J. Bruin Associates Inc.

City of Hamilton and Metrolinx
Hamilton Light Rail Transit (LRT)
Environmental Project Report (EPR) Addendum

APPENDIX C: TECHNICAL SUPPORTING DOCUMENTS

APPENDIX C-9: NOISE AND VIBRATION REPORT

PART 1/1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF EXHIBITS

1.0 INTRODUCTION AND BACKGROUND

On December 22, 2011, the Ontario Ministry of the Environment and Climate Change (MOECC) issued a Notice to Proceed to the City of Hamilton for the B-line Rapid Transit Project.

The basis for the Notice was the Environmental Project Report prepared in October 2011, under the Transit Project Assessment Process (TPAP) found in Ontario Regulation 231/08 (O. Reg. 231/08). The purpose of the 2011 EPR was to assess the potential environmental impacts associated with the Hamilton Light Rail Transit (LRT) B-Line Project, identify measures to mitigate those impacts, and to develop systems to monitor the progress of implementing those mitigation measures.

The 2011 EPR and 2011 Noise and Vibration Impact Assessment (the original Assessment) included a study area that consisted of the alignment and related road layout changes for the Light Rail Transit (LRT) along the B-line corridor, from McMaster University to Eastgate Square via Downtown Hamilton, and running along Main Street West, King Street West, King Street East, Main Street East and Queenston Road.

The 2017 EPR addendum (and associated noise and vibration assessment) is being submitted to address the proposed changes to the original alignment and to evaluate the addition of several new components.

1.1 Description of Changes

The changes, as compared to the alignment reviewed in the 2011 EPR, are as follows:

- Moving some sections of the LRT route from side-running at the edge of the street to centre-running in the middle of the roadway, generally between Dundurn Street and the Gage Park stop near the Delta
- Moving a small section (~300m long) of the LRT route from centre-running to side running, between Dalewood and McMaster University
- Terminating the eastern extent of the LRT at the Queenston Traffic circle
- Terminating the western extent of the LRT on Main Street at McMaster in lieu of carrying the LRT tracks farther north into the campus
- Reconfigure the existing MacNab Street bus terminal and include a high order pedestrian connection from King Street B-Line to the Hamilton GO Centre
- Construction of a new bus terminal at the Queenston Road traffic circle
- Construction of a new bus terminal at McMaster University to replace the existing bus terminal at that site
- Construction of an OMSF where light rail vehicles (LRVs) would be maintained and stored, along with its run-in track in mixed traffic on Frid Street and Longwood Road to Main Street West, across the Longwood Road bridge; and
- Construction of the Frid Street extension, connecting the existing east and west portions of Frid Street through the OMSF property.

Figure 1 in Appendix A provides the revised overall LRT plan. Note that the A-line spur to the West Harbour GO Station is not included within this assessment.

1.2 Comparison of Changes

This section compares the revised alignment to the original and identifies whether an updated assessment of noise and/or vibration would be required to address those changes.

Moving tracks from side-running to centre-running between Dundurn Street and Queenston Road (Queenston traffic circle):

Due to the displacement of traffic, the original noise assessment identified either no change or decreases in the sound levels along the corridor between Dundurn Street and Queenston Road. The move to centre-running will not notably alter the findings of the noise assessment within this section. The vibration benefits will generally be positive as the tracks would no longer be very close to adjacent structures. It is recommended that a more detailed review be completed during Detailed Design to verify the noise and vibration control requirements. At the current level of design, updating the analysis at this stage for this particular change would not provide more clarity on the noise or vibration impacts of the LRT.

Moving tracks from centre-running to side-running between Dalewood and McMaster University:

The original assessment included a side-running component at McMaster. The revision moves the start of the side-running track farther east, at Dalewood, resulting in approximately 300m more of side-running track. As a result, some homes may be affected by an increase in vibration due to the decreased setback to the tracks. It is not expected that there will be notable noise impacts. However, an updated assessment has been completed to account for the increase in vibration and to demonstrate that there is no notable change in the overall sound levels. Figure 2 in Appendix A compares the previous 2011 configuration to the currently proposed configuration.

Termination of the LRT at Queenston Road:

The original LRT alignment extended east to the Centennial Parkway. The current route terminates at Queenston Road, though it may be extended farther east in the future.

If the alignment were to be extended eastwards, an updated vibration assessment would be required for the area just east of the Queenston traffic circle as the tracks would be located closer to some houses and upgraded mitigation may be needed. Otherwise, if the alignment remained consistent with the 2011 alignment, a completely new noise and vibration assessment would not be necessary. Based on the current proposed alignment, an updated noise and vibration assessment would not be required to address the termination of the LRT at Queenston Road.

Termination of the LRT at McMaster University:

The original LRT alignment included a stop at the McMaster medical centre and another stop ~200m farther into the campus at McMaster University. The currently proposed alignment terminates the LRT at McMaster University on Main Street.

As the LRT no longer extends north into the campus, the noise and vibration changes are generally positive. There would be less potential to affect the sensitive equipment. Given the positive change, an updated assessment is not warranted.

McMaster Bus Terminal:

A new bus terminal is to be constructed at the terminus of the LRT. This bus terminal would affect a different group of receptors than the existing terminal to the north. As a result, an assessment of noise from the bus terminal has been completed.

MacNab Bus Terminal:

The existing MacNab bus terminal is located west of James Street south, and extends between King Street and Main Street. The proposed changes to the terminal will create an L-shaped facility that will generate increased noise at nearby receptors. As a result, an assessment of noise from the bus terminal has been completed.

Queenston Bus Terminal:

The original route terminated at Centennial Parkway where there was an existing bus terminal. As the route now terminates at Queenston Road, a new bus terminal will be built. Given that this terminal is in a residential area, an assessment of noise from this new terminal has been completed.

Operations, Maintenance, and Storage Facility:

In order to maintain the light rail vehicles and associated LRT infrastructure, a maintenance and storage facility is to be constructed. The original assessment did not include the OMSF. As a result, the proposed OMSF on Frid Street has been assessed. This assessment addresses the noise and vibration from the OMSF itself as well as the spur track connecting the OMSF to the main B-line LRT.

Table 1 summarizes the changes noted above and if an updated assessment is warranted based on those changes.

Table 1: Effects of Changes to Project

Change	Noise Effects	Vibration Effects	Updated Assessment Required?
Moving tracks from side-running to centre-running (Dundurn Street to Queenston Circle)	Neutral	Positive	No
Moving tracks from centre-running to side-running (Dalewood to McMaster)	Neutral	Negative	Yes
Termination of LRT at Queenston Traffic Circle	Neutral	Neutral	No
Termination of LRT at McMaster	Positive	Positive	No
McMaster Bus Terminal	Negative	Neutral	Yes
Operations, Maintenance, and Storage Facility	Negative	Negative	Yes
MacNab Bus Terminal	Negative	Neutral	Yes
Queenston Bus Terminal	Negative	Neutral	Yes

2.0 NOISE AND VIBRATION IMPACT CRITERIA

The noise and vibration impact assessment criteria used to evaluate the effects of the Hamilton LRT are based on a set of draft protocols developed through the combined efforts of the Ministry of the Environment and Climate Change (MOECC) and the Toronto Transit Commission (TTC). These protocols are used in the absence of any existing and approved province-wide protocols for transit projects, specifically relating to light rail transit. The protocol that most directly relates to this project is the MOEE/TTC Draft Protocol for Noise and Vibration Assessment for the Proposed Waterfront West Light Rail Transit Line (November 11, 1993). This protocol is similar to many of the other protocols developed by the TTC and the MOECC for other rapid transit projects within Ontario.

For stationary noise sources, such as bus terminals and maintenance facilities, the draft protocols used the guidelines in *NPC-105*. These guidelines have since been updated by *NPC-300*. Hence, *NPC-300* is used to assess such facilities.

2.1 Definition of Sensitive Receptors

As per the MOECC/TTC protocol, sensitive receptors are identified as existing or municipally-approved residential developments, nursing homes, group homes, hospitals, and other such institutional land uses where people reside. Residential receptors dominate the sensitive receptors along the proposed routes. Henceforth, any reference to sensitive receptors will be in reference to residential receptors unless otherwise noted.

2.2 Noise Impact Criteria

The first and most common component in transit projects is the noise impact as a result of changes to the roadway sound levels at the receptors. Essentially, this is a comparison of sound levels with and without the project's implementation using a typical horizon year of at least 10 years after the project's completion. For this analysis, sound levels without the LRT in 2031 are compared to the sound levels with the LRT in 2031. The horizon year used to project the traffic volumes on the affected streets is 2031, to allow for the project and its surrounding roadways to reach a mature level of use. The comparison is based on a daytime (0700-2300 hours) and nighttime (2300-0700 hours) equivalent sound level comparison, which is appropriate for non-highway projects. In some cases, the future sound levels are relatively low. In such conditions, minimum exclusion criteria of 55 dBA L_{eq} during the daytime and 50 dBA L_{eq} during the nighttime are used instead of the lower actual ambient sound levels. Where the sound levels with the project exceed the sound levels without the project by at least 5 dB, noise control needs to be considered where it would be technologically, economically and administratively feasible. While existing sound levels do not play a role in the assessment, they have been calculated to provide an indication of the overall change from today's sound levels.

The second set of noise criteria applies to ancillary facilities. The ancillary facilities analyzed as part of this project include a new Operations, Maintenance, and Storage Facility (OMSF) as well as three new or modified bus terminals. These facilities are treated as stationary noise sources and are evaluated based on the Ministry of the Environment and Climate Change's *NPC-300* Publication "Environmental Noise Guidelines". The hourly equivalent ($L_{eq,1hr}$) sound level from stationary sources is compared to the $L_{eq,1hr}$ of the ambient sound or the minimum exclusion criteria (50 dB daytime, 47 dB evening, 45 dB nighttime), whichever is greater. The ambient sound level consists of the noise generated from roadway sources and excludes sources such as lightly used railways and aircraft. Heavily used railways with at least 40 trains per day can be included in the ambient, after a -10 dB adjustment. Typically, the quietest ambient sound level period is used as an evaluation of the worst-case situation. If the facility's sound level can remain below the quietest ambient sound level during that period, then the facility is likely to meet the guidelines during all periods of the day. Where the facility exceeds the guidelines by any measurable amount, noise control needs to be implemented, as per *NPC-300*.

The inclusion of the OMSF and the bus terminals are the most significant change from the original EPR. As a result, the focus of this Noise and Vibration Assessment is to document the expected noise and vibration impacts emanating from these new facilities.

2.3 Vibration Impact Criteria

The vibration impact criteria attempt to address two potential impacts from vibration generated by the LRT.

- First, the criteria consider perceptible (ground-borne) vibration levels. This addresses vibration that can be felt by residents in a building.
- Second, the criteria document also mentions the sound from vibration (vibration-induced sound) but does not set a limit.

The limit for perceptible vibration levels has been set to 0.1mm/s rms (root-mean-square) velocity. If absolute vibration levels are expected to exceed this limit, mitigation methods need to be determined during the Detailed Design phase to meet it to the extent technologically, economically, and administratively feasible.

There are no specific criteria in Ontario that set limits for the sound resulting from vibration (vibration-induced sound). The relatively lower limit of 0.1mm/s instead of 0.14mm/s (suitable for hospital vibration levels) attempts to reduce this issue. The possibility for a noise impact as a result of vibration still exists. It is dependent on the frequency spectrum of the vibration as well as the levels. Based on the United States' Federal Transit Administration guidelines (2006), a guideline level of 35 dBA is used in this report for residential rooms and other rooms (e.g., hospitals) where people generally sleep, for cases where the ground-borne, vibration-generated noise dominates the impression of the passby.

The vibration-induced noise criterion level of 35 dBA should be taken into context along with the air-borne noise. New LRT vehicles typically exhibit maximum sound levels ranging from 78 to 80 dBA at 7.5m while traveling at 40km/h, similar to a medium-sized truck. For rooms with exposure to the LRT and other traffic, outdoor sound levels in this range would indicate indoor sound levels of 48 to 50 dBA, assuming a general 30 dB noise reduction from closed windows. In this case, the contribution from vibration-induced noise would be negligible and often indistinguishable compared to the air-borne noise coming through the closed window. Thus, the criterion level for vibration induced noise is mainly applicable to those rooms with little or no window exposure to the LRT. Examples of these would be flanking apartments/houses with little or no window exposure, inset bedrooms separated from the LRT exposure by another room, or basement apartments with small windows.

Vibration levels are evaluated at the nearest point of a residential or sensitive-use building. The review of vibration-induced noise potential involves identifying the locations where the rail system passes close to buildings, or where there is special track work prone to creating vibration (switches). One critical or representative receptors have been selected, the use of these buildings and the proximity of sensitive rooms to the source of vibration must be determined. Vibration levels can then be estimated and, where impacts are anticipated, a level of vibration control specified.

The points of reception for each of the sensitive receptors are generally the closest façade or point of a building. The exception would be for development types where bedrooms may be shielded from the roadway's airborne noise but not the ground vibration-induced sound.

3.0 SCOPE OF ASSESSMENT

As discussed earlier, the entire alignment will not be reviewed again for noise and vibration impacts as part of this assessment. The focus of this assessment will be on those changes that result in increased noise and/or vibration impacts.

3.1 Light Rail Vehicles and Vehicular Traffic

Noise and vibration impacts of the LRT operating on the roadway was evaluated in the 2011 EPR and generally found no noise impacts. Substantial vibration mitigation was recommended in some areas due to the side-running tracks. An updated analysis will be completed for the section of track between Dalewood Avenue and McMaster University, as the LRT will be moving much closer to the residences than originally reviewed.

The operational noise and vibration of the spur track connecting the OMSF to the main B-Line LRT route is also included. While there are no noise sensitive receivers along this route, there are several buildings and vibration sensitive receivers that will need to be considered.

A more detailed noise and vibration assessment will be completed during the Detailed Design phase that will include in-situ testing of soil conditions to verify and detail the vibration control requirements. Further, the vehicle chosen will also have the potential to affect both the noise and vibration analysis.

3.2 Bus Terminals

Three bus terminals (McMaster, MacNab, and Queenston) have been evaluated for noise. The bus terminals are treated as stationary noise sources. The analysis is based on preliminary information regarding the volumes and configuration of the terminal. Mitigation options have been determined and should serve as a guide during the Detailed Design phase, when the noise control measures will be finalized.

3.3 Operations, Maintenance, and Storage Facility

The noise and vibration effects of the new OMSF have been reviewed. This assessment includes noise from both circulating LRVs as well as mechanical rooftop equipment. Process noise (maintenance noise) is also considered though this is usually insignificant when doors can be kept closed. As the detailed design of the OMSF is incomplete and specific equipment are not yet selected, only a general assessment can be completed. The purpose of this assessment is to identify the feasibility of the site for its intended purpose and describe generally the noise and vibration mitigation measures that may be required.

A much more detailed noise and vibration assessment of the site will be completed during the Detailed Design phase of the project. The facility would also require such a study to be completed in support of an Environmental Compliance Approval (ECA) from the MOECC.

3.4 Power Substations

As noted in the original 2011 EPR, several power substations will be required along the route. The details of such substations, including exact locations, have not yet been determined. As a result the assessment of the power substations will not be updated in this report.

The substation associated with the OMSF has been considered. However, as the substation is located more than 20m away from the nearest receptor, it is unlikely to be a significant noise source.

4.0 BUS TERMINAL NOISE ASSESSMENT

This section of the report summarizes the predicted impacts from the three new or modified bus terminals.

Noise from slow moving buses and buses idling at stops needs to be considered. While sound levels from moving buses generally drop with speed, there are decreasing returns to scale. That is, as a bus moves slower and slower compared to a reference speed, the decrease in noise tends to become less and less. The sound level difference, for example, between a bus moving at 40 km/hr and 20 km/hr is much higher than the sound level difference between a bus moving at 20 km/hr and 10 km/hr. As a result, slowing down buses too much while in bus terminals can have a detrimental effect to the overall sound level, as the noise source is now present for a longer period of time (it takes the bus longer to navigate the terminal).

The optimal speed for a bus terminal is typically 15 to 20 km/hr. A speed of 15 km/hr is used in this assessment.

Measurements of city buses such as those used by the TTC indicate idling sound levels are typically around 60 dBA at 15m (a sound power level of 92 dBA Lw). Slow moving buses of 15 to 20 km/hr were measured to produce approximately 70 dBA at 15m (a sound power level of 102 dBA). The typical source height for a city bus is 2m. The FTA provides a source height of 2 ft. for city buses and 8 ft. for inter-city buses.

On average, bus sound levels can be 5 dB higher depending on the mix of old and newer buses. As a result, and to be conservative in the estimate of noise from the bus terminals, this assessment uses a sound level of 65 dBA at 15m (a sound power level of 97 dBA Lw) for idling buses and a sound level of 75 dBA at 15m (a sound power level of 107 dBA Lw). Mitigation options are presented for both scenarios.

Idling is typically operationally restricted. It is assumed that each bus travelling through the terminal will idle for a maximum of 4 minutes. Bus terminal volumes have been provided by Steers Davies Gleave and are listed in Table 2. As indicated, buses are not expected to use the terminals between 2 a.m. and 5 a.m. They will instead use only street stops.

Table 2: Bus Terminal Volumes

Hourly Period	Bus Volume		
	McMaster	MacNab	Queenston
12 - 1 AM	10	12	24
1 - 2 AM	4	6	12

Hourly Period	Bus Volume		
	McMaster	MacNab	Queenston
2 - 3 AM	0	None	None
3 - 4 AM	0	None	None
4 - 5 AM	0	None	None
5 - 6 AM	8	8	8
6 - 7 AM	36	28	56
7 - 8 AM	36	28	56
8 - 9 AM	36	28	56
9 - 10 AM	24	18	36
10 - 11 AM	24	18	36
11 - 12 PM	24	18	36
12 - 1 PM	24	18	36
1 - 2 PM	24	18	36
2 - 3 PM	24	18	36
3 - 4 PM	36	24	56
4 - 5 PM	36	24	56
5 - 6 PM	36	24	56
6 - 7 PM	24	24	56
7 - 8 PM	24	18	36
8 - 9 PM	18	18	36
9 - 10 PM	18	18	36
10 -11 PM	18	12	24
11 PM - 12 AM	10	12	24

Sound levels have been predicted at nearby receptors using the ISO-9631 prediction procedure within the CadnaA computer program. The assessment of each terminal follows.

