representative, above-ground noise sensitive receptors (sensitive receptors) along the Project alignment and surrounding the stations. Sensitive receptor locations were identified based on stakeholder input and regulatory guidance (i.e., City of Vancouver bylaws).

Sensitive receptors considered include residential and educational areas, located near proposed stations and guideway sites, but also medical facilities and churches within 300 m of the Alignment. Sensitive receptors included in the Review Area are summarized in Table 1 and shown in Figure 2. Table 1 describes each sensitive receptor, as well as the nearest Project component, approximate distance to the center of the Alignment, and the noise zone in which the receptor is located, according to the City of Vancouver Noise Control By-Law No. 6555 (City of Vancouver 2016)

Sensitive receptors included in this study are representative of the nearest and/or most affected receptors within the Review Area. Because noise decreases with distance, the review focusses on a selection of receptors located near the Alignment, as they are more likely to experience Project-related noise effects.



S:\1232\projects\115814099\gis\figures\reports\technical_data_report_final\noise\fig_2_EN-NO-003.mxd Revised: 2020-01-20 By: tcardinal

DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

LOCATION OF NOISE SENSITIVE RECEPTORS

SCALE 1:15,000	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 17-11-29			
SHEET NO.		FIGURE 2	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

Table 1 Project Noise Sensitive Receptors

Receptor ID	Description (residential, educational, medical, places of worship)	Nearest Project Component	Noise Zone[1] According to the Noise Bylaw (quiet, intermediate, activity, event zone)	Land Use Category according to US FTA (Category 1, 2 or 3)[2]	Universal Transverse Mercator (UTM) Coordinates		Approximate Distance to Centre of Alignment (m)
					Easting	Northing	
R01	Residential	above ground rail	quiet zone	2	493732	5457021	135
R02	Educational (St. Francis Xavier School) and places of worship (St. Francis Xavier church)	above ground rail, portal and GNW station	activity zone	3	493071	5457103	36
R03	Residential	above ground rail, portal and GNW station	activity zone	2	493051	5457151	13
R04	Residential	Main Street station	intermediate	2	492636	5456699	11
R05	Residential	Cambie station	intermediate	2	491765	5456759	39
R06	Residential	Oak station	intermediate	2	490930	5456724	18
R07	Medical (Pacific Laser Centre)	Granville station	intermediate	3	490075	5456781	16
R08	Residential	Granville station	quiet zone	2	490109	5456706	58
R10	Educational (Emily Carr University)	above ground rail, portal and GNW station	quiet zone	3	493209	5457233	38
R11	Educational (Emily Carr University)	above ground rail, portal and GNW station	quiet zone	3	493371	5457233	21
R12	Future residential	above ground rail	quiet zone	2	493617	5457165	25
R13	Residential, Educational (St. Augustine's Elementary School)	Arbutus station	quiet zone	2	488837	5456853	56
R14	Educational (BC Institute for Technology/ Emily Carr University)	above ground rail	quiet zone	3	493481	5457164	60
R15	Residential	above ground rail	quiet zone	2	493451	5457093	136
R16	Residential	Arbutus station	intermediate	2	488991	5456780	13
R17	Residential	Main Street station	intermediate	2	492716	5456673	12
R18	Residential	Main Street station	intermediate	2	492620	5456623	66
R19	Residential	Main Street station	intermediate	2	492499	5456675	18
R20	Residential	Main Street station	intermediate	2	492543	5456706	14
R21	Residential	Arbutus station	quiet zone	2	488796	5456728	70
R22	Residential	Arbutus station	intermediate	2	489064	5456772	19
R23	Residential	Granville station	quiet zone	2	489989	5456701	66
R24	Residential	Granville station	intermediate	2	490048	5456832	67
R25	Residential	Oak station	intermediate	2	490735	5456725	22
R26	Residential	Oak station	intermediate	2	490915	5456800	57
R27	Residential	Cambie station	activity zone	2	491612	5456602	122
R28	Residential, places of worship and Spirit of Life Lutheran Church, Vancouver Korean Presbyterian Church and Good Shepherd Anglican Church	Cambie station	quiet zone	3	491803	5456649	70
R29	Residential	Cambie station	intermediate	2	491700	5456817	95
R30	Residential	above ground rail, portal and GNW	quiet zone	2	493129	5457037	123
R31	Medical (Vancouver General Hospital)	Oak station	intermediate	2	490924	5456614	128
R32	Medical (AIM Medical Imaging)	Granville station	intermediate	3	490166	5456780	18

Table 1 Project Noise Sensitive Receptors

Receptor ID	Description (residential, educational, medical, places of worship)	Nearest Project Component	Noise Zone[1] According to the Noise Bylaw (quiet, intermediate, activity, event zone)	Land Use Category according to US FTA (Category 1, 2 or 3)[2]	Universal Transverse Mercator (UTM) Coordinates		Approximate Distance to Centre of Alignment (m)
					Easting	Northing	
R33	Medical (Canadian Diagnostic Centre CT & MRI)	Cambie station	activity zone	3	491535	5456494	233
R34	Medical (False Creek Healthcare)	Cambie station	intermediate	3	491542	5456840	113
R47	Places of worship (Grace Vancouver Church)	Granville station	intermediate	3	489587	5456942	164
R48	Places of worship (Fairview Gospel Hall Fairview and Presbyterian Church)	Granville station	quiet zone	3	489628	5456651	125
R49	Places of worship (Tenth Church Mount Pleasant)	Main Street station	quiet zone	3	492315	5456631	69
R50	Places of worship (Holy Trinity Ukrainian Orthodox church)	Main Street station	quiet zone	3	492572	5456574	117

NOTES:

1 No receptor is located in an event zone. If a zone was not defined in the By-Law it has been conservatively set to “quiet zone”. See Section 3.2.2.1 for a description of the zones.

2 See Section 3.2.2.2 for a description of the categories.

3.0 REGULATORY REQUIREMENTS

This section provides an overview of applicable regulatory/policy frameworks used in this review as well as a description of the noise indicators used in these frameworks.

3.1 NOISE INDICATORS

Noise in urban settings is typically not steady but varies, with time, due to the timing and intensity of specific activities that influence noise conditions. As such, time-averaging and statistical analyses are used to characterize noise meaningfully. “Energy” averaging is the most common form of noise time-averaging and represented by using the continuous equivalent sound level (L_{eq}) descriptor. L_{eq} represents a steady, continuous sound level that has the same noise energy as the original time-averaging sound over the same period. Calculated L_{eq} values therefore represent the average energy over different time periods.

Periods commonly used for L_{eq} measurements and regulatory thresholds are daytime (07:00 AM to 10:00 PM) and nighttime (10:00 PM to 07:00 AM). See below for a list of L_{eq} indicators used in this review:

- L_d: The daytime equivalent sound level (L_d) is the 15-hour energy equivalent sound level for the period from 07:00 AM to 10:00 PM.
- L_n: The nighttime equivalent sound level (L_n) is the 9-hour energy equivalent sound level for the period from 10:00 PM to 07:00 AM.
- L_{dn}: The day-night equivalent sound level (L_{dn}) is a 24-hour time-averaged L_{eq}, describing a receiver’s cumulative noise exposure from all events over a full day. The L_{dn} includes a +10 decibels adjustment during the nighttime as a penalty for sounds occurring during the night period to account for greater nighttime sensitivity to noise.
- $L_{eq}(t)$: Equivalent sound level for a specific period of time. Similar to the equivalent sound level indicators listed above. The $L_{eq}(t)$ is the equivalent continuous level for a specific time interval length.
- In contrast to the energy equivalent sound levels, sound can also be described by single-event noise descriptors such as L_{max}. L_{max} is the maximum noise level measured during a certain time period. L_{max} is used in this review to describe pass-by noise levels when a train is passing by.

These noise indicators are commonly expressed in decibels (dB) using A-weighting. A-weighting accounts for the relative loudness perceived by the human ear, as it is less sensitive to lower audible frequencies (i.e., 20 Hz to 200 Hz). The A-weighted unit for L_{eq} is the A-weighted decibel level (dBA).

3.2 REGULATORY AND POLICY FRAMEWORK

The following sections summarize the various regulatory and policy frameworks applicable to the review of potential noise effects associated with the Project. Noise guidance and policies are outlined separately for construction and operation noise. Noise thresholds are applicable at the sensitive receptors along the alignment (see Section 2.2 for a description of sensitive receptors included in this review).

3.2.1 Construction

Construction activities that are anticipated to generate noise include building of the underground stations and above and below ground rail segments. The results of predictive noise modelling of the construction phase of the Project, presented in Section 5.0 of this report, are compared to thresholds listed in the City of Vancouver By-Law.

3.2.1.1 City of Vancouver Noise By-Law

The City of Vancouver Noise Control By-Law No. 6555 (City of Vancouver 2016) regulates construction noise within the City of Vancouver. Section 15 of the By-Law provides a sound level threshold of 85 dBA pertaining to continuous construction noise. Continuous sound, according to City of Vancouver noise By-Law, means any sound occurring for a duration of more than three minutes, or occurring continually, sporadically or erratically but totaling more than three minutes in any 15-minute period of time. For the purposes of this study, this is interpreted to mean that the L_{eq} (3 min) is not to exceed 85 dBA at any sensitive receptors during construction activities (see Table 2) and when measured at the property line, of the parcel of land where the construction is taking place, nearest to the point of reception of the sound or noise.

Table 2 Applicable City of Vancouver Noise By-Law Threshold for Construction Noise

Description	Noise Type	Noise Threshold
Construction Noise	Continuous (i.e., 3 minutes or more within a 15-minute period)	L_{eq} (3 min) = 85 dBA

The By-Law further identifies time periods during which construction noise is allowed. For constructions on streets, Section 16 states, that construction noise is only allowed between the hours of 7:00 am to 8:00 pm from Monday to Saturday and between 10:00 am to 8:00 pm on any Sunday or holiday (City of Vancouver 2016). Where construction activities are expected to persist beyond these hours, special permits must be obtained prior to commencing work.

3.2.2 Operation

Noise due to operation of the Project may be separated into two distinct components:

- **Station Ventilation noise**—Station ventilation fan noise travelling through the ventilation shafts from the underground stations
- **Above ground train noise**—Noise associated with the movement of trains on sections of the Project that are on elevated guideways and not contained within the underground alignment. This includes trains in transit as well as the portal noise (sound radiated from tunnel openings when trains enter or exit the portal). The movement of trains while underground is not expected to generate audible noise at sensitive receptors above ground.

The review of noise associated with the ventilation system is guided by thresholds associated with the Vancouver By-Law (City of Vancouver 2016). The US Federal Transit Administration (US FTA) noise guideline (FTA 2006) is used to support the review of noise during train operation. Details associated with the application of each of these policy frameworks, and how they are applied in the review, of the Project are presented in the following sections.

3.2.2.1 City of Vancouver Noise By-Law

The City of Vancouver Noise By-Law (City of Vancouver 2016) prescribes daytime and nighttime noise thresholds for both “continuous” and “non-continuous” noise when assessed at sensitive receptors. For the purposes of this study, it was conservatively assumed that ventilation noise is “continuous” noise.

Section 6 of the noise By-Law prescribes different thresholds for different zones within the city. The four zones are “quiet zone”, “intermediate zone”, “event zone” and “activity zone”, based on the following definitions:

- **Quiet zone**—A quiet zone means any portion of the City not defined as one of the intermediate, event or activity zones. Zones are based on limits of zoning districts and can be identified on VanMap (City of Vancouver 2018).
- **Intermediate zone**—An intermediate zone means those areas described in Schedule B of the Noise By-Law (City of Vancouver 2016).
- **Event zone**—An event zone means those areas described in Schedule G and Schedule B.2 of the Noise By-Law (City of Vancouver 2016). Event zones are not applicable to this noise review, as no part of this Project is located in an event zone.
- **Activity zone**—An activity zone means those areas described in Schedule A of the Noise By-Law (City of Vancouver 2016).

Each zone is assigned different noise thresholds by the By-Law. Based on desktop studies of the Vancouver Noise By-Law, the Project alignment is located in a mix of “quiet/intermediate” and “activity zones”. According to district zoning within the City of Vancouver, most of the Project area is categorized, within Schedule B of the By-Law, as zone C-3A, which is considered an “intermediate zone” according to the By-Law (City of Vancouver 2018, 2016).

Where underground stations are located beneath roads, ventilation shafts will be at street level. As such, during operation, noise from ventilation shafts (i.e., ventilation fan and noise propagation through the shaft during the train arrival and departure from a station) at the underground stations is anticipated to occur at street level in areas adjacent to ventilation shafts. Based on Section 9 of the By-Law, noise or sound emanating from a source on a street shall be deemed as emanating from an “activity zone”.

Section 6 of the City of Vancouver Noise By-Law states that no person shall, in an “activity zone”, cause or permit to be made or caused, continuous sound the sound level of which:

- During the daytime exceeds a rating of 70 (dBA) on an approved sound meter when received at a sensitive receptor within an activity zone or an intermediate zone, or 60 (dBA) on an approved sound meter when received at a sensitive receptor within a quiet zone. Based on the definition of “continuous sound” in the By-Law, this threshold is interpreted as an L_{eq} (3 min).
- During the nighttime exceeds a rating of 65 (dBA) on an approved sound meter when received at a sensitive receptor within an activity zone or an intermediate zone, or 55 (dBA) on an approved sound meter when received at a sensitive receptor within a quiet zone. Based on the definition of “continuous sound” in the By-Law, this threshold is interpreted as an L_{eq} (3 min).

The above noise thresholds are applicable at sensitive receptors located in an “activity”, “intermediate” or a “quiet” zone.

Table 3 summarizes the applicable noise thresholds in different zones for daytime and nighttime. Section 2.2 (see Table 1) summarizes noise zone classifications for each sensitive receptor.

Table 3 Applicable Noise Criteria for Ventilation Noise During Operation

Location of Receptor	L_{eq} (3 min) (dBA) daytime	L_{eq} (3 min) (dBA) nighttime
Activity Zone	70	65
Intermediate Zone	70	65
Quiet Zone	60	55
NOTE: See Section 2.2 to see which noise receptors are located in which noise zone		

3.2.2.2 US Federal Transit Administration Noise and Vibration Impact Assessment Guideline

The US FTA Transit Noise and Vibration Impact Assessment document (FTA-VA-90-1003-06; May 2006) is selected as a guideline for assessing operational noise impact on the basis that it was developed for assessment of transit including light rail and has been used in previous assessments of noise from SkyTrain projects. The FTA guideline procedure and criteria are very similar to the BC Ministry of Transportation and Infrastructure (MOTI) Noise Policy whose stated scope is limited to numbered highways.

The US FTA guideline provides noise impact criteria for transit projects based on the existing and post-project sound levels. Three levels of noise impact are created: “no impact”, “moderate impact”, or “severe impact”. Three land use categories are considered for determining the noise impact level.

- **Category 1**—is defined as non-residential tracts of land where quiet is an essential element to their intended purpose such as concert halls and outdoor amphitheaters.
- **Category 2**—is defined as residences and buildings where people normally sleep.
- **Category 3**—is defined as institutional uses with primarily daytime and evening use such as schools, libraries, theaters, and churches.

The existing noise level descriptor for Category 1 and 2 land uses is the Day-Night level L_{dn}. For Category 3 land uses, the existing noise level descriptor is L_{eq} (1 hr, max) which is the loudest hour of the day.

Project-generated noise in the “no impact” range is not likely to be found annoying, and therefore no noise mitigation should be required. Project noise levels in the “severe” range should be avoided and represents a compelling need for mitigation. “Moderate” impact is defined as a change which is noticeable, but may not be sufficient to cause strong, adverse reactions from the community. The need for noise mitigation in areas of “moderate” impact should be considered in conjunction with factors such as the number of sites affected, increase over existing sound levels, noise sensitivity of the property, effectiveness of possible mitigation measures, community views on the project, and cost.

Under the guideline, as demonstrated in Figure 3, as existing levels of ambient noise increase, the allowable level of project noise increases, but the total allowable increase for community noise exposure is reduced. This is based on the idea that people exposed to already high levels of noise should not be expected to tolerate substantial additional increases in noise. Conversely, for areas with quieter existing ambient noise levels, a greater change in overall noise levels is allowed.

