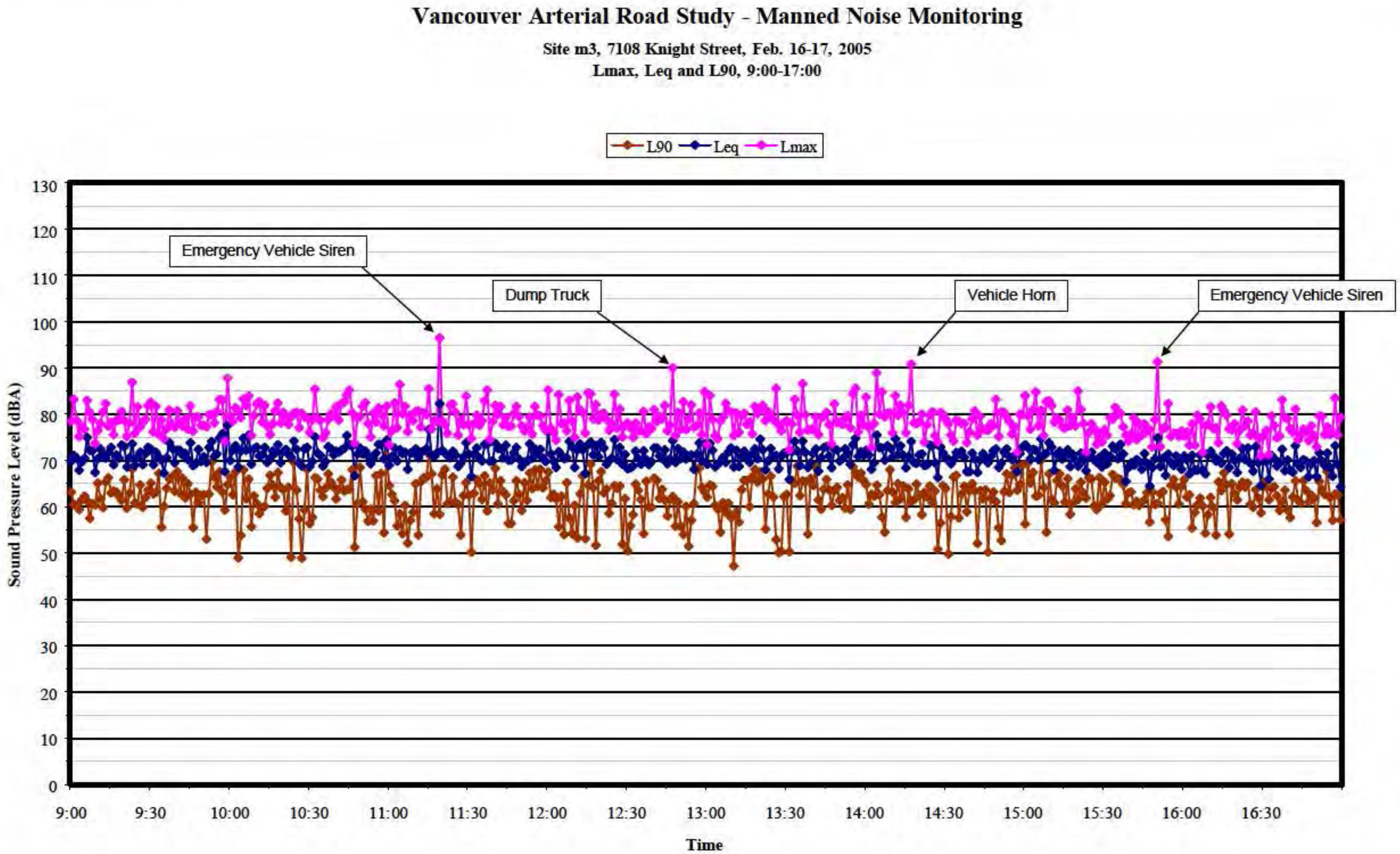
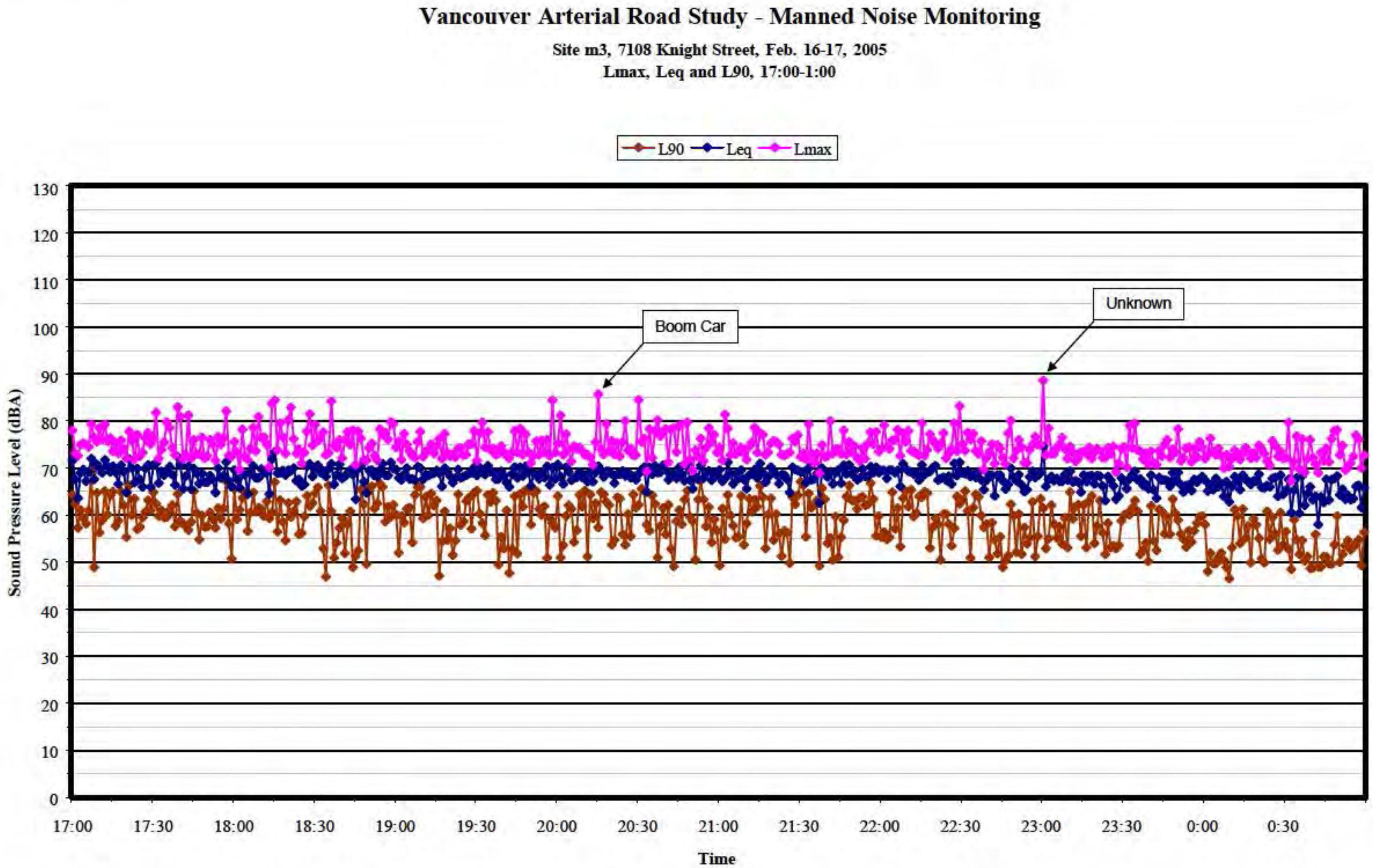
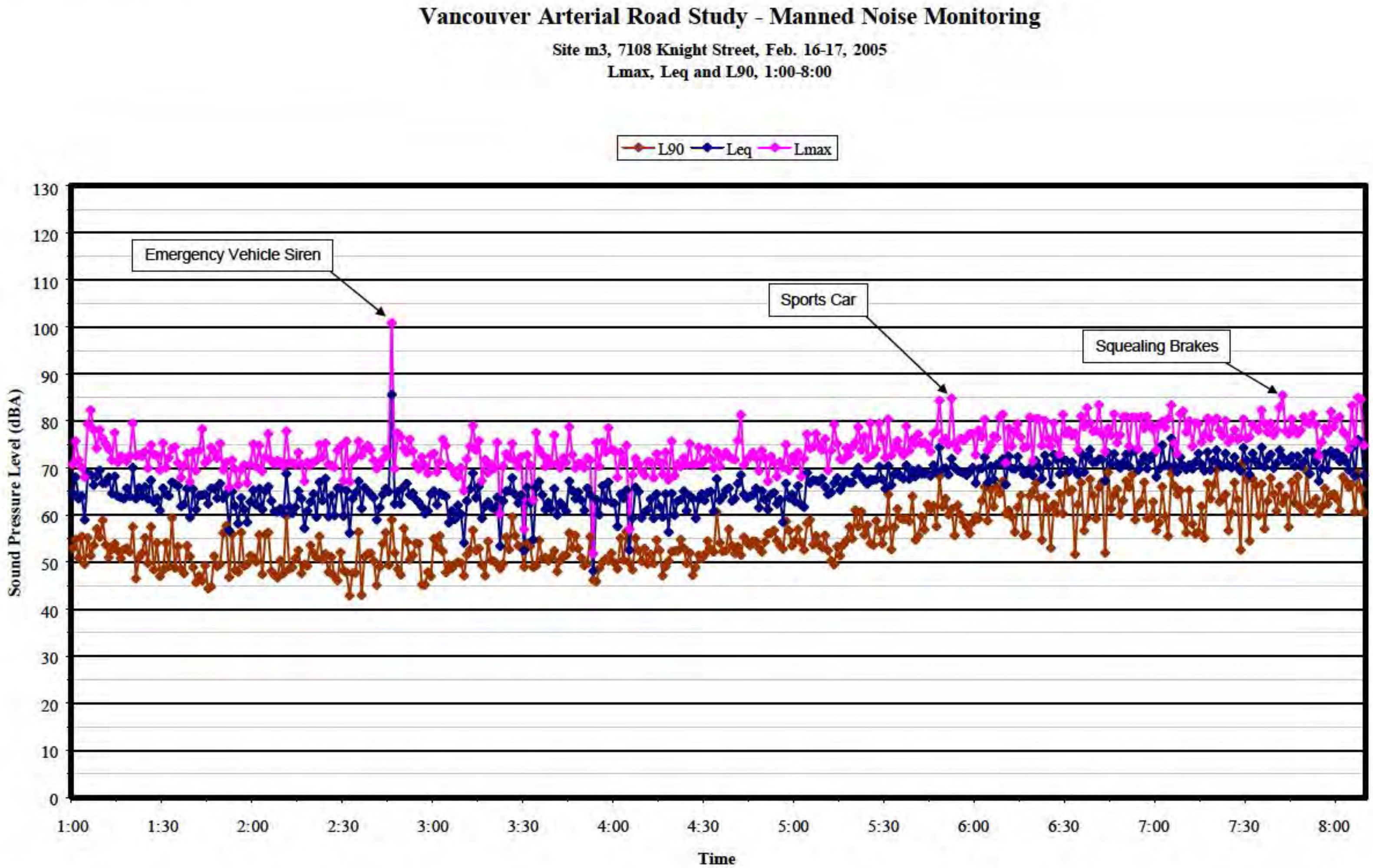
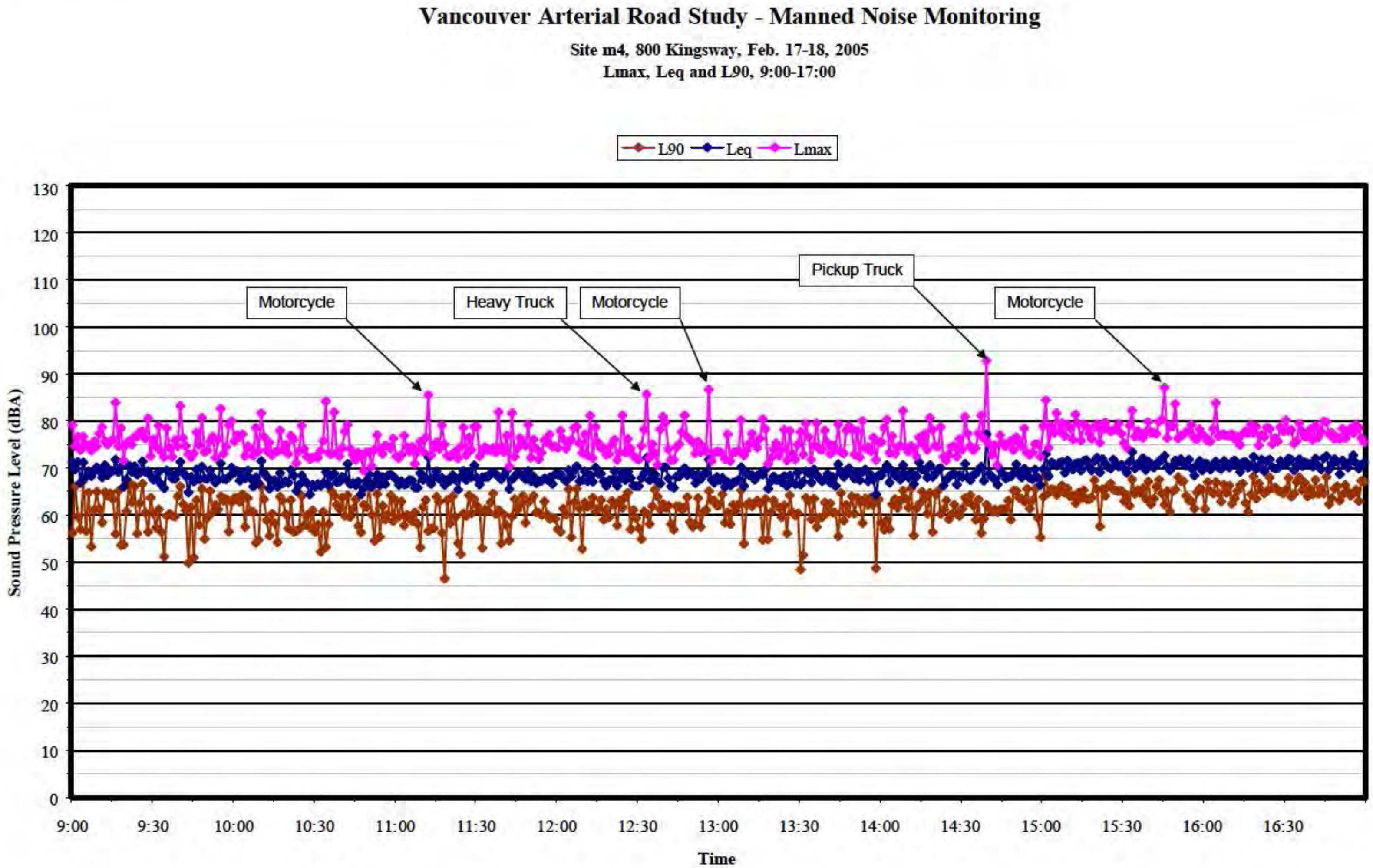

Vancouver Arterial Road Study - Manned Noise Monitoring
Site m3, 7108 Knight Street, Feb. 16-17, 2005
Lmax, Leq and L90, 9:00-17:00
L90
Leq
Lmax
Emergency Vehicle Siren
Dump Truck
Vehicle Horn
Emergency Vehicle Siren
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
Time


Vancouver Arterial Road Study - Manned Noise Monitoring
Site m3, 7108 Knight Street, Feb. 16-17, 2005
Lmax, Leq and L90, 17:00-1:00
L90
Leq
Lmax
Boom Car
Unknown
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
17:00
17:30
18:00
18:30
19:00
19:30
20:00
20:30
21:00
21:30
22:00
22:30
23:00
23:30
0:00
0:30
Time



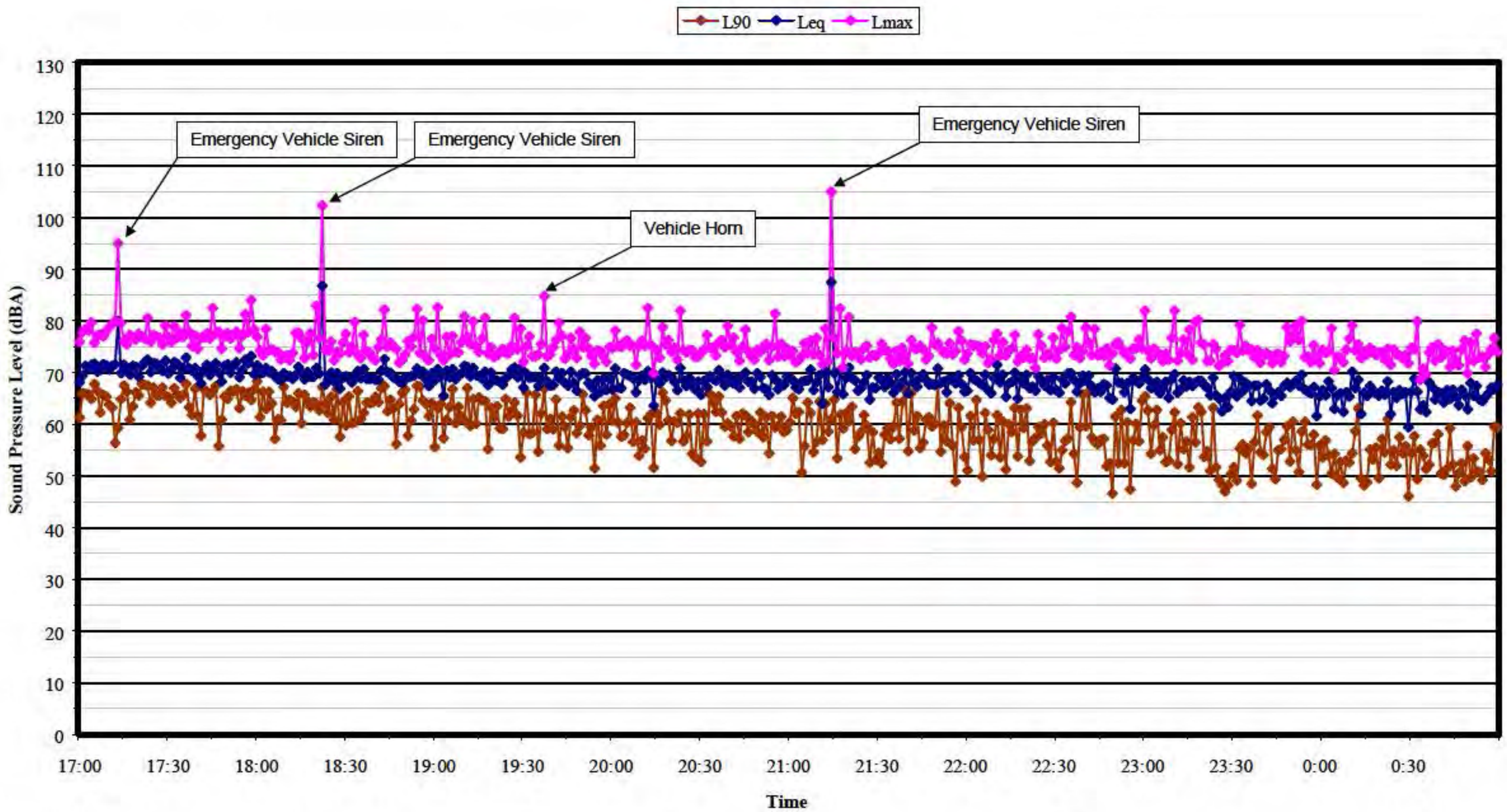



City of Vancouver FOI #2017-525, page 0123


Vancouver Arterial Road Study - Manned Noise Monitoring
Site m4, 800 Kingsway, Feb. 17-18, 2005
Lmax, Leq and L90, 9:00-17:00
L90
Leq
Lmax
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Motorcycle
Heavy Truck
Motorcycle
Pickup Truck
Motorcycle
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
Time

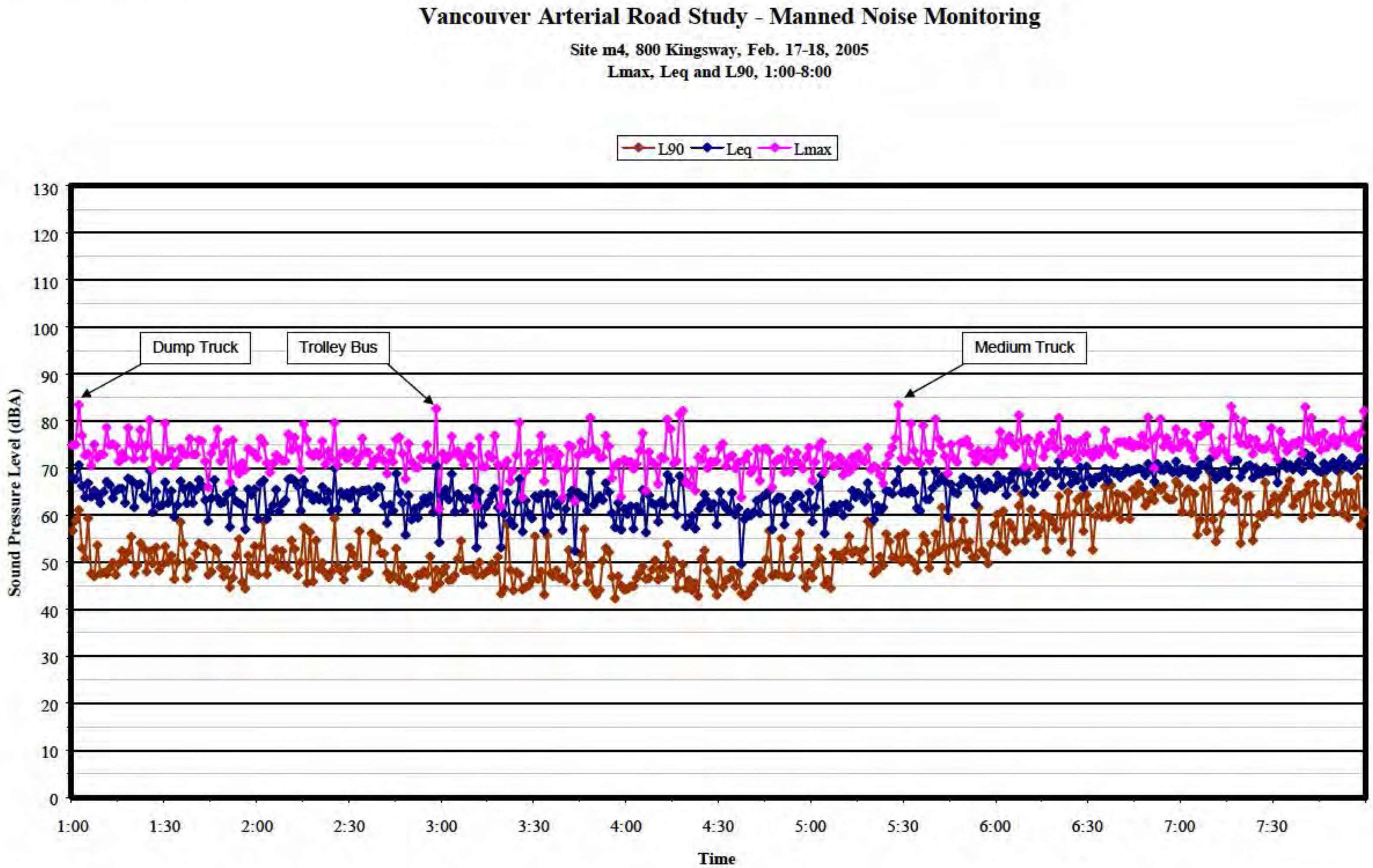
## Vancouver Arterial Road Study - Manned Noise Monitoring