4.1 McMaster Bus Terminal

The McMaster bus terminal will be located on the northeast corner of Cootes Drive and Main Street West. The bus terminal is being constructed in consultation with McMaster University. The previous bus terminal on the campus was located in a less noise sensitive part of the campus.

The layout of the McMaster terminal has yet to be finalized.

4.1.1 Noise Sensitive Receptors and Criteria

The most critical noise sensitive receptor adjacent to the bus terminal is the Ronald McDonald House, located on the northwest corner of Cootes Drive and Main Street West. This facility includes rooms where people are likely to sleep.

NPC-300 would also consider schools to be equally noise sensitive. The new McMaster engineering building is located immediately to the east and north of the new bus terminal. As a result, given its proximity to the bus terminal, the impact at the engineering building has been considered. Finally, there is a school on the south side of Main Street West that is also considered.

Table 3: Receptors Near McMaster Bus Terminal

Receptor Number	Type	Description
1	Residential	Ronald McDonald House
2	Institutional	McMaster Engineering Technology Building
3	Institutional	Canadian Martyrs Catholic Elementary School

Exhibit 1 provides the receptor locations for the evaluation of the McMaster bus terminal.

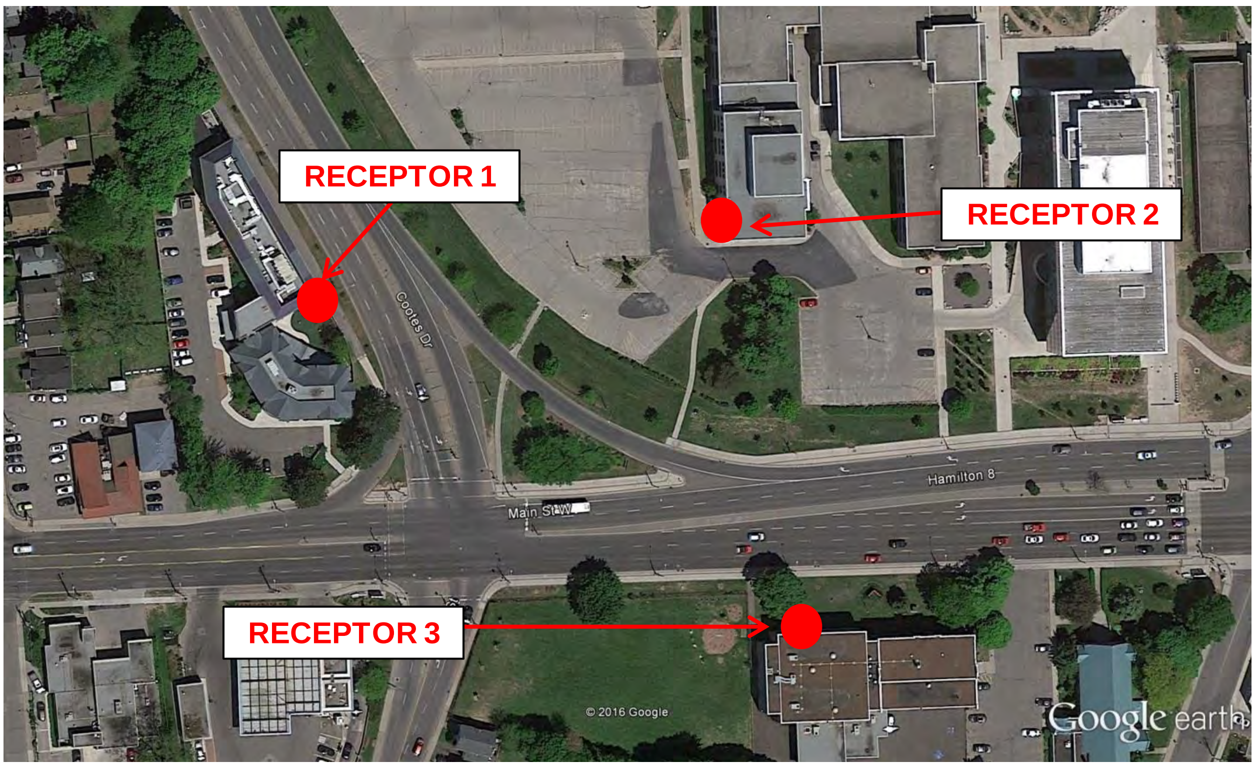


Exhibit 1: Location of Receptors Near McMaster Bus Terminal

The sound levels were measured directly at Receptor 1 over a one-week period. Baseline measurements are provided in Appendix B. The lowest hourly sound levels resulting from the measurement period are summarized in Table 4. Based on these measured sound levels at Receptor 1, the approximate ambient sound level has been extrapolated at Receptor 2 and Receptor 3 using CadnaA and treating the roadways as a line source.

Table 4: McMaster Bus Terminal Ambient (Guideline) Sound Levels

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)		
	Receptor 1	Receptor 2	Receptor 3
12 - 1 AM	58	50	56

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)		
	Receptor 1	Receptor 2	Receptor 3
1 - 2 AM	55	47	53
2 - 3 AM	56	48	54
3 - 4 AM	53	45	51
4 - 5 AM	55	47	53
5 - 6 AM	56	48	54
6 - 7 AM	58	50	56
7 - 8 AM	59	51	57
8 - 9 AM	60	52	58
9 - 10 AM	62	54	60
10 - 11 AM	63	55	61
11 - 12 PM	63	55	61
12 - 1 PM	64	56	62
1 - 2 PM	64	56	62
2 - 3 PM	65	57	63
3 - 4 PM	64	56	62
4 - 5 PM	63	55	61
5 - 6 PM	64	56	62
6 - 7 PM	63	55	61
7 - 8 PM	63	55	61
8 - 9 PM	63	55	61
9 - 10 PM	62	54	60
10 -11 PM	61	53	59
11 PM - 12 AM	60	52	58

4.1.2 Summary of Recommendations

As the layout of the terminal is being developed, detailed calculations of predicted sound levels cannot be completed. It is expected that noise attenuation measures will need to be incorporated into the design of the McMaster bus terminal due to the proximity to the nearby institutional use The Detailed Design phase should use updated predictions on volumes, types of buses and sound levels, and finalized layouts to determine the details of the noise control measures.

4.2 MacNab Bus Terminal

The MacNab bus terminal will be located on the southeast quadrant of King Street and James Street South.

4.2.1 Noise Sensitive Receptors and Criteria

The terminal is located in a mostly commercially zoned area. The most critical noise sensitive receptor adjacent to the bus terminal is the condominium immediately to the south. *NPC-300* does not consider places of worship (churches) located in commercially or industrially zoned lands as noise sensitive receptors.

Table 5: Receptors Near MacNab Bus Terminal

Receptor Number	Type	Description
4	Residential	High Rise Condominium

Exhibit 2 shows the receptor locations for the evaluation of the MacNab bus terminal.

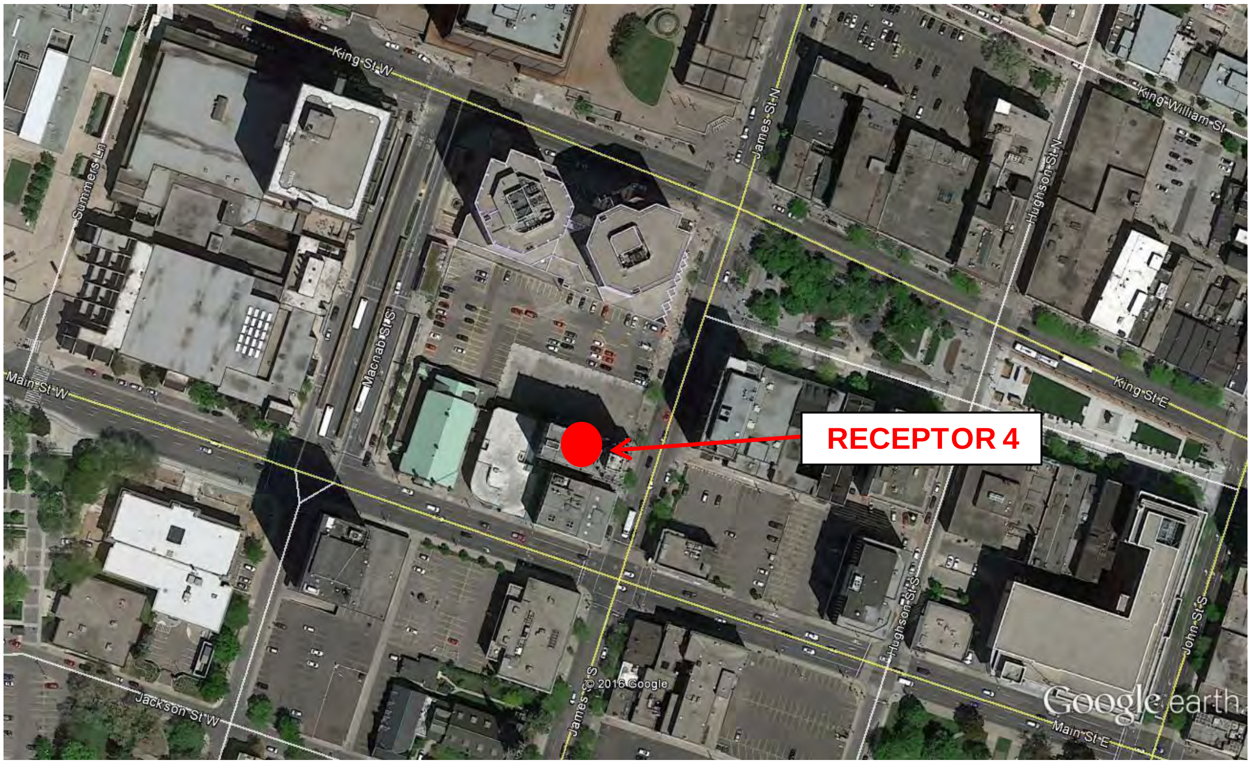


Exhibit 2: Location of Receptors Near MacNab Bus Terminal

The sound levels were measured directly at Receptor 4 over a one-week period. The lowest hourly sound levels resulting from the measurement period are summarized in Table 6.

Table 6: MacNab Terminal Ambient (Guideline) Sound Levels

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)
	Receptor 4
12 - 1 AM	57
1 - 2 AM	56
2 - 3 AM	53
3 - 4 AM	54
4 - 5 AM	52
5 - 6 AM	56
6 - 7 AM	58

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)
	Receptor 4
7 - 8 AM	57
8 - 9 AM	57
9 - 10 AM	60
10 - 11 AM	60
11 - 12 PM	60
12 - 1 PM	59
1 - 2 PM	60
2 - 3 PM	59
3 - 4 PM	59
4 - 5 PM	61
5 - 6 PM	59
6 - 7 PM	59
7 - 8 PM	59
8 - 9 PM	59
9 - 10 PM	59
10 -11 PM	59
11 PM - 12 AM	58

4.2.3 Summary of Recommendations

As the layout of the terminal is being developed, detailed calculations of predicted sound levels cannot be completed. It is expected that noise attenuation measures will need to be incorporated into the design of the MacNab bus terminal due to the proximity to the nearby high-rise residential development The Detailed Design phase should use updated predictions on volumes, types of buses and sound levels, and finalized layouts to determine the details of the noise control measures.

4.3 Queenston Bus Terminal

The Queenston Terminal will be located to the east of the existing Queenston Road traffic circle (which will be removed), where Main Street East branches off into Queenston Road. The construction of the terminal will result in the demolition of the existing structures (including residential) on the site.

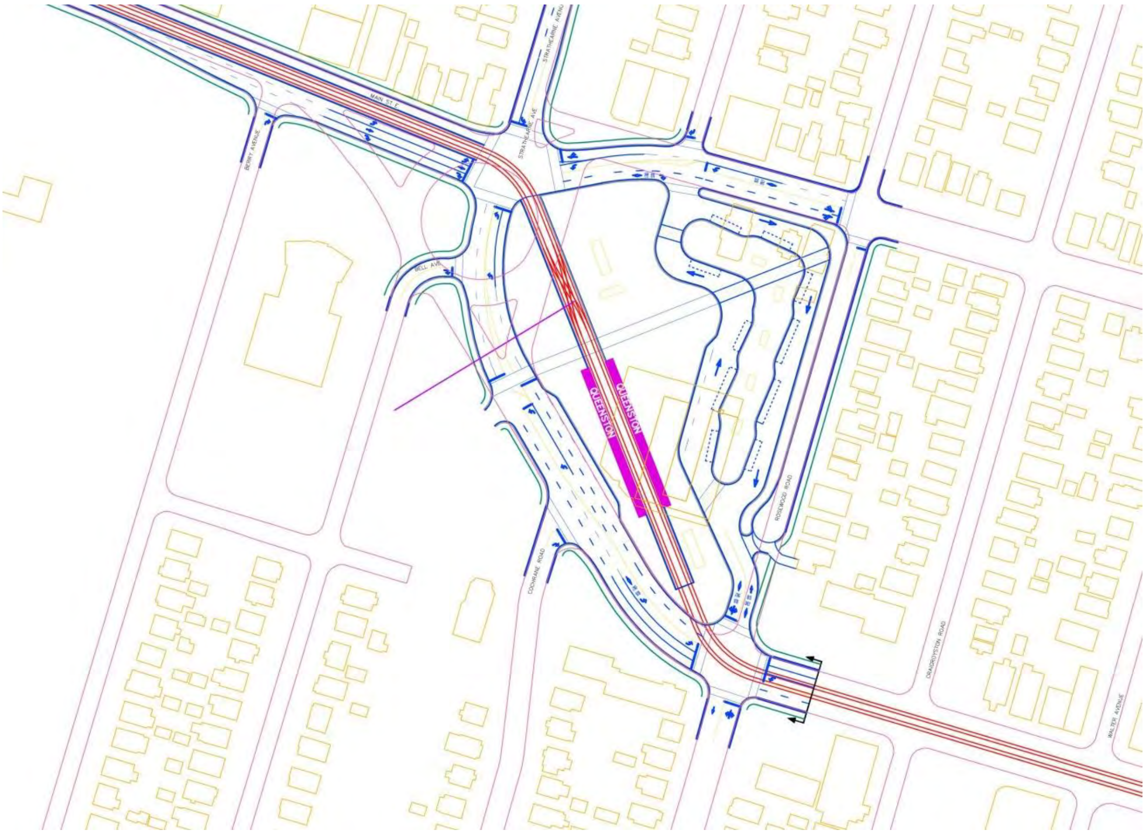


Exhibit 3: Queenston Bus Terminal Layout Concept Plan

4.3.1 Noise Sensitive Receptors and Criteria

The most critical noise sensitive receptors adjacent to the bus terminal are the residences located to the north and east of the facility.

Table 7: Receptors Near Queenston Bus Terminal

Receptor Number	Type	Description
5	Residential	2-storey home on Main Street East
6	Residential	2-storey home on Rosewood Road
7	Residential	2-storey home on Rosewood Road

Exhibit 4 below provides the receptor locations for the evaluation of the Queenston bus terminal.

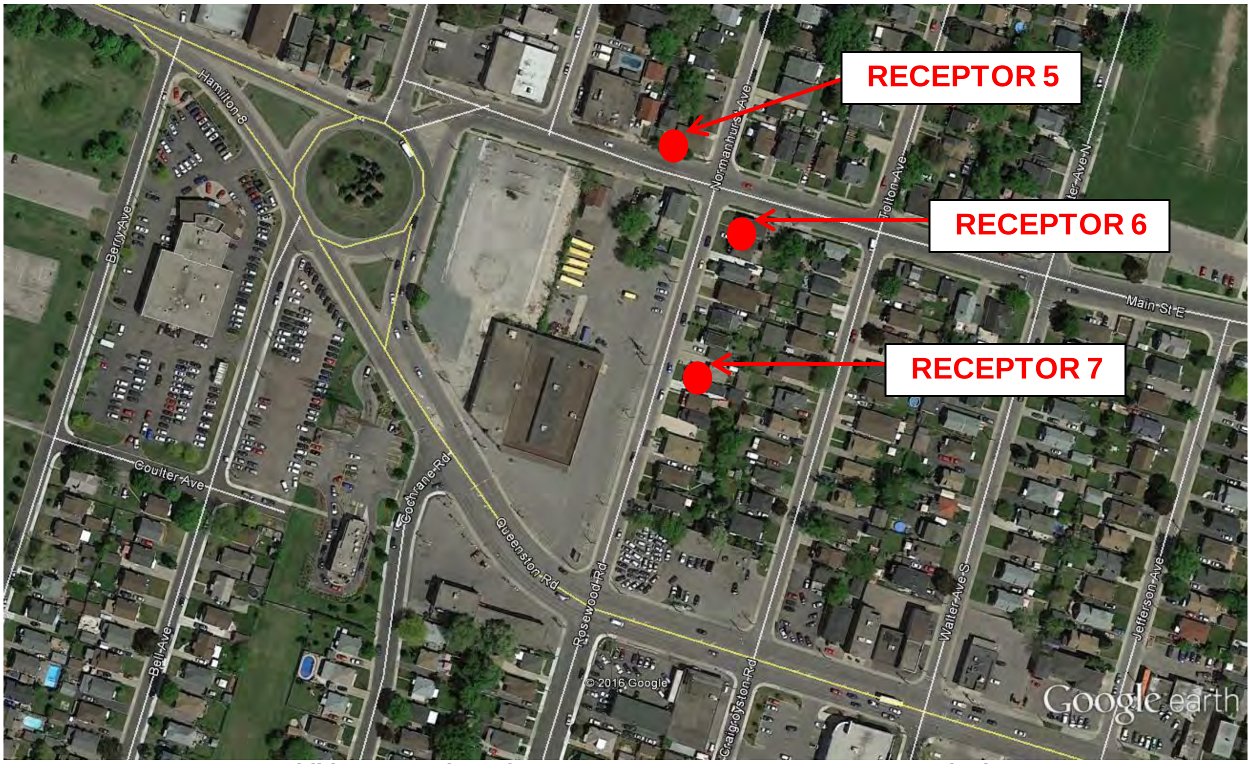


Exhibit 4: Location of Receptors Near Queenston Bus Terminal

The sound levels were measured directly at Receptor 5 over a one-week period. The lowest hourly sound levels resulting from the measurement period are summarized in Table 8. Based on these measured sound levels at Receptor 5, the approximate ambient sound level has been extrapolated at Receptor 6 and Receptor 7 using CadnaA and treating the roadways as line sources. Traffic on Rosewood Road and Normanhurst Avenue is relatively minor, carrying less than 10% of the vehicles on Main Street East and even less compared to Queenston Road.