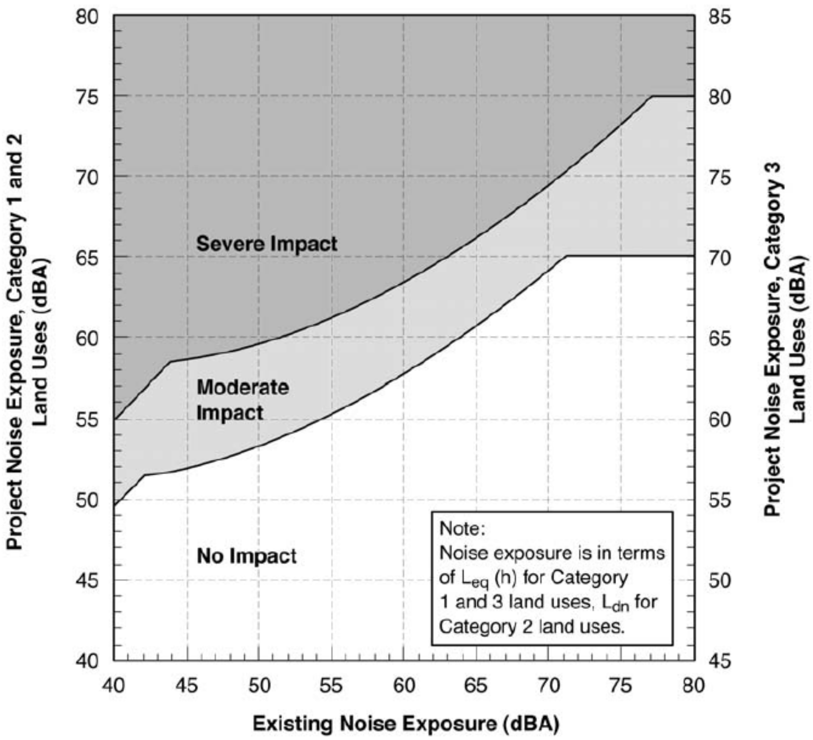


Figure 3 US FTA Transit Project-Related Noise Impact Thresholds

4.0 EXISTING SOUND LEVEL

4.1 SCOPE

A noise monitoring program was undertaken in August and September 2017 to characterize existing sound levels for representative sensitive receptors along the Project alignment. These data were also used to establish pre-Project L_{dn} values for Project operation (see Section 4.4).

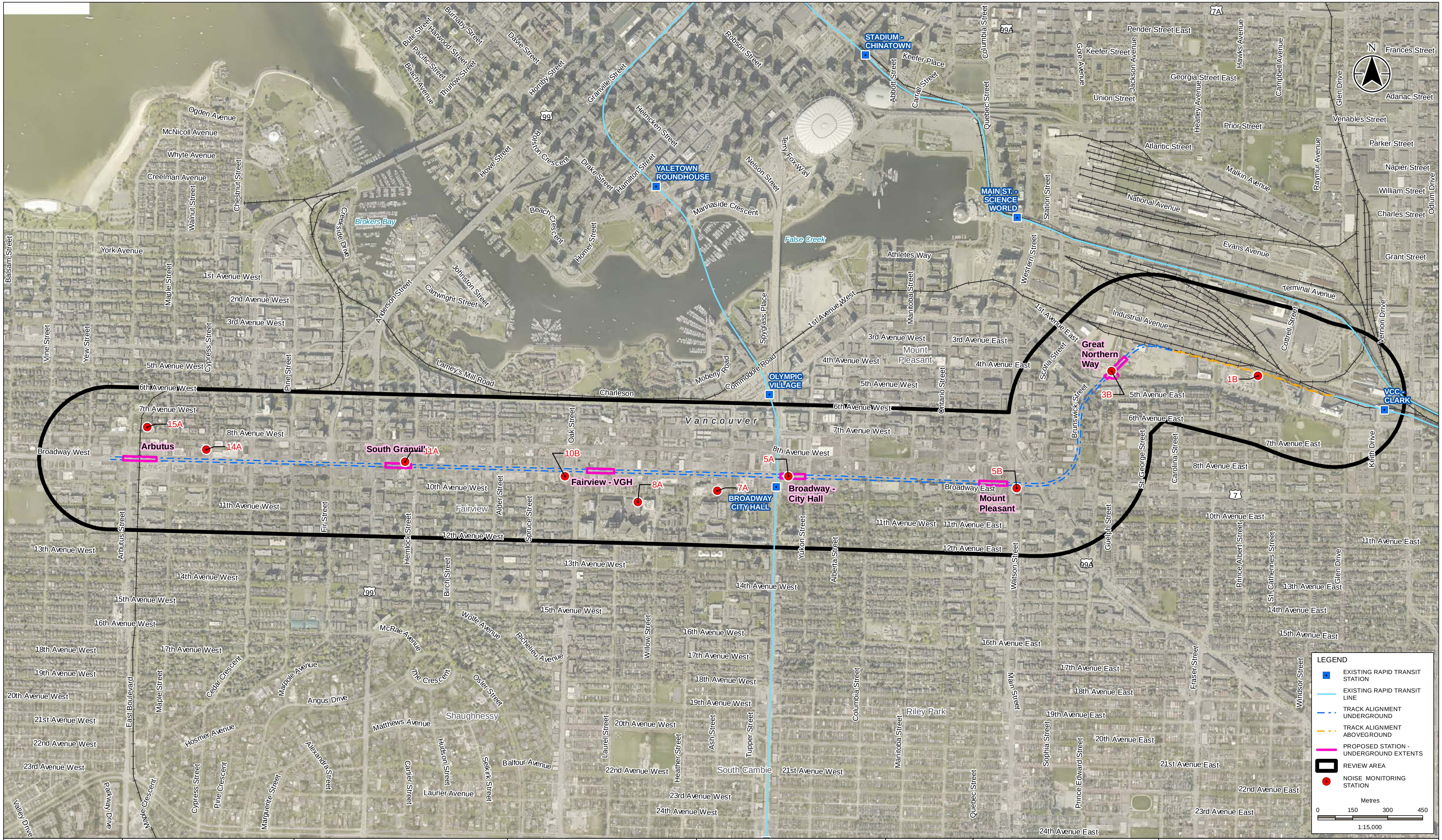
Sections 4.2 and 4.3 summarize the survey methods and results, respectively. Section 4.4 outlines how the results are used in this review. Additional details of the monitoring program can be found in Appendix A.

4.2 METHODS

The noise monitoring program quantified the existing sound level at ten different locations within the Review Area. The Review Area used to support the study is defined as a 300 m buffer on either side of the Project centerline (see Figure 4). The ten measurement locations (i.e., 1B–15A) are considered representative of sensitive receptors along the Alignment. These locations include the first and second streets (running parallel to Broadway) north and south of the Alignment.

Unattended sound pressure level measurements were conducted over a period of approximately 24 to 48 hours at these ten locations during week days only.

The sound pressure level measurements were made using Brüel and Kjaer 2250 Type I integrating sound level meters. Each meter was set to log sound data and perform continuous audio recording. The collected noise monitoring data was post processed and subsequent results for environmental noise descriptors such as L_d, L_n, L_{dn} were calculated.



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

NOISE MONITORING LOCATIONS

SCALE 1:15,000 | DATE 17-11-29 | CONTRACT NO. | SUBCONSULTANT PROJECT NO. 115814099

SHEET NO. | FIGURE 4 | A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

S:\1232\projects\115814099\gis\figures\reports\technical_data_report_final\noise\fig_4_EN-NO-002.mxd Revised: 2020-01-20 By: tcardinal

4.3 RESULTS

The noise monitoring program results for each measurement location are summarized in Table 4. The table includes site ID, monitoring periods, and L_d, L_n, L_{dn}, L_{eq} (1 hr, max) results for each of the ten monitoring locations. General characteristics of the acoustic environment are described for each location as well as the approximate distance of the measurement location to the Project alignment center line.

The noise survey results indicate that measured L_d levels at most monitoring locations along Broadway were in the high 50s to low 70s dBA. Measured nighttime L_n values were in the mid-50s to mid-60s dBA. Lowest L_{dn} values were measured at 7A (near West 10th Avenue and Heather Street) of 60.8 dBA and highest L_{dn} values at 5A (near West Broadway and Cambie) of 75.2 dBA.

Collected data are typical of a busy urban environment and at most of the monitored locations the data were dominated by road traffic (i.e., traffic movements, vehicle acceleration and/or deceleration, air brakes, horns, engine starts). The loudest activities included traffic movement/parking, trucks, and first responder vehicles. Detailed analysis of these results is presented in Appendix A.

The results for location 8A (near West 10th Avenue and Willow Street), 10B (near West Broadway and Oak Street), 11A (near West Broadway and Hemlock Street), 14A (near West Broadway and Cypress Street) are considered conservative. At these locations, the meter was set up on terraces of building or on roofs of buildings, mainly because of security reasons. Consequently, the meter was slightly removed from noise sources at street levels. Therefore, the measured sound levels might be quieter than the actual noise environment, which results in a conservative estimate of existing levels.

Location 5A (near West Broadway and Cambie) was set up through a window on a third floor of a building, close to the reflecting surface of the building wall itself. This might have impacted the measured sound level resulting in an overestimated sound level of up to +3dB compared to the actual existing level. A -3 dB adjustment was applied to the measured sound levels at this location to obtain a conservative estimate of the existing sound level. The resulting L_{dn} has hence been adjusted from 75.2 dBA to 72.2 dBA for this noise review.

Having “quieter” existing levels is considered a more conservative approach, as a lower existing sound level will result in a higher potential change or noise effect in the review.

Table 4 Noise Monitoring Results

Site ID	Nearest Main Cross Streets	Dates	Monitoring Period (hours)		Measured Sound Level (dBA)				Characteristics of Existing Noise	Approximate Distance to the center of the Alignment(m)
			Total	Used	L_d	L_n	L_{dn}	L_{eq} (1 hr, max)		
1B	Foley Street and Finning Way	Sep 19–21	50.37	46.28	64.2	59.9	67.0	68.9	Road traffic, rail traffic, use of haul truck parking lot and minimal air traffic.	15
3B	Thornton Way and Great Northern Way	Sep 12–13	24.68	22.52	61.5	54.6	63.0	66.1	Road traffic, first responder vehicles and minimal air traffic	3
5A*	Cambie Street and West Broadway	Sep 6–7	23.82	23.03	72.5	67.6	72.2 (75.2)	75.4	Busy road traffic, first responder vehicles, buses, truck parking nearby.	2
5B	Main Street and West Broadway	Sep 13–14	24.52	23.85	68.8	65.4	72.5	72.2	Busy road traffic, first responder vehicles, use of public parking lot and pedestrians.	18
7A	West 10th Avenue and Heather Street	Sep 21–22	24.52	23.97	56.8	53.8	60.8	58.5	Road traffic, first responder vehicles and some air traffic.	72
8A*	West 10th Avenue and Willow Street	Sep 20–22	46.88	45.78	59.5	54.3	62.0	53.5	Road traffic and some air traffic.	129
10B*	West Broadway and Oak Street	Sep 6–7	24.05	23.93	65.4	57.7	66.4	67.9	Busy road traffic, first responder vehicles, some air traffic and daytime construction activities.	27
11A*	West Broadway and Hemlock Street	Aug 30–31	27.83	27.28	66.3	60.2	68.0	70.5	Busy road traffic, first responder vehicles, daytime construction activities, pedestrians, and some air traffic.	17
14A*	West Broadway and Cypress Street	Aug 31–Sep 1	24.27	23.87	59.7	54.8	62.4	62.3	Road traffic, first responder vehicles, and HVAC use on nearby roof.	48
15A	West 8th Avenue and Arbutus Street	Sep 14–15	24.68	22.70	58.7	53.4	63.0	61.0	Road traffic, some construction activities, school activities, and pedestrians.	136

NOTE:

* Note that measurement results for location 8A, 10B, 11A, 14A are considered conservative as the meter was set up on buildings lips and or roofs and is hence slightly removed from noise sources at street level resulting in quieter measurements. Location 5A was set up through a window on the third floor, close to the reflecting surface of the building wall. This might have impacted the measured sound level resulting in a louder measurement. As a correction and to maintain conservative estimates of the existing sound levels a -3dB correction has been applied to the measured sound levels at 5A, the Ldn has hence been reset to 72.2 dBA. This is considered a more conservative approach as a lower existing sound level will result in a higher change or noise effect in the review.

4.4 EXISTING SOUND LEVEL AT RECEPTORS

The measured results L_{dn} at the 10 monitoring locations were used to establish existing sound level at each sensitive receptor used in this review; the monitoring locations are considered to be representative of the identified sensitive receptors.

The following approach has been followed to determine existing sound level L_{dn} values for each of the sensitive receptors presented in Table 5:

- If the monitoring location was near a sensitive receptor, then this L_{dn} value has been assigned to this sensitive receptor.
- If no monitoring location was situated near a sensitive receptor that is part of the noise review, then the lowest measured L_{dn} value from a representative monitoring location that has been measured has been assigned to that sensitive receptor.

These existing L_{dn} values for each receptor are used to represent the pre-project sound level for operation noise analysis completed in Section 5.0.

Table 5 Noise Sensitive Receptor Existing Sound Levels

Receptor ID	Nearest Representative Monitoring Location	Existing Sound Level L_{dn} (dBA)	Existing Sound Level L_{eq} (1h, max) (dBA)
R01	1B	67.0	68.9
R02	3B	63.0	66.1
R03	3B	63.0	66.1
R04	5B	72.5	72.2
R05	5A	72.2	75.4
R06	10B	66.4	67.9
R07	11A	68.0	70.5
R08	8A	62.0	53.5
R10	3B	63.0	66.1
R11	1B	67.0	68.9
R12	1B	67.0	68.9
R13	15A	63.0	61.0
R14	1B	67.0	68.9
R15	3B	63.0	66.1
R16	15A	63.0	61.0
R17	5B	72.5	72.2
R18	8A	62.0	53.5
R19	5B	72.5	72.2
R20	5B	72.5	72.2

Table 5 Noise Sensitive Receptor Existing Sound Levels

Receptor ID	Nearest Representative Monitoring Location	Existing Sound Level L_{dn} (dBA)	Existing Sound Level L_{eq} (1h, max) (dBA)
R21	7A	60.8	58.5
R22	15A	63.0	61.0
R23	8A	62.0	53.5
R24	8A	62.0	53.5
R25	10B	66.4	67.9
R26	10B	66.4	67.9
R27	8A	62.0	53.5
R28	7A	60.8	58.5
R29	8A	62.0	53.5
R30	7A	60.8	58.5
R31	8A	62.0	53.5
R32	11A	68.0	70.5
R33	7A	60.8	58.5
R34	7A	60.8	58.5
R47	7A	60.8	58.5
R48	7A	60.8	58.5
R49	7A	60.8	58.5
R50	8A	62.0	53.5

NOTE:
See Figure 2 and Figure 4 for the locations of the sensitive receptors and the noise monitoring locations

5.0 NOISE MODELLING

Noise modelling was undertaken to predict sound levels for Project construction and operation activities that have the potential to affect existing noise conditions. This section outlines general model settings as well as detailed input and assumptions for the construction and operation model respectively.

5.1 GENERAL MODEL SETTINGS

Noise modelling was performed using Cadna/A (Version 2017 MR1, build 159.4707) modeling software from DataKustik, which incorporates ISO 9613 prediction algorithms (DataKustik 2017). ISO 9613 prediction algorithms are commonly used by noise practitioners and are accepted by regulatory bodies across Canada. ISO 9613 standards include:

- ISO 9613-1: Acoustics—Attenuation of sound during propagation outdoors—Part 1: Calculation of the absorption of sound in atmosphere (ISO 1993)
- ISO 9613-2: Acoustics—Attenuation of sound during propagation outdoors—Part 2: General method of calculation (ISO 1996)

These standards incorporate geometrical divergence (distance attenuation (i.e., reduction in sound levels)), barrier effects (e.g., building structures), ground effects (e.g., paved versus vegetated), atmospheric absorption (e.g., relative humidity), and topography.

Table 6 summarizes the parameters incorporated in the construction and operations noise models. The models predict day (L_d), night (L_n) and day-night (L_{dn}) sound levels at the sensitive noise receptors included in the Review Area.

Only Project related construction and operation noise sources within the Review Area were modelled, other existing noise sources in the Review Area (i.e., within 300 m on either side of the Alignment) were not modelled.

Table 6 Modelling Parameters

Item	Model Parameter	Model Setting
1	Temperature	10°C
2	Relative Humidity	70%
3	Wind speed	Downwind condition, wind speed of 1 to 5 m/s
4	Propagation Standard	ISO 9613-1, ISO 9613-2
5	Ground conditions and attenuation factor	Ground absorption (G) of 0.3 (low factor assuming reflecting hard surface). G can range from 0 to 1 with 0 being reflecting and 1 being absorbing.
6	Receptor height	1.5 to 10 m (depending on height of receptor (e.g., one-story building versus a high-rise).
7	Topography/Terrain Parameters	Flat, no elevation
8	Building	Buildings have been included near sensitive noise receptors to account for the shielding and reflection effects.
9	Foliage attenuation	None
10	Number of reflection	3
11	Railroad standard	United States Federal Railroad Administration/ United States Federal Transit Administration

5.2 CONSTRUCTION MODEL

This section presents information, including key assumptions regarding equipment used to support construction and Project design details that support modelling of potential construction phase noise. Assumed sources of noise, associated with Project construction, are summarized below as a function of equipment type, frequency of operation and associated sound power levels. This section also summarizes the general modelling approach used to support the development of noise estimates during the construction phase.