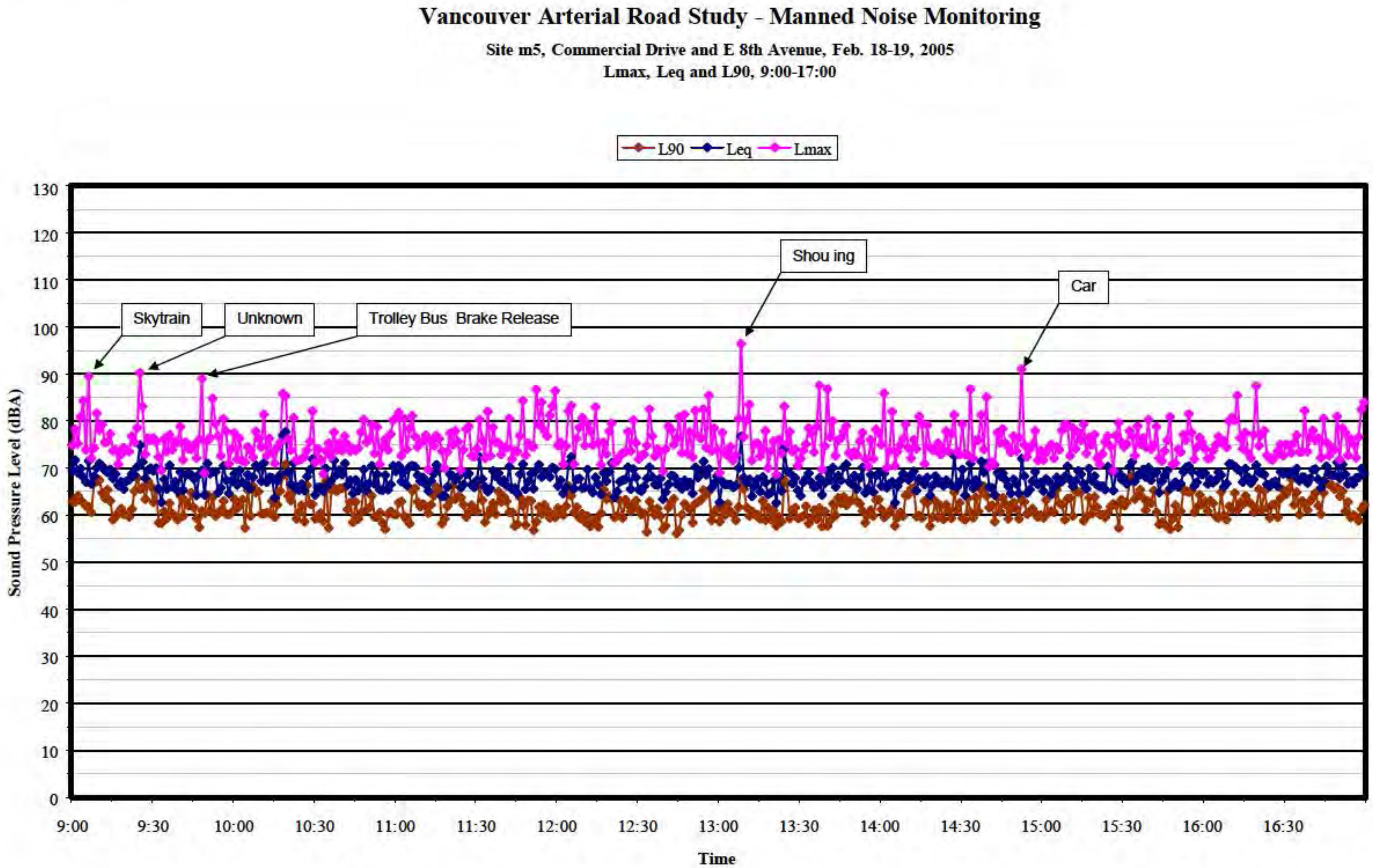
**Site m4, 800 Kingsway, Feb. 17-18, 2005**
**Lmax, Leq and L90, 17:00-1:00**

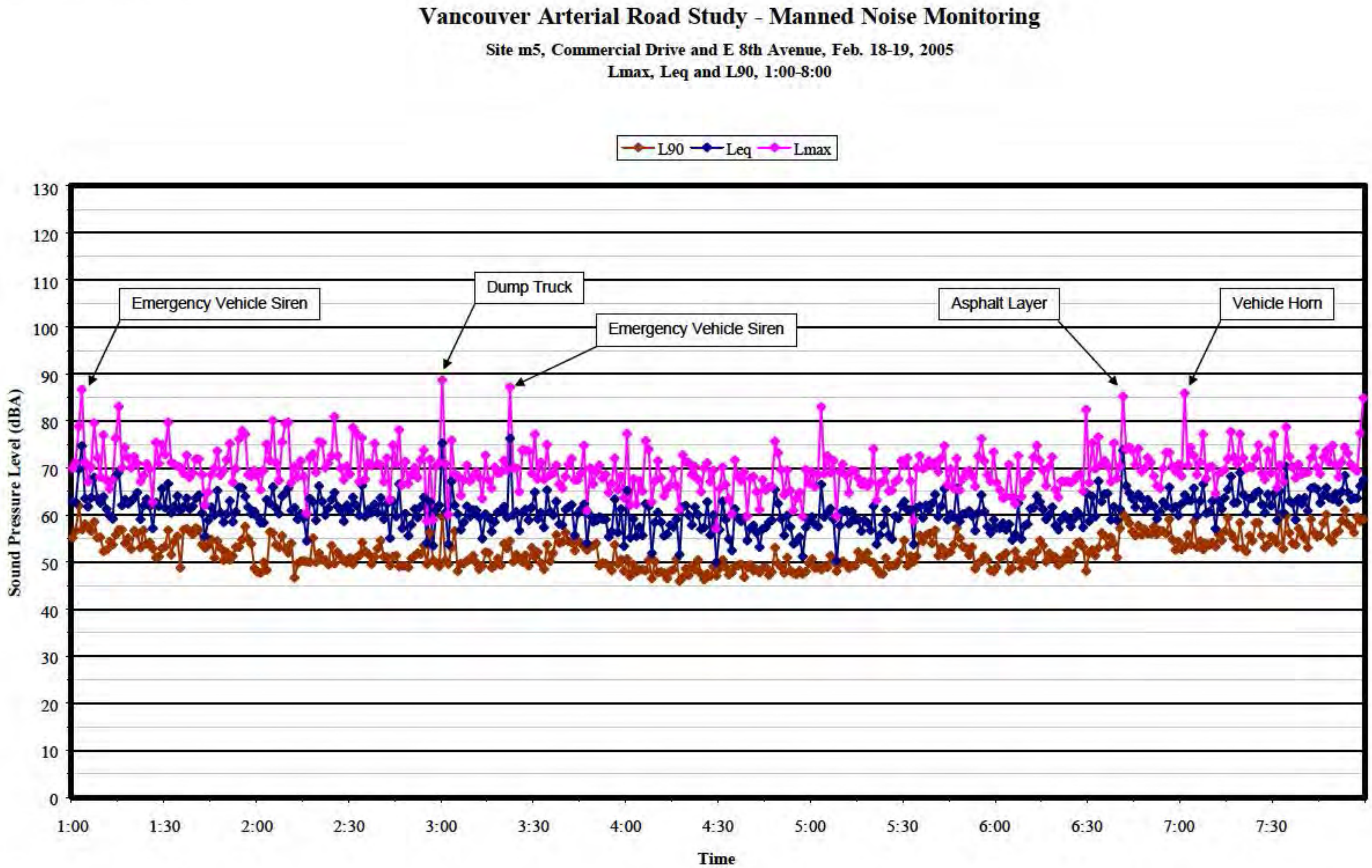





City of Vancouver FOI #2017-525, page 0125

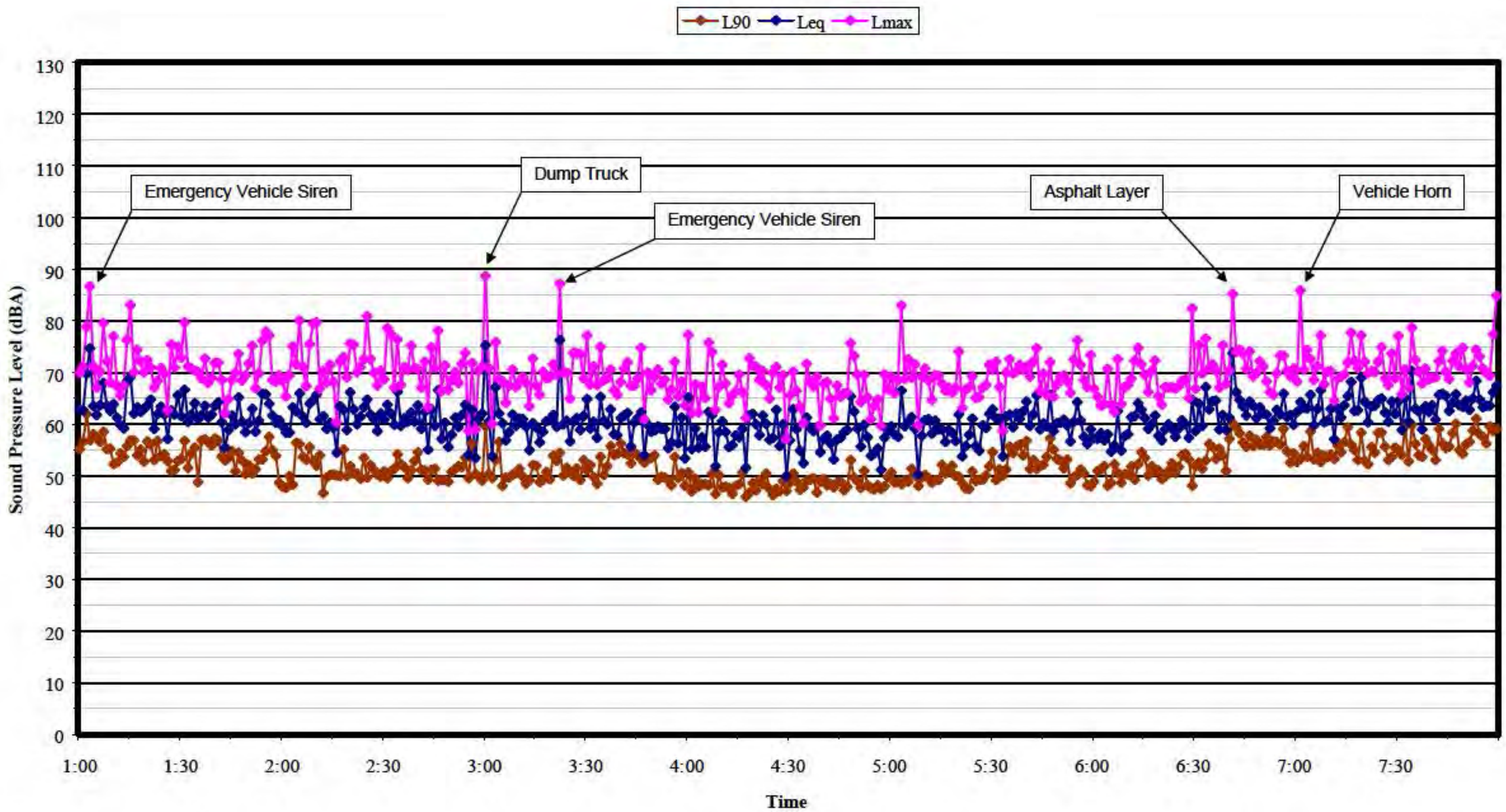

Vancouver Arterial Road Study - Manned Noise Monitoring
Site m4, 800 Kingsway, Feb. 17-18, 2005
Lmax, Leq and L90, 1:00-8:00
L90
Leq
Lmax
Dump Truck
Trolley Bus
Medium Truck
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
Time


Vancouver Arterial Road Study - Manned Noise Monitoring
Site m5, Commercial Drive and E 8th Avenue, Feb. 18-19, 2005
Lmax, Leq and L90, 9:00-17:00
L90
Leq
Lmax
Skytrain
Unknown
Trolley Bus Brake Release
Shou ing
Car
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
16:30
Time


Vancouver Arterial Road Study - Manned Noise Monitoring
Site m5, Commercial Drive and E 8th Avenue, Feb. 18-19, 2005
Lmax, Leq and L90, 1:00-8:00
L90
Leq
Lmax
Emergency Vehicle Siren
Dump Truck
Emergency Vehicle Siren
Asphalt Layer
Vehicle Horn
Sound Pressure Level (dBA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
Time

## Vancouver Arterial Road Study - Manned Noise Monitoring

**Site m5, Commercial Drive and E 8th Avenue, Feb. 18-19, 2005**
**Lmax, Leq and L90, 17:00-1:00**



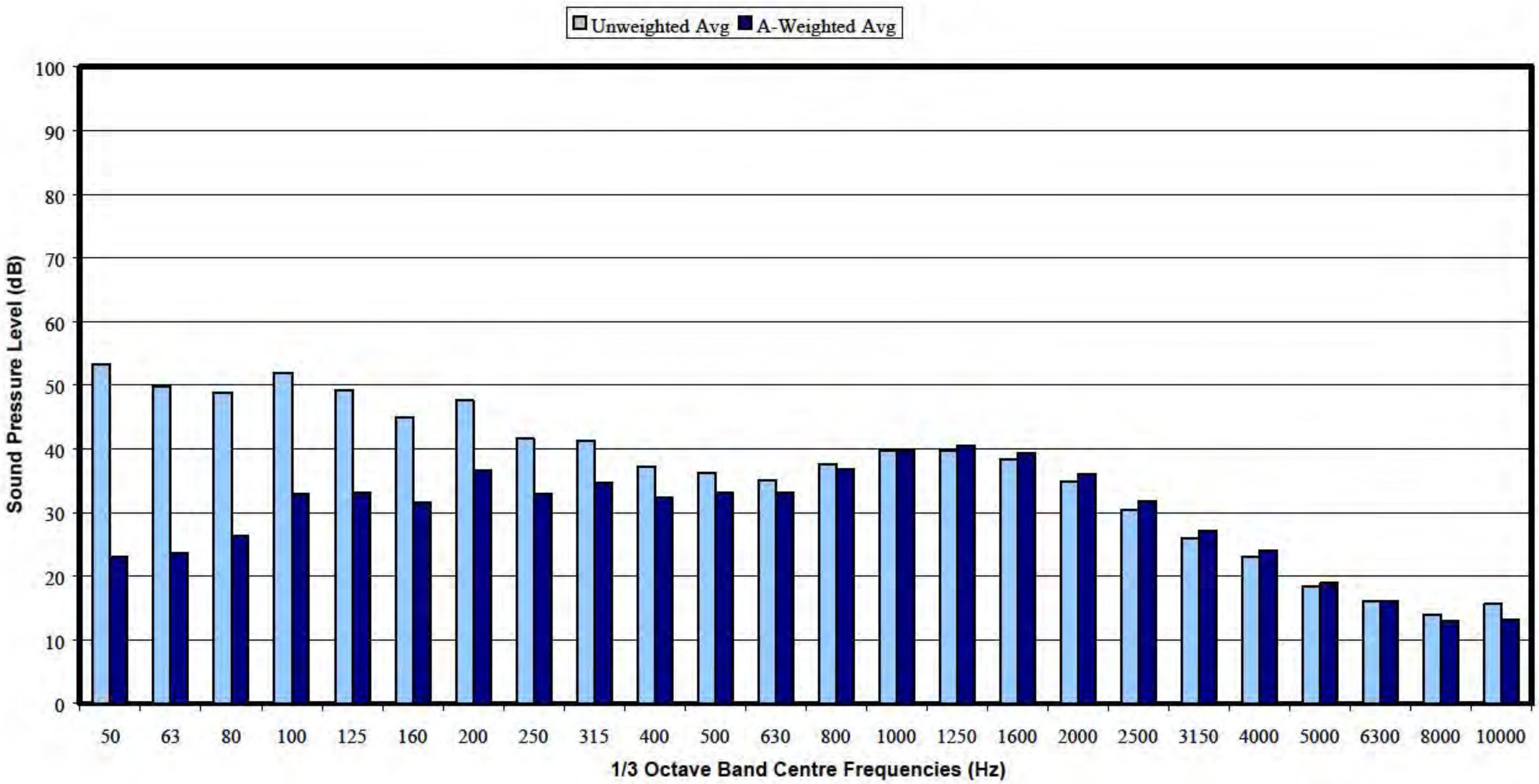
# APPENDIX E

# AVERAGE FREQUENCY SPECTRA OF PROMINENT ARTERIAL ROAD NOISE SOURCES

**Vancouver Arterial Road Study - Manned Noise Monitoring**

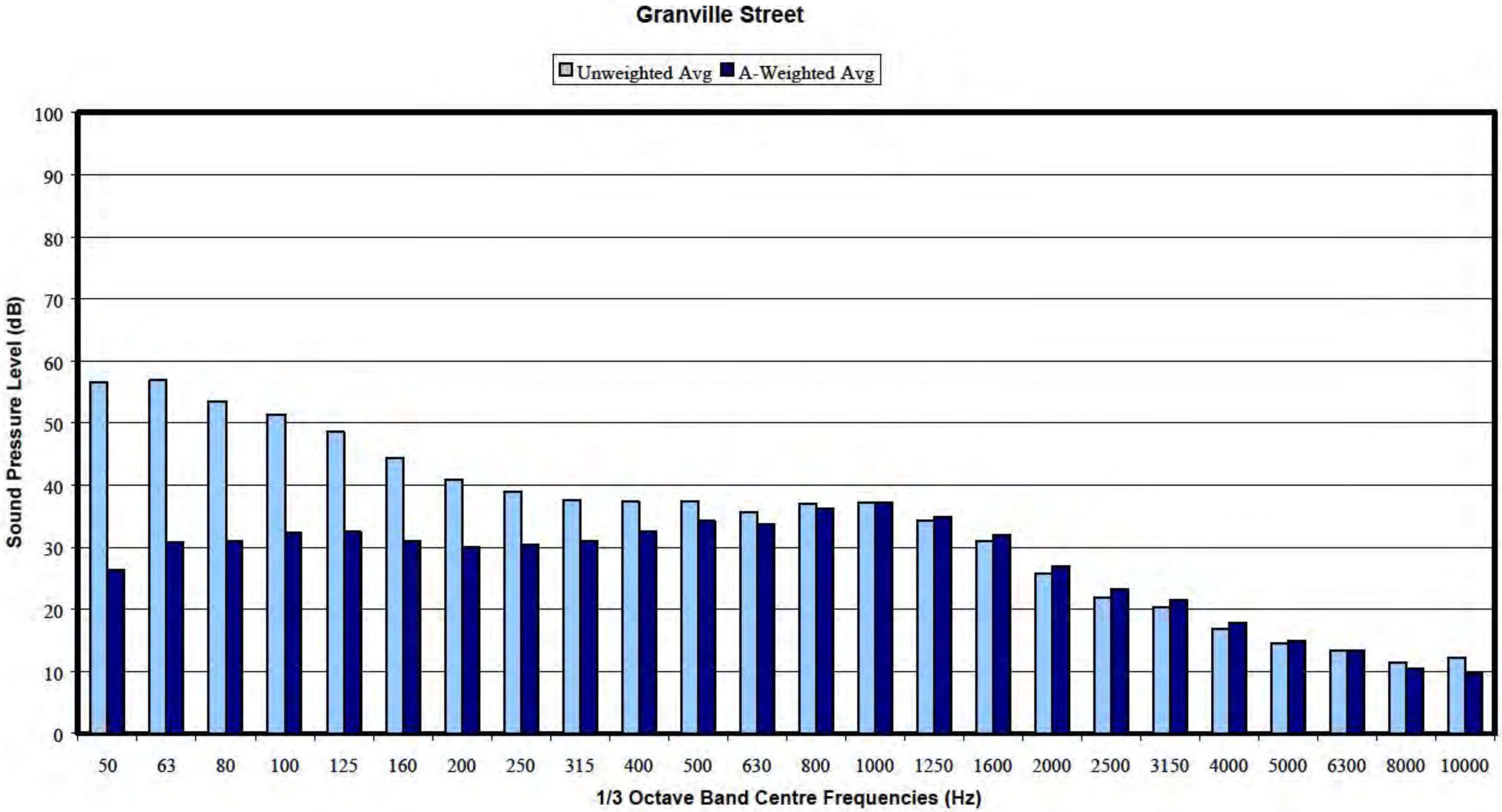
**May 1, 2005**
**Background Noise Level Spectrums**

**41st Avenue West**



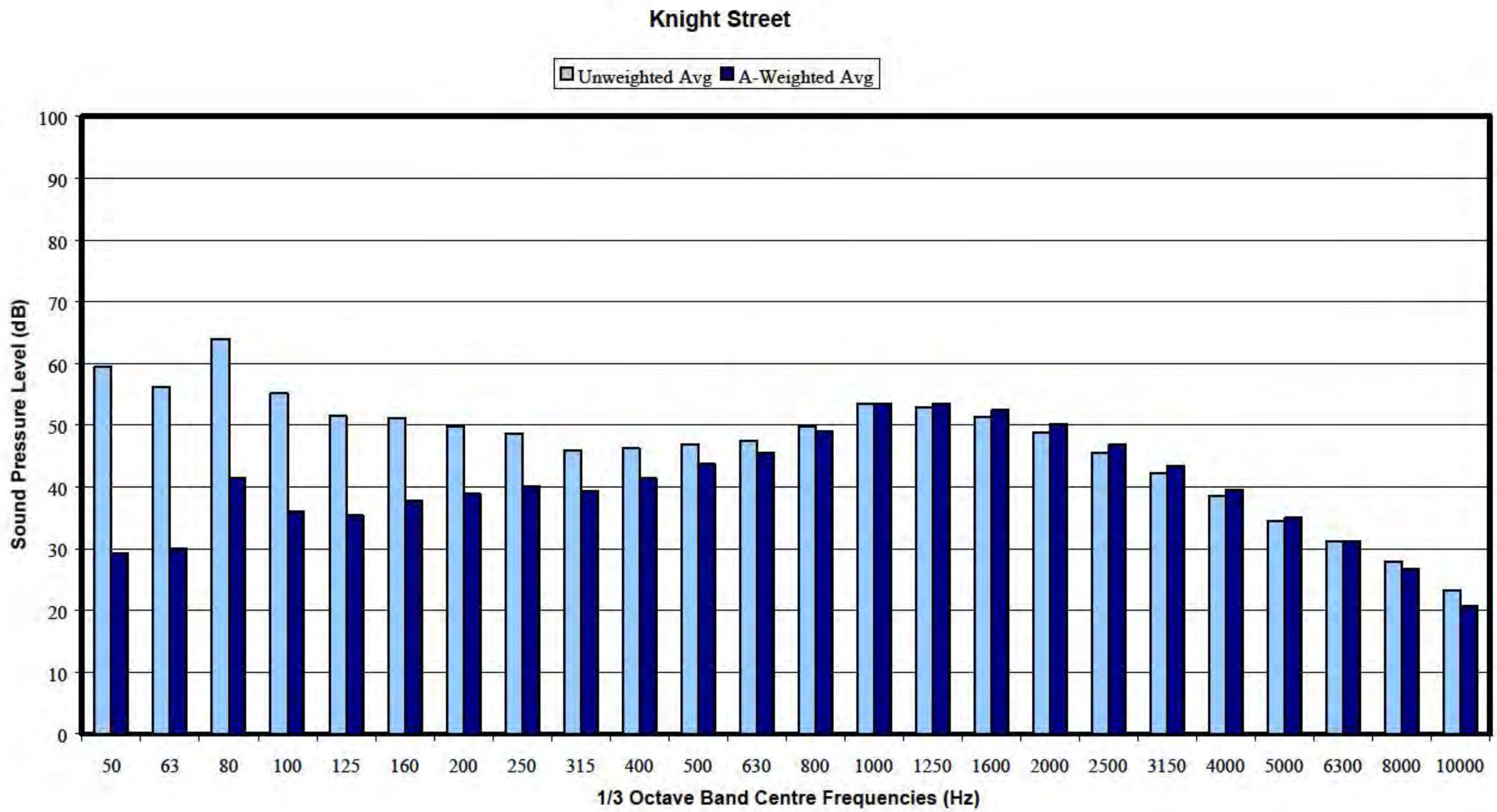
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**May 1, 2005**
**Background Noise Level Spectrums**



