NOISE AND VIBRATION IMPACT ASSESSMENT
STAGE 2 ION: LIGHT RAIL TRANSIT, FROM KITCHENER TO CAMBRIDGE
REGION OF WATERLOO, ONTARIO

FOR

WSP

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1.0 INTRODUCTION AND BACKGROUND

The Regional Municipality of Waterloo (the Region or Waterloo Region) is undertaking a Transit Project Assessment (TPA) for the proposed extension of their ION Light Rail Transit (LRT) System from the current southern terminus at Fairway Station in Kitchener to Downtown Cambridge.

The first stage of the ION light rail transit system, extending from Conestoga Station to Fairway Station, has been completed in the Cities of Waterloo and Kitchener. This assessment addresses the Stage 2 of the ION system, which extends LRT to Downtown Cambridge.

J.E. COULTER ASSOCIATES LIMITED was retained by WSP Canada Inc. to conduct a noise and vibration impact assessment of the proposed Stage 2 ION Light Rail Transit route as part of the Transit Project Assessment process. Figure 1 in Appendix A provides an overall plan of the alignment.

1.1 Description of Project

In June 2011, the Region of Waterloo Council approved the implementation of a staged Light Rail Transit (LRT) system from Waterloo to Cambridge to link the major urban centres of the City of Cambridge, City of Kitchener and City of Waterloo. The Region is encouraging development and growth within existing urban areas and by focusing development and investment in the core, Waterloo Region will build up, instead of out: limiting urban sprawl and protecting the environment.

Stage 1 ION includes LRT from Kitchener to Cambridge, which was launched in June 2019, as well as Bus Rapid Transit (BRT) from Cambridge to Kitchener which commenced in September 2015. Stage 2 ION will replace the BRT route from Cambridge to Kitchener with LRT, creating a continuous and seamless LRT route across the region’s three urban centres. After evaluating and analysing many route options with many opportunities for public input, the Project Team presented a preferred route for Regional Council’s consideration. This route was endorsed by the Regional Council as the “Preferred Route for Stage 2 ION” in June 2019.

ION encourages better use of land and efficient use of existing services and infrastructure. More compact, intensified development means it’s easier and more cost-effective for the Region and the Cities to provide services such as water, sewer, waste and emergency services to residents. ION offers residents transportation choice. The Region of Waterloo Rapid Transit (RT) is consistent with adopted Provincial and Regional planning policies and legislation that support the need for more sustainable development and alternative modes of transportation.

1.2 Study Area

For potential noise and vibration impacts, the study area is limited to 100 m and 50 m, respectively to either side of the proposed Stage 2 ION corridor. The study area encompasses the most critical receptors along the corridor and would represent the worst-case in terms of potential noise and vibration impacts. Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6 in Appendix A provide the 50 m and 100 m study area zones. Beyond these zones, the LRT will not generate significant noise and vibration levels that have the potential to exceed the limits. Further, most representative points of reception (worst-case impacts) are within 50m and 100m, respectively.

2.0 NOISE AND VIBRATION IMPACT CRITERIA

The noise and vibration impact assessment criteria used to evaluate the effects of Stage 2 ION are based on a set of draft protocols developed through the combined efforts of the Ministry of the Environment, Conservation, and Parks (MECP) 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 MOEE (now MECP) for other rapid transit projects within Ontario. Elements of the United States' Federal Transit Administration's Noise and Vibration Impact Assessment guidelines have also been used on recent transit projects.

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 MOEE/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 future horizon year beyond the project's completion. For this analysis, sound levels without Stage 2 ION in 2031 are compared to the sound levels with Stage 2 ION 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 (decibels), 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 traction power substations. No new off-street bus terminals are proposed, though on-street bus stops will be added in areas. Off-street bus terminals and traction power substations are treated as stationary noise sources and are evaluated based on the Ministry of the Environment'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 dBA daytime and 45 dBA 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*.

2.3 Vibration Impact Criteria

The vibration impact criteria attempt to address two potential impacts from vibration generated by Stage 2 ION:

- First, the criteria document considers 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 0.1 mm/s rms (root-mean-square) velocity. If absolute vibration levels are expected to exceed this limit, mitigation methods need to be determined during the future design phase to meet the limit 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 0.1 mm/s instead of 0.14 mm/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 (2018), 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 7.5 m while traveling at 40 km/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. This is a slightly conservative approach as it assumes less noise enters through 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 corridor. 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. Once 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

The Stage 2 ION system features a variety of different facilities throughout its route. The following sections outline the aspects of this project that have been evaluated within the scope of this noise and vibration impact assessment.

3.1 Light Rail Vehicles and Vehicular Traffic

The traffic volumes used in the assessment consider the reduction in traffic resulting from a mode shift from cars to buses and light rail vehicles.

The vibration assessment applies only to the Stage 2 ION route. The potential vibration from switches, double-crossovers and double-ended pocket track is considered generally, although the specific locations are not yet known.

3.2 Power Substations

The preliminary design calls for a total of 13 traction power substations (TPSS) along the route These TPSS have been considered in the assessment of noise and vibration.

3.3 Construction

The noise and vibration impact that results from the anticipated construction methods required to build the Stage 2 ION system has also been examined. This will include the installation of tracks, the construction of ancillary facilities, road widening, and any new bridges to accommodate the LRT. At the TPA stage, typical construction means and methods are assumed. This report will serve to reiterate the basic construction noise and vibration guidelines, provide recommendations to mitigate construction noise and vibration impacts, and flag potential issues with the anticipated construction methods.

As noted above, the noise and vibration assessment addresses all the proposed project components but does not analyse in detail the noise and vibration impacts from special trackwork or construction as the details around such components have not been developed.

Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6 in Appendix A provide the location of key project features in relation to the alignment.

4.0 OPERATIONAL LRV NOISE ASSESSMENT

The proposed Stage 2 ION system runs through a variety of different land uses. A discussion of the land uses located along the entire route is in order, as the system does not run along a single roadway. In some areas, the Stage 2 ION route shares or occupies existing rail rights-of-way.

4.1 Description of Corridor

Table 1 outlines the various stretches along the Stage 2 ION corridor, the nature of adjacent land uses, and the track conditions along those stretches.

Table 1: Corridor Description

From	To	Length (m)	Roadway/Railway Name	Track Position	Track[1] Type	Land Uses	Distance to Closest Sensitive Receptor (m)	Points of Reception
Fairview Park Mall	Hidden Valley Road	600	-	Dedicated Alignment	C	Commercial	-	-
Fairway Road	Deer Ridge Drive	3000	Highway 8 (adjacent)	Dedicated Alignment	C	Residential and Park Land	25	1,2,3
Deer Ridge Drive	Sportsworld Drive	500	King Street East	Centre Running	C	Commercial	-	-
Sportsworld Drive	Highway 401	1300	King Street East	Centre Running	C	Commercial and Residential	30	4-8
Highway 401	Fountain Street South	700	Shantz Hill Road	Centre Running	C	Residential and Commercial	17	9-11
Fountain Street South	Eagle Street North	600	-	Dedicated Alignment	TB	Residential, Commercial and Industrial	9	12,13
King Street East	Hedley Street	700	Eagle Street North	North Side of Road	C	Residential and Commercial	18	14-18
Hedley Street	Speedsville Road	900	CP Rail unused railway spur	Dedicated Alignment	TB	Residential and Commercial	18	14-18
Speedsville Road	North of Eagle Street	2000	CP Rail unused railway spur	Dedicated Alignment	TB	Industrial and Some Residential	20	19
North of Eagle Street	Hespeler	400	CN Spur Railway	South of Railway Tracks	TB	Industrial and Commercial	-	-
Sheldon Drive	Brooklyne Road	3400	Hespeler Road	Centre Running	C	Residential and Commercial	23	20-25
Hespeler Road	Samuelson Street	1000	CP Railway and Former Great Western Railway	East of Railway Tracks	TB	Residential and Some Industrial	15	26,27
Samuelson Street	Main Street	1300	-	Dedicated Alignment	TB	Residential and Some Industrial	10	28 -35
Main Street	Ainslie Street	350	Wellington Street	Centre Running	C	Residential and Commercial	13	36,37
Wellington Street	Water Street South	200	Bruce Street	Centre Running	C	Residential and Commercial	18	38

1. TB = Tie-on-ballast
C = Concrete Track Base (Embedded or direct fixation)

4.2 Selection of Sensitive Receivers

Based on the Stage 2 ION alignment as endorsed by Regional Council, traffic volumes, and receptor characteristics, 38 representative Points of Reception (POR) have been identified. Table 2 generally identifies the locations of these sensitive receptors. These receptors have been chosen because they are the most sensitive to the noise from the proposed Stage 2 ION route. Generally, receptors at intersections and adjacent to high traffic roads are less sensitive as the existing sound levels are higher than areas with lower road traffic. Hence, the greatest impact, if any, will be in areas with lower existing (or future "no project") sound levels. The specifics of each of these receptors are summarized in Table 2. Each of these receptors will help provide a representative indication of the change in sound levels resulting from the introduction of the Stage 2 ION system. Figure 7 to Figure 34 show the locations of the PORs.

In areas dominated by hard, reflective ground, receptors on the lower floors will generally be at least as sensitive to increases in adjacent road traffic as receptors on the upper floors. As the elevation of the receptor increases, the contribution to the overall noise from other roadways also increases. Only first- and second-storey levels are evaluated as an indication of the worst-case situation. As hard ground is assumed, the exact height of the receptor does not affect the predicted sound levels in STAMSON unless barriers are being reviewed. The appropriate height of receptors (1.5m above grade for daytime) is used for the evaluation of noise barriers.

Table 2: Points of Reception

POR	Type	Dominant Noise Source
1	Residential House	Highway 8
2	Residential House	Highway 8
3	Residential House	King Street East
4	Residential House	King Street East
5	Residential House	King Street East
6	Residential House	King Street East
7	Residential House	King Street East
8	Motel	King Street East
9	Residential House	Shantz Hill Road
10	Residential House	Shantz Hill Road
11	Residential House	Shantz Hill Road
12	Residential House	King Street East
13	Residential House	King Street East
14	High-Rise Residential	Eagle Street North
15	Church	Eagle Street North
16	Mid-Rise Residential	Eagle Street North and Hwy. 401
17	Low-Rise Residential	Hwy. 401
18	Residential House	Speedsville Road
19	Residential House	Eagle Street North
20	Motel	Hespeler Road
21	Low-Rise Residential	Hespeler Road
22	Motel	Hespeler Road
23	Residential House	Hespeler Road

POR	Type	Dominant Noise Source
24	Church	Hespeler Road
25	Residential House	Hespeler Road
26	Residential House	Hespeler Road
27	Residential House	Dundas Street North
28	Residential House	Dundas Street North
29	Residential House	Dundas Street North
30	Residential House	Dundas Street North
31	Residential House	Beverly Street
32	Residential House	Beverly Street
33	Residential House	Beverly Street
34	Residential House	Beverly Street
35	Church	Main Street
36	Townhouses	Wellington Street
37	Townhouses	Wellington Street
38	Residential House	Bruce Street

The above receptors are spread out along the proposed alignment and represent the worst-case noise and vibration impacts. Development and intensification along the corridor may occur that will introduce new receptors. Generally, new development is less likely to be affected by noise and vibration by the future LRT due to increased setback requirements, modern construction means and methods, or the use of intervening non-sensitive uses such as retail on the ground floor. In any case, the Region and the municipalities will require new developments to include the future LRT as a noise and vibration source. In addition, developments proposed between the TPAP and a future design phase can be considered during that future design phase, as is typical for many projects with longer gaps between the TPAP and construction phase.

4.3 Light Rail Vehicle Noise Characteristics

The noise impact assessments completed for some of the Toronto Transit Commission's Transit City LRT routes and the Region's Stage 1 ION system used LRV sound levels approximately 82 dB at a distance of 7.5 m for a comparable vehicle travelling at 40 km/hr. on concrete. These were specifications only and not actual sound levels. Recently measured data from the Jerusalem LRT indicate maximum sound levels of 75 dBA at 7.5 m for a 35 m long, two-motor bogie vehicle travelling at 40 km/hr. Bombardier's own modeling indicated 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 71 dB at 15 m while travelling at 40 km/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. This approach is consistent with that used for the noise assessment of the Stage 1 ION project.

Additional passby measurements were completed of the operational sound levels of Stage 1 ION on both the tie-on-ballast sections and the embedded rail sections. The measurements were completed on January 30, 2020 between 11 am and 4 pm. The weather during the measurements was cloudy with an average temperature of approximately -2C and humidity of

80%. The detailed weather conditions are provided in Appendix B. These measurements are summarized in Table 3.

Table 3: Sound Measurements of Stage 1 LRT Vehicle

Track Type	Setback (m)	Speed (km/h)	Maximum Sound Pressure Level (dBA)	Sound Exposure Level
Ballast	7.5	35	70	75
Embedded	7.5	35	72	77

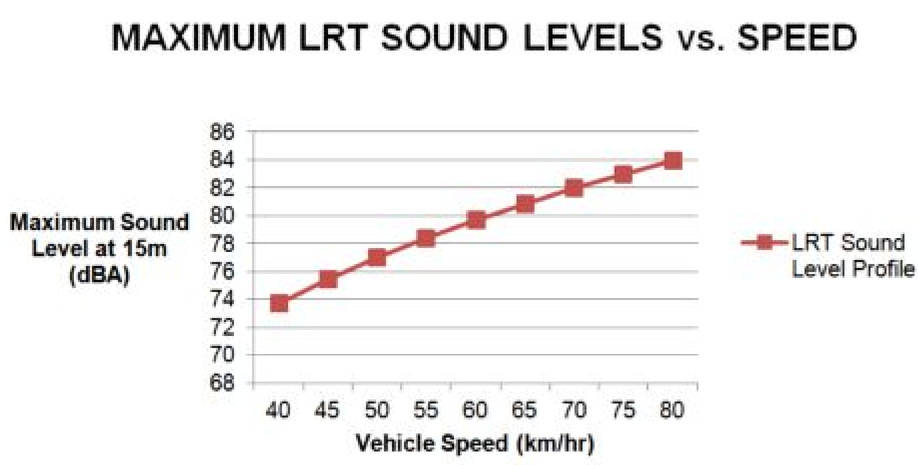
As seen, the actual sound levels measured are lower than the specification sound levels and lower than the maximum sound levels used during the Stage 1 ION assessment. Conservative sound levels will be used again for this assessment to be consistent with the Stage 1 ION approach.

Modelling the vehicles as medium trucks also allows a convenient method to model different speeds. For example, in segments where Stage 2 ION operates on a dedicated alignment or adjacent to a railway corridor, the LRVs may move more quickly than when on the roadway, even with a dedicated median corridor. Within the ORNAMENT procedure, the profile would follow this equation:

$$Lmax = 33.9\log(S)+19.4^{*}$$

* Where Lmax is the mean or average of the maximum or peak sound levels in decibels (dBA) and S represents the speed of the vehicle in kilometres per hour.

The above equation results in the following sound level vs. speed profile.



During the future design stage, the Region will complete an updated noise impact assessment based on final equipment specifications, final alignment, and more detailed topographical information. It is assumed the ORNAMENT procedure and the sound level criteria discussed in this report will still be applicable during the future design stage.

4.4 Traffic Volumes

Traffic volumes along the route were prepared from forecasts developed by WSP using the Region's traffic demand model. Two scenarios were evaluated and compared: the future "with project" sound levels are compared with the future "no project" sound levels. Table 4 provides the "no project" traffic volumes used in the assessment. Table 5 provides the "with project" sound levels used in the assessment. The LRV volumes (i.e. the headways and schedule) are assumed to be the same as for Stage 1 ION.

Table 4: Future (2031) No Project Traffic Volumes

Section	POR	Daytime			Nighttime		
		Cars	Medium Trucks	Heavy Trucks	Cars	Medium Trucks	Heavy Trucks
Highway 8 (King Street E. and Fairway Road)	1, 2 and 3	90,387	2,379	2,379	22,597	595	595
King Street East (Highway 8 and Sportsworld Crossing)	4	32,137	2,102	2102	3571	234	234
King Street East (Sportsworld Crossing and Sportsworld Drive	5 and 6	32,894	744	744	3655	83	83
King Street East (Sportsworld Drive and Tu Lane Street	7 and 8	32,803	768	768	3645	85	85
Shantz Hill Road and Preston Parkway	9	22,585	304	304	2285	23	23
Shantz Hill Road and Preston Parkway (South Leg)	10	20,059	184	184	2229	20	20
Fountain Street South and Shantz Hill Road	11	15,069	51	51	1674	6	6
King Street East and Eagle Street South (West Leg)	12 and 13	22,782	170	170	2531	19	19
King Street East and Eagle Street South (North Leg)	14, 15, 16 and 17	8,618	172	172	958	19	19
Highway 401	15, 16 and 17	114,518	6,362	6,362	28,629	1591	1591
Eagle Street and Speedsville Road	18	25,488	120	120	2,832	13	13
Eagle Street and Industrial Road (West Leg)	19	14,306	669	669	1,590	74	74
Hespeler Road and Avenue Road (North Leg)	20 - 25	52,554	554	554	5,839	62	62
Hespeler Road and Brooklyne Road (South Leg)	26 and 27	36,868	390	390	4,096	43	43
Dundas Street North and Beverly Street (West Leg)	28 and 29	22,715	342	342	2,524	38	38
Dundas Street North and Beverly Street (South Leg)	30-34	9,999	403	403	1,111	45	45
Main Street and Wellington Street (East Leg)	35	4,983	55	55	554	6	6
Main Street and Wellington Street (South Leg)	36 and 37	6,202	231	231	689	26	26
Ainslie Street South and Bruce Street	38	4,671	57	57	519	6	6

Table 5: Future (2031) with Project Traffic Volumes

Section	POR	Daytime				Nighttime			
		Cars	Medium Trucks	Heavy Trucks	LRT	Cars	Medium Trucks	Heavy Trucks	LRT
Highway 8 (King Street E. and Fairway Road)	1, 2 and 3	90,387	2,379	2,379	244	22,597	595	595	32
King Street East (Highway 8 and Sportsworld Crossing)	4	31,261	2,119	2,119	244	3,473	235	235	32
King Street East (Sportsworld Crossing and Sportsworld Drive)	5 and 6	32,313	780	780	244	3,590	87	87	32
King Street East (Sportsworld Drive and Tu Lane Street)	7 and 8	32,241	802	802	244	3,582	89	89	32
Shantz Hill Road and Preston Parkway (North Leg)	9	22,330	303	303	244	2,271	23	23	32
Shantz Hill Road and Preston Parkway (South Leg)	10	19,824	183	183	244	2,203	20	20	32
Fountain Street South and Shantz Hill Rd	11	14,943	52	52	244	1,660	6	6	32
King Street East and Eagle Street South (West Leg)	12 and 13	22,596	171	171	244	2,511	19	19	32
King Street East and Eagle Street South (North Leg)	14, 15, 16 and 17	8,335	174	174	244	1,847	19	19	32
Highway 401	15, 16 and 17	114,518	6,362	6,362	244	28,629	1591	1591	32
Eagle Street and Speedsville Road	18	25,181	121	121	244	2,798	13	13	32
Eagle Street and Industrial Road (West Leg)	19	13,950	694	694	244	1,550	77	77	32
Hespeler Road and Avenue Road (North Leg)	20 to 25	49,484	532	532	244	5,498	59	59	32
Hespeler Road and Brooklyne Road (South Leg)	26 and 27	35,235	381	381	244	3,915	42	42	32
Dundas Street North and Beverly Street (West Leg)	28 and 29	21,752	358	358	244	2,417	40	40	32
Dundas Street North and Beverly Street (South Leg)	30 to 34	9,747	394	394	244	1,083	44	44	32
Main Street and Wellington Street (East Leg)	35	4,983	55	55	244	554	6	6	32
Main Street and Wellington Street (South Leg)	36 and 37	6,098	263	263	244	678	29	29	32
Ainslie Street South and Bruce Street	38	4,582	62	62	244	509	7	7	32

4.5 LRV Noise Assessment Results

Table 6 summarizes the results of the noise assessment.

Table 6: Stage 2 ION Sound Levels and Expected Impacts

POR	No Project Sound Levels (dB)		With Project Sound Levels (dB)						Impact (dB)	
			Daytime ($L_{eq,16hr}$)			Nighttime ($L_{eq,8hr}$)				
	Daytime ($L_{eq,16hr}$)	Nighttime ($L_{eq,8hr}$)	Traffic Only	LRT Only	Combined	Traffic Only	LRT Only	Combined	Daytime	Nighttime
1	55	50	50	48	52	46	43	48	0	0
2	64	61	64	53	64	61	48	61	0	0
3	63	60	63	53	63	60	48	60	0	0
4	62	56	61	46	61	56	40	56	-1	0
5	65	59	65	46	65	59	40	59	0	0
6	68	61	68	55	68	61	49	61	0	0
7	68	61	68	55	68	61	49	61	0	0
8	68	62	68	55	68	62	49	62	0	0
9	67	61	67	56	67	60	51	61	0	0
10	66	60	66	58	67	60	52	61	1	1
11	64	57	64	54	64	57	49	58	0	1
12	55	50	48	58	58	42	52	52	3	2
13	55	50	53	61	62	48	55	56	**7**	**6**
14	61	55	60	55	61	54	49	55	0	0
15	55	50	49	53	54	42	48	49	0	0
16	55	50	50	56	57	45	50	51	2	1
17	55	50	51	55	56	46	49	51	1	1
18	61	55	61	53	62	55	48	56	1	1
19	55	50	53	55	57	53	49	54	2	4
20	67	60	67	52	67	60	46	60	0	0
21	70	64	70	55	70	64	49	64	0	0
22	70	62	69	54	69	63	48	63	-1	1
23	70	62	69	54	69	63	48	63	-1	1
24	70	63	69	54	69	63	48	63	-1	0
25	70	63	70	55	70	63	49	63	0	0
26	57	56	57	57	60	56	51	57	3	1
27	55	50	48	51	53	44	45	48	0	0
28	55	50	49	51	53	46	45	49	0	0
29	56	51	56	56	59	51	50	54	3	3
30	59	54	59	52	60	54	48	55	1	1
31	55	50	52	55	57	46	50	51	2	1
32	55	50	51	55	56	45	49	50	1	0
33	55	50	50	60	60	44	52	53	**5**	3
34	55	50	51	54	56	45	48	50	1	0
35	55	50	53	57	58	46	51	52	3	2
36	66	59	65	59	66	58	53	59	0	0
37	66	59	64	58	65	57	52	58	-1	-1
38	64	57	61	58	63	54	52	56	-1	-1

As shown in Table 6, the LRT corridor does not generate a notable increase in sound levels when introduced along busy roadways or railways with regular vehicle traffic. Where Stage 2 ION operates in abandoned railway corridors or as it crosses through residential areas with minimal road traffic, the sound level increases range up to a maximum of 4 dB. Due to the close proximity of the Stage 2 ION LRT and low ambient sound levels, increases of 7 dB and 6 dB are expected during the daytime and nighttime period, respectively, at Receptor 13. At Receptor 33, on Kerr Street in Downtown Cambridge, the increase in sound levels during the daytime (at the OLA) is expected to be 5 dB due to the proximity of the Stage 2 ION LRT corridor.

4.5 Wheel Squeal and Special Trackwork

The LRV-only sound levels will be higher in areas with tight curves or special trackwork (crossovers, pocket track, etc.). The special trackwork locations will be detailed during the next phase of the project's design, and will be avoided in residential areas where possible. If necessary, track design can be adjusted to minimize the additional noise generated by special trackwork. Short noise barriers, built close to the tracks, can also be very effective in areas with low-rise residential. This item will be reviewed further during a future design phase.

For curves, rail and/or wheel lubrication will be employed or wheel-damping technologies will be employed. Measurements of existing Bombardier Flexity Freedom vehicles on curves indicated sound levels of approximately 82 dBA maximum at 7.5 m. On tight curves (with radii of ~25m), vehicles travelled at a speed of approximately 15 km/h. The sound exposure level was measured to be approximately 90 dBA for a given passby. On curves without control for wheel squeal, the LRT-only sound levels can be expected to be higher by 13 dB overall.

According to the US Federal Transit Administration's Transit Noise and Vibration Impact Assessment Guidelines (2018), the introduction of resiliently mounted and/or constrained damping of the wheels reduces this sound by as much as 20 dB. In some cases, proper damping of the wheels can completely eliminate the increase in sound levels as a result of wheel squeal. Proper track maintenance and rail lubrication (operational factors) can also reduce this sound level, with varying levels of noise reduction.

It is assumed wheel squeal control measures will be implemented on this project to minimize the impact of such issues in residential areas.

4.6 LRV Noise Control Recommendations

In standard tangent sections, noise impacts as a result of the introduction of Stage 2 ION are not expected. In some areas, increases in sound levels of up to 4 dB are expected, below the 5 dBA threshold requiring a review of mitigation measures.

Sound level increases of 5 dB or more have been predicted at 2 locations: Receptor 13 and Receptor 33.

At Receptor 13, the predicted increase in sound levels is 7 dB during the daytime and 6 dB during the nighttime. As a result, noise mitigation measures are reviewed for their economic, administrative, and technical feasibility. A 4.3m high noise barrier along the property line is recommended to meet the target sound levels of 55 dBA $L_{eq,16hr}$ during the daytime at the OLA and 50 dBA $L_{eq,8hr}$ during the nighttime at the 2nd floor windows. The barrier would run for a length of approximately 65 m, as shown in Figure 35 in Appendix A.

At Receptor 33, the predicted increase in sound levels is 5 dB during the daytime. As a result, noise mitigation measures should be considered here. As the excess is during the daytime, and there are no windows directly facing the LRT, a 2.0 m high noise barrier along the property line would be sufficient. The barrier would run for a length of approximately 55 m, as shown in Figure 36 in Appendix A.

In some areas with relatively low ambient sound levels, the actual increase in sound levels is expected to be significant. While not required under the applicable draft protocols, the Region may review such areas for noise control measures during a future design stage.

LRV wheel squeal noise control should be implemented in the form of rail and/or wheel lubricators and/or wheel damping.

Special trackwork in residential areas will be avoided to the extent possible. In any case, once locations are finalized, such areas should be assessed in more detail during the future design stage.

5.0 TRACTION POWER SUBSTATION NOISE ASSESSMENT

As noted, the Stage 2 ION LRT does not include new or modified off-street bus terminals. The only stationary sources considered as part of the Stage 2 ION LRT are the traction power substations (TPSS).

There are a total of 13 TPSS. It is assumed the substations will be designed similar to those on Stage 1 ION. In many cases, the substations are located in non-residential areas. Because the substations are located in enclosures, the dominant noise sources are often the cooling equipment for the TPSS. The transformer substations as observed in operation are not tonal.

Table 7 provides the recommended total sound power level needed at each of the TPSS in order to meet the minimum nighttime exclusion criteria at each of the nearest sensitive receptors. Note that the closest point of the façade was used as the nighttime period was assessed. This is a slightly conservative approach as the actual quietest ambient hourly sound levels may be higher than those used in this analysis. Additionally, the nighttime noise may be slightly lower due to reduced cooling requirements. Where there are no nearby receptors, the minimum criteria at 50 m are used. This is a conservative approach that would allow future development near the TPSS locations without any onerous modifications to the systems. Note that the criteria below apply to the total cumulative noise from the TPSS, including any transformer noise.

Table 7: Recommended TPSS Sound Power Levels

TPSS	Distance to Nearest Receptor (m)	Sound Power Level (dBA)
1	175	87
2	85	87
3	115	87
4	170	87
5	150	87
6	5	67

TPSS	Distance to Nearest Receptor (m)	Sound Power Level (dBA)
7	65	87
8	75	87
9	105	87
10	105	87
11	28	82
12	34	84
13	30	82

The TPSS locations that are less than 50m away from receptors are shown in Figure 42, Figure 47, Figure 48, and Figure 49. At all other TPSS, the receptors are located more than 50m away. These TPSS are shown in Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, Figure 43, Figure 44, Figure 45, and Figure 46.

A more detailed assessment of the TPSS should be completed during a subsequent design phase, when more information is known and when their locations are finalized. These assessments should include tonality corrections, as applicable. Should the selected TPSS be tonal, a 5 dB penalty to that noise would need to be applied, in accordance with the requirements from *NPC-300* and *NPC-104*.

6.0 OPERATIONAL LRV VIBRATION ASSESSMENT

The vibration impact assessment is based on a prediction of future vibration levels due to the operation of Stage 2 ION in the rapid transit corridor. The closest sensitive receptors to the corridor are considered but vibration impacts will be negligible beyond 50 m from tangent track. This setback distance is shown in Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6 in Appendix A. As outlined in the criteria section, the upper limit for vibration levels is 0.10 mm/s rms, based on the MOEE/TTC Draft Protocol for the Scarborough Rapid Transit Extension. A limit of 35 dBA in quiet sleeping quarters has been suggested for vibration-induced noise, as per the Federal Transit Administration (FTA) guidelines.

This analysis will evaluate primarily the effects from tangent track. Special trackwork, such as switches, crossovers, and double-ended pocket track will be addressed during the future design phase as their locations have not yet been finalized. As noted in the noise impact assessment, efforts will be made to locate these track features in less sensitive areas such as commercial zones or where there is greater setback between the track and nearby sensitive receptors

6.1 Light Rail Vibration Isolation Systems

There are several forms of vibration isolation that can be used for light rail systems running on both embedded-in-concrete and tie-on ballast.

For concrete rail systems the typical vibration isolation systems are:

- Rubber-embedded or encapsulated track (also referred to colloquially as the rubber boot). The rubber material reduces the vibration transmission into the concrete and subsequently into the adjacent structures. There are various embedded rail systems with differing properties.