Table 8: Queenston Bus Terminal Ambient (Guideline) Sound Levels

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)		
	Receptor 5	Receptor 6	Receptor 7
12 - 1 AM	58	50	49
1 - 2 AM	55	45	45
2 - 3 AM	56	46	45
3 - 4 AM	53	46	45
4 - 5 AM	55	45	45
5 - 6 AM	56	49	48
6 - 7 AM	58	50	49
7 - 8 AM	59	52	51
8 - 9 AM	60	53	52
9 - 10 AM	62	55	54
10 - 11 AM	63	55	54
11 - 12 PM	63	56	55

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)		
	Receptor 5	Receptor 6	Receptor 7
12 - 1 PM	64	58	57
1 - 2 PM	64	58	57
2 - 3 PM	65	57	56
3 - 4 PM	64	58	57
4 - 5 PM	63	58	57
5 - 6 PM	64	57	56
6 - 7 PM	63	56	55
7 - 8 PM	63	56	55
8 - 9 PM	63	56	55
9 - 10 PM	62	55	54
10 -11 PM	61	54	53
11 PM - 12 AM	60	52	51

Note: Minimum exclusion criteria have been used where the ambient levels are lower.

4.3.2 Predicted Sound Levels

The sound levels at the above three receptors have been calculated and are summarized in Table 9.

Table 9: Predicted Sound Levels from Queenston Bus Terminal

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)					
	Receptor 5		Receptor 6		Receptor 7	
	Predicted	Impact	Predicted	Impact	Predicted	Impact
12 - 1 AM	61	8	61	11	63	14
1 - 2 AM	58	11	58	13	60	15
2 - 3 AM						
3 - 4 AM						
4 - 5 AM						
5 - 6 AM	57	5	57	8	59	11
6 - 7 AM	65	12	65	15	67	18
7 - 8 AM	65	10	65	13	67	16
8 - 9 AM	65	9	65	12	67	15
9 - 10 AM	63	5	63	8	65	11
10 - 11 AM	63	5	63	8	65	11
11 - 12 PM	63	4	63	7	65	10
12 - 1 PM	63	2	63	5	65	8
1 - 2 PM	63	2	63	5	65	8
2 - 3 PM	63	3	63	6	65	9
3 - 4 PM	65	4	65	7	67	10

Hourly Period	Hourly Equivalent Sound Level (dBA, $L_{eq,1hr}$)					
	Receptor 5		Receptor 6		Receptor 7	
	Predicted	Impact	Predicted	Impact	Predicted	Impact
4 - 5 PM	65	4	65	7	67	10
5 - 6 PM	65	5	65	8	67	11
6 - 7 PM	65	6	65	9	67	12
7 - 8 PM	63	4	63	7	65	10
8 - 9 PM	63	4	63	7	65	10
9 - 10 PM	63	5	63	8	65	11
10 -11 PM	61	4	61	7	63	10
11 PM - 12 AM	61	6	61	9	63	12

The results indicate that significant noise impacts can be expected due to the operational noise from the bus terminal. The impact is greatest at Receptor 7 (18 dB) and occurs between 6 a.m. and 7 a.m. when traffic is still ramping up but bus volumes have reached their peak levels.

Assuming the use of quieter buses, such as those used by the TTC and other transit agencies, the noise impacts from Table 9 above would be 5 dB lower.

4.3.3 Summary of Recommendations

The assessment of bus terminal noise from the new Queenston bus terminal indicates impacts ranging from 13 to 19 dB at the nearest receptors during the worst-case period. In all cases, the greatest noise impact occurs between 6 a.m. and 7 a.m. as bus traffic ramps up earlier than ambient roadway traffic.

Noise mitigation measures will likely be required in order for the terminal (as it is currently configured) to comply with the guidelines. Noise mitigation measures could include noise barriers or an enclosed terminal.

It is recommended that this terminal and layout be reviewed during Detailed Design to orient and optimize the location, so as to minimize the noise impacts. Designing a diagonal bus terminal, and moving the buses away from the residences on Rosewood Road would reduce potential noise mitigation.

.

4.4 Bus Terminal Assessment Summary

An assessment of the bus terminals has been completed using two scenarios. The first scenario assumes realistic and modern bus idling and movement sound levels and provides a more accurate picture of the expected sound levels from the bus terminals. The second scenario assumes louder than average bus idling and movement sound levels and provides a picture of the worst-case mitigation requirements needed to control the bus-terminal noise. The detailed review will need to consider the actual sound levels of the buses using the terminal, including the mix of city and intercity buses.

In all cases, bus passby noise is far more critical to the overall sound level than bus idling noise. Therefore, the detailed design should carefully account for how the buses move through the terminals. The typical bus and sound level should also be further refined during the Detailed Design phase.

5.0 OPERATIONS, MAINTENANCE, AND STORAGE FACILITY ASSESSMENT

The assessment of the OMSF is broken down into two categories. First, and most significant, is the air-borne noise from the OMSF and its operations. This would include passby noise from LRVs, switch noise as the vehicles pass over switches, curve noise as vehicles navigate the turns with the facility, mechanical and electrical equipment noise such as exhaust fans and paint booth fans, and process noise emanating from the building such as maintenance noise. The second category focuses on the vibration effects of the OMSF and the spur tracks used to access the facility. This includes a review of the ground-borne vibration and noise associated with LRVs navigating the tracks (including special trackwork) of the facility itself as well as the spur track used to access the OMSF from the main B-Line route.

5.1 OMSF Noise Assessment

Exhibit 5 shows the layout of the OMSF. It is located in an industrial and commercially zoned area immediately north of the CP railway corridor. There are several residential receptors located across the railway tracks from the OMSF facility. There are no noise sensitive receptors located along the Longwood Road spur line used to access the OMSF from the B-Line tracks on Main Street West.

The purpose of this assessment is to identify the types of noise control measures that may be required for the final facility and to determine the feasibility of the site to house such a facility. The exact noise and vibration control measures required will be determined during the Detailed Design phase when the OMSF pursues and Environmental Compliance Approval from the MOECC. This assessment could not be extensive enough to meet the requirements of an application for an ECA as sufficient progress has not yet been made on the design of the OMSF to allow that level of detail to be prepared. The assessment and recommendations then should be regarded as a feasibility study at the EA level.

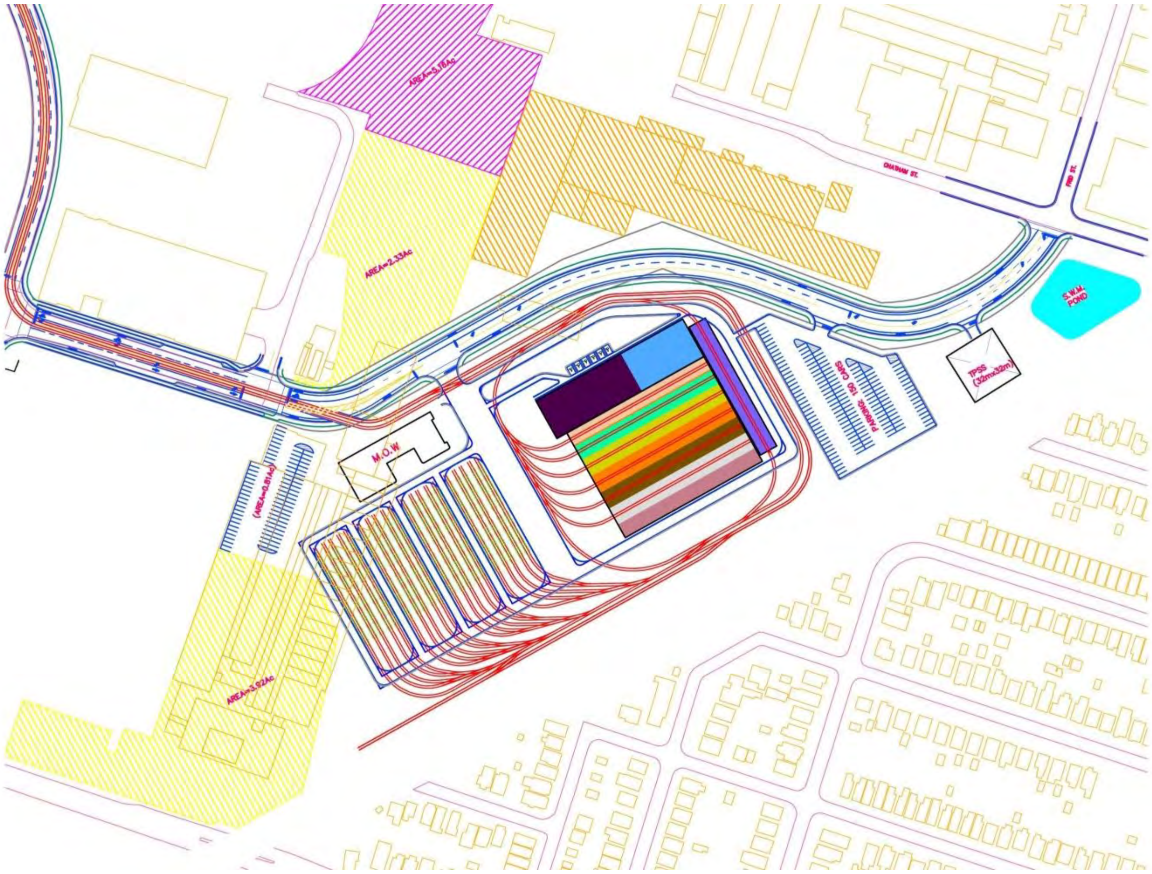


Exhibit 5: OMSF Layout

5.1.1 Facility Description and Operations

The OMSF will include the following components:

- run-in track access from Frid
- LRV wash facility – likely integrated with Main repair shop
- Main Repair Facility
- Maintenance of Way Building
- Electrical Substation
- Stabling track area (likely outdoor).

The Main Repair Facility, at ±135,000 sq.ft, will include the following functions:

- daily service: 25 LRVs at maximum planned service levels
    - service inspection
    - sweep and dust
    - sand replenishment (storage is filled periodically from an exterior truck with filling equipment).
- weekly service:
    - exterior wash – could be more often in winter – up to daily
- periodic service:
    - interior clean, every 2 to 3 weeks or as required

  - scheduled undercar steam cleaning prior to scheduled inspection and maintenance – steam washer and compressor are part of the system
  - scheduled compressed air cleaning – of trucks and overhead systems, below cars and at roof level. Ventilation and dust collection is part of the system
  - repairs include separating track with lifting equipment for large component removal and compressed air delivery system for tools and equipment
  - body shop work including a separate facility for sheet metal and other component repairs, including the use of compressed air for tools and equipment
  - separate tracks for wheel truing with in-floor lathe and a filing collection system
  - enclosed paint booth including exhaust system and compressed air system
  - warehouse for storage of parts and materials

The Maintenance of Way building at ±11,000 sq.ft., will likely be a single-storey, high height facility with bay doors, which will include the equipment and facilities for maintaining:

- Track and Structures
  - Could include mobile cranes, snow removal equipment, etc. for guideway maintenance
- Signals and Communications
  - Signaling system repairs and installation
  - Radio repairs and installations
- Overhead Contact System Services
  - Servicing and maintenance of overhead wires, cables, poles and associated infrastructure.

The electrical substation will provide power to the overhead contact system in the vicinity of the OMSF and run-in track, as well as to the OMSF facility itself.

The operations/administration area will include general office areas, training rooms, operator assembly, locker and recreation areas etc.

The outdoor stabling area will provide storage for the LRV vehicles, with special trackwork to allow movement of vehicles to and from the main repair shop and to position vehicles for next day deployment. This includes track switches, and potentially low-radius curves on the site.

5.1.2 Facility Noise Sources

The noise sources from the facility can be broken down into the following major categories:

1. Outdoor mechanical and electrical equipment noise
2. Indoor maintenance and service noise
3. Outdoor vehicle passby noise including noise from switches and squeal or squawking from low-radius curves on site
4. Traction power substation noise.

For the B-Line LRT, single vehicle consists are expected to be used until 2041. As a result, vehicles are not expected to be shunted together regularly.

The mechanical design of the building has not yet commenced. Instead, typical equipment from similarly sized and purposed facilities is used in this assessment to identify potential noise issues from the OMSF equipment.

Table 10 identifies the type of equipment assumed, the quantity of the equipment, and the sound power level of that equipment. While most maintenance (and associated mechanical load) is expected to occur during the daytime, this assessment includes continuous operation of the mechanical equipment during the daytime and nighttime.

Table 10: OMSF Equipment Quantities and Sound Levels

Equipment Type	Quantity	Sound Power Level (dBA Lw)
Air-Handling Units	6	90
Cooling Tower	1	95
Make-Up Air Units	2	95
Paint Booth Fan	1	85
Exhaust Fans	10	85
Dust Collector Fans	1	110
Air-Conditioning Condensers	2	75

There will also be a series of emergency generators. Provided they are located outdoors and under 700 kW each, these generators cannot exceed 75 dBA at 7m (100 dBA sound power level). The testing of emergency generators can typically be assessed separately from the operational noise of the OMSF.

Detailed LRV noise data have yet to be provided by Metrolinx for this project. The LRV specification provides a maximum allowable sound level of 82 dBA at 7.5m for an LRV moving at 40 km/hr. on embedded rail. Predictions from Bombardier indicate that their LRV is likely to be 4 to 5 dB quieter than the specification. As the LRVs will be moving significantly slower through the EMSF (at a speed of 15 km/hr), and given that the vehicles are notably quieter than the specifications allow, the sound level of an LRV moving through the yard is assumed to be 75 dBA at 7.5m.

It is assumed each LRV leaving or returning to the facility will complete one full cycle of movement around the yard. The movement is generally in a counter clockwise motion.

Aside from the vehicles moving on tangent (straight) track, LRVs will also move on curved track and over crossovers/switches. It is expected the wheels of the new LRVs will be damped, replacing the typical rail car squealing noise with more of a squawking noise. In addition, the LRVs can also be equipped with lubricators for the wheels such as those used occasionally in the newer TTC Flexity Outlook fleet. As a result, the passby of an LRV on curved track will be louder than on tangent track, but should not produce the tonal squeal associated with Toronto's older subway fleet. A sound level of 85 dBA at 7.5m is assumed for the LRVs moving along curved track, which is approximately twice as loud as an LRV moving on tangent track.

In addition, there are a few areas where the LRVs will move over a series of switches. The increase in noise is approximately 10 dBA locally for the section of track with switches. Note that switch noise can be reduced at the source with appropriate switch design. Given a vehicle length of 30m and a yard speed of 15 km/hr, the duration of switch noise for each car passby is approximately 4 seconds (switch noise does not occur continuously, only when wheels pass over). Crossovers noise acts as a point source whereas squeal and tangent track noise act as line sources.

5.1.3 Facility Operations

Steers Davies Gleave have provided approximate vehicle movements through the OMSF site throughout the day. These are summarized in Table 11.

Table 11: OMSF LRV Movements

Hourly Period	LRVs Exiting	LRVs Returning	Internal LRV Movements
12 - 1 AM	0	0	2
1 - 2 AM	0	6	0
2 - 3 AM	0	0	2
3 - 4 AM	0	0	2
4 - 5 AM	0	0	2
5 - 6 AM	12	0	2
6 - 7 AM	0	0	2
7 - 8 AM	0	0	2
8 - 9 AM	0	0	2
9 - 10 AM	0	6	0
10 - 11 AM	0	0	2
11 - 12 PM	0	0	2
12 - 1 PM	0	0	2
1 - 2 PM	0	0	2
2 - 3 PM	0	0	2
3 - 4 PM	6	0	2
4 - 5 PM	0	0	2
5 - 6 PM	0	0	2
6 - 7 PM	0	6	0
7 - 8 PM	0	0	2
8 - 9 PM	0	0	2

Hourly Period	LRVs Exiting	LRVs Returning	Internal LRV Movements
9 - 10 PM	0	0	2
10 -11 PM	0	0	2
11 PM - 12 AM	0	0	2

Some vehicles, usually 1 or 2, will not be put into service. Instead, they will be moved from the storage yard directly to the maintenance buildings. It is assumed that an average of 2 internal movements will occur throughout the day during lulls in OMSF activity as noted in the table above. All returning vehicles will be run through the wash facility before being stored or will be taken to the maintenance building. The exact details of operation, and the associated noise impacts, will be clarified during the Detailed Design phase.

The facility's repair activities take place within the main OMSF building. Specific sound levels are unavailable for equipment within the facility. Typically, sound levels in a maintenance facility average approximately 75 dBA during operating hours. This noise can sometimes include tonal or quasi-steady impulsive components. With the corrections from *NPC-104* applied, the sound level would typically be 85 dBA on average, inside at the doorways, during the loudest periods of maintenance noise. Given the doors will remain closed at all times except to permit vehicle entry and exist, the noise of maintenance activity is not expected to be significant. The exterior walls and roof construction of the building is assumed to meet an STC 45 to 50 standard.

There are 12 doors for the maintenance and cleaning area of the facility. Each door would typically be 3mx3m in size. With an interior sound level of 85 dBA, each door, when completely open, would transmit a sound power level of 95 dBA L_W. The doors will remain mostly closed during maintenance periods, being open only to allow vehicle entrance and egress. With 6 doors at each end of the facility and only 25 vehicles to service, the typical open time for a door in a given hour would be less than 5 minutes, a correction factor of 11 dB. This means each door would transmit a sound level of 84 dBA L_W on average during peak maintenance activities.

The details of the traction power substations are not yet known. Based on similar units specified for the Eglinton Crosstown LRT, a set of two 1.5MW traction power units may be needed. Traction power substation noise would include noise from the transformer itself, as well as noise from any supplemental ventilation units.

Table 12: Traction Power Substation Equipment and Sound Levels

Equipment Type	Quantity	Sound Power Level (dBA Lw)
Transformers	2	80 (including 5 dB tonality adjustment)
Traction Power Cooling Systems	4	75

5.1.4 Nearby Receptors and Criteria

The nearest noise sensitive receptors are the groups of low-rise residences on the opposite side of the CP railway tracks. The ambient noise in this area is relatively low due to the absence of major roadway traffic.

