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Intersection Noise Measurements

Great King Street, Dunedin

Intersection Noise Measurements

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Executive Summary

In July 2010 the New Zealand Transport Agency (NZTA) upgraded the intersection of State Highway 1 Great King Street North (SH1) and Duke Street, Dunedin, from a non-signalised intersection where SH1 had right-of-way, to a signalised intersection.

AECOM was commissioned by the NZTA to measure and assess the traffic noise levels in the vicinity of the intersection before and after the signalisation, and to provide data to inform the NZTA for future signalisations of intersections.

The noise level criteria prescribed by New Zealand Standard 6806:2010 "Acoustics – Road Traffic Noise – New and Altered Roads" were used as a benchmark for the purpose of the assessment; however, NZS 6806:2010 does not strictly apply to the particular case under consideration as the signalisation is not classified as an altered road under NZS 6806:2010. There are several criteria that must be met in order to be classified as an altered road, including a change in the alignment. In the case under consideration here, there is no change to the road alignment.

Noise measurements ($L_{Aeq(24h)}$) were performed over 7-day periods before and after the signalisation, at a location near to the corner of the SH1 / Duke Street, in general accordance with NZS 6806:2010. Shorter term measurements, ranging from 15 minutes to 7 hours, were also performed before and after the signalisation at seven other locations in the vicinity of the intersection. Counting of traffic volumes on SH1 and Duke Street was undertaken by an NZTA contractor in parallel with the noise measurements.

After allowing for differences in traffic volume, comparison of the $L_{Aeq(24h)}$ noise levels at the intersection before and after signalisation shows an increase of approximately +1 dB $L_{Aeq(24h)}$, from 65 dB $L_{Aeq(24h)}$ (before signalisation) to 66 dB $L_{Aeq(24h)}$ (after signalisation)[1]. The L_{AFmax} noise levels were found to increase by approximately +5 dB(A). The measurement uncertainty has been estimated to be ± 3.8 dB(A) with a confidence level of 95%. This suggests that the change in L_{AFmax} noise level is statistically significant, but the change in $L_{Aeq(24h)}$ noise level may not be i.e. the difference in measured $L_{Aeq(24h)}$ noise level may be due largely to measurement uncertainties.

Based on the $L_{Aeq(24h)}$ noise levels measured, the noise mitigation requirements of NZS 6806:2010 would not be applicable at the affected receptors in the vicinity of the Duke Street Intersection, as, aside from the signalisation not being classified as an altered road, the noise levels after the signalisation are less than 68 dB $L_{Aeq(24h)}$ and have not increased by more than +3 dB $L_{Aeq(24h)}$ as a result of the signalisation[2].

The shorter term measurements performed in the wider vicinity of the intersection showed that the noise effects resulting from the signalisation were limited to within approximately 50m of the intersection.

Overall, the noise level increase measured is less than typically reported in literature on the subject, and the measured effects are limited to a smaller area around the intersection. Possible explanations for this are hypothesised in the body of the report.

One observation worthy of mention is that vehicles travelling over the traffic sensors, which were installed near to the stop line on SH1 as part of the signalisation, generated additional noise when compared with sections of unmodified road surface. This effect was not apparent in the measurements that were performed at the similar SH1 / Dundas Street intersection, suggesting that variations in installation method or quality of installation may have a significant bearing on the noise levels generated by traffic sensors. The potential impacts of variability in these factors should therefore be considered when assessing the noise effects of intersection signalisation where traffic sensors are to be installed near to noise sensitive locations.

In addition to the noise measurements, AECOM conducted a brief investigation into three potential methodologies for predicting the noise from signalised intersections, using the SH1 / Duke Street intersection as a case study.

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[1] These noise levels are for a distance of 9m from SH1 under free-field conditions. This is equivalent to the assessment position that would apply under NZS 6806:2010 for the potentially most-affected receptor in the vicinity of the intersection (the Mercure Hotel).

[2] Under NZS 6806:2010 the requirement for mitigation assessment is not triggered by a road alteration unless the "do minimum" noise level for the altered road would be greater than 64 dB $L_{Aeq(24h)}$ and would increase by more than +3 dB $L_{Aeq(24h)}$, or the "do minimum" noise level for the altered road would be greater than 68 dB $L_{Aeq(24h)}$ and would increase by more than +1 dB $L_{Aeq(24h)}$.