5.2.1 Construction Noise Sources

BSP construction is expected to take approximately six years, and will include station box construction, tunneling and rail construction. Although overall construction is expected to take about six years, construction activities will occur at different locations over varying periods of time.

Table 7 lists the assumed composition of the Project construction fleet associated with the various construction activities, including the number of units, equipment rating, load factor, operating time and resulting sound power levels.

5.2.1.1 Station Box

The Project will include six underground stations and supporting infrastructure. As detailed construction methods are not available until the contractor is procured, it is assumed that the development of stations will include some top-down excavation with excavation material transported away from the site by truck. It is also assumed that excavated station locations will be covered, when appropriate, in order to reduce general construction noise and traffic effects on adjacent areas.

5.2.1.2 Portal/Tunneling

The BSP will travel above ground for approximately 700 m after VCC-Clark station before it transitions underground for the remainder of the Alignment. It is assumed development of the underground rail tracks will require tunnel boring for the Alignment between Great Northern Way and Arbutus Street.

The reference design assumes the bored tunnel will consist of two side-by-side tunnels. Tunnel boring, and associated noise is included in noise modelling for sensitive noise receptors adjacent to the tunnel portal at Great Northern Way. Once the tunnel boring machine is underground, noise effects are assumed to not transmit to above ground sensitive noise receptors.

5.2.1.3 Above Ground Rail

The Project will include a section of elevated guideway extending approximately 700 m westward, from the existing terminus of the Millennium Line at VCC-Clark Station, and transition to an underground alignment in the vicinity of Great Northern Way and Thornton Street. Detailed design of the above ground rail is not available at this stage of the design process.

Table 7 Construction Sound Power Levels

Equipment Description	Units	Equipment Rating (hp)	Load Factor (%)	Operating Time (hr/day)	Operating Time (hr/night)	Operating Time (hr/year)	Sound Power Level (dBA)
Station Box							
Articulated Dump Truck (17 m^3 capacity)[3]	2	464	80	13	0	<1 yr	108
Concrete Pumper (Stationary)	2	27	21	13	0	<1 yr	89
Excavator	2	160	59	13	0	<1 yr	103
Compressor	2	283	59	13	0	<1 yr	103
Rock Drill / Soil Nail Drills	2	200	59	13	0	<1 yr	106
Crane	1	230	59	13	0	<1 yr	99
Vibratory Piling	1	270	59	13	0	<1 yr	114
Backup Alarm—Broadband[2]	4	-	10	13	0	<1 yr	100
Portal/Tunneling							
66 000 lb HDD rig	1	200	59	13	0	<1 yr	103
Centrifuge, S/S High Speed	1	27	59	13	0	<1 yr	90
Mud Pump	1	1000	59	13	0	<1 yr	113
Zoom Boom	1	100	21	13	0	<1 yr	104
Backhoe	2	268	21	13	0	<1 yr	95
Backup Alarm—Broadband[2]	2	-	10	13	0	<1 yr	102
Above Ground Rail Construction							
Vibratory Tamper	1	-	59	13	0	<2 months	88
Bulldozer	1	190	59	13	0	<2 months	100
Skid Steer	1	120	59	13	0	<2 months	98
Backhoe	1	83	59	13	0	<2 months	97
Grader	1	120	59	13	0	<2 months	98
Front End Loader—Towing	1	247	59	13	0	<2 months	101

Table 7 Construction Sound Power Levels

Equipment Description	Units	Equipment Rating (hp)	Load Factor (%)	Operating Time			Sound Power Level (dBA)
				(hr/day)	(hr/night)	(hr/year)	
Welding Rig	1	350	59	13	0	<2 months	106
Track Lifting Rig	1	160	59	13	0	<2 months	97
Backup Alarm– Broadband[2]	4	-	10	13	0	<2 months	105
Miscellaneous Sources[1]							
Articulated Dump Truck (17 m^3 capacity)—Idle for Loading[3]	1	464	80	13	0	<1 yr	111
Portable Light Generator	1	30	45	13	0	<1 yr	94

NOTES:

1 The miscellaneous sources are included in the model as part of the above ground rail construction, the portal/tunneling as well as the station box construction activities

2 Broadband alarms do not have tonal quality of sound.

3 Noise emissions from dump trucks activities are included in the model while within the project development area (i.e., Project construction footprint) but not while hauling on public roads.

5.2.2 Construction Noise Model Assumptions

The following assumptions have been made for the modelling of construction noise:

- Construction activities will rely on a fleet of equipment including on-road and off-road vehicles. As the detailed fleet inventory will be developed by the Contractor, it was not available to support noise modelling. In the absence of such information, modelling of construction noise assumed a similar quantity and type of equipment to that used on similar projects in the region.
- Construction activities are assumed to occur between 7:00 am to 8:00 pm from Monday to Saturday and between 10:00 am to 8:00 pm on any Sunday or holiday.
- Construction activities at the underground stations, elevated guideway, and tunnel entrance/portal will occur during different time periods. However, the noise model assumed that these activities occur at the same time. Therefore, the estimated results represent a conservative scenario for noise impacts at the sensitive receptors.
- The above ground rail way is assumed to be constructed in segments of 200 m at a time. Each segment construction is assumed to last no longer than two months.
- Construction zone length, per station box, is assumed to be 120 m by 20 m
- Approximately 85 dump trucks are assumed per day per excavation site
- No blasting and no impact piling will be required for the construction
- Construction equipment is assumed to only use broadband backup alarms

5.2.3 Nighttime Construction Activity

Nighttime construction works have not been modelled separately, however they will be necessary to support the continuous tunnel boring operation and to avoid interference with traffic. Nighttime construction activity will take place near the tunnel portal throughout the Project and at times near station box excavation sites. The primary contractor may be required to adhere to a lower threshold for noise from nighttime construction activity than has been assumed for daytime, to be established in consultation with the City of Vancouver.

In order to verify reduced noise emission during nighttime activity, the primary contractor has the responsibility to prepare a detailed construction noise impact assessment and noise monitoring program specific to nighttime operations with their selected construction equipment prior to engaging in nighttime works. The primary contractor may use a combination of noise mitigation measures such as temporary noise barriers, and administrative controls to achieve this lower threshold.

5.3 OPERATION MODEL

Noise modelling of operation activities incorporates above ground train noise, ventilation noise sources and Project design details. This section also summarizes assumptions supporting the operation noise model.

5.3.1 Operation Noise Sources

Operation of the Project is expected to start in 2025. Noise sources included for the noise review associated with Project operation include train noise (i.e., moving trains and tunnel opening) and ventilation noise. Noise from trains travelling on the underground portion of the track alignment is not included in the review, as it is assumed that noise from train in underground segments of the alignment will not be transmitted to above ground sensitive noise receptors. A high-level description of operational phase noise sources, and associated sound power levels, is presented in Table 8 to Table 12.

5.3.1.1 Station Box Ventilation

Each underground station is assumed to have four ventilation openings (13 m^2 each) for forced air ventilation at the extent of the station boxes on street level; each shaft is assumed to be equipped with fans to provide ventilation in emergencies (mechanical ventilation). Normal ventilation occurs through the piston effect of train movements through the tunnels. It is assumed that the design of the ventilation shafts will include noise attenuation to reduce fan noise and noise from passing trains to a level consistent with previous SkyTrain projects.

Table 8 Operation Sound Power Levels—Ventilation Noise

Noise Source	Units per Station	Sound Power Level (dBA)[1,2]
Tunnel Ventilation	4	92

NOTE:
1 This is the sound power level before mitigation
2 Ventilation shafts will be designed to a continuous noise level of 45 dBA or less at the closest point of reception in a residential zone

5.3.1.2 Above Ground Train Operation

Above ground train noise is generated by vehicles in motion (US FTA 2006). According to US FTA (2006) and Crocker (2007), rail noise sources include noise from electric control systems and traction motors that propel rapid transit cars, as well as noise from wheel/track interaction. Wheel/track noise can further be broken down into rolling noise, impact noise (e.g., rail joint, turnout or crossover) and squeal generated by friction on tight curves (i.e., turning radius greater than 300 m). In general, noise created by trains increases with speed as well as with train length.

Noise from trains travelling on the above ground rail section is based on the US Federal Transit Administration train class for "conventional electric commuter trains". This train class is included in Cadna and best represents SkyTrain noise (see Table 11). Table 9 presents the reference sound exposure levels (SEL_ref) for a conventional electric commuter train. Information in Table 10 was used to derive project-specific sound levels scaled of the "conventional electric commuter train" sound, as a function of speed, train length, track type and train schedule (see Table 10).

Table 9 Operation Sound Power Levels—Conventional Commuter Locomotive Electric

Noise Source	Reference Conditions	SEL_ref (dBA)
FTA Conventional Commuter Locomotive, electric[1]	15 m away and 80 km/h	90
SOURCE: [1] US FTA 2006, tables 5-1, 6-3, 6-4, 6-5.		

Table 10 Project Specific Operational Noise Model Input

Train Class	Number of Trains (two directions)		Train Speed (km/h)	Train Length (m)	Type of Tracks
	Daytime	Nighttime			
FTA Conventional Commuter Locomotive Electric	600	180	40	80	Arial structure while elevated and embedded track on grade

To test the appropriateness of using the FTA "Conventional Commuter Locomotive Electric" sound levels as input for noise modelling, modelled pass-by noise levels from this train type were compared with measured real-life pass-by SkyTrain sound levels from the existing Millennium line. Table 11 summarizes modelled and measured sound levels as a function of distance and speed. The resulting pass-by levels indicate that the noise model provides a conservative estimate for SkyTrain vehicles.

Table 11 Comparison between Modelled and Measured Pass-by Levels

Conventional Commuter Electric Train Modelled Pass-by Level (L_{max} [dBA])	Millennium Line Measured Pass-by Level (L_{max} [dBA])[1]	Other SkyTrain Measured Pass-by Level (L_{max} [dBA])[2]
84 (18 m away, 80 km/h)	77 to 80 (18 m away, 80 km/h)	77-78 (15 m away, speed unknown)
NOTES: [1] Pass-by levels from the Millennium Line were sourced from the Evergreen assessment (Hatch 2010). Presented pass-by levels reflect different position of the receiver: above, below or at the same level as the guideway. [2] Pass-by levels from another SkyTrain Line were sourced from BKL (1991).		

Table 12 presents information on noise originating from the tunnel opening near the Great Northern Way station, when trains exit the tunnel. Noise radiated from a tunnel mouth can have a limited local effect on receptors nearby the opening. Methods following Probst (2008) have been applied to estimate noise associated with the tunnel opening.

Table 12 Operation Sound Power Levels—Tunnel Opening

Noise Source	Sound Power Level (dBA)[1]
Tunnel opening	88
NOTE: [1] Estimated following methods from Probst (2008).	

5.3.2 Operation Noise Model Assumptions

The following operation assumptions have been made for the modelling of operation noise:

- Trains travelling underground do not emit substantial noise to the above-ground environment and are not included in the noise review.
- It is assumed that the train frequency is identical to the current Millennium SkyTrain schedule, which results in 600 trains during the day (7:00 am to 10:00 pm) and 180 trains during the night (10:00 pm to 7:00 am) (representing two directions).
- The speed and train length are based on current SkyTrain statistics: speed 40 km/h and train length approximately 80 m (4 X Mark II train cars).
- It is assumed that there are no horns or bells used during normal operation since the Project does not include any at grade crossings.
- The elevated guideway is assumed to be 7 m high and descends gradually down to grade level before transiting underground before the Great Northern Way underground station.
- Each underground station is assumed to have four ventilation shafts at each corner of the station box on street level.
- During normal operation, ventilation occurs via the “piston effect” of trains transiting through the tunnel (i.e., do not require the use of fans). Conservatively it is assumed that fans are running continuously.
- Noise, from inbound and outbound trains, through the ventilation shafts will be negligible compared to the fan noise itself.
- Ventilation shafts will be equipped with silencers as required.
- The Cadna integrated sound levels of an FTA “conventional electric commuter train with locomotive” is assumed in the model. Tracks are assumed to be “aerial structure with slab track” while elevated and “embedded track” while travelling on grade.
- Parapet (barriers) are assumed on the south side of the above-grade railway
- Self-screening of the railway is included in the modelling for the tracks that are elevated
- Tunnel opening noise is estimated for an area of 10 m by 6 m, assuming the worst-case scenario of two trains passing at the same time.

- Noise from trains passing over crossovers is assumed negligible. This is confirmed by measurements of the existing Millennium SkyTrain line, presented in the Evergreen report (Hatch 2010). This report showed that crossover noise was not noticeable from SkyTrain pass-bys.

6.0 RESULTS

6.1 CONSTRUCTION

Noise modelling was performed to estimate construction phase noise levels at the identified sensitive receptors. The results were compared against the City of Vancouver By-Law thresholds (see Table 14). The results are also presented as noise contours within the Review Area (see Figure 5).

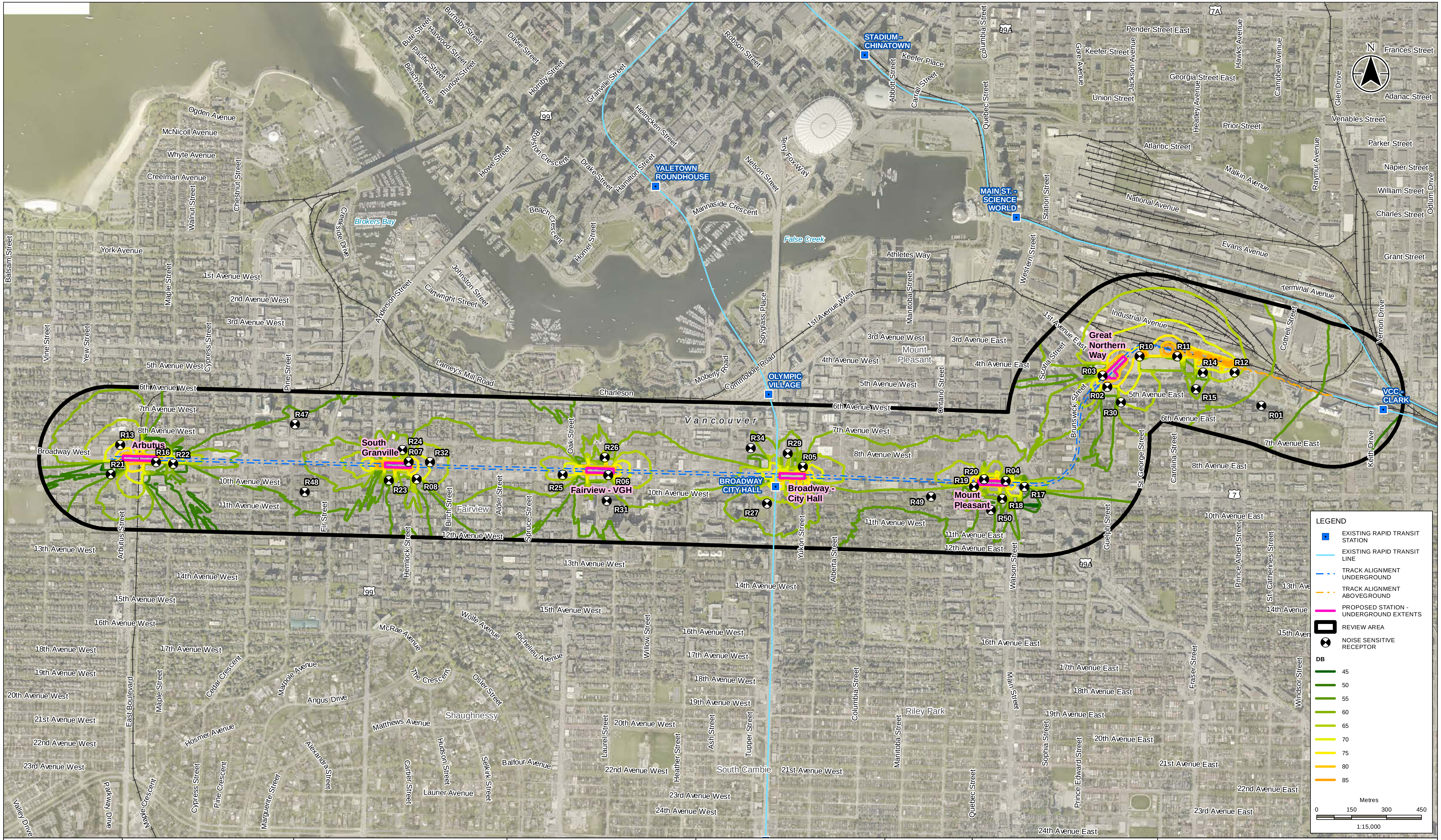
Construction noise modelling results show that construction noise levels will be below 85 dBA at all receptors and at the extents of station construction areas indicating compliance with the City of Vancouver Noise By-Law.