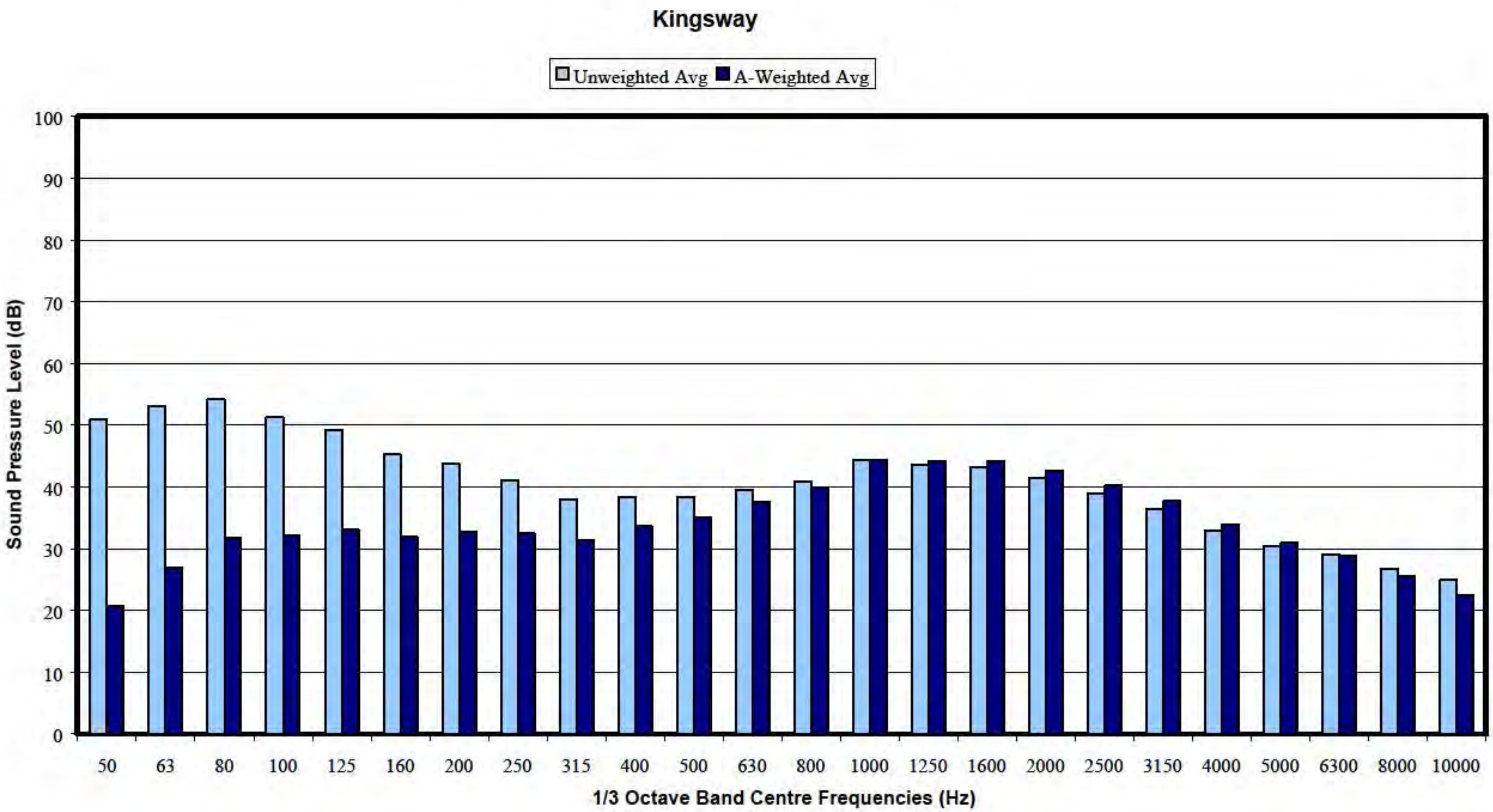
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**May 1, 2005**
**Background Noise Level Spectrums**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

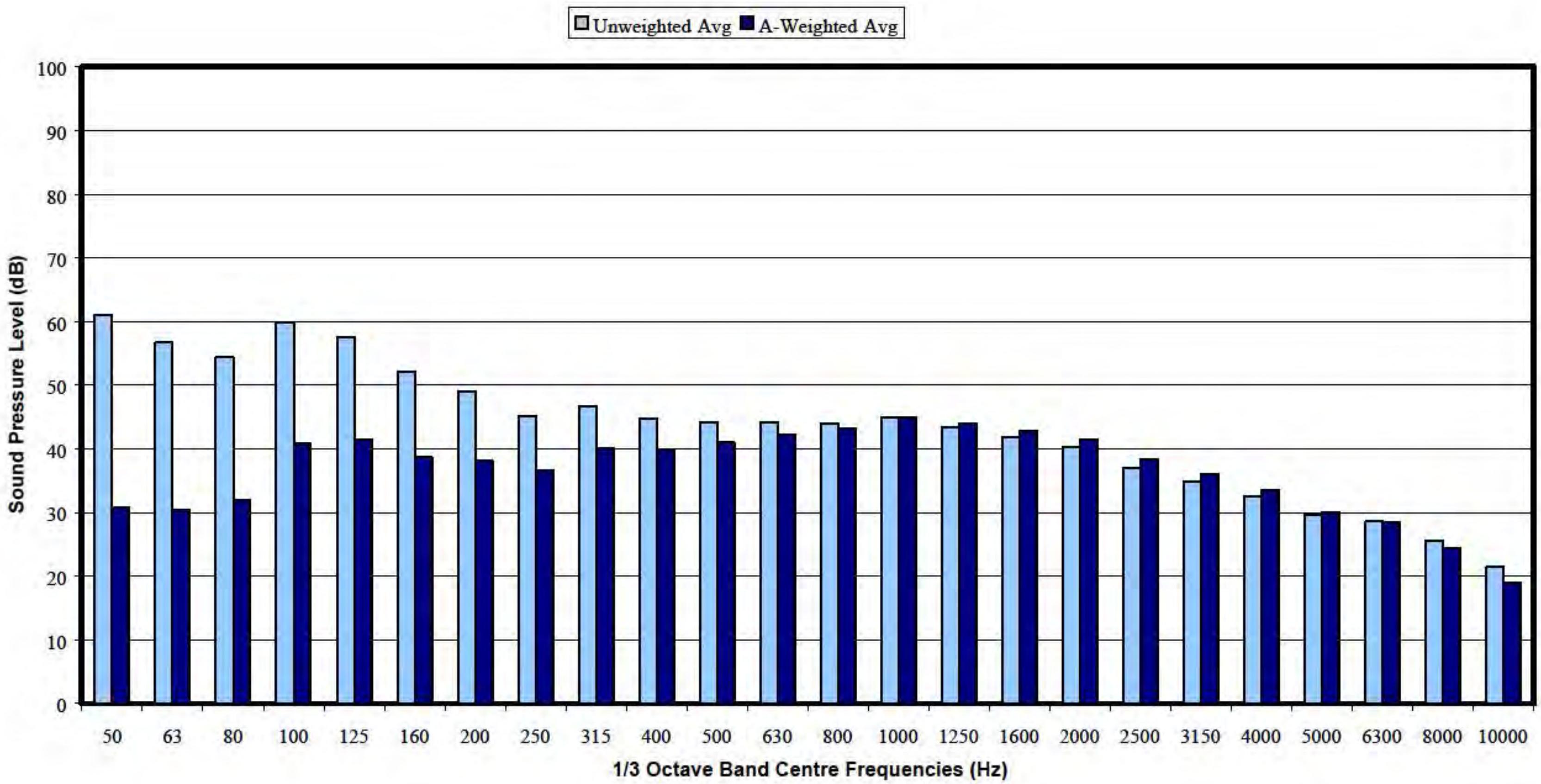
**May 1, 2005**
**Background Noise Level Spectrums**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

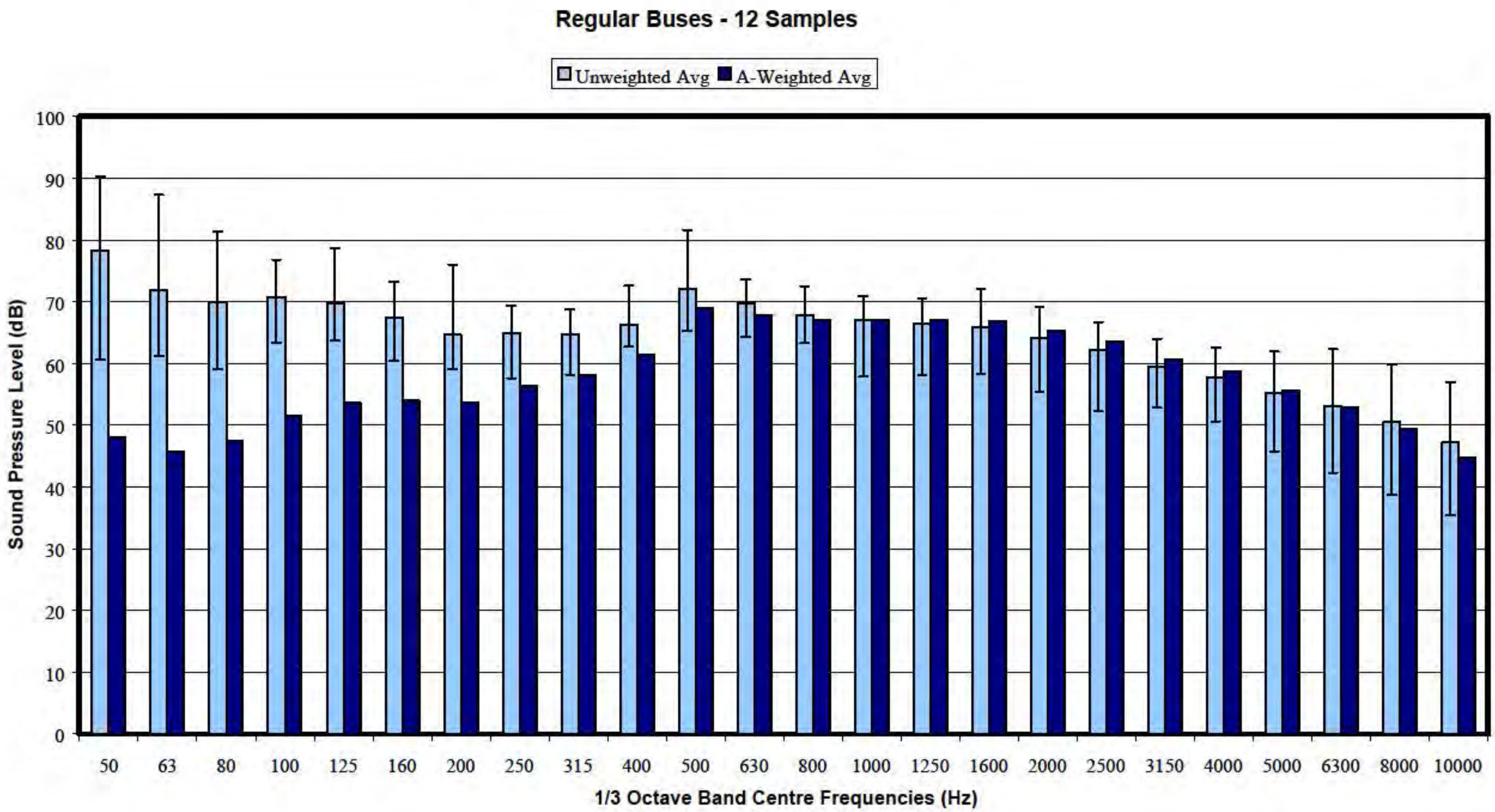
**May 1, 2005**
**Background Noise Level Spectrums**

## Commercial Drive



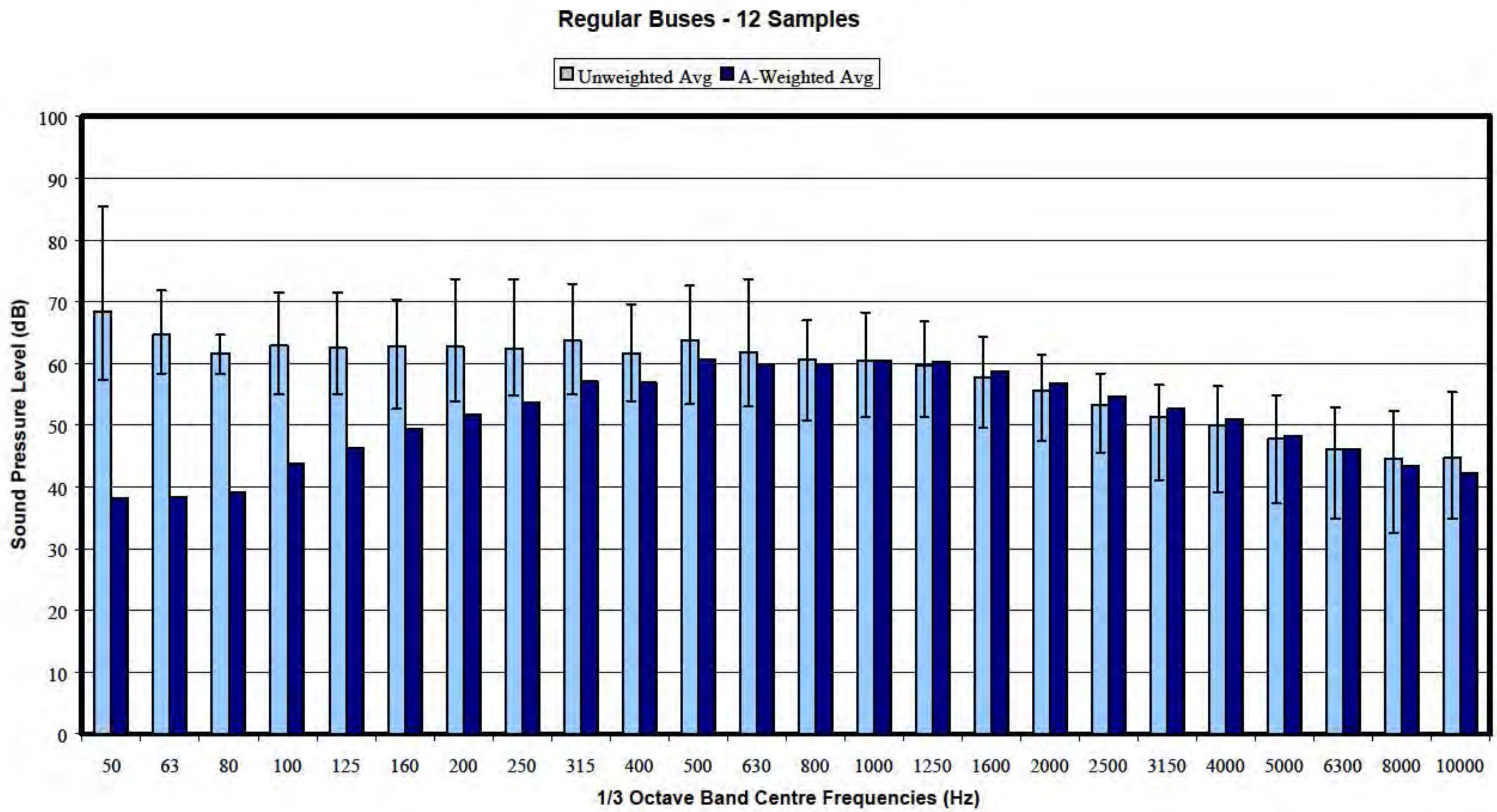
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



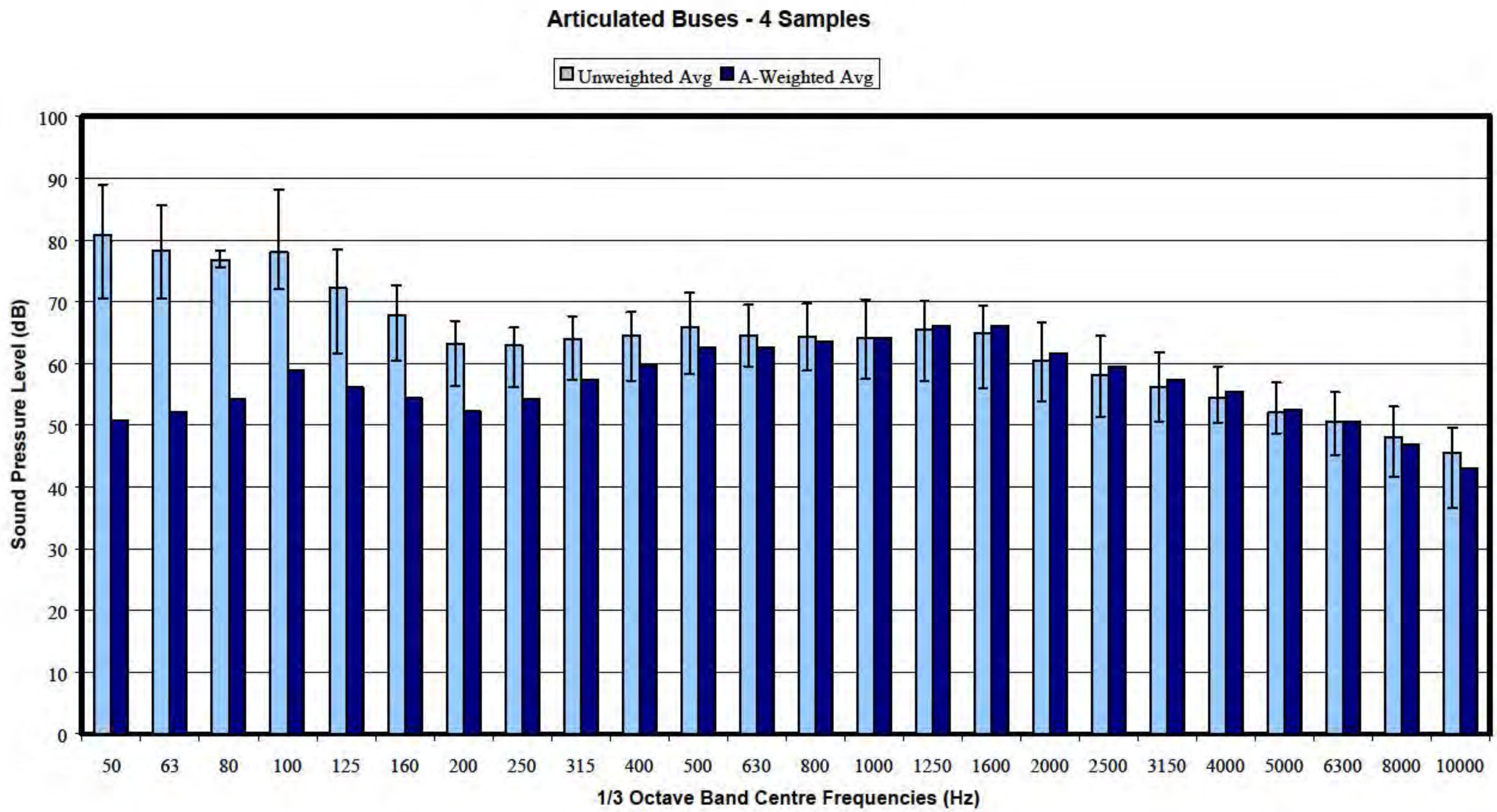
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**

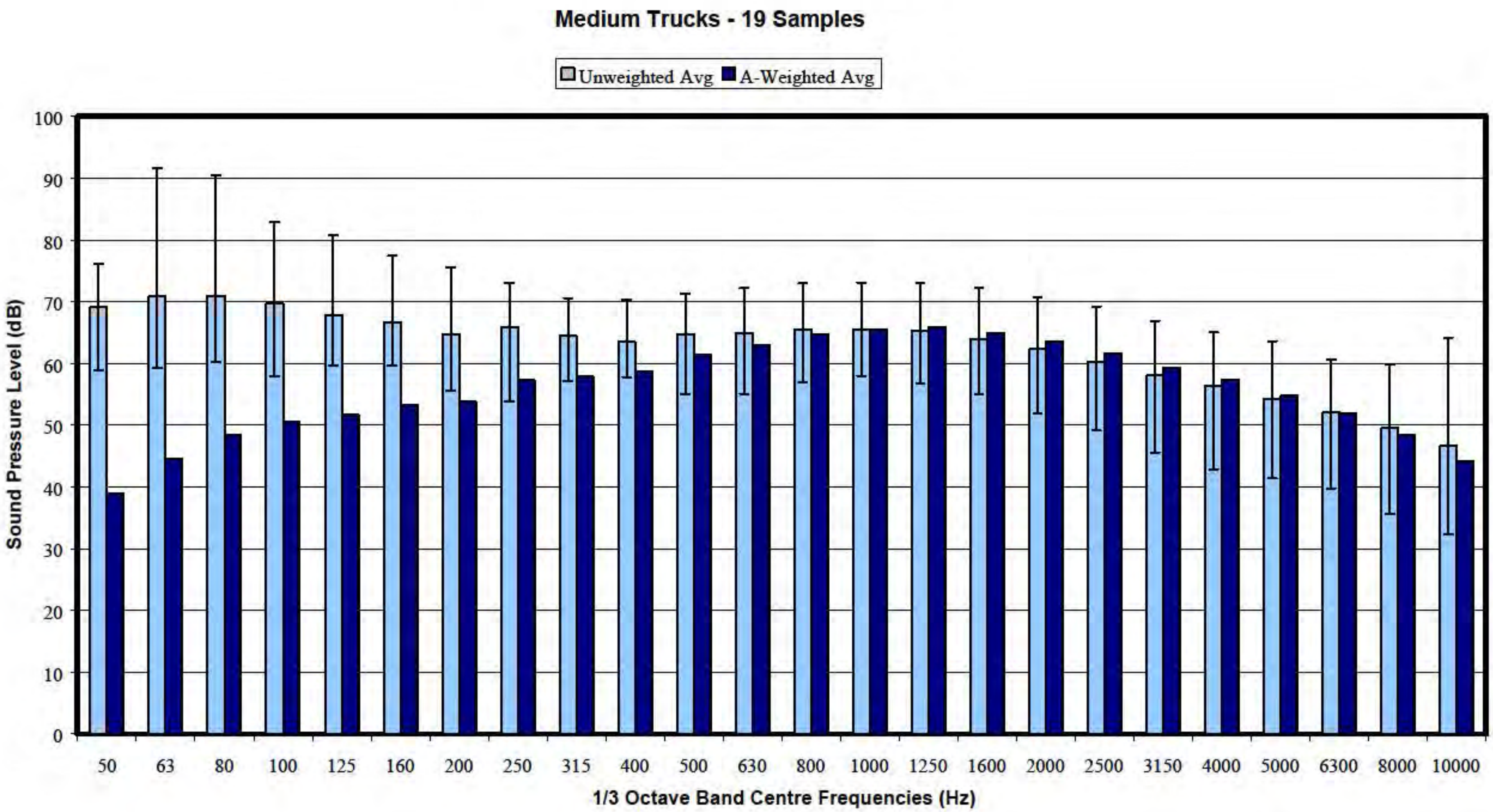





City of Vancouver FOI #2017-525, page 0138

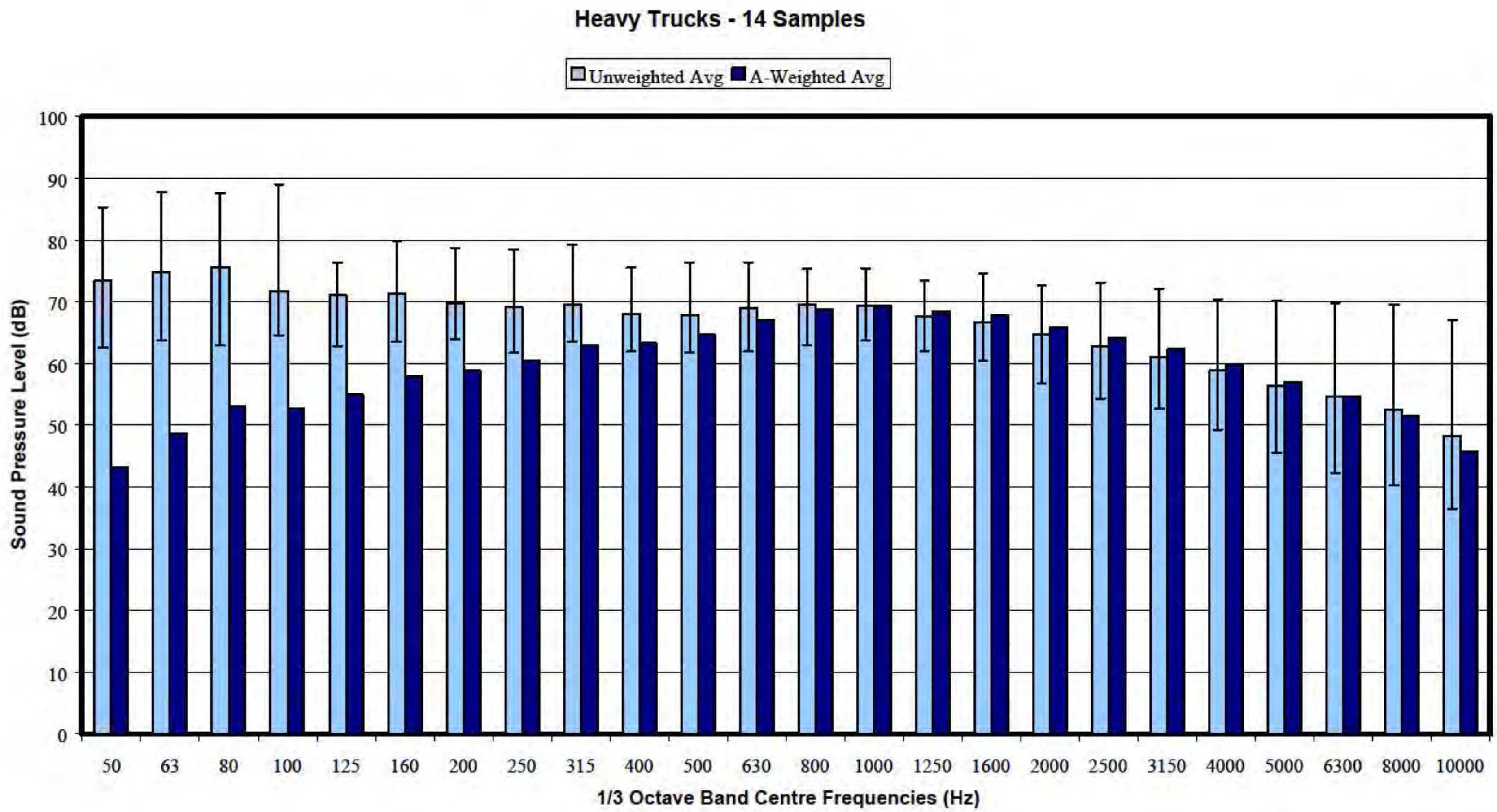
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