A total of 3 receptors were selected to evaluate the impact from the various components of the OMSF noise. These receptors are described in Table 13 and shown in Exhibit 6.

Table 13: OMSF Sensitive Receptors

Receptor Number	Type	Description
8	Residential	2-storey home on Hawthorne Avenue
9	Residential	2-storey home on Stanley Avenue
10	Residential	2-storey home on Charlton Avenue

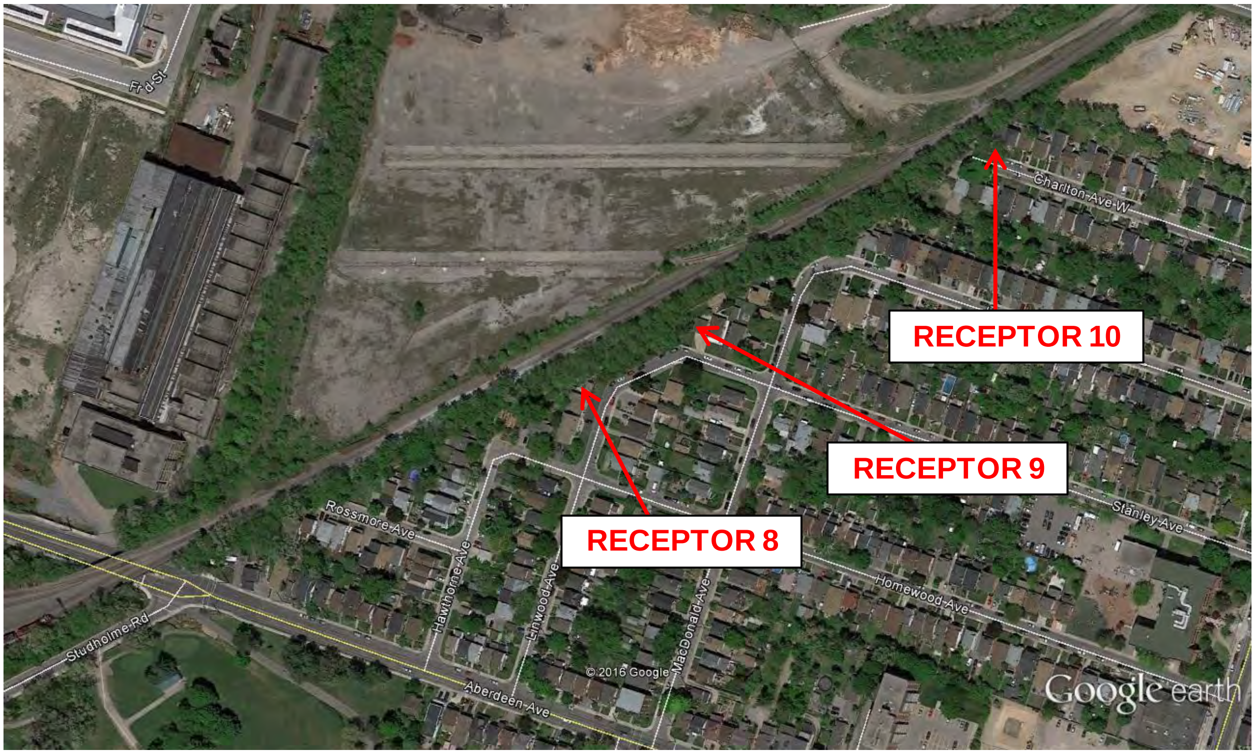


Exhibit 6: Receptor Locations Near OMSF

Sound levels were measured directly at Receptor 9 for a period of one week. Measurement data indicated the sound levels were relatively low and that the minimum exclusion criteria from *NPC-300* would be applicable. The minimum exclusion criteria for an urban environment are 50 dBA $L_{eq,1hr}$ during the daytime and 45 dBA $L_{eq,1hr}$ during the nighttime. The exclusion criteria are applicable for all 3 receptors considered.

5.1.5 Predicted OMSF Sound Levels

Based on the equipment and operations noted above, the sound levels have been calculated at the nearest receptors. Calculations were completed using the CadnaA implementation of the ISO-9631 prediction procedures.

Based on Table 11, above, the worst-case period for noise from the OMSF would be the period between 5 a.m. and 6 a.m. when all 12 of the in-service vehicles leave the site. The guideline sound level for all three receptors during this period would be 45 dBA $L_{eq,1hr}$. This period would also include maintenance noise from the building and rooftop equipment. Vehicle departure noise is particularly significant for this site as all of the switches and curved trackwork are located on the side of the facility closest to the residential receptors.

Table 14 summarizes the predicted sound levels at the receptors.

Table 14: Predicted OMSF Sound Levels

Time Period	Receptor 8 Sound Levels (dBA $L_{eq,1hr}$)		Receptor 9 Sound Levels (dBA $L_{eq,1hr}$)		Receptor 10 Sound Levels (dBA $L_{eq,1hr}$)	
	Predicted	Impact	Predicted	Impact	Predicted	Impact
5 AM to 6 AM	60	15	60	15	57	12

The analysis indicates the dominant noise sources on site are the dust collector fans, noise from trains traveling on the curves, and noise from trains traveling across switches. Once these have been controlled, the remaining mechanical equipment also contribute somewhat to the overall sound levels.

Rail lubrication can reduce wheel squeal by an assumed 5 dB. Movable-point frogs can reduce the impact noise, also assumed to provide a 5 dB reduction. Silencers will be required for some of the rooftop equipment, especially the dust collectors and air-handling units. Finally, a 7.5m high barrier may be needed between the OMSF and the railway corridor. This barrier should be absorptive with a minimum noise reduction coefficient (NRC) of 0.75.

5.1.6 OMSF Noise Control Measures

The ambient sound levels at nearby residential receptors are fairly low, as evidenced by baseline noise measurement data. As a result, even the modest sound levels generated by typical light rail maintenance facilities has resulted in a significant noise impact at the nearest residential receptors Table 15 summarizes the noise control measures that can be expected to be required for the facility based on the current design and layout.

Table 15: OMSF Noise Control Measures

Noise Source	Noise Control Measure	Expected or Desired Reduction (dB)
Curve/Turning Noise	Rail Lubrication	5
Switch Noise	Movable Point Frogs	5
Air Handling and Make-up Air Units	Alternative Selection, Silencers, and/or Rooftop Barrier	5
Dust Collector	Alternative Selection, Silencers, and/or Rooftop Barrier	20
Cooling Tower	Alternative Selection, Silencers, and/or Rooftop Barrier	5

In addition to the source-based mitigation measures, a noise barrier will likely be needed along the southern property line of the OMSF. The details and exact height of the barrier will be subject to Detailed Design. This barrier should be absorptive with an NRC rating of 0.75 to ensure that freight train noise reflections do not present another impact on nearby residences.

The noise barrier may present access issues between the OMSF and the railway tracks. Most MSF facilities are located near railways to facilitate delivery or transfer of vehicles. A more ideal location for the barrier may be at the property line between the residences and the CP railway corridor. This would benefit the residences doubly by reducing railway noise as well as noise from the future OMSF while also maintaining easy access between the railway and OMSF. Property requirements/agreements may make this option challenging. Figure 5 and Figure 6 in Appendix A show the approximate locations of the recommended noise barriers, depending on the desired location.

It should be noted that while maintenance noise is not the main cause of the excess, it is close to being a significant noise source. Excessive opening of the doors during periods of high maintenance noise has the potential to generate a noise impact. The Detailed Design should consider providing the maintenance area with acoustic roof deck or acoustic spray. With acoustic absorption in the space, the sound levels at the doors from maintenance noise will be significantly lower and will further negate the significance of maintenance activity noise.

Ensuring the building is constructed to minimize noise transfer through the walls and ceilings is also important. An STC 45 to 50 wall and ceiling construction for the perimeter of the building should be considered.

5.2 OMSF Vibration Assessment

There are two main sources of vibration associated with the OMSF. The first is the vibration generated by the access track between the OMSF and the B-Line route on Main Street. The second is the vibration generated by the light rail vehicles moving around on the tracks within the OMSF, especially the special trackwork such as the switches.

Both of these vibration sources must be evaluated to verify their adherence to the vibration criteria noted.

5.2.1 Vibration Receptors

There are no residential receptors located within 50m of the spur track between the B-Line. There are several residential receptors located within or approximately 50m from the tracks (and switches) of the OMSF. These receptors, located on Rosemore Avenue, Homewood Avenue, Hawthorne Avenue, Linwood Avenue, Stanley Avenue, McDonald Avenue, and Herkimer Street are all considered for vibration impacts from the OSMF. Exhibit 8 shows the homes closest to the LRT tracks that have been reviewed.

During the course of site selection for the OMSF, McMaster University and Natural Resources Canada identified some vibration sensitivity from their facilities located along Longwood Road. In addition, McMaster University's main campus previously identified itself as housing several pieces of vibration sensitive equipment. The sensitivity of the campus' buildings and equipment was acknowledged in the 2011 EPR and identified as an area where more detailed study was required.

This assessment considers briefly the potential vibration issues at CanMET, the testing facility located at 183 Longwood Road, and McMaster's Innovation Park, located at 175 Longwood Road.

CanMET includes equipment such as scanning electron microscopes, high magnification optical microscopes, and transmission electron microscopes. Much of this equipment has been isolated from the structure already to ensure footfall and other ambient vibration do not affect their operation. As with McMaster University during the 2011 EPR, a much more detailed analysis will need to be completed to verify the impact from the operation of LRVs on the spur line and OMSF on these sensitive pieces of equipment.

This assessment considers only generally what the vibration levels at the facility will be and does not predict the vibration levels at the equipment.

5.2.2 Approach to Vibration Assessment

The Noise and Vibration Impact Assessment completed in support of the 2011 EPR used measured streetcar vibration levels in Toronto and adjusted these levels to reflect the various speeds and conditions of the Hamilton B-Line LRT.

The measured vibration levels of streetcars operating at 25 to 30 km/hr are provided again below.

Table 16: Measured Vibration Levels

Distance from Track Centreline (m)	Vibration Levels (mm/s rms)
3	0.19
7	0.13
12	0.11

While the original assessment accounted for the fact that most new light rail lines include at least a basic vibration isolation system capable of providing a 5 dB (44%) reduction in the vibration levels, the same assumption will not be made during the review of the OMSF vibration. This is because much of the OMSF trackwork may actually consist of tie-on-ballast construction (either concrete or wooden ties).

The FTA also provides generalized surface vibration curves for various types of transit vehicles. The data provided in the 2006 Transit Noise and Vibration Impact Assessment guide are provided in Table 17.

Table 17: Typical Rail Transit Vibration Levels from FTA Guide

Distance from Track Centreline (m)	Vibration Levels (mm/s rms)
3.3	0.30
6.4	0.20
12	0.14

The vibration data above must be adjusted to reflect the fact that the measurements in Toronto were taken at speeds of approximately 30 km/hr, whereas the FTA curves reflect vehicles travelling at 50 miles per hour or 80 km/hr. The FTA would indicate that the speed adjustment should be approximately 8 dB for such a reduction in speeds.

Adjusting for this speed, the FTA curves would indicate the following vibration levels.

Table 18: Adjusted Typical FTA Transit Vibration Levels

Distance from Track Centreline (m)	Vibration Levels (mm/s rms)
3.3	0.12
6.4	0.08
12	0.06

The FTA adjustment is based on a direct or proportional relationship between speed and vibration level. However, the document does note that the speed factor can vary. As can be seen above, the speed adjustment results in significantly lower vibration levels than were actually measured. This can be as a result of many factors such as the age and condition of the Toronto streetcar system (both vehicles and tracks).

5.2.3 Criteria for Sensitive Equipment

The Institute of Environmental Sciences and Technology published the document *Considerations in Clean Room Design* in 1993. This document provided typical target maximum 1/3 octave vibration levels between 8 Hz and 80 Hz for various types of rooms, depending on vibration sensitivity. The paper *Generic Vibration Criteria for Vibration-Sensitive Equipment* by Colin Gordon, who helped author the IEST and SPIE guidelines, provided an update the work completed previously. Table 19 contains these guidelines and is directly excerpted from the paper.

Table 19: Vibration Limits from *Generic Vibration Criteria for Vibration-Sensitive Equipment*

Criterion Curve	Max Level (mm/s rms)	Detail Size (microns)	Description of Use
Workshop (ISO)	0.8	N/A	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office (ISO)	0.4	N/A	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day (ISO)	0.2	75	Barely feelable vibration. Appropriate to sleep areas in most instances. Probably adequate for computer equipment, probe test equipment, and low-power (to 20X) microscopes.
Op.Theatre (ISO)	0.1	25	Vibration not clearly feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100X and for other equipment of low sensitivity.
VC-A	0.05	8	Adequate in most instances for optical microscopes to 400X, microbalances, optical balances, proximity, and projection aligners, etc.
VC-B	0.025	3	An appropriate standard for optical microscopes to 1000X, inspection and lithography equipment (including steppers) to 3 micron line widths.
VC-C	0.0125	1	A good standard for most lithography and inspection equipment to 1 micron detail size.
VC-D	0.006	0.3	Suitable in most instances for the most demanding equipment including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of their capability.
VC-E	0.003	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding of sensitive

Criterion Curve	Max Level (mm/s rms)	Detail Size (microns)	Description of Use
			systems including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

Based on the equipment used within the CanMET and the McMaster Innovation Park, the target vibration level at the building would be 0.006 mm/s RMS.

5.2.4 Predicted Vibration Levels

It is expected that non-revenue service vehicles, such as those operating on the spur track, will not need to travel at speeds greater than 30 km/hr. The yard speed within the OMSF will be limited to 15 km/hr.

The following table provides the predicted vibration levels at various setbacks for the two speeds of concern.

Table 20: Predicted OMSF Vibration Levels from Tangent Track

Distance from Track Centreline (m)	Vehicle at 30 km/hr	Vehicle at 15 km/hr
	Vibration Levels (mm/s RMS)	Vibration Levels (mm/s RMS)
3	0.19	0.10
7	0.13	0.07
12	0.11	0.06
40	0.04	0.02

For the OMSF, there are several switches that would increase the vibration levels resulting from vehicles passing over. While such vibration levels would die off rapidly with distance, their effect should be considered as well.

Table 21, below, provides the predicted vibration levels at low speeds resulting from special trackwork.

Table 21: Predicted OMSF Vibration Levels from Special Trackwork

Distance from Track Centreline (m)	Vehicle at 30 km/hr over Special Trackwork	Vehicle at 15 km/hr over Special Trackwork
	Vibration Levels (mm/s RMS)	Vibration Levels (mm/s RMS)
3	0.60	0.32
7	0.41	0.22
12	0.35	0.19
40	0.13	0.06

The nearest residential receptors to the OMSF tracks and special trackwork are located at least 40m away. As can be seen in the above analysis, the vibration criterial limit of 0.10 mm/s RMS is expected to be met at all receptors located 40m or more from special trackwork with vehicles moving as slowly as 15 km/hr. Note that the decrease in vibration levels from 12m to 40m is based on the standard propagation data within the FTA guide.

At 0.06 mm/s, the vibration-induced noise could be an issue. The vibration-induced sound levels in the 2011 assessment were calculated by converting the vibration velocity to sound based on the impedance of air. Using that same approach, vibration levels of 0.06 mm/s would generate induced sound levels of between 41 and 46 dBA, depending on the frequency content of the vibration.

The FTA guide would imply a vibration-induced sound level of 33 to 48 dBA depending on the frequency content of the vibration. As switch noise can typically be higher frequency, sound levels of 46 to 48 dBA are reasonable. These are well in excess of the criterion level of 35 dBA.

Low-impact or moveable point frogs could reduce the vibration levels by 5 dB. Resilient fasteners could reduce the levels a further 5 dB. Overall, reductions of 10 dB in the A weighted sound levels can be readily achieved. The residual 1 to 3 dB impact can likely be eliminated with more detailed testing of the site conditions to verify the propagation of a point source such as the switches. Vibration at higher frequencies also decreases more rapidly with distance than vibration at lower frequencies.

The vibration levels at the closest points of the CanMET and McMaster Innovation Park buildings are expected to be approximately 0.11 mm/s RMS without any vibration control measures. A simple embedded rail system capable of providing 5 dB reduction would result in an overall level of approximately 0.06 mm/s, which is still 10x or 20 dB higher than the limit for such equipment.

A 20 dB reduction at the source would require a floating slab. However, it is not expected that such measures will be required if the equipment has been provided with sufficient isolation at the receiver.

For the special trackwork at the OMSF site, the nearest switch is more than 110m from CanMET's building. The vibration level at CanMET from slow moving trains would be 0.01 mm/s, which would be confirmed during detailed field testing. These levels are still approximately 2x or 6 dB too high. In this case, additional reduction can be achieved easily through moveable point frogs (reduces impact noise and vibration) or through improved resilient fasteners.

It is recommended that each piece of sensitive equipment be reviewed on a case-by-case basis to determine the residual vibration impacts, if any. It may be more cost effective to provide additional isolation at the receptor as opposed to installing floating slab track. There would be almost 400m of double track that would need to be treated.

5.2.5 Summary and Recommendations

The vibration analysis has indicated the tangent track at the OMSF and spur line will have no impacts on nearby residential receptors.

The special trackwork located closest to the residential receptors to the south of the OMSF will meet the ground-borne vibration criteria of 0.1mm/s RMS but are expected to exceed the vibration-induced noise criterion of 35 dBA by at least 10 dB or so. As a result, the use of moveable point frogs and simple resilient fasters are recommended for those switches and crossovers. In any case, the Detailed Design will need to review the exact location of the special trackwork and determine the efficiency of vibration propagation in the soil to choose the vibration isolation measures that may be required. Yard speeds should be limited to 15 km/hr.

The tangent track located closest to the vibration sensitive equipment in the McMaster Innovation Park and CanMET buildings has the potential to generate some vibration impacts if the sensitive equipment has not already been sufficiently isolated. It is recommended the tangent track be provided with vibration embedded rail capable of at least a 5 dB (44%) reduction in the vibration levels. The speed of vehicles on the spur line should be limited to 30 km/hr. Otherwise, additional vibration control measures may be required. At the OMSF, the closest special trackwork has the potential to modestly exceed the design guidelines at the CanMET building. Modest vibration isolation upgrades to the switches would be needed. Consideration may need to be given to isolating individual pieces of vibration sensitive equipment as opposed to further upgrades of the spur track.