The first method was based on comparison to a similar existing signalised intersection, with noise levels measured at different distances from the intersection. This method appeared produce reasonably reliable L_{Aeq} predictions, but required extensive field measurements to characterise the subject intersection and the comparison intersection, and as such may be costly to implement in practice.

The second method was to apply the RLS90 traffic signal corrections to the noise levels from the existing intersection (pre-signals). This was found to over-predict the measured noise levels by 1 to 2 dB(A) in general.

The FHWA TNM calculation methodology was the third method investigated. It differs from the CRTN traffic noise modelling methodology traditionally adopted by the NZTA in that it incorporates specific procedures to account for the effects of traffic signals. This method appears promising as a method for predicting the noise level changes due to intersection signalisations; however, the based on the investigations performed here, the TNM methodology needs to be applied with caution where low traffic volumes or low average traffic speeds are present on one or more of the roads at the intersection.

1.0 Introduction

1.1 Background

In July 2010 the New Zealand Transport Agency (NZTA) upgraded the intersection of State Highway 1 Great King Street North (SH1) and Duke Street, Dunedin, from a non-signalised intersection where SH1 had right-of-way, to a signalised intersection. During the course of this work, the Mercure Hotel, which is located at the north-eastern corner of the intersection, raised concerns about possible traffic noise effects due to the signalisation.

NZS 6806:2010 *Acoustics – Road Traffic Noise - New and Altered Roads* (NZS 6806) is the traffic noise standard that has been adopted by the NZTA for assessing traffic noise from new and altered State Highways, but it does not specifically address, or apply to, traffic noise effects associated with intersection signalisations where there is no change in the layout / alignment. Further to this, the NZTA has not undertaken any recent research into noise effects from intersection signalisations.

In order to address the concerns of the Mercure Hotel, and to provide information to improve the NZTA's understanding of the noise effects associated with the signalisation of intersections, AECOM was commissioned by the NZTA to undertake a noise survey and investigation relating to the noise effects associated with the signalisation of the Duke Street Intersection.

1.2 Objectives of the Investigation

The first objective of the investigation was to assess the noise levels before and after the signalisation of the Duke Street intersection to provide the NZTA project team with the necessary information to assure the owners of properties adjacent to the intersection that the noise levels resulting from the signalisation were not unreasonable, or to prompt the consideration of noise mitigation measures if necessary.

The second objective of the investigation was to provide measurement data to improve the NZTA's understanding of the changes in traffic noise that may occur as a result of intersection signalisations, to inform future signalisation projects..

Daily-average noise levels ($L_{Aeq(24h)}$) are currently the primary metric used to assess noise from State Highways in New Zealand, and although this is believed to be generally appropriate, there is evidence in the literature (see Section 0) to suggest that the perceived noise impacts of signalised intersections are correlated more closely with shorter term noise levels and changes in the character of the traffic noise i.e. a change from continual noise associated with smooth flowing traffic to fluctuating noise associated accelerating / decelerating traffic.

In addressing the objectives of the investigation AECOM has therefore sought to explore the following questions:

- How does signalisation of the intersection affect the $L_{Aeq(24h)}$ noise level at the intersection?
- Does signalisation of the intersection affect the level of variability in the shorter term noise levels such as the $L_{Aeq(15min)}$ and $L_{Aeq(1min)}$?
- Are the L_{AFmax} noise levels affected?
- Are there any notable changes in the frequency spectra of the noise measured at the intersection?
- How does signalisation of the intersection affect the noise levels at various distances away from the intersection, along the State Highway?
- How might the noise level changes associated with signalisation of the intersection be best represented in traffic noise modelling?

1.3 Investigative Approach

During the early stages of the investigation, AECOM undertook a preliminary literature survey to establish the measurement metrics that would be most appropriate in assessing the changes due to the signalisation, and to identify other relevant research and findings that are already published.

Based on the results of the preliminary literature survey, a measurement methodology was developed that would allow a range of analyses to be conducted. Both long- and short-term measurements were performed at the SH1 / Duke Street intersection before and after the signalisation upgrade, and the results were analysed with respect to the objectives of the investigation.