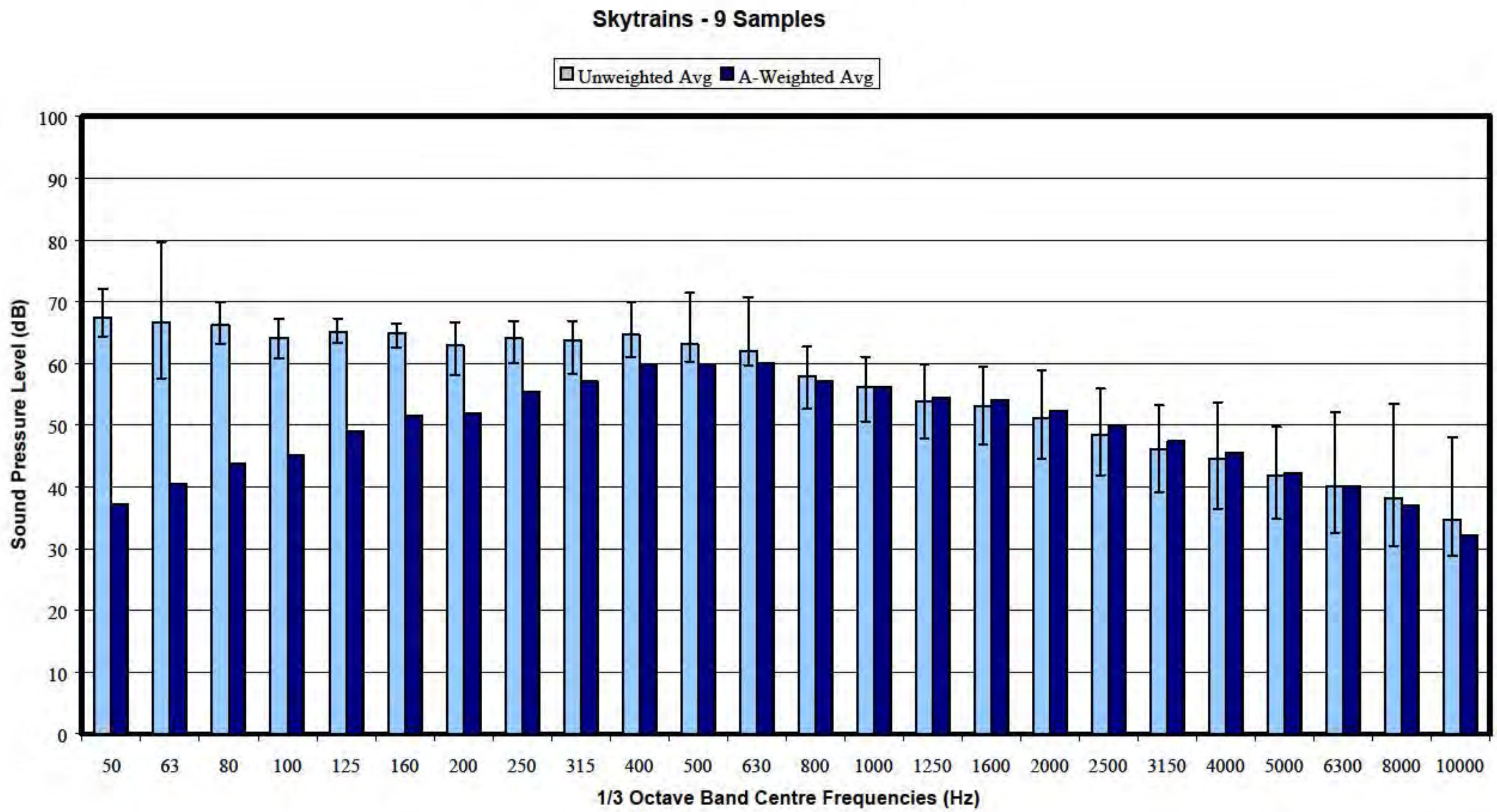
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



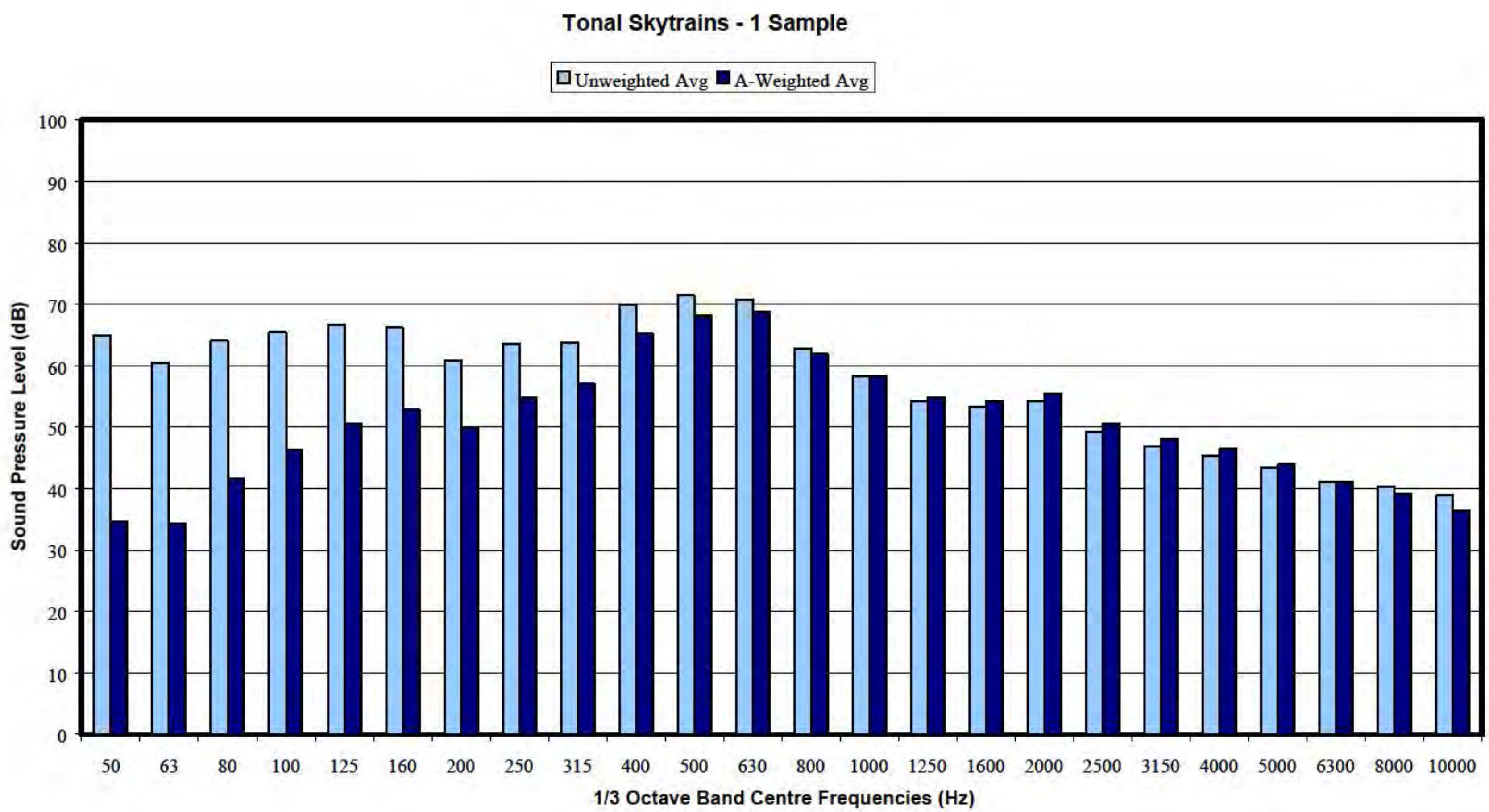
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



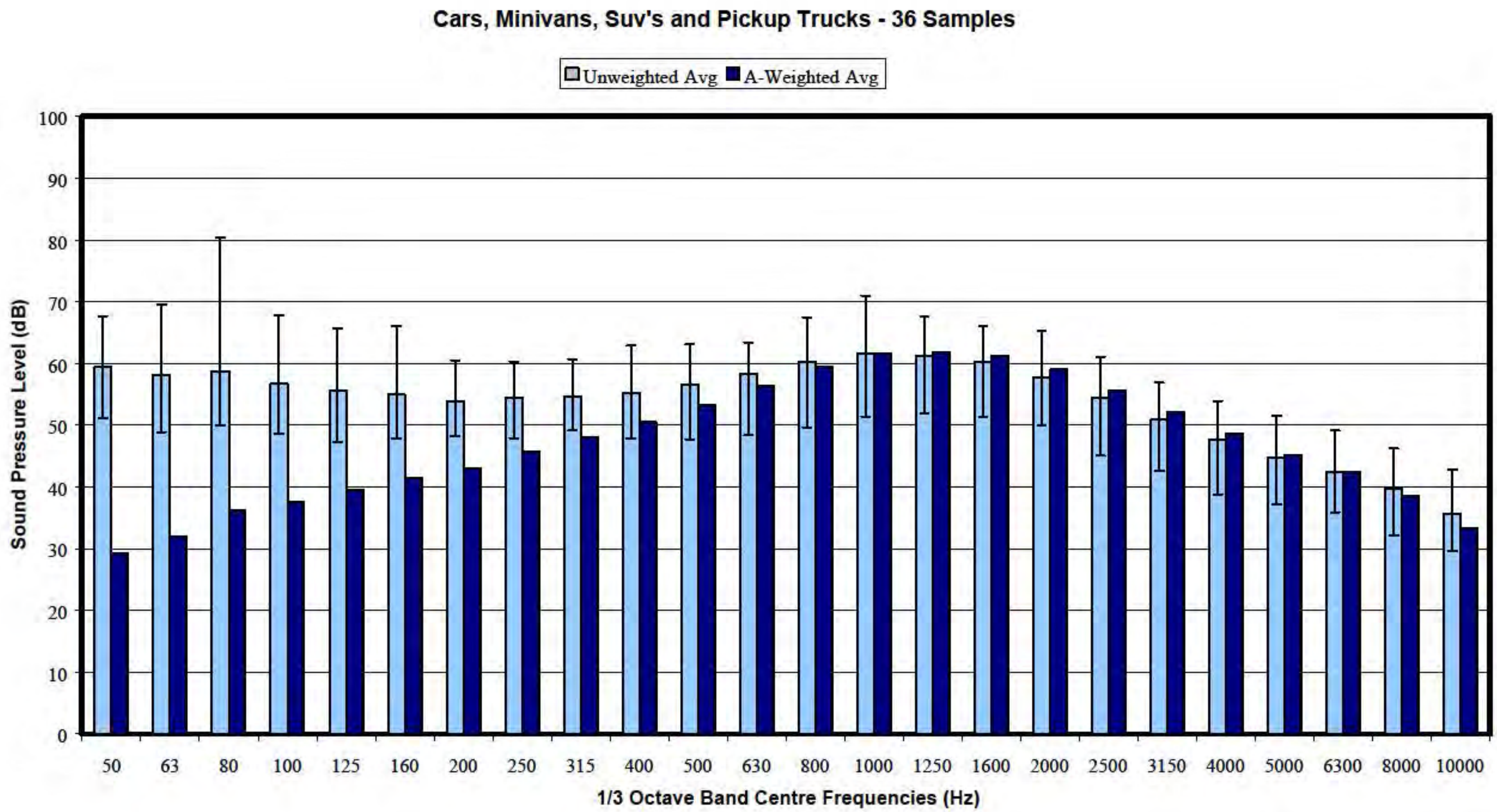
**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

**Feb 14-18, 2005**
**Noise Level Spectrums**

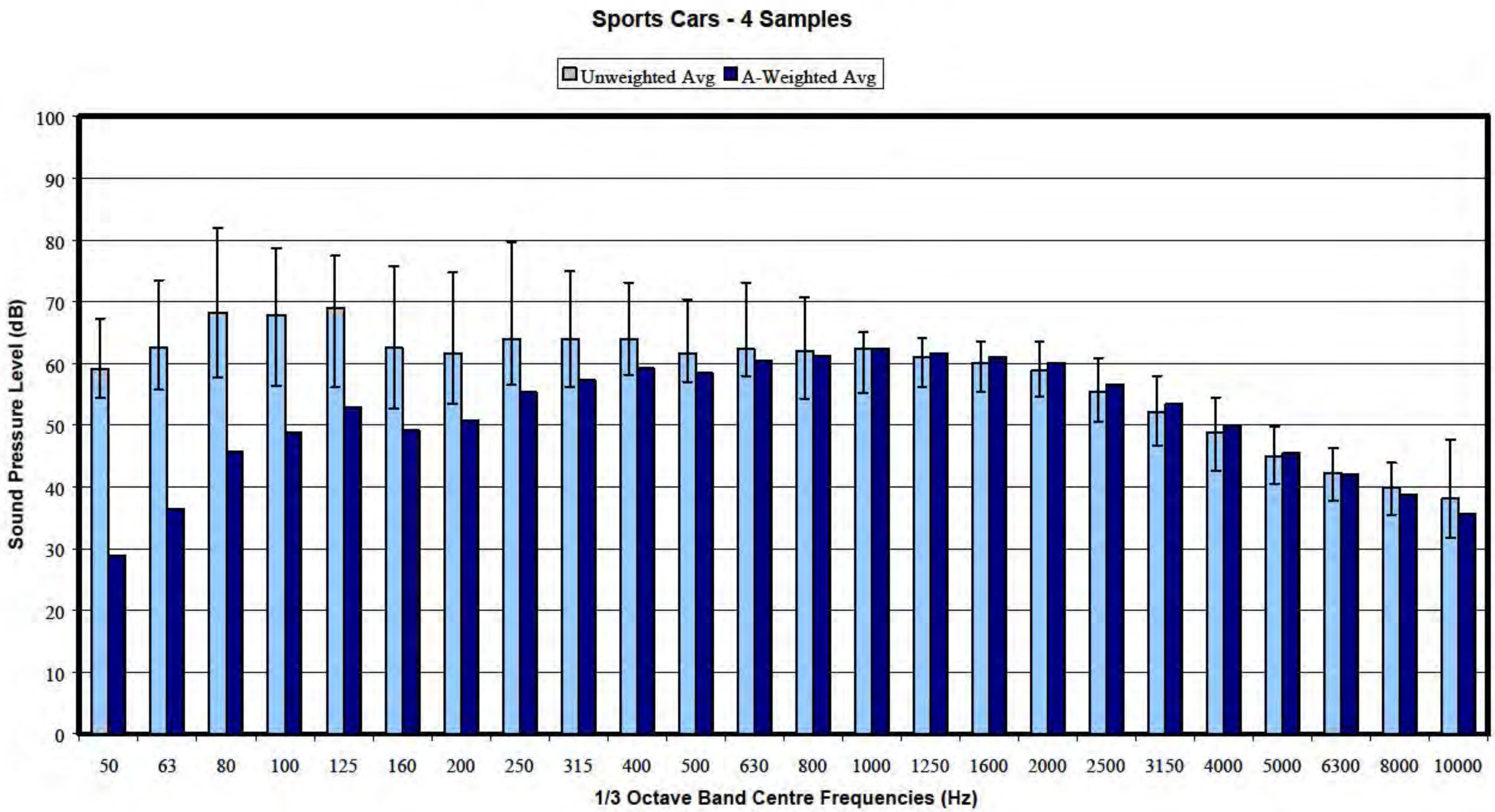





City of Vancouver FOI #2017-525, page 0143

**Vancouver Arterial Road Study - Manned Noise Monitoring**

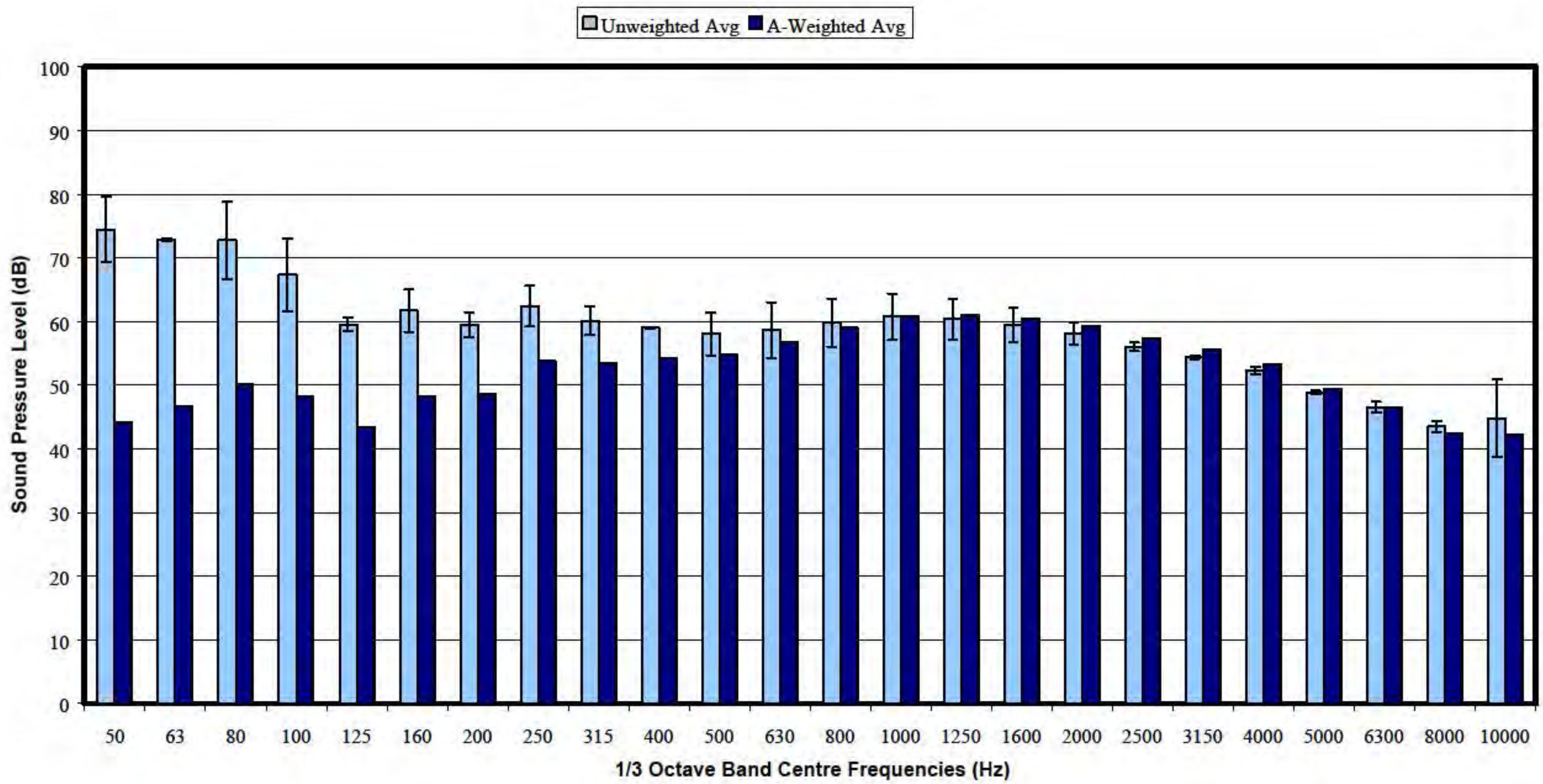
**Feb 14-18, 2005**
**Noise Level Spectrums**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

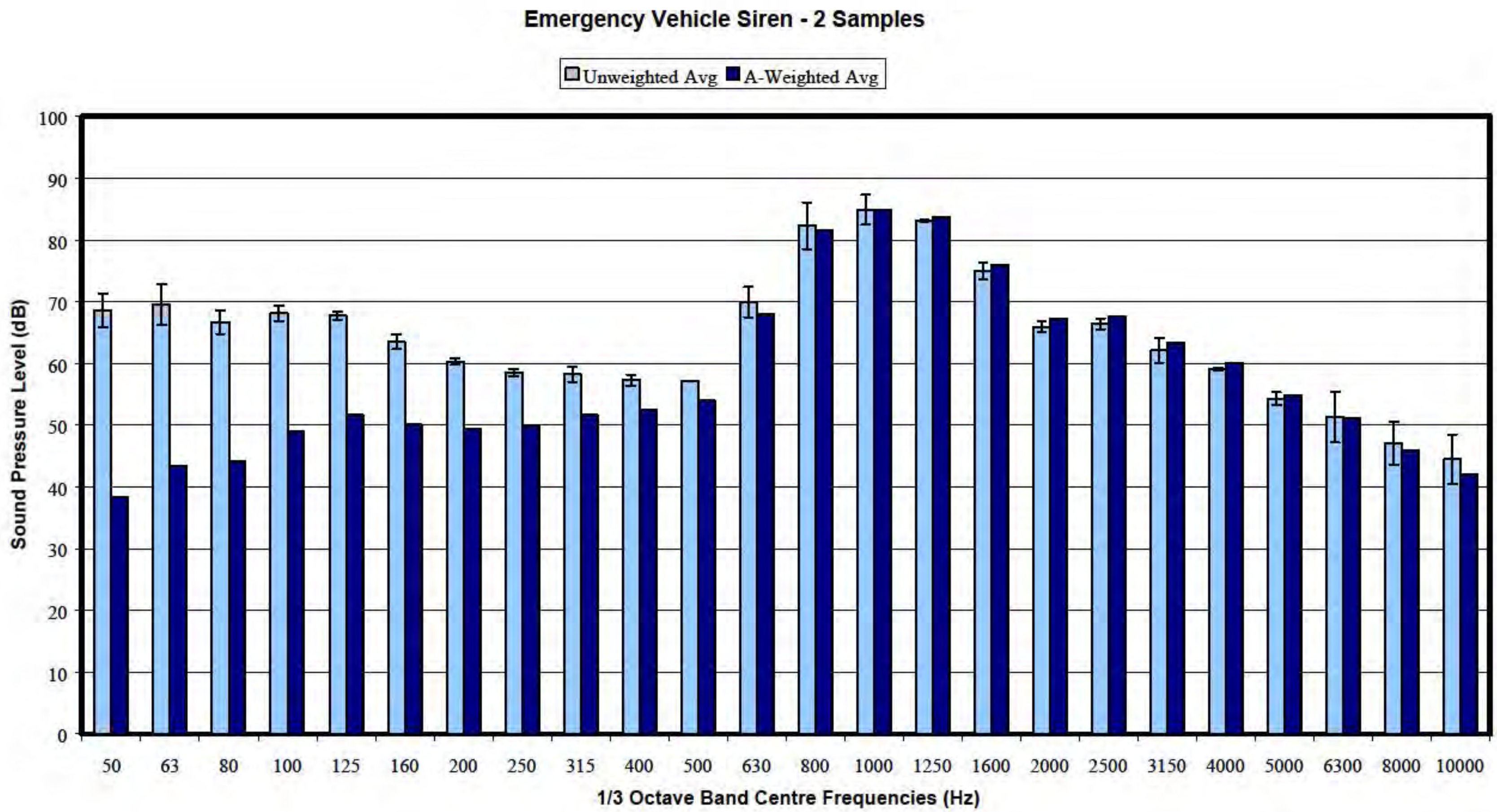
**Feb 14-18, 2005**
**Noise Level Spectrums**

**'Boom' Cars - 2 Samples**



**Vancouver Arterial Road Study - Manned Noise Monitoring**

**May 1, 2005**
**Noise Level Spectrums**



# TRAFFIC NOISE LEVELS

# AND TRAFFIC NOISE COMPOSITION

# ON ARTERIAL ROADS STUDY;

# DELIVERABLE 3

## *EVALUATION OF MITIGATION APPROACHES*

Prepared for:

***City of Vancouver***
453 West 12th Avenue
Vancouver, British Columbia
V5Y 1V4

Prepared by:

***Wakefield Acoustics Ltd.***
301 – 2250 Oak Bay Avenue
Victoria, British Columbia
V8R 1G5

April, 2006

# Table of Contents

# 1.0 INTRODUCTION

This report, Deliverable 3 of Contract PS04083 - a study of "Traffic Noise Levels and Traffic Noise Composition on Arterials Roads" for the City of Vancouver - presents the results of investigations into the effectiveness of various approaches that may be considered to mitigate the impacts of arterial traffic noise on the residents of Vancouver. To a large degree these investigations have utilized the Cadna/A traffic noise model developed as part of Deliverable 2 to assess the effects of noise barriers, heavy vehicle restrictions, speed controls and grades on average daily noise exposures from the entire traffic stream as well as on the levels of individual intrusive noise events, in particular heavy vehicle pass-bys. Preliminary discussions of these mitigation approaches (including noise barriers, speed controls, pavement design, heavy vehicle restrictions and other regulatory and educational approaches) were included in Section 4.2 of Wakefield Acoustics Ltd. Report 04-994-2, Deliverable 2, of October 2005.