A more detailed Noise and Vibration Impact Assessment will be completed during Detailed Design. Aside from the normal scope of such reviews, the following should be addressed as part of the detailed assessment to confirm and design the vibration mitigation measures.

- Conduct vibration propagation testing of the OMSF site and surroundings to confirm the reduction in vibration with distance
- Verify the performance of the existing vibration isolation systems provided for the sensitive equipment at CanMET and the McMaster Innovation Centre. This may entail in-field vibration measurements in addition to reviews of manufacturer's data
- Confirm the vibration design criteria and acceptable levels at the sensitive equipment within CanMET and the McMaster Innovation Centre.

6.0 OPERATIONAL LRV NOISE AND VIBRATION ASSESSMENT

In most cases, the revised alignment reduces vibration impacts and remains neutral in terms of noise impacts. At one location, just west of Dalewood Avenue, the alignment shifts to side-running sooner than it did in the 2011 version of the alignment. As a result, this one area is now considered again for potential noise and vibration impacts.

6.1 Operational Noise Assessment

The noise impact assessment compares the sound levels along the route under two different conditions for the design year of 2031. The sound levels without the project are higher than the current sound levels due to traffic growth within the corridor. The sound levels with the project will be comprised of existing car and truck traffic and the addition of the LRVs, as well as some minor bus traffic during the day.

Given the noise limits for the light rail vehicle and the traffic volumes (with and without the project) the noise impact of the LRV component of the project can be determined.

Sound levels are calculated using the Ministry of the Environment's ORNAMENT prediction procedure. The computer program used for this analysis is the MOE's STAMSON 5.04 computer program, which incorporates both ORNAMENT (road) and STEAM (rail) prediction methods. Although on rail, the LRVs are treated as roadway sources and are evaluated based on the ORNAMENT procedure as medium trucks.

For this small section of the route, only one typical receptor is necessary for the evaluation. This receptor is a 2-storey home located farthest south on Forsyth Avenue.

6.1.1 Traffic Volumes

Traffic volumes with and without the project have been provided by Steers Davies Gleave. As per the previous EPR, the hourly volumes have been scaled up by a factor of 12.53 to determine the overall daily volume.

Table 22 summarizes the traffic volumes used in the assessment of noise at this receptor.

Table 22: Future Traffic Volumes

Condition	Roadway	Cars	Heavy Trucks	Medium Trucks and Buses	LRVs	Speed
No Project	Main Street	43,266	1028	1354	None	60
With Project	Main Street	39,219	1021	1397	449	60

1. With the exception of the LRT volumes, daily traffic has been divided into daytime and nighttime volumes, using a typical 90% daytime/10% nighttime split.
2. Nighttime LRT operations are expected to stop between 0130 and 0500 hours for maintenance, resulting in 72 LRV movements at night.
3. The operating speed of the LRT will be the same as regular traffic and 50km/h in the downtown section with no regular traffic.
4. Due to the nature of sound, changes in traffic volumes of +25%/-20% would change the overall sound levels by 1 dB only.

6.1.2 Predicted Sound Levels

Since the LRVs have not been selected as yet, specific noise data are unavailable. The noise impact assessments completed for some of the Toronto Transit Commission's Transit City LRT routes indicate sound levels of approximately 82 dB at a distance of 7.5m for a comparable vehicle travelling at 40km/hr on concrete. These are specifications only and not actual sound levels. Recently measured data from the Jerusalem LRT indicate maximum sound levels of *75 dBA at 7.5m* for a 35m long, two-motor bogie vehicle travelling at 40km/h. Bombardiers own modeling indicate sound levels at least 5 dB lower than the specification. For the purposes of this assessment, the focus is on the sound level of an LRV in operation. According to the *ORNAMENT* procedure, a medium truck produces *71dB at 15m* while travelling at 40km/hr. Thus, modelling each LRV consist (train) as two medium trucks slightly over-estimates the LRT system noise, but can be representative of the actual sound levels that can be expected from this technology. Note that this approach is more accurate than using a custom source setting within STAMSON, as the custom source setting cannot take into account the length of the exposure.

Table 23 summarizes the sound levels with and without the project.

Table 23: Predicted Operation LRT Sound Levels

POR	No Project Sound Levels (dB)		With Project Sound Levels (dB)						Impact (dB)	
	Daytime (16hr L_{eq})	Nightime (8hr L_{eq})	Daytime (16hr L_{eq})			Nighttime (8hr L_{eq})			Daytime	Nighttime
			Traffic Only	LRT Only	TOTAL[1]	Traffic Only	LRT Only	TOTAL[1]		
11	70	63	69	62	70	63	58	64	0	1

The change in alignment results in a 1 dB increase in noise at the most. This is as a result of two factors. The introduction of a new noise source 15m away from the homes raises the sound levels. However, this is offset by the slight shift in alignment of the roadway and the associated decrease in overall volumes due to the displacement of traffic and mode shift of cars into passengers on the LRVs.

The analysis indicates that this modest change in alignment has not triggered a noise impact. The operational noise of the LRVs within the corridor continues to have a neutral or slightly beneficial impact on the sound levels along the route.

6.1.3 Recommendations

In no case does the introduction of the project generate a noise impact in excess of 5 dB along its route. Hence, no noise mitigation is warranted as per the MOE/TTC protocol.

Similar to the 2011 Noise and Vibration Impact Assessment, and for most other light rail vehicle noise assessments completed in Ontario in the last 10 years, special trackwork has not been considered.

The contribution to the air-borne sound levels from the special trackwork should be reviewed during Detailed Design. Moveable point frogs and other noise reducing control measures can be implemented to minimize the impact noise, but such measures cannot completely eliminate the noise. Slow orders over special trackwork can also be considered in specific cases, provided such orders do not negatively affect the schedule.

As noted in the 2011 EPR, wheel squeal may also be an issue. Constrained layer damping of the wheels, lubricated rails and wheels, and go-slow orders can be used to control wheel squeal. These aspects should be addressed during the Detailed Design, when specifics of the selected light rail vehicle are known or can be controlled.

6.2 Operational Vibration Assessment

The operational vibration assessment is based on the same prediction and procedures used in the 2011 Assessment and as noted in Section 5.2 of this report.

6.2.1 Vibration Receptors and Assessment

The nearest noise sensitive receptor is also the vibration receptor used for this analysis. The closest point of the building is approximately 13m away from the nearest tracks.

The predicted vibration level at such a setback, based on Table 9 of the 2011 Assessment report, is 0.12 mm/s. Measurement data indicate the increase in vibration due to the extended length of the vehicle does not occur in practice. Instead, the vibration level persists for a longer period of time. As a result, the vibration levels from the 2011 Assessment are slightly overestimated.

In any case, even with some vibration isolation included in the design, the predicted level at the nearest receptor exceeds the criterion of 0.10 mm/s RMS. The induced noise for such vibration levels would be approximately 37 to 40 dBA. As a result, improved vibration isolation is required for this area of trackwork. A more resilient embedded rail isolation system should be capable of providing a further 5 dB reduction.

6.2.2 Recommendations

The movement from the tracks from centre-running to side-running in the area just west of Dalewood Avenue and east of McMaster University has triggered some vibration impacts that cannot be addressed by a simple Level 1 embedded rail system. Instead, an upgraded Level 2 embedded rail system is recommended in this area as shown in Figure 9 in Appendix A.

As before, the recommendations should be confirmed during Detailed Design. The detailed design will also review the increased vibration levels from special trackwork.

7.0 CONSTRUCTION NOISE AND VIBRATION

The impact of construction noise and vibration on nearby sensitive receptors has been reviewed. As the project has not reached the detailed design level, neither the specifics of equipment to be used in the construction process, nor the construction process itself have been determined. The focus of the construction noise and vibration impact assessment is to develop a generic guideline to be further refined and expanded when more information becomes available during the detailed design phase. As the project is quite extensive, consideration is given not only to structural and health-related effects of construction noise and vibration, but also to community annoyance.

Aside from the spur line to the OMSF, the construction noise and vibration associated with the project will not change significantly with the revised alignment. There will be some additional construction noise and vibration at the sites of the three bus terminals reviewed.

7.1 Identification of Noise and Vibration Sensitive Receptors

Receptors sensitive to noise and vibration during construction would be the same as those during the operations. Residences, schools, places of worship, etc. would all be sensitive to noise and vibration during construction. Buildings with vibration sensitive equipment such as at McMaster's main campus or their Innovation Centre and at CanMET would be susceptible to short-term impact during construction.

7.2 General Construction Requirements

Provincial and municipal guidelines provide basic restrictions and recommendations with regard to construction noise and vibration. The City of Hamilton enforces a noise bylaw which prescribes appropriate hours of operation for construction activities.

The applicable guidelines can be found in the following documents:

1. MOE's Model Municipal Noise Control By-law
2. The City of Hamilton By-Law No. 03-020, enacted January 22, 2003
3. *NPC-115 Construction Equipment*
4. *NPC-300 Environmental Noise Guidelines.*

The Provincial guidelines with regard to sound levels place specific restrictions on source equipment sound levels. The guidelines are written to restrict maximum allowable sound levels for equipment used in certain construction activities. The applicable guidelines can be found in *NPC-115. NPC-300* excludes noise sources related to construction activities.

Additional equipment limits can be found within the FTA, FHWA, and Boston Big Dig By-law. The sound level limits from such equipment are summarized in Table 24.

Table 24: Construction Equipment Sound Level Restrictions

Equipment Description	Sound Level Limit (dBA, L_{max} at 15m)	Source of Limit
All Other Equipment > 5 HP	85	FHWA/Big Dig Spec 721.560
Auger Drill Rig	85	FHWA/Big Dig Spec 721.560
Backhoe < 75 kW	82	NPC-115
Backhoe > 75 kW	85	NPC-115
Ballast Equalizer	82	FTA
Ballast Tamper	83	FTA
Bar Bender	80	FHWA/Big Dig Spec 721.560
Blasting	94	FHWA/Big Dig Spec 721.560
Boring Jack Power Unit	80	FHWA/Big Dig Spec 721.560
Chain Saw	85	FHWA/Big Dig Spec 721.560
Clam Shovel (dropping)	94	FHWA/Big Dig Spec 721.560
Compactor (ground)	80	FHWA/Big Dig Spec 721.560
Compressor (air)	69	NPC-115
Concrete Batch Plant	83	FHWA/Big Dig Spec 721.560
Concrete Mixer Truck	85	FHWA/Big Dig Spec 721.560
Concrete Pump Truck	82	FHWA/Big Dig Spec 721.560
Concrete Saw	90	FHWA/Big Dig Spec 721.560
Concrete Vibrator	76	FTA
Crane (Fixed)	85	FHWA/Big Dig Spec 721.560
Crane (Mobile)	83	FTA
Dozer < 75 kW	82	NPC-115
Dozer > 75 kW	85	NPC-115
Drill Rig Truck	84	FHWA
Drum Mixer	80	FHWA
Excavator < 75 kW	82	NPC-115
Excavator > 75 kW	85	NPC-115
Excavator	85	FHWA/Big Dig Spec 721.560
Flat Bed Truck	84	FHWA/Big Dig Spec 721.560
Front End Loader (<75 kW)	82	NPC-115
Front End Loader (> 75 kW)	85	NPC-115
Generator (>25 KVA)	81	FTA
Generator (<25 KVA, VMS Signs)	70	FHWA/Big Dig Spec 721.560
Gradall	85	FHWA/Big Dig Spec 721.560

Equipment Description	Sound Level Limit (dBA, L_{max} at 15m)	Source of Limit
Grader	85	FHWA/Big Dig Spec 721.560
Grapple (on backhoe)	85	FHWA
Horizontal Boring Hydraulic Jack	80	FHWA/Big Dig Spec 721.560
Hydra Break Ram	90	FHWA/Big Dig Spec 721.560
Impact Pile Driver	95	FHWA/Big Dig Spec 721.560
Impact Wrench	85	FTA
In Site Soil Sampling Rig	84	Big Dig Spec 721.560
Jackhammer	85	FHWA/Big Dig Spec 721.560
Loader (see Front End Loader)	--	
Man Lift	85	FHWA
Mounted Impact Hammer (hoe ram)	90	FHWA/Big Dig Spec 721.560
Pavement Scarifier	83	FTA
Paver	85	FHWA/Big Dig Spec 721.560
Pickup Truck	55	FHWA/Big Dig Spec 721.560
Pneumatic Pavement Breaker	79	NPC-115
Pneumatic Tools (excluding Pavement Breaker)	85	FHWA/Big Dig Spec 721.560
Pumps	76	FTA
Rail Saw	90	FTA
Refrigerator Unit	82	FHWA
Rivet Buster/Chipping Gun	85	FHWA
Rock Drill	85	FHWA/Big Dig Spec 721.560
Roller	74	FTA
Sand Blasting (single nozzle)	85	FHWA
Saw	76	FTA
Scraper	85	FHWA/Big Dig Spec 721.560
Sheers (on backhoe)	85	FHWA
Shovel	82	FTA
Slurry Plant	78	FHWA/Big Dig Spec 721.560
Slurry Trenching Machine	82	FHWA/Big Dig Spec 721.560
Soil Mix Drill Rig	80	FHWA/Big Dig Spec 721.560
Spike Driver	77	FTA
Tie Cutter	84	FTA
Tie Handler	80	FTA
Tie Inserter	85	FTA
Tractor	84	FHWA/Big Dig Spec 721.560
Vacuum Excavator (Vac-Truck)	85	FHWA/Big Dig Spec 721.560
Vacuum Street Sweeper	80	FHWA/Big Dig Spec 721.560
Ventilation Fan	85	FHWA
Vibrating Hopper	85	FHWA

Equipment Description	Sound Level Limit (dBA, L_{max} at 15m)	Source of Limit
Vibratory Concrete Mixer	80	FHWA/Big Dig Spec 721.560
Vibratory Pile Driver	95	FHWA/Big Dig Spec 721.560
Warning Horn	85	FHWA
Welder/Torch	73	FHWA/Big Dig Spec 721.560

7.3 Construction Scheduling Restrictions

By-Law No. 03-020 places restrictions on the hours of operation for all construction activity: in particular, construction is limited to between 7 a.m. and 7 p.m. on weekdays and Saturdays, with more stringent hours on Sundays and holidays. Due to the nature of the construction activities within the corridor, it is likely that much of the construction will need to be carried out through the night, to minimize the impact on local traffic in the area. As such, special exemptions will need to be obtained where the night construction is to occur. Because of the potential impact on receptors during the nighttime periods, it is recommended the residents in the area be notified several weeks in advance of pending nighttime construction activities.

7.4 Construction Vibration Limits

The City of Hamilton does not provide limits on vibration levels similar to those stipulated by the City of Toronto in By-law 514-2008. These limits are provided below.

Table 25: City of Toronto Prohibited Vibration Levels from By-law 514-2008

Vibration Frequency (Hz)	Vibration Peak Particle Velocity (mm/s)
Less than 4	8
4 to 10	15
More than 10	25

The FTA provides limits for construction vibration depending on the type of structure.

Table 26: FTA Construction Vibration Limits

Building Category	Peak Particle Velocity (in/sec)	Peak Particle Velocity (mm/s)
Reinforced concrete, steel or timber (no plaster)	0.5	12.7
Engineered concrete and masonry	0.3	7.62
Non-engineered timber and masonry buildings	0.2	5.08
Buildings extremely susceptible to vibration damage	0.12	3.05

It is recommended that the contractor building the LRT be asked to adhere to one or both of the above noted construction vibration limitations.

7.5 Nature of Construction Impacts

It is assumed that for the concrete-embedded sections, the LRT construction will be carried out in a manner similar to the other light rail projects in the country. Much of the noise resulting from this construction activity will be that which is typical of road construction, including utilities' relocation. The total length of the construction activity will be long; however, the impact to a specific area will be comparatively short, as construction will progress from one area to the next. Intersections and areas with stops may be slightly longer in construction duration.

Some consideration should be given to employing the construction methods developed in Europe to construct light rail transit lines in heavily urbanized areas.

Similarly, the construction of the bus terminals will use fairly standard equipment found in most urban construction sites.

The construction of the LRT guideway over Highway 403 may see some atypical equipment such as pile drivers. In such cases, the use of vibratory or sonic pile drivers is recommended.

The OMSF construction will be fairly stationary for 1 to 2 years. As the site is relatively quiet, construction impacts may prove significant. In other cases, the MSF sites have usually required large scale soil compaction using dynamic compactors or vibratory compaction. Vibratory compaction is generally lower in amplitude, though it can result in annoyance. Dynamic compaction can result in significantly higher amplitudes.

It is recommended a prediction of the construction noise and vibration impacts be completed prior to the start of construction. This construction assessment should identify typical sound levels during construction and recommend mitigation measures to help control the noise and vibration impacts during construction.

Construction noise and vibration mitigation measures can include:

1. Use of alternative methods of construction and types of equipment
2. Scheduling changes to move construction to less sensitive time periods (should be weighed against prolonging construction)
3. For vibration-sensitive equipment, construction may be able to be scheduled around the use of such equipment. Alternatively, expedited 24/7 construction may significantly shorten the construction schedule and reduce the overall impact, which can be a function of both duration and intensity.
4. Localized noise barriers such as around stationary equipment, staging areas, or long-term work areas such as the OMSF and bus terminals
5. Designing haul and truck routes to minimize truck traffic through lightly travelled residential streets.

7.6 Construction Noise and Vibration Recommendations

Construction will be inherently noisy. In most areas, construction should not last for more than 2 years and in many areas should last for substantially less time as activity proceeds along the route.

Controlling construction noise and vibration comes at a trade-off with cost and scheduling impacts. Construction noise and vibration will be controlled where practical and economically feasible. However, elevated sound and vibration levels should be expected along the entire corridor and near the OMSF.

The following summarize the recommendations to help control noise and vibration during construction.