An investigation was also carried out to examine the validity of three potential methodologies for predicting noise effects associated with intersection signalisations. Each potential methodology was used to predict the signalised noise levels at the SH1 / Duke Street intersection and the results produced by each methodology were compared to the noise levels measured at the intersection following its signalisation. The three prediction methodologies investigated were:

- *Method 1: Prediction by Comparison*
  - For this method, the predictions were calculated by adjusting the noise levels measured at a similar already-signalised intersection to account for any differences in traffic volume and traffic composition. For the specific example here, noise measurements were carried out at the already-signalised SH1 Great King Street North / Dundas Street intersection, approximately 500m to the south of the SH1 / Duke Street intersection.
- *Method 2: Application of the Traffic Signal Adjustments Recommended by RLS-90*
  - The German RLS-90 "*Guidelines for Noise Protection at Roads*" [Ref (27)] presents a simple set of recommended adjustments to account for the effects of traffic signals when modelling noise at intersections. Predictions of the noise levels that would occur in the vicinity of the SH1 / Duke Street Intersection after signalisation were performed by applying these adjustments to the noise levels measured at the intersection prior to it having traffic signals installed.
- *Method 3: Prediction using the US Federal Highways Administration (FHWA) Traffic Noise Model (TNM)*
  - The FHWA TNM has an in-built mechanism to take account of the effect of traffic signals. Further detail in relation to this method is presented in Section 6.3.

Note, for practical application to other situations, the first two of these methodologies would generally be suitable only for predicting the effects of simple intersection signalisations where there are no significant changes to the intersection layout such as new lanes, widening, or realignment, etc. Where there are changes to the intersection layout, it would be necessary to find an intersection equivalent to the upgraded intersection in order to use Method 1. To use Method 2 it would be necessary to combine the method with another predictive model (such as CRTN) that takes account of the changes to the layout.

1.4 Scope of Report

This report presents:

- The main findings of the literature survey that was carried out;
- A description of the intersections used as the basis for this study;
- The methodology and results of the noise measurements that were carried out before and after signalisation of the SH1 / Duke Street intersection;
- Analysis of the measurement results, addressing the objectives of the investigations outlined above in Section 1.2;
- A preliminary investigation into potential methods for predicting the noise effects associated with simple intersection signalisations; and
- The conclusions drawn from the study.

The report aims to address the quantifiable effects on the noise levels at the SH1 / Duke Street intersection due to the signalisation, for the purpose of providing information to the NZTA about the noise level changes that occur when any other intersection is signalised.

Investigation of how the objectively measured changes in noise level correlate with the subjectively perceived noise effects of the signalisation is beyond the scope of this report. Further research would be necessary in order to develop an understanding of this relationship if guidance on the overall noise effects of intersection signalisations is to be developed.

Definitions of the acoustic nomenclature used in this report are presented in Appendix A.

2.0 Literature Survey

2.1 Noise Effects of Intersection Signalisation

Urban traffic noise is known to vary significantly with time. The variations occur over both a short timescale, due to events such as individual vehicle pass-bys or traffic flow fluctuations related to traffic signal sequences, and over longer timescales, due to rush hours, differences in traffic volume and composition between day and night, and seasonal variations such as holiday periods.

From observation of signalised intersections it can be noted that the interrupted traffic flow associated with signalised intersections generates noise with different acoustic characteristics to the noise associated with uninterrupted flows, or to the noise associated with intersections with other types of traffic control.

Various studies have been undertaken to investigate the overall noise level changes due to installation of traffic signals at intersections, with varying results.

Desarnaulds et al [Ref (10)] cite a Japanese study [Ref (32)] which found that noise levels close to a signalled controlled junction were typically +2.4 dB(A) higher for the equivalent volume of continuous traffic. However, Desarnaulds et al cites another study [Ref (15)] which found that although installation of traffic signals at an intersection often increased the noise levels at the intersection by around +2 dB(A), careful sequencing of the lights (e.g. synchronising the green light phase with that of other nearby intersections before and after to create a "green wave") had actually been observed to result in noise reductions of up to -2 dB(A) in some instances.

Another study [Ref (13)] considered the differences in noise level when traffic signals were removed and the intersection replaced with a grade-separated interchange. In this study, the noise levels with traffic signals were found to be +1.5 to +3.5 dB(A) higher than without.