- Resilient track fastening systems such as resilient tie plates for when direct fixation track is used. These systems introduce a rubber pad between the track fixation plate and the concrete slab.
- Floating slab system. This system floats on a concrete rail bed mounted on rubber isolators, reducing the transmission of vibration from the concrete into the soil and adjacent structures.

For track mounted on tie-on ballast, the typical vibration isolation method is a ballast mat. Ballast mats are placed below the stone ballast and serve to reduce the vibration levels transmitted into the soil. As with embedded rail, there are varying levels of ballast mats with differing properties. Resilient tie plates are also a form of vibration control, although their benefit can be marginal depending on the properties of the underlying structure and/or soil. Resilient tie plates serve to reduce the vibration transmitted into the ballast and subsequently into the soil and adjacent structures. Resilient tie plates or fasteners are also used in direct fixation track systems. Such systems can be more effective at controlling vibration levels given the stiff concrete base.

Table 8 below summarizes the different levels of vibration isolation and their expected performance.

Table 8: Vibration Isolation Description

Track Type	Level	Assumed Reduction (dB)	Description
Concrete	0	0	Embedded, stiff rubber, mostly for electrical insulation or direct fixation drack
	1	5	Embedded, softer rubber or resilient fixation method
	2	10	Embedded, more resilient than Level 1; thicker material or thicker resilient fixation method.
	3	15	Floating slab is most common, though other methods may provide the needed reduction
Ballast	0	0	Standard tie-on-ballast
	1	1 to 2	Resilient tie plates
	2	5 +	Ballast mats

6.2 Predicted Vibration Levels

Both the ground-borne vibration (perceptible vibration) and the vibration-induced noise resulting from the proposed Stage 2 ION system have been estimated. The perceptible vibration levels are evaluated based on the MOEE/TTC Protocol's guideline limit of 0.10 mm/s RMS. The vibration-induced noise from the Stage 2 ION LRT is evaluated based on the FTA guideline level of 35 dBA, wherever the air-borne noise would not dominate the vibration-induced sound.

The predicted vibration levels are based on a speed of 40 km/hr. on concrete track and 50 km/hr on tie-on ballast track.

The vibration assessment carried out for Stage 1 ION in 2011 used measurements of light rail vehicles in operation, and was used for the Stage 2 ION assessment with adjustments for speed and operational characteristics. Table 9 summarizes the measured vibration levels used in the Stage 1 ION assessment.

Table 10 summarizes the expected vibration levels for Stage 2 ION as a result of longer and faster moving vehicles.

Table 9: Measured Vibration Levels in Concrete Track

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

Table 10: Expected LRT Vibration on Concrete Track

Distance from Track Centreline (m)	Vibration Levels (mm/s rms)
5	0.17
10	0.10
15	0.09

Measurements of the Stage 1 ION LRT line in operation were taken in several places. Measurements were conducted on January 30, 2020 between 10 am and 4 pm. Measurements were conducted on the ground at certain setbacks, depending on site-specific conditions. These measurements are summarized in Table 11. In general, the vehicle speeds were approximately 30 km/hr. in areas with embedded rail.

Table 11: Measured Vibration Levels of Current LRT Vehicle in Concrete Track

Distance from Track Centreline (m)	Vibration Levels (mm/s rms)
3	0.23
6	0.14
8	0.08
15	0.05

In general, the predicted vibration levels from the previous assessment and the measured vibration levels after construction seem to correlate well.

Based on these measured vibration levels, residential receivers located beyond 15 m from the nearest track centreline will not require significant vibration control measures. Residential receptors located less than 15 m from the nearest track centreline may require vibration control beyond the standard embedded rail vibration isolation. Detailed vibration testing and analysis, including more detailed field measurements and a review of soil propagation conditions, will be conducted during the next phase of the design to confirm the vibration isolation requirements.

6.3 Vibration-Induced Sound

The indoor sound levels could not be measured. As a result, indoor sound levels are estimated based on the predicted vibration levels above. Table 12 summarizes the sound levels that can be expected in various rooms as a result of vibration-induced noise. It has been generally assumed there is usually one room with window exposure to the Stage 2 ION LRT route, with a second bedroom set back within the building that does not have any window exposure to the route. As per the FTA guidelines, the recommendation for vibration-induced noise in the otherwise quiet bedroom (i.e., back rooms) is 35 dBA.

Table 12 depicts the various vibration-induced sound levels that can be expected under various circumstances. The distances listed are based on the most common setbacks between the track centreline and sensitive receptors along the Stage 2 ION LRT corridor. The air-borne sound level is the sound level that can be expected in the first room with window exposure facing the Stage 2 ION LRT, where the air-borne noise always dominates the vibration-induced noise. Hence, the vibration-induced noise would not be noticeable in rooms with window exposure to the LRT corridor. In back rooms, the air-borne sound levels would generally be very low, as they may not be exposed to any road noise. These areas are the most critical as it is where the vibration-induced noise would be audible.

Table 12: Expected Vibration Induced Sound Levels for Concrete Embedded Track

Distance from Track to Building Foundation	Floor	Room	Air-borne Sound Level from LRT (dBA)	Vibration-Induced Sound Level under Various Isolation Systems (dBA)		
				Level 1 Isolation	Level 2 Isolation	Level 3 Isolation
7 m	1	Front	52	45	40	35
		Back	-	44	39	34
	2	Front	52	40	35	-
		Back	-	39	34	-
12 m	1	Front	50	39	34	-
		Back	-	38	33	-
	2	Front	50	35	-	-
		Back	-	34	-	-

Beyond 24 m, vibration control above the standard Level 1 embedded rail isolation is not expected to be required. For residences between 12 and 24m away from the nearest track, upgraded vibration isolation is required. Unlike the Stage 1 ION LRT route, which ran adjacent to several residences, the Stage 2 ION route stays at least 12m away from most residences. There are a few exceptions as indicated in Table 13. The areas noted in Table 13 in particular may require upgraded vibration isolation, subject to a detailed review during the future design stage. These locations are shown in Figure 50, Figure 51, Figure 52, Figure 53, Figure 54, and Figure 55

Table 13: Buildings within 12m of Nearest Track Centreline

Building Location	Distance to Nearest Track Centreline (m)
231 Queenston Road	7
29 Russ Street	8
3 Avenue Road	8
159 Samuelson Street	8
145 Beverly Street	10
39 Kerr Street	8

7.0 CONSTRUCTION NOISE AND VIBRATION

The impact of construction noise and vibration on nearby sensitive receptors has been reviewed. It should be noted that the specifics of equipment to be used in the construction process and the construction process itself will be developed by the Contractor prior to the start of construction during the future design phase. The focus of the construction noise and vibration impact assessment as part of this study is to assess typical construction means and methods for projects of this type and develop a representative guideline to be further refined and expanded when more information becomes available during the future design phase. As the project is quite extensive, consideration is given not only to structural effects of construction noise and vibration, but also to community annoyance.

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.

7.2 General Construction Requirements

Provincial and municipal guidelines provide basic restrictions and recommendations with regard to construction noise and vibration. The City of Cambridge and City of Kitchener enforce noise bylaws that prescribe 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 Kitchener, Municipal Code Chapter 450, Noise, February 2011
3. Corporation of the City of Cambridge, By-law Number 32-04, passed February 9, 2004
4. *NPC-115 Construction Equipment*
5. *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, which may be further considered for application during the future design phase. The sound level limits from such equipment are summarized in Table 14.

Table 14: Construction Equipment Sound Level Restrictions

Equipment Description	Sound Level Limit (dBA, L_{max} at 15 m)	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

Equipment Description	Sound Level Limit (dBA, L_{max} at 15 m)	Source of Limit
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
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

Equipment Description	Sound Level Limit (dBA, L_{max} at 15 m)	Source of Limit
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
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

The noise bylaws are qualitative and do not prescribe a maximum sound level at the receptors during construction. Nuisance is controlled by placing restrictions on the hours of operation for 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 some 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 Kitchener and City of Cambridge do not provide limits on vibration levels similar to those stipulated by the City of Toronto in By-law 514-2008. These limits are provided in Table 15.

Table 15: 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 as shown in Table 16.

Table 16: 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 the contractor building the Stage 2 ION 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 construction of Stage 1 ION and 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 construction activity will encompass a relatively long corridor; however, the impact to a specific area will be comparatively short, as construction will generally progress from one area to the next. Intersections and areas with ION stations may be longer in construction duration.

The construction of the Stage 2 ION LRT guideway on bridges over railways and rivers, including associated elevated sections, may see some atypical equipment such as pile drivers. In such cases, the use of vibratory or sonic pile drivers is recommended.

It is recommended that 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 specific mitigation measures to help control the noise and vibration impacts during construction.

Construction noise and vibration mitigation measures may 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). 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.
3. Localized noise barriers such as around stationary equipment, staging areas, or long-term work areas.
4. The use of broadband back-up alarms in lieu of tonal alarms, especially for nighttime construction.
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.

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

1. Construction equipment must adhere to the requirements in *NPC-115*.
2. Additional construction equipment limits within the FTA, FHWA, and Boston Big Dig By-law may be further considered for application during the future design phase as a best practice, though there are no current Provincial or Municipal requirements to do so. The sound level limits from such equipment are summarized in Table 14.
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 (rebar 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. Conduct active briefing and review of contractors' practices and operations, to ensure they continue to adhere to the requirements.

8.0 CONCLUSIONS

This assessment has reviewed the potential noise and vibration impacts of the Stage 2 ION LRT through the Cities of Kitchener and Cambridge in the Region of Waterloo.

8.1 Noise Impact Assessment Conclusions

The noise study compared the sound levels that would be present along the corridor with and without the project's implementation, based on a design year of 2031. Wherever the increase in sound levels between these two cases, or a set of minimum exclusion criteria, is 5 dB or higher, the feasibility of noise control has been investigated.

In most cases, the project does not generate an increase of 5 dB or more at nearby residential receivers. In two areas, the proximity to adjacent residences and low ambient sound levels have triggered the review of noise barriers. A 2.0m high noise barrier is recommended for Receptor 33 and a 4.3m high noise barrier is recommended for Receptor 13. These two areas, and others, will be further reviewed during a future design phase of the project. Consideration will also be given to implementing noise barriers in areas that are relatively quiet but have not triggered the need for noise control under the current protocol.

Unlike Stage 1 ION, the Stage 2 ION LRT does not have many sharp corners. As a result, the potential for wheel squeal is significantly lower. The primary areas of concern for wheel squeal are in the residential area south of Eagle Street and where the LRT terminates along Ainslie Street. Wheel squeal will be controlled by rail and/or wheel lubrication along with wheel damping systems. These areas will again be reviewed further during a future design stage.

The final locations of special trackwork have not been determined. In most cases, vehicles travel slower over special trackwork, especially at the terminus stations. Special trackwork will be located in areas with few residential receptors where possible. Where located in areas with residences, consideration will be given to using moveable point frogs, spring frogs, and/or monoblock-welded frogs. These systems have proven effective at reducing or even eliminating the additional noise generated by vehicles passing over special trackwork.

The traction power substations are generally located in acoustically insensitive areas. Sound level emission limits have been recommended depending on the nearest residences or to facilitate future development nearby. These limits have been conservatively estimated using the minimum exclusion criteria. The emission limits can be further refined during the future design phase.

8.2 Vibration Assessment Conclusions

The objective of the vibration assessment is to determine areas where vibration control may be required. As per the MOEE/TTC criteria and the FTA criteria, vibration levels are to be limited to 0.10 mm/s RMS at residences and vibration induced sound levels are to be limited to 35 dBA within residences, where direct air-borne noise is not greater.

For the most part, this assessment has found that residences beyond 12 m from the nearest track would not require extensive vibration control. Variations or improvements to the standard encapsulated rail systems should suffice. All areas with embedded rail will be provided with at least a basic level of vibration isolation.

The areas within 12 m from the nearest track, of which there are six, may require significantly more vibration control in order to meet the applicable criteria. These areas in particular should be reviewed more closely during a future design phase.

Similarly, areas with special trackwork will require further evaluation during a future design stage. Areas with special trackwork in residential areas or near vibration-sensitive receptors may require upgrades. The mechanisms used to reduce switch noise (moveable point or spring frogs and monoblock frogs) often also reduce vibration levels. The track base can also be installed on vibration isolation instead of poured in place to provide further reduction in the vibration levels.

8.3 Construction Assessment

Construction sound and vibration levels have not been modelled in detail, as the approach and sequence of construction will be determined by the Contractor at the time of construction. Operational controls in the form of vehicle sound level emission restrictions, usage of broadband alarms, and restricted work hours are some of the most effective ways to control construction noise. Proactive monitoring/supervision and communications with nearby stakeholders is also essential to minimize the impacts of construction noise and vibration. A more detailed construction noise and vibration assessment and monitoring plan will be developed during a future design phase to guide the Contractor responsible for building Stage 2 ION.

Overall, the noise and vibration impacts from the operations of the Stage 2 ION LRT are expected to be minor. Where excesses above the guidelines are predicted, there are several options available to practically meet the noise and vibration criteria. The construction phase of such light rail systems are often the source of greatest noise and vibration impact. Recommendations have been made to limit such impacts, where practical.