1. Equipment should adhere to the sound level limits provided within *NPC-115*, the FHWA guide, and the Boston Big Dig bylaw, as noted in Table 26 above.
2. Vibration should be limited at receptors as noted in Section 7.4
3. Trucks should adhere to Transport Canada regulation 1106, as this provides stricter limits than *NPC-118.*
4. All construction equipment used for this project, except for equipment used less than once per day (re-bar delivery, etc.) should use broadband backup alarms instead of tonal backup alarms
5. All equipment used during nighttime (2300-0700) construction, regardless of size, should use broadband backup alarms. Broadband backup usage is becoming more common in construction of transit and transportation projects, having previously been mostly used by industry to reduce complaints and improve safety.
6. Implement the construction vibration limits noted in Section 7.4
7. Conduct a detailed assessment of construction noise and vibration and determine practical control measures to help reduce impacts.
8. Consideration should be given to constructing any permanent noise barriers warranted by the project's impacts first, so that the barriers also serve to help reduce construction noise impacts.
9. Design and enact a communications and complaints protocol for the public to inform them of construction activities and allow them a forum to voice their concerns and complaints.
10. Implement a comprehensive construction noise and vibration-monitoring program, including regular site visits, to measure construction sound and vibration levels and continuously reduce/improve the impact.
11. Active briefing and review of contractors' practices and operations, to ensure they continue to adhere to the requirements.