# 2.0 EVALUATION OF MITIGATION OPTIONS

## 2.1 APPROACH

As part of Deliverable 2, Wakefield Acoustics Ltd. developed a city-wide model of Vancouver's arterial road system using DataKustik's Cadna/A sound propagation and control software. As input, the model utilized known 24-hour traffic volumes, posted speeds and heavy vehicle mixes. The output of the Cadna/A model was validated using measured noise exposures obtained from the project's baseline noise monitoring program. The model was then used to predict 24-hour equivalent sound levels, or $L_{eq}(24)$'s, along all of the City's arterial roads. Selected sections of this model (along Knight Street) have been used in this third phase of the study to evaluate the effects of vehicle speed reductions, of reducing heavy vehicle traffic through the banning/rerouting of trucks and of noise barriers. Other mitigation options such as pavement design, law enforcement, vehicle inspection and modification and education, which are not amenable to computer modeling, have been evaluated based on professional experience and judgment and input from agencies which have participated on the project review team including the Commercial Vehicle Unit of the Vancouver Police Department and Vancouver Coastal Health.

## 2.2 NOISE IMPACT MITIGATION THROUGH TRAFFIC CONTROLS

### 2.2.1 Reductions in Average Vehicle Speed

At typical highway speeds (i.e., 80 to 110 kmph) overall noise output from a traffic stream increases quite rapidly with average vehicle speed. While this trend is in part due to increased engine, exhaust and transmission noise, it is primarily due to increased noise from the interaction of the tires with the roadway, i.e., 'tire noise". Within the lower end of the typical range of average vehicle speeds on urban arterial roads (approximately 30 to 50 kmph), the noise emissions of heavy vehicles are dominated by engines and exhaust systems while the emissions of most light vehicles are already beginning to be controlled by the tires. Therefore, on arterials serving as truck routes, the benefit of speed reductions below 50 kmph is very small. In fact, the Cadna/A modeling indicates that overall traffic noise emissions from arterials with large truck volumes will actually increase slightly if the average speed is reduced from the most commonly posted speed of 50 kmph. However, traffic speed studies on sections of Knight Street have shown that over 50% of vehicles are traveling between 50 and 80 kmph. It is therefore of interest to assess the potential effects of reducing average arterial traffic speeds to something closer to the typical posted speed of 50 kmph.

Table 1 compares the effects (as predicted with Cadna/A model) on average traffic noise levels of reducing average vehicle speed under four heavy truck mix scenarios:

1. current Knight Street heavy truck mixes (approximately 8% daytime and 11% nighttime),

2. nighttime heavy truck ban on Knight Street (resulting in 0% trucks between 22:00 and 07:00 hours, 8% trucks between 07:00 and 22:00 hours and a 24-hour average of 5% heavy trucks),

3. heavy truck mix of 2% during daytime and nighttime (more typical of non-truck route arterials), and

4. total (24-hour) heavy truck ban (i.e., 0% heavy trucks day and night).

It is seen that under current Knight Street conditions, if the average vehicle speed was currently 80 kmph and it could be reduced 50 kmph, noise exposures would be reduced by a worthwhile 2.6 dBA. If, more realistically, the current average vehicle speed was


City of Vancouver FOI #2017-525, page 0150

**Table 1; Effects of Average Vehicle Speed and Heavy Truck Mix on Overall Arterial Road Traffic Noise Output**

| Heavy Truck Scenario | Noise Metric (dBA) | Average Vehicle Speed (kmph) | | | |
|---|---|---|---|---|---|
| | | 50 | 60 | 70 | 80 |
| Current Knight Street truck mixes (8% day, 11% night) | $L_{eq}(24)$ | 68.8 | 69.5 | 70.3 | 71.4 |
| | Change re. 50 kmph | -- | 0.7 | 1.5 | 2.6 |
| Nighttime Heavy Truck Ban (8% day, 0% nighttime, i.e., average 5% over 24-hours) | $L_{eq}(24)$ | 68.2 | 69.0 | 69.9 | 71.0 |
| | Change re. 50 kmph | -- | 0.8 | 1.7 | 2.8 |
| Most heavy truck traffic diverted elsewhere (2% daytime, 2% nighttime) | $L_{eq}(24)$ | 66.3 | 67.6 | 68.8 | 70.0 |
| | Change re. 50 kmph | -- | 1.3 | 2.5 | 3.7 |
| 24-Hour Truck Heavy Ban (0% daytime, 0% nighttime) | $L_{eq}(24)$ | 65.1 | 66.8 | 68.2 | 69.4 |
| | Change re. 50 kmph | -- | 1.7 | 3.1 | 4.3 |

70 or 60 kmph and could be reduced to 50 kmph, more modest noise reductions of 1.5 and 0.7 dBA respectively would be expected.

Since heavy vehicle noise output increases less rapidly with speed than does the noise from light vehicles, reductions in average vehicle speed will yield larger noise reduction benefits along roadways which carry fewer heavy trucks. Accordingly, Table 1 shows that if a nighttime heavy truck ban was to be imposed along Knight Street, the noise reductions that would be result from decreasing the average vehicle speed to 50 kmph from 80, 70 and 60 kmph would be 2.8, 1.7 and 0.8 dBA respectively. In the hypothetical situation where most of Knight Street's heavy truck traffic was diverted elsewhere, so that only 2% heavy trucks remained, these speed-related noise reductions would be larger still, namely 3.7, 2.5 and 1.3 dBA respectively. Finally, under a total, 24-hour heavy truck ban (0% heavy trucks), the reductions in $L_{eq}(24)$ attainable by reducing average speeds to 50 kmph from 80, 70 or 60 kmph, are predicted to be 4.3, 3.1 and 1.7 dBA respectively.


City of Vancouver FOI #2017-525, page 0151

In reality the average vehicle speed will vary with time of day and with location along Knight Street. Taken over a 24-hour period, the potential benefit of speed reductions under a given heavy truck mix scenario would then be expected to be a "blend" of the effects shown in Table 1. Of course achieving significant reductions in average vehicle speeds on an existing arterial road may not be as simple as putting up new speed limit signs. Traffic calming measures as well as enforcement efforts may also be required. Further, any significant speed reduction achieved may be expected to have other effects – on the negative side, a possible reduction in road capacity and increased travel times, while on the positive side, potential reduced accident rates and fuel consumption.

### 2.2.2 Effects of Speed Reduction and other Measures on Engine Brake Noise

#### *2.2.2.1 Engine Brakes – an Overview*

Engine brake (or more accurately, "compression release engine brake") noise is a distinctive component of the noise environment along highways and arterial roads which serve as truck routes. When activated, these auxiliary braking systems effectively transform the truck's engine into an energy-absorbing air compressor and in doing so acts to retard the engine, thereby slowing down the truck. Air is compressed in the engine's cylinders and ejected through the exhaust system resulting in the characteristic staccato, "barking" sound. The number of engine brake noise events observed during the attended noise monitoring portion of this study was not large with just 13 events observed with maximum levels between 72 and 83 dBA and only one exceeding the 80 dBA Intrusive Noise Event threshold. However, this outcome may have been influenced by the locations selected for this monitoring. Engine brakes are most frequently used on long downhill grades, highway off-ramps and in tight curves. However, they may be applied at any location in traffic if the sudden need to decelerate arises. Further, because this noise has some rather unpleasant characteristics, such as its sudden onset (which can cause startle) and its staccato character, it may be considered inherently more intrusive than the sound of a typical heavy truck pass-by of equal intensity/loudness. It is therefore worthwhile considering measures that could be taken to reduce the likelihood that truckers will use their engine brakes while on arterial roads and/or to minimize the intensity of the resulting noise should it prove necessary to employ engine brakes for safety or other reasons.

#### *2.2.2.2 HMMH Field Studies*

Most newer heavy trucks are fitted with engine brakes, some are manually controlled and others automatically activated. In either case, the noise levels generated may be expected to increase as the speed at which the brakes are engaged increases. While no hard data supporting this trend has been found, Harris Miller Miller & Hanson Inc. (HMMH), the U.S. acoustical consulting firm that has collaborated with Wakefield Acoustics Ltd. on the Vancouver Arterial Road Study, conducted field studies in 2000 at four locations along Route17/50 in Virginia which experienced frequent engine brake use to assess the effectiveness of various mitigation measures in reducing the numbers and intensities of engine brake noise events. One such measure was to reduce the posted speed within the study area from 55 to 45 mph (88 to 72 kmph). A second measure was the posting of signs encouraging truckers to "Reduce Noise – Please Limit the Use of Engine Braking", while the third involved the installation of three sets of "Rumble Strips" on the north bound lanes of Route 17, presumably to alert truckers and get them to reduce their speeds. Before and after studies showed that while the numbers of engine brake noise events was not reduced significantly and there was no associated reduction in overall traffic noise exposures [as indicated by the $L_{eq}(24)$], reductions in the average maximum noise level created by engine brake events of 2, 5, 8 and 13 dBA were observed at the four assessment locations. The three mitigation measures were introduced simultaneously making it difficult to determine which measure had the greatest effect. However, based on field observations it was concluded that "the signs warning truckers to limit engine braking noise was the mitigation measure primarily effective in reducing the loudness of the events". It may then be concluded that the warning signs did not generally prevent truckers from applying their engines brakes but did influence how "aggressively" they were applied. It would also appear that truckers, while not uniformly observing the posted speed reductions, did generally try to minimize the noise produced by their engine brakes.

*2.2.2.3 Effects of Truck Speed on Engine Brake Noise Levels*

Engine brake noise is created by the ejection of a burst of compressed air from each engine cylinder as it reaches "top dead centre". Since the pressure of the compressed air at the instant it is released is independent of the speed of the engine, the noise created by each such release of air remains essentially constant as well. However, the faster the engine turns over, the more such bursts of noise there will be per second. Therefore if the engine brake is applied when the engine is operating at 3,000 rpm, there will be twice as many bursts of noise per second as would occur if the engine was turning at 1,500 rpm. Subjectively, this would speed up the staccato character of the sound and would cause the average sound energy level, as expressed by the $L_{eq}$, to increase by about 3 dBA. The maximum noise level, or $L_{max}$, that would determine whether the noise event would be considered truly intrusive, would also increase, but not quite as much as the $L_{eq}$. Engine brake noise is then more directly related to truck engine speed (rpm), than vehicle speed (kmph). It then appears that the noise level created by a given engine brake event will depend on a combination of factors – the engine speed (which depends on gear the truck is in and its rolling speed), the condition of the exhaust system (see Section 2.2.2.4), and, at least for manually-controlled systems, the aggressiveness with which the brake is applied. Given these multiple factors, it is difficult to estimate the overall effect of reducing posted speeds on typical engine braking noise levels, however, it appears safe to say that lowering average heavy truck speeds would have a positive effect on engine brake noise – both in terms of the likelihood that these brakes would have to be applied and the maximum noise levels created when they are applied.

*2.2.2.4 Effects of Exhaust Muffler Condition on Engine Brake Noise*

Since compressed air released by the engine brake passes through the truck's exhaust system, the type and condition of the exhaust mufflers would be expected to have a significant effect on engine brake noise levels. Jacobs Vehicle Systems, a major manufacturer of air-compression engine brakes, has published data showing that engine brake noise levels created by trucks with ineffective or absent mufflers can be up to 18 dBA higher (250% louder) than the levels created by trucks fitted with effective mufflers in good repair. Surveys conducted on U.S. highways have found that over 5% of heavy trucks operate without functioning mufflers while about half as many have "straight stacks", i.e., no mufflers. Clearly there is potential through vehicle inspection to reduce the numbers trucks producing unnecessarily high levels of engine brake noise when decelerating as well as excessive exhaust noise while accelerating and cruising.

### 2.2.3 Restricting or Rerouting of Heavy Vehicles

At a speed of 50 kmph, the maximum noise level produced by typical heavy vehicle (truck or diesel bus) when passing a given spot is about 18 dBA higher than that produced by typical light vehicle in good repair. At 70 kmph, heavy vehicle noise output is about 15 dBA higher than that of light vehicles. Therefore, in terms of their contribution to the daily average noise exposure at residential facades, elimination of one heavy vehicle is equivalent to elimination of roughly 30 automobiles where the average speed is 70 kmph or 60 automobiles where the average speed is 50 kmph. Further, with each heavy vehicle eliminated, a truly intrusive[1] noise event ($L_{max} \geq 80$ dBA) is potentially avoided. The potential benefits associated with prohibiting heavy vehicle traffic on a particular arterial roadway - either during nighttime hours or for all 24-hours - would then include; 1) the elimination of large numbers of intrusive noise events (e.g., Knight Street carries about 78 heavy trucks per nighttime hour), and 2) the reduction of daily average noise exposures such as $L_{eq}(24)$ and $L_{dn}$ by from about 2.0 dBA where average vehicle speeds are higher (70 kmph) to 4 to 5 dBA where they are lower (40 to 50 kmph).

[1] In Deliverable 2, to assist in identifying the most significant arterial road noise sources, a truly intrusive noise event was defined as one which produced a maximum noise levels of 80 dBA or more at a residential façade.

This approach would also reduce or eliminate noise events associated with the use of engine (air-compression) brakes. However, while these noise events can reach or exceed the "truly intrusive" threshold of 80 dBA, they were observed to occur quite infrequently[2] given the large numbers of heavy trucks on the arterial road system.

In practice, the noise-reduction benefits gained locally through the restriction and/or rerouting of heavy truck traffic, would tend to have offsetting negatives effects elsewhere – assuming a fixed arterial road system. For example, if a certain arterial was closed to trucking at night, then either the trucks would find another, likely less direct, route, thereby increasing nighttime noise exposures in other neighbourhoods while increasing overall exhaust emissions, or they would make their trips during the daytime, thereby increasing congestion on the arterial road in question and possibly others nearby. It would appear that the restriction and/or rerouting of truck traffic from a particular arterial road would only achieve a clearly positive overall noise impact if a desirable alternative route existed with significantly lower residential densities along it. From the City's zoning map, it would appear that a hypothetical example of such an alternate route (for Knight Street trucks) would be Fraser Street. Since Fraser Street has much less residential and more commercial zoning between S.E. Marine Drive and Kingsway, overall residential traffic noise exposures would be reduced if heavy trucks were to be diverted from Knight Street to Fraser Street. However, even in this case, there are likely to be significant numbers of residents living in second floor apartments above commercial premises along Fraser Street. These residents, as well as others working and shopping along this largely commercial corridor, would be impacted by such a rerouting of truck traffic. There is also the concern as to whether Fraser Street, or any other north-south arterial, would have the capacity to handle the additional traffic.

## 2.3 PAVEMENT DESIGN – "QUIET PAVEMENTS"

Various types of asphalt pavements including Open-Graded Asphalt (OGA) and Rubberized Asphalt (ARC) can reduce tire noise emissions sufficiently to achieve overall traffic noise reductions of up to 5 to 7 dBA under highway conditions. These results have been verified in B.C. installations. Quiet pavements (particularly OGA) have open-surfaces with many interconnecting voids (typically 10% to 20% voids) leading down into the pavement. These voids allow water to drain away laterally within the pavement itself thereby improving traction, reducing spray as well as the risk of hydroplaning during heavy rains. The voids reduce tire noise by allowing air trapped within the tire tread patterns to vent into the pavement, thereby avoiding the "suction cup effect" that is responsible for most of the high-frequency "hissing or swooshing" noise created by tire rolling on conventional dense-graded pavements. Rubberized

[2] Only 13 events engine brake noise events were identified during the attended 24-hour monitoring at five sites.


City of Vancouver FOI #2017-525, page 0155

asphalt appears to achieve its noise reduction effect (which has been found to equal or exceed that of OGA) through a combination of surface porosity and the degree of resilience provided by the crumb rubber content.

Quiet pavements work best at higher speeds (70 kmph and above) for which tire noise is clearly dominant over engine and exhaust noise. However, they can also produce worthwhile effects at lower speeds, particularly where heavy vehicle percentages are low. At typical arterial road speeds of 40 to 70 kmph, reductions of 2 to 4 dBA are more likely achievable depending on traffic mix and flow conditions. These pavements are somewhat more expensive than regular asphalt pavements and their long-term durability in high traffic volume situations has not been confirmed locally. There is also potential for surface deterioration when exposed to repeated freeze-thaw cycles, but this is not really a concern in Vancouver. Further it his been found that when used on lower speed arterials, open-graded pavements tends to become clogged with dirt and tire rubber debris thereby gradually losing their noise reduction and drainage benefits. In contrast, when used on high-speed roads, these pavements tend to be self-cleaning. A widely used asphalt pavement called "Superpave" has some capacity to control tire noise, however, local experience indicates that it provides reductions of only about 1.5 dBA at highway speeds and 1 dBA or less at typical arterial road speeds.

## 2.4 PAVEMENT MAINTENANCE

Regular maintenance of pavement (to keep a smooth, even surface profile) will minimize that component of tire noise (a steady rumbling/roaring sound) which results from the impact of tire treads with minor surface irregularities/roughness and the associated vibration of the tire tread and casing. Elimination of more severe pavement irregularities such as uneven joints, patches or potholes will also eliminate the discrete, impulsive and therefore intrinsically more intrusive noises that otherwise occur each time vehicle tires strike them.

## 2.5 LAW ENFORCEMENT AND REGULATION

Vancouver Police Officers can ticket the drivers of excessively loud vehicles including motorcycles under the B.C. Motor Vehicles Act. The Commercial Vehicle Unit (CVPE) of the Vancouver Police Department (VPD) helps regulate the safety and operation of heavy vehicles, including their noise emissions. When enforcing vehicle noise emission regulations, the police employ a stationary noise test methodology as specified in several standard procedures including SAE J1297 and ISO 5130. This method focuses on exhaust noise and involves the measurement if noise levels at a position 0.5 m and 45 degrees from the exhaust outlet of the stationary vehicle while its engine is revved up to a prescribed speed. The enforced noise limit is 96 ± 1.5 dBA which reportedly can


City of Vancouver FOI #2017-525, page 0156

be met by all new certified factory motorcycles. At a more relevant distance from the perspective of community noise exposures, for example 15 m or 50 ft., this 0.5 m noise limit would correspond to approximately 66 dBA.

Application of this vehicle noise regulation by police during their regular traffic-related operations then provides a means of eliminating some of the noisiest vehicles - at least temporarily. However the effectiveness of this approach will be limited by the resources available and the emphasis placed on this task. Perhaps, in addition, consideration could be given to implementing periodic "noise checks" on arterial roads much in the manner of current speed and "Drinking and Driving Counterattack" checks.

## 2.6 VEHICLE INSPECTION AND MAINTENANCE

In the 1970's, Motor Vehicle Inspection Stations in Vancouver, Victoria and Nanaimo were fitted with noise level monitoring and display systems that permitted inspection station staff to run each vehicle up to a prescribed engine speed and measure the resulting noise level generated within the testing station. Owners of excessively loud vehicles were then ordered to have the noisy component (engines, exhausts) repaired and then to return to the station for a retest. However, these Provincially-operated stations were discontinued many years ago and there does not appear to be an interest in reinstating them at the Provincial level. There may however, be some potential for integrating police inspection and ticketing with the current Air-Care testing facilities. There are roughly twenty fixed Air-care testing facilities around the Lower Mainland as well as two mobile units which are used to test heavy vehicles.

The VPD currently uses a sound level meter which must be calibrated prior to use. The public can gain access to similar meters and thus are able to dispute their tickets in court if they obtain different results from the ticket-issuing officer. The court dispute process could be avoided if officers could refer ticketed motorists to an Air-Care facility for noise testing using advanced (more accurate) testing equipment. If vehicles passed the Air-Care facility noise test, the ticket would be voided. If they failed the test, the owner would have to pay the indicated fine. It seems unlikely the Air-Care test results would be disputed, since they would be based on the tests using more accurate sound level meters.

## 2.7 VEHICLE MODIFICATION (NOISE CONTROL)

This approach refers to the mitigation of individual intrusive noise events as well as overall traffic noise levels that might be achieved through the cooperation of owners (private and public) of vehicles for which there is potential to reduce noise emissions through relatively straight-forward and inexpensive measures such as better mufflers,


City of Vancouver FOI #2017-525, page 0157

tuning up of engines, tightening up of body panels or use of less noisy tires. There would be some overlap between this approach to noise control and that associated with the reintroduction of some form of noise tests at Air-Care stations or other similar facilities distributed around the City or region. This approach would likely only succeed if combined with an effective public education program.

This approach to traffic noise control could also include the installation of alternative engine technologies or fuels to fleet or individual vehicles. As an example of this approach, the City of Vancouver's line-painting vehicles were recently upgraded to run on gasoline rather than diesel in order reduce vehicle idling noise, a concern during late-night operations. Similarly, transit buses used during off-peak hours (when general traffic noise levels tend to be lower) could be upgraded to reduce engine noise.

## 2.8 EDUCATION

The Commercial Vehicle Unit of the Vancouver Police currently attempts to educate commercial vehicle operators and the broader public about safety issues, including noise, through events such as car and motorcycle shows and trucking association meetings. However, efforts to inform the public about noise as a form of pollution and a threat to our personal and communal health should ideally begin in the elementary schools along with discussions of personal health and of air and water pollution. Noise should also be discussed in high school health and biology classes since many students are exposing themselves to excessive and damaging noise levels from their portable music players as well as from powerful sound systems in cars, at home and in commercial venues such as nightclubs, movie theatres and video arcades. Noise Risk Awareness could also be targeted at the broader population in the manner of healthy eating, anti-smoking and "drinking and driving" campaigns.

## 2.9 RESIDENTIAL FAÇADE ENHANCEMENT

As discussed in detail in the City of Vancouver's "SoundSmart" Noise Control Manual[3], there are a variety of measures which residents can take to reduce their exposure to urban noise, particularly from arterial traffic, with the objective of achieving noise environments compatible with guidelines such as provided by the Canada Mortgage and Housing Corporation (CMHC) – namely $L_{eq}(24)$'s of 35 dBA in bedrooms, 40 dBA in living, dining and recreation rooms, 45 dBA in kitchens, bathrooms, halls, etc., and 55 dBA in an outdoor recreation area. The most direct and effective approach is to enhance the sound insulation performance of residential façade(s) facing towards arterial roadways. This involves determining which among the various façade elements

3 Prepared by Wakefield Acoustics Ltd. for the City of Vancouver's Engineering Services Department and available on the City's website.

represent the "weakest links" and taking the proper steps to improve their sound insulation. This will often, but not always, point to the upgrading of windows and/or doors. In some cases walls may also need to be improved if significant noise reductions are to be achieved, particularly reductions in low-frequency noise such as from truck and bus engines and exhausts, boom cars and "chopper" type motorcycles. Sealing up any gaps and cracks around windows and doors will be effective in reducing the transmission of high-frequency sounds (including much of tire noise) into the home. Generally, the effective upgrading of residential facades (which must include keeping windows shut and therefore often providing mechanically assisted ventilation) can improve their overall sound insulation by from 10 to 20 dBA thereby reducing the loudness of traffic noise indoors by 50 to 75%. Many of these measures, such as replacing old, leaky single-glazed windows with new, tight-fitting double-glazed units, installing storm windows outside of existing single glazed windows and insulating exterior walls, will reduce heating costs as well as the penetration of traffic noise.