Table 13 Predicted Project Construction Noise Levels

Receptor	City of Vancouver Construction Threshold L_{eq} (3 min)	Estimated Noise Contribution from Construction (dBA) Daytime (L_{eq} [3 min])[1]
R01	85	57.8
R02	85	75.6
R03	85	82.0
R04	85	84.8
R05	85	77.3
R06	85	82.9
R07	85	83.6
R08	85	70.5
R10	85	78.1
R11	85	83.4
R12	85	67.2
R13	85	71.7
R14	85	67.3
R15	85	59.6
R16	85	83.9
R17	85	70.5
R18	85	69.3
R19	85	75.8

Table 13 Predicted Project Construction Noise Levels

Receptor	City of Vancouver Construction Threshold L_{eq} (3 min)	Estimated Noise Contribution from Construction (dBA) Daytime (L_{eq} [3 min])[1]
R20	85	84.5
R21	85	59.6
R22	85	69.9
R23	85	55.8
R24	85	62.3
R25	85	69.1
R26	85	70.0
R27	85	63.7
R28	85	69.1
R29	85	68.7
R30	85	63.9
R31	85	57.1
R32	85	69.4
R33	85	58.9
R34	85	56.5
R47	85	55.9
R48	85	56.5
R49	85	56.0
R50	85	54.4



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

Leq(3min) Noise Contours for City of Vancouver Noise Bylaw - Construction

SCALE 1:15,000	CONTRACT NO.	SUB CONSULTANT PROJECT NO. 115814099
DATE 17-11-29		

SHEET NO. FIGURE 5 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

6.2 OPERATION

Noise modelling was performed to estimate noise levels associated with operational phase activities at the identified sensitive receptors. The results are compared to the City of Vancouver Noise By-Law (see Table 14) as well as against the US FTA Transit Noise guideline (see Table 15). In addition, the results are also presented as noise contours within the Review Area (see Figure 6 and Figure 7). As outlined in Section 3.2.2, ventilation noise sources, from the underground stations, are assessed against the City of Vancouver Noise By-Law (City of Vancouver 2016) nighttime noise threshold limits and operations noise sources, including trains, ventilation, and tunnel portals are assessed using the US FTA Transit Noise guideline.

Under the FTA guideline, at receptor locations near above ground train sections, the pre-project level (L_{dn} or $L_{eq\ (1h,\ max)}$ is compared against the post-project level for affected sensitive receptors. The pre-project sound level is based on the existing sound level result (see Table 4). The post-project sound level is the combined value of the estimated project-only sound level (i.e., operation of the train) and the pre-project sound level. Table 15 presents the pre-project, estimated project only, and post-project sound level for the sensitive receptors near the above ground rail portion.

Based on the difference between the pre-project and post-project sound levels, the impact classification (no impact, moderate, or severe impact) is determined from Figure 3 (see Section 3.2.2.2). The impact classification results for these receptors are shown in Table 15. The results indicate “moderate” at most locations and “severe” impact at two receptors (R01 and R12). These receptors are representative of locations immediately adjacent to the above ground rail section near Great Northern Way.

At the closest receptor to the tunnel opening (R11), the dominant noise contributor is the pass-by sound levels from the train rather than the tunnel opening effect. Noise modelling estimated that noise originating from the tunnel opening is greater than 10 dB below the train noise contribution at R11. This estimate is comparable to the noise assessment associated with the Evergreen Project, which were based on measurements at the Millennium line tunnel opening (Hatch 2010). However, the tunnel opening is expected to prolong the noise effects of a pass-by noise event, as trains exiting the tunnel can be heard before they cross the tunnel mouth.

Table 14 Estimated Results for Station Ventilation Noise

Receptor	Noise Contribution from Operation (dBA)		City of Vancouver By-Law Sound Level Threshold		City of Vancouver By-Law	
	Daytime L_{eq} (3 min) (dBA)	Nighttime L_{eq} (3 min) (dBA)	Daytime L_{eq} (3 min) (dBA)	Nighttime L_{eq} (3 min) (dBA)	Meet Daytime Threshold (yes/no)	Meet Nighttime Threshold (yes/no)
R01	12.3	22.5	60	55	Yes	Yes
R02	33.7	33.7	70	65	Yes	Yes
R03	45.5	45.5	70	65	Yes	Yes
R04	45.1	45.1	70	65	Yes	Yes
R05	37.2	37.2	70	65	Yes	Yes
R06	41.0	41.0	70	65	Yes	Yes
R07	45.6	45.6	70	65	Yes	Yes
R08	32.5	32.5	60	55	Yes	Yes
R10	30.9	30.9	60	55	Yes	Yes
R11	17.7	17.7	60	55	Yes	Yes
R12	11.0	11.0	60	55	Yes	Yes
R13	36.9	36.9	60	55	Yes	Yes
R14	6.3	6.3	60	55	Yes	Yes
R15	15.5	15.5	60	55	Yes	Yes
R16	52.7	52.7	70	65	Yes	Yes
R17	27.5	27.5	70	65	Yes	Yes
R18	23.3	23.3	70	65	Yes	Yes
R19	42.7	42.7	70	65	Yes	Yes
R20	43.2	43.2	70	65	Yes	Yes
R21	21.4	21.4	60	55	Yes	Yes
R22	32.8	32.8	70	65	Yes	Yes

Table 14 Estimated Results for Station Ventilation Noise

Receptor	Noise Contribution from Operation (dBA)		City of Vancouver By-Law Sound Level Threshold		City of Vancouver By-Law	
	Daytime L_{eq} (3 min) (dBA)	Nighttime L_{eq} (3 min) (dBA)	Daytime L_{eq} (3 min) (dBA)	Nighttime L_{eq} (3 min) (dBA)	Meet Daytime Threshold (yes/no)	Meet Nighttime Threshold (yes/no)
R23	23.0	23.0	60	55	Yes	Yes
R24	23.2	23.2	70	65	Yes	Yes
R25	32.0	32.0	70	65	Yes	Yes
R26	25.3	25.3	70	65	Yes	Yes
R27	29.8	29.8	70	65	Yes	Yes
R28	32.2	32.2	60	55	Yes	Yes
R29	27.3	27.3	70	65	Yes	Yes
R30	26.0	26.0	60	55	Yes	Yes
R31	22.8	22.8	70	65	Yes	Yes
R32	31.3	31.3	70	65	Yes	Yes
R33	24.1	24.1	70	65	Yes	Yes
R34	22.0	22.0	70	65	Yes	Yes
R47	18.0	18.0	70	65	Yes	Yes
R48	19.2	19.2	60	55	Yes	Yes
R49	21.8	21.8	60	55	Yes	Yes
R50	19.0	19.0	60	55	Yes	Yes

Table 15 Estimated Results for Operation—Train Noise

Receptor [1]	Land Use Category per US FTA Guideline	Pre-Project Sound Level [2,3]	Project Only Sound Level [4]	Post-Project Sound Level [5]	Post-Project and Pre-Project Difference (dBA)	US FTA Impact Level [6]
		L_{dn} or L_{eq} (1 hr, max) (dBA)	L_{dn} or L_d (dBA)	L_{dn} or L_{eq} (1 hr, max) (dBA)		
R01	2	67.0	60.8	67.9	0.9	severe
R02	3	66.1	41.4	66.1	0.0	moderate
R03	2	63.0	52.6	63.4	0.4	moderate
R10	3	66.1	50.2	66.2	0.1	moderate
R11	3	68.9	64.0	70.1	1.2	moderate
R12	2	67.0	68.8	71.0	4.0	severe
R14	3	68.9	59.4	69.4	0.5	moderate
R15	2	63.0	55.8	63.8	0.8	moderate
R30	2	60.8	46.8	61.0	0.2	moderate

NOTES:

1 Only representative receptors that are affected by above ground train noise sources are listed.

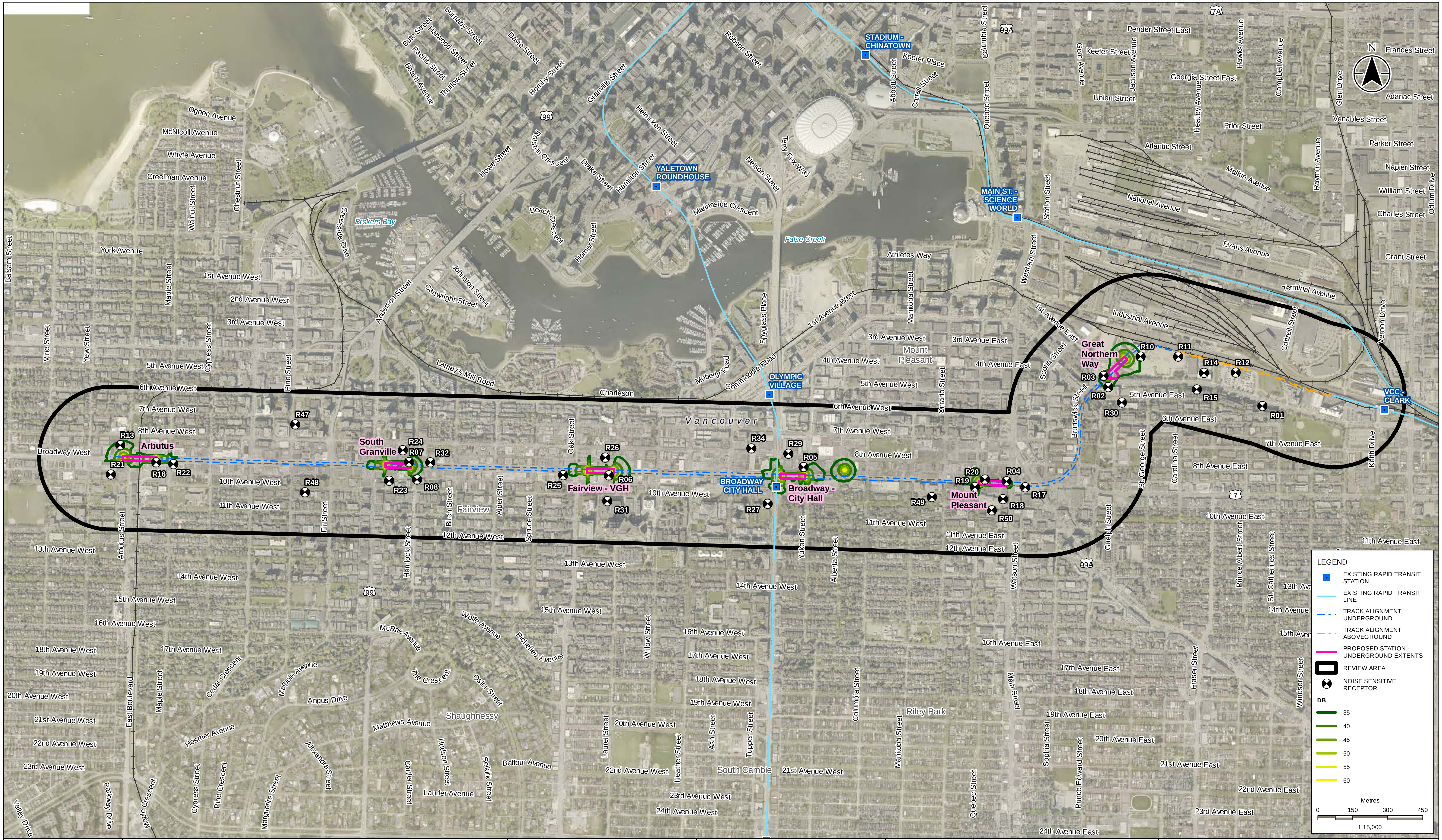
2 Day-Night Sound Level (L_{dn}) is used for Category 2 land use. Highest 1 Hr L_{eq} (1 hr, max) is used for Category 3 land use.

3 Based on existing sound level from Section 4.4.

4 Model estimated results. L_{dn} is used for Category 2 land use, L_d is used for Category 3 land use.

5 Energetic addition of Pre-Project Sound Level and Project Only sound level.

6 Based on Figure 3.



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

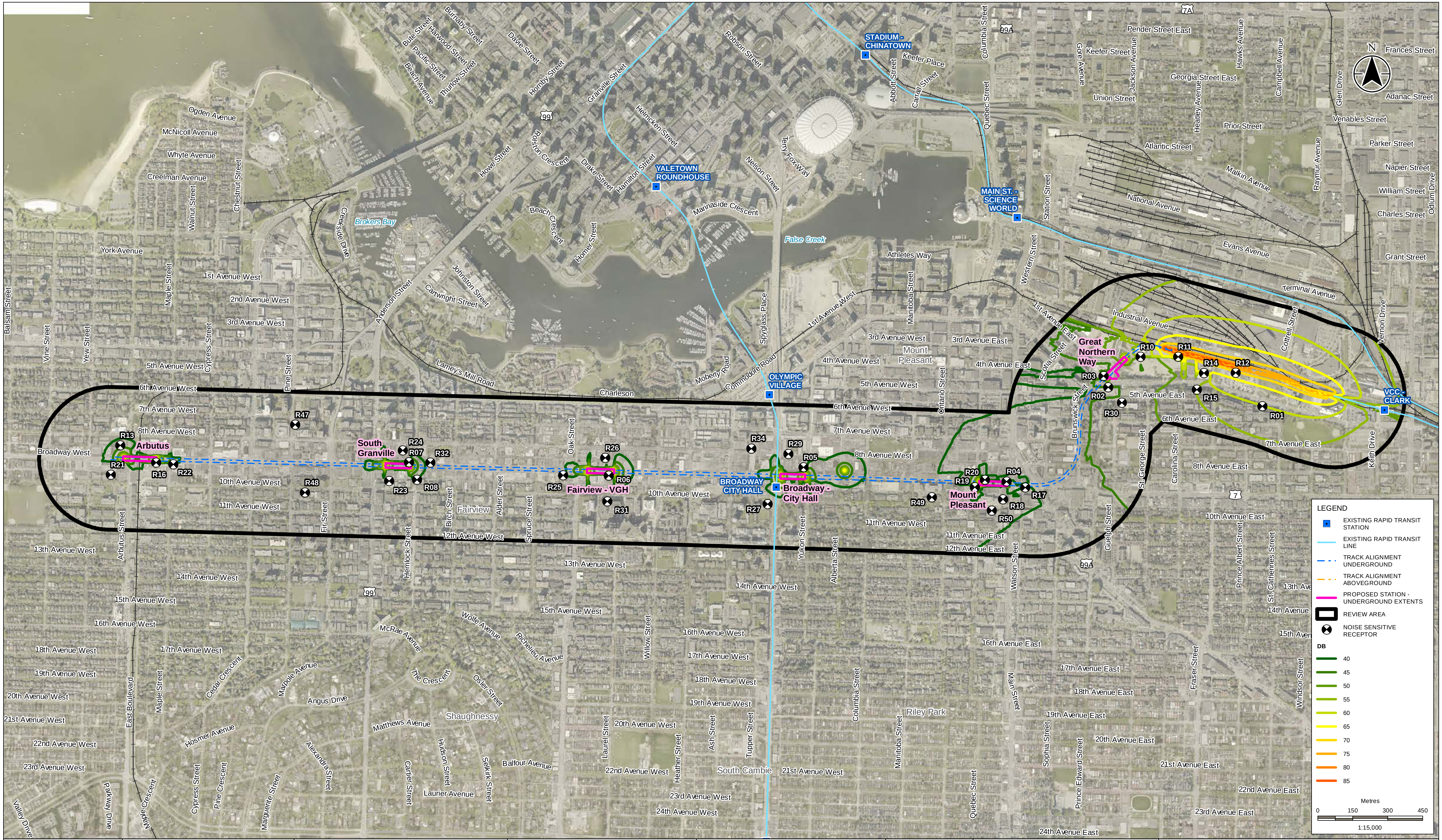
Stantec

BROADWAY SUBWAY PROJECT

Leq(3min) Noise Contours for City of Vancouver Noise Bylaw – Operation Ventilation Noise

SCALE 1:15,000
DATE 17-11-29
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO.
FIGURE 6
A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

Ldn Noise Contours for US FTA – Operation Train Noise

SCALE 1:15,000
DATE 17-11-29
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO.