Hothersall and Jones [Ref (16)] investigated the L_{10}, L_{50} and L_{90} noise levels around two signalised cross-junctions in the UK and found that noise levels at the intersections were typically +5 to +7 dB(A) higher than on the approach to the intersection, outside the queuing zone.

The recommendations given in the German RLS-90 guidelines [Ref (27)] suggest that the traffic noise level at signalised intersections can be up to +3 dB(A) higher than the noise level due to the traffic approaching the intersection. The recommendations provided suggest that the effects of the traffic signals diminish with distance from the intersection, and do not typically extend beyond 100m from the intersection.

Abo-Qudais and Alhiary [Ref (1)] studied 40 signalised intersections in Amman, Jordan, and observed the variations in noise level at distances of up to 250m around the intersections. Abo-Qudais and Alhiary found that although the traffic volume had a significant influence on the absolute noise levels, the relative noise level variation with distance from the stop line was fairly consistent. It was found that, on average, the L_{Aeq} noise level decreased with distance from the stop line up to about 50m, after which the noise levels started to increase up to about 250m, where they stabilised to a fairly constant level. At distances between 50 and 100m from the intersection, the noise levels were found to be between +1.5 dB(A) and +2.0 dB(A) less than those at the signal stop line, which is consistent with the results of most other studies which have not considered distances of much more than 100m from the intersection.

However, while the above studies investigate the overall noise level differences due to installation of traffic signals, and there is much research correlating overall noise levels with annoyance [Ref (9), (20), (23)], there is also a significant body of research suggesting that the overall noise level is not the only factor that needs to be considered in determining the noise impacts of any given source of traffic noise, especially when considering the potential changes in noise character associated with intersection signalisation.

In particular, Jones and Waters [Ref (19)] investigated the relationship between noise level and annoyance at signal controlled intersections versus free flowing traffic. Noise from interrupted traffic flow was generally found to be more annoying than noise from freely flowing traffic at the same level, and at noise levels above 65 dB L_{A10} the level of annoyance from interrupted traffic became increasingly greater with noise level, relative to the annoyance from freely flowing traffic (which also increased with increasing noise level, but at a slower rate).

In addition to this, various research exists that relates sleep disturbance to the number of noise events occurring with maximum noise levels over a certain value [Ref (2), (14), (21)], illustrating the importance of also investigating temporal variations in the traffic noise level.

Furthermore, Raggam et al [Ref (26)] present research correlating the psycho-acoustical parameters of roughness, sharpness and loudness, (which are all related to temporal and/or spectral characteristics of the noise) with the annoyance and discomfort caused by any particular traffic noise source. Raggam et al conclude that these factors should be taken into consideration when regulating traffic noise emissions, but does not propose any metrics that could be conveniently implemented in practice.

This view is supported papers by Can et al [Ref (4), (5)], which suggest that the descriptors conventionally set by noise legislation, such as the $L_{Aeq(24h)}$ descriptor used by NZS 6806:2010, are suitable for assessing the total amount of noise exposure, but are poor at capturing the spectral and temporal variations that characterise urban traffic flow and associated variations in perception.

Can et al propose measuring the traffic noise levels at the intersection in time intervals of less than the signal sequence scale. The proposed method of measurement and analysis begins with measuring the $L_{Aeq(1s)}$ noise levels at the intersection over many signal sequences, and correlating the results with the periods corresponding to the green phase and the red phase. A range of metrics are then derived from the data and used to describe the traffic noise dynamics.

While the approach suggested by Can et al provides a useful way of concisely characterising the noise dynamics at an intersection, the ability to implement this method of analysis in a practical situation may however be limited, due to the need to know the timing of the green and red phases with respect to the noise measurements (which implies a need for attended noise measurements) and the fact that several days of continuous measurements may be required to obtain a truly representative sample (which would be impractical for an attended measurement).

Moreover, Can et al notes that the correlation between the proposed metrics and the subjective assessment of noise annoyance is as yet unknown and further research in this area is required before any meaningful criteria using these metrics can be developed. No more-recent research on this topic from this author has been found in the literature. Contacting the Can et al authors to enquire about any further research that may have been conducted since the paper cited here was written in 2007 may be a good starting point for any further investigation if this approach to characterising traffic noise levels at intersection is of interest.