/pt

APPENDIX A: FIGURES

Figure 1: Revised Route for Updated Assessment

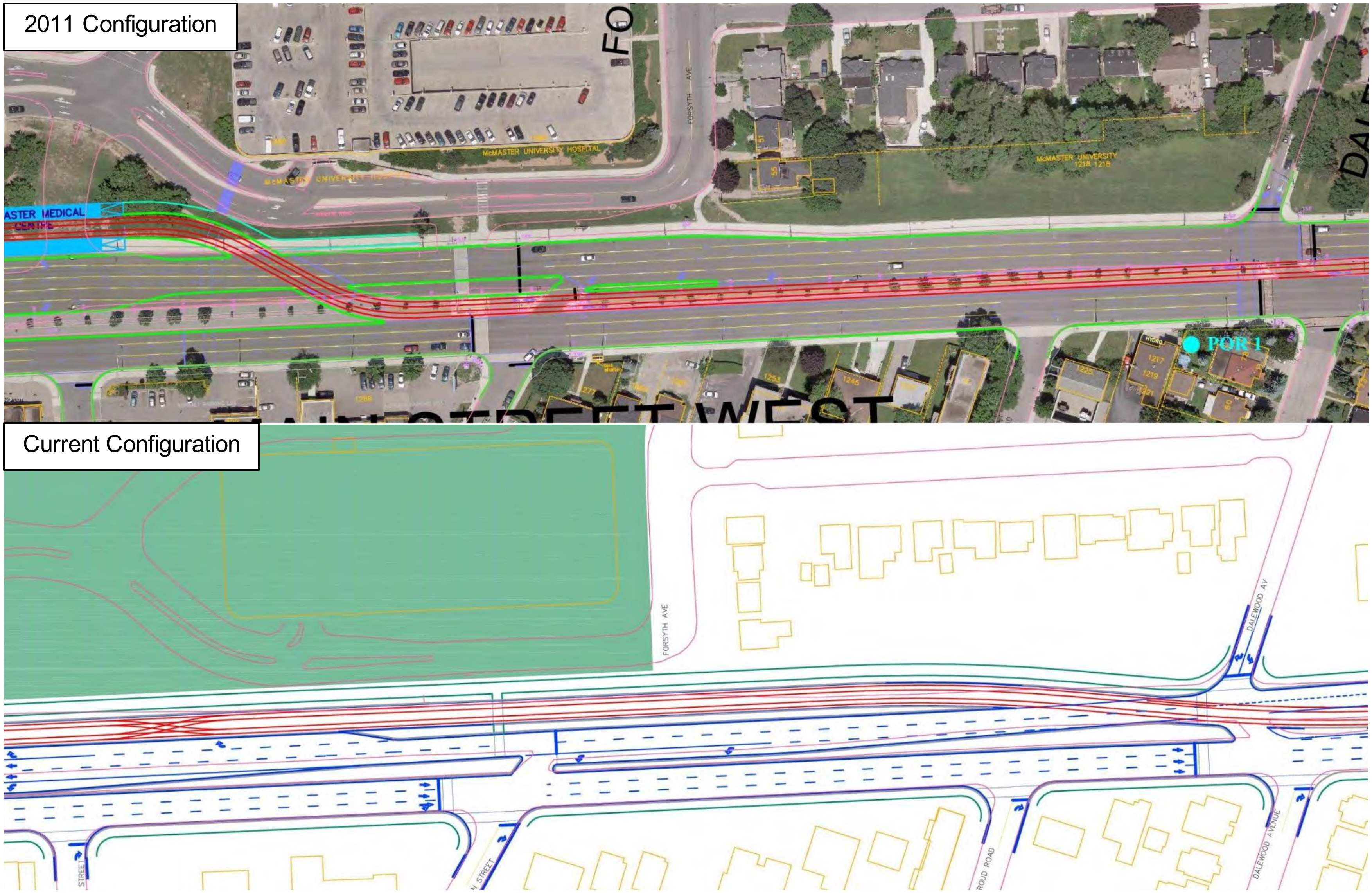


Figure 2: Layout at Dalewood Avenue - 2011 vs. Current

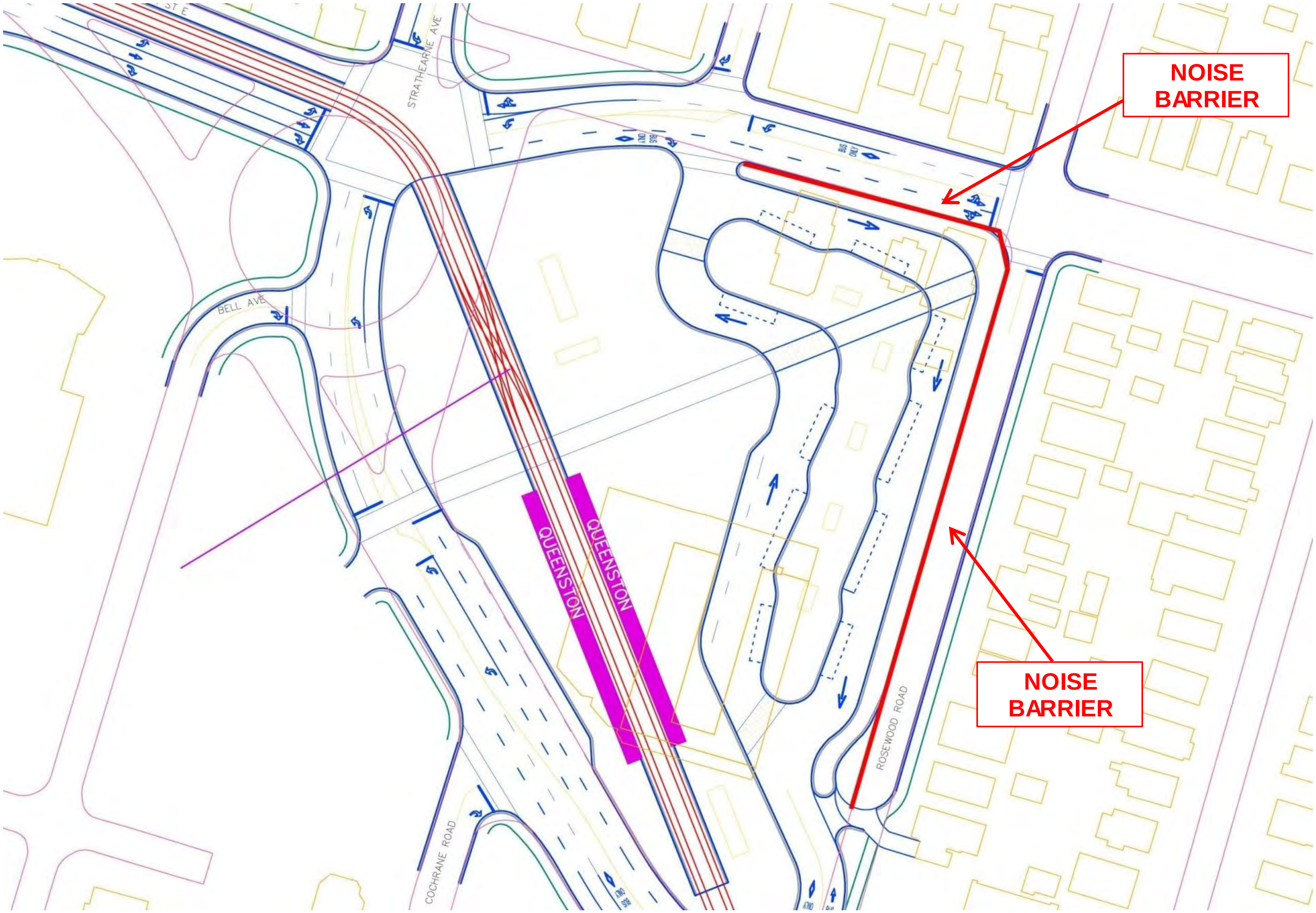


Figure 3: Queenston Bus Terminal - Mitigation Option 1

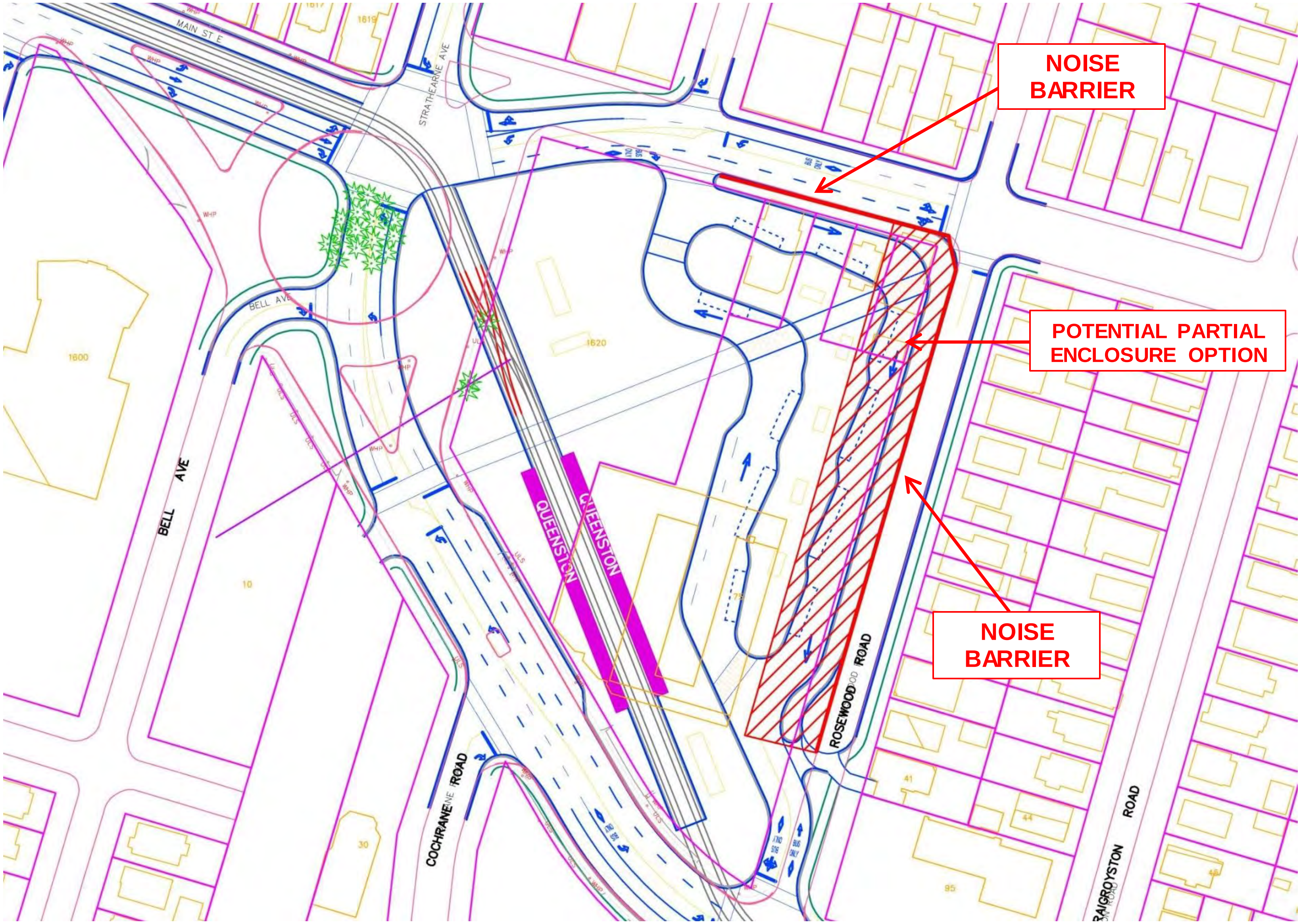


Figure 4: Queenston Bus Terminal - Mitigation Option 2

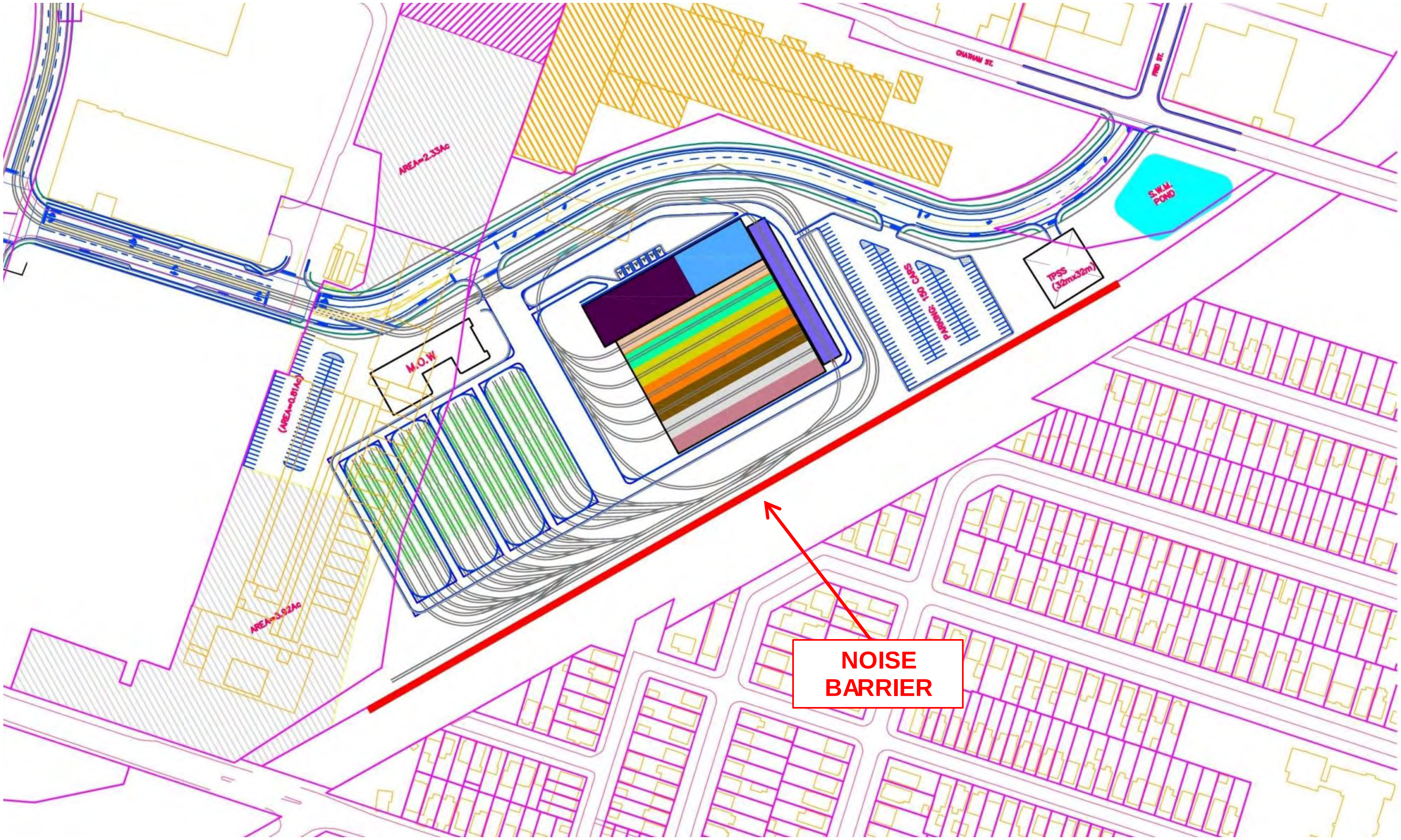


Figure 5: OMSF Mitigation Option 1

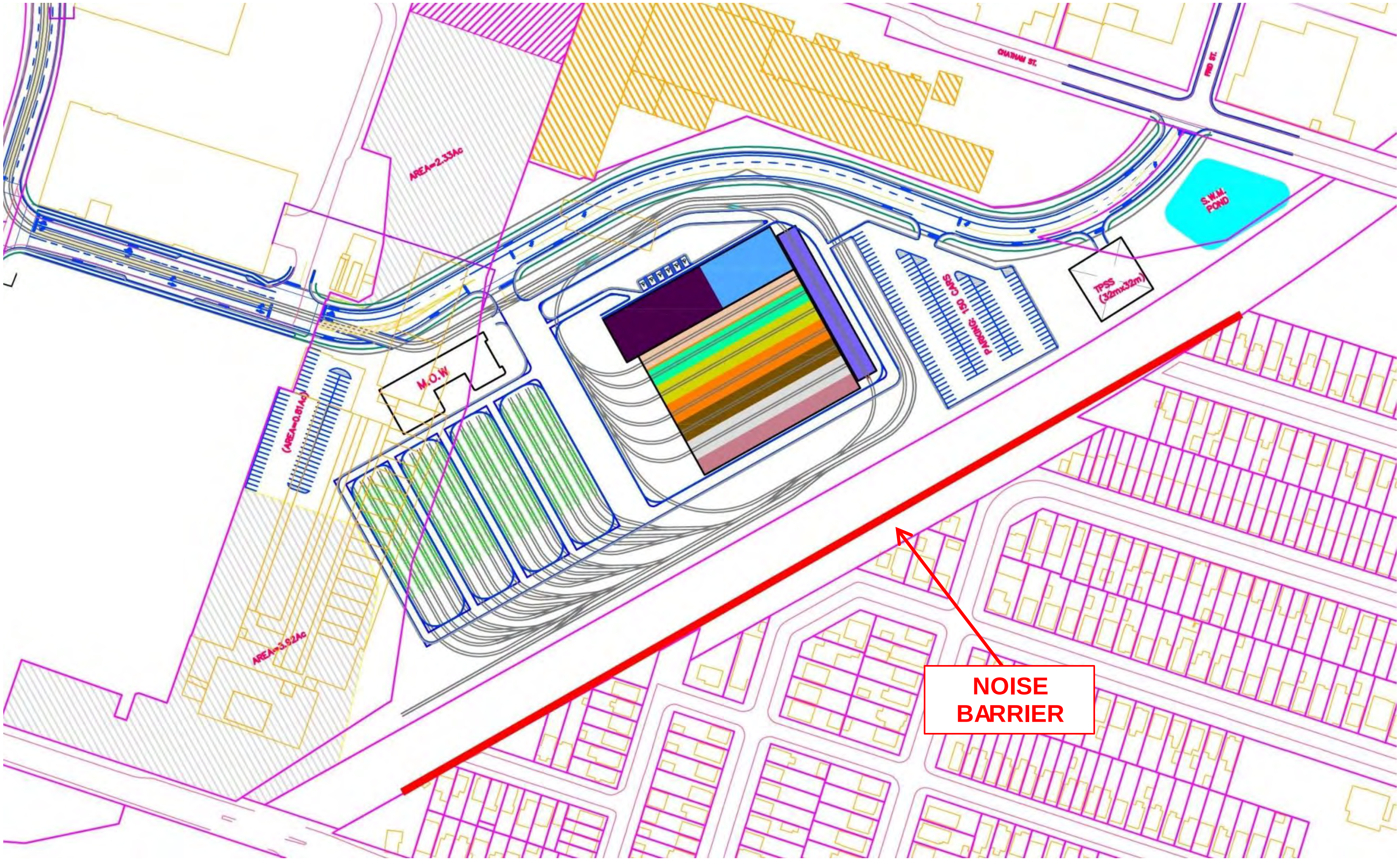


Figure 6: OMSF Mitigation Option 2

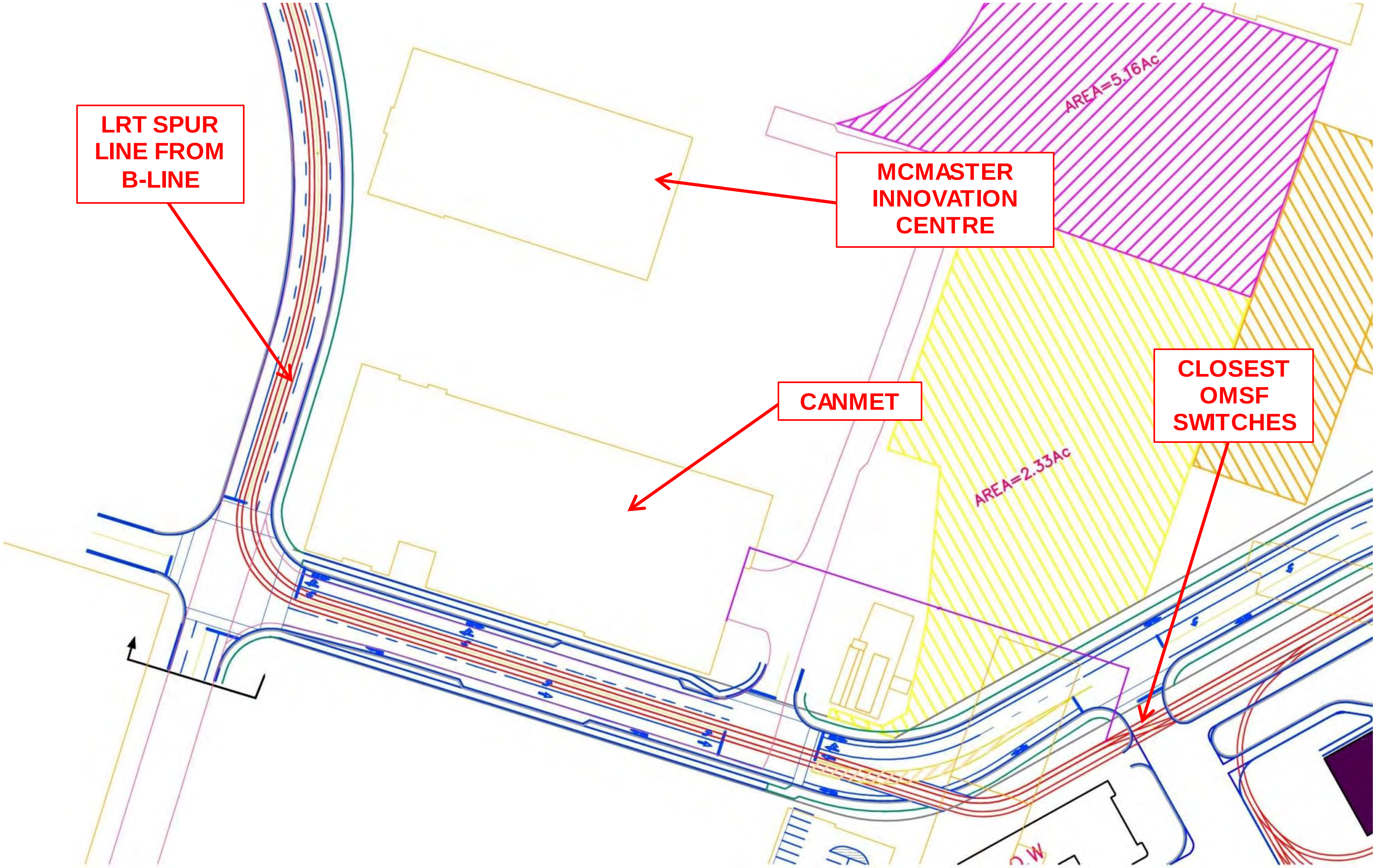


Figure 7: Sensitive Receptors and OMSF Spur Line Layout

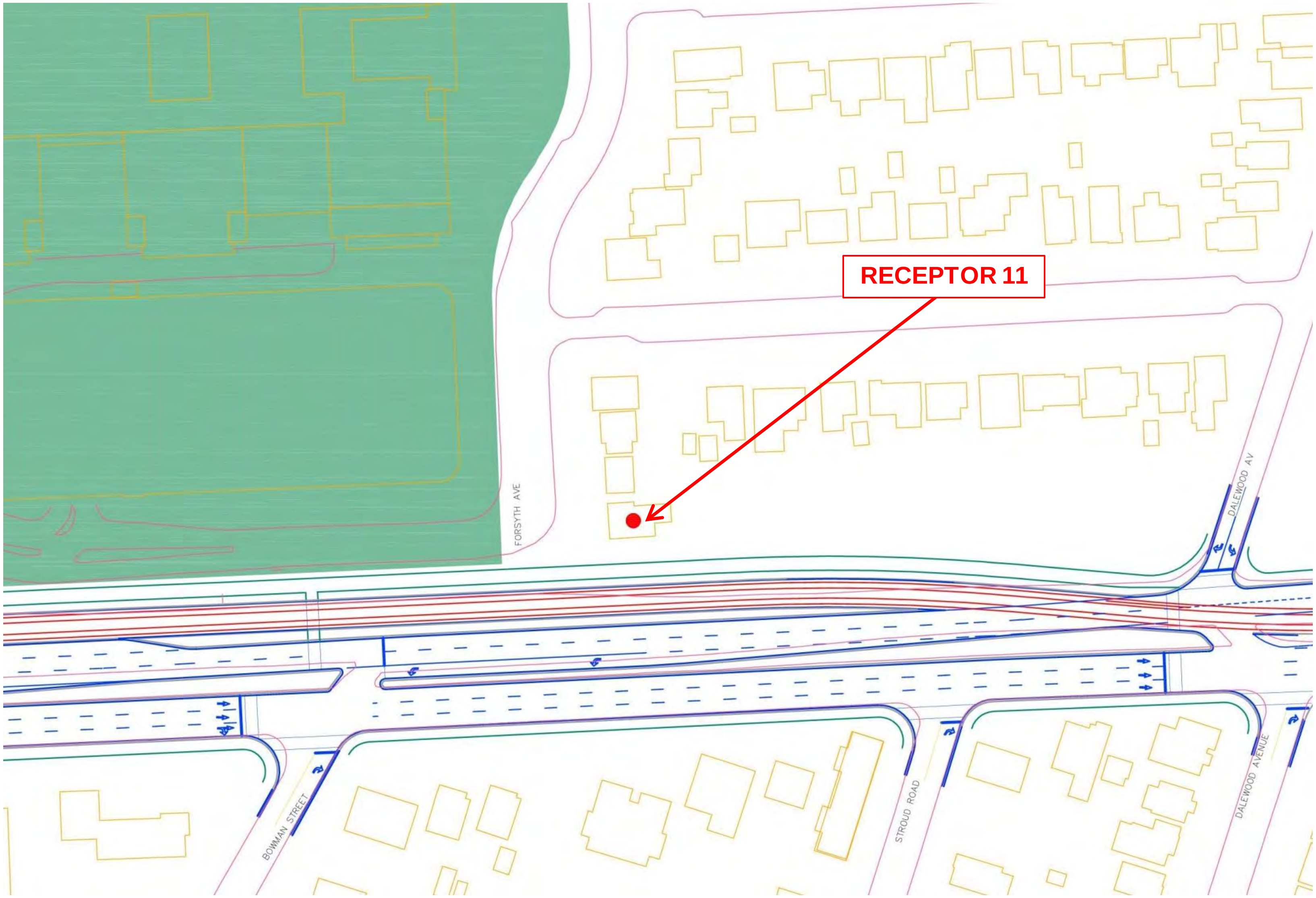


Figure 8: Operational Noise and Vibration Receptor 11

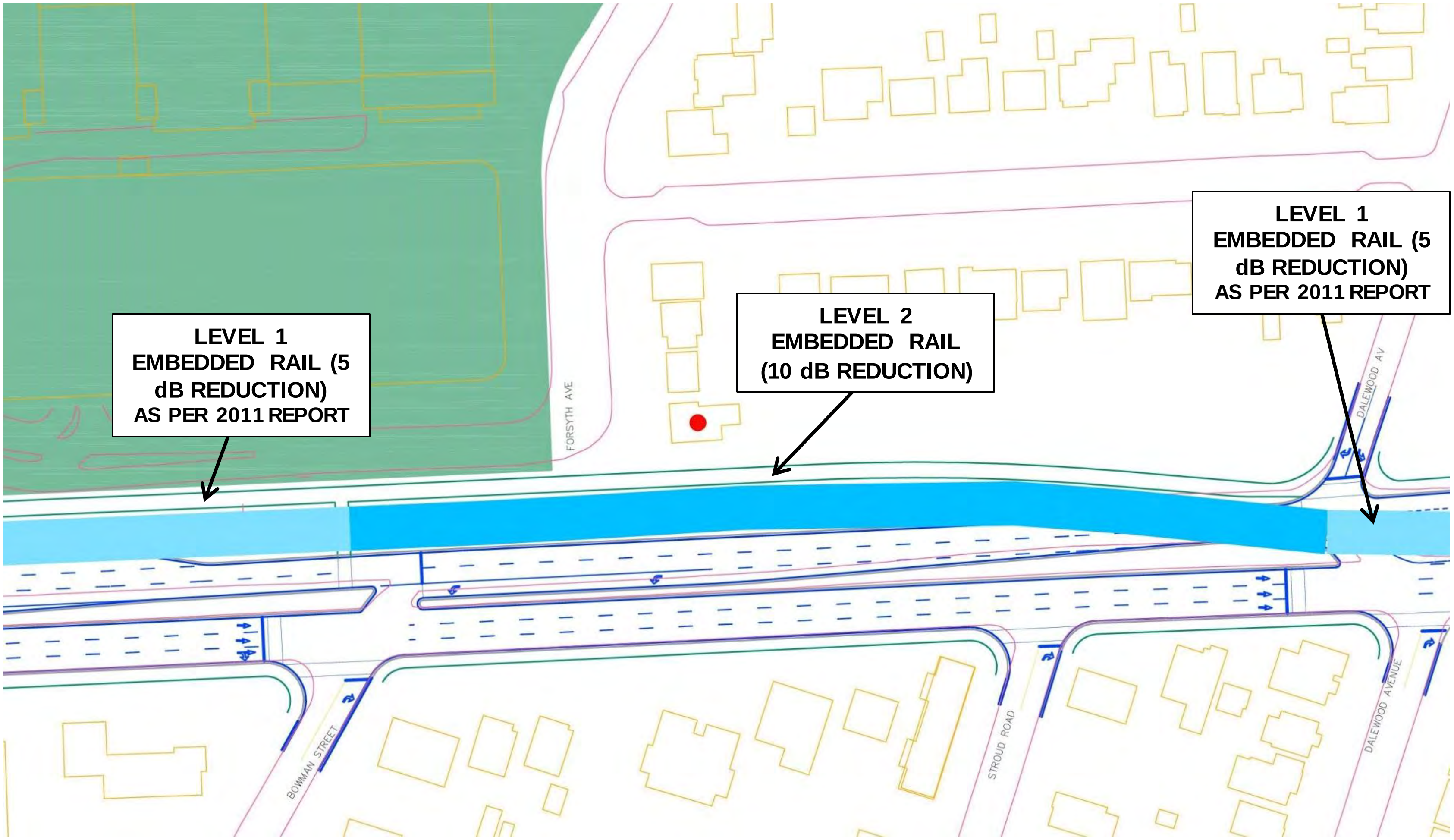


Figure 9: Vibration Control Recommended for Receptor 11

APPENDIX B: DATA AND SAMPLE CALCULATIONS

Figure B1: Measurement Location (McMaster Bus Terminal)

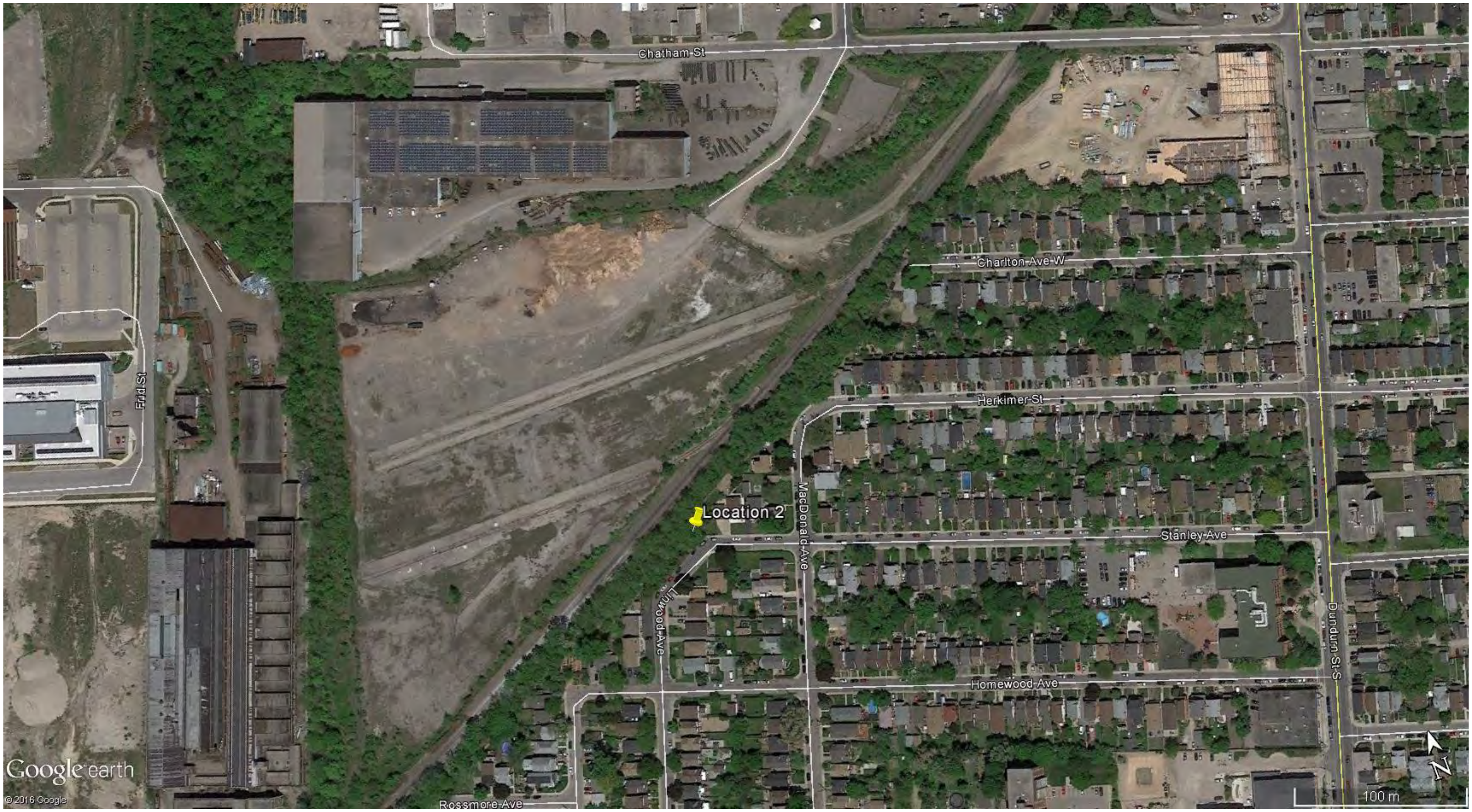
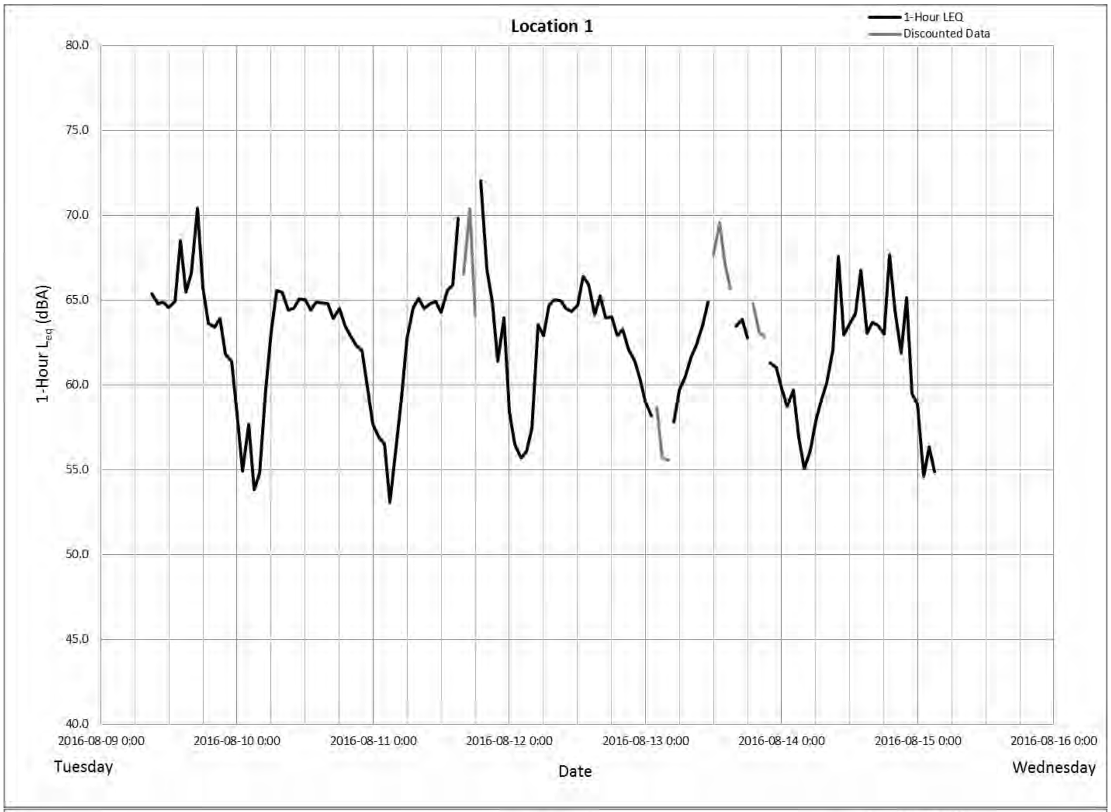
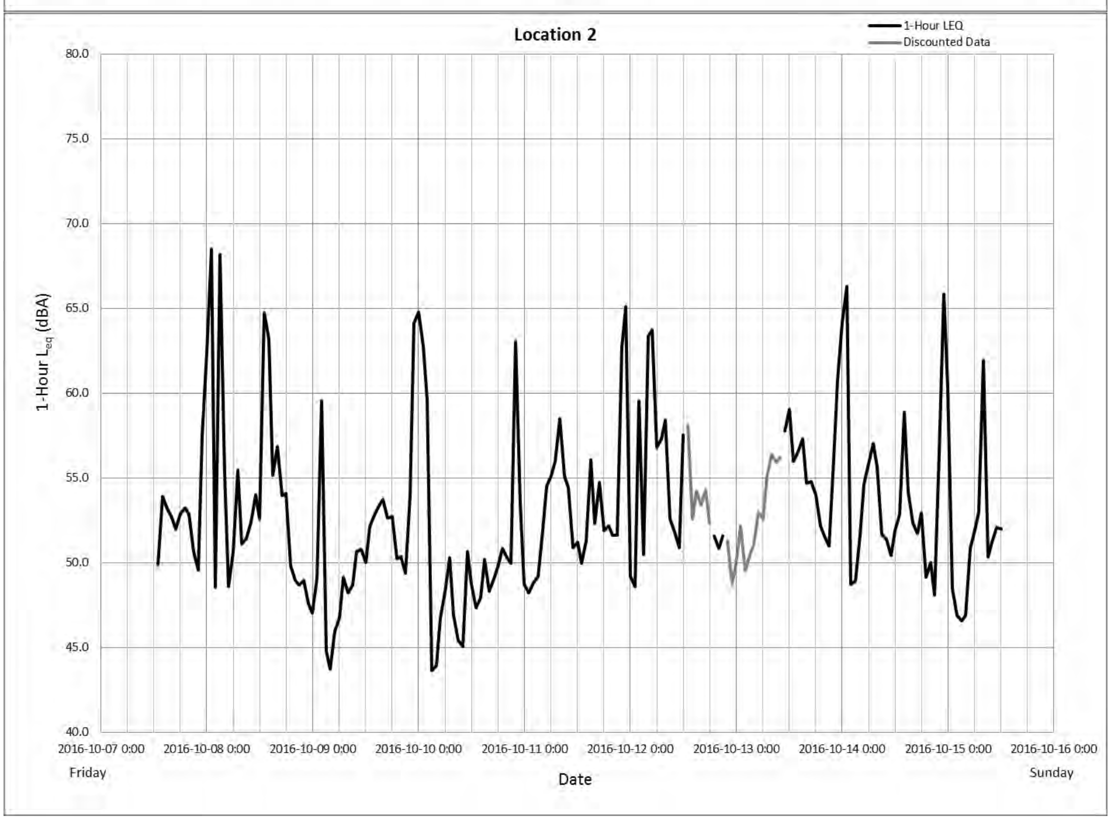