## 2.10 VEGETATION

While the presence of vegetation tends to "soften" and mitigate the harsher aspects of urban environment in many ways, it is often given more credit for sound reduction than it deserves. Vegetation, in the amounts which could conceivably be planted around an urban residence, is just too open (i.e., too many air gaps and spaces between the branches and leaves) to act as an effective barrier to sound transmission, particularly lower-frequency sounds. Vegetation can, however, scatter and absorb sound (particularly at higher frequencies) and, as such, when planted in front of a wall or a residence, it will reduce the amount of sound energy reflected directly back towards the source (roadway). Therefore while dense, leafy vegetation in the front yards of residences will extract some energy from sound waves arriving from the adjacent roadway, the effect on overall noise levels at the façade will be very small. However, when vegetation (such as a hedge or trees) screens the noise source from view, the psychological effect (i.e., "out-of-sight, out-of-mind") can be much more significant. This may explain, at least in part, why people often perceive vegetation to be an effective noise barrier. An exception to the general rule that vegetation reduces noise (however slightly) can occur where vegetation (in particular, broad-leafed trees) overtops a solid, sturdy fence, wall or other noise barrier. In such situations, the vegetation tends to scatter higher-frequency sound back down behind the barrier, thereby slightly increasing noise levels on the residential side of the barrier. Since scattering principally affects higher frequency sounds, it is most clearly perceptible outdoors.


City of Vancouver FOI #2017-525, page 0159

## 2.11 NOISE BARRIERS

### 2.11.1 Noise Barrier Fundamentals

As an introduction to the potential use of noise barriers as a means of reducing residential exposures to arterial traffic noise, the following overview of noise barrier concepts has been extracted, with some modifications, from the "SoundSmart - City of Vancouver Noise Control Manual" which Wakefield Acoustics Ltd. recently prepared for the Engineering Services Department. The complete manual is available on the City's website.

#### *2.11.1.1 Key Noise Barrier Requirements*

Noise barriers most often take the form of vertical walls, but other types, such as earth berms, berm/wall combinations and buildings may also be used where sufficient space if available. This will not, however, generally be the case along Vancouver's arterial roads. An effective noise barrier must meet the following three requirements:

1. It must be tall enough and long enough to clearly block the line of sight from the noise receiver to the noise source zone. For free-flowing arterial traffic, tires are the dominant noise source, so that the source zone is close to the pavement where it can often be shielded by barriers of moderate height. Where average speeds are lower, and particularly where the heavy truck mix is high, engine and exhaust noise are also important and, to be effective, noise barriers must be higher,

2. It must be dense (heavy) enough - generally at least 10 $kg/m^2$ (2 $lb/ft^2$) and be free from gaps and cracks so that there is no significant transmission of sound through it,

3. It must be continuous throughout the noise source zone. For example, a traffic noise barrier will not be effective if it must be frequently interrupted to accommodate sidewalks or driveways.

In particular because of requirements 1 and 3 above, noise barriers tend to be more effective along limited-access highways (freeways, expressways) where they can be erected more or less continuously since few interruptions/gaps are required to provide access.

#### *2.11.1.2 General Effectiveness of Noise Barriers*

Noise barriers work by blocking the direct (straight) line of sight (and sound) from the noise source to the receiver. The farther that sound must divert from this straight path (i.e., the greater the extra path length created) in order to bend (or diffract) over or


City of Vancouver FOI #2017-525, page 0160

around the barrier, the greater is the resulting noise reduction. A noise barrier that just blocks this line of sight from the receiver to the dominant noise source region (e.g. the tires of vehicles on a free-flowing roadway with few heavy vehicles) can provide about 5 decibels of noise reduction, which corresponds to about a 30% reduction in subjective loudness. As the height of the noise barrier increases, its effectiveness improves by roughly 1.5 dBA per extra metre of height. Assuming the barrier is also of sufficient length (see below), this improvement with height may be continued up to a practical noise reduction limit of about 10 dBA (approximately 50% as loud) in most cases and perhaps, under extremely favourable geometric conditions, 15 dBA (approximately 35% as loud). A significant challenge in building effective noise barriers in the form of a solid fences or walls relates to making them high enough, given the fence height limitations specified in Vancouver's bylaws, namely 1.22 m (4 ft.) in front of the house and 1.83 m (6 ft.) in the rear and side yards. If such height limitations were imposed on noise barriers in the arterial road context, then it would be generally impossible to provide any traffic noise shielding for the upper floors of multi-storey residences.

To be effective, a noise barrier must also screen essentially all the dominant noise source zone from view. As such, building a solid fence or wall across the front of a single residential lot will generally not be very effective in reducing traffic noise exposures in the front yard or at the front windows unless the lot is very wide or the neighbours on each side agree to construct similar walls. A rule of thumb is that "to achieve maximum performance from a noise barrier, it should extend beyond either end of the receiver zone by a distance two three or four times that from the receiver to the barrier ". If lower noise barriers are contemplated or lesser attenuations sought, (say 5 to 8 dBA), then the barrier's horizontal extent may be correspondingly reduced. Where even this is not possible, an option may be to "return" the noise wall along the property lines on either side of the lot to be shielded.

*2.11.1.3 Non-acoustical Issues with Noise Barriers*

In some situations, traffic noise barriers may raise security issues. Noise barriers tend to screen the view of residences from the street and/or sidewalk. They may also screen the view of pedestrians from the street or from residences. Other non-acoustical factors to be considered when planning a noise barrier are the potential restriction of access to residences from the street and sidewalk and the aesthetic impacts of the noise wall or structure (visual dominance and potential for graffiti) on residents, pedestrians and motorists alike. Shade created by high noise barriers may also impact lawns and gardens as well as promote icy/frosty conditions on sidewalks.

### 2.11.2 Modeling Noise Barrier Performance on Arterials such as Knight Street

*2.11.2.1 Traffic and Roadway Parameters used in Cadna/A Modeling*

A section of Knight Street between 49$^{th}$ and 51$^{st}$ Avenues has been used to predict the effectiveness of noise barriers in shielding adjacent residences from arterial traffic


City of Vancouver FOI #2017-525, page 0161

noise. However, the results of this investigation are considered to be generally applicable to most arterial road situations in the City. The noise prediction point (receiver location) is representative of the central portion of the block where there would be no significant loss of noise shielding effect due to the flanking (leaking) of traffic noise around the ends of the noise barrier. Unless otherwise indicated, the traffic flow/roadway conditions used during the Cadna/A modeling were: 50 kmph posted speed, 2400 vehicle per hour (vph) and 8% heavy trucks during daytime hours and 700 vph and 11% heavy trucks during nighttime hours (22:00 to 07:00 hours). Normal asphalt pavement in good condition is assumed. In addition, where the presence of a "Grade" is indicated, the modeling relates to sections of Knight Street or similar arterials with significant grades so that northbound trucks have been assumed to be a full throttle, a condition which will tend to reduce noise barrier effectiveness.

In assessing the effectiveness of continuous noise barriers (i.e., those which extend continuously for at least a full city block) in reducing arterial traffic noise exposures at the front facades of residences, the Cadna/A model has been used to explore the following parameters:

- continuous noise barriers (walls) on both sides of the street, located just outside the curb, between the street and the sidewalk,

- continuous noise barriers (walls) on both sides of the street, located just outside the sidewalk, between the sidewalk and the residences,

- noise barriers of various heights: 2.3, 4.0, 5.0, 6.0, 7.0, 8.0 and 9.8 ft. (0.7, 1.22, 1.52, 1.83, 2.43 and 3.0 m), note that 2.3 ft (0.7 m) is the standard height of concrete roadside safety barrier, or CRB,

- noise barriers with hard (sound-reflecting) surfaces facing the traffic and noise barriers with sound-absorbing (non-reflective) surfaces facing the traffic,

- effects of road grade on noise barrier performance,

- effects of heavy truck mix on noise barrier performance.

In addition, the Cadna/A model has been used to examine traffic noise exposures in the rear yards of single family residences and of "row-houses". Of particular interest here were the effects on traffic noise exposures in back yards of noise barriers which would "span the gaps" between adjacent residences.


City of Vancouver FOI #2017-525, page 0162

The effectiveness of noise barriers has been quantified in two ways. In most cases this has been by predicting reductions in daily average noise exposures as may be expressed in terms of the 24-hour equivalent sound level, or $L_{eq}$ (24), and the Day-Night Average Noise Level, or $L_{dn}$, and its daytime and nighttime $L_{eq}$ components, $L_d$ and $L_n$. In a limited number of cases involving heavy truck traffic only, the effectiveness of noise barriers has been assessed in terms of their ability to reduce the maximum noise levels ($L_{max}$) created during individual heavy vehicle pass-bys. In all cases the noise reduction provided by a barrier will be referred to as its "Insertion Loss", or IL, as it represents the reduction of "loss" of sound level (in dBA) that would result from the "insertion" of the barrier between the sound source (roadway) and the sound receivers (residences).

*2.11.2.2 Effect of Barrier Location and Height on IL Performance*

Figures 1 and 2 illustrate the IL's that are predicted to accompany the insertion of noise barriers (vertical walls) of various heights at two locations between the roadway and the residences. In Figure 1 the noise receiver is assumed to be standing near the façade of the residence at ground level (head position 1.7 m above ground). In Figure 2 the noise receiver is again near the façade but the elevation of the main floor of a home with a "daylight basement" so that head (or window) position would be approximately 3.2 m above ground level. In both cases the road is assumed to have a significant grade.

<u>Roadside Noise Barrier</u>

A "roadside" barrier would be located just outside the curb (between curb and sidewalk). The *potential advantages* of such a barrier location would include:

- barrier is as close as possible to the noise source – therefore more effective for barriers of modest height (4 ft. or lower),

- barrier provides physical separation between traffic and pedestrians – some safety benefit in terms of potential vehicle/pedestrian collisions,

- higher barriers may provide some air quality benefits for both pedestrians and residents,

- the presence of barriers close to the roadside tends to create "side friction" that acts to slow drivers down, thereby reducing traffic noise emissions and increasing safety.

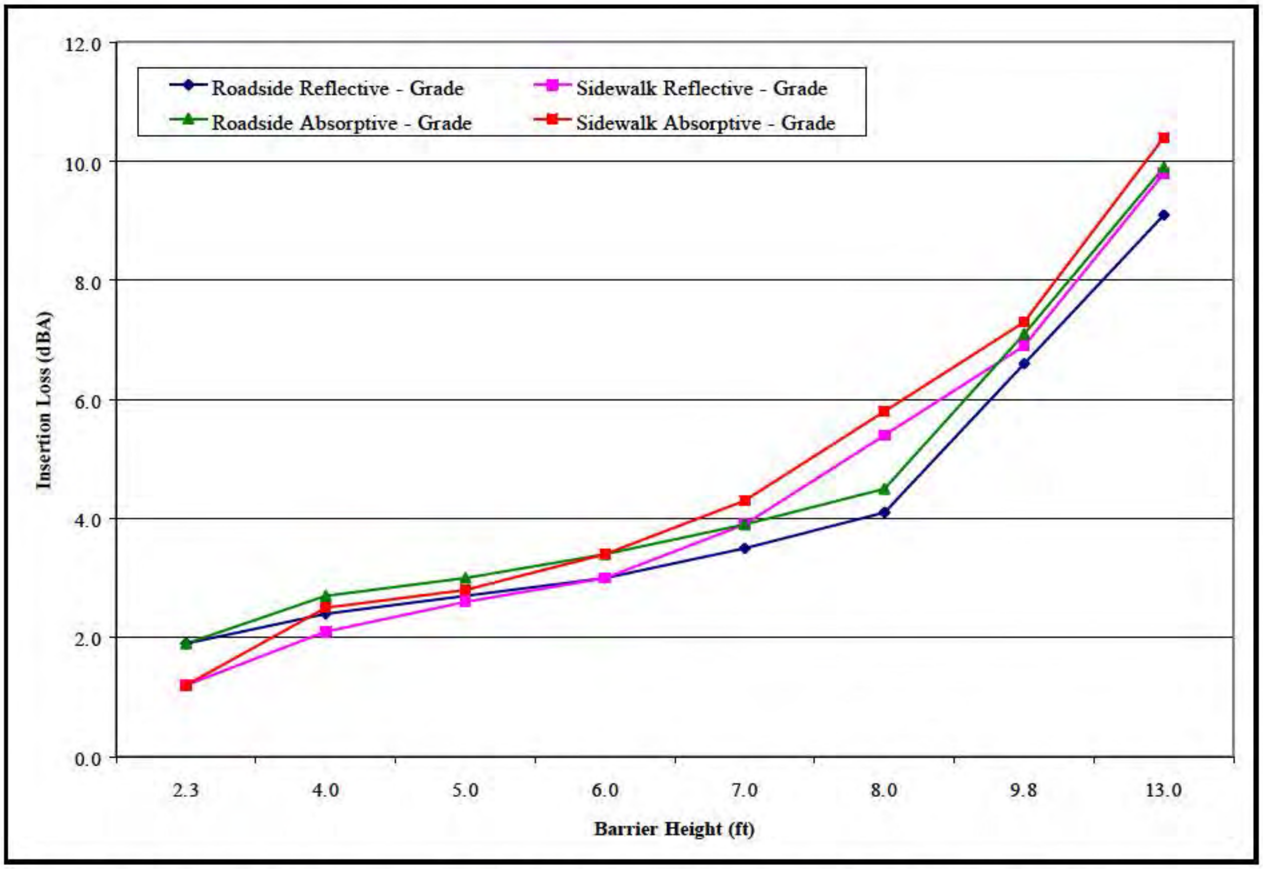



**Figure 1; Variation of Insertion Loss with Barrier Height for Roadside and Sidewalk Barrier Locations at Ground Level (1.7 m) Receiver**

The *potential disadvantages* of roadside noise barriers would include:

- opaque barriers more than about 4 ft. high would present possible security concerns by blocking view of and access to pedestrians (particularly young children) from the roadway,
- may restrict driver sight distances if close intersections,
- may conflict with driveway access requirements,
- may be subject to damage from errant vehicles unless protected by concrete road side barrier (CRB), or similar, which significantly increases costs,
- may reduce the visual quality of the route from the driver's perspective.

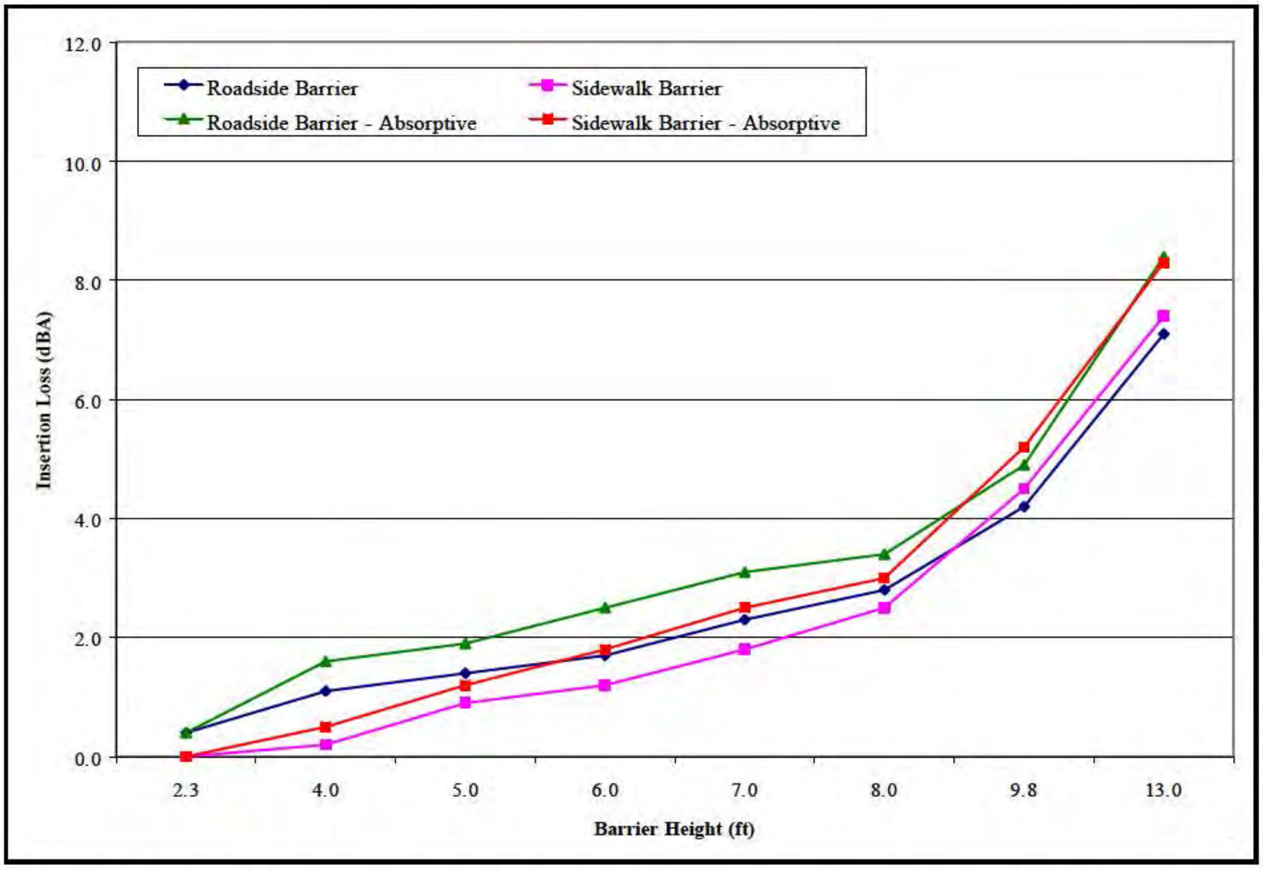



**Figure 2; Variation of Insertion Loss with Barrier Height for Roadside and Sidewalk Barrier Locations at Main Floor Level (3.2 m) Receiver**

Sidewalk Noise Barrier

Such a barrier would be located just beyond the sidewalk and generally just inside the property line of the residential lot - much like a typical front yard fence. The *potential advantages* of such a barrier location would include:

- for the geometry studied (quite small setback distances from road to residences), a barrier outside the sidewalk is more effective for noise sources of medium height (7 to 9 ft.) which approach, but do not reach, the typical heights of heavy truck exhausts,
- barrier provides physical separation between sidewalk/pedestrians and residences – some potential security benefits regarding trespassers/intruders,
- higher barriers may provide some air quality benefits for residents.

The *potential disadvantages* of such a barrier location would include:

- opaque barriers more than about 4 ft. high would present possible security concerns by blocking view of and access to pedestrians (particularly young children) from the residences and also by restricting visibility of residence from sidewalk and street,

- may conflict with driveways access as well as sidewalk access to individual residences unless solid gates of same height were provided,

- reflection of traffic noise from non-absorptive barriers in this location would slightly increase noise exposures of pedestrians on the sidewalk.

*2.11.2.3 Comparison of IL's Achieved with Roadside and Sidewalk Barriers*

<u>IL's Provided for Daily Average Noise Exposures – $L_{eq}$(24)'s</u>

Figure 1 has shown that, for low barrier walls (4 ft. or less), the overall noise reduction effect, or IL, on the noise output of the entire traffic stream, as expressed in terms of $L_{eq}$(24) and as experienced at a ground level receiver, is quite small (less than 3 dBA - representing loudness reductions of 20% or less) and may not be readily perceptible. However, comparing Figure 1 and 2, it is seen that roadside barriers in this height range are slightly more effective than outside-of-sidewalk barriers. To show why this is so, Figures 3a to 3e provide the output of the Knight Street Cadna/A model in the form of colour-coded $L_{eq}$(24) contours in vertical planes, or "sections", through the roadway, sidewalks and typical residences. Sections are provided for the following cases: no barriers (Figure 3a), 4 ft. barriers on both sides of the road in "roadside" (Figure 3b) and "sidewalk" (Figure 3c) locations and 8 ft barriers on both sides of the road in "roadside" (Figure 3d) and "sidewalk" (Figure 3e) locations. In all cases, the barriers have been considered totally sound absorptive, so that there are no sound reflections.

By referring to the colour-coded noise level legend of Figure 3b, it may be seen that, because it is closer to the road, a relatively low (4 ft.) roadside barrier can quite substantially block the direct line of sight from the tire noise generation zone near the pavement to a front yard ground level receiver and therefore provide significant tire noise shielding. A barrier located outside the sidewalk and therefore farther from the traffic (see Figure 3c) cannot interrupt this direct sound path as well and therefore creates less "extra path length" and smaller IL's. Whether located at the roadside or


City of Vancouver FOI #2017-525, page 0166

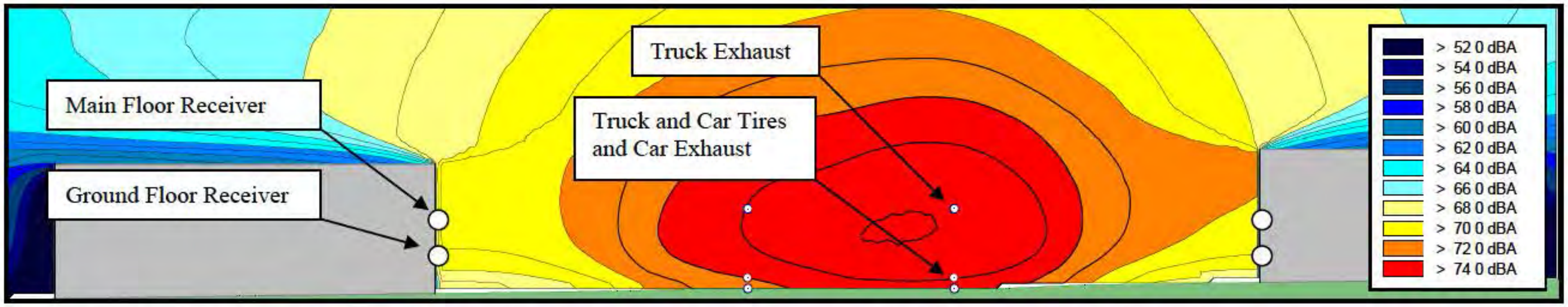



**Figure 3a; Cross-Section through Knight Street w/ Cadna/A Colour-Coded $L_{eq}$(24) Contours – No Barriers**

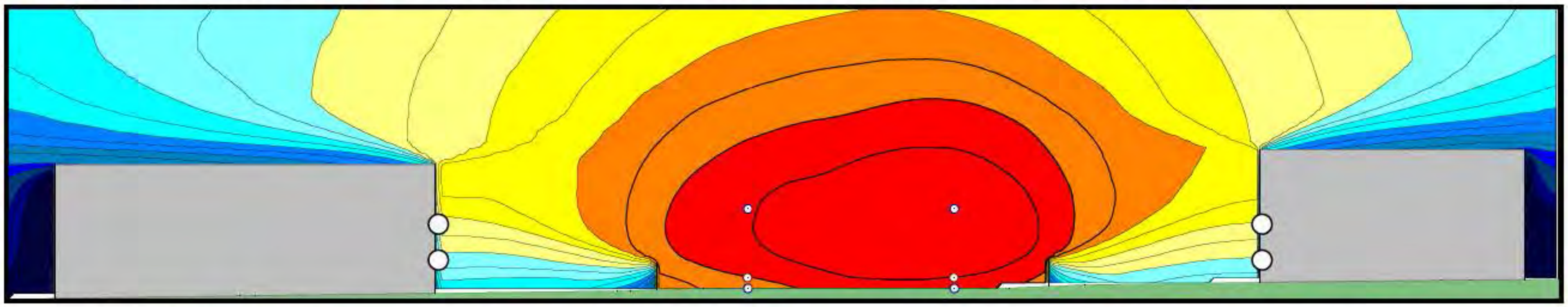


**Figure 3b; Cross-Section through Knight Street w/ Cadna/A Colour-Coded $L_{eq}$(24) Contours with 4-ft Absorptive Roadside Barriers**