2.2 Noise Prediction Methodologies for Signalised Intersections

The UK CRTN methodology [Ref (8)] predominantly used for the prediction of road traffic noise in New Zealand takes a simplistic approach to the modelling of noise effects at junctions.

The approach used by CRTN is to model the traffic flow at the average traffic speed of the uninterrupted traffic flow right up to the junction, without accounting for the reduced traffic speeds that normally occur around the junction. Justification for this simplification is provided in the UK Highways Design Agency Design Manual for Roads and Bridges [Ref (9)]. The Design Manual states that the “speed variations at junctions should generally be ignored in assessing noise nuisance as there is a trade-off between the effects of reducing speed and the additional engine noise generated by deceleration and acceleration”. All intersections are treated the same way, regardless of the traffic control method used. Therefore, the CRTN model does not differentiate noise effects between signalised and unsignalised intersections.

In practice, the CRTN approach to modelling junctions is often found to be valid, but as it relies on the approximation that any decrease in noise effects due to slower vehicle speeds will be offset by an increase in noise effects due to acceleration and deceleration of vehicles, there may be situations where it fails to accurately reflect the actual noise levels or noise effects..

However, there are several other noise prediction methodologies which include specific mechanisms to account for the effects of traffic signals, to varying levels of sophistication.

Samuels [Ref (30)] developed one of the earlier known models specifically aimed at predicting traffic noise at signalised intersections. This model was based on analysis of the behaviour of “platoons” of vehicles passing through the intersection during each signal phase. A software package to implement the model, named ITFNS (Interrupted Traffic Flow Noise Simulation), was produced by the Australian Road Research Board (ARRB). As part of Transit New Zealand research that published in 1991, Hunt and Samuels [Ref (17)] evaluated this model for New Zealand conditions and concluded that, with some modification for New Zealand vehicles, it had potential suitability for use in New Zealand. However, it is understood that the model was never widely adopted in New Zealand or Australia, and the ARRB has so far been unable to supply a copy of the software for AECOM's evaluation.

The most basic of the common methods currently used to account for the effects of traffic signals is the German RLS-90 method, which simply applies an adjustment of up to +3 dB to the predicted noise level, depending on the distance of the receptor from the intersection.

Other prediction methods such as the Nordic model [Ref (18)] and the Japanese ASJ RTN Model 2008 [Ref (33)] account for the effects of traffic signals by providing different emission equations for vehicles under various driving conditions such as accelerating, cruising and decelerating. The user of the model must however manually define the locations in the model where the particular driving conditions occur.

The US Federal Highway Administration's (FHWA) TNM methodology [Ref (22)] uses a similar approach but incorporates predefined source level adjustments to account for the change in speed and driving conditions, based on typical vehicle speed and acceleration profiles at intersections that have been determined by the FHWA for different types of intersection and vehicle.

The French NMPB model [Ref (6), (12)] is understood to include a similar level of detail in its calculation algorithms.

Validation studies of the TNM, Nordic, and NMPB traffic noise models have been carried out in Ref (28),(29) (TMN), (24) (Nordic), and (3),(11) (NMPB). However, these studies focus largely on the accuracy of the propagation components of the models with respect to different distances from the road, different ground and terrain types. None of the validation studies evaluate the accuracy of the models for signalised intersections.

Steele [Ref (31)] reviewed six of the commonly used traffic noise models that were available in 2001, including many of the models mentioned above. Steele concluded that none of the models provided a truly satisfactory capability for modelling the complex interrupted traffic flows observed at many signalised intersections, or for investigation of how different signal sequences may affect noise levels.

More recent modelling research represents a trend away from the development of simple empirical relationships towards more analytical models which include increasingly detailed and realistic representation of the actual traffic flows. The models developed by Chevalier and Can et al [Ref (7),(5)] are such examples, which use micro-simulation noise modelling, where the noise modelling is based on a detailed traffic flow model that takes into account the likely interactions between individual vehicles at the intersection during both free and congested flow. However, these types of models are unlikely to be widely adopted unless micro-simulation of traffic flows becomes more common in road design and transport planning, as it is this information which is required to form the basis of the micro-simulation of traffic noise levels.