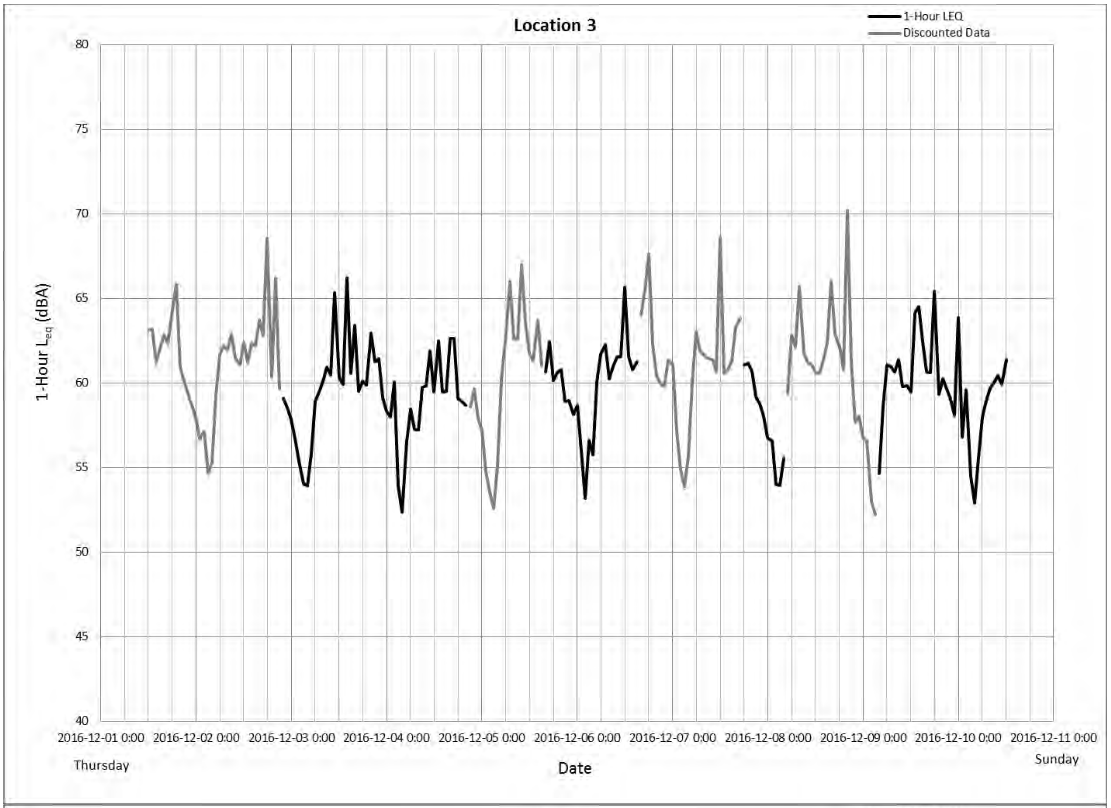
Figure B1: Receptor Locations (OMSF)

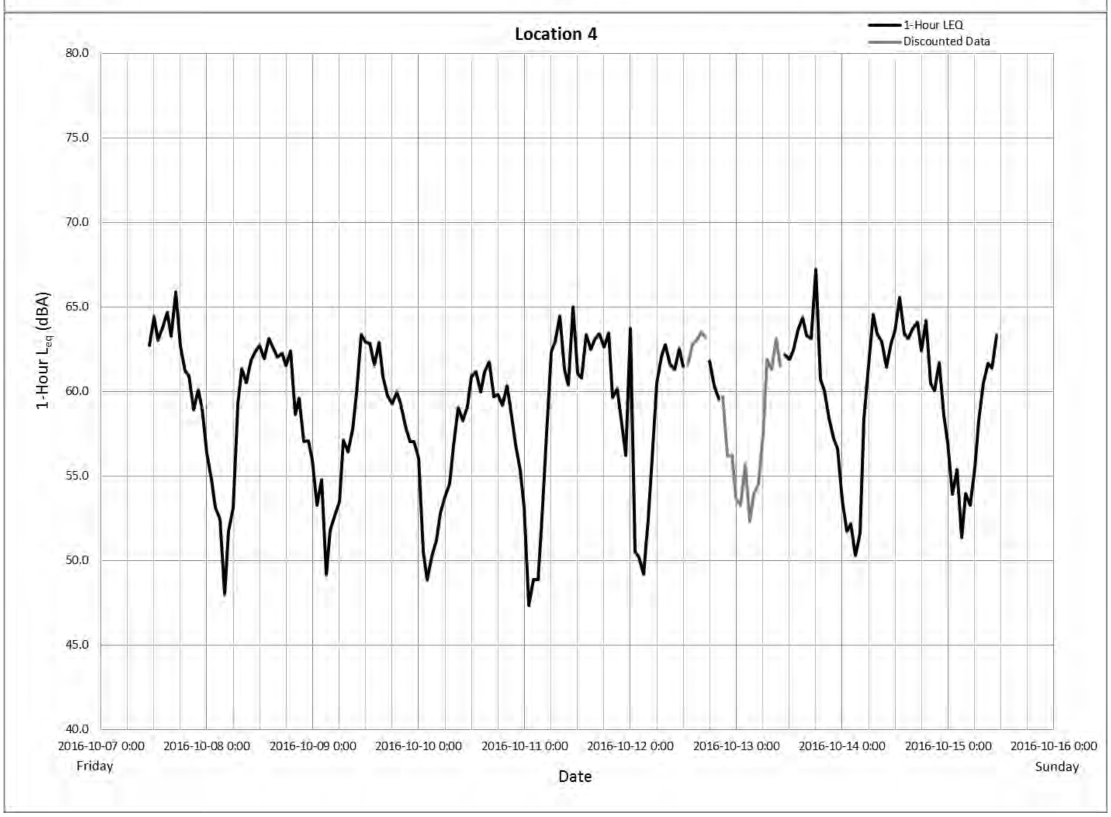
Figure B3: Receptor Locations (MacNab Bus Terminal)

Figure B4: Receptor Locations (Queenston Bus Terminal)


Location 1
1-Hour LEQ
Discounted Data
1-Hour L_{eq} (dBA)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
2016-08-09 0:00
2016-08-10 0:00
2016-08-11 0:00
2016-08-12 0:00
2016-08-13 0:00
2016-08-14 0:00
2016-08-15 0:00
2016-08-16 0:00
Tuesday
Date
Wednesday


Location 2
1-Hour LEQ
Discounted Data
1-Hour L_{eq} (dBA)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
2016-10-07 0:00
2016-10-08 0:00
2016-10-09 0:00
2016-10-10 0:00
2016-10-11 0:00
2016-10-12 0:00
2016-10-13 0:00
2016-10-14 0:00
2016-10-15 0:00
2016-10-16 0:00
Friday
Date
Sunday


Location 3
1-Hour LEQ
Discounted Data
1-Hour L_{eq} (dBA)
80
75
70
65
60
55
50
45
40
2016-12-01 0:00
2016-12-02 0:00
2016-12-03 0:00
2016-12-04 0:00
2016-12-05 0:00
2016-12-06 0:00
2016-12-07 0:00
2016-12-08 0:00
2016-12-09 0:00
2016-12-10 0:00
2016-12-11 0:00
Thursday
Sunday
Date


Location 4
1-Hour LEQ
Discounted Data
1-Hour L_{eq} (dBA)
80.0
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
2016-10-07 0:00
2016-10-08 0:00
2016-10-09 0:00
2016-10-10 0:00
2016-10-11 0:00
2016-10-12 0:00
2016-10-13 0:00
2016-10-14 0:00
2016-10-15 0:00
2016-10-16 0:00
Friday
Sunday
Date

```
STAMSON 5.0        NORMAL REPORT        Date: 03-01-2017 08:34:27
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: lrt.te                Time Period: Day/Night 16/8 hours
Description: Receptor 11 - LRT Only Sound Levels NOTE: Volumes have been increased by
a factor of 10 due to STAMSON vehicle/hour limits.


Road data, segment # 1: LRT Only (day/night)
--------------------------------------------
Car traffic volume  :     0/0     veh/TimePeriod
Medium truck volume :  7540/1440  veh/TimePeriod
Heavy truck volume  :     0/0     veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: LRT Only (day/night)
------------------------------------------
Angle1   Angle2           : -90.00 deg   90.00 deg
Wood depth                :      0       (No woods.)
No of house rows          :      0 / 0
Surface                   :      2       (Reflective ground surface)
Receiver source distance  :  15.00 / 15.00  m
Receiver height           :   1.50 / 5.00   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00



Results segment # 1: LRT Only (day)
-----------------------------------

Source height = 0.50 m

ROAD (0.00 + 72.39 + 0.00) = 72.39 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  72.39   0.00   0.00   0.00   0.00   0.00   0.00  72.39
----------------------------------------------------------------------------

Segment Leq : 72.39 dBA

Total Leq All Segments: 72.39 dBA



Results segment # 1: LRT Only (night)
-------------------------------------

Source height = 0.50 m

ROAD (0.00 + 68.21 + 0.00) = 68.21 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  68.21   0.00   0.00   0.00   0.00   0.00   0.00  68.21
----------------------------------------------------------------------------

Segment Leq : 68.21 dBA

Total Leq All Segments: 68.21 dBA
```

```
TOTAL Leq FROM ALL SOURCES (DAY): 72.39
                         (NIGHT): 68.21




STAMSON 5.0        NORMAL REPORT        Date: 03-01-2017 08:36:10
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: np.te                Time Period: Day/Night 16/8 hours
Description: Receptor 11 - No Project Roadway Sound Levels


Road data, segment # 1: MainatDalewo (day/night)
------------------------------------------------
Car traffic volume  : 38939/4327  veh/TimePeriod
Medium truck volume :  1219/135   veh/TimePeriod
Heavy truck volume  :   925/103   veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: MainatDalewo (day/night)
----------------------------------------------
Angle1   Angle2           : -90.00 deg   90.00 deg
Wood depth                :      0       (No woods.)
No of house rows          :      0 / 0
Surface                   :      2       (Reflective ground surface)
Receiver source distance  :  27.00 / 27.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00


Results segment # 1: MainatDalewo (day)
---------------------------------------

Source height = 1.22 m

ROAD (0.00 + 69.77 + 0.00) = 69.77 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  72.32   0.00  -2.55   0.00   0.00   0.00   0.00  69.77
----------------------------------------------------------------------------

Segment Leq : 69.77 dBA

Total Leq All Segments: 69.77 dBA


Results segment # 1: MainatDalewo (night)
-----------------------------------------

Source height = 1.23 m

ROAD (0.00 + 63.24 + 0.00) = 63.24 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
```

```
-----------------------------------------------------------------------------
   -90     90   0.00  65.79   0.00  -2.55   0.00   0.00   0.00   0.00  63.24
-----------------------------------------------------------------------------

Segment Leq : 63.24 dBA

Total Leq All Segments: 63.24 dBA



TOTAL Leq FROM ALL SOURCES (DAY): 69.77
                         (NIGHT): 63.24



STAMSON 5.0        NORMAL REPORT        Date: 03-01-2017 08:36:44
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: wp.te                Time Period: Day/Night 16/8 hours
Description: Receptor 11 - With Project Roadway Sound Levels


Road data, segment # 1: MainatDalewo (day/night)
------------------------------------------------
Car traffic volume  : 35297/3922  veh/TimePeriod
Medium truck volume :  1257/140   veh/TimePeriod
Heavy truck volume  :   919/102   veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: MainatDalewo (day/night)
----------------------------------------------
Angle1   Angle2           : -90.00 deg   90.00 deg
Wood depth                :      0       (No woods.)
No of house rows          :      0 / 0
Surface                   :      2       (Reflective ground surface)
Receiver source distance  :  30.00 / 30.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00


Results segment # 1: MainatDalewo (day)
---------------------------------------

Source height = 1.25 m

ROAD (0.00 + 69.16 + 0.00) = 69.16 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
-----------------------------------------------------------------------------
   -90     90   0.00  72.17   0.00  -3.01   0.00   0.00   0.00   0.00  69.16
-----------------------------------------------------------------------------

Segment Leq : 69.16 dBA

Total Leq All Segments: 69.16 dBA
```

```
Results segment # 1: MainatDalewo (night)
-----------------------------------------

Source height = 1.25 m

ROAD (0.00 + 62.63 + 0.00) = 62.63 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  65.64   0.00  -3.01   0.00   0.00   0.00   0.00  62.63
----------------------------------------------------------------------------

Segment Leq : 62.63 dBA

Total Leq All Segments: 62.63 dBA




TOTAL Leq FROM ALL SOURCES (DAY): 69.16
                         (NIGHT): 62.63
```

APPENDIX C: REFERENCES

1. Ministry of the Environment. *Environmental Noise Guideline, Stationary and Transportation Sources – Approval and Planning*. Publication NPC-300. August 2013.

2. MOEE/GO Transit. *Draft Protocol for Noise and Vibration Assessment*. Draft #9, January 1995.

3. J.E. Coulter Associates Limited. *Noise and Vibration Impact Assessment, Proposed Light Rail Transit System, City of Hamilton*. October 4, 2011.

4. Federal Transit Administration. *Transit Noise and Vibration Impact Assessment*. FTA-VA-90-1003-06, May 2006.

5. Ministry of the Environment. Model Municipal Noise Control By-Law, Final Report. August 1978.

6. Model Municipal Noise Control By-Law, Final Report, Publication NPC-115, Construction Equipment, August 1978

7. US Department of Transportation. Federal Highway Administration. *Roadway Construction Noise Model User's Guide*. January 2006.

8. Commonwealth of Massachusetts. *Construction Noise Control Specification.* 721.560 – Big Dig Noise Control Law (Big Dig Spec 721.560)

9. Colin G. Gordon. *Generic Vibration Criteria for Vibration-Sensitive Equipment*. SPIE Conference. November 1999.