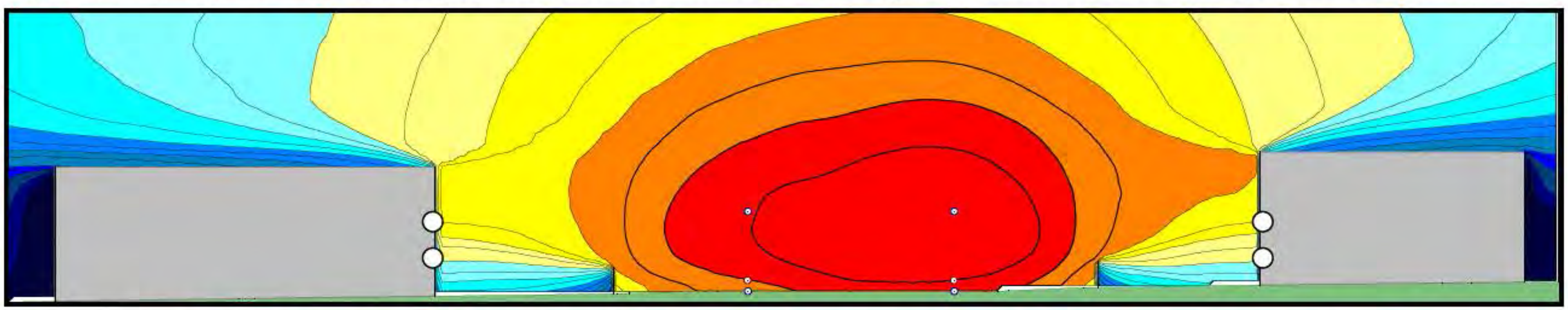


**Figure 3c; Cross-Section through Knight Street w/ Cadna/A Colour-Coded $L_{eq}$(24) Contours with 4-ft Absorptive Sidewalk Barriers**

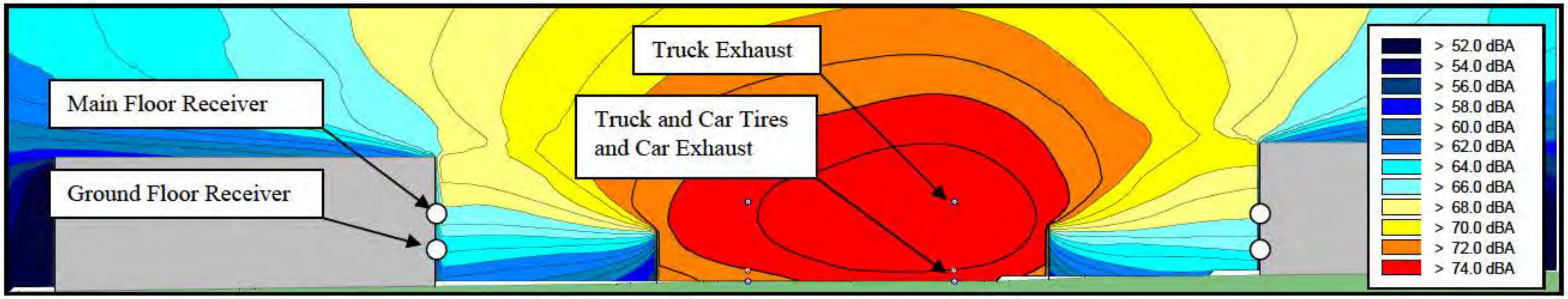



**Figure 3d; Cross-Section through Knight Street w/ Cadna/A Colour-Coded $L_{eq}$(24) Contours with 8-ft Absorptive Roadside Barriers**

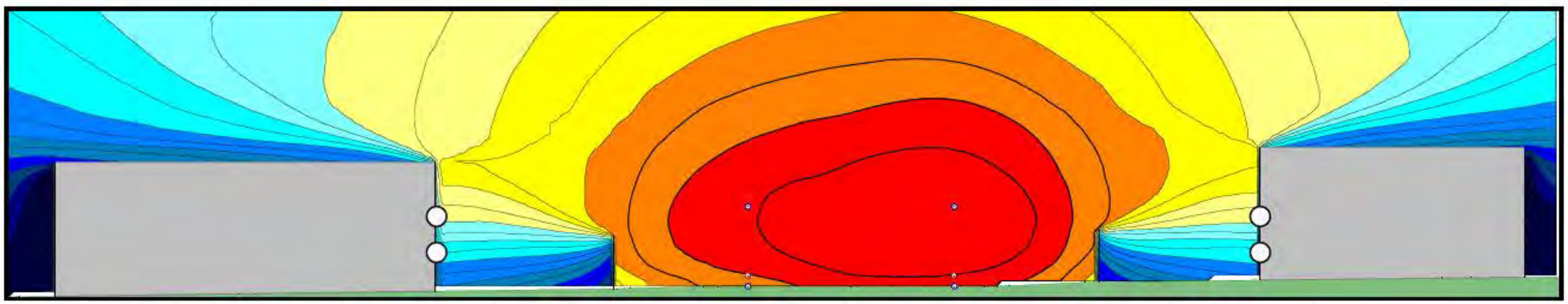


**Figure 3e; Cross-Section through Knight Street w/ Cadna/A Colour-Coded $L_{eq}$(24) Contours with 8-ft Absorptive Sidewalk Barriers**



City of Vancouver FOI #2017-525, page 0168

outside the sidewalk, barriers 6 ft. or less in height are not able to interrupt the line of sight from ground level receivers to heavy truck exhausts - typically located 10 to 12 ft. (3 to 3.5 m) above pavement. As barrier height begins to approach truck exhaust height, the location of the barrier become more critical in determining ground floor noise shielding. Figure 1 showed that for an 8 ft. (2.4 m) barrier, an outside-of-sidewalk location will provide about 1.5 dBA more IL than a roadside barrier location, an effect that may be clearly seen by comparing Figures 3d and 3 e. As their heights increase beyond 8 ft., barriers at the two locations begin to again attenuate heavy truck exhaust noise more equally.

Figure 2 provided IL results for the case of a receiver located 3.2 m above ground – representative of the main floor of a house with a daylight basement. At this receiver location it is seen that overall IL's are lower than at ground level receivers and roadside barriers are found to be more consistently superior to outside-of-sidewalk barriers of the same height – but only by about 0.5 to 1 dBA. Barriers of almost 10 ft (3 m) are required before readily perceptible (approaching 5 dBA and 30% loudness reduction) traffic noise reductions can be achieved at this receiver level. Even higher barriers would then be required to substantially shield the second floors of houses with at-grade entrances (i.e., receivers located approximately 4.7 m above ground level).

IL's Provided for Maximum Heavy Truck Pass-by Noise Levels – $L_{max}$'s

A key objective of this study has been the identification and control of "intrusive noise events". It is then appropriate to examine the effects of noise barriers of various heights and locations on the maximum noise levels created during typical heavy truck pass-bys. Figures 4 and 5 show the IL's that barriers of various heights would provide against heavy truck pass-by $L_{max}$'s for ground floor receivers. In this analysis, truck noise was broken into its two main components; tire noise, which is created near the pavement, and exhaust noise, which originates much higher above the road. Separate IL's are then provided for tire noise, exhaust stack noise and for total truck noise. A roadside barrier (see Figure 4) 4 ft. or more high, can block tire noise quite effectively (i. e., provide IL's of 6 dBA or more). However, to shield truck exhaust noise equally well, a barrier must be over 10 ft. high. Figure 5 indicates that similar trends would generally exist in the case of an outside-the-sidewalk barrier. Finally, Figure 6 compares the total truck noise IL's for roadside and outside-the sidewalk barriers. Their performance is seen to be similar except when barrier height is about 8 ft. At this height, the barrier is approaching the level of the elevated truck noise sources and, as such, can shield a ground floor receiver more effectively when located outside the sidewalk.

Clearly, maximum truck pass-by IL's will become progressively smaller for receivers located at upper floor levels.

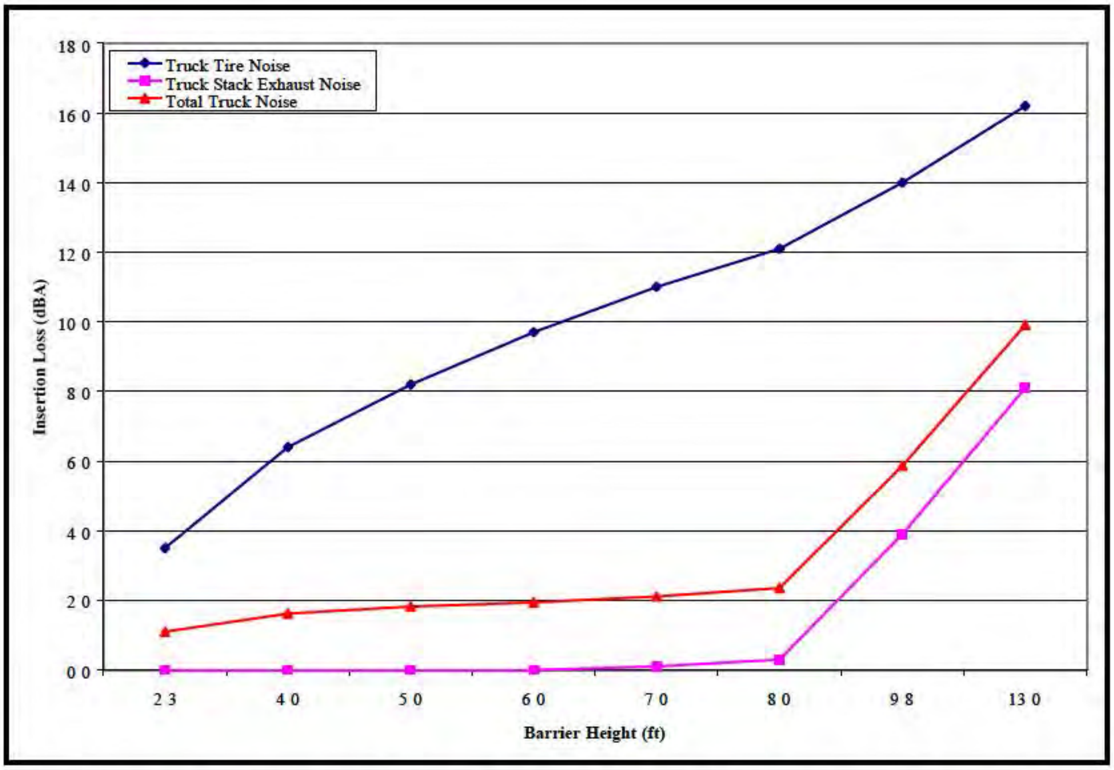



**Figure 4; Variation of Insertion Loss with Barrier Height for Maximum Truck Pass-By Noise Levels - Roadside Barrier, Ground Floor Level Receiver.**

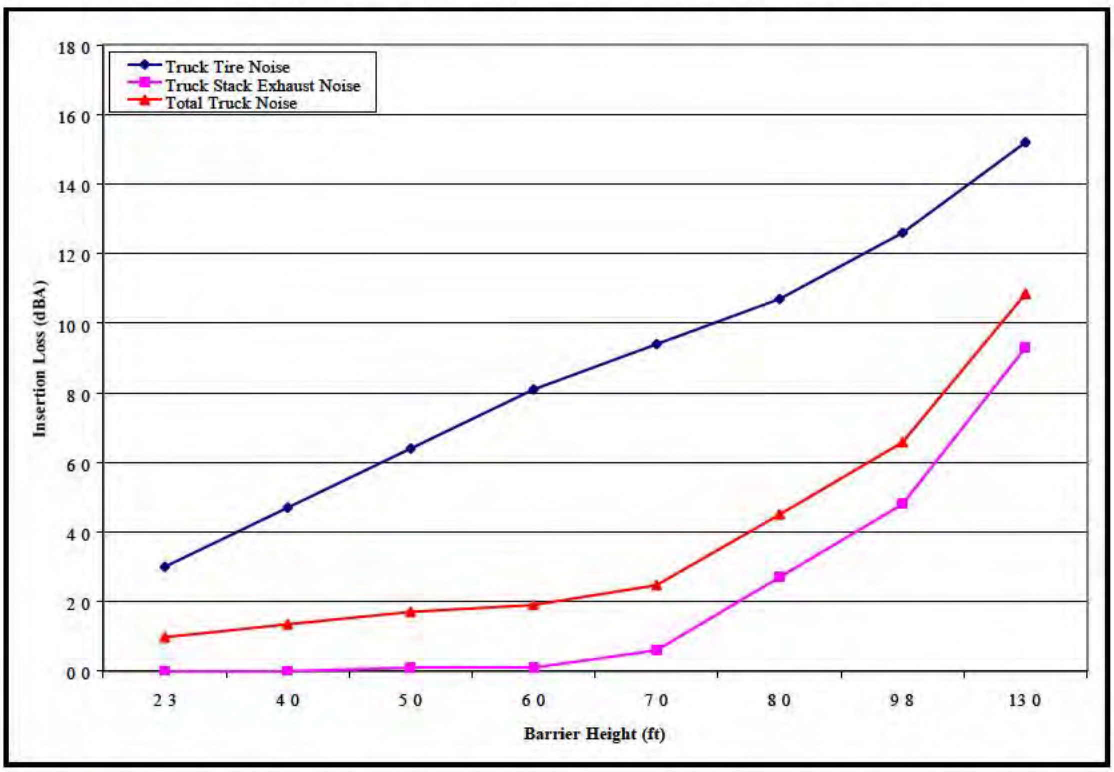



**Figure 5; Variation of Insertion Loss with Barrier Height for Maximum Truck Pass-By Levels - Sidewalk Barrier, Ground Floor Level Receiver.**

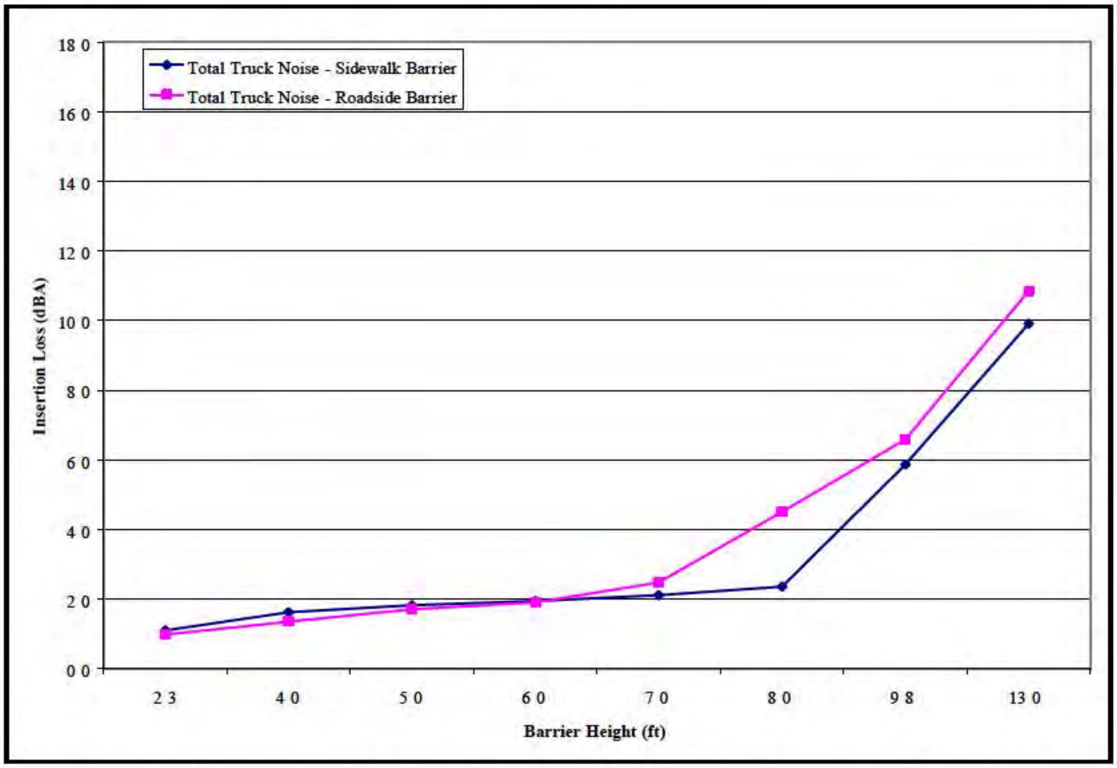



**Figure 6; Variation of Insertion Loss with Barrier Height for Maximum Truck Pass-By Levels - Sidewalk versus Roadside Barrier, Ground Floor Level Receiver.**

### *2.11.2.4 Sound-Absorbing versus Sound-Reflecting Noise Barriers*

When noise barriers made of concrete, steel or other hard, sound-reflecting materials are constructed on both sides of a roadway, the reflection of sound back and forth between the parallel walls will reduce the IL's achievable on both sides of the road. The higher the parallel noise barriers and the closer they are together, the greater this IL degradation effect. However, the greater the heavy vehicle mix, the greater the proportion of overall traffic noise emissions created high above the pavement where parallel barriers effects are smaller. As a result, as shown in Figures 1 and 2, within the Knight Street corridor (six lane roadway, 8 to 11 % trucks) the reflective surfaces of parallel noise barriers would reduce attainable IL's by less than 1 dBA. If the noise barrier is located outside of the sidewalk, a hard barrier surface would also reflect noise back at pedestrians on the sidewalk, thereby making an already noisy environment slightly (maximum 2 to 3.0 dBA) noisier.

### *2.11.2.5 Effects of Road Grade on Barrier Performance*

Since the presence of a significant road grade causes vehicles, particularly heavy vehicles, to employ higher throttle settings, there is an associated increases in engine and exhaust noise relative to the tire noise component (which is speed dependent but not grade dependent). This tends to reduce the effectiveness of noise barriers for two reasons: 1) because heavy truck engine and exhaust noise originates at elevations well above the pavement, and 2) heavy truck engine and exhaust noises tend to have much more low-frequency content than tire noise and noise barriers are less effective in blocking lower-frequency sounds than higher-frequency ones. Figure 7 shows that the effect of road grade on the overall IL's provided at ground floor level (1.7 m above ground) receivers by roadside and outside-of-sidewalk barriers of various heights is typically between 0.5 to 1.2 dBA.

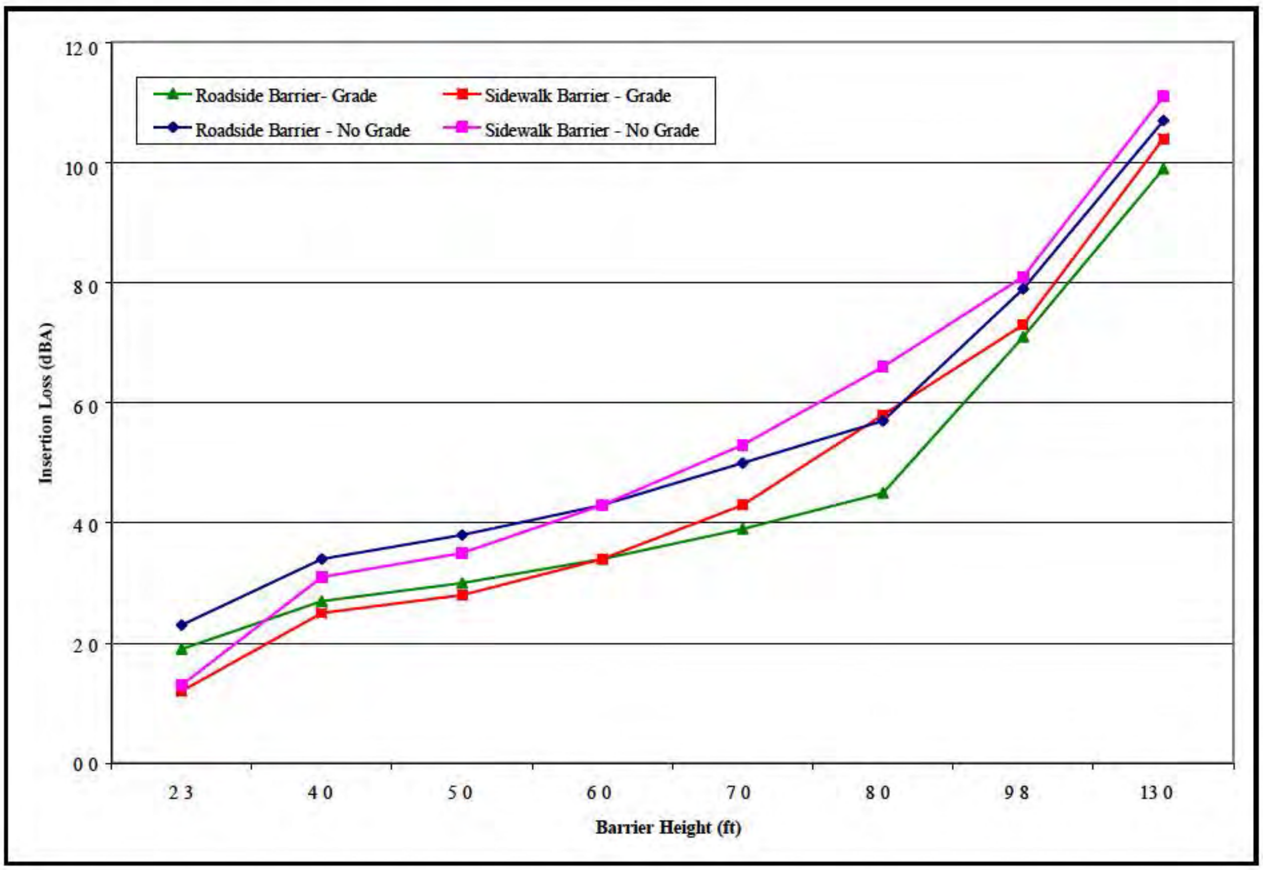



**Figure 7; Effects of Grade on Roadside and Sidewalk Barrier Insertion Loss, Ground Floor Level Receiver**

### *2.11.2.6 Effects of Heavy Truck Mix on Performance of Noise Barriers*

Since the presence of heavy trucks increases the effective height of the traffic noise source zone above the pavement, it follows that noise barriers become more effective as heavy truck mix decreases. Figure 8 illustrates the effect of truck mix on IL for various barrier heights under normal Knight Street conditions (8 to 11% heavy trucks) and in the limiting cases of 0% trucks at night and then 0% trucks for the full 24-hour day. It is seen that if a truck ban was introduced only at night, there is very little improvement in the average IL based on reductions in $L_{eq}(24)$. However, when trucks are prohibited 24-hours per day, these IL's increase by 1.5 to 2 dBA – equivalent to increasing the barrier height by 3 to 5 ft. (1 to 1.5 m).

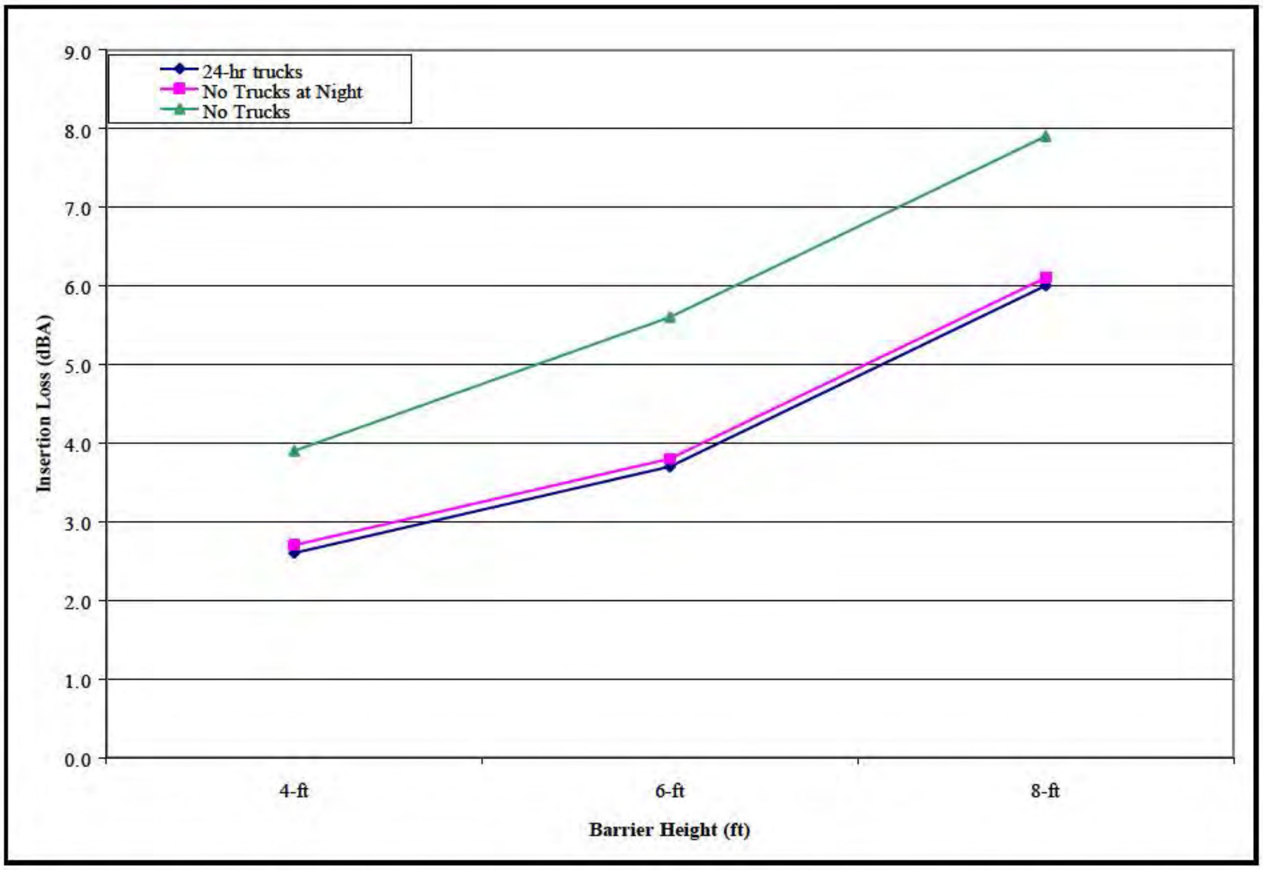



**Figure 8; Effects of Truck Mix on Insertion Loss for Sidewalk Barriers in Terms of $L_{eq}(24)$**

Figure 9 shows the same type of information but with the barrier IL's based on reductions in $L_{dn.}$ rather than $L_{eq}(24)$. Any changes in trucking volumes at night therefore become much more important and it is seen that a nighttime truck ban would effectively increase barrier IL's by from 0.5 to 1.0 dBA. Comparing Figures 8 and 9, it is seen that the effects of a 24-hour truck ban (i.e., no trucks) on IL's would be quite similar whether based on reductions in $L_{dn}$ or $L_{eq}(24)$.