3.0 Site Description

The SH1 Great King Street North / Duke Street intersection and the SH1 Great King Street North / Dundas Street intersection are both four-armed intersections, located approximately 2km and 1.5km north of the Dunedin city centre respectively, as shown in Figure 1.

Figure 1 Locality Map of Intersections (Base Map Source: Google Earth Pro / Google Maps)

At both intersections, SH1 Great King Street North carries traffic in two lanes, with both lanes carrying traffic in the northbound direction only. The southbound State Highway traffic is carried by SH1 Cumberland Street North, approximately 120m to the east of SH1 Great King Street North.

Dundas Street and Duke Street both carry two-way traffic, with one lane for each direction.

The terrain in the area of both intersections is relatively flat.

3.1 Duke Street Intersection

There are a number of potentially noise-sensitive locations in the vicinity of the Duke Street intersection, including the Mercure Hotel, which is located at the northeast corner of the intersection, and a number of residences along the south side of Duke Street. There is also a residence located above the bookshop on the southeast corner of the intersection.

Giltech Precision Castings is located at the northwest corner of the intersection, and there is an automotive workshop on the southwest corner. Neither of these sites is considered to be noise sensitive.

Duke Street typically carries a two-way traffic volume of approximately 2,000 to 2,500 vehicles per day. The northbound State Highway traffic volume at Duke Street is around 10,000 vehicles per day. Traffic noise from the State Highway therefore dominates the general noise environment, as the traffic volumes on Duke Street are comparatively low.

Prior to traffic signals being installed at the Duke Street intersection, SH1 Great King Street North had unrestricted right of way through the intersection. Traffic crossing or entering the State Highway from Duke Street was controlled by Give Way signs.

In the present situation, traffic signals are installed at the intersection and are configured to provide a green light to SH1 Great King Street North, except when a signal change is activated by traffic sensors on Duke Street, or by the pedestrian crossing over SH1 Great King Street North. The signal change typically occurs within 1 minute of activation, and allows a 5 second green light period for Duke Street, or 15 seconds when the pedestrian crossing is activated.

No significant changes to the road layout occurred as part of the signalisation. The main changes, other than the traffic signals themselves, were installation of sensors in each traffic lane approaching the intersection, and replacement of some of the kerb and channel at the corners of the intersection.

Road surface types on SH1 in the area of the Duke Street intersection were slurry seal except for:

- the last 21 metres approaching the intersection and through the intersection, where the road surface was asphaltic concrete; and
- 44 metres departing the intersection, where the road surface of one traffic lane was asphaltic concrete and the road surface of the other traffic lane was 18 year old open-graded porous asphalt.

Figure 2 to Figure 4 show photographs of the intersection, part way through installation of the signals.

Figure 2 View of Duke Street Intersection from Southeast Corner

Figure 3 View of Duke Street Intersection from Southwest Corner (Mercure Hotel Visible on the Left)

Figure 4 View of Duke Street Intersection from Northwest Corner (Upstairs Residence Visible in the Centre)

3.2 Dundas Street Intersection

The Dundas Street intersection is a signalised cross-junction similar in layout to the Duke Street intersection.

The traffic flows at the Dundas Street intersection are slightly higher than at the Duke Street intersection, with Dundas Street carrying a two-way traffic volume of approximately 3,700 vehicles per day, and SH1 Great King Street North carrying a northbound traffic volume of approximately 11,000 vehicles per day.

The signal sequence at the Dundas Street intersection is biased towards SH1 Great King Street North, typically alternating between a 50-second green light period for SH1 Great King Street North and a 10-second green light period for Dundas Street. At times when there is no traffic on Dundas Street, the green signal remains on SH1 Great King Street North until such time as traffic on Dundas Street activates a signal change.

As for the Duke Street intersection, traffic noise from the State Highway dominates the general noise environment due to the comparatively low traffic volumes, and short green signals, on Dundas Street.

Road surface types on SH1 in the area of the Dundas Street intersection were slurry seal except for the last 18 metres approaching the intersection, through the intersection, and 120 metres departing the intersection, where the road surface was asphaltic concrete

Figure 5 presents a photograph of the Dundas Street intersection.