FIGURE 7

A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

7.0 SUMMARY

A noise review was carried out to estimate noise effects associated with Project construction and operation. As part of this review, a noise field survey was conducted at ten locations along the Project alignment, representative of sensitive receptors, to quantify existing sound levels. Selected receptors for this review include residential areas, educational or medical buildings as well as places of worship. These receptors were considered representative of the most affected receptors in the Review Area. The results from this field survey, together with design information associated with the reference design, were used to estimate project-related construction and operation noise.

Measured existing L_{dn} values were mostly in the high 60 dBA range with some locations exceeding 70 dBA. The noise measurement results are considered representative of nearby sensitive receptors in the review area.

Noise effects from project-related daytime construction activities were estimated at the sensitive receptors and compared against the City of Vancouver Noise By-Law. At all receptors adjacent to station construction area extents and further away, estimated sound levels are predicted to be below the City of Vancouver construction noise threshold. For nighttime work, where required, the contractor will be required to comply with nighttime noise thresholds (lower than daytime) established by the Project.

Noise effects from project-related operation activities were estimated at the sensitive receptors. The results were compared against the City of Vancouver Noise By-Law and the US FTA noise guideline. Underground station ventilation noise levels at receptors are expected to be below the City of Vancouver Noise By-Law with implementation of appropriate mitigation measures.

As per the method prescribed in the US FTA guideline, estimated train noise results in “moderate” impact at seven receptor locations and “severe” impact at two locations, although estimated noise would be below City of Vancouver thresholds. Locations at a “severe” noise impact level represent a compelling need for noise mitigation. Noise barriers can be used to effectively reduce “severe” noise impacts to “moderate”. The need for noise mitigation should be considered for locations at the “moderate” level in conjunction with factors such as receptor sensitivity, effectiveness of mitigation strategies, and the increase in ambient noise.

This noise review is based on preliminary Project design information, associated with the reference design, and assumes a conservative construction fleet and operation design parameters to estimate the noise impact.

8.0 REFERENCES

BKL Consultants Ltd. 1991. A Comparison of Single Event SkyTrain Noise Levels to Noise from Other Transportation Sources - prepared for B.C. Transit. - File: 1462-91A.

Bruel & Kjaer, 2000. Environmental Noise. Sound & Vibration Measurement A/S.

Census Mapper. 2018. Canada Census 2016. Available online at: https://censusmapper.ca/maps/new#14/49.1865/-122.8348. Accessed: Jan 2018.

City of Vancouver. 2018. VanMap. Available online at: http://vancouver.ca/your-government/vanmap.aspx. Accessed December 2017.

City of Vancouver. 2016. Noise Control By-Law No. 6555. November 15, 2016.

Crocker M.J. 2007. Handbook of Noise and Vibration Control.

DataKustik. 2017. DataKustik (DataKustik GmbH). 2017. Cadna/A Computer Aided Noise Abatement Model, Version 2017 MR 1 (64 Bit). Munich, Germany.

Hatch. 2010. Evergreen Line Rapid Transit Project 2010. Environmental Assessment Certificate Application. Section 13: Noise and Vibration Assessment.

ISO (International Organization for Standardization). 1993. ISO 9613-1. Acoustics – Attenuation of Sound During Propagation Outdoors – Part 1: Calculation of the Absorption of Sound by the Atmosphere

ISO. 1996. ISO 9613-2. Acoustics – Attenuation of Sound During Propagation Outdoors – Part 2: General Method of calculation

Ministry of Transportation and Infrastructure (MoTI). 2016. Policy for Assessing and Mitigation Noise Impact from New and Upgraded Numbered Highways. April 2014. Wakefield Acoustics Ltd. Victoria, BC. April 2014, revised October 27, 2016.

StatCan. 2017. Table 1 The 10 highest population densities among municipalities (census subdivisions) with 5,000 residents or more, Canada, 2016. Available online at: https://www.statcan.gc.ca/daily-quotidien/170208/t001a-eng.htm.

United States Environmental Protection Agency (US EPA). 1974. Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. Report No. 550/9-74-004.

United States Federal Transit Administration (US FTA). Transit Noise and Vibration Impact Assessment. May 2006.

United States Department of Transportation. Federal Railroad Administration. High-Speed Ground Transportation Noise and Vibration Impact Assessment. October 2005.

Wolfgang Probst. 2008. Prediction of Sound radiated from Tunnel Openings. DataKustik GmbH and ACCON GmbH. Germany.

APPENDIX A

Measured Noise Levels

Stantec

Noise Baseline

October 30, 2019

Prepared for:

Broadway Subway Project
Ministry of Transportation and Infrastructure

Prepared by:

Stantec Consulting Ltd.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

Abbreviations

ANSI	American National Standards Institute
B&K	Bruel & Kjaer
dB	decibel
dBA	decibel A-weighted
ESR	Environmental and Socio-economic Review
HVAC	heating, ventilation, and air conditioning
kph	kilometers per hour
Ld	daytime equivalent sound level
Ldn	day-night equivalent sound level
Leq	energy equivalent sound level
Leq(h)	hourly energy equivalent sound level
Ln	nighttime equivalent sound level
MLBE	Millennium Line Broadway Extension
MoTI	Ministry of Transportation and Infrastructure
SLM	sound level meter

1.0 INTRODUCTION

The Broadway Subway Project (the Project) will be constructed in a bored tunnel beneath West Broadway, with six underground stations located at key intersections (see Figure 1). As part of the Environmental and Socio-Economic Review (ESR) being undertaken for the Project, noise from construction and operation of the Project has been identified as a Review Element for further consideration.

The initial component of the evaluation of noise along the Project Alignment was the establishment of baseline noise data. Baseline noise monitoring was undertaken at ten receptor locations that are representative of the area along the Project Alignment to quantify the existing acoustic environment (see Figure 1). The noise monitoring was conducted over a 24-hour to 48-hour period during the months of August and September 2017.

This report presents the noise monitoring locations, applicable reference protocols and guidelines used to guide the monitoring program, and monitoring methods used to quantify acoustic baseline conditions. The report outlines how the data were processed and summarizes baseline conditions at representative locations along the Project Alignment. The report concludes with an explanation of how the data will be used in the ESR process and the technical data report.

2.0 STUDY AREA

The Project is located in an urban area that includes densely-populated residential neighborhoods, commercial districts, business, medical facilities, as well as recreational and educational facilities.

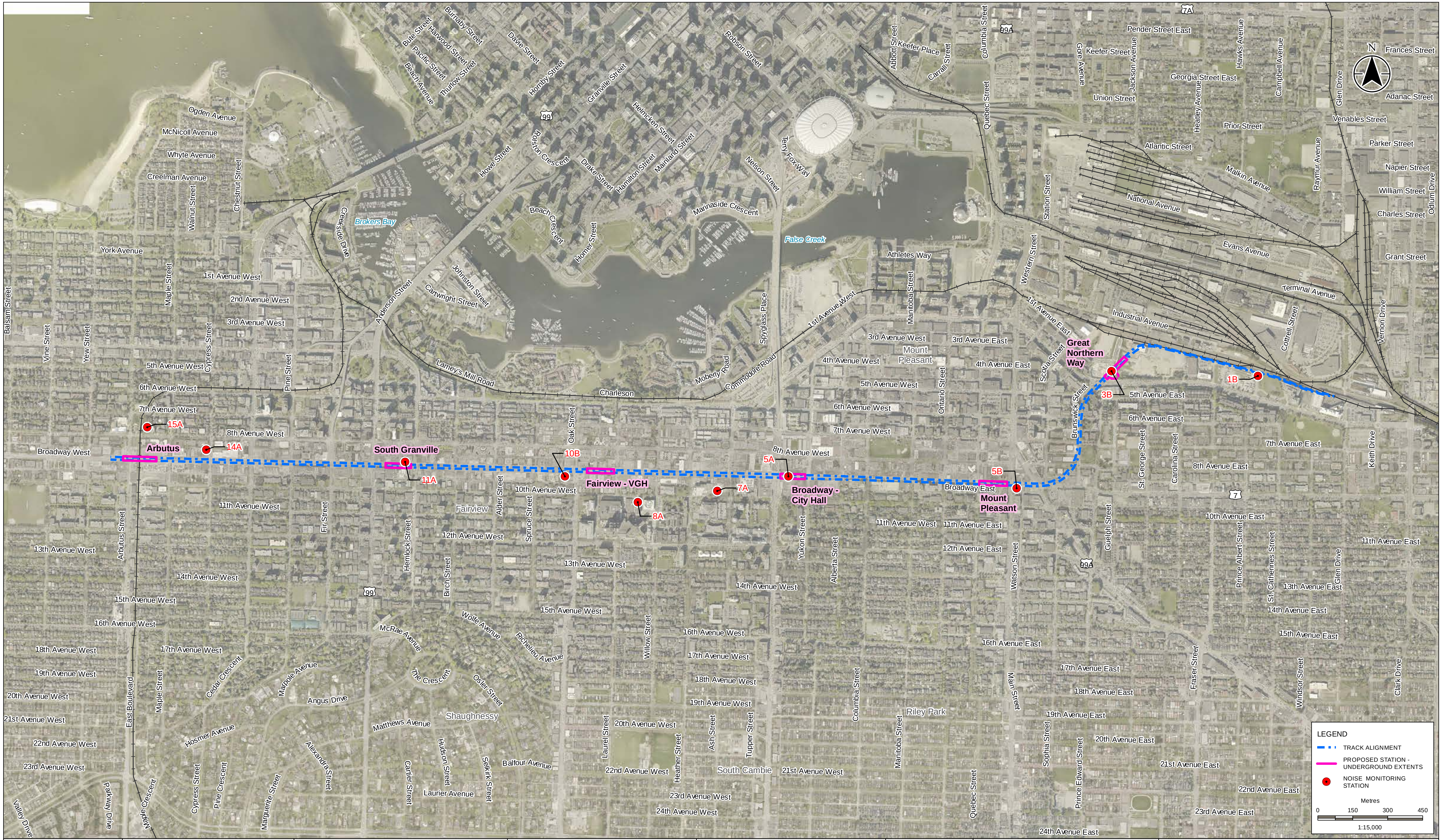
Baseline noise monitoring was undertaken at ten locations along the Alignment (see Table 1; Figure 1). Potential monitoring locations were selected based on presence of sensitive noise receptors and proximity to Project noise sources. Examples of sensitive receptors are residential buildings, schools and medical facilities. For example, potential locations were located near sensitive receptors that are located close to future Project noise sources, like the above ground rail section. Also important for the selection of locations were security concerns, local short-term noise circumstances (e.g., nearby ongoing construction), access restrictions and they needed to be on publicly accessible land or land owned by the City of Vancouver or TransLink. Final selection of monitoring locations was made in consultation between TransLink, City of Vancouver, as well as various stakeholders (e.g., Vancouver General Hospital).

The selected locations are considered representative of the local acoustic environment along different sections of the Alignment.

Study Area
October 30, 2019

Table 1 Noise Monitoring Locations

Location ID	Location (Main Intersections)	Setting Description	Microphone Equipment Setup	Location (UTM)	
				Easting (m)	Northing (m)
1B	Foley Street and Finning Way	Open space surrounded by medium density residential, haul truck parking, high density office space and active railway.	Car setup on street	493,713	5,457,151
3B	Thornton Way and Great North Way	Medium density residential area adjacent to a school and mixed office and commercial use.	Car setup on street	493,085	5,457,171
5A	Cambie Street and West Broadway	Medium to high density residential area mixed with dense commercial and office space along a major traffic roadway.	Third floor window setup	491,700	5,456,720
5B	Main Street and West Broadway	High density commercial and office area at a major traffic intersection.	Car setup in parking lot	492,679	5,456,669
7A	West 10 Avenue and Heather Street	Empty lot surrounded by low to high density office space.	Tripod on gravel empty lot	491,396	5,456,658
8A	West 11 Avenue between Willow Street and Oak Street	Medium density residential area mixed with high density office buildings.	Tripod on building lip/roof	491,055	5,456,610
10B	West Broadway and Oak Street	High density residential mixed with high density commercial and office space along a major traffic roadway.	Tripod on building roof	490,742	5,456,720
11A	West 11 Avenue between Heather Street and Oak Street	High density commercial and office space along a major traffic roadway.	Tripod on building roof	490,058	5,456,782
14A	West Broadway and Cypress Street	High density commercial and office space along a major traffic roadway.	Tripod on building roof	489,206	5,456,835
15A	West Broadway and Arbutus Street	Medium density residential mixed with two schools and commercial space.	Car setup on gravel	488,903	5,456,858



DESIGNED	INIT	YY-MM-DD DATE
DRAWN	INIT	YY-MM-DD DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

BASELINE NOISE MONITORING LOCATIONS

SCALE 1:15,000
DATE 17-11-29
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO.
FIGURE 1
A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

3.0 METHODS

3.1 INDICATORS

The indicator used for evaluating the baseline acoustic environment, is the energy equivalent sound level (L_{eq}). The L_{eq} may be quantified by different time periods such as, hourly (L_{eq}(h)), daytime (L_d), nighttime (L_n), and the day-night equivalent sound level (L_{dn}). The indicator L_{eq}(h) is the continuous hourly equivalent sound level. For example, the L_{eq}(overall) is the energy equivalent sound level over the entire measurement period (usually between 24 to 48 hours) and the L_{eq} (1 hr, max) is the maximum 1-hour L_{eq} measured over the monitoring period. In general, a L_{eq} value describes a receiver's cumulative noise exposure from all events over a specified time period. The use of these indicators permits the description of time-varying acoustic environments as single numbers.

The indicators L_d and L_n are the equivalent sound levels established for the daytime (07:00 to 22:00) and nighttime (22:00 to 07:00) periods. The L_{dn} is a 24-hour day-night equivalent sound level calculated using L_n and L_d, with a 10 decibel (dB) penalty (addition of 10 dB) applied to the L_n. As a result, the L_{dn} value can be higher than the L_d and L_n values.

The indicators L_{eq}(overall), L_{eq} (1 hr, max), L_d, L_n, and L_{dn} are based on A-weighted sound pressure levels. The A-weighting adjustment to sound pressure levels accounts for the relative loudness perceived by the human ear by frequency bands.

3.2 REFERENCE PROTOCOLS AND GUIDELINES

Baseline noise surveys were conducted to determine the existing (baseline) conditions of the acoustic environment in the representative areas surrounding the Project. These baseline conditions were used to support the assessment of potential project-related noise effects in consideration of the following noise guidelines, policies, and protocols:

- British Columbia Ministry of Transportation and Infrastructure (MoTI). Policy for assessing and mitigating noise impacts(MoTI 2016)
- City of Vancouver Noise Control By-Law No. 6555 (City of Vancouver 2016)
- Health Canada Guidance for Evaluating Human Health Impacts in Environmental Assessment: Noise (Health Canada 2017)

Collected existing noise data along the track alignment was used to quantify the existing noise levels, prior to Project implementation. Measured noise data can be put in context against default baseline noise levels, published by Health Canada, to determine if the measured values are below or above the estimates of Health Canada. Additionally, the existing noise levels are needed, when the project emissions are assessed against regulatory thresholds. For example, the MoTI policy requires that the post-Project L_{dn} noise levels are compared against pre-Project noise levels to assess the noise impact.

3.3 NOISE MONITORING EQUIPMENT

Noise monitoring was conducted at each location for 24-hours to 48-hours on weekdays. Weekdays were selected to capture the main traffic pattern but also because construction and operation will mostly impact weekdays. Bruel & Kjaer (B&K) type 1 integrating sound level meters (SLMs) were used for the measurements. The SLMs are compliant with the American National Standards Institute (ANSI) S1.43-1997 standard for measurement precision.

The B&K SLMs used a type 4952 outdoor microphone and preamp. The microphone setup varied with each location to accommodate location or security constraints. Some locations relied on the use of a tripod and in others, the microphone was mounted onto a building or car adapter. Table 1, above, summarizes equipment setup at each location. Examples of monitoring setup are shown in Figure 2.

The SLMs were set to measure sound levels with the logging frequency of one minute during the measurement period. Along with sound pressure levels, SLMs were set to concurrently record audio. Each audio recording was used in conjunction with the measured sound levels to help identify extraneous events. An extraneous event is defined as an isolated occurrence not representative of baseline conditions and may include events such as field technician activities, construction work, or conversations occurring adjacent to the monitoring equipment. These extraneous events were not included in the data analysis.