APPENDIX A: FIGURES

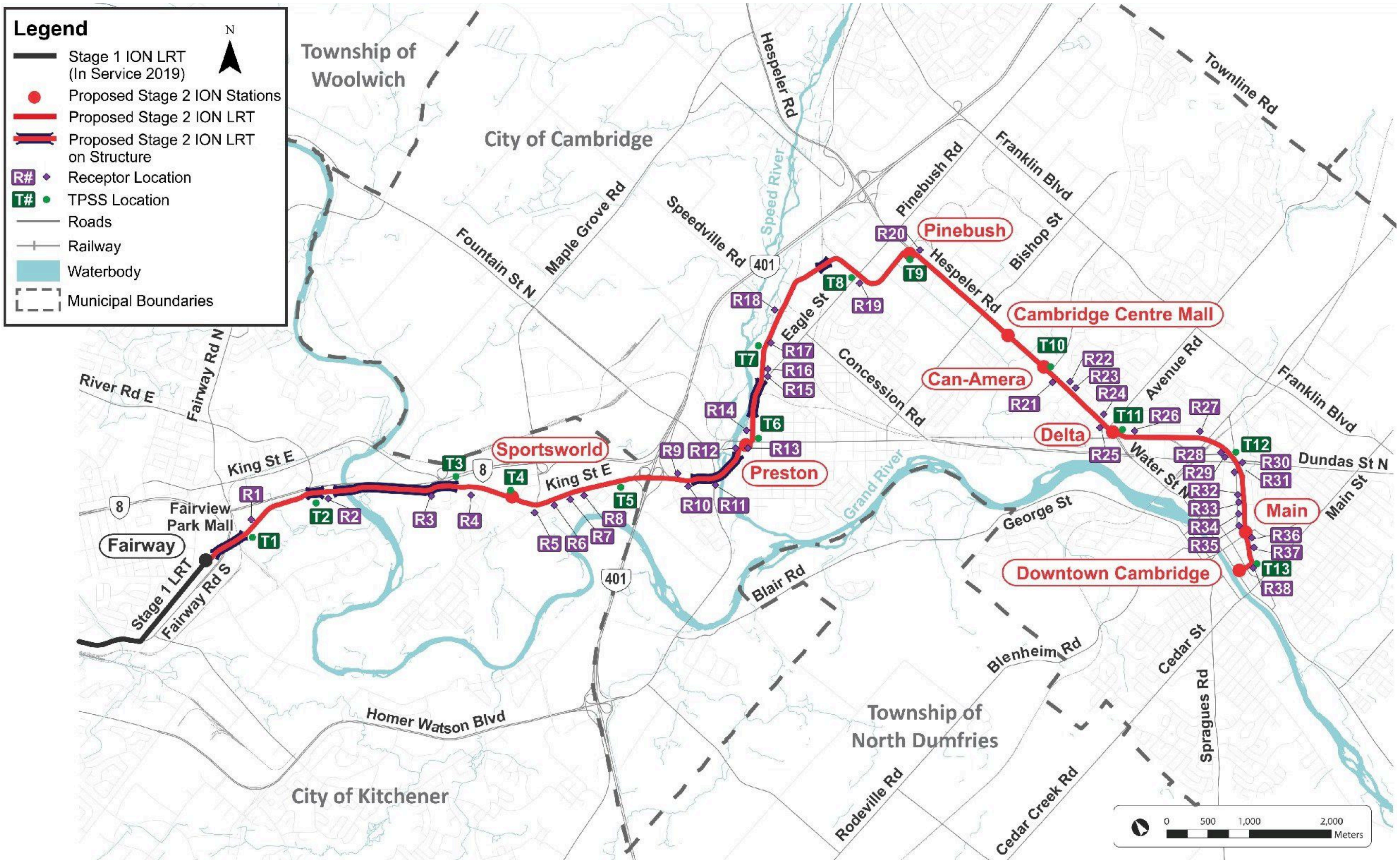


Figure 1: Overall Key Plan

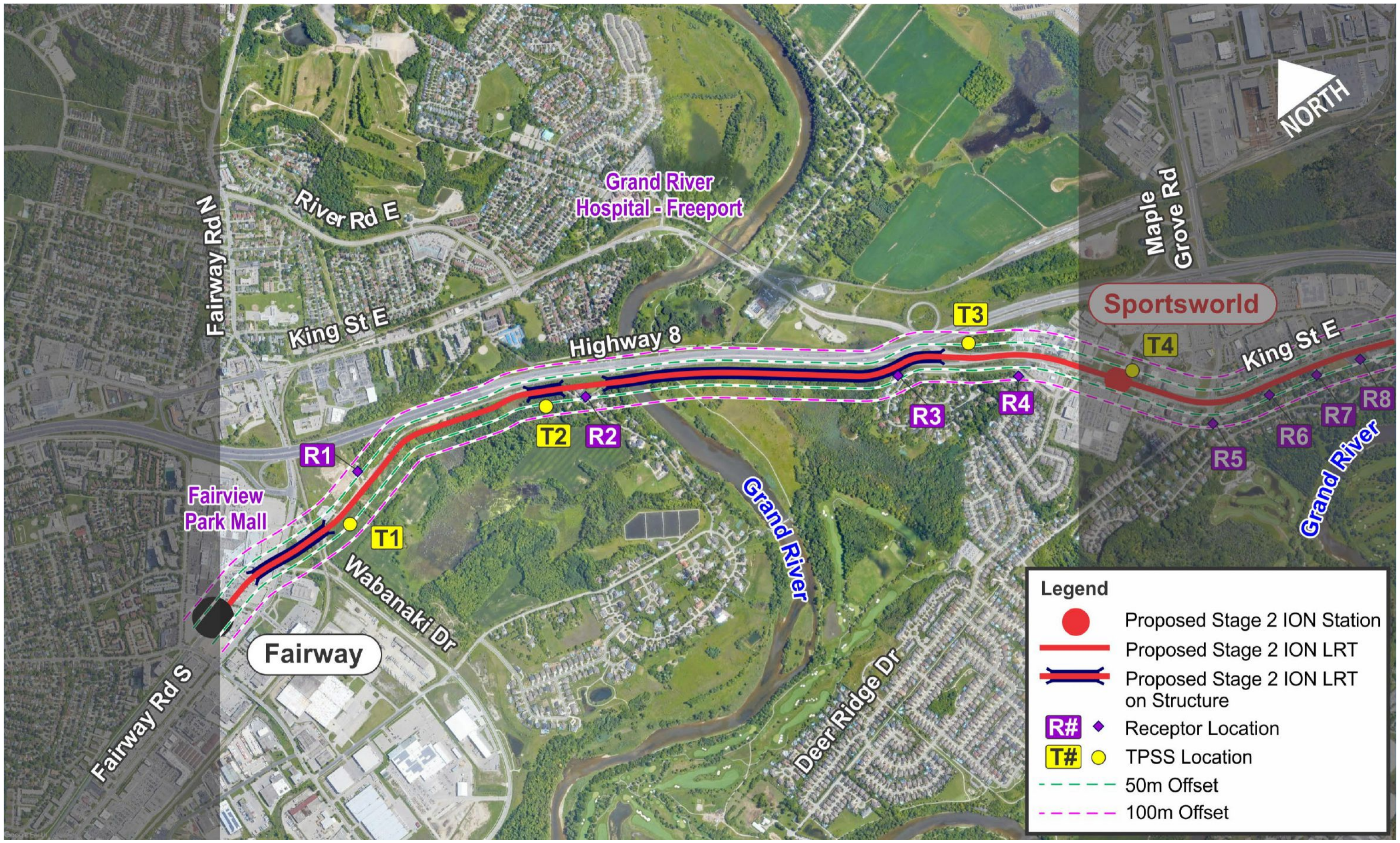


Figure 2: Key Project Elements and Receptors 1 to 4

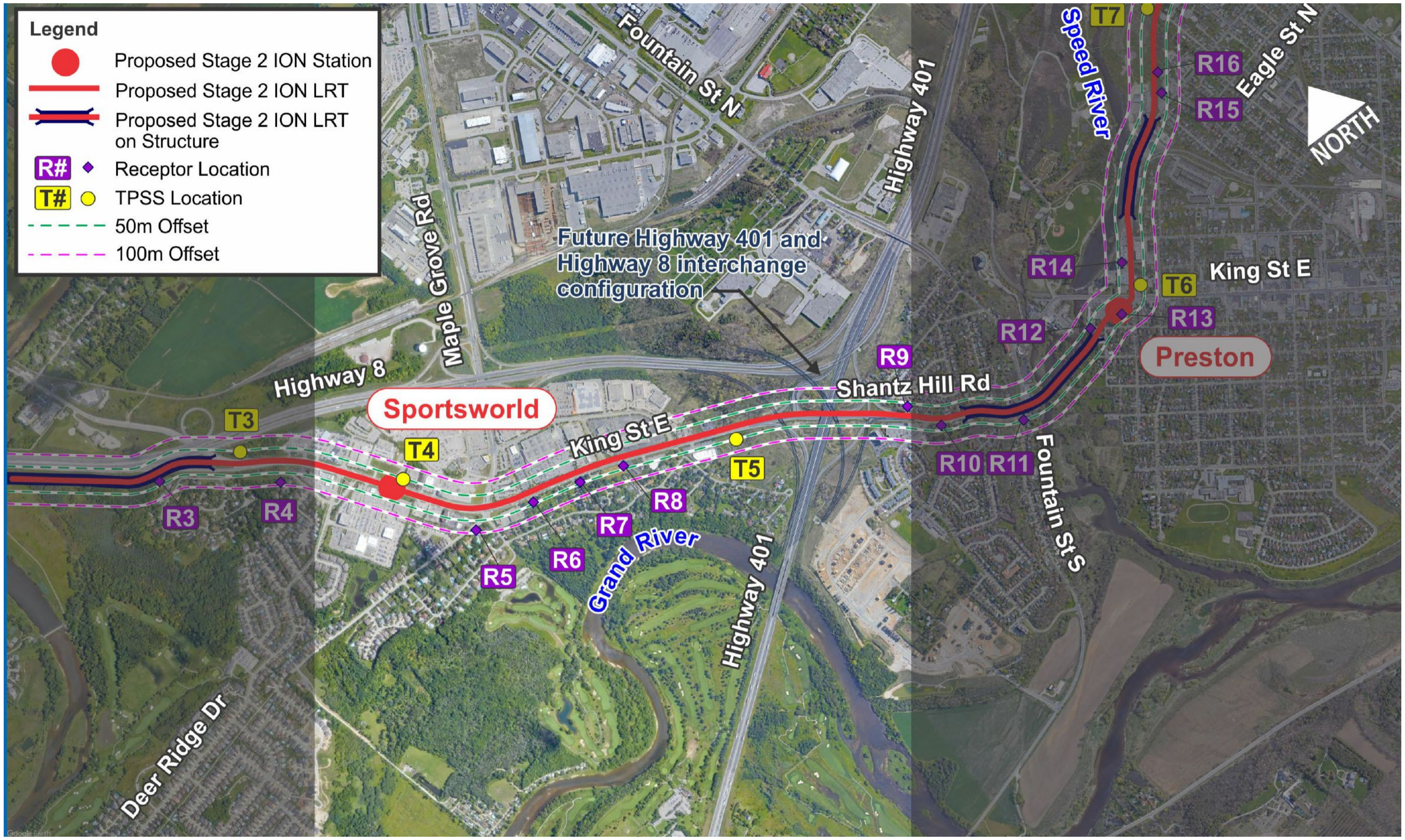


Figure 3: Key Project Elements and Receptors 5 to 9

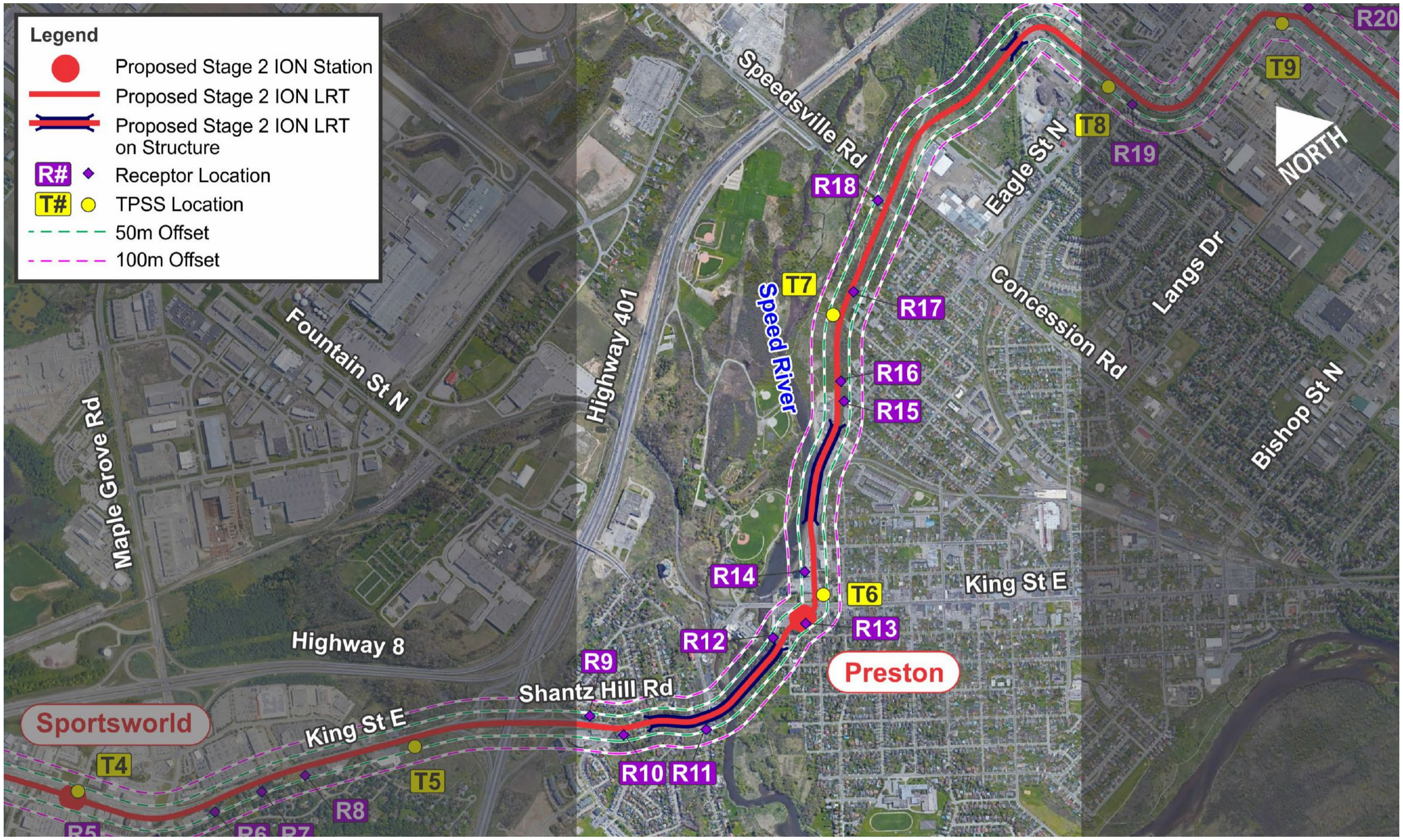


Figure 4: Key Project Elements and Receptors 9 to 18

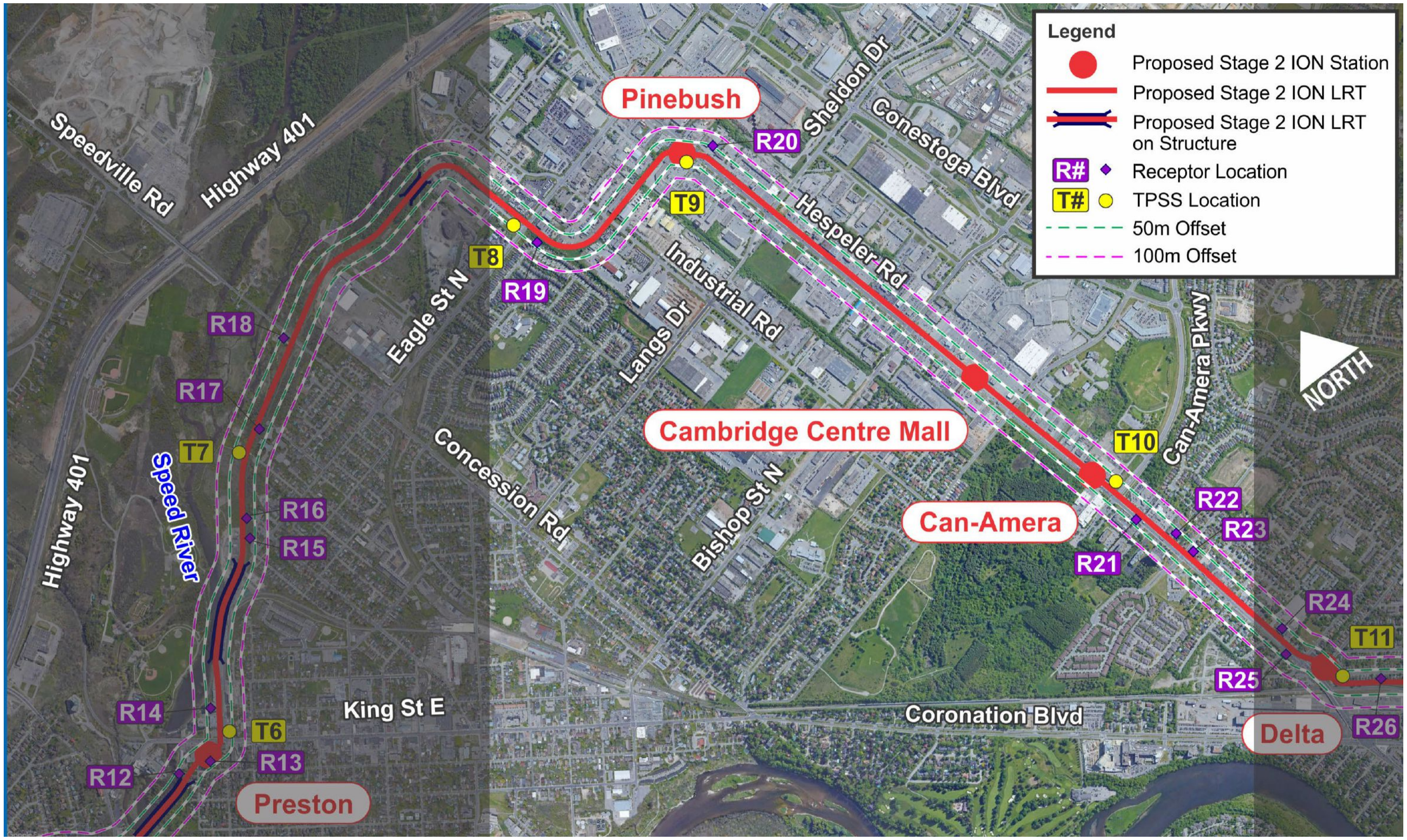


Figure 5: Key Project Elements and Receptors 19 to 23

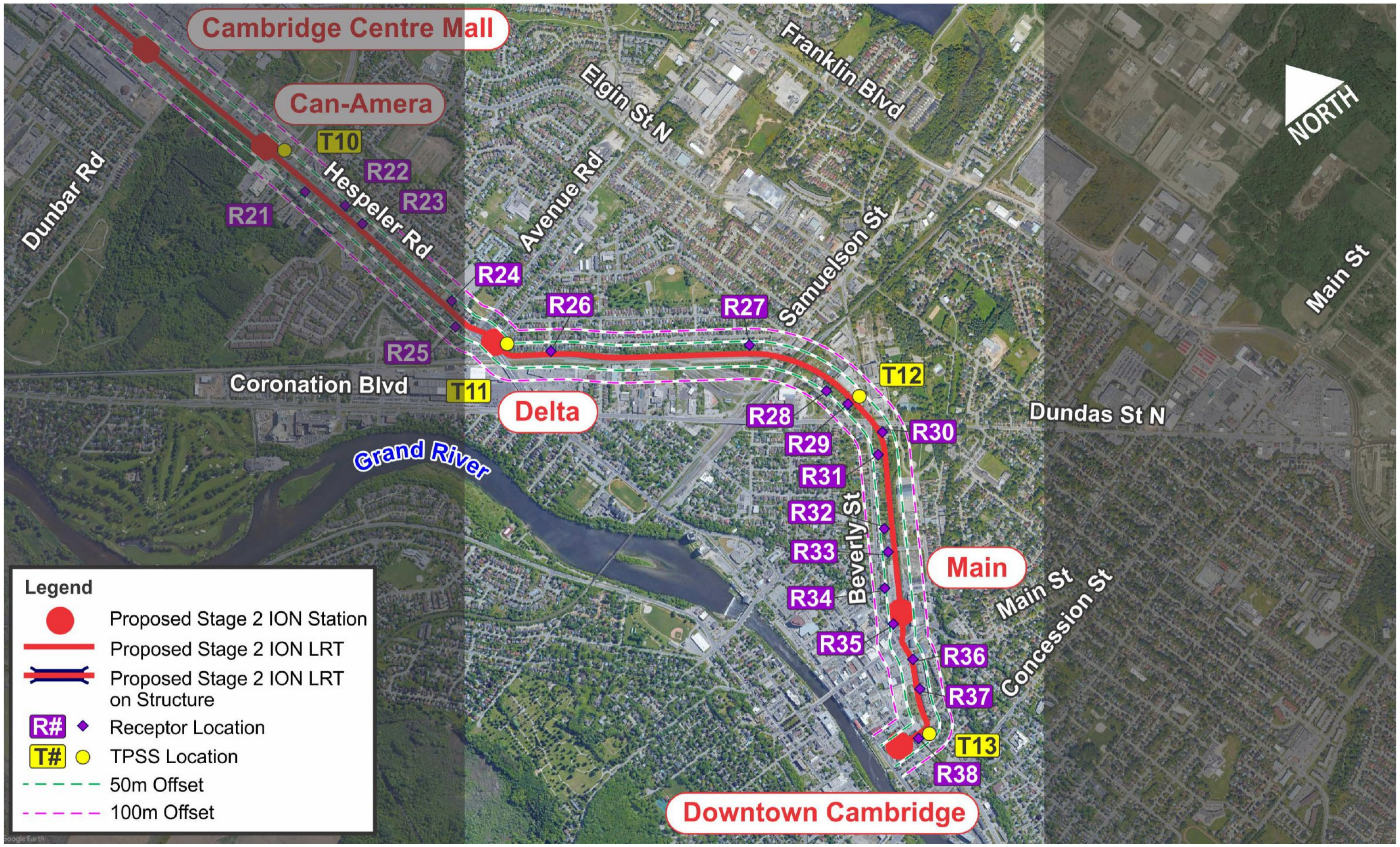


Figure 6: Key Project Elements and Receptors 24 to 38

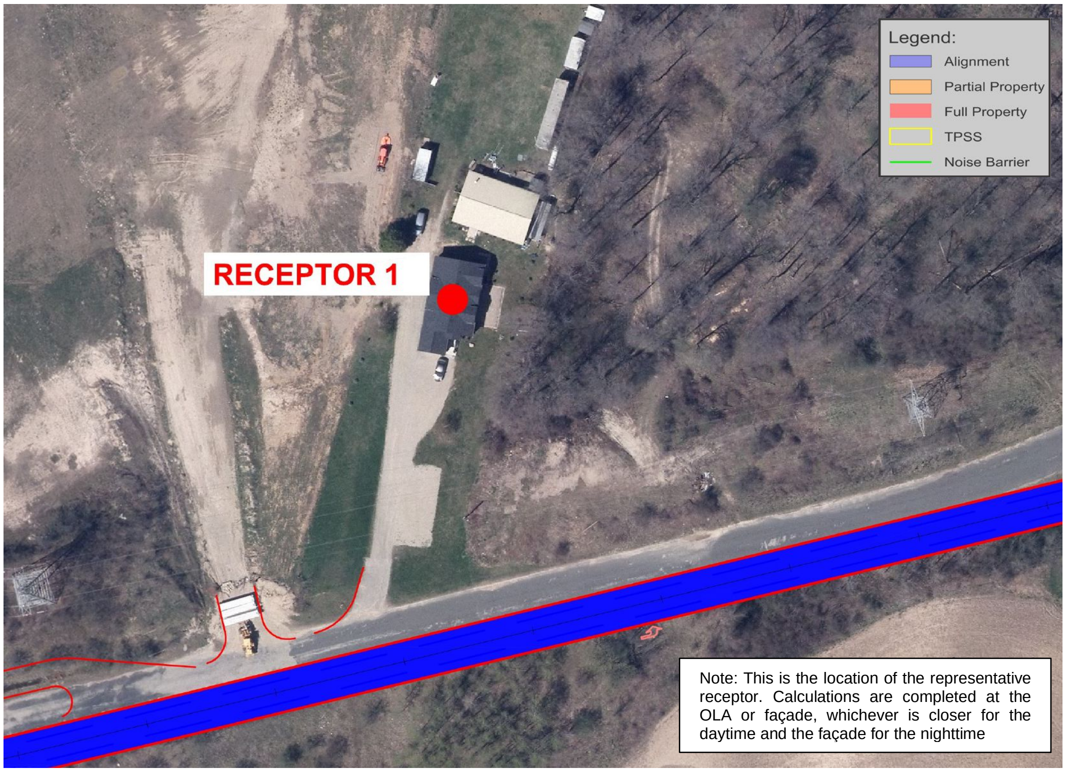


Figure 7: POR 1

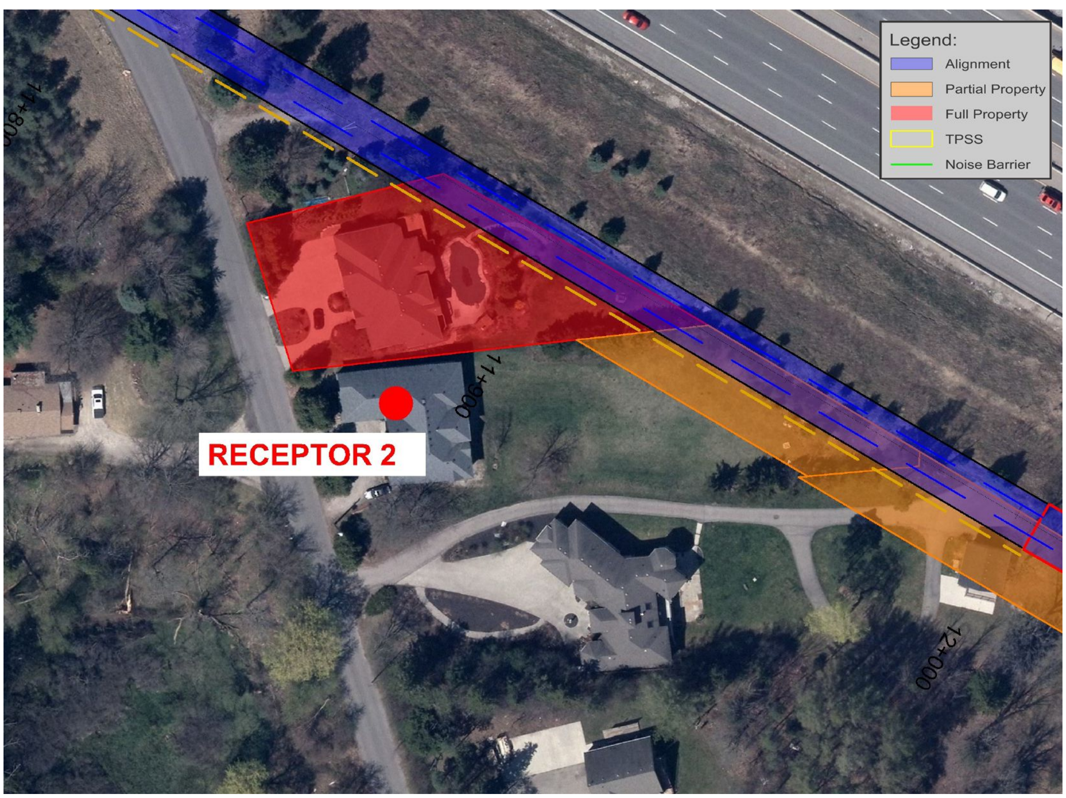


Figure 8: POR 2

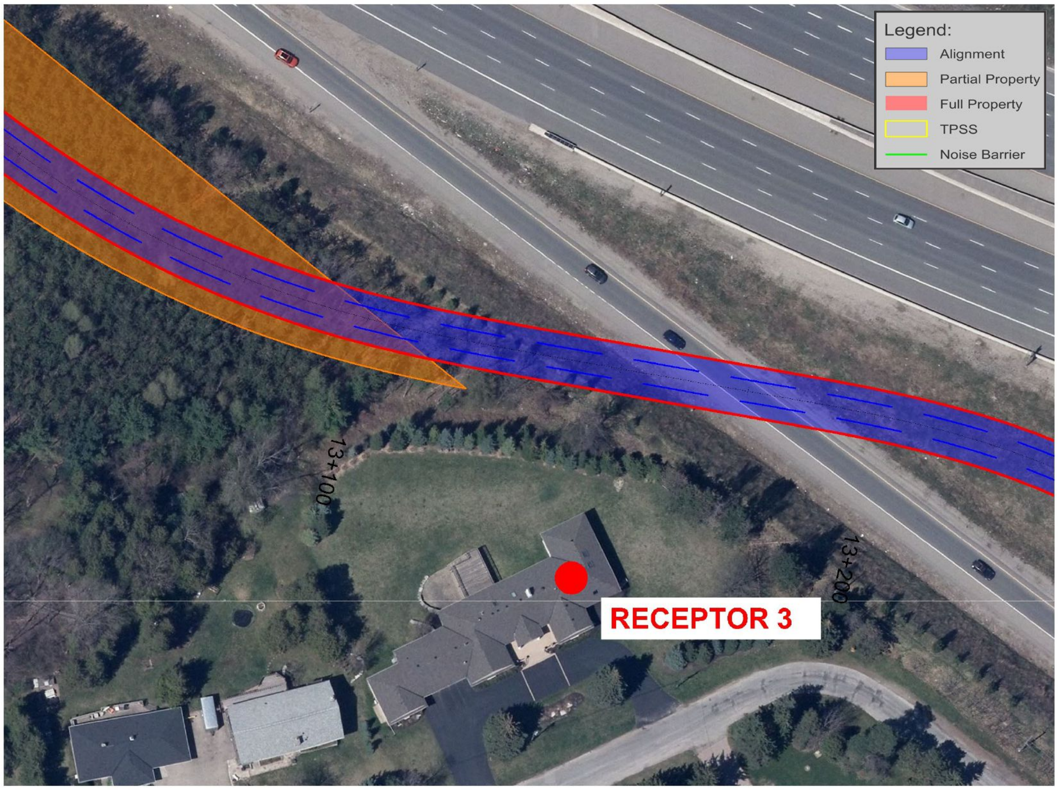


Figure 9: POR 3