Figure 5 View of Dundas Street Intersection from Southeast Corner

4.0 Measurement Methodology

4.1 General Procedure

Measurements of the traffic noise levels at each intersection were undertaken in terms of L_{Aeq} Sound Pressure Levels, in accordance with the requirements of NZS 6806:2010, with the exception that the sample time interval used was 1 minute[3], rather than 15 minutes. This deviation was made in order to provide a greater level of temporal detail for analysis if required. (Note that the 15-minute L_{Aeq} Sound Pressure Level can be calculated from the corresponding fifteen 1-minute L_{Aeq} Sound Pressure Levels, but not vice versa).

In addition to the L_{Aeq} noise levels, the L_{AFmax}, and a range of other statistical noise levels were logged. (Only the L_{Aeq} and L_{AFmax} noise levels are analysed in this report, as these are considered to be the two most relevant metrics for this investigation).

For the SH1 / Duke Street intersection, a set of simultaneous noise measurements was performed at specific locations around the intersection, using time-synchronised measurement equipment, before and after the traffic signals were installed. For the already-signalised Dundas Street intersection, only one set of measurements was performed, but the methodology was the same.

4.2 Measurement Locations

The measurement locations were selected to enable a range of comparisons to be undertaken, to investigate the questions raised in Section 1.2 of this report.

Three measurement distances away from the intersection along the State Highway were used on both the SH1 approach side and the departure side of each intersection. These were nominally, 1) at the intersection, 2) 50m from the intersection, and 3) 100m from the intersection[4].

However, in practice the exact measurement locations varied slightly from the above due to considerations such as the availability of a suitable place in the vicinity of the desired measurement location to secure the noise measurement equipment, the granting of permission to install the equipment if it were located on private property, and the avoidance as far as possible of any locations where noise sources other than traffic might significantly influence the noise measurements.

In addition to the measurements at various distances along the State Highway from each intersection, measurements were also performed on Duke Street and Dundas Street to the east and west of the State Highway.

The resulting measurement locations around each intersection are presented in Figure 6 and Figure 7. Further details in relation to each measurement location are presented in Appendix B.

[3] Noise measurement data at a finer timescale (as short as 0.1 seconds), and recordings of the actual sound, were stored for some of the measurement locations. It was not practical to monitor at this level of detail at all locations due to limitations imposed by the capabilities and memory capacity of the some of the monitoring equipment that was available for the study.
[4] Literature on the subject as described in Section 0 suggests that the noise effects of traffic signals are generally not significant at distances over 100m from traffic signals, therefore the measurements performed at 100m from the intersection were intended to act as something of a “control sample”.