Bruel & Kjaer type 4231 acoustical calibrators were used to calibrate each SLM before and after each measurement session. The B&K Type 4231 complies with the ANSI S1.40-2006 Class 1 calibrator requirement with an estimated uncertainty for sound pressure level of ±0.12 dB at a 99% confidence level. Calibration level discrepancy did not exceed ±0.5 dB during the measurement period. The meters and supplementary calibrator units were laboratory-calibrated within the past 24 months.

(a) Tripod setup (site 7A only)

(b) Car setup (sites 1B,3B,5B,15A)

(c) Window setup (site 5B only)

(d) Tripod setup on rooftop (sites 8A,10B,11A,14A)

Figure 2 Typical Noise Monitoring Equipment Setup

3.4 WEATHER MONITORING EQUIPMENT

Rainy weather or winds greater than 15 kilometers per hour (kph) cause an increase in the measured sound level. As such, days with favorable weather forecasts were selected as representative of baseline conditions (i.e., no rain, winds less than 15 kph). Meteorological data were either collected on-site (i.e., Kestrel 4500) or obtained from Metro Vancouver.

3.4.1 Kestrel

A stand-alone weather station (i.e., Kestrel 4500) was set up on a tripod a few meters away from the SLM. Kestrel logged the following parameters on a one-minute interval:

- Wind direction
- Wind speed
- Ambient temperature
- Ambient pressure
- Relative humidity

3.4.2 External Data Sources

If the Kestrel unit could not be deployed due to security concerns (at locations 1B, 3B, 5B, 15A), meteorological data were obtained from Metro Vancouver (MV 2017) to inform screening and identify time periods where noise data were not representative. One-minute interval weather data were obtained from the Clark Drive (wind data), North Vancouver Station (precipitation), and Vancouver International Airport (precipitation) stations.

3.5 DATA ANALYSIS

Noise monitoring data were downloaded and analyzed to identify any extraneous noise events captured by the instrument. The SLM measured sound levels with the logging frequency of one minute during the measurement period. The one minute L_{eq} sound levels were averaged to determine equivalent sound levels for longer periods such as L_{eq}(overall), L_{eq}(1h, max), L_d, L_n, and L_{dn}. Measurements during extraneous noise events and non-representative weather conditions (i.e., rain and wind speed exceeding 15 kph) were isolated. The isolated measurements were not included in the determination of equivalent sound levels for different time periods.

4.0 RESULTS

Baseline noise monitoring was completed at ten key receptor locations along the Alignment. Section 4.1 summarizes monitoring results, while Section 4.2 details noise monitoring characteristics at each receptor location.

4.1 BASELINE MONITORING RESULTS

Baseline noise monitoring results are summarized in Table 2. The table includes site ID, monitoring dates, total and adjusted monitoring period (hours with and without extraneous data), and measured sound levels (in dBA). Measured sound levels are reported in terms of L_{eq}(overall), L_{eq}(1h, max), L_d, L_n and L_{dn}. The table also summarizes the main sources of noise at each location and the distance (in units of meters, m) of each monitoring location to the centre line of the Project Alignment.

Characteristics of baseline noise were dominated by road traffic (i.e., passerby traffic, vehicle acceleration/deceleration, air brakes, horns, backup alarms, engine starts). Baseline noise conditions are considered representative of a busy urban transportation corridor particularly along West Broadway. The loudest activities that influence baseline conditions were associated with passerby/ truck engines, first responder vehicles, motorcycles, and rail activities. Details specific to each monitoring location are discussed in Section 4.2. Plots of measured raw data are also provided for each location.

Table 2 Baseline Noise Results

Site ID	Dates	Monitoring Period (hours)		Measured Sound Level (dBA)					Characteristics of Baseline Noise	Approximate Distance to the Center Line of Rail Track (m)
		Total	Used	L_{eq} (overall)	L_{eq} (1h, max)	L_d	L_n	L_{dn}		
1B	Sep 19–21	50.37	46.28	63.1	68.9	64.2	59.9	67.0	Road traffic, rail traffic, use of haul truck parking lot and aircraft traffic.	15
3B	Sep 12–13	24.68	22.52	59.9	66.1	61.5	54.6	63.0	Road traffic, first responder vehicles and aircraft traffic	3
5A	Sep 6–7	23.82	23.03	71.1	75.4	72.5	67.6	75.2	Busy road traffic, first responder vehicles, buses, truck parking nearby.	2.0
5B	Sep 13–14	24.52	23.85	67.8	72.2	68.8	65.4	72.5	Busy road traffic, first responder vehicles, use of public parking lot and pedestrians.	18
7A	Sep 21–22	24.52	23.97	55.9	58.5	56.8	53.8	60.8	Road traffic, first responder vehicles and some aircraft traffic.	72
8A	Sep 20–22	46.88	45.78	58.1	63.5	59.5	54.3	62.0	Road traffic and aircraft traffic.	129
10B	Sep 6–7	24.05	23.93	63.8	67.9	65.4	57.7	66.4	Busy road traffic, first responder vehicles, aircraft traffic and daytime construction activities.	27
11A	Aug 30–31	27.83	27.28	65.1	70.5	66.3	60.2	68.0	Busy road traffic, first responder vehicles, daytime construction activities, pedestrians, and aircraft traffic.	17
14A	Aug 31–Sep 1	24.27	23.87	58.5	62.3	59.7	54.8	62.4	Road traffic, first responder vehicles, and HVAC use on nearby roof.	48
15A	Sep 14–15	24.68	22.70	57.3	61.0	58.7	53.4	63.0	Road traffic, some construction activities, school activities, and pedestrians.	136

4.2 SITE SPECIFIC QUALITATIVE OBSERVATIONS

4.2.1 Monitoring Location 1B

Monitoring equipment at location 1B was set up in a car along Foley Street. The location sits adjacent a recreational park to the east, truck parking area to the west, rail tracks/ yard to the north, with Great Northern Way and medium density housing to the south. Monitoring was conducted for approximately 48 hours, with some intermittent rainfall and low winds reported on September 19 and 20, 2017.

Noise from rail activities (i.e., locomotives, rail car movement) was intermittent during daytime and nighttime hours and reflected freight and commuter passenger trains at the adjacent rail yard and along active train tracks. Other sources of noise included trucking activities (mostly truck tractors and trailers) at the truck parking area. Noise was also produced by road traffic along Great Northern Way and infrequent aircraft traffic.

The overall and 1-hour maximum L_{eq} were 63.1 and 68.9 dBA respectively. The L_d was 64.2 dBA and the L_n was 59.9 dBA, resulting in a L_{dn} of 67.0 dBA. This data indicates a noticeable difference between daytime and nighttime values which is primarily due to lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 3. The first 24 hours do not show a visible difference in sound levels between daytime and nighttime hours. This is likely due to weather conditions with intermittent rainfall and wind events on September 19 and 20, 2017. In instances where inclement weather conditions were confirmed from available meteorological station data (i.e., no rain, winds less than 15 kph), the acoustic data were removed from the overall analysis. Most of the peaks shown in Figure 3 were a function of rail/truck activities (i.e., engine use, engine breaks, honking, train horns) and passerby first responder vehicles. These sources of noise are part of the overall baseline condition for this location.

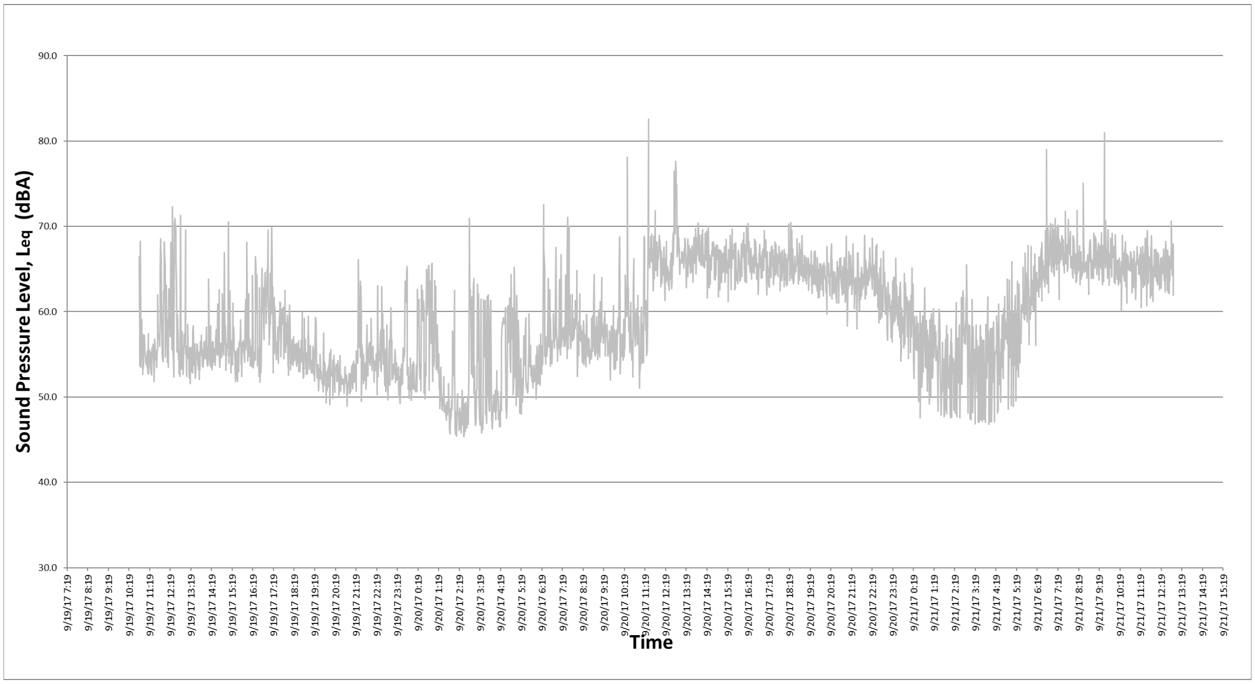


Figure 3 Site 1B Time-History Plot

4.2.2 Monitoring Location 3B

Monitoring equipment at location 3B was set up in a car along Thornton Street and near the Great Northern Way intersection. To the west of Thornton Street is medium density residential development, to the east is a recreational park and the new Emily Carr University of Art and Design complex, and to the north are rail tracks/rail yard. Monitoring was conducted for approximately 24 hours. Although meteorological data showed no rainfall, winds speeds were identified to be greater than 15 kph. Data collected during these instances were identified and not included in the analysis.

Road traffic noise dominated the acoustic environment along Great Northern Way. In addition, the recreational park was under intermittent construction during the monitoring period (i.e., construction equipment, water pump). Extraneous (temporary) sources of construction noise (e.g., water pump, concrete grinding) were identified and excluded from the analysis. Other sources of noise included intermittent aircraft traffic and first responder vehicles. Although location 3B is relatively close to the rail tracks, rail activities (i.e., engine use, engine brakes and train horns) were not as distinguishable as with location 1B, but are likely part of the acoustic baseline.

The overall L_{eq} and 1-hour maximum L_{eq} were 59.9 and 66.1 dBA respectively. The L_d was 61.5 dBA and the L_n was 54.6 dBA, resulting in a L_{dn} of 63.0 dBA. There is a noticeable difference between daytime and nighttime values, mostly due to lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 4. Most of the peaks were a function of truck activities along Great Northern Way (i.e., engine use, engine breaks, honking) and passerby first responder vehicles. These sources of noise are part of the overall baseline analysis for this location.

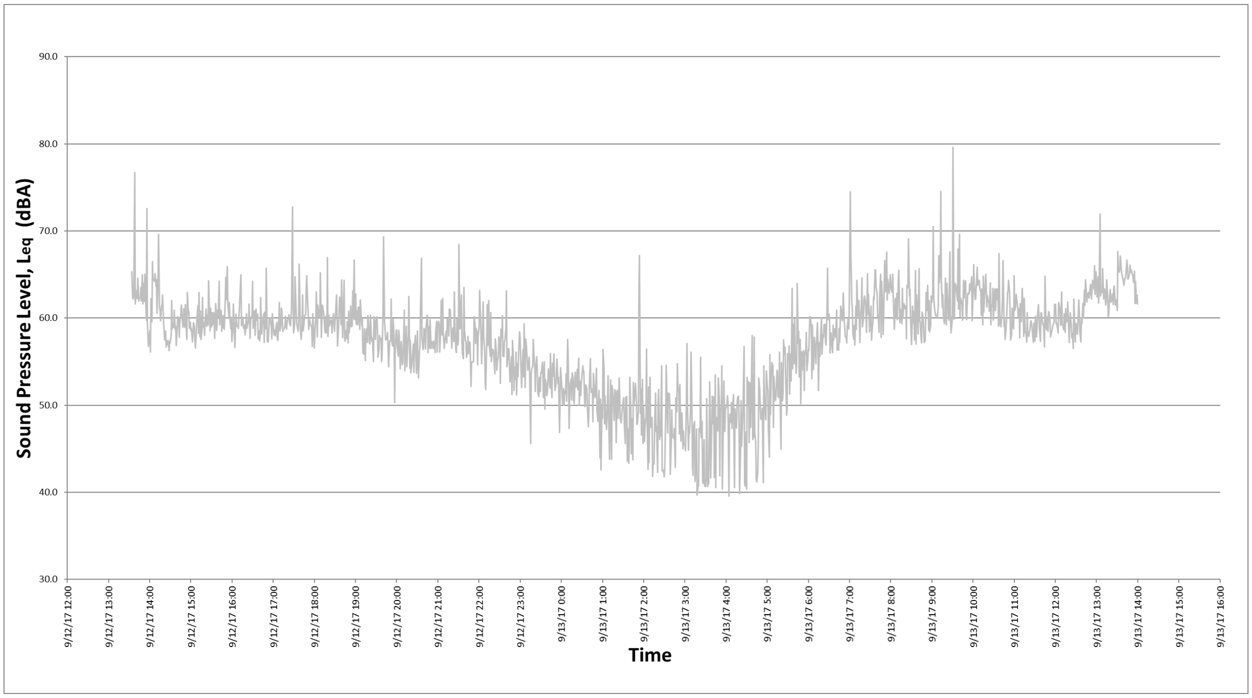


Figure 4 Site 3B Time-History Plot

4.2.3 Monitoring Location 5A

Monitoring equipment at location 5A was set up outside a third-floor window in a building along West Broadway near the Cambie Street intersection. The area is predominantly commercial and includes the Cambie SkyTrain/bus stop adjacent to the monitoring location. Monitoring was conducted for approximately 24 hours. Meteorological data showed no rainfall and low wind speeds (i.e., wind speeds < 15 kph) during this monitoring period.

The acoustic environment at 5A was dominated by road traffic along West Broadway. (i.e., vehicles, buses, trucks, first responder vehicles), adjacent bus stop, and pedestrian activities along the main sidewalk.

The overall L_{eq} and 1-hour maximum L_{eq} were 71.1 and 75.4 dBA respectively. The L_d was 72.5 dBA and the L_n was 67.6 dBA, resulting in a L_{dn} of 75.2 dBA. This data indicates a noticeable difference between daytime and nighttime values, mostly due to lower traffic volumes and reduced commercial activity during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 5. Most of the peaks are a function of first responder vehicles and truck activities along West Broadway (i.e., engine use, engine breaks, honking). These sources of noise are part of the overall baseline analysis for this location.