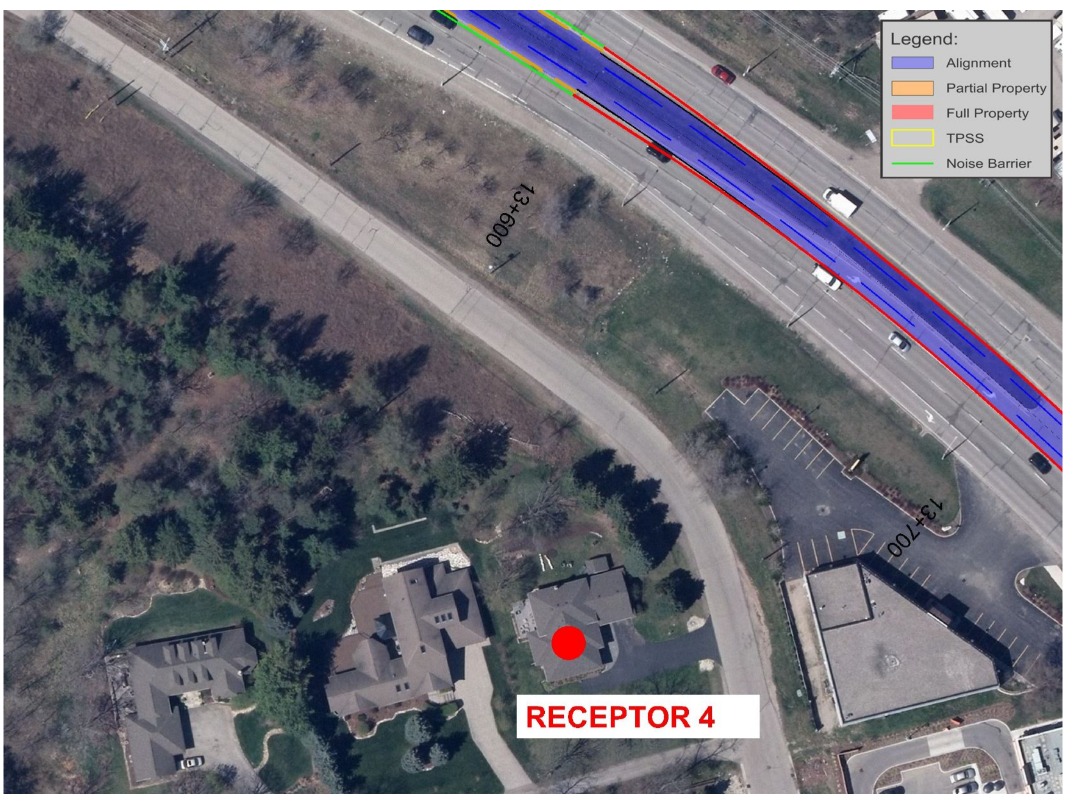


Figure 10: POR 4

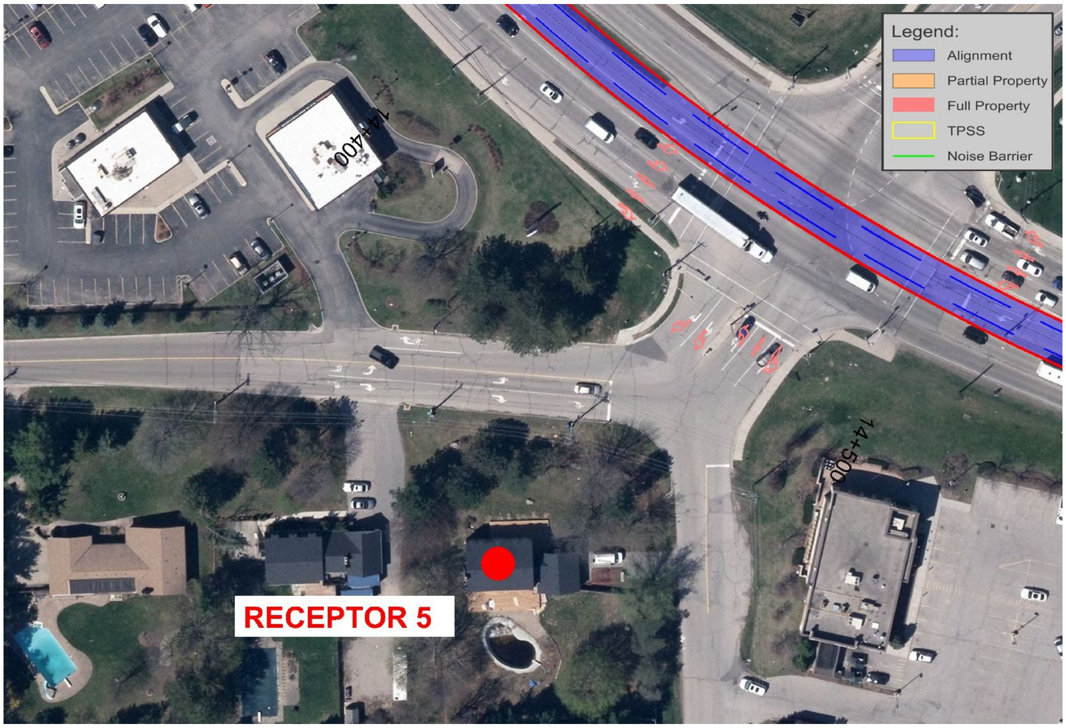


Figure 11: POR 5

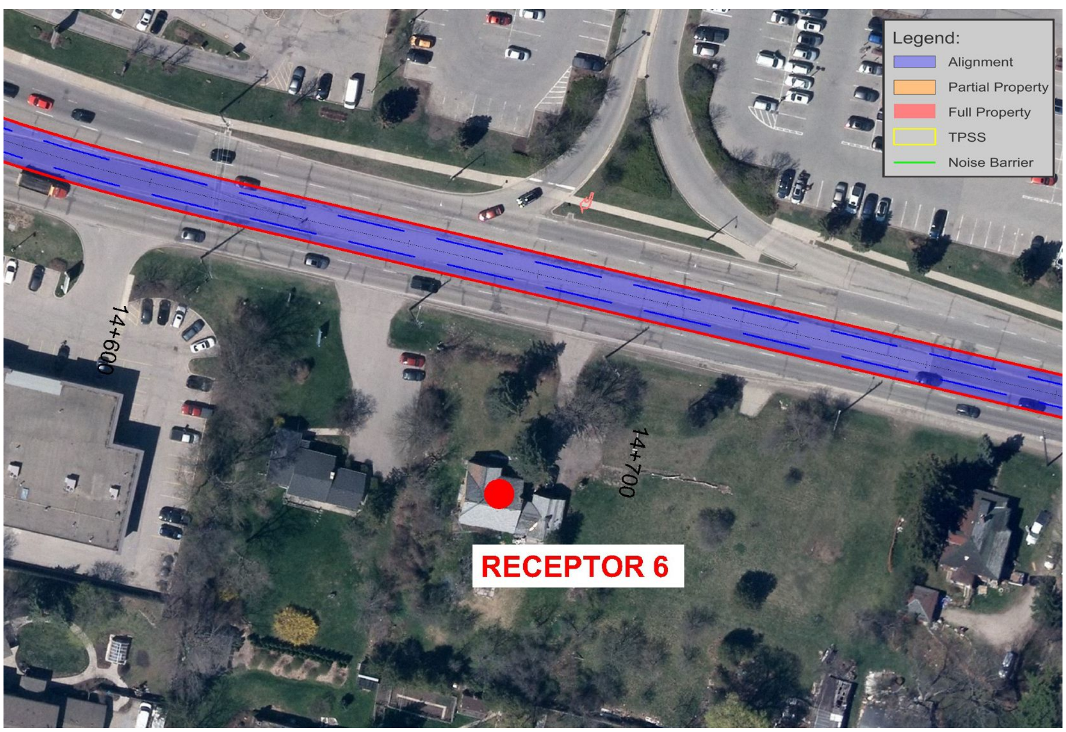


Figure 12: POR 6

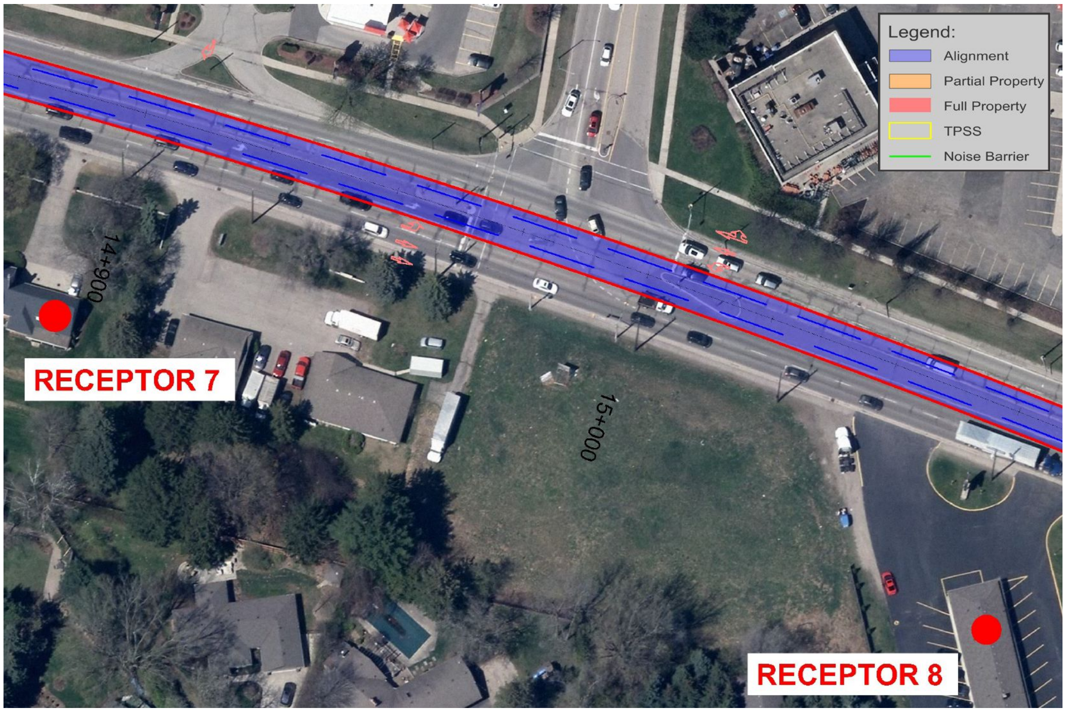


Figure 13: POR 7 and 8

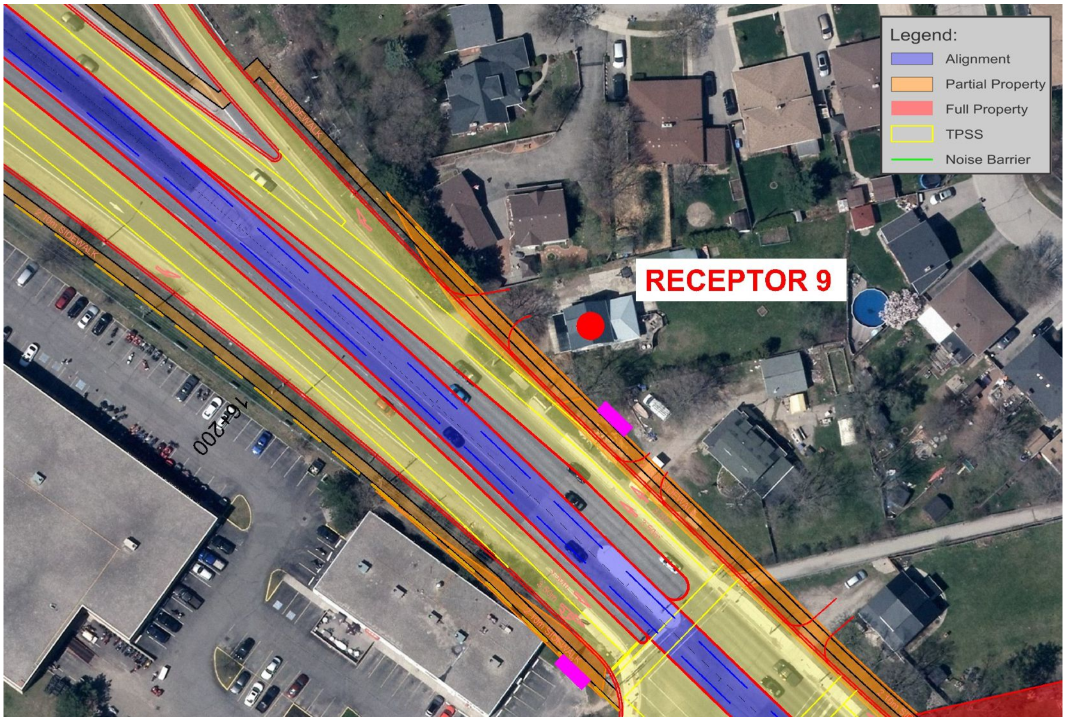


Figure 14: POR 9

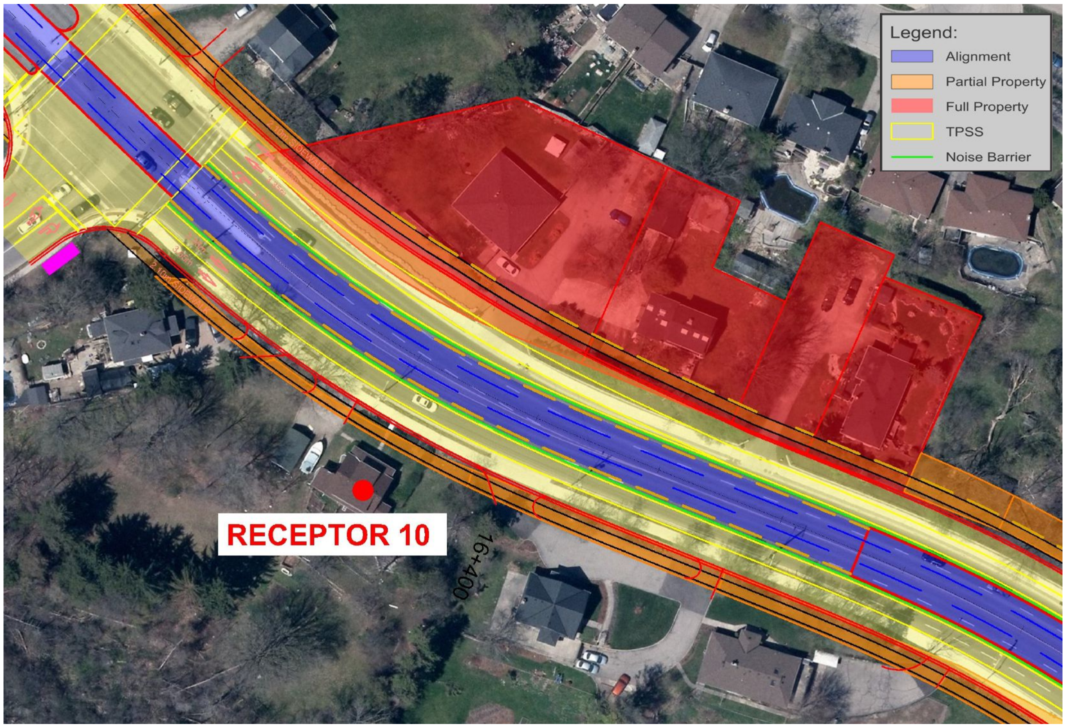


Figure 15: POR 10

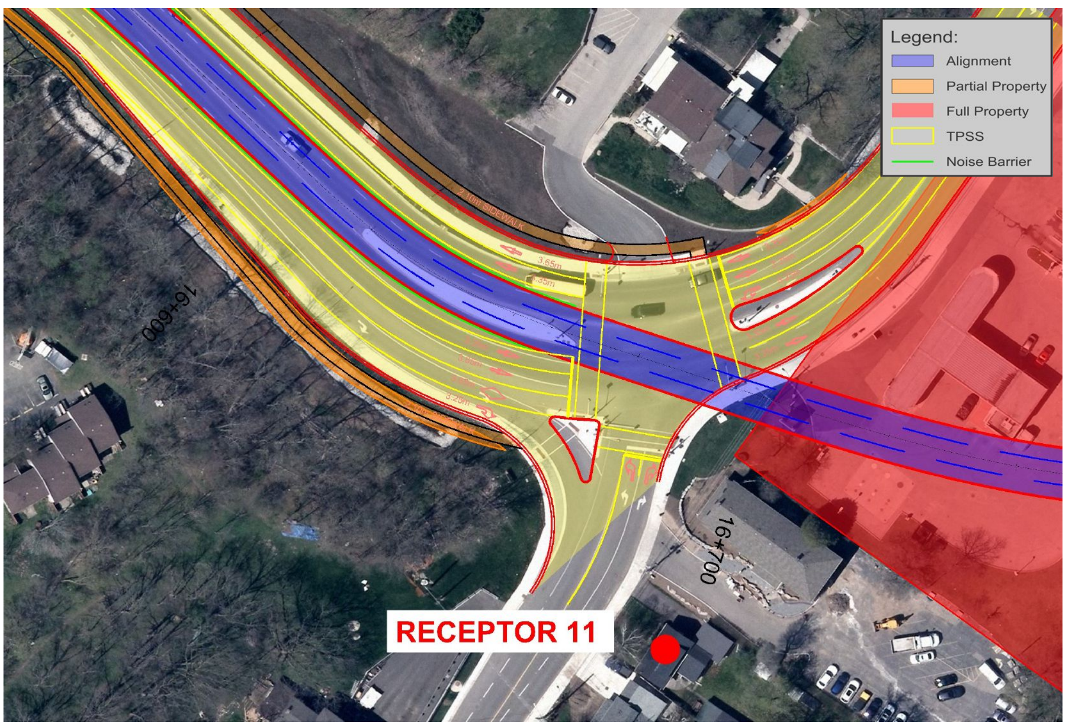


Figure 16: POR 11

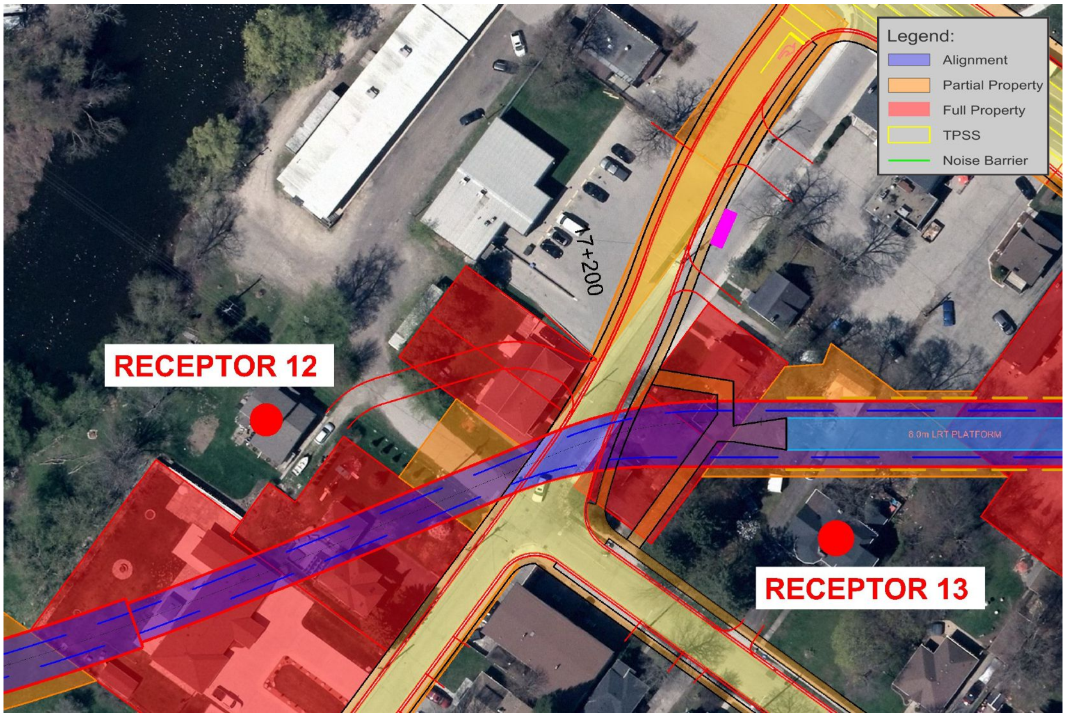


Figure 17: POR 12 and 13

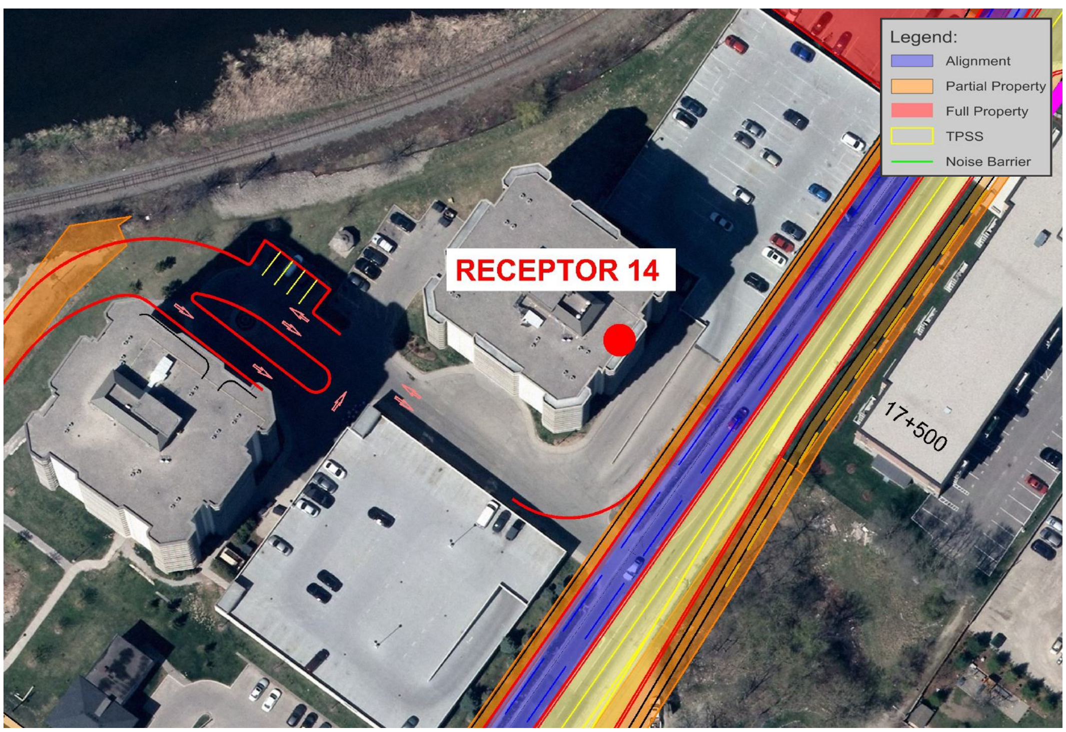


Figure 18: POR 14

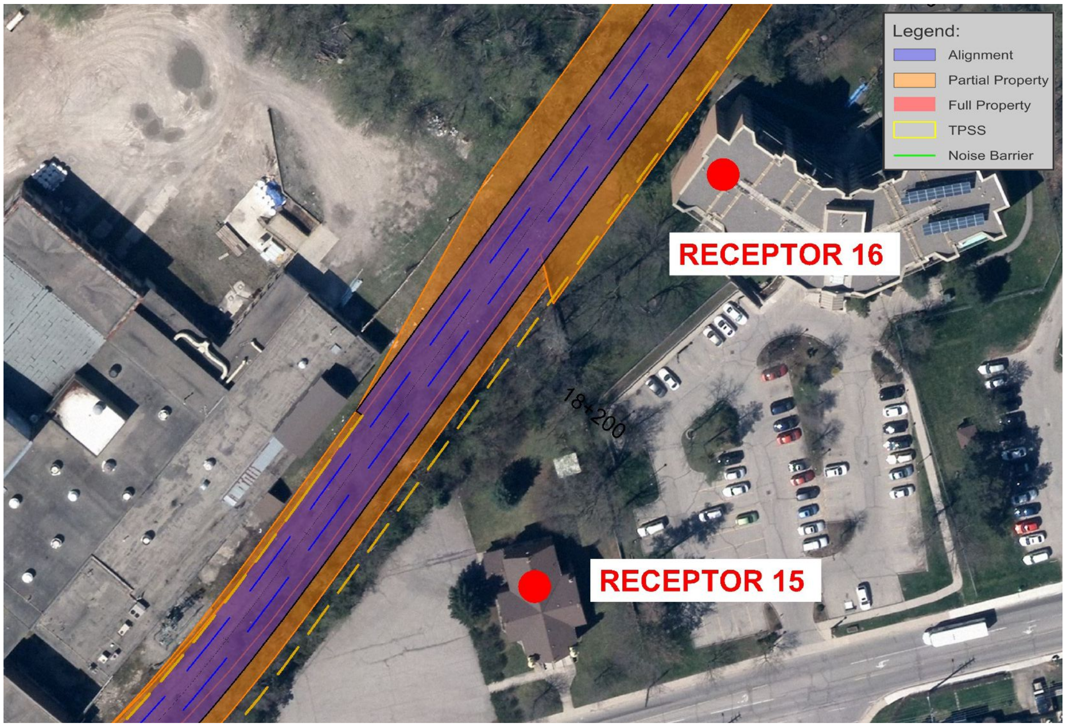


Figure 19: POR 15 and 16

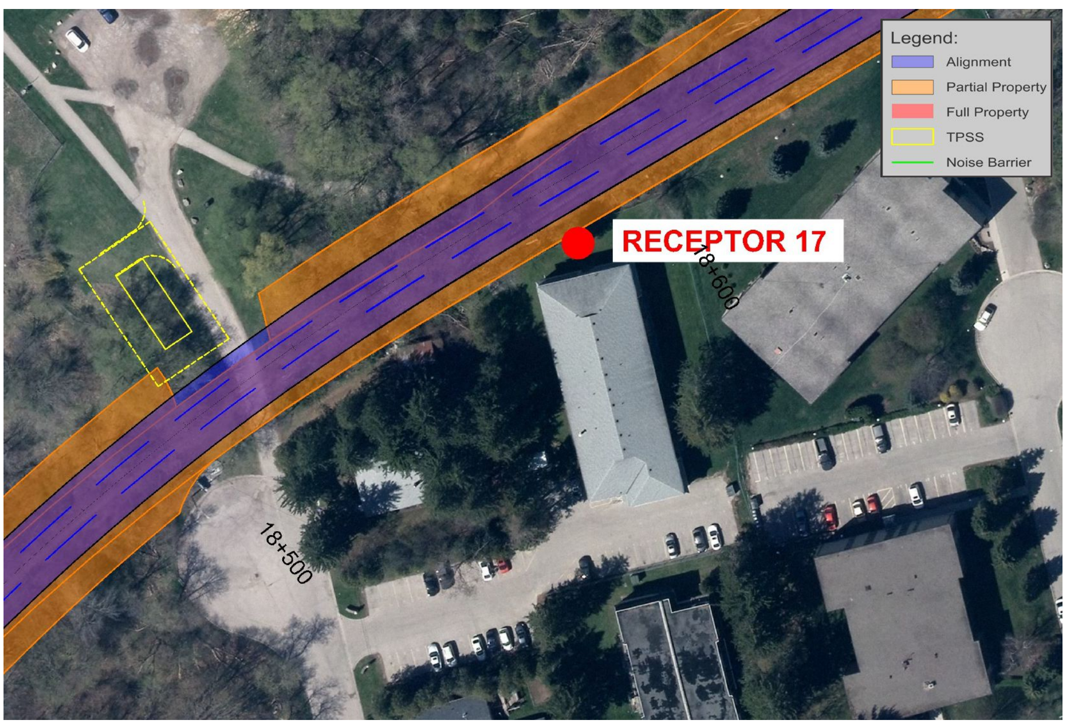


Figure 20: POR 17

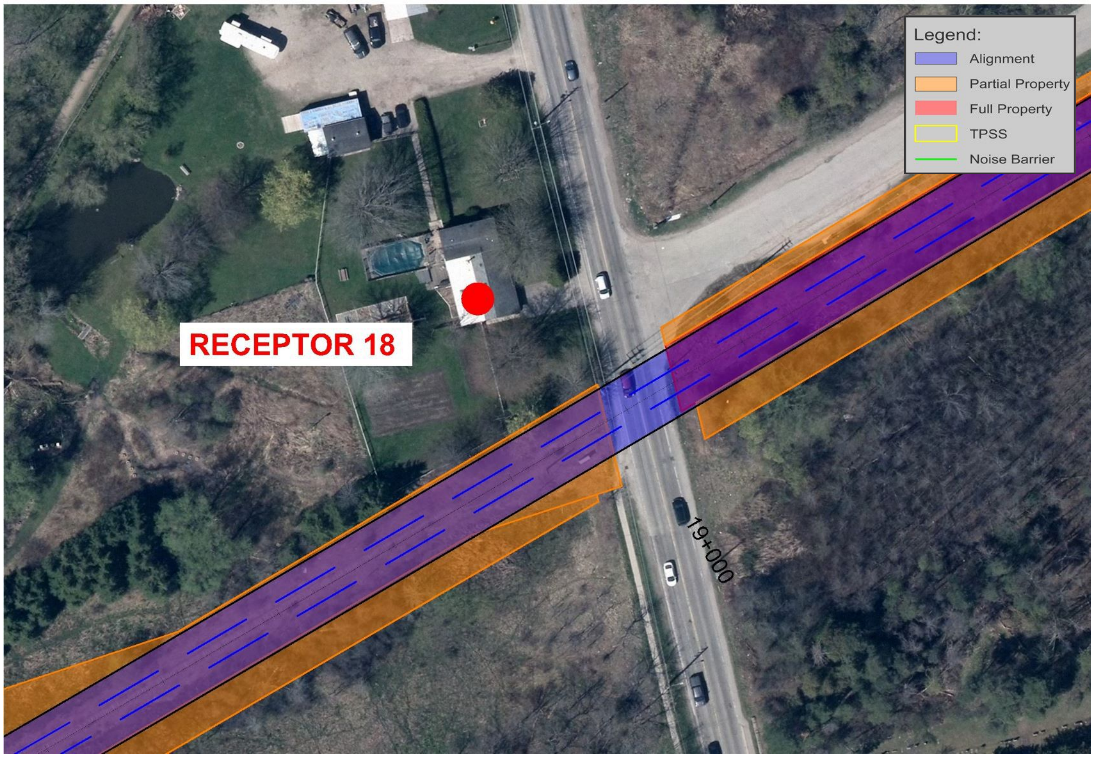


Figure 21: POR 21