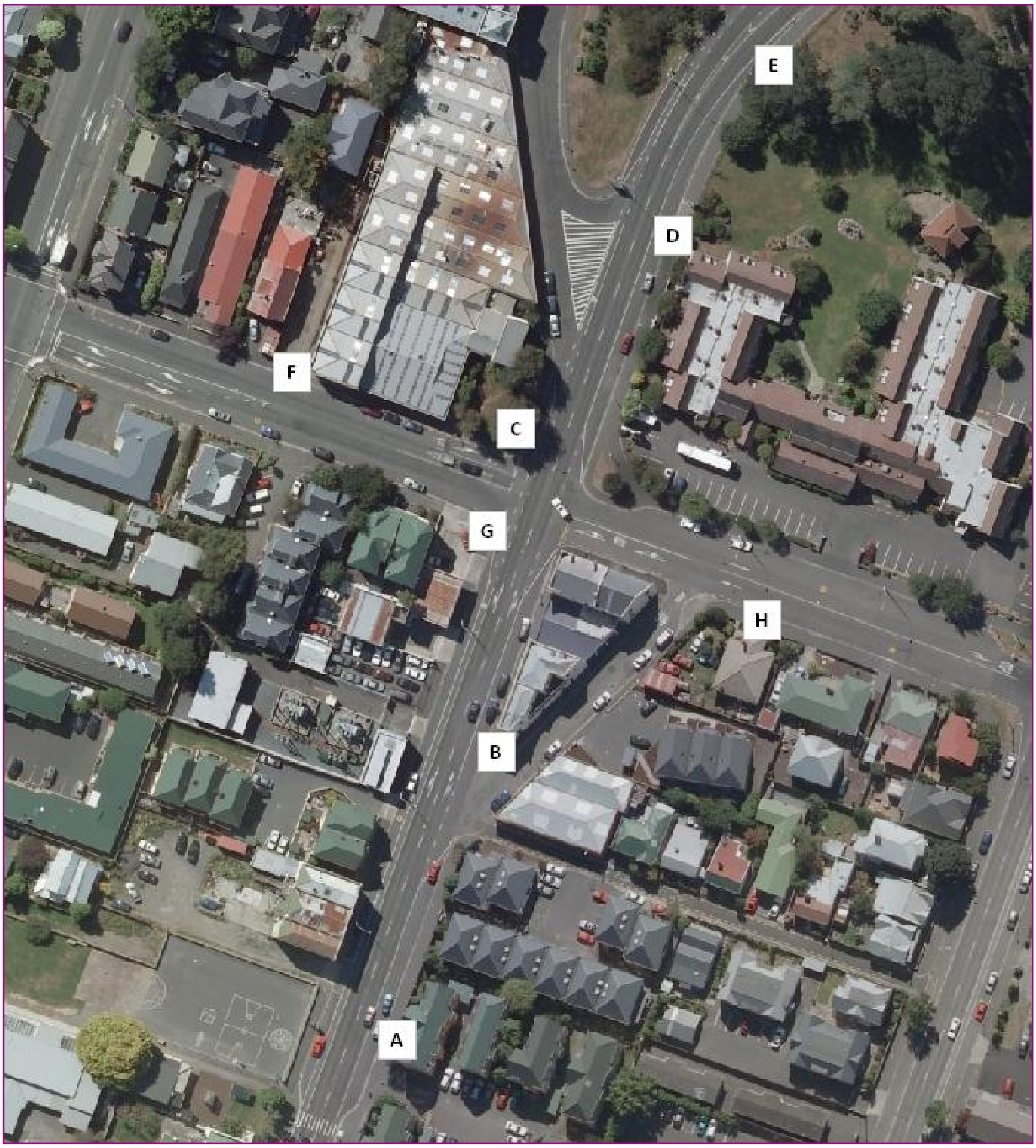

Figure 6 Measurement Locations at Duke Street Intersection

Figure 7 Measurement Locations at Dundas Street Intersection

Each set of measurements was performed during the daytime. For the locations where the main comparative noise measurements were performed, the measurement duration was between 3 and 7 hours. The locations where the measurement period differed from this are as follows:

- At Locations F, G, H, N, O, P short-term attended measurements ranging from 15 minutes to nominally 1 hour were performed. Shorter measurements were used at these locations because:
  - The measurements performed at Location G were primarily for the purpose of quantifying the influence of noise from vehicles driving over the traffic sensors which were installed in the road adjacent to this location as part of the signalisation.
  - The measurements performed at Location O were primarily for the purpose of investigating the difference between the noise levels on the immediate approach (Location K) and immediate departure side (Location O) of a signalised intersection on SH1 Great King Street. The close proximity of these two locations meant correlation of the noise levels was straightforward, enabling a reliable comparison using a shorter measurement period.
  - The measurements at Locations F, H, N, and P were performed primarily for the purpose of confirming the contribution of traffic noise from Duke Street and Dundas Street to the overall traffic noise levels around the intersections. As the noise levels were not significant compared with those of SH1 it was determined that traffic noise from Duke Street and Dundas Street did not need to be considered in any greater level of detail. The noise levels at these locations were generally dominated by traffic noise from the State Highway, rather than the local Street itself.
- At Location C, longer-term logging was performed over a 7-day period before the signalisation and again for another 7-day period after the signalisation, to enable a good comparison of the L_{Aeq} noise levels over several 24 hour periods, in order to gauge day-to-day variability.

Additionally, one-third octave band frequency spectra were measured at Location C (and at Location K at the Dundas Street intersection) to enable a frequency analysis of the noise at the intersection to be undertaken, for the purpose of determining whether there were any significant changes in the typical traffic noise spectrum due to the signalisation. Frequency spectra were not measured at any other locations as it was not part of the scope of this investigation.

4.3 Instrumentation

Table 1 presents details of the acoustic instruments that were used for the noise measurements. Information regarding which instrument was used at each location, for each particular set of measurements, is presented in Appendix B.

Table 1 Details of the Acoustic Instrumentation Used for the Noise Measurements

Instrument Reference	Make	Model	Description	Serial No.	Laboratory Calibration Status at Time