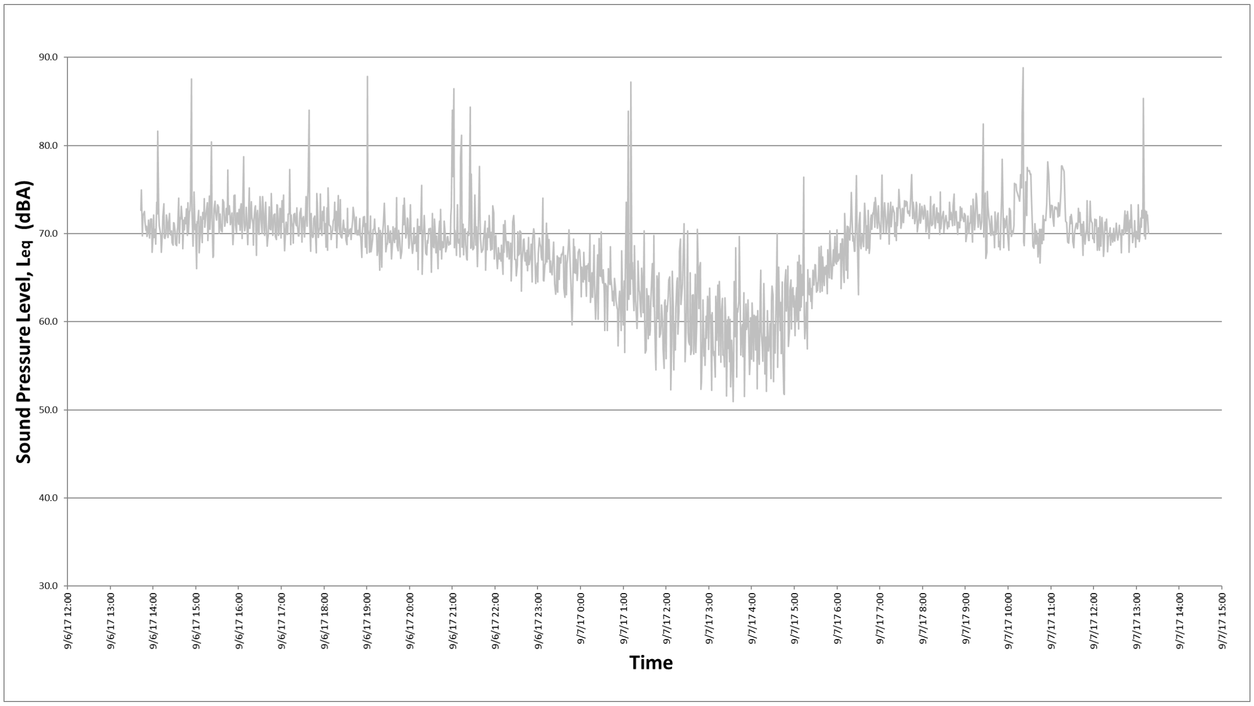


Figure 5 Site 5A Time-History Plot

4.2.4 Monitoring Location 5B

Monitoring equipment at location 5B was set up in a car in a public parking lot on the northwest corner of the West Broadway and Main Street intersection. This is a busy intersection surrounded by high density commercial businesses. Monitoring was conducted for approximately 24 hours. Although meteorological data showed no rainfall, winds speeds were identified to be greater than 15 kph. Data collected during these instances were identified and not included in the analysis.

The acoustic environment at 5B was dominated by road traffic through the West Broadway and the Main Street intersection (i.e., vehicles, buses, trucks, first responder vehicles), intermittent road construction activities, as well as building construction adjacent to the parking lot, public parking use, and pedestrian activities.

The overall L_{eq} and 1-hour maximum L_{eq} were 67.8 and 72.2 dBA respectively. The L_d was 68.8 dBA and the Ln was 65.4 dBA, resulting in a L_{dn} of 72.5 dBA. The data indicates a noticeable difference between daytime and nighttime values, mostly due to lower traffic volume and reduced commercial and construction activity during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 6. Most of the peaks are a function of first responder vehicles and truck activities (i.e., engine use, engine breaks, honking). These sources of noise are part of the overall baseline analysis for this location.

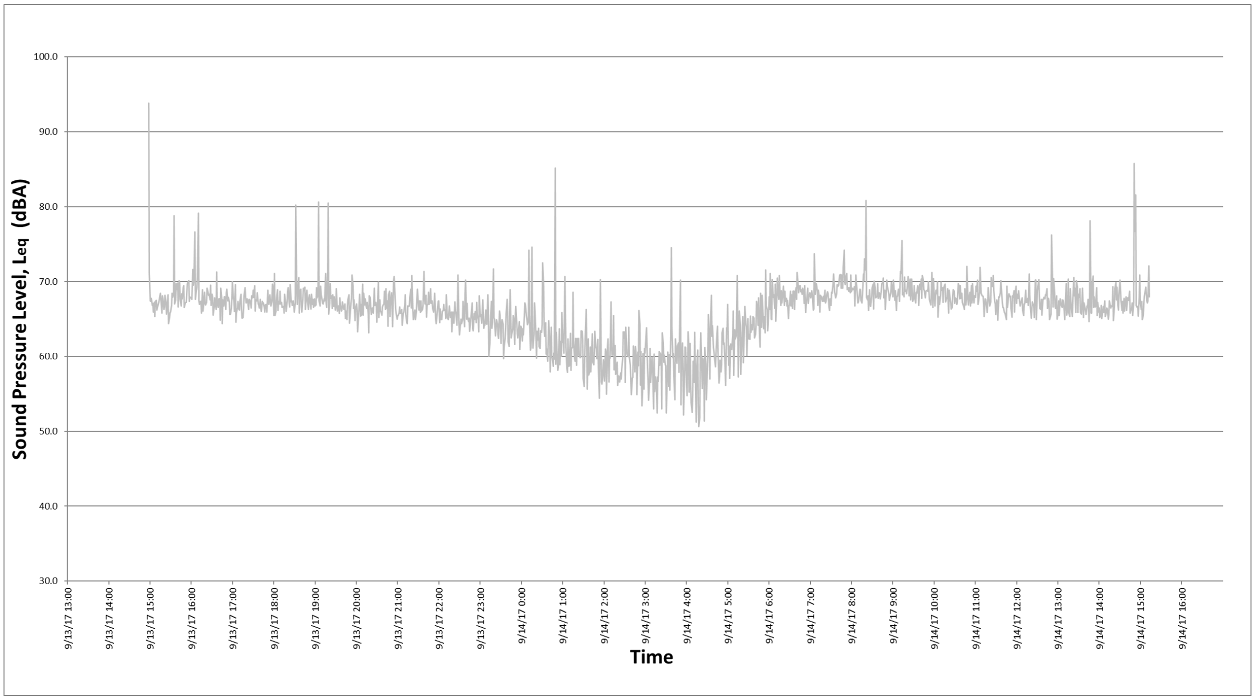


Figure 6 Site 5B Time-History Plot

4.2.5 Monitoring Location 7A

Monitoring equipment at location 7A was set up on a tripod in an empty lot next to the British Columbia Cancer Agency building, between West 10th Avenue and the alley south of West Broadway. This location is surrounded by low to high rise office buildings and is not directly adjacent to West Broadway. Monitoring was conducted for approximately 24 hours. Meteorological data showed no rainfall and low wind speeds (i.e., wind speeds less than 15 kph) during this monitoring period.

The acoustic environment at 7A was dominated by light road traffic along adjacent roads and some aircraft traffic.

The overall L_{eq} and 1-hour maximum L_{eq} were 55.9 and 58.5 dBA respectively. The L_d was 56.8 dBA and the L_n was 53.8 dBA, resulting in a L_{dn} of 60.8 dBA. As this area has a lower level of activity, relative to monitoring sites located directly adjacent to Broadway, the difference between daytime and nighttime noise levels is smaller but still noticeable and is primarily influenced by lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 7. Most of the peaks are a function of first responder vehicles and truck activities (i.e., engine use, engine breaks, honking). These sources of noise are part of the overall baseline analysis for this location.

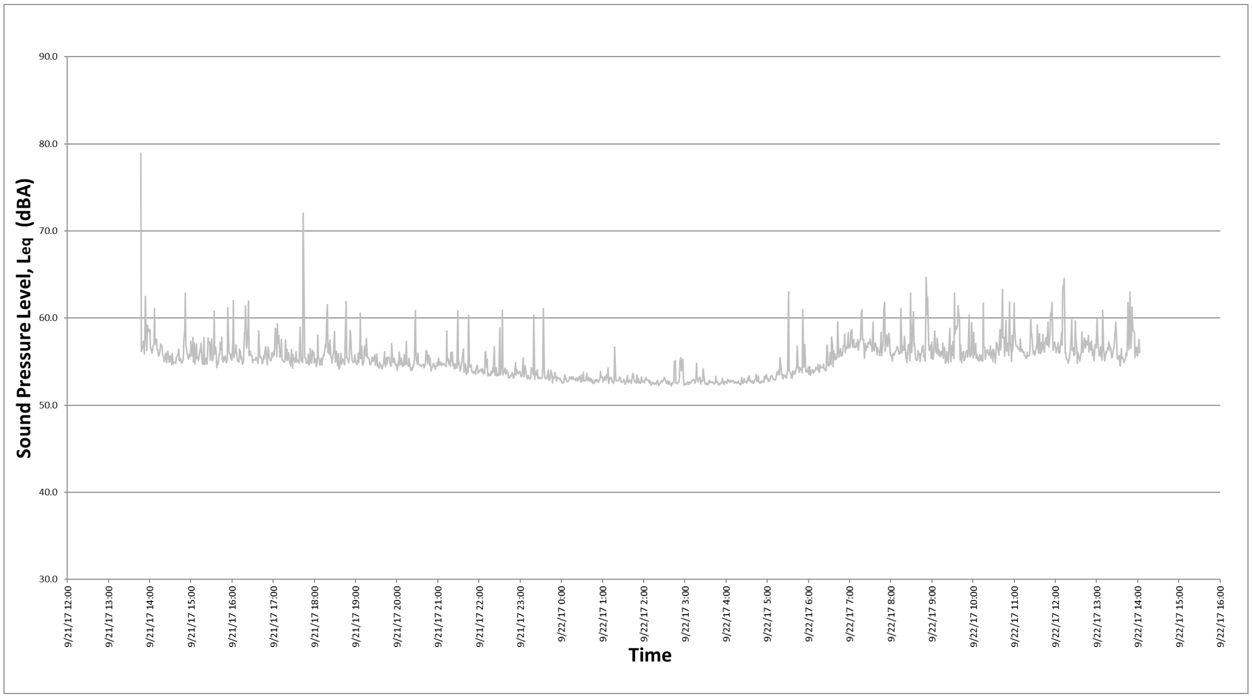


Figure 7 Site 7A Time-History Plot

4.2.6 Monitoring Location 8A

Monitoring equipment at location 8A was set up on a tripod on the lip of the second floor of a multi-story building on West 10th Avenue, near the Vancouver General Hospital. The location is surrounded by medium density residential and high rise office buildings, and not directly adjacent to West Broadway. Monitoring was conducted for approximately 48 hours. Meteorological data showed no rainfall and low wind speeds (i.e., wind speeds less than 15 kph) during this monitoring period.

The acoustic environment at 8A was dominated by road traffic along adjacent roads and occasional aircraft traffic likely associated with the Vancouver General Hospital. Noise associated with temporary road construction activities, taking place at the time of monitoring, were removed from the dataset prior to analysis.

The overall L_{eq} and 1-hour maximum L_{eq} were 58.1 and 63.5 dBA respectively. The L_d was 59.5 dBA and the L_n was 54.3 dBA, resulting in a L_{dn} of 62.0 dBA. As this area has less road traffic, relative to monitoring sites directly adjacent to Broadway, the difference between daytime and nighttime is smaller, but still noticeable. The difference between daytime and nighttime noise levels is primarily influenced by lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 8. Most of the peaks are a function of truck activities along adjacent roads (i.e., engine use, engine breaks, beeping).

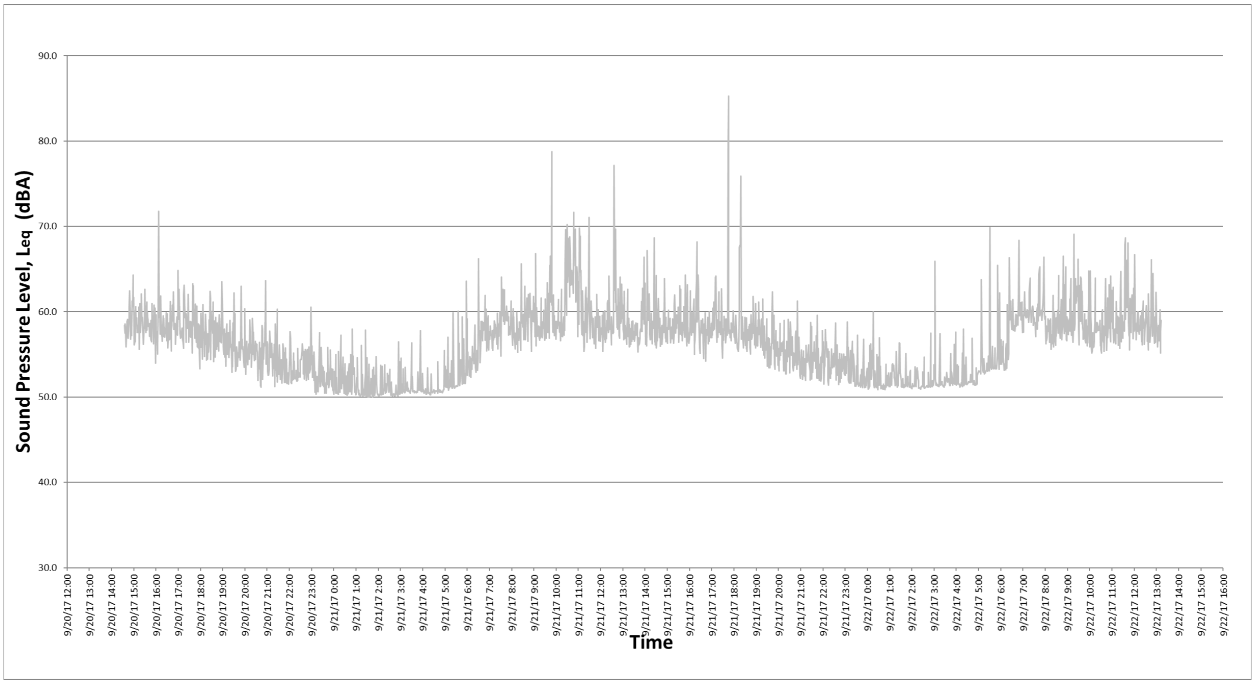


Figure 8 Site 8A Time-History Plot

4.2.7 Monitoring Location 10B

Monitoring equipment at location 10B was set up on top of a one-story commercial building adjacent to West Broadway near the intersection with Oak Street. The area is predominantly high-density residential and high-density commercial. Monitoring was conducted for approximately 24 hours. Meteorological data showed no rainfall and low wind speeds (i.e., wind speeds less than 15 kph) during this monitoring period.

The acoustic environment at 10B was dominated by road traffic along West Broadway (i.e., vehicles, buses, trucks, first responder vehicles), and pedestrian activities along the main sidewalk. Noise associated with temporary construction at the southeast corner of the intersection of Oak Street and West Broadway, that was ongoing during monitoring, was removed from the analysis where noise from such activities was clearly distinguishable.

The overall L_{eq} and 1-hour maximum L_{eq} were 63.8 and 67.9 dBA respectively. The L_d was 65.4 dBA and the Ln was 57.7 dBA, resulting in a L_{dn} of 66.4 dBA. The data indicate a noticeable difference between daytime and nighttime values, primarily due to lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 9. Most of the peaks are a function of first responder vehicles and truck activities (i.e., engine use, engine breaks, honking) along West Broadway. These sources of noise are part of the overall baseline analysis for this location.

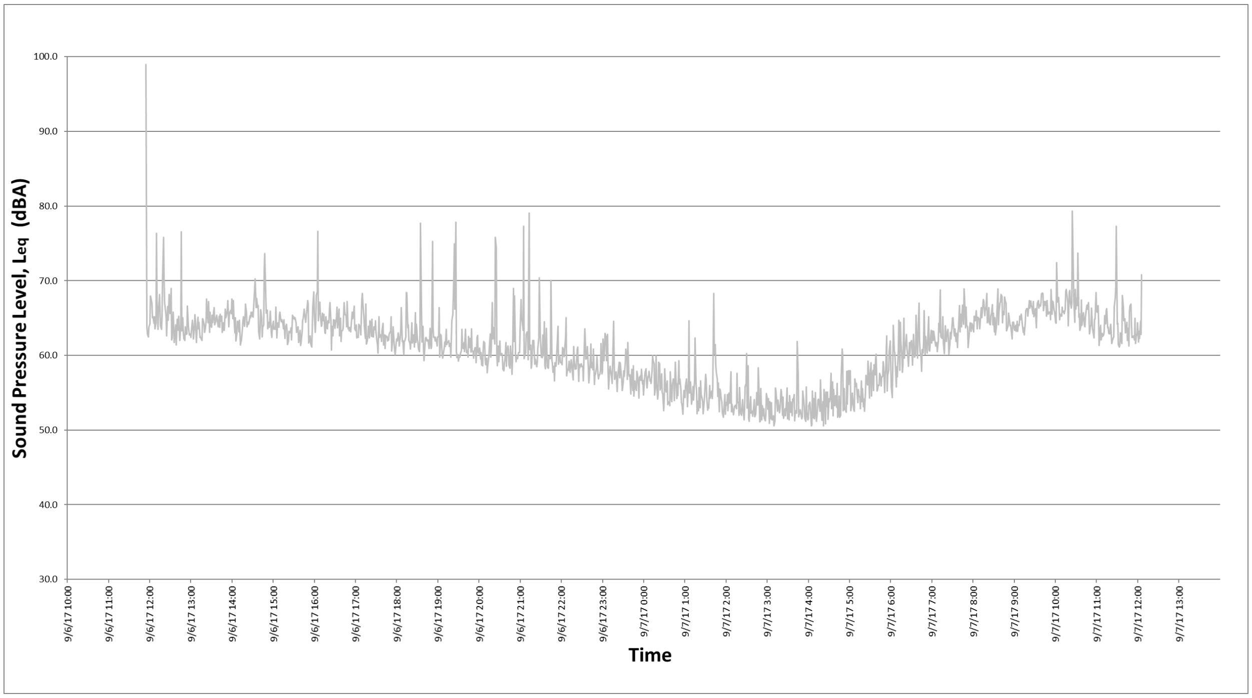


Figure 9 Site 10B Time-History Plot

4.2.8 Monitoring Location 11A

Monitoring equipment at location 11A was set up on a tripod on the roof of a one-story building along West Broadway. The location is surrounded by high density commercial and office space along a major traffic roadway. Monitoring was conducted for approximately 24 hours. Although meteorological data showed no rainfall, winds speeds were identified to be greater than 15 kph. Data collected during these instances were identified and not included in the analysis.