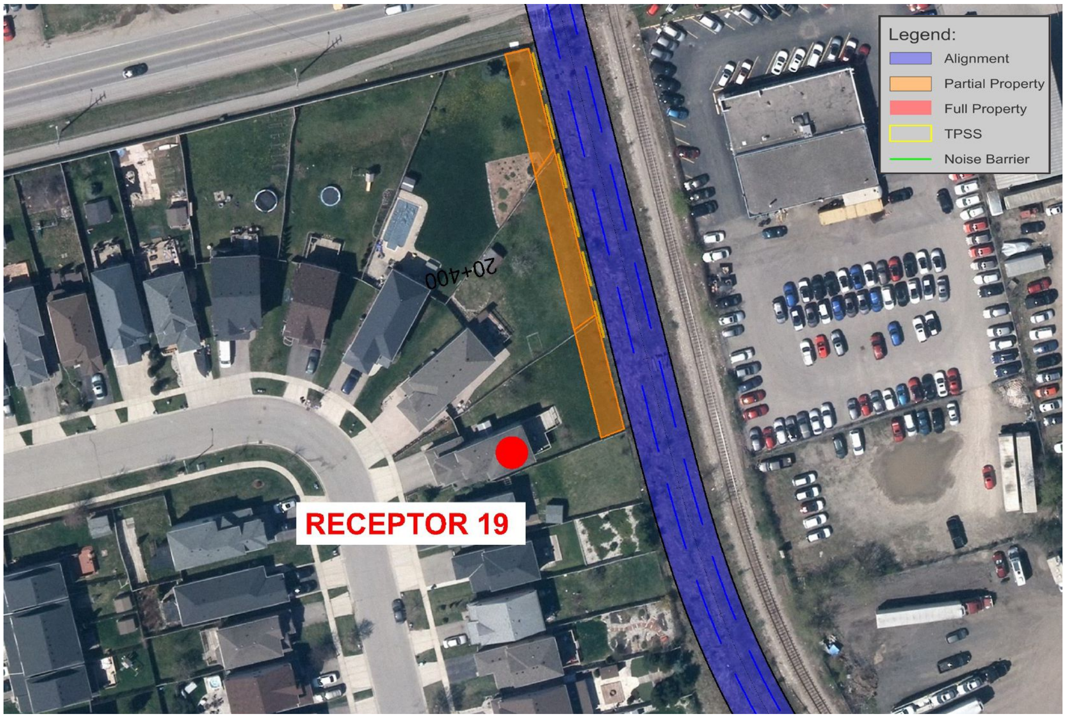


Figure 22: POR 19

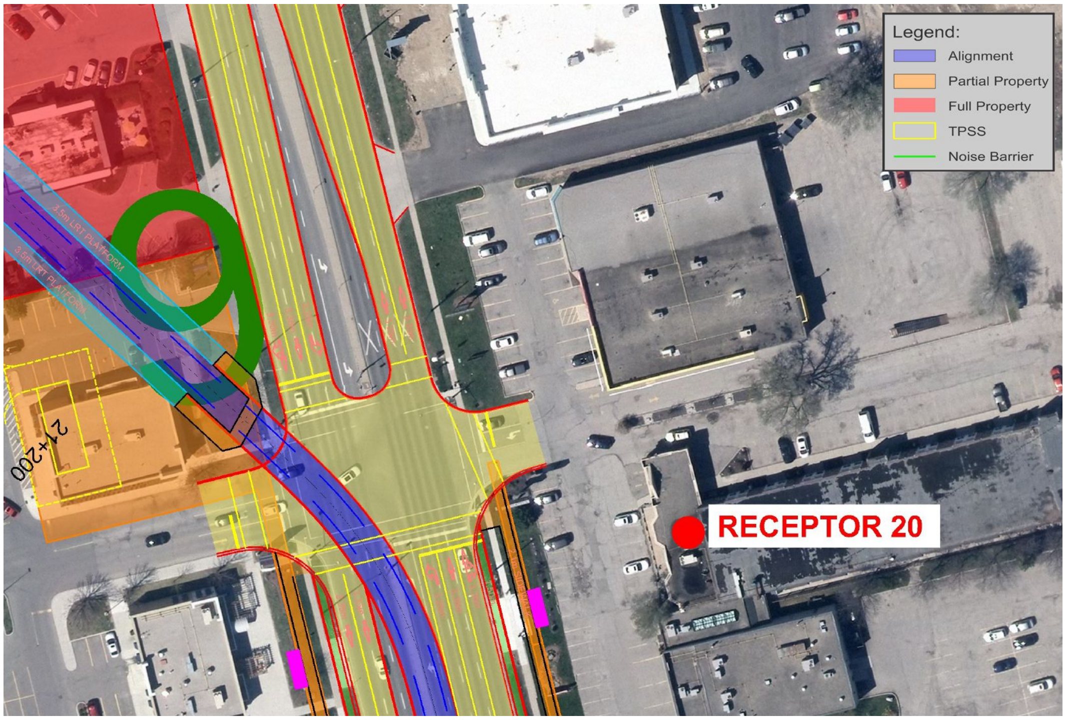


Figure 23: POR 20

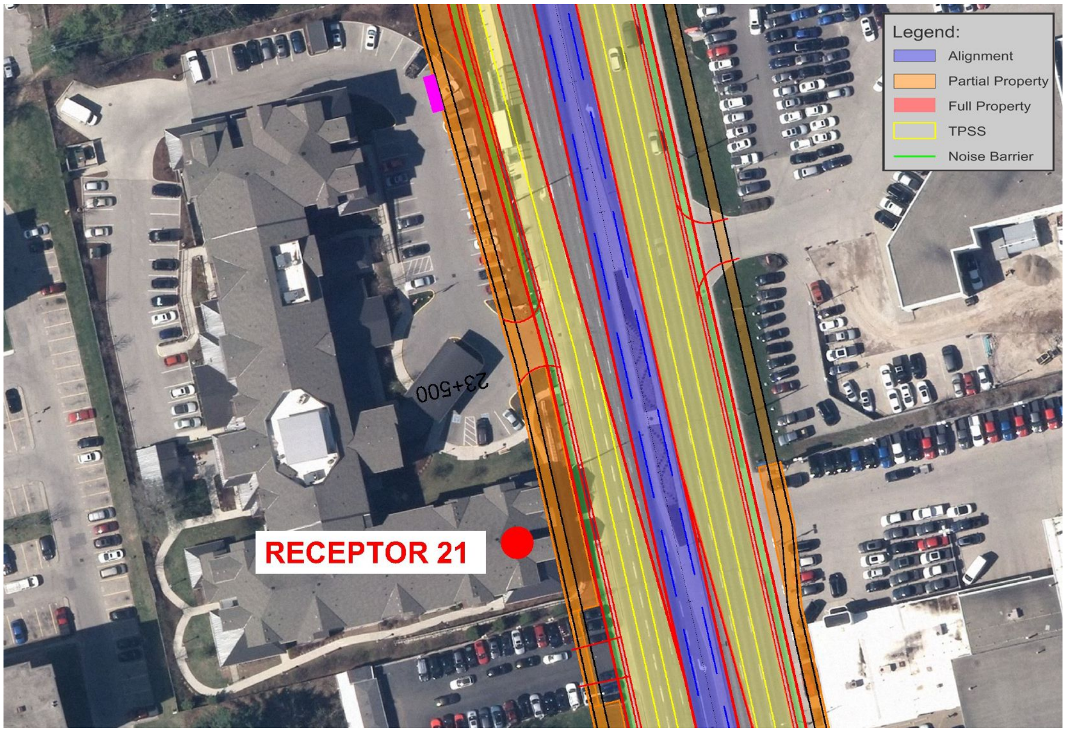


Figure 24: POR 21

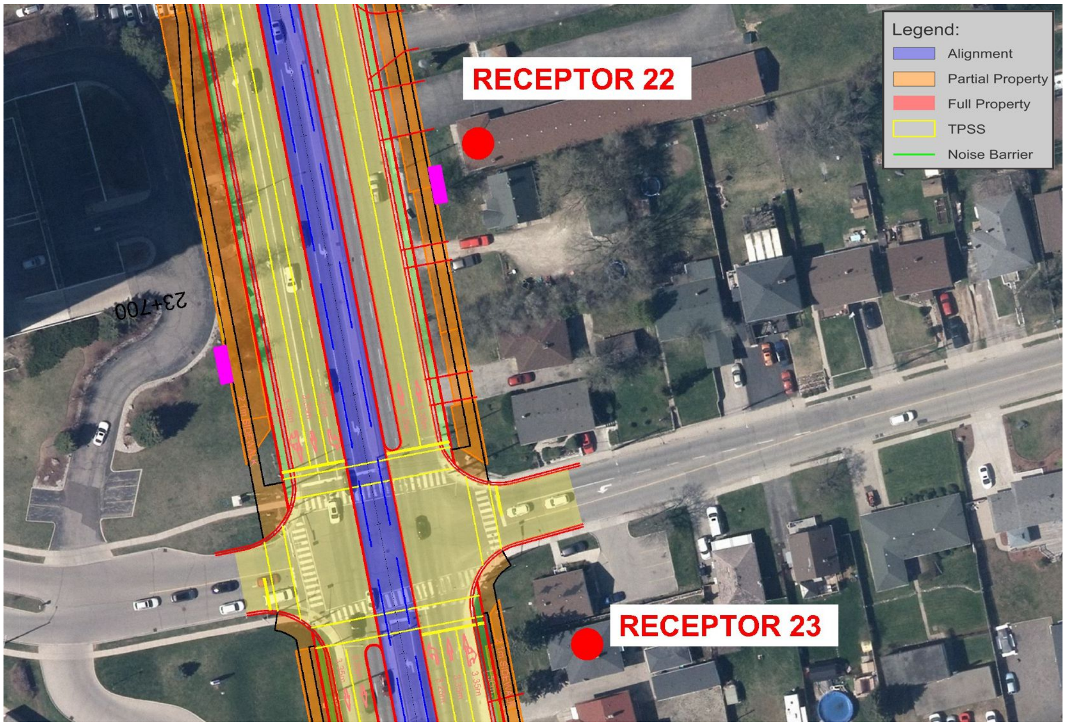


Figure 25: POR 22 and 23

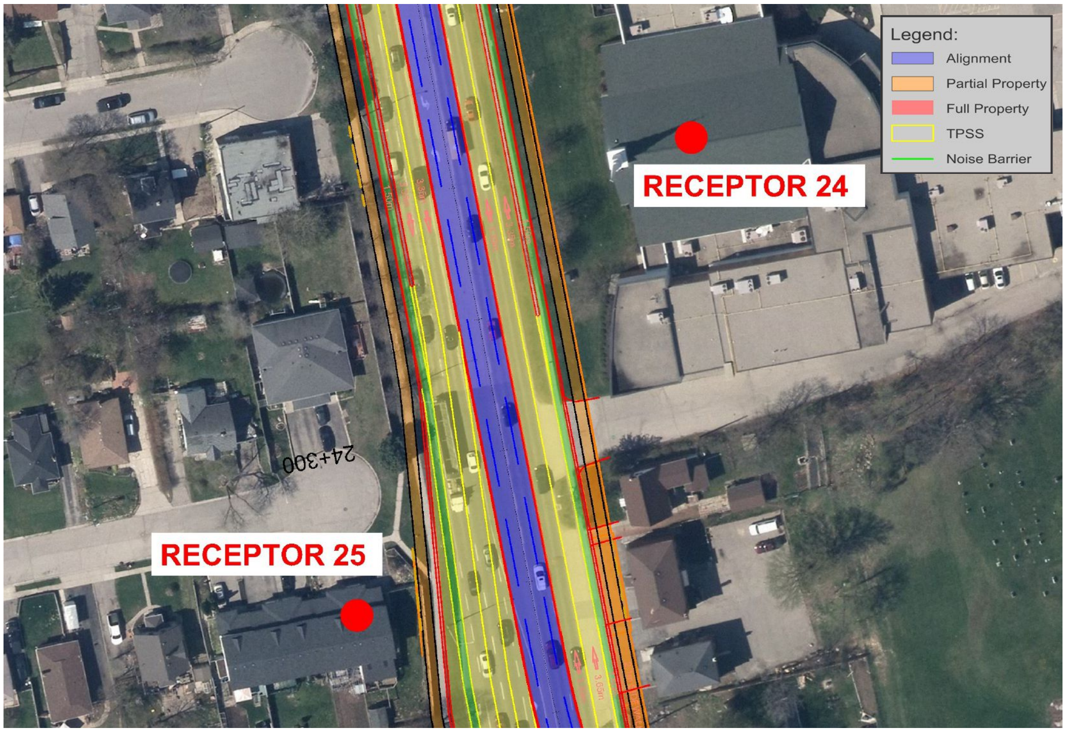


Figure 26: POR 24 and 25

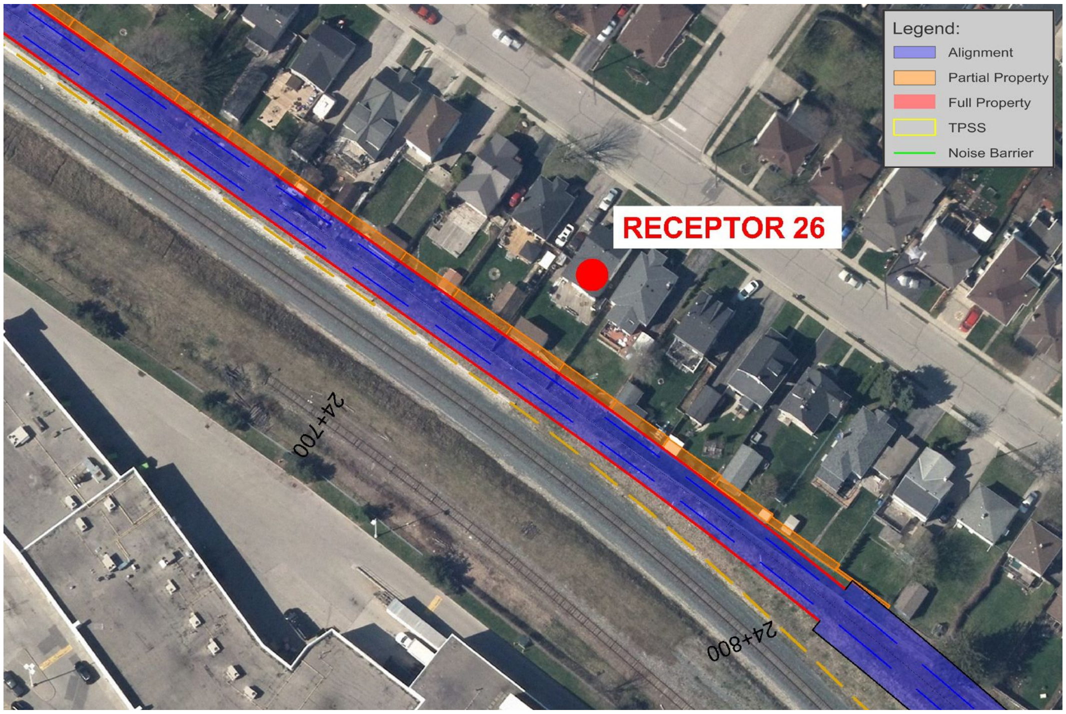


Figure 27: POR 26

Figure 28: POR 27

Figure 29: POR 28 and 29

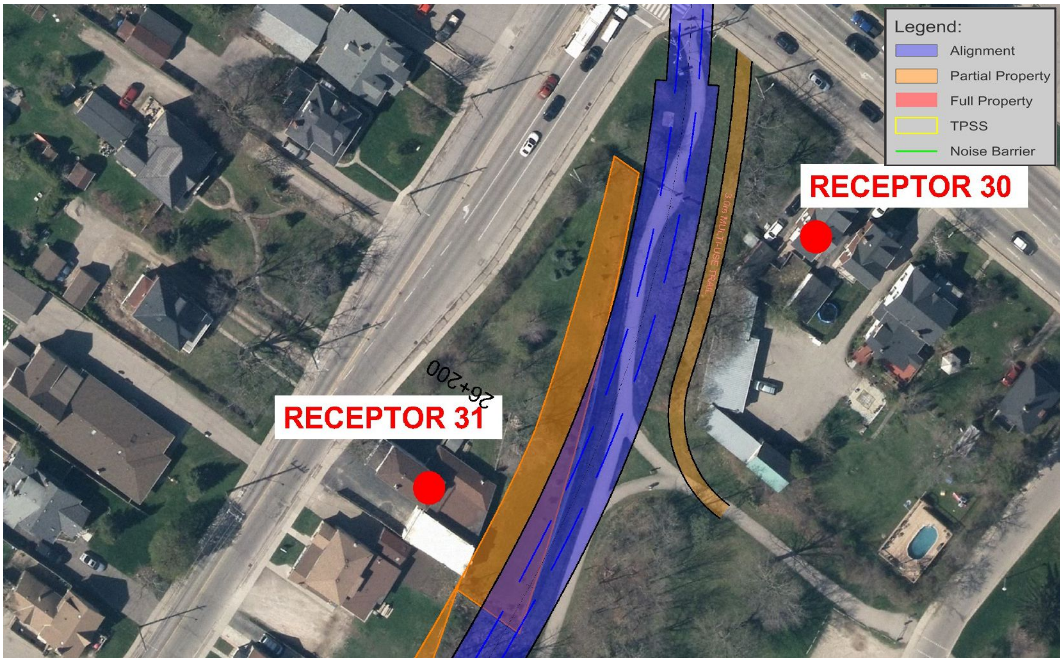


Figure 30: POR 30 and 31

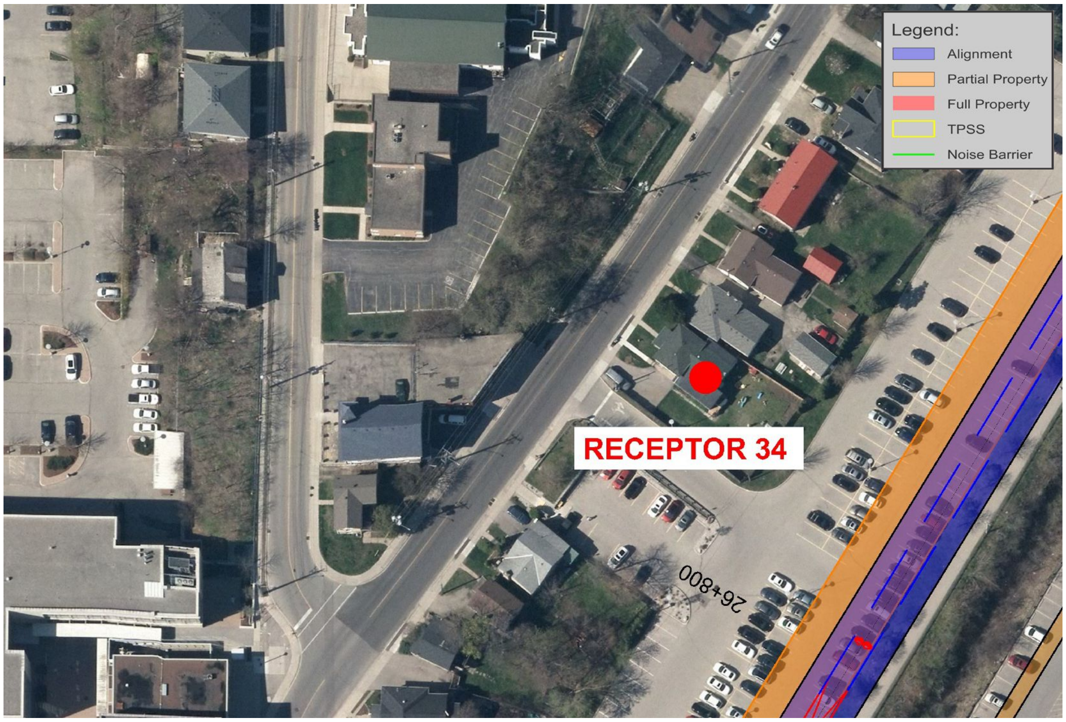


Figure 31: POR 34

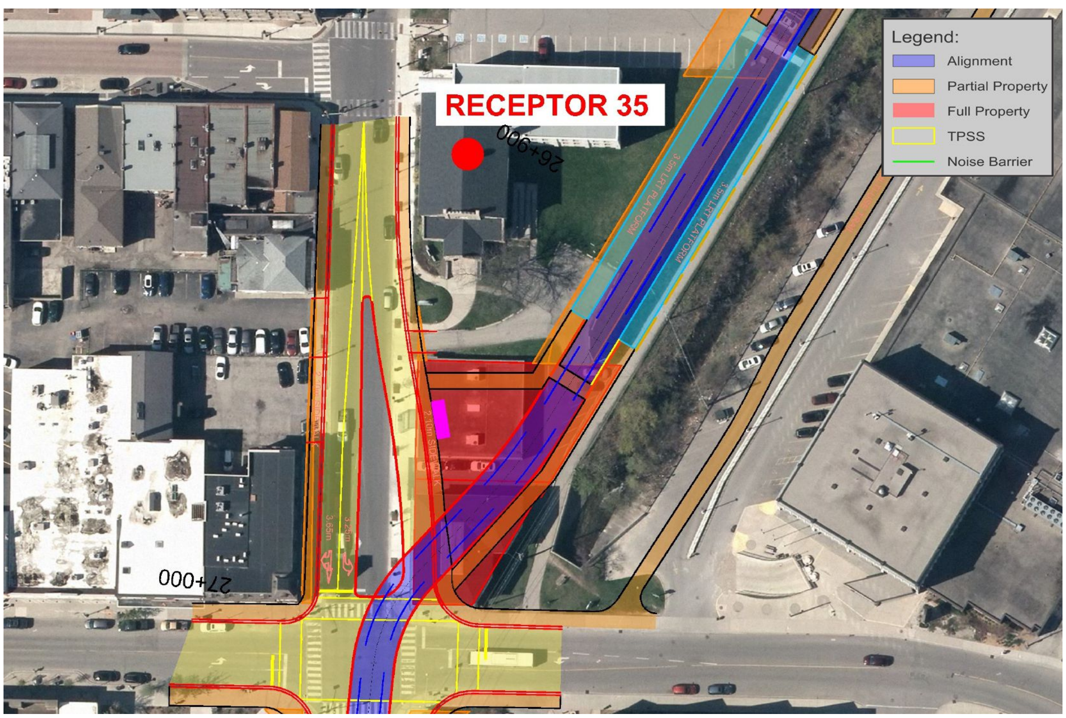


Figure 32: POR 35

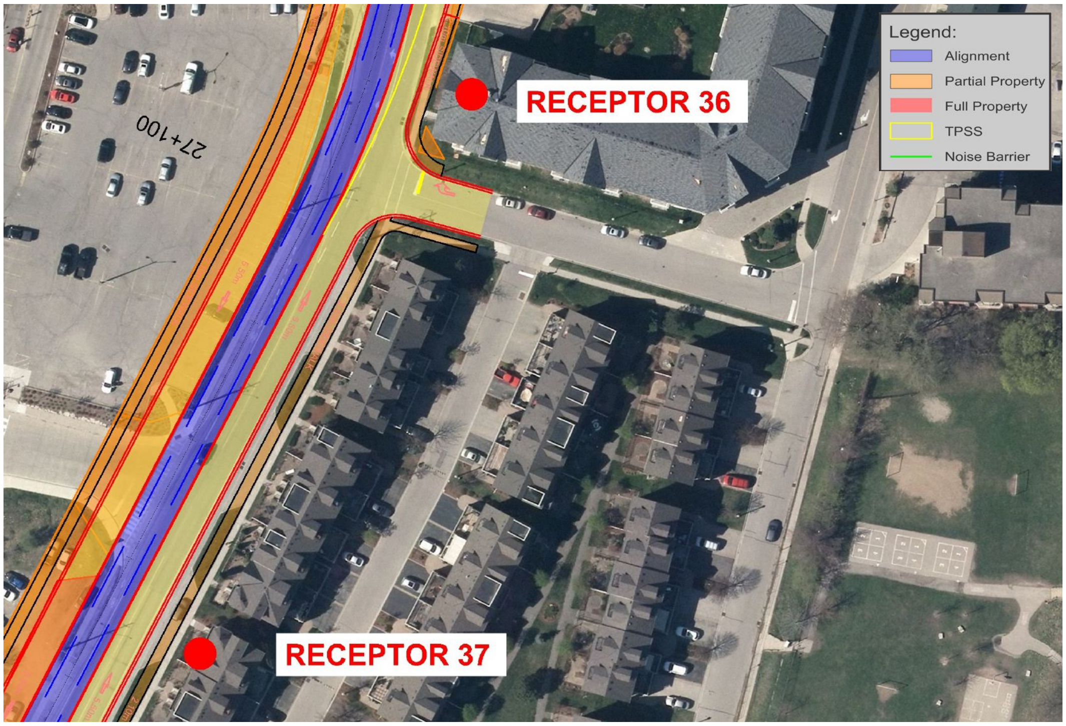


Figure 33: POR 36 and 37

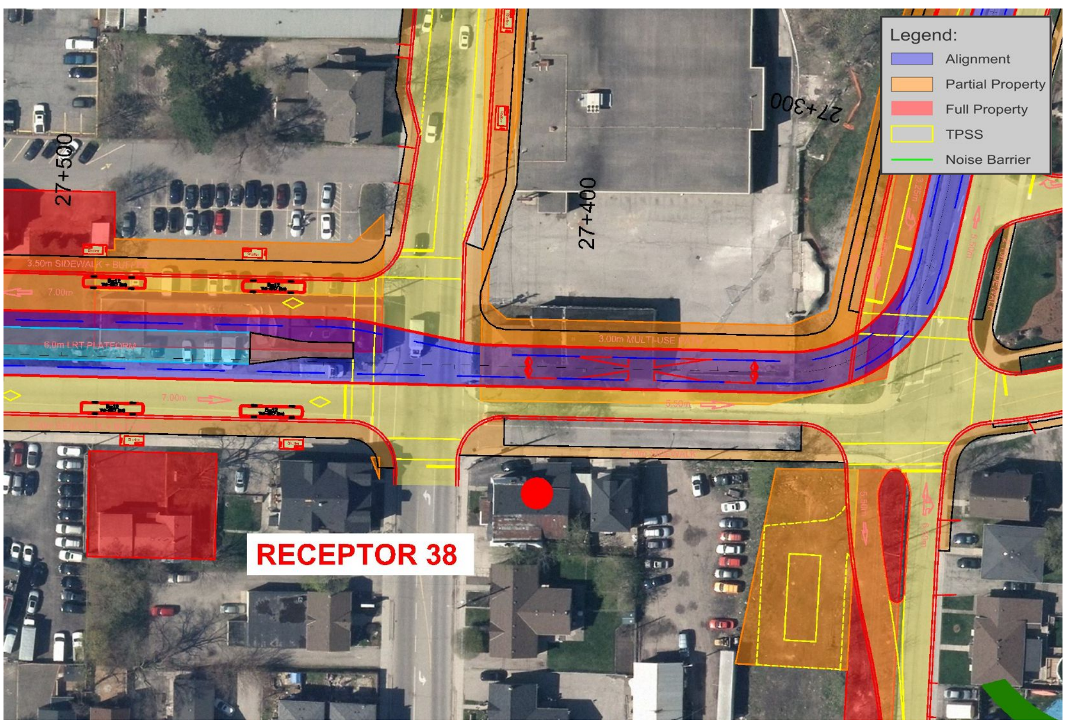


Figure 34: POR 38