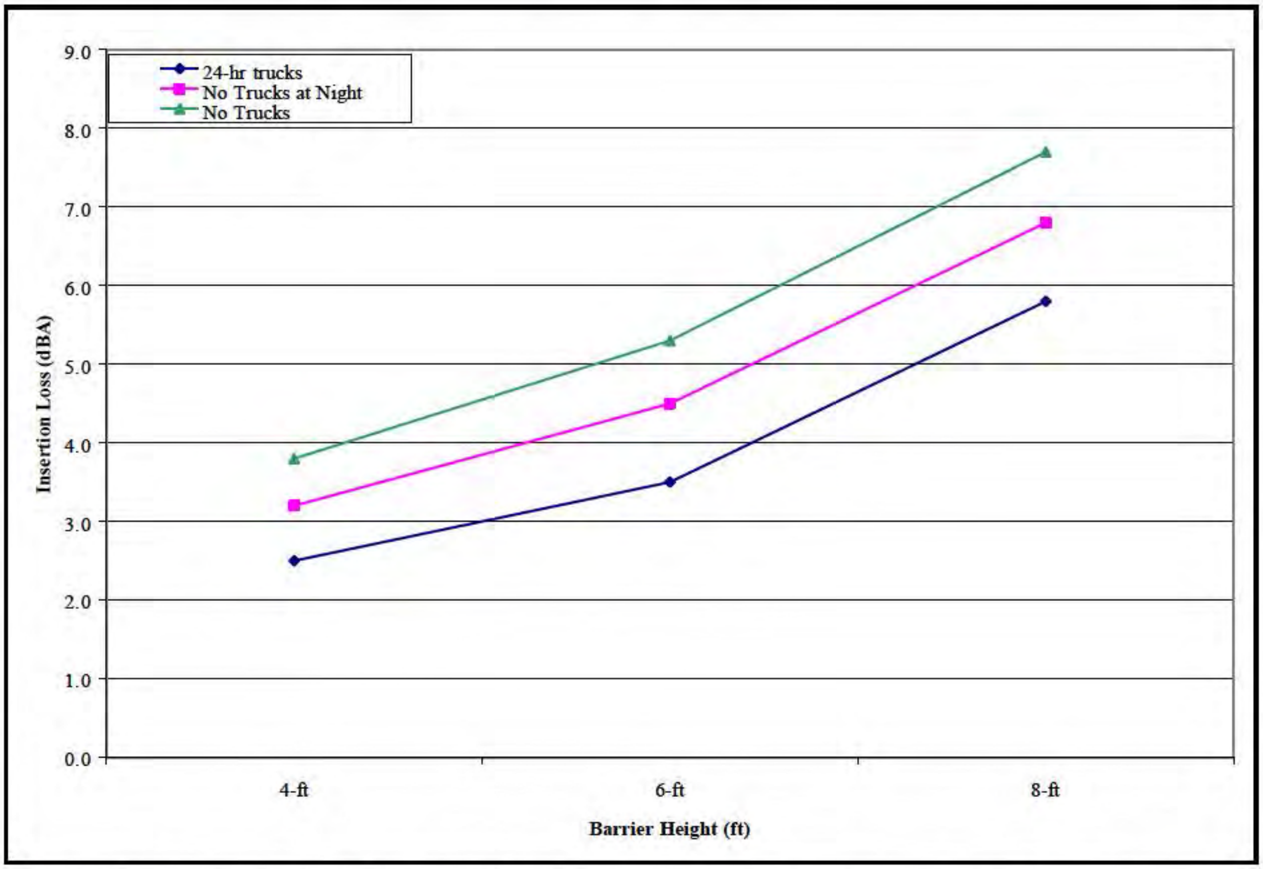



**Figure 9; Effects of Truck Mix on Insertion Loss for Sidewalk Barriers in Terms of $L_{dn}$**

### *2.11.2.7 Effects of Inter-Residence Noise Barriers on Backyard Noise Exposures*

In any detached housing situation, a certain amount of traffic noise will leak between individual houses and thereby limit the degree of noise shielding that the row of houses can provide for receiver locations in the backyards. To assess the degree to which noise barriers spanning between adjacent houses (so as to eliminate these gaps) could reduce this noise leakage, a row of typical Vancouver houses was modeled in Cadna/A with two receiver locations in the rear yard – one just behind the house (i.e. a typical deck or patio location) and one near the back fence line (a garden or lawn location). Two fairly extreme cases were examined – one in which adjacent houses were 1.52 m (5 ft.) apart and one in which they were 7.6 m (25 ft.) apart. In both cases, the height of the house (to the roof line) was assumed to be 8 m (26 ft.) so as to minimize the effects of sound diffraction over the tops of the houses.

For current Knight Street traffic volumes and truck mix, the $L_{eq}(24)$'s predicted in typical backyards of residences spaced 5 ft. apart with no inter-residence barriers present were 44.9 dBA at deck/patio locations and 48.4 dBA at rear fence locations. For residences spaced 25 ft. apart, the corresponding levels were 47.2 dBA at deck/patio locations and 56.0 dBA at rear fence locations – the latter level then just exceeding the noise exposure limit of $L_{eq}(24)$ 55 dBA for outdoor recreation spaces as recommended by the CMHC and other agencies. When inter-residence noise barriers were introduced in the 5 ft. gap case, no significant noise reduction was predicted at the deck/patio location, even with inter-residence barriers as high as 5 m. Reductions were predicted, however, at the rear fence location, and these ranged from 0.9 to 1.2 dBA for 1 and 2 m high barriers and from 1.7 to 2.0 dBA for 3 m to 5 m high barriers. For houses spaced 25 ft. apart, the noise reduction achievable at the deck/patio location was 1.2 dBA with a 1 m barrier and increased only very gradually to 1.6 dBA as barrier height was increased to 5 m. However, noise reductions attainable at the rear fence location increased quite rapidly with barrier height, ranging from 2.0 dBA with 1 m barriers, to 3.1 dBA with 2 m barriers and 6.3 dBA with 5 m barriers.

#### *2.11.2.8 Effects of Row Houses on Backyard Noise Exposures*

An obvious approach to providing quiet outdoor spaces in association with residences along arterial roads would be to create continuous (attached) row housing or townhouse developments. This approach may be considered an extension of the inter-residence barrier concept. By eliminating the gaps between residences entirely, their shielding effect can be maximized – being limited only by the height of the buildings. The Knight Street Cadna/A model was used to calculate the amount of traffic noise shielding such a development could provide. It was found that the introduction of 8 m (26 ft.) high row houses for the full length of a city block can reduce noise levels in the rear yard at ground floor level from about 60 dBA, with no residences present, to about 45 dBA with row housing in place – i.e., a 15 dBA shielding effect against arterial traffic noise. Based on the above investigation of inter-residence barriers, it appears that, at locations well back in the rear yards, such row housing would provide 4 to 11 dBA more shielding against traffic noise than would typical detached housing with average spacing between houses of 1.52 m (5 ft.) to 7.6 m (25 ft.).

# 3.0 RATING THE POTENTIAL EFFECTIVENESS OF THE VARIOUS MITIGATION APPROACHES

## 3.1 RATING THE POTENTIAL EFFECTIVENESS OF MITIGATION APPROACHES IN CONTROLING SPECIFIC SOURCES OF INTRUSIVE NOISE

In Section 4.1 of Deliverable 2, an analysis of the inherent intrusiveness of all major arterial road noise sources was presented. This analysis was intended to assist in identifying measures that the City could consider implementing to reduce the overall impact of arterial traffic noise on the citizens of Vancouver. Provided that the limitations of this analysis are acknowledged (i.e., limited number of attended monitoring sites, and considerable dependence on professional judgment), its results can provide initial directions towards an arterial road traffic noise mitigation plan. Towards this end, a table was generated (reproduced herein as Table 2) which listed ten mitigation approaches and assigned each approach a rating (based on a three-point sale) indicative of its anticipated effectiveness when applied to each of the ten most intrusive arterial road traffic noise sources.

The mitigation approach ratings of Table 2 are meant to be representative of the general applicability and potential effectiveness of each approach to the City as a whole. However, some of these options, such as noise barriers, would clearly be more appropriate and effective in some residential areas than others (e.g. in areas of largely single or two storey homes rather than in areas with many multi-storey apartment buildings and condos). Other options, such as Façade Enhancement, Vehicle Inspection and Vehicle Modification, would be expected to have fairly similar effectiveness throughout the City. Still other mitigation approaches, such as Law Enforcement & Regulation, Vehicle Inspection and Education, would require the cooperation and involvement of other agencies.

While not a mitigation approach within the City's direct purview, Residential Façade Enhancement is considered to have considerable potential to mitigate noise from all ten of the most prominent sources so that it received the highest possible Average Mitigation Potential Rating of 3.0. The degree of mitigation attainable will, however, depend on the conditions of the existing façade, with older homes having leaky single-paned windows standing to benefit the most from such upgrading. Homeowners would also generally benefit from the improved thermal insulation that would accompany such noise-related façade enhancements. The obvious limitation of this approach is that it provides no benefit at outdoor receiver locations.


City of Vancouver FOI #2017-525, page 0176

Low Noise Barriers received the second highest average Mitigation Potential Rating at 2.2 and are considered particularly effective in attenuating noises which originate close to the pavement and which have substantial high-frequency content such as tire noise. Low noise barriers (4 to 6 ft. or 1.2 to 1.8 m high) would be somewhat less effective in reducing noise from sources, which while close to pavement, have substantial low-frequency content such motorcycle or sports car exhausts. These barriers would be least effective in mitigating low-frequency noise which originates well above the pavement such as heavy truck and diesel bus exhaust noise.

## 3.2 OVERALL EFFECTIVENESS OF MITIGATION APPROACHES IN CONTROLLING ALL ASPECTS OF ARTERIAL ROAD NOISE

This report has introduced a variety of approaches to the mitigation of arterial road traffic noise within the City of Vancouver. None are without challenges, either in terms of their potential impacts on traffic handling capacity, on access to private property, on the visual environment, on other neighbourhoods, on the City's human and/or financial resources or on the financial resources of residents and property owners. The final decisions regarding whether any of these mitigation approaches appears sufficiently cost-effective or desirable to be implemented will be up to the City. However, to facilitate this decision making process, the relevant information regarding the potential effectiveness of each mitigation approach has been summarized in Table 3 below. In many cases this information has been derived from the Cadna/A modeling described above or from other quantitative sources. The effects of other approaches, such as Vehicle Testing, Vehicle Modification, Law and Regulation Enforcement and Education cannot be accurately modeled or quantified. However, they can be estimated using professional judgment in combination with acoustical principals and qualitative descriptions.

The rightmost column of Table 3 contains ratings of the overall (City-Wide) effectiveness of the thirteen mitigation approaches. These ratings represent an attempt to compare: 1) the potential effectiveness of each approach in terms of the amount by which it may generally be able to reduce traffic noise impacts along Vancouver's arterial roadways, 2) the side-effects (positive and negative) likely to be associated with each approach and 3) the potential costs for capital expenditures, maintenance and staff/personnel resources. Overall effectiveness has been rated on a simple three-point scale (Low, Moderate and High) with some ratings spanning two categories.

The highest overall potential mitigation effectiveness rating, namely, "Moderate to High", have been assigned to the development of "Row Housing" and to "Residential Façade Enhancement". While not a form of noise mitigation that can be implemented widely in the short term, row housing (or similarly townhouse or condominium buildings)


City of Vancouver FOI #2017-525, page 0177

represents a form of urban housing that is advantageous from the viewpoints of both residential noise exposure control and efficient land utilization. The development of row housing, condominiums or other multi-family residential forms along busy arterials and the requirement within such developments of adequate façade sound insulation (i.e., to achieve CMHC guidelines) is consistent with the City's "N" Zone permitting procedure. This procedure flags all proposed residential developments along arterial roads for acoustical assessment and the provision of adequate sound insulation. In addition, the backyards of such residences will have very satisfactory acoustical environments.

A localized or city-wide "Residential Façade Enhancement" program for arterial roads would obviously require the cooperation of many individual home owners and have substantial cost implications. However, this approach has potential to significantly improve the livability of a substantial portion of the City's existing housing stock but again would not provide noise benefits at outdoor receiver locations. Any consideration given to the implementation of such an approach to arterial traffic noise impact control should include its possible integration with Federal and/or Provincial (BC Hydro, Terasen Gas) energy conservation and home insulation programs. To encourage homeowners to participate in such a program, consideration might be give to the use of property tax credits or rebates.

Law Enforcement and Regulation and Vehicle Inspection and Maintenance, which both focus on individual particularly noisy vehicles, represent the most effective means of reducing the numbers of unnecessary intrusive noise events without associated major capital costs and visual impacts (like noise barriers) and without disrupting current traffic patterns (like banning or rerouting trucks). These approaches would of course have implications for staffing levels and payrolls.

Low noise barriers have been given a "Low to Moderate" overall effectiveness rating since, while they may be effective (i.e., achieve noise reductions of 5 dBA or more) when installed along non-truck route arterials with fairly high average speeds, to be effective on truck routes such as Knight Street, barriers would need to be 8 to 10 ft. high and, as such, may be considered inappropriate for urban arterial situations. There is also the significant issue of the cost of such barriers and how they would be financed. Here, it should be recognized that excessive traffic noise exposures and the other proximity effects of major arterial roads have been generally found to depress the market values of adjacent residences. Conversely, measures which effectively lower traffic noise exposures may result in increased property values and therefore growth in the local tax base.


City of Vancouver FOI #2017-525, page 0178

**Table 2; Potential Effectiveness of Various Mitigation Approaches for the Ten Most Intrusive Arterial Road Noise Sources**

| Noise Source | Mitigation Approach | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Law Enforcement & Regulation | Vehicle Inspection/ Maintenance | Vehicle Modification (Noise Control) | Speed Control / Signage | Nighttime Heavy Vehicle Ban / Rerouting | Pavement Design or Maintenance | Education | Residential Façade Enhancement | Vegetation | Low Noise Barriers |
| Heavy Trucks | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 2 |
| Squealing Brakes | 2 | 3 | 2 | 1 | 1 | 1 | 2 | 3 | 2 | 3 |
| Vehicle Horns | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 |
| Emergency Vehicle Sirens | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 |
| Motorcycles | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 3 | 1 | 2 |
| Loud Exhausts | 3 | 3 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 2 |
| Sports Cars | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 3 | 1 | 2 |
| Medium Trucks | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 2 |
| City Buses (Diesel) | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 1 | 2 |
| Tire Squeal | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 |
| Average Rating | 1.8 | 1.8 | 1.6 | 1.6 | 1.2 | 1.3 | 1.7 | 3 | 1.2 | 2.2 |

**Mitigation Potential Ratings;** 1. Little or No Potential, 2. Some Potential, 3. Considerable Potential



City of Vancouver FOI #2017-525, page 0179

## Table 3; Potential Overall Effectiveness of Various Approaches to Mitigation of Arterial Road Traffic Noise in the City of Vancouver (Part 1 of 3)

| Mitigation Approach | Noise Reduction Capabilities | | Spatial Applicability | Temporal Applicability | Advantages/Benefits | Disadvantages/Concerns | Cost/Resource Implications | Overall Effectiveness Rating |
|---|---|---|---|---|---|---|---|---|
| | Daily Average Levels - Leq(24) | Lmax Intrusive Events (dBA) | | | | | | |
| **Law Enforcement and Regulation** | Modest<br>- less than 1 dBA | Significant potential to eliminate particularly intrusive events | City Wide | 24-hours/day | - Focuses on creators of some of most intrusive noise events,<br>- Could be combined with other Police operations | - None obvious | - Consumes Police resources,<br>- Limited coverage,<br>- Direct noise control costs borne by noise makers | **Low to Moderate** |
| **Vehicle Inspection and Maintenance** | Modest<br>- less than 1 dBA | Significant potential to eliminate particularly intrusive events | City Wide | 24-hours/day | - Focuses on creators of some of most intrusive noise events,<br>- Could be combined with Air-Care operations | - None obvious | - Consumes Air-Care or Other Resources,<br>- Direct noise control costs borne by noise makers,<br>- broader reach | **Moderate** |
| **Vehicle Modification** | Modest<br>- less than 1 dBA | Some potential to eliminate particularly intrusive events | City Wide | 24-hours/day | - May have side-benefits such as improved air quality and safety | - Relies on initiative of vehicle owners/drivers | - Significant information and public relations requirements | **Low** |
| **Speed Control/Signage** | -1. to 1.5 for 50 to 30 kmph,<br>1.5 to 3 dBA for 70 to 50 kmph | -1. to 1 for 50 to 30 kmph,<br>3 to 4 dBA for 70 to 50 kmph | Practical on only some arterials | 24-hours/day | - Potential safety improvements/accident reductions | - reduced roadway capacity,<br>- potential negative effects on air quality | - Signage costs,<br>- Enforcement costs | **Moderate** |
| **Heavy Vehicle Restrictions** | 2 to 5 dBA | Eliminates substantial numbers of intrusive noise events | Practical on only selected arterials | Nighttime only,<br><br>or 24-hours | - Reduce traffic congestion,<br>- Improve safety and air quality | - Within a fixed arterial system, would often transfer noise and congestion to other areas,<br>- Nighttime ban could increases daytime congestion and noise | - Signage costs,<br>- Enforcement costs | **Low to Moderate** |
| **Pavement Design** | 2 to 4 dBA depending on speed and truck % | Minimal | most higher-speed arterials | 24-hours/day | - No visual impact, screening or security concerns,<br>- improved safety in rain | - Little or no effect on most significant intrusive noise events.<br>- Potential maintenance issues | - Extra paving costs, approx 15 to 30%,<br>- maintenance ? | **Moderate** |
| **Education** | Modest<br>- less than 1 dBA | Some potential to eliminate particularly intrusive events | City Wide | 24-hours/day | - Could be combined with other Police, Industry, Community or School programs<br>- Presents opportunity to reach young people, | - Relies on initiative of current or future vehicle owners/drivers | -Significant public information/relations and training requirements | **Low** |



City of Vancouver FOI #2017-525, page 0180

## Table 3; Potential Overall Effectiveness of Various Approaches to Mitigation of Arterial Road Traffic Noise in the City of Vancouver (Part 2 of 3)

| Mitigation Approach | Noise Reduction Capabilities | | Spatial Applicability | Temporal Applicability | Advantages/Benefits | Disadvantages/Concerns | Cost/Resource Implications | Overall Effectiveness Rating |
|---|---|---|---|---|---|---|---|---|
| | Daily Average Levels Leq(24) (dBA) | Lmax Intrusive Events (dBA) | | | | | | |
| **Residential Façade Enhancement** | Substantial - potentially 10 to 20 dBA | Substantial - potentially 10 to 20 dBA | Feasible along most arterials, particularly with older housing stock | 24-hours/day | - Side-benefits such as improved thermal insulation of homes and possibly indoor air quality | - Would rely on homeowner's consent or initiative,<br>- Does not benefit outdoor areas | - Costs potentially substantial depending on treatments required,<br>- $5,000 to $20,000 per house ballpark | **Moderate to High** |
| **Vegetation** | Modest - less than 1 dBA | Modest - less than 1 dBA | Feasible in most locations - less in commercial areas | 24-hours/day | - Associated aesthetic and air quality benefits,<br>- Often is a perceived, if not actual, reduction in noise | -Some maintenance required,<br>- May create unwanted visual screening | - Variable but not large compared to other options | **Low to Moderate** |
| **Low (4 to 6 ft.) Absorptive[1] Noise Barriers (Located at Roadside)** | IL's 3 to 4.5 dBA[1] at ground level (1.7 m), IL's 2 to 3 dBA[1] at main floor level (3.2 m ) | 1.7 to 2.0 dBA at ground level for heavy trucks, 6 to 10dBA for tire/brake squeals | Feasible along many arterials with single family residences but few driveways | 24-hours/day | - Location close to source is better for very low (less than 4 ft.) barriers,<br>- Could provide some physical protection for pedestrians | - Must be interrupted at side streets,<br>- May obstruct driveways,<br>- Subject to vehicle damage,<br>- Some Visual impact for drivers<br>- Some maintenance concerns | - $250-$400/linear meter,<br>- Approx. $2500 - $4,000 per house,<br>- Located on City property | **Low to Moderate** |
| **Low (4 to 6 ft.) Absorptive[1] Noise Barriers (Located Outside Sidewalk)** | IL's 3 to 4.5 dBA[1] at ground level (1.7 m) IL's 1 to 3 dBA[1] at main floor level (3.2 m ) | 1.5 to 2.0 dBA at ground level for heavy trucks, 4 to 6 dBA for tire/brake squeals | Feasible along most arterials with single family residences but few driveways | 24-hours/day | Physical separation of residences from sidewalk, | - Gates required to maintain access to walkways, driveways,<br>- visibility (security) of residences and pedestrians restricted.<br>-Some maintenance concerns | - $250-$400/linear meter,<br>- Approx. $2500 - $5,000 per house,<br>- Located on private property | **Low to Moderate** |

1. Barrier IL's would be 0.5 to 1 dBA lower in arterial locations with significant grades. IL's would be slightly (about 0.5 dBA) lower if barriers in this height range were not sound absorptive.



City of Vancouver FOI #2017-525, page 0181

## Table 3; Potential Overall Effectiveness of Various Approaches to Mitigation of Arterial Road Traffic Noise in the City of Vancouver (Part 3 of 3)

| Mitigation Approach | Noise Reduction Capabilities: Daily Average Levels - Leq(24) | Noise Reduction Capabilities: Lmax Intrusive Events (dBA) | Spatial Applicability | Temporal Applicability | Advantages/Benefits | Disadvantages/Concerns | Cost/Resource Implications | Overall Effectiveness Rating |
|---|---|---|---|---|---|---|---|---|
| **Noise Barriers between houses (4 to 6 ft.)** | IL's 0.9 to 1.2 dBA with 5 ft. gaps between houses, IL's 2 to 3 dBA with 25 ft. gaps between houses | Approx 1 dBA with 5 ft. gaps, 1 to 4 dBA with 25 ft. gaps | Feasible along most arterials with single family residences | 24-hours/day | - Minimal visual impact,<br>- Minimal security concerns. | - No noise control benefit in front yard or at front façade,<br>- Requires consent of residents to build on private property | - More custom work,<br>- $250-$400/linear meter,<br>- Approx. $1,000 - $3,000 per house | **Low to Moderate** |
| **Row Houses** | Approx. 15 dBA total shielding provided, 4 to 11 dBA more than single family houses | Approx. 15 dBA total shielding, 3 to 10 dBA more than single family houses | Dependent on obtaining land and appropriate rezoning | 24-hours/day | - Very effective in rear yards,<br>- In new developments, should be combined with good façade design to achieve acceptable noise levels inside and outside | - No benefit in front yard or within rooms facing front façade unless involves new construction or renovations featuring façade upgrade. | - No costs directly due to creation of row houses<br>- Will be costs for façade upgrade | **Moderate, High when combined with façade upgrade** |



City of Vancouver FOI #2017-525, page 0182