The acoustic environment at 11A was dominated by road traffic along adjacent roads. Noise associated with (temporary) road construction activities, identified during the monitoring period, was removed from the dataset prior to analysis. Other sources of noise included pedestrians along the street sidewalk and occasional aircraft traffic.

The overall L_{eq} and 1-hour maximum L_{eq} were 65.1 and 70.5 dBA respectively. The L_d was 66.3 dBA and the Ln was 60.2 dBA, resulting in a L_{dn} of 68.0 dBA. The data indicates a difference between daytime and nighttime noise levels, primarily due to lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 10. Most of the peaks are a function of first responder vehicles and truck activities along adjacent roads (i.e., engine use, engine breaks, beeping).

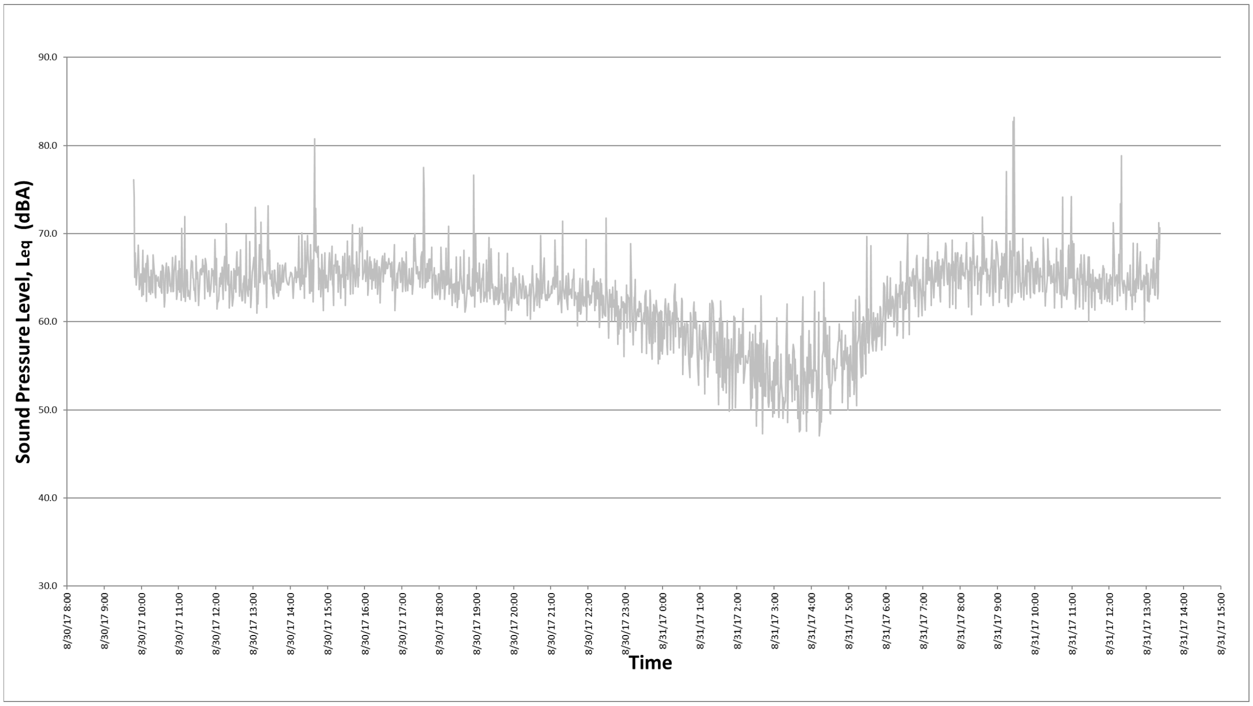


Figure 10 Site 11A Time-History Plot

4.2.9 Monitoring Location 14A

Monitoring equipment at location 14A was set up on a tripod on the roof of a two-story building on the intersection of West Broadway and Cypress Street. Monitoring equipment was set up on the north-east corner of the building facing Cypress Street. This location was selected to minimize the impact of multiple heating, ventilation, and air conditioning (HVAC) systems running on top of the roof. The location is surrounded by high density commercial and office space along a major traffic roadway. Monitoring was conducted for approximately 24 hours. Although meteorological data showed no rainfall, winds speeds were identified to be greater than 15 kph. Data collected during these instances were identified and not included in the analysis.

The acoustic environment at 14A was dominated by road traffic along adjacent roads. Other sources of noise included pedestrians along the street sidewalk and aircraft traffic. The HVAC system was also used sporadically during the daytime and nighttime hours and is included in the overall baseline characterization.

The overall L_{eq} and 1-hour maximum L_{eq} were 58.5 and 62.3 dBA respectively. The L_d was 59.7 dBA and the Ln was 54.8 dBA, resulting in a L_{dn} of 62.4 dBA. The data indicates a difference between daytime and nighttime noise levels, primarily due to lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 11. Most of the peaks are a function of first responder vehicles and truck activities along adjacent roads (i.e., engine use, engine breaks, beeping).

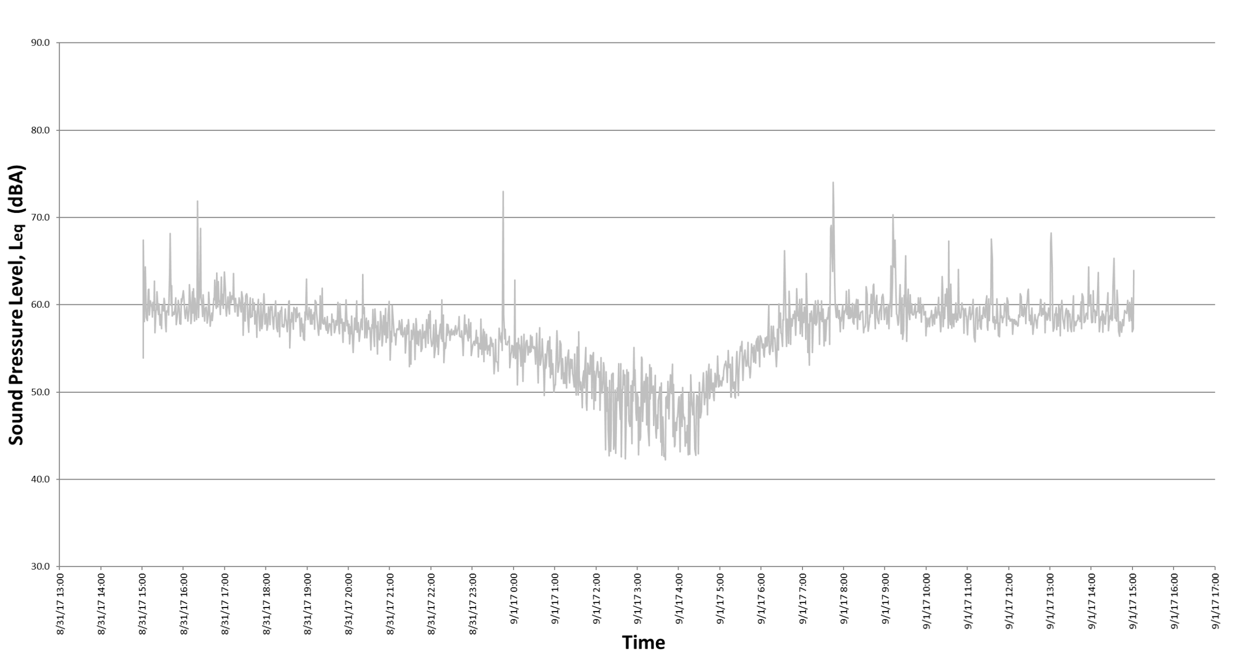


Figure 11 Site 14A Time-History Plot

4.2.10 Monitoring Location 15A

Monitoring equipment at location 15 was set up in a car near Arbutus Street and West 8th Avenue. The location is surrounded by medium density residential buildings mixed with two schools and commercial spaces. Monitoring was conducted for approximately 24 hours. Although meteorological data showed no rainfall, winds speeds were identified to be greater than 15 kph. Data collected during these instances were identified and not included in the analysis.

The acoustic environment at 15A was dominated by noise from road traffic along surrounding roads, pedestrian and nearby school activities. Noise associated with (temporary) road construction activities, identified during the monitoring period, was removed from the dataset prior to analysis. There was also intermittent construction during the monitoring period. Distinguishable sound levels produced by these extraneous sources were identified and excluded from the analysis.

The overall L_{eq} and 1-hour maximum L_{eq} were 57.3 and 61.0 dBA respectively. The L_d was 58.7 dBA and the Ln was 53.4 dBA, resulting in a L_{dn} of 63.0 dBA. The data indicates a difference between daytime and nighttime noise levels, with lower nighttime noise levels associated with lower traffic volumes during the nighttime.

Raw one-minute average L_{eq} values collected during the monitoring period are shown graphically in Figure 12. Most of the peaks are a function of first responder vehicles and truck activities along adjacent roads (i.e., engine use, engine breaks, beeping).

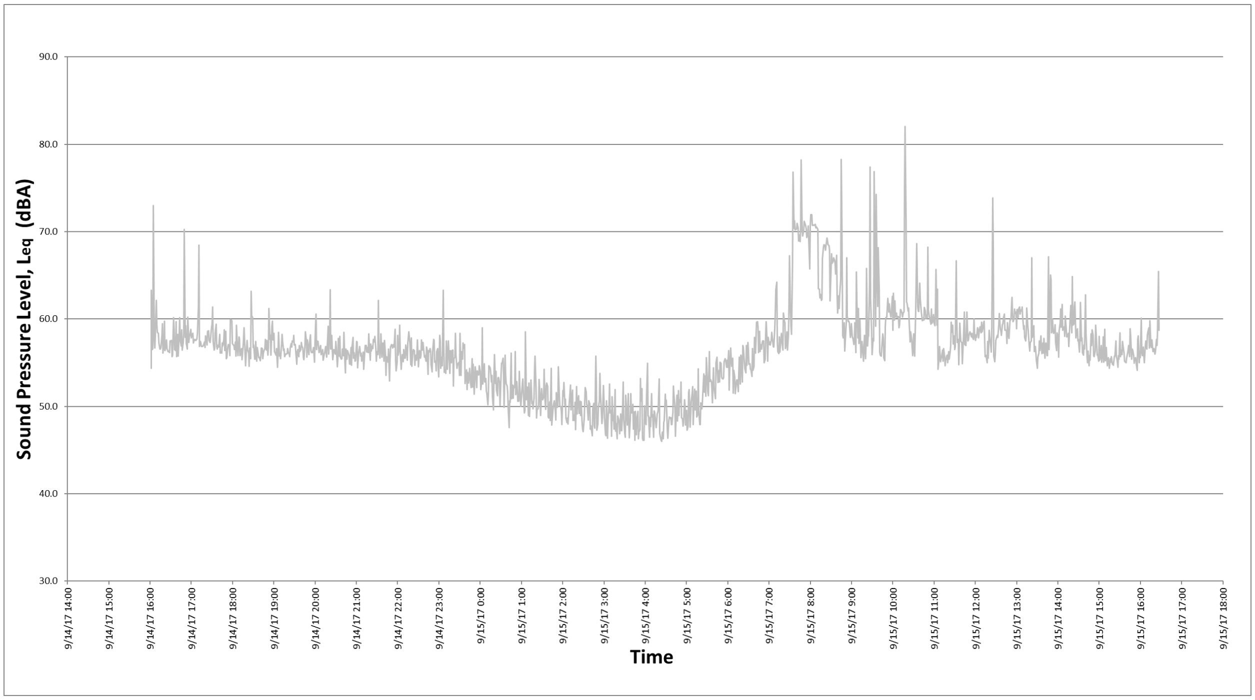


Figure 12 Site 15A Time-History Plot

5.0 DISCUSSION

Monitoring data were collected to quantify the existing acoustic environment and support predictive modeling of potential changes in noise associated with the construction and operation phases of the Project and guide the development of noise mitigation where necessary.

Noise monitoring data collected at the ten locations are considered representative of acoustic baseline conditions for noise sensitive receptors along the Project Alignment. The monitoring results indicate that the acoustic environment at monitored locations is typical of a busy urban environment, with road traffic (i.e., passerby traffic, air brakes, horns, backup alarms, engine starts) being the dominant noise source. The loudest activities included passerby/trucks, first responder vehicles, and rail locomotives.

Of the ten locations monitored, site 5A was the loudest overall (overall L_{eq} and 1 hour max L_{eq} were 71.1 and 75.4 dBA), as well as during daytime (L_d of 72.5 dBA) and nighttime (L_n of 67.6 dBA) hours. This is expected given its location near the intersection of two busy streets (West Broadway and Cambie Street). The acoustic environment at site 5A was dominated by heavy vehicle traffic, particularly delivery trucks, buses and first responder vehicles.

Site 5B recorded the second loudest measurements, which is also a function of heavy vehicle traffic through the West Broadway and the Main Street intersection. Sources of noise at site 5B were very similar to those observed at site 5A. The difference between the site 5A and site 5B results may be a result of general equipment setup with site 5A relying on the use of a third-floor window adopter, whereas site 5B equipment setup was at street level with the use of a car adopter. Measured noise levels at site 5A could be slightly overestimated as the microphone was mounted outside the window, close to a reflecting surface. The proximity of the building façade at site 5A likely increases the overall sound levels as a result of surface reflection. Non-equipment related differences could include different traffic flow trends (i.e., more delivery trucks using the West Broadway and Cambie Street intersection). Detailed traffic flow data could be used to determine whether this is indeed the case. The acoustic environment at sites 5B, 5A, as well as 10A and 11A were all dominated by heavy traffic along West Broadway, particularly during daytime hours.

Of the ten locations monitored, site 7A was the quietest overall (overall L_{eq} and 1 hour max L_{eq} were 55.9 and 58.5 dBA), as well as during daytime hours (L_d of 56.8 dBA). This is expected given its location (sheltered from traffic noise along West Broadway). Site 15A was the quietest during nighttime hours (L_n 53.4 dBA) followed closely by site 7A (L_n 53.8 dBA). Both locations are not near West Broadway, and so would not be as influenced by traffic noise. Similarly, low sound levels were observed at sites 3B, 8A, 14A and 15A. Noise monitoring data collected at locations 8A,10B,11A,14A may underestimate ambient street-level noise levels because they were set up on the roofs of buildings, and may have been partially shielded by the building's roof line.

The acoustic environment at site 1B was situated adjacent to a busy rail track/yard active during both daytime and nighttime hours. This location was also adjacent to a truck tractor and trailer parking lot which was found to be quite busy during daytime hours.

The baseline noise data collected will be used in conjunction with noise information for typical construction and operational noise sources to generate predications of the noise that may be anticipated at these receptor locations. This information will be documented in the noise Technical Data Report in support of the ESR being completed for Project.

6.0 REFERENCES

6.1 LITERATURE CITED

ANSI S1.43 1997. Specifications for Integrating-Averaging Sound Level Meters. American National Standards Institute (ANSI). Reaffirmed by ANSI 16 March 2007.

ANSI S1.40-2006 (R2011). Specification and Verification Procedures Sound Calibrators. American National Standards Institute (ANSI).

BC Ministry of Transportation and Infrastructure. 2014. Policy for Assessing and Mitigating Noise Impacts from New and Upgraded Numbered Highways. Revised October 27, 2016.

City of Vancouver. 2016. Noise Control By-Law No. 6555. November 15, 2016.

Health Canada. 2017. Guidance for Evaluating Human Health Impacts in Environmental Assessment: Noise, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

6.2 PERSONAL COMMUNICATIONS

Pers. Comm. Metro Vancouver (MV). October 16, 2017 Re: MLBE/SNGL – Metro Vancouver Information Request.