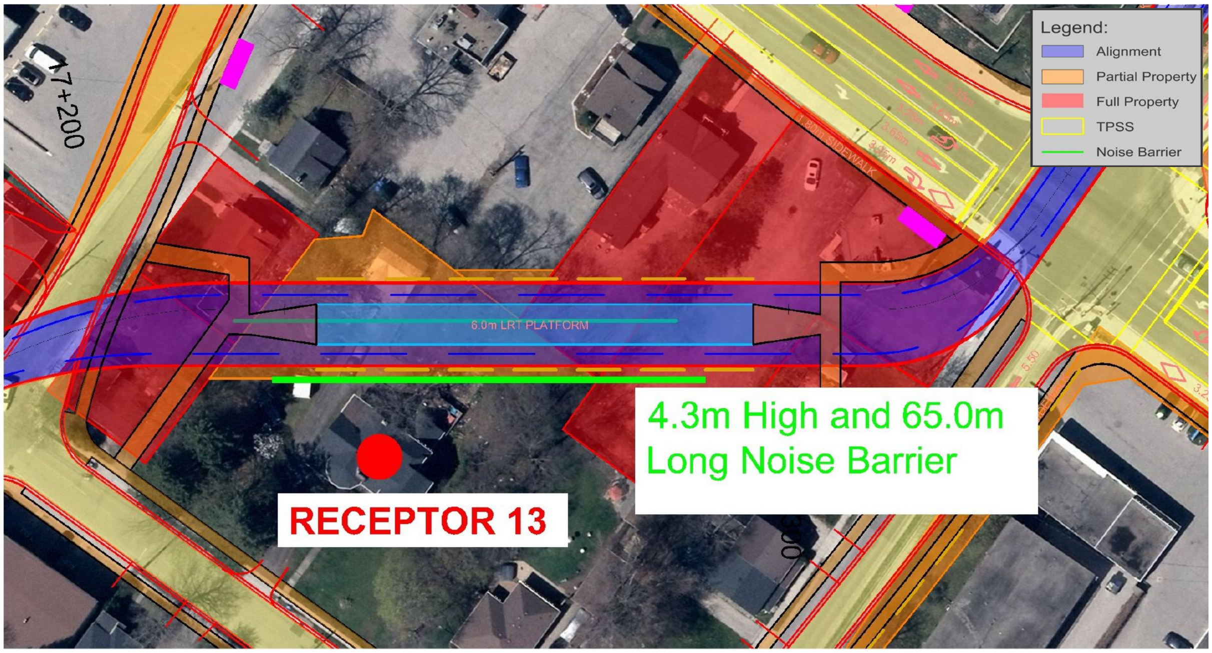


Figure 35: POR 13 Noise Barrier Location

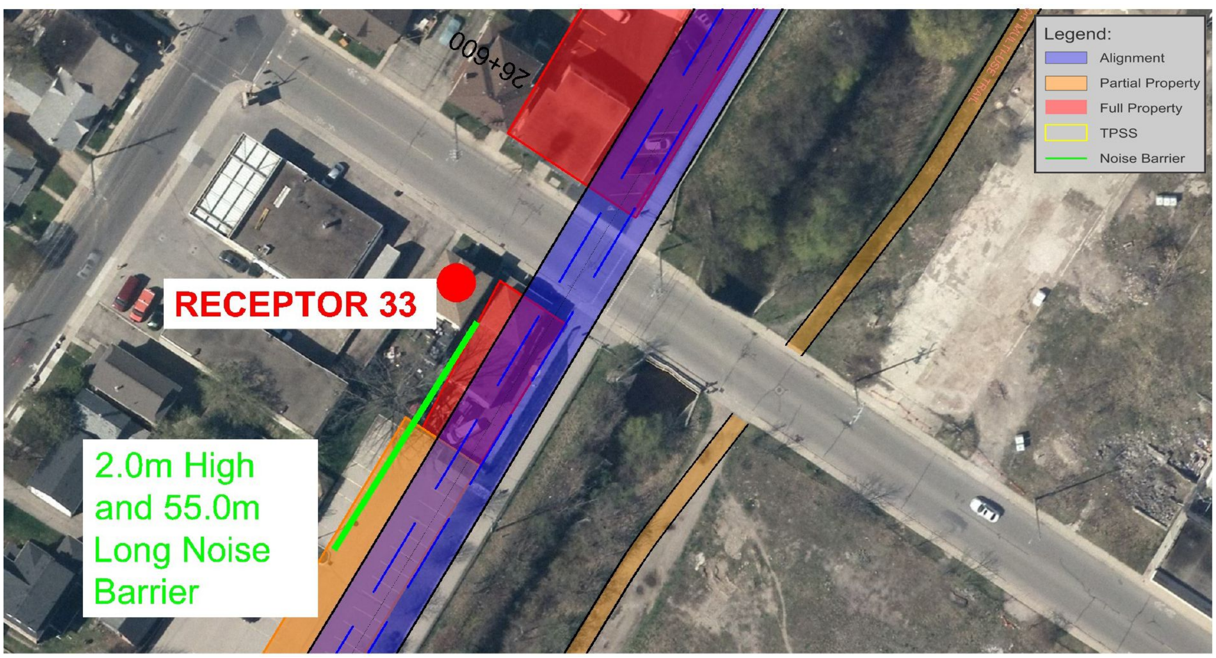


Figure 36: POR 33 Noise Barrier Location

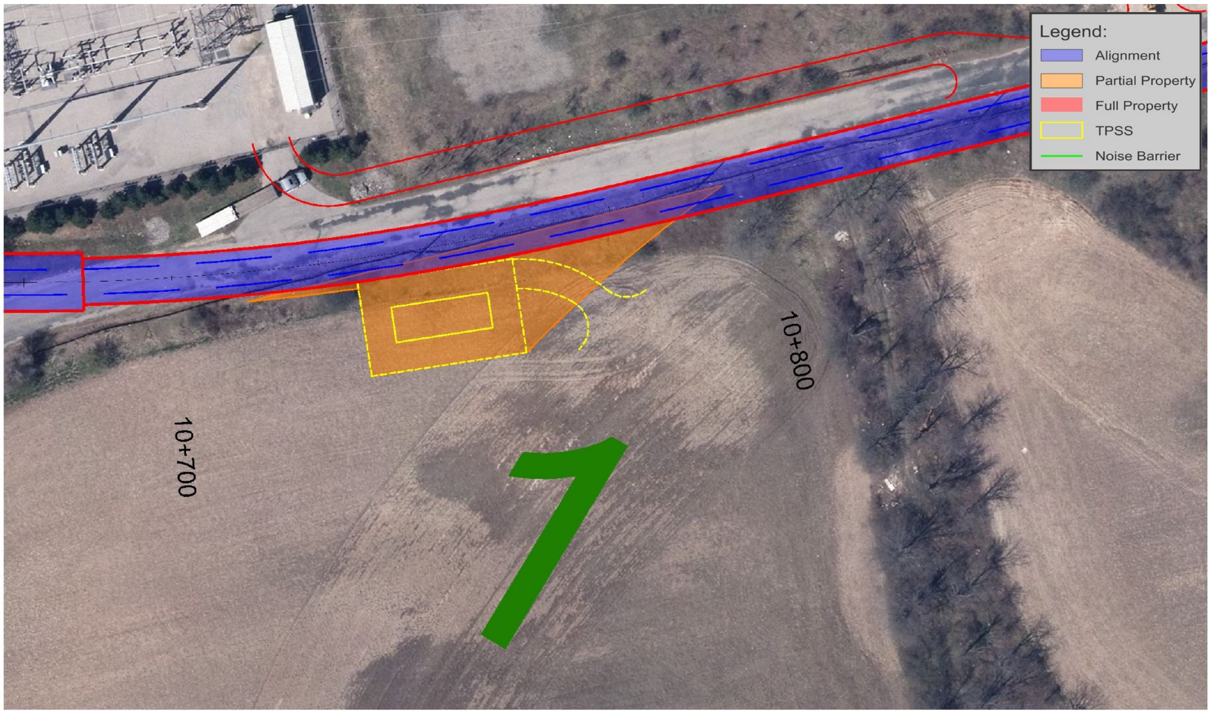


Figure 37: TPSS 1

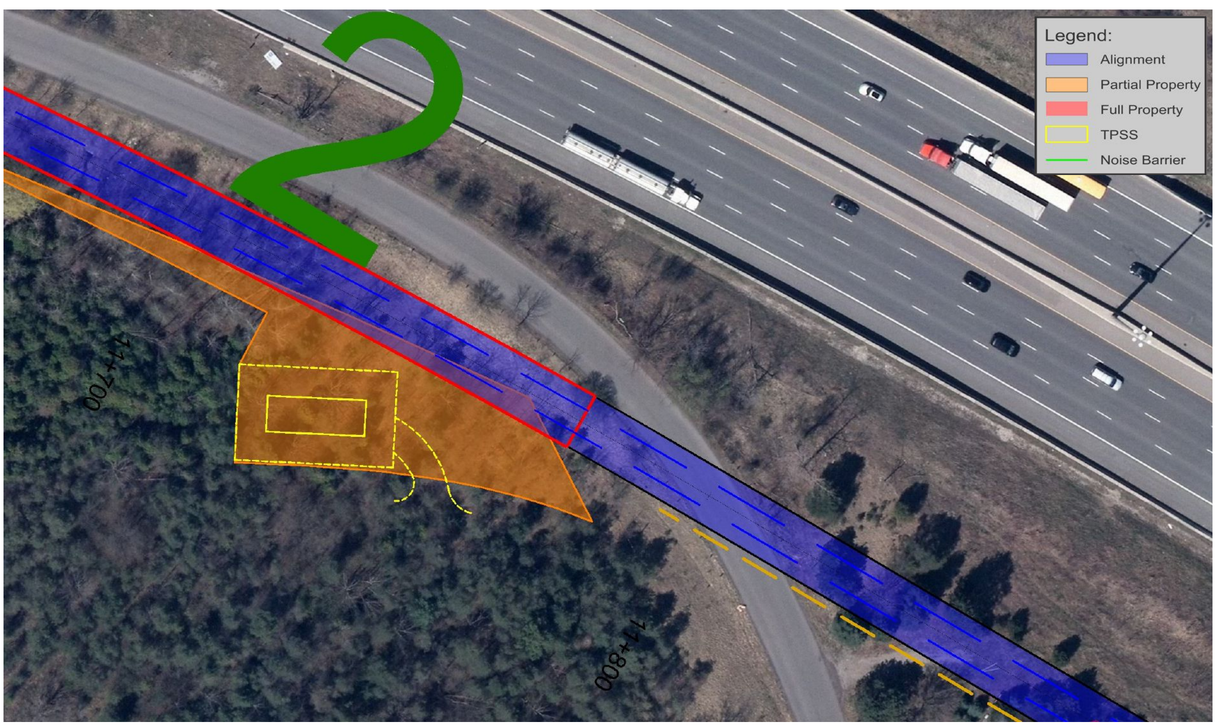


Figure 38: TPSS 2

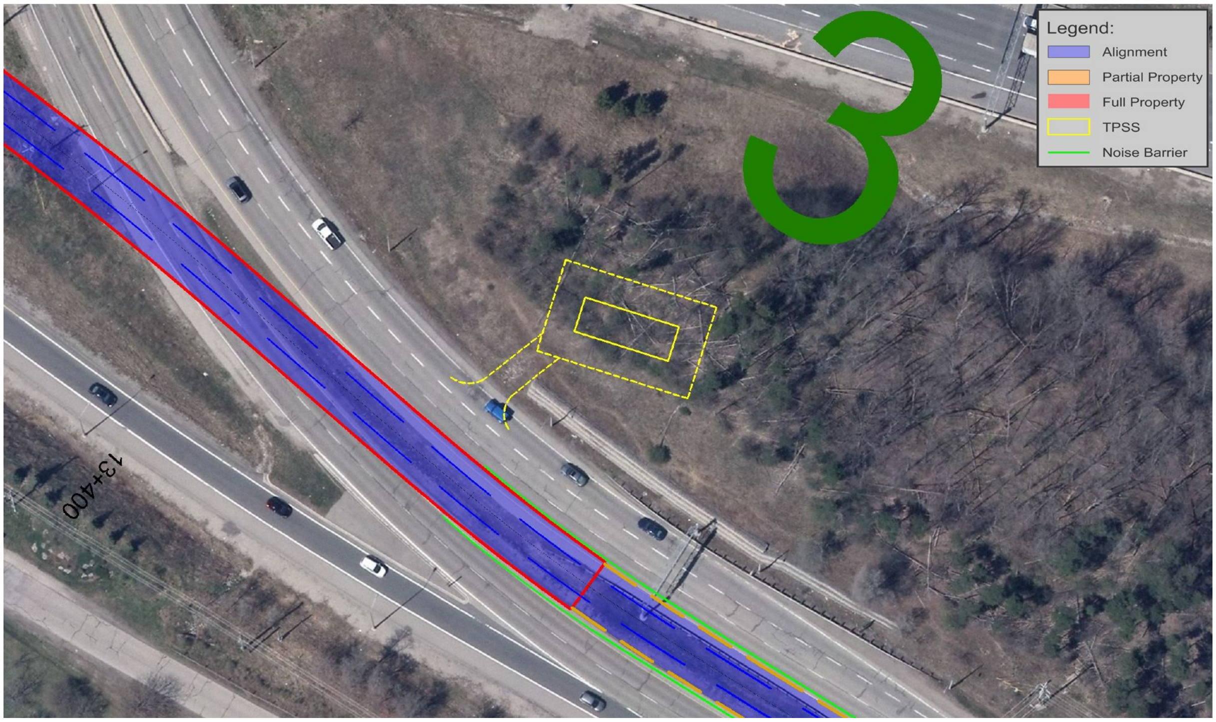


Figure 39: TPSS 3

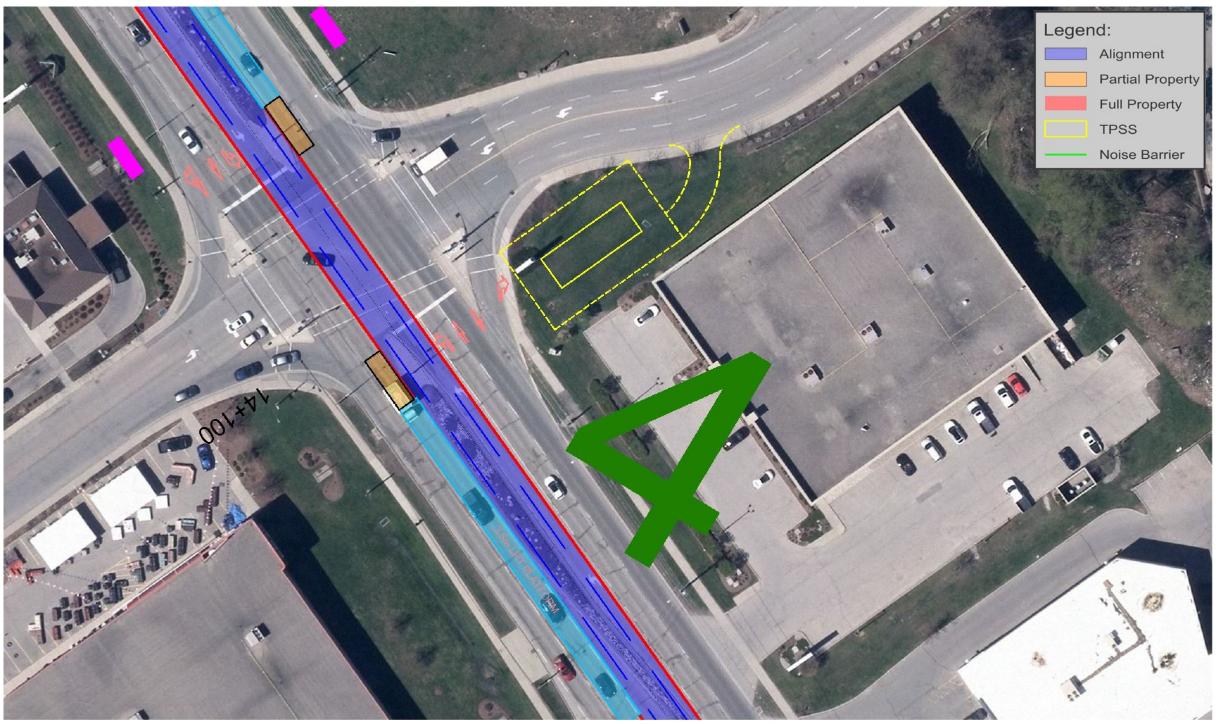


Figure 40: TPSS 4

Figure 41: TPSS 5

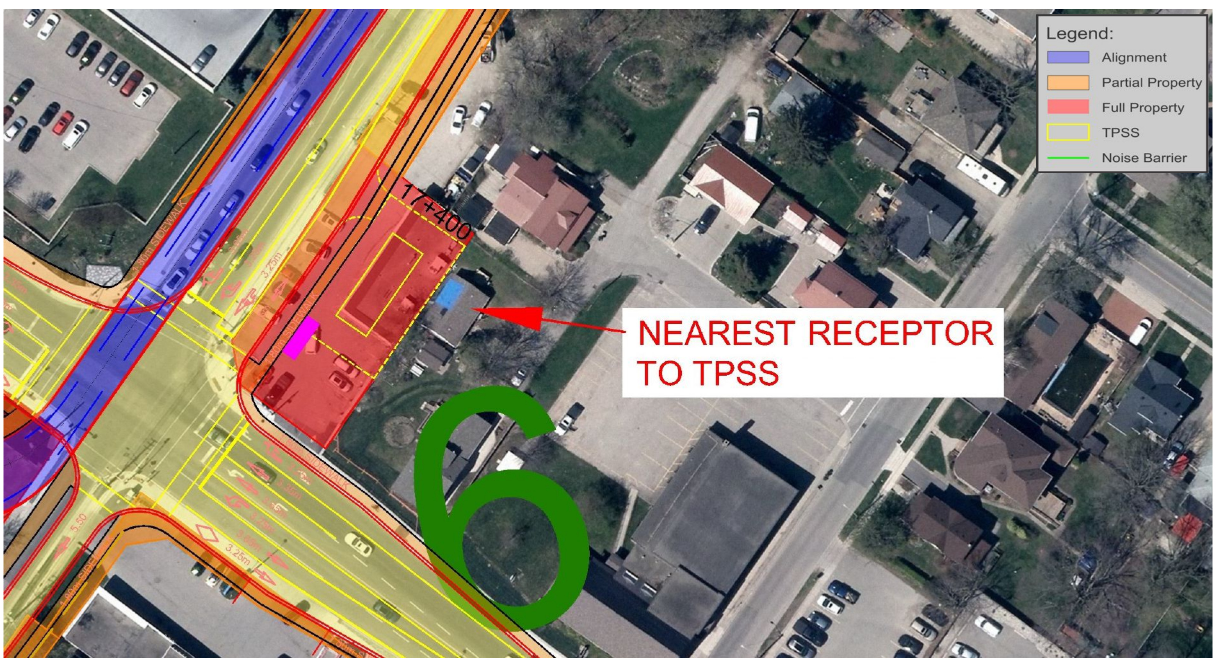


Figure 42: Nearest Receptor to TPSS 6

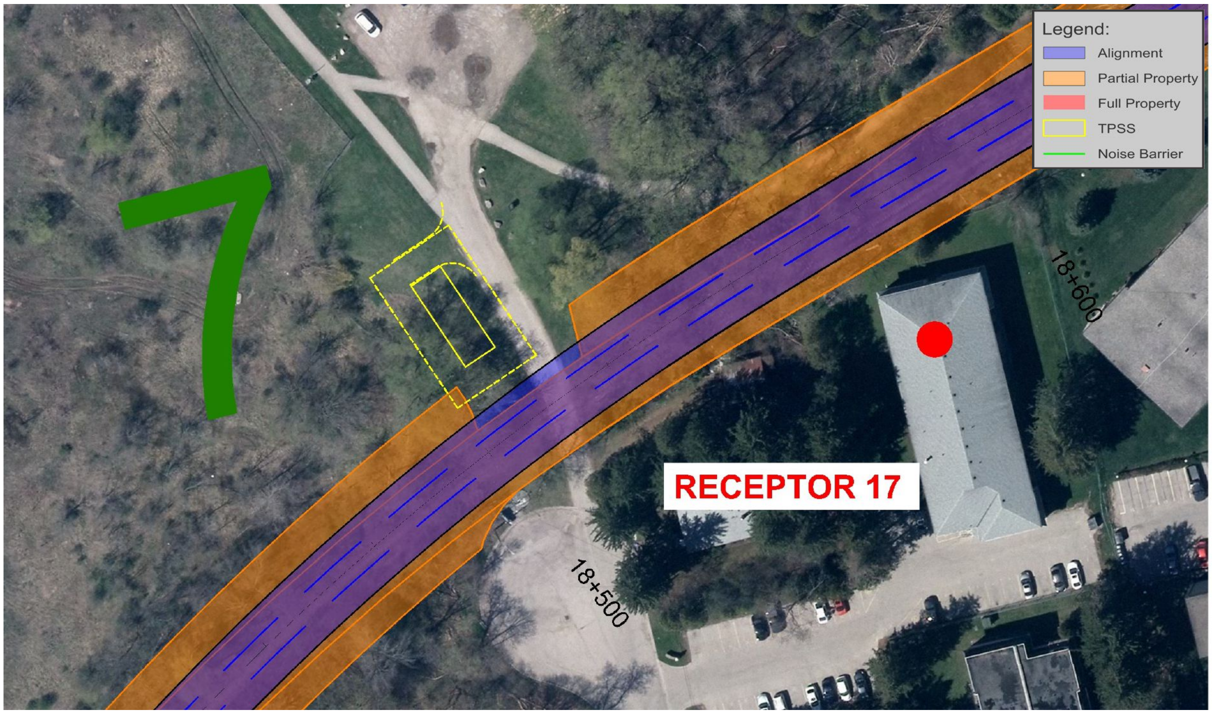


Figure 43: TPSS 7 (Note that Receptor 17 is 50m+ away)

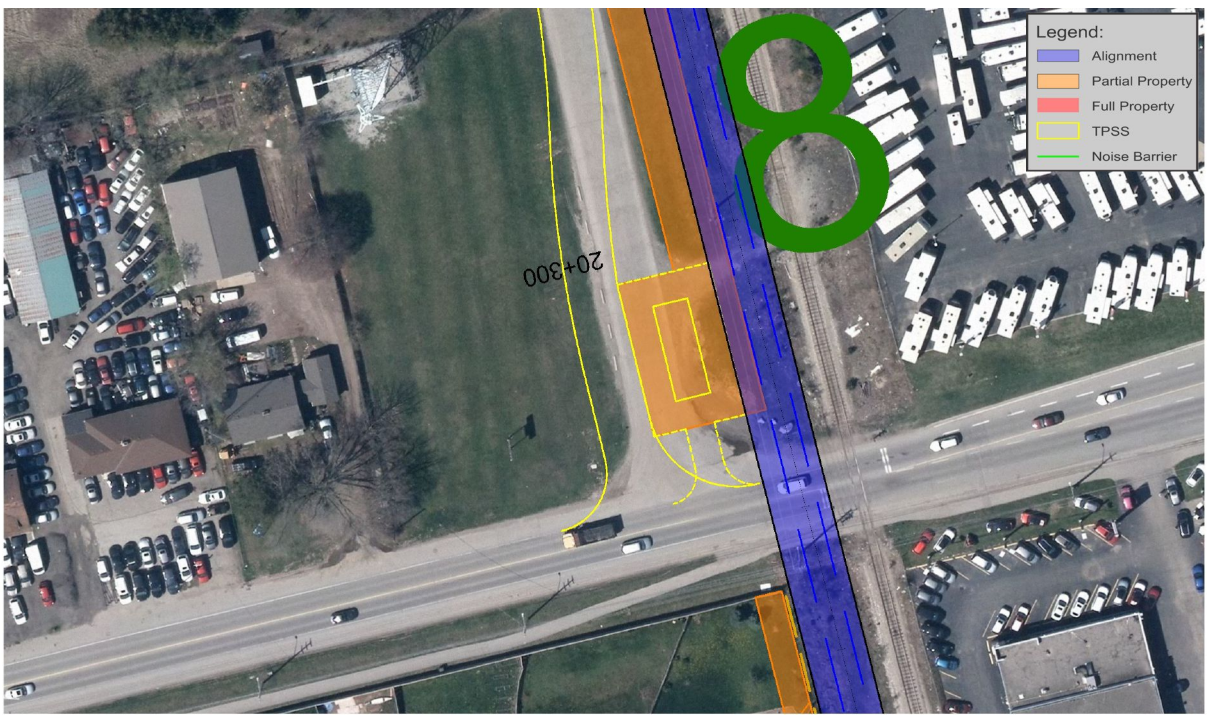


Figure 44: TPSS 8

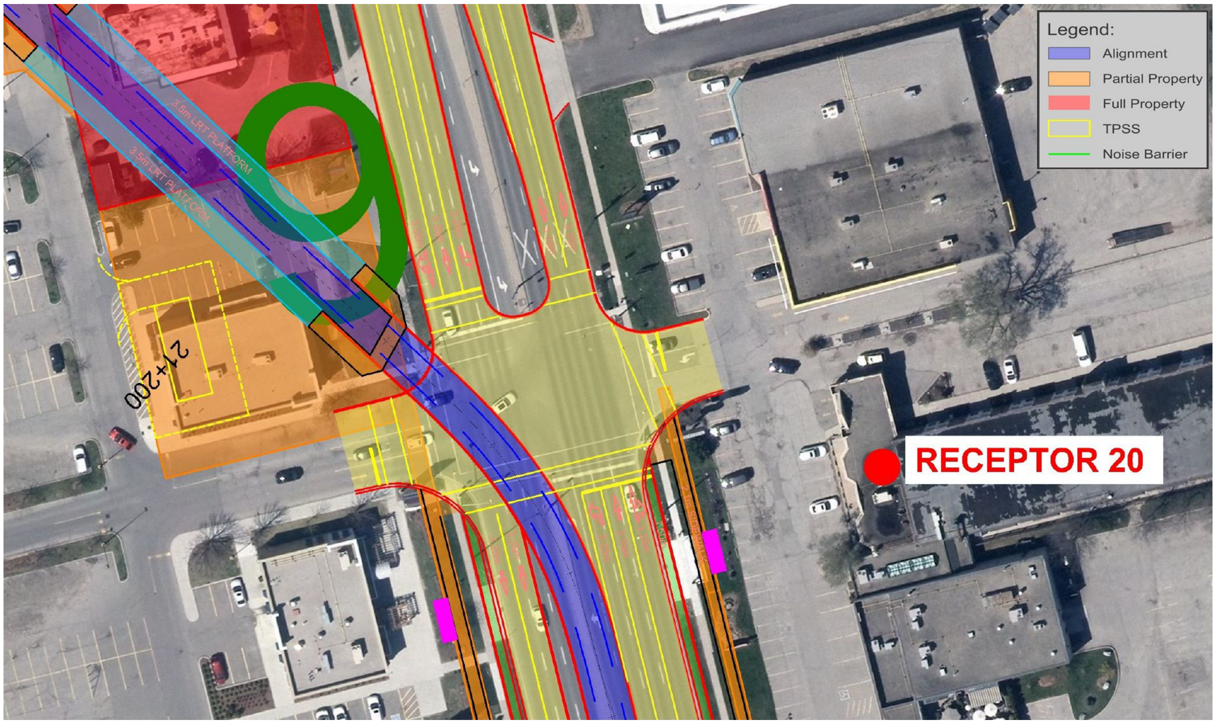


Figure 45: TPSS 9 (Note that Receptor 20 is 50m+ away)

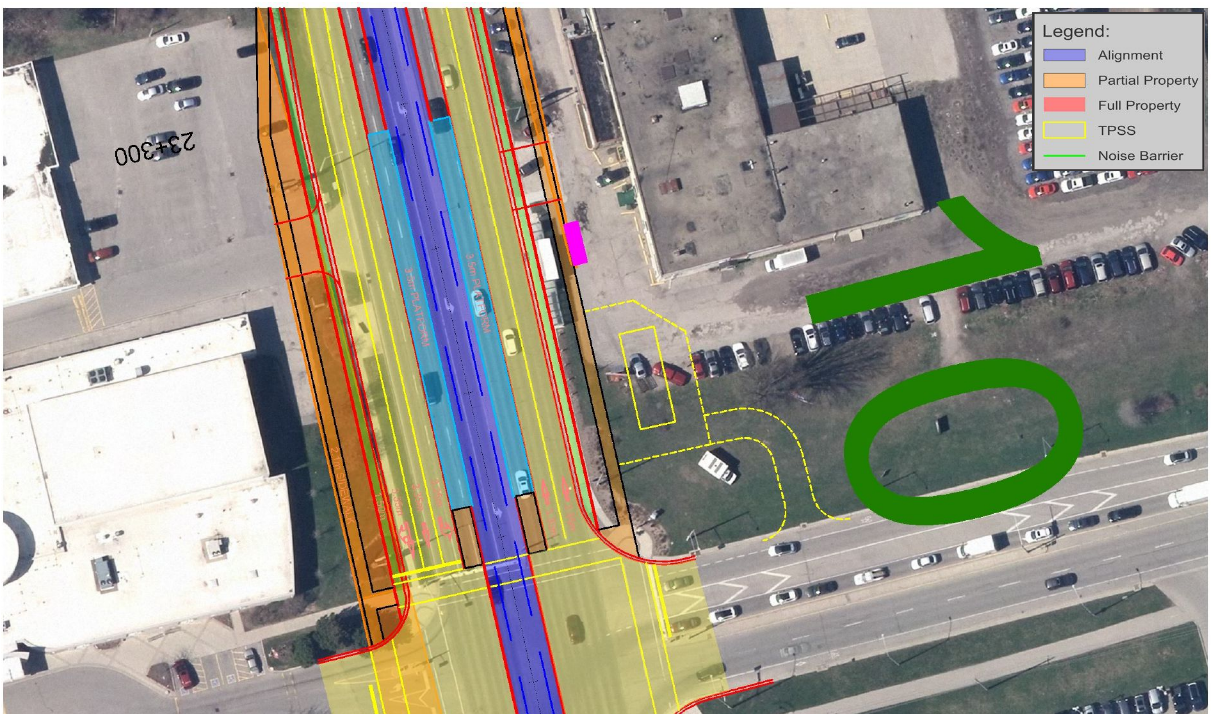


Figure 46: TPSS 10

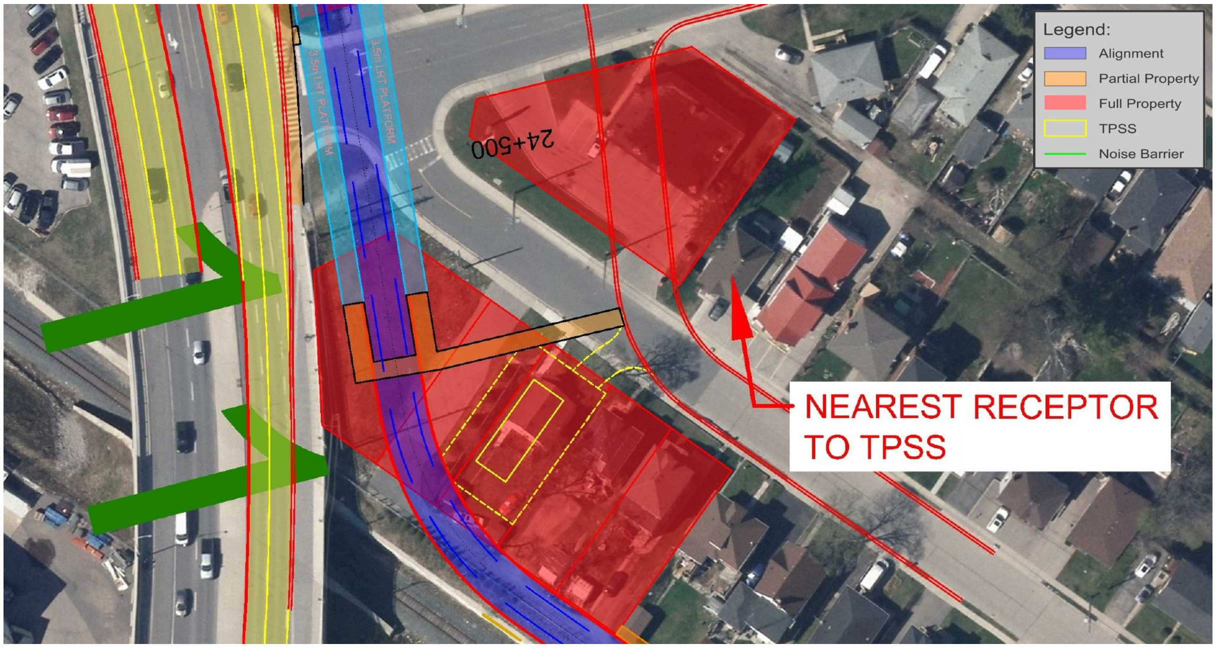


Figure 47: Nearest Receptor to TPSS 11

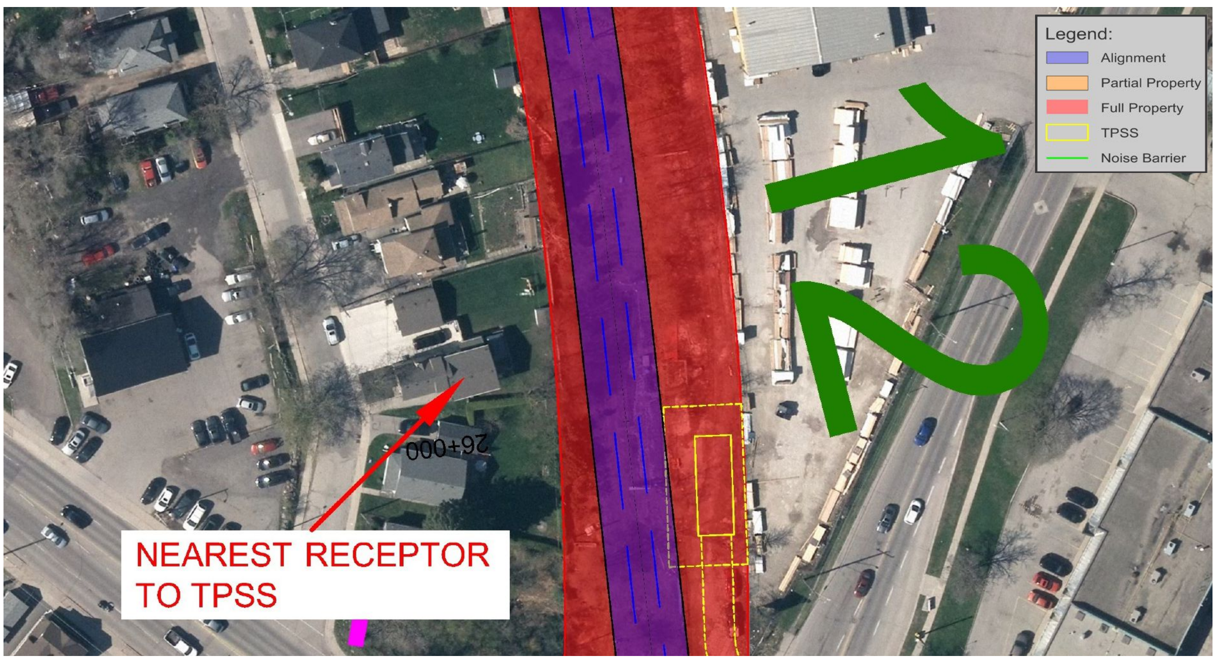


Figure 48: Nearest Receptor to TPSS 12

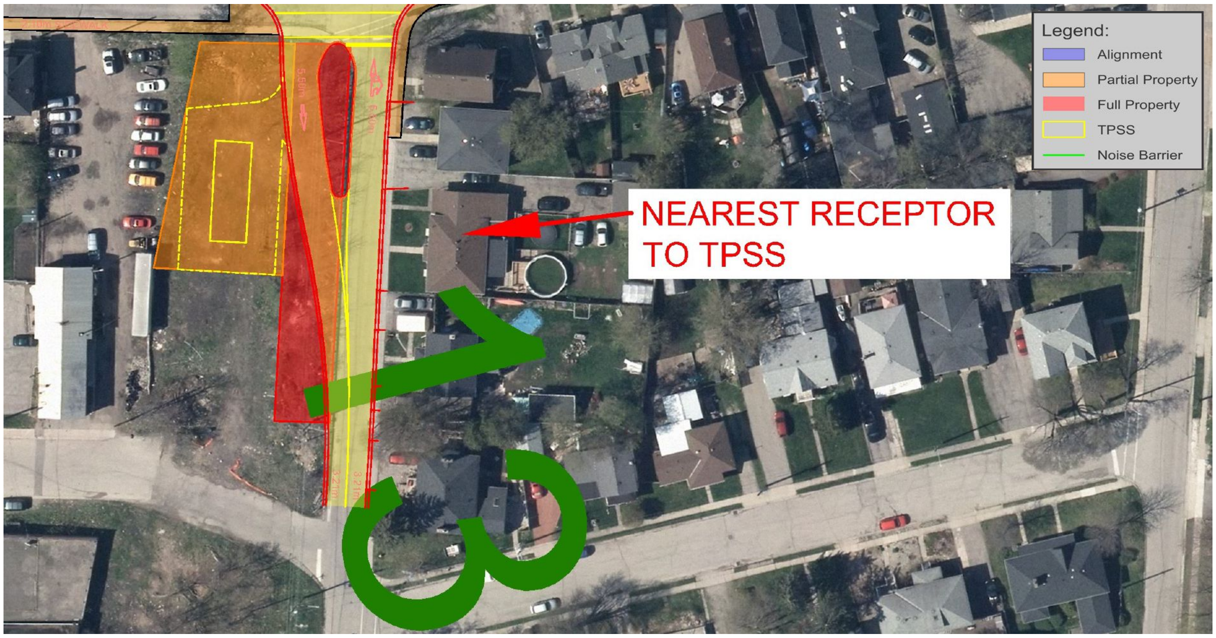


Figure 49: Nearest Receptor to TPSS 13

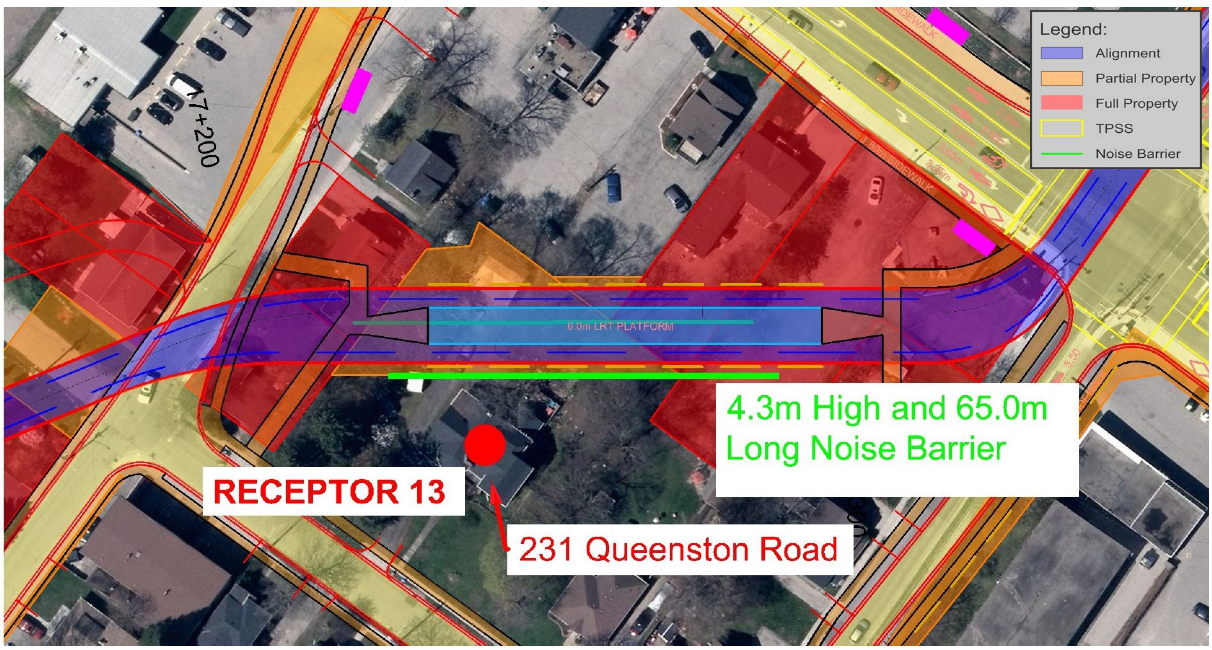


Figure 50: 231 Queenston Road

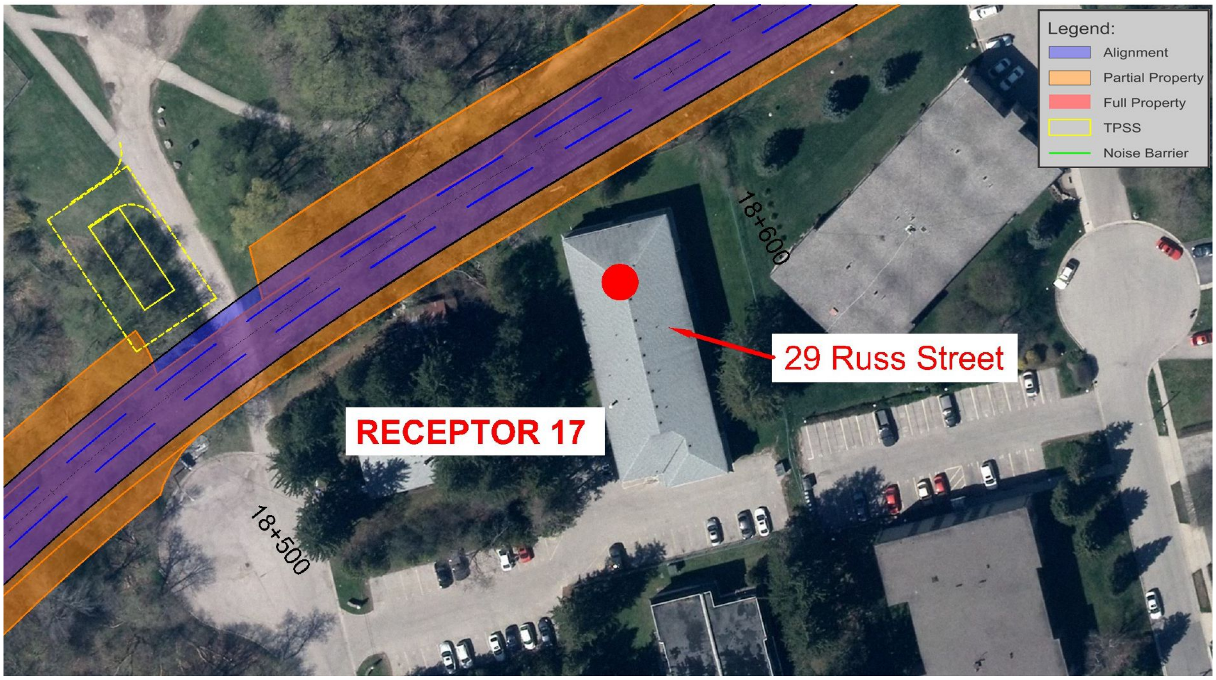


Figure 51: 29 Russ Street

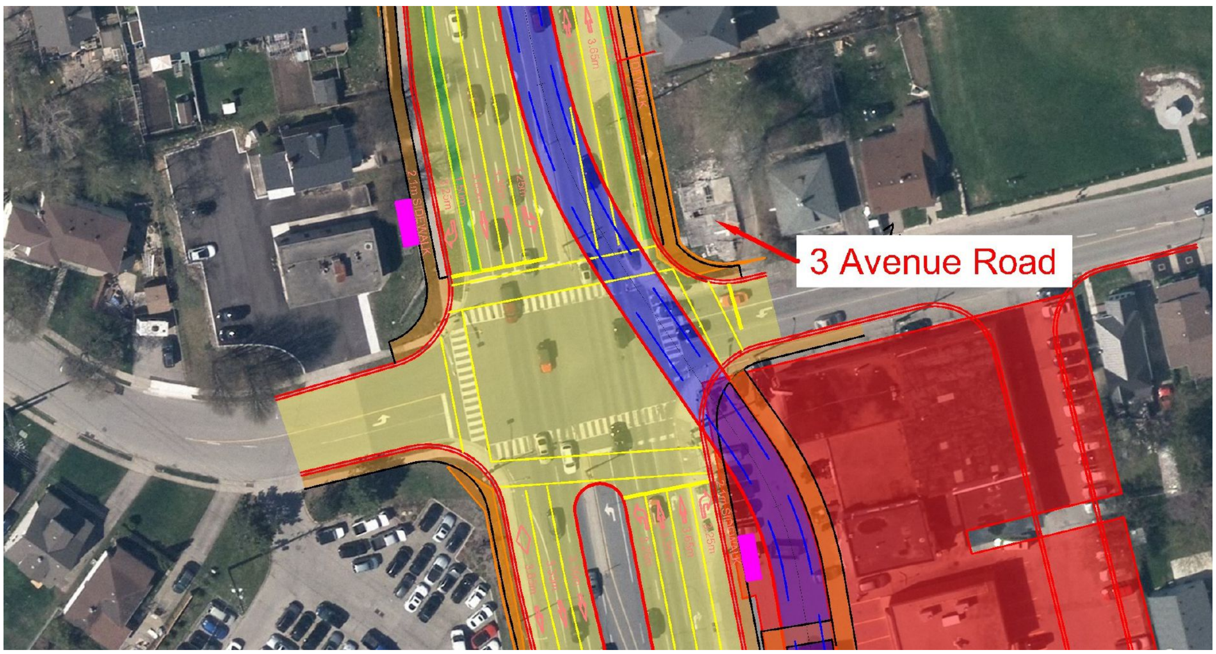


Figure 52: 3 Avenue Road

Figure 53: 159 Samuelson Street

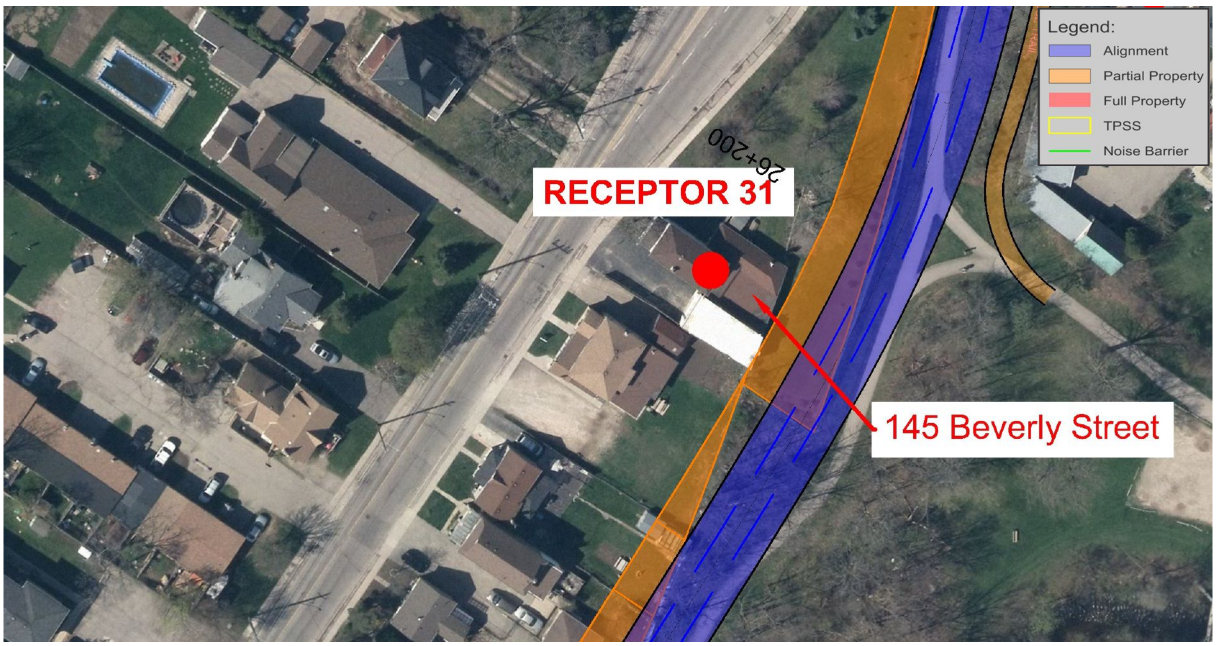


Figure 54: 145 Beverly Street

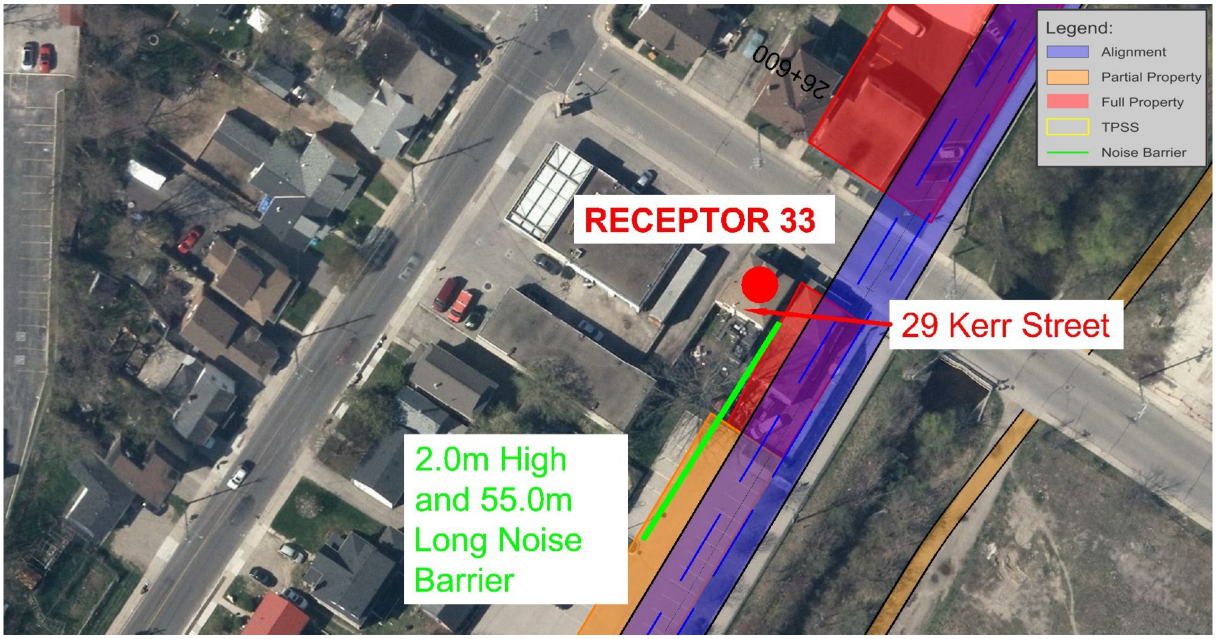


Figure 55: 29 Kerr Street

APPENDIX B: DATA AND SAMPLE CALCULATIONS

Intersection	NB/SB Street	GeoID	Period	By Movement							
				Total Volume				Trucks Only			
				SB	WB	NB	EB	*SB*	*WB*	*NB*	*EB*
King St E and Deer Ridge Dr	King St	16248	2011	22,740	829	16,781	2,985	1,426	11	656	290
		16248	2031 Ph1 LRT	22,003	829	16,334	4,803	3,203	11	737	536
		16248	2031 Ph2 LRT	21,538	829	15,899	4,741	3,212	11	768	537
King St E and Sportsworld Crossing	King St	31432	2011	21,029	1,980	15,133	2,976	316	0	499	15
		31432	2031 Ph1 LRT	18,860	1,980	14,464	2,976	1,992	0	523	15
		31432	2031 Ph2 LRT	18,439	1,980	14,085	2,976	2,002	0	549	15
King St E and Sportsworld Dr	King St	16064	2011	20,947	8,654	15,573	1,650	164	980	233	61
		16064	2031 Ph1 LRT	18,686	5,726	16,861	3,463	1,768	345	407	63
		16064	2031 Ph2 LRT	18,314	5,631	16,605	3,409	1,775	299	471	63
King St E and Tu Ln St	King St	16034	2011 PM	21,997	4,692	13,985	0	288	0	209	0
		16034	2031 Ph1 LRT PM	19,530	4,692	15,233	0	1,141	0	368	0
		16034	2031 Ph2 LRT PM	19,230	4,692	14,984	0	1,153	0	425	0
Shantz Hill Rd and Preston Pkwy	Shantz Hill	16008	2011	13,823	0	11,502	2,431	175	0	216	132
		16008	2031 Ph1 LRT	15,326	0	9,607	3,321	334	0	274	226
		16008	2031 Ph2 LRT	15,215	0	9,413	3,310	335	0	270	226
Fountain St S and Shantz Hill Rd	Fountain St	17179	2011	11,046	0	5,336	12,290	199	0	101	65
		17179	2031 Ph1 LRT	11,799	0	6,735	12,220	240	0	104	126
		17179	2031 Ph2 LRT	11,723	0	6,618	12,154	235	0	107	127
King St E and Eagle St S	Eagle St	17338	2011	5,757	8,028	1,840	11,457	300	161	109	155
		17338	2031 Ph1 LRT	5,922	9,796	0	11,704	293	139	0	128
		17338	2031 Ph2 LRT	5,795	9,804	0	11,567	296	136	0	136
Eagle St N and Speedsville Rd	Speedsville Rd	16278	2011	6,518	5,927	5,966	4,823	19	288	117	310
		16278	2031 Ph1 LRT	13,546	7,821	12,335	5,487	101	357	130	339
		16278	2031 Ph2 LRT	13,372	7,680	12,233	5,390	98	369	139	352
Eagle St N and Industrial Rd	Industrial Rd	15344	2011	2,231	8,651	3,820	7,125	71	582	169	503
		15344	2031 Ph1 LRT	2,464	9,727	4,892	8,442	90	907	283	737
		15344	2031 Ph2 LRT	2,400	10,047	5,666	8,266	94	1,188	290	753
Hespeler Rd and Brooklyne Rd	Hespeler Rd	18120	2011	21,476	1,030	14,883	0	347	39	494	0
		18120	2031 Ph1 LRT	25,392	1,470	17,839	0	370	71	528	0
		18120	2031 Ph2 LRT	23,796	1,380	17,272	0	356	69	519	0
Dundas St N and Beverly St	Beverly St	18248	2011	6,591	8,853	3,830	10,400	343	272	298	222
		18248	2031 Ph1 LRT	7,985	10,814	5,899	13,297	473	152	631	361
		18248	2031 Ph2 LRT	7,997	10,496	5,936	12,745	483	204	528	420
Samuelson St and Elgin St N	Elgin St	19024	2011	4,418	3,878	324	5,368	227	179	10	352
		19024	2031 Ph1 LRT	5,988	4,856	427	6,067	404	224	29	546
		19024	2031 Ph2 LRT	5,873	4,697	423	6,103	413	226	23	545
Main St and Wellington S	Wellington St	14517	2011	3,564	2,467	2,207	2,670	175	62	118	102
		14517	2031 Ph1 LRT	5,243	2,985	3,894	3,384	280	42	347	163
		14517	2031 Ph2 LRT	5,127	3,092	3,898	3,387	277	40	425	100
Ainslie St S and Bruce St	Ainslie St	18305	2011	4,613	1,577	6,017	248	152	74	216	6
		18305	2031 Ph1 LRT	6,337	2,881	7,487	1,843	165	36	207	90
		18305	2031 Ph2 LRT	6,209	2,846	7,298	1,790	173	35	226	109
Hespeler Rd and Avenue	Hespeler Rd	20086	2011	28,503	3,618	20,386	220	435	107	708	0
		20086	2031 Ph1 LRT	33,856	3,941	25,331	220	447	175	779	0
		20086	2031 Ph2 LRT	31,604	4,035	24,270	220	406	198	762	0

Intersection	NB/SB Street	GeoID	Period	By Approach				
				Total Volume				
				North Leg	East Leg	South Leg	West Leg	North Leg
King St E and Deer Ridge Dr	King St	16248	2011	40,206	1,647	37,962	6,854	2,489
		16248	2031 Ph1 LRT	40,378	1,647	35,347	9,939	4,671
		16248	2031 Ph2 LRT	39,443	1,647	34,491	9,859	4,708
King St E and Sportsworld Crossing	King St	31432	2011	37,843	3,164	37,080	4,148	973
		31432	2031 Ph1 LRT	35,227	3,164	34,047	4,148	2,731
		31432	2031 Ph2 LRT	34,370	3,164	33,279	4,148	2,771
King St E and Sportsworld Dr	King St	16064	2011	36,308	14,145	39,461	3,734	670
		16064	2031 Ph1 LRT	33,408	10,633	38,202	7,230	2,300
		16064	2031 Ph2 LRT	32,673	10,498	37,636	7,110	2,335
King St E and Tu Ln St	King St	16034	2011 PM	36,146	5,830	39,373	0	499
		16034	2031 Ph1 LRT PM	34,927	5,830	38,154	0	1,512
		16034	2031 Ph2 LRT PM	34,378	5,830	37,605	0	1,583
Shantz Hill Rd and Preston Pkwy	Shantz Hill	16008	2011	25,325	0	24,670	5,518	388
		16008	2031 Ph1 LRT	25,771	0	22,698	8,039	677
		16008	2031 Ph2 LRT	25,484	0	22,432	7,960	673
Fountain St S and Shantz Hill Rd	Fountain St	17179	2011	21,456	364	12,744	22,780	345
		17179	2031 Ph1 LRT	23,302	364	16,857	20,985	453
		17179	2031 Ph2 LRT	23,166	364	16,719	20,743	451
King St E and Eagle St S	Eagle St	17338	2011	10,151	16,669	2,964	24,379	489
		17338	2031 Ph1 LRT	9,958	18,575	1,163	25,691	382
		17338	2031 Ph2 LRT	9,648	18,677	1,062	25,487	386
Eagle St N and Speedsville Rd	Speedsville Rd	16278	2011	12,000	11,574	12,058	10,837	95
		16278	2031 Ph1 LRT	28,586	15,159	22,309	12,323	266
		16278	2031 Ph2 LRT	28,247	14,870	22,084	12,147	268
Eagle St N and Industrial Rd	Industrial Rd	15344	2011	2,715	18,965	6,799	15,176	89
		15344	2031 Ph1 LRT	3,567	21,719	8,385	17,381	126
		15344	2031 Ph2 LRT	3,474	22,363	9,879	17,041	128
Hespeler Rd and Brooklyne Rd	Hespeler Rd	18120	2011	36,395	3,232	35,154	0	865
		18120	2031 Ph1 LRT	43,992	3,580	41,830	0	942
		18120	2031 Ph2 LRT	41,606	3,292	39,997	0	915
Dundas St N and Beverly St	Beverly St	18248	2011	12,424	19,440	7,826	19,658	791
		18248	2031 Ph1 LRT	15,049	22,935	12,006	25,999	1,189
		18248	2031 Ph2 LRT	15,186	22,490	11,707	24,965	1,199
Samuelson St and Elgin St N	Elgin St	19024	2011	8,241	7,248	475	12,011	566
		19024	2031 Ph1 LRT	11,164	8,712	676	14,124	937
		19024	2031 Ph2 LRT	11,079	8,303	664	14,147	927
Main St and Wellington S	Wellington St	14517	2011	6,371	4,888	4,323	6,235	346
		14517	2031 Ph1 LRT	10,036	5,523	7,404	8,050	737
		14517	2031 Ph2 LRT	9,930	5,658	7,361	8,058	715
Ainslie St S and Bruce St	Ainslie St	18305	2011	10,252	2,582	10,998	1,080	287
		18305	2031 Ph1 LRT	13,376	5,317	14,830	3,572	395
		18305	2031 Ph2 LRT	13,047	5,230	14,464	3,545	434
Hespeler Rd and Avenue	Hespeler Rd	20086	2011	48,669	7,110	49,046	629	1,163
		20086	2031 Ph1 LRT	59,623	7,193	59,251	629	1,230
		20086	2031 Ph2 LRT	56,165	7,417	56,046	629	1,183

Trucks Only			Cars Total				Half Truck Volume				Cars Daytime				Cars Nighttime				Half Truck Volume Daytime				Half Truck Volume Nighttime			
East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg	North Leg	East Leg	South Leg	West Leg
11	974	845	37,717	1,636	36,988	6,009	1245	6	487	423	33945	1472	33289	5408	3,772	164	3,699	601	1120	5	438	380	124	1	49	42
11	2,745	1,403	35,707	1,636	32,602	8,536	2335	6	1373	702	32137	1472	29342	7682	3,571	164	3,260	854	2102	5	1235	632	234	1	137	70
11	2,786	1,405	34,735	1,636	31,705	8,454	2354	6	1393	702	31261	1472	28535	7609	3,473	164	3,171	845	2119	5	1254	632	235	1	139	70
0	670	21	36,870	3,164	36,410	4,128	487	0	335	10	33183	2847	32769	3715	3,687	316	3,641	413	438	0	302	9	49	0	34	1
0	2,375	21	32,496	3,164	31,672	4,128	1365	0	1188	10	29246	2847	28505	3715	3,250	316	3,167	413	1229	0	35	9	137	0	1153	1
0	2,409	21	31,599	3,164	30,870	4,128	1385	0	1205	10	28439	2847	27783	3715	3,160	316	3,087	413	1247	0	1084	9	139	0	120	1
1,269	546	251	35,638	12,875	38,915	3,483	335	635	273	126	32075	11588	35024	3135	3,564	1,288	3,892	348	301	571	245	113	33	63	27	13
792	1,653	265	31,108	9,841	36,549	6,966	1150	396	827	132	27997	8857	32894	6269	3,111	984	3,655	697	1035	356	744	119	115	40	83	13
729	1,732	264	30,338	9,769	35,903	6,846	1167	365	866	132	27304	8792	32313	6161	3,034	977	3,590	685	1051	328	780	119	117	36	87	13
0	541	0	35,646	5,830	38,831	0	250	0	271	0	32082	5247	34948	0	3,565	583	3,883	0	225	0	244	0	25	0	27	0
0	1,706	0	33,414	5,830	36,448	0	756	0	853	0	30073	5247	32803	0	3,341	583	3,645	0	681	0	768	0	76	0	85	0
0	1,782	0	32,795	5,830	35,824	0	791	0	891	0	29516	5247	32241	0	3,280	583	3,582	0	712	0	802	0	79	0	89	0
0	286	318	24,937	0	24,384	5,200	194	0	143	159	22444	0	21946	4680	2,494	0	2,438	520	174	0	128	143	19	0	14	16
0	409	504	25,095	0	22,288	7,535	338	0	205	252	22585	0	20059	6782	2,509	0	2,229	754	304	0	184	227	34	0	20	25
0	406	504	24,811	0	22,026	7,456	336	0	203	252	22330	0	19824	6710	2,481	0	2,203	746	303	0	183	227	34	0	20	25
0	133	262	21,111	364	12,611	22,518	173	0	66	131	19000	327	11350	20266	2,111	36	1,261	2,252	155	0	60	118	17	0	7	13
0	113	376	22,849	364	16,744	20,608	227	0	56	188	20564	327	15069	18547	2,285	36	1,674	2,061	204	0	51	169	23	0	6	19
0	116	373	22,715	364	16,603	20,370	225	0	58	186	20443	327	14943	18333	2,271	36	1,660	2,037	203	0	52	168	23	0	6	19
194	154	569	9,663	16,475	2,810	23,810	244	97	77	285	8697	14828	2529	21429	966	1,648	281	2,381	220	87	69	256	24	10	8	28
201	84	378	9,576	18,374	1,079	25,313	191	101	42	189	8618	16537	971	22782	958	1,837	108	2,531	172	90	38	170	19	10	4	19
205	84	380	9,262	18,472	978	25,107	193	102	42	190	8335	16625	881	22596	926	1,847	98	2,511	174	92	38	171	19	10	4	19
591	160	662	11,905	10,982	11,898	10,176	48	296	80	331	10714	9884	10708	9158	1,190	1,098	1,190	1,018	43	266	72	298	5	30	8	33
695	221	717	28,320	14,464	22,089	11,606	133	348	110	359	25488	13017	19880	10445	2,832	1,446	2,209	1,161	120	313	99	323	13	35	11	36
716	229	752	27,979	14,154	21,855	11,395	134	358	114	376	25181	12738	19670	10255	2,798	1,415	2,186	1,139	121	322	103	339	13	36	11	38
1,203	413	1,031	2,626	17,762	6,386	14,145	45	601	206	516	2364	15986	5748	12731	263	1,776	639	1,415	40	541	186	464	4	60	21	52
1,858	701	1,486	3,441	19,861	7,684	15,895	63	929	351	743	3097	17875	6916	14306	344	1,986	768	1,590	57	836	316	669	6	93	35	74
2,175	1,077	1,541	3,346	20,188	8,802	15,500	64	1088	539	771	3011	18169	7922	13950	335	2,019	880	1,550	58	979	485	694	6	109	54	77
99	808	0	35,530	3,133	34,345	0	433	50	404	0	31977	2820	30911	0	3,553	313	3,435	0	389	45	364	0	43	5	40	0
149	866	0	43,050	3,431	40,964	0	471	74	433	0	38745	3088	36868	0	4,305	343	4,096	0	424	67	390	0	47	7	43	0
145	848	0	40,691	3,147	39,150	0	458	72	424	0	36622	2832	35235	0	4,069	315	3,915	0	412	65	381	0	46	7	42	0
418	493	510	11,633	19,022	7,332	19,148	395	209	247	255	10470	17120	6599	17233	1,163	1,902	733	1,915	356	188	222	229	40	21	25	25
305	896	760	13,860	22,630	11,110	25,239	595	153	448	380	12474	20367	9999	22715	1,386	2,263	1,111	2,524	535	137	403	342	59	15	45	38
346	877	796	13,986	22,144	10,830	24,169	600	173	438	398	12588	19930	9747	21752	1,399	2,214	1,083	2,417	540	156	394	358	60	17	44	40
343	11	675	7,676	6,905	464	11,336	283	172	6	338	6908	6214	417	10202	768	690	46	1,134	255	154	5	304	28	17	1	34
467	38	1,002	10,228	8,245	638	13,121	468	233	19	501	9205	7421	574	11809	1,023	825	64	1,312	421	210	17	451	47	23	2	50
475	32	1,006	10,152	7,828	633	13,141	464	238	16	503	9136	7045	570	11827	1,015	783	63	1,314	417	214	14	453	46	24	2	50
130	213	228	6,024	4,759	4,109	6,007	173	65	107	114	5422	4283	3698	5407	602	476	411	601	156	58	96	102	17	6	11	11
123	512	297	9,298	5,400	6,891	7,753	369	61	256	148	8368	4860	6202	6978	930	540	689	775	332	55	231	134	37	6	26	15
121	585	233	9,215	5,537	6,775	7,825	357	61	293	116	8293	4983	6098	7043	921	554	678	783	322	55	263	105	36	6	29	12
129	384	50	9,966	2,453	10,613	1,031	143	65	192	25	8969	2207	9552	928	997	245	1,061	103	129	58	173	22	14	6	19	2
127	361	120	12,980	5,191	14,469	3,453	198	63	181	60	11682	4671	13022	3107	1,298	519	1,447	345	178	57	163	54	20	6	18	6
139	399	127	12,613	5,091	14,065	3,418	217	69	200	64	11352	4582	12658	3076	1,261	509	1,406	342	195	62	180	57	22	7	20	6
199	1,171	0	47,506	6,911	47,875	629	581	100	586	0	42755	6220	43088	566	4,751	691	4,788	63	523	90	527	0	58	10	59	0
307	1,273	0	58,393	6,885	57,978	629	615	154	637	0	52554	6197	52180	566	5,839	689	5,798	63	554	138	573	0	62	15	64	0
313	1,237	0	54,982	7,104	54,809	629	592	156	619	0	49484	6394	49328	566	5,498	710	5,481	63	532	141	557	0	59	16	62	0

ISO 9613-2 - Simplified Method for Calculating Overall (dBA) Sound Level **v4.12**
Assumptions: Source is not tonal, Barrier Effect (500 Hz) Reference

Project: **Waterloo LRT Stage 2**
Location: **TPSS 6**

			Overall SPL w/No Barrier:	**45.0**	**dBA**
Source to Receiver:	**5.0**	m	Temp. (0/10/20/30°C):	**20**	°C
Source Height:	**0.00**	m	Rel. Humidity (10-90%):	**50**	%
Source Base Elev:	**0.00**	m			
Top of Source Elev:	0.00	m	Foliage depth, A(foilage), 200m max:	**0.00**	m
Receiver Height:	**10.00**	m	Housing depth:	**0.00**	m
Receiver Base Elev:	**0.00**	m	Housing density, A(housing):	**0.00**	%
Top of Receiver Elev:	10.00	m	Industrial depth, A(site):	**0.00**	m

Ground Condition (**F**lat/Gentle slope or **E**levated): **E**

Mean Propogation Height:	5.00	m			
Minimum Elevation S-R:	**0.00**	m	N/A	**0.00**	m
Receiver to B1:	**0.00**	m	Barrier Thickness:	**0.00**	m
Barrier Height (B1):	**0.00**	m	Barrier Length (N/A):	**999.00**	m
B1 Base Elevation:	**0.00**	m			
Receiver to B2 (N/A) -->	**0.00**	m	Barrier Length (N/A):	**999.00**	m
Barrier Height (B2):	**0.00**	m			
B2 Base Elevation:	**0.00**	m			

SUMMARY **NO BARRIER**

Use PWL or SPL (P/S)? Impulse Data (Y/N): **N**
p

Source PWL (dBA re pW):	**67.0**	**dBA**
Source Area Adjustment (dB):	0.0	dB
Source Directivity (dB):	**0.0**	dB

Source PWL (dBA):	**67.0**	**dBA**
A(directivity):	-3.0	dB
A(div):	25.0	dB
A(gr)	0.0	dB
A(bar), No Barrier:	0.0	dB
A(air):	0.0	dB
A(foilage):	0.0	dB
A(housing):	0.0	dB
A(site):	0.0	dB

```
STAMSON 5.0        NORMAL REPORT        Date: 04-03-2020 60:43:57
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec10lrt.te          Time Period: Day/Night 16/8 hours
Description: POR10 LRT Sound Level Calculations
```

LRT VOLUME INCREASED BY 10

```
Road data, segment # 1: LRT (day/night)
---------------------------------------
Car traffic volume  :     0/0     veh/TimePeriod
Medium truck volume :  4880/640   veh/TimePeriod
Heavy truck volume  :     0/0     veh/TimePeriod
Posted speed limit  :    50 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: LRT (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  :  18.00 / 18.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00

Results segment # 1: LRT (day)
------------------------------
Source height = 0.50 m

ROAD (0.00 + 67.82 + 0.00) = 67.82 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  68.61   0.00  -0.79   0.00   0.00   0.00   0.00  67.82
--------------------------------------------------------------------------
Segment Leq : 67.82 dBA

Total Leq All Segments: 57.82 dBA (10 dB correction down to account for 10
times volume increase)

Results segment # 1: LRT (night)
--------------------------------
Source height = 0.50 m

ROAD (0.00 + 62.01 + 0.00) = 62.01 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  62.80   0.00  -0.79   0.00   0.00   0.00   0.00  62.01
----------------------------------------------------------------------------

Segment Leq : 62.01 dBA

Total Leq All Segments: 52.01 dBA (10 dB corrction down to account for 10
times volume increase)


TOTAL Leq FROM ALL SOURCES (DAY): 57.82
                         (NIGHT): 52.01
```

```
STAMSON 5.0        SUMMARY REPORT        Date: 04-03-2020 63:02:36
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec10ph2.te          Time Period: Day/Night 16/8 hours
Description: POR10 With Project Traffic Sound Level Calculations


Road data, segment # 1: King Street (day/night)
-----------------------------------------------
Car traffic volume  : 19824/2203  veh/TimePeriod
Medium truck volume :   183/20    veh/TimePeriod
Heavy truck volume  :   183/20    veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: King Street (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  :  18.00 / 18.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00

Result summary (day)
--------------------
                    !  source  !   Road   !  Total
                    !  height  !   Leq    !   Leq
                    !   (m)    !  (dBA)   !  (dBA)
--------------------+----------+----------+----------
 1.King Street      !     0.98 !    66.40 !    66.40
--------------------+----------+----------+----------
                      Total                    66.40 dBA

Result summary (night)
----------------------

                    !  source  !   Road   !  Total
                    !  height  !   Leq    !   Leq
                    !   (m)    !  (dBA)   !  (dBA)
--------------------+----------+----------+----------
 1.King Street      !     0.97 !    59.89 !    59.89
--------------------+----------+----------+----------
                      Total                    59.89 dBA


TOTAL Leq FROM ALL SOURCES (DAY): 66.40
                         (NIGHT): 59.89
```

STAMSON 5.0   NORMAL REPORT   Date: 04-03-2020 62:42:25
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec33lrt.te   Time Period: Day/Night 16/8 hours
Description: POR33 LRT Sound Level Calculations

Distance Doubled and LRT Volume Increased by 10

Road data, segment # 1: LRT (day/night)

Car traffic volume	: 0/0	veh/TimePeriod
Medium truck volume	: 4880/640	veh/TimePeriod
Heavy truck volume	: 0/0	veh/TimePeriod
Posted speed limit	: 50 km/h	
Road gradient	: 0 %	
Road pavement	: 1 (Typical asphalt or concrete)	

Data for Segment # 1: LRT (day/night)

Angle1 Angle2	: -90.00 deg 90.00 deg/0.00 deg	90.00 deg
Wood depth	: 0	(No woods.)
No of house rows	: 0 / 0	
Surface	: 2	(Reflective ground surface)
Receiver source distance	: 20.00 / 20.00 m	
Receiver height	: 1.50 / 4.50 m	
Topography	: 1	(Flat/gentle slope; no barrier)
Reference angle	: 0.00	

Results segment # 1: LRT (day)

Source height = 0.50 m

ROAD (0.00 + 67.36 + 0.00) = 67.36 dBA

Angle1	Angle2	Alpha	RefLeq	P.Adj	D.Adj	F.Adj	W.Adj	H.Adj	B.Adj	SubLeq
-90	90	0.00	68.61	0.00	-1.25	0.00	0.00	0.00	0.00	67.36

Segment Leq : 67.36 dBA

Total Leq All Segments: 60.36 dBA (10 dB correction down to account for volume increase and 3 dB correction up to account for doubling distance)

Results segment # 1: LRT (night)

Source height = 0.50 m

ROAD (0.00 + 58.54 + 0.00) = 58.54 dBA

Angle1	Angle2	Alpha	RefLeq	P.Adj	D.Adj	F.Adj	W.Adj	H.Adj	B.Adj	SubLeq
0	90	0.00	62.80	0.00	-1.25	-3.01	0.00	0.00	0.00	58.54

Segment Leq : 58.54 dBA

Total Leq All Segments: 51.54 dBA (10 dB correction down to account for volume increase and 3 dB correction up to account for doubling distance)

TOTAL Leq FROM ALL SOURCES (DAY): 60.36 dBA
(NIGHT): 51.54 dBA

```
STAMSON 5.0        NORMAL REPORT        Date: 19-03-2021 17:51:14
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec19lrt.te          Time Period: Day/Night 16/8 hours
Description: POR19 LRT Sound Level Calculations
```

LRT VOLUME INCREASED BY 10

```
Road data, segment # 1: LRT (day/night)
---------------------------------------
Car traffic volume  :     0/0     veh/TimePeriod
Medium truck volume :  4880/640   veh/TimePeriod
Heavy truck volume  :     0/0     veh/TimePeriod
Posted speed limit  :    40 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: LRT (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  :  19.00 / 22.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00
Results segment # 1: LRT (day)
------------------------------
Source height = 0.50 m

ROAD (0.00 + 65.27 + 0.00) = 65.27 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  66.29   0.00  -1.03   0.00   0.00   0.00   0.00  65.27
--------------------------------------------------------------------------
Segment Leq : 65.27 dBA

Total Leq All Segments: 55.27 dBA (10 dB correction down to account for 10
times volume increase)

Results segment # 1: LRT (night)
--------------------------------
Source height = 0.50 m
ROAD (0.00 + 58.82 + 0.00) = 58.82 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  60.48   0.00  -1.66   0.00   0.00   0.00   0.00  58.82
--------------------------------------------------------------------------
Segment Leq : 58.82 dBA

Total Leq All Segments: 48.82 dBA (10 dB correction down to account for 10
times volume increase)

TOTAL Leq FROM ALL SOURCES (DAY): 55.27
                         (NIGHT): 48.82
```

```
STAMSON 5.0        NORMAL REPORT        Date: 24-03-2021 15:03:44
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec21lrt.te          Time Period: Day/Night 16/8 hours
Description: POR21 LRT Sound Level Calculations
```

LRT VOLUME INCREASED BY 10

```
Road data, segment # 1: LRT (day/night)
---------------------------------------
Car traffic volume  :     0/0     veh/TimePeriod
Medium truck volume :  4880/640   veh/TimePeriod
Heavy truck volume  :     0/0     veh/TimePeriod
Posted speed limit  :    40 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: LRT (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  :  21.00 / 21.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00

Results segment # 1: LRT (day)
------------------------------
Source height = 0.50 m
ROAD (0.00 + 64.83 + 0.00) = 64.83 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  66.29   0.00  -1.46   0.00   0.00   0.00   0.00  64.83
--------------------------------------------------------------------------
Segment Leq : 64.83 dBA

Total Leq All Segments: 54.83 dBA (10 dB correction down to account for 10
times volume increase)

Results segment # 1: LRT (night)
--------------------------------
Source height = 0.50 m
ROAD (0.00 + 59.02 + 0.00) = 59.02 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  60.48   0.00  -1.46   0.00   0.00   0.00   0.00  59.02
--------------------------------------------------------------------------

Segment Leq : 59.02 dBA
Total Leq All Segments: 49.02 dBA (10 dB correction down to account for 10
times volume increase)

TOTAL Leq FROM ALL SOURCES (DAY): 54.83
                         (NIGHT): 49.02
```

```
STAMSON 5.0        NORMAL REPORT        Date: 24-03-2021 15:09:06
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec21ph1.te          Time Period: Day/Night 16/8 hours
Description: POR21 No Project Traffic Sound Level Calculations

Road data, segment # 1: HESPLER (day/night)
-------------------------------------------
Car traffic volume  : 52554/5839  veh/TimePeriod
Medium truck volume :   554/62    veh/TimePeriod
Heavy truck volume  :   554/62    veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: HESPLER (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  :  21.00 / 21.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00

Results segment # 1: HESPLER (day)
----------------------------------
Source height = 1.01 m

ROAD (0.00 + 70.23 + 0.00) = 70.23 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  71.69   0.00  -1.46   0.00   0.00   0.00   0.00  70.23
--------------------------------------------------------------------------
Segment Leq : 70.23 dBA

Total Leq All Segments: 70.23 dBA

Results segment # 1: HESPLER (night)
------------------------------------
Source height = 1.01 m

ROAD (0.00 + 63.71 + 0.00) = 63.71 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
--------------------------------------------------------------------------
   -90     90   0.00  65.17   0.00  -1.46   0.00   0.00   0.00   0.00  63.71
----------------------------------------------------------------------------

Segment Leq : 63.71 dBA

Total Leq All Segments: 63.71 dBA

TOTAL Leq FROM ALL SOURCES (DAY): 70.23
                         (NIGHT): 63.71
```

```
STAMSON 5.0        NORMAL REPORT        Date: 24-03-2021 15:09:42
MINISTRY OF ENVIRONMENT AND ENERGY / NOISE ASSESSMENT

Filename: rec21ph2.te          Time Period: Day/Night 16/8 hours
Description: POR21 With Project Traffic Sound Level Calculations


Road data, segment # 1: HESPLER (day/night)
-------------------------------------------
Car traffic volume  : 49484/5498  veh/TimePeriod
Medium truck volume :   532/59    veh/TimePeriod
Heavy truck volume  :   532/59    veh/TimePeriod
Posted speed limit  :    60 km/h
Road gradient       :     0 %
Road pavement       :     1 (Typical asphalt or concrete)

Data for Segment # 1: HESPLER (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  :  21.00 / 21.00  m
Receiver height           :   1.50 / 4.50   m
Topography                :      1       (Flat/gentle slope; no barrier)
Reference angle           :   0.00

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

Source height = 1.01 m

ROAD (0.00 + 70.00 + 0.00) = 70.00 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  71.46   0.00  -1.46   0.00   0.00   0.00   0.00  70.00
----------------------------------------------------------------------------

Segment Leq : 70.00 dBA

Total Leq All Segments: 70.00 dBA

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

Source height = 1.01 m

ROAD (0.00 + 63.47 + 0.00) = 63.47 dBA
Angle1 Angle2  Alpha RefLeq  P.Adj  D.Adj  F.Adj  W.Adj  H.Adj  B.Adj SubLeq
----------------------------------------------------------------------------
   -90     90   0.00  64.93   0.00  -1.46   0.00   0.00   0.00   0.00  63.47
----------------------------------------------------------------------------

Segment Leq : 63.47 dBA

Total Leq All Segments: 63.47 dB

TOTAL Leq FROM ALL SOURCES (DAY): 70.00
                         (NIGHT): 63.47
```

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/TTC, *Draft Protocol for Noise and Vibration Assessment for the Proposed Waterfront West Light Rail Transit Line*. (November 11, 1993).

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 Manual*. FTA Report No. 0123, September 2018.

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.

APPENDIX D: GUIDELINES

MOEE/TTC
DRAFT
PROTOCOL FOR NOISE AND VIBRATION ASSESSMENT FOR THE PROPOSED SCARBOROUGH RAPID TRANSIT EXTENSION

May 11, 1993

TABLE OF CONTENTS

PROTOCOL FOR NOISE AND VIBRATION ASSESSMENT

PART A. PURPOSE

The Toronto Transit Commission (TTC) and the Ministry of the Environment and Energy (MOEE) recognize that transit facilities produce noise and vibration which may affect neighbouring properties within urbanized areas. This document identifies the framework within which criteria will be applied for limiting wayside air-borne noise and ground-borne noise and vibration from the TTC's proposed Scarborough Rapid Transit Line Extension (the "Line"). This proposed extension is to run from McCowan station to Markham Road and Sheppard Avenue East. The framework presented in this document is to be applied for planning purposes in order to address the requirements of the Environmental Assessment Act and is to be utilized during implementation of the Line.

The passby sound levels and vibration velocities in this protocol have been developed specifically for the Line and this protocol is not to be applied retroactively to existing TTC transit Lines, routes or facilities, including the existing SRT line, nor to transit authorities other than TTC. Further, the criteria specified for this project are not precedent setting for future projects.

Prediction and measurement methods are being developed by the TTC. This will be done in consultation with MOEE and the Ministry of Transportation (MTO). Studies pertaining to noise and vibration levels are also being conducted by TTC. Upon completion of these studies, the TTC may revisit the assessment criteria and methods in this protocol to modify them as required in consultation with MOEE and the Ministry of Transportation (MTO).

PART B. GENERAL

During design of the Line, predicted wayside sound levels and vibration velocities are to be compared to criteria given in this protocol. This will permit an impact assessment and help determine the type or extent of mitigation measures to reduce that impact. Sound levels and vibration velocities will be predicted from sound levels and velocities of TTC's existing rail technologies.

The criteria presented in this document are based on good operating conditions and the impact assessment assumes this condition. Good operating conditions exist when well maintained vehicles operate on well maintained continuous welded rail without significant rail corrugation. It is recognised that wheel flats or rail corrugations will inevitably occur and will temporarily increase sound and vibration levels until they are corrected. Levels in this protocol do not reflect these occasional events, nor do they apply to maintenance activities on the Line. TTC recognizes that wheel rail squeal is a potential source of noise which may pose a concern to the community. TTC is investigating and will continue to investigate measures to mitigate wheel rail squeal and will endeavour to mitigate this noise source. TTC endeavours to minimize the noise and vibration impacts associated with its transit operations and is committed to providing good operating conditions to the extent technologically, economically and administratively feasible.

It is recognised that levels of sound and vibration at special trackwork, such as at crossovers and turnouts, are inevitably higher than along tangent track. Also, there is a limit to the degree of mitigation that is feasible at special trackwork areas. This is to be taken into account in predicting sound and vibration levels near these features and in applying the levels in this protocol. Special trackwork, such as at crossovers and turnouts, is encompassed within the framework of this document.

This protocol applies to existing and proposed residential development having municipal approval on the date of this protocol. The protocol also applies to existing and municipally approved proposed nursing homes, group homes, hospitals and other such institutional land uses where people reside. This protocol does not apply to commercial and industrial land uses.

This protocol does not apply closer than 15 m to the centreLine of the nearest track. Any such cases shall be assessed on a case by case basis.

Part D of this document deals with airborne noise from the Line and its construction. Part E deals with groundborne noise and vibration from the Line.

PART C. DEFINITIONS

The following definitions apply to both parts D and E of this document:

Ancilary Facilities:

Subsidiary locations associated with either the housing of personnel or equipment engaged in TTC activities or associated with mainLine revenue operations. Examples of ancillary facilities include, but are not limited to, subway stations, bus terminals, emergency services buildings, fans, fan and vent shafts, substations, mechanical equipment plants, maintenance and storage facilities, and vehicle storage and maintenance facilities.

Passby Time Interval:

The passby time interval of a vehicle or train is given by its total length and its speed. The start of the pass-by is defined as that point in time when the leading wheels pass a reference point. The end of the pass-by is defined as that point in time when the last wheels of the vehicle or train pass the same reference point. The reference point is to be chosen to give the highest level at the point of reception or point of assessment, i.e. usually at the point of closest approach. From a signal processing perspective, the passby time interval will be defined in the prediction and measurement methods being developed.

PART D. AIR BORNE NOISE

1.0 DEFINITIONS

The following definitions are to be used only within the context of Part D of this document.

Ambient:

The ambient is the sound existing at the point of reception in the absence of all noise from the Line. In this protocol the ambient is taken to be the noise from road traffic and existing industry. The ambient specifically excludes transient noise from aircraft and railways, except for pre-existing TTC rail operations.

Daytime Equivalent Sound Level:

$L_{eq,16h}$ is the daytime equivalent sound level. The definition of equivalent sound level is provided in Reference 2. The applicable time period is from 07:00 to 23:00 hours.

Nighttime Equivalent Sound Level:

$L_{eq,8h}$ is the nighttime equivalent sound level. The applicable time period is from 23:00 to 07:00 hours.

Point of Reception:

Daytime: 07:00 - 23:00 hours

Any outdoor point on residential property, 15 m or more from the nearest track's centreLine, where sound originating from the Line is received.

Nighttime: 23:00 - 07:00 hours

The plane of any bedroom window, 15 m or more from the nearest track's centreLine, where sound originating from the Line is received. At the planning stage, this is usually assessed at the nearest facade of the premises.

Passby Sound Level, L_{passby} :

Within the context of this document, the passby sound level is defined as the A-weighted equivalent sound level, L_{eq} [Reference 2] over the passby time interval.

2.0 RAIL TRANSIT

In the assessment of noise impact, rail transit is considered to include the movement of trains between stations, the movement and idling of trains inside stations as well as the movement of trains between the mainline and ancillary facilities. Ancillary facilities are not considered part of the rail transit and are assessed as stationary sources. Trains idling in maintenance yards and storage facilitities are part of the stationary source.

The assessment of noise impact resulting from Line is to be performed in terms of the following sound level descriptors:

1) Daytime equivalent sound level, $L_{eq,16h}$,
2) Nighttime equivalent sound level, $L_{eq,8h}$,
3) Passby Sound Level, L_{passby}.

The predicted daytime and nighttime equivalent sound levels include the effects of both passby sound level and frequency of operation and are used to assess the noise impact of the Line. The Passby Sound Level criterion is used to assess the sound levels received during a single train passby. The criteria and methods to be used are discussed in Sections 2.1 and 2.2.

2.1 Criteria

Noise impact shall be predicted and assessed during design of the Line using the following sound level criteria:

DAYTIME EQUIVALENT SOUND LEVEL:

The limit at a point of reception for the predicted daytime equivalent sound levels for rail transit operating alone (excluding contributions from the ambient) is 55 dBA or the ambient $L_{eq,16h}$, whichever is higher.

NIGHTTIME EQUIVALENT SOUND LEVEL:

The limit at a point of reception for the predicted nighttime equivalent sound levels for rail transit operating alone (excluding contributions from the ambient) is 50 dBA or the ambient $L_{eq,8h}$, whichever is higher.

PASSBY SOUND LEVEL:

The limit at a point of reception for predicted L_{passby} for a single train operating alone and excluding contributions from other sources is 80 dBA. This limit is based on vehicles operating on tangent track. It does not apply within 100m of special trackwork and excludes wheel rail squeal.

Mitigating measures will be incorporated in the design of the Line when predictions show that any of the above limits are exceeded by more than 5 dB. All mitigating measures shall ensure that the predicted sound levels are as close to, or lower than, the respective limits as is technologically, economically, and administratively feasible.

2.2 Prediction

In most cases, a reasonable estimate of the ambient sound level can be made using a road traffic noise prediction method such as that described in Reference 9, and the minimum sound levels in Table 106-2 of Reference 6. Prediction of road traffic L_{eq} is preferred to individual measurements in establishing the ambient. Prediction techniques for the L_{eq} from road traffic and the L_{eq} or L_{passby} from transit shall be compatible with one another. Any impact assessment following this protocol shall include a description of the prediction method and the assumptions and sound level data inherent in it. Prediction and measurement methods compatible with MOEE guidelines and procedures are being developed by the TTC at the date of this protocol in consultation with MTO and MOEE.

3.0 ANCILLARY FACILITIES

Predicted noise impacts from ancillary facilities shall be assessed during the design of the Line in accordance with the stationary source guideLines detailed in Reference 5. The predictions used shall be compatible with and at least as accurate as CSA Standard Z107.55.

4.0 BUSES IN MIXED TRAFFIC

Where buses are part of the road traffic there are no additional criteria requirements beyond those presented in the Ministry of Transportation of Ontario Protocol for dealing with noise concerns during the preparation, review and evaluation of Provincial Highways Environmental Assessments [Reference 1]. Buses should be considered as medium trucks in the traffic noise prediction models.

5.0 CONSTRUCTION

Noise impacts from the construction of the Line are to be examined. For the purposes of impact assessment and identifying the need for mitigation, the Ministry of the Environment and Energy guideLines for construction presented in Reference 7 are to be referred to.

PART E. GROUND-BORNE VIBRATION

The assessment of ground-borne vibration impact is confined to the vibration that is produced by the operation of the Line and excludes vibration due to maintenance activities.

In recognition of the fact that the actual vibration response of a building is affected by its own structural characteristics, this document deals with the assessment of ground borne vibration only on the outside premises. Structural characteristics of buildings are beyond the scope of this protocol and beyond the control of the TTC.

1.0 DEFINITIONS

The following definitions are to be used only within the context of Part E of this document.

Point of Assessment:

A point of assessment is any outdoor point on residential property, 15 m or more from the nearest track's centreLine, where vibration originating from the Line is received.

Vibration Velocity:

Vibration Velocity is the root-mean-square (rms) vibration velocity assessed during a train pass-by. The unit of measure is metres per second (m/s) or millimetres per second (mm/s). For the purposes of this protocol only vertical vibration is assessed. The vertical component of transit vibration is usually higher than the horizontal. Human sensitivity to horizontal vibration at the frequencies of interest is significantly less than the sensitivity to vertical vibration.

2.0 VIBRATION ASSESSMENT

Vibration velocities at points of assessment shall be predicted during design of the Line. If the predicted rms vertical vibration velocity from the Line exceeds 0.1 mm/sec, mitigation methods shall be applied during the detailed design to meet this criterion to the extent technologically, economically, and administratively feasible.

Any impact assessment following this protocol shall include a description of the prediction method and the assumptions and data inherent in it. Prediction and measurement methods are being developed by the TTC at the date of this protocol in cooperation with MTO and MOEE.

References

1)**A Protocol for Dealing With Noise Concerns During the Preparation, Review and Evaluation of Provincial Highways Environmental Assessments**, Ministry of Transportation, February 1986.

2)**Model Municipal Noise Control By-Law, Final Report, Publication NPC-101 Technical Definitions**, Ministry of the Environment, August 1978.

3)**Model Municipal Noise Control By-Law, Final Report, Publication NPC-103 Procedures**, Ministry of the Environment, August 1978.

4)**Model Municipal Noise Control By-Law, Final Report, Publication NPC-104 Sound Level Adjustments**, Ministry of the Environment, August 1978.

5)**Model Municipal Noise Control By-Law, Final Report, Publication NPC-105 Stationary Sources**, Ministry of the Environment, August 1978.

6)**Model Municipal Noise Control By-Law, Final Report, Publication NPC-106 Sound Levels of Road Traffic**, Ministry of the Environment, August 1978.

7)**Noise Control GuideLine For Class Environmental Assessment of Undertakings**, February 1980, Ministry of the Environment.

8)**Toronto Subway System Track Vibration Isolation System (Double Tie) - Technical Report**, TTC Engineering Department, June 1982.

9)**STAMSON 4.1**, Ontario Ministry of the Environment Road and Rail Noise Prediction Software

MOEE/TTC

DRAFT

PROTOCOL FOR NOISE AND VIBRATION ASSESSMENT FOR THE PROPOSED WATERFRONT WEST LIGHT RAIL TRANSIT LINE

November 11, 1993

TABLE OF CONTENTS

PROTOCOL FOR NOISE AND VIBRATION ASSESSMENT

PART A. PURPOSE

The Toronto Transit Commission (TTC) and the Ministry of the Environment and Energy (MOEE) recognise that transit facilities produce noise and vibration which may affect neighbouring properties within urbanised areas. This document identifies the framework within which criteria will be applied for limiting wayside air-borne noise, ground-borne noise and vibration from the TTC's proposed Waterfront West Light Rail Transit Line (the "Line"). The proposed line is to run from Spadina and Queen's Quay West to the CNE Dufferin Street Gate and from the Humber Loop to Legion Road. The framework presented in this document is to be applied for planning purposes in order to address the requirements of the Environmental Assessment Act and is to be utilized during implementation of the Line.

The passby sound levels and vibration velocities in this protocol have been developed specifically for the Line and this protocol is not to be applied retroactively to existing TTC transit lines, routes or facilities, including the existing lines with which this line will intersect, nor to transit authorities other than TTC. Further, the criteria specified for this project are not precedent setting for future projects.

Prediction and measurement methods are being developed by the TTC. This will be done in consultation with MOEE and the Ministry of Transportation (MTO). Studies pertaining to noise and vibration levels are also being conducted by TTC. Upon completion of these studies, the TTC may revisit the assessment criteria and methods in this protocol to modify them as required in consultation with MOEE and the Ministry of Transportation (MTO).

PART B. GENERAL

During design of the Line, predicted wayside sound levels and vibration velocities are to be compared to criteria given in this protocol. This will permit an impact assessment and help determine the type or extent of mitigation measures to reduce that impact. Sound levels and vibration velocities will be predicted from sound levels and velocities of TTC's existing rail technologies.

The criteria presented in this document are based on good operating conditions and the impact assessment assumes this condition. Good operating conditions exist when well maintained vehicles operate on well maintained continuous welded rail without significant rail corrugation. It is recognised that wheel flats or rail corrugations will inevitably occur and will temporarily increase sound and vibration levels until they are corrected. Levels in this protocol do not reflect these occasional events, nor do they apply to maintenance activities on the Line. TTC recognizes that wheel rail squeal is a potential source of noise which may pose a concern to the community. TTC is investigating and will continue to investigate measures to mitigate wheel rail squeal and will endeavour to mitigate this noise source. TTC endeavours to minimize the noise and vibration impacts associated with its transit operations and is committed to providing good operating conditions to the extent technologically, economically and administratively feasible.

It is recognised that levels of sound and vibration at special trackwork, such as at crossovers and turnouts, are inevitably higher than along tangent track. Also, there is a limit to the degree of mitigation that is feasible at special trackwork areas. This is to be taken into account in predicting sound and vibration levels near these features and in applying the levels in this protocol. Special trackwork, such as at crossovers and turnouts, is encompassed within the framework of this document.

This protocol applies to existing and proposed residential development having municipal approval on the date of this protocol. The protocol also applies to existing and municipally approved proposed nursing homes, group homes, hospitals and other such institutional land uses where people reside. This protocol does not apply to commercial and industrial land uses.

This protocol does not apply closer than 15 m to the centreline of the nearest track. Any such cases shall be assessed on a case by case basis.

Part D of this document deals with air-borne noise from the Line and its construction. Part E deals with ground-borne noise and vibration from the Line.

PART C. DEFINITIONS

The following definitions apply to both parts D and E of this document.

Ancillary Facilities:

Subsidiary locations associated with either the housing of personnel or equipment engaged in TTC activities or associated with mainline revenue operations. Examples of ancillary facilities include, but are not limited to, subway stations, bus terminals, emergency services buildings, fans, fan and vent shafts, substations, mechanical equipment plants, maintenance and storage facilities, and vehicle storage and maintenance facilities.

Passby Time Interval:

The passby time interval of a vehicle is given by its total length and its speed. The start of the pass-by is defined as that point in time when the leading wheels pass a reference point. The end of the pass-by is defined as that point in time when the last wheels of the vehicle pass the same reference point. The reference point is to be chosen to give the highest level at the point of reception or point of assessment, i.e. usually at the point of closest approach. From a signal processing perspective, the passby time interval will be defined in the prediction and measurement methods being developed.

PART D. AIR-BORNE NOISE

1.0 DEFINITIONS

The following definitions are to be used only within the context of Part D of this document.

Ambient:

The ambient is the sound existing at the point of reception in the absence of all noise from the Line. In this protocol the ambient is taken to be the noise from road traffic and existing industry. The ambient specifically excludes transient noise from aircraft and railways, except for pre-existing TTC rail operations.

Daytime Equivalent Sound Level:

$L_{eq,16h}$, is the daytime equivalent sound level. The definition of equivalent sound level is provided in Reference 2. The applicable time period is from 07:00 to 23:00 hours.

Nighttime Equivalent Sound Level:

$L_{eq,8h}$ is the nighttime equivalent sound level. The applicable time period is from 23:00 to 07:00 hours.

Point of Reception:

Daytime: 07:00 - 23:00 hours

Any outdoor point on residential property, 15 m or more from the nearest track's centreline, where sound originating from the Line is received.

Nighttime: 23:00 - 07:00 hours

The plane of any bedroom window, 15 m or more from the nearest track's centreline, where sound originating from the Line is received. At the planning stage, this is usually assessed at the nearest facade of the premises.

Passby Sound Level, L_{passby} :

Within the context of this document, the passby sound level is defined as the A-weighted equivalent sound level, L_{eq} [Reference 2] over the passby time interval.

2.0 RAIL TRANSIT

In the assessment of noise impact, rail transit is considered to include the movement of vehicles between stations, the movement and idling of vehicles inside stations as well as the movement of vehicles between the mainline and ancillary facilities. Ancillary facilities are not considered part of the rail transit and are assessed as stationary sources. Vehicles idling in maintenance yards and storage facilities are part of the stationary source.

The assessment of noise impact resulting from the Line is to be performed in terms of the following sound level descriptors:

1) Daytime equivalent sound level, $L_{eq,16h}$,
2) Nighttime equivalent sound level, $L_{eq,8h}$,
3) Passby Sound Level, L_{passby}.

The predicted daytime and nighttime equivalent sound levels include the effects of both passby sound level and frequency of operation and are used to assess the noise impact of the Line. The Passby Sound Level criterion is used to assess the sound levels received during a single vehicle passby. The criteria and methods to be used are discussed in Sections 2.1 and 2.2.

2.1 Criteria

Noise impact shall be predicted and assessed during design of the Line using the following sound level criteria:

DAYTIME EQUIVALENT SOUND LEVEL:

The limit at a point of reception for the predicted daytime equivalent sound levels for rail transit operating alone (excluding contributions from the ambient) is 55 dBA or the ambient $L_{eq,16h}$, whichever is higher.

NIGHTTIME EQUIVALENT SOUND LEVEL:

The limit at a point of reception for the predicted nighttime equivalent sound levels for rail transit operating alone (excluding contributions from the ambient) is 50 dBA or the ambient $L_{eq,8h}$, whichever is higher.

PASSBY SOUND LEVEL:

The limit at a point of reception for predicted L_{passby} for a single vehicle operating alone and excluding contributions from other sources is 80 dBA. This limit is based on vehicles operating on tangent track. It does not apply within 100m of special trackwork and excludes wheel rail squeal.

Mitigating measures will be incorporated in the design of the Line when predictions show that any of the above limits are exceeded by more than 5 dB. All mitigating measures shall ensure that the predicted sound levels are as close to, or lower than, the respective limits as is technologically, economically, and administratively feasible.

2.2 Prediction

In most cases, a reasonable estimate of the ambient sound level can be made using a road traffic noise prediction method such as that described in Reference 8, and the minimum sound levels in Table 106-2 of Reference 6. Prediction of road traffic L_{eq} is preferred to individual measurements in establishing the ambient. Prediction techniques for the L_{eq} from road traffic and the L_{eq} or L_{passby} from transit shall be compatible with one another. Any impact assessment following this protocol shall include a description of the prediction method and the assumptions and sound level data inherent in it. Prediction and measurement methods compatible with MOEE guidelines and procedures are being developed by the TTC at the date of this protocol in consultation with MTO and MOEE.

3.0 ANCILLARY FACILITIES

Predicted noise impacts from ancillary facilities shall be assessed during the design of the Line in accordance with the stationary source guidelines detailed in Reference 5. The predictions used shall be compatible with and at least as accurate as CSA Standard Z107.55.

4.0 BUSES IN MIXED TRAFFIC

Where buses are part of the road traffic there are no additional criteria requirements beyond those presented in the Ministry of Transportation of Ontario Protocol for dealing with noise concerns during the preparation, review and evaluation of Provincial Highways Environmental Assessments [Reference 1]. Buses should be considered as medium trucks in the traffic noise prediction models.

5.0 CONSTRUCTION

Noise impacts from the construction of the Line are to be examined. For the purposes of impact assessment and identifying the need for mitigation, the Ministry of the Environment and Energy guidelines for construction presented in Reference 7 are to be referred to.

PART E. GROUND-BORNE VIBRATION

The assessment of ground-borne vibration impact is confined to the vibration that is produced by the operation of the Line and excludes vibration due to maintenance activities.

In recognition of the fact that the actual vibration response of a building is affected by its own structural characteristics, this document deals with the assessment of ground-borne vibration only on the outside premises. Structural characteristics of buildings are beyond the scope of this protocol and beyond the control of the TTC.

It is recognised that ground-borne vibration can produce air-borne noise inside a structure and there is a direct correlation between the two. The TTC can only control ground-borne noise by controlling ground-borne vibration. Accordingly, ground-borne noise will be predicted and assessed in terms of vibration measured at a point of assessment using the limit in Section 2.0, Vibration Assessment.

1.0 DEFINITIONS

The following definitions are to be used only within the context of Part E of this document:

Point of Assessment:

A point of assessment is any outdoor point on residential property, 15 m or more from the nearest track's centreline, where vibration originating from the Line is received.

Vibration Velocity:

Vibration Velocity is the root-mean-square (rms) vibration velocity assessed during a vehicle pass-by. The unit of measure is metres per second (m/s) or millimetres per second (mm/s). For the purposes of this protocol only vertical vibration is assessed. The vertical component of transit vibration is usually higher than the horizontal. Human sensitivity to horizontal vibration at the frequencies of interest is significantly less than the sensitivity to vertical vibration.

2.0 VIBRATION ASSESSMENT

Vibration velocities at points of assessment shall be predicted during design of the Line. If the predicted rms vertical vibration velocity from the Line exceeds 0.14 mm/sec, mitigation methods shall be applied during the detailed design to meet this criterion to the extent technologically, economically and administratively feasible.

Any impact assessment following this protocol shall include a description of the prediction method and the assumptions and data inherent in it. Prediction and measurement methods are being developed by the TTC at the date of this protocol in cooperation with MTO and MOEE.

NPC-115

Construction Equipment

1. **Scope**

This Publication sets sound emission standards for various items of new construction equipment according to the date of manufacture of the equipment.

2. **Technical Definitions**

The technical terms used in this Publication are defined in Publication NPC101 Technical Definitions.

3. **Sound Emission Standards**

Tables 115-1 to 115-4 inclusive list Residential Area sound emission standards and Quiet Zone sound emission standards for specific items of new construction equipment measured in accordance with the procedures indicated.

TABLE 115-1

Quiet Zone and Residential Area Sound Emission Standards for Excavation Equipment, Dozers, Loaders, Backhoes or Other Equipment Capable of Being Used for Similar Application

Maximum Sound Level (dBA) as determined using Publication NPC - 103 - Procedures, section 6		
	dBA	
Date of Manufacture	Power Rating Less than 75 kW	Power Rating 75 kW and Larger
January 1, 1979 to December 31, 1980	85	88
January 1, 1981 and after	83	85

TABLE 115-2

Sound Emission Standards for Pneumatic Pavement Breakers

Standard	Date of Manufacture	Maximum Sound Level (dBA) as measured using Publication NPC - 103
Quiet Zone Sound Emission	January 1, 1979 and after	85
Residential Area Sound Emission Standard	January 1, 1979 to December 31, 1980	90
	January 1, 1981 and after	85

TABLE 115-3

Sound Emission Standards for Portable Air Compressors

Standard	Date of Manufacture	Maximum Sound Level (dBA) as measured using Publication NPC - 103
Quiet Zone Sound Emission Standard	January 1, 1979 to December 31, 1980	76
	January 1, 1981 and after	70
Residential Area Sound Emission	January 1, 1979 and after	76

TABLE 115-4

Sound Emission Standard for Tracked Drills

Standard	Date of Manufacture	Maximum Sound Level (dBA) as measured using Publication NPC - 103 Procedures, section 6
Quiet Zone and Residential Area Sound Emission Standard	January 1, 1981 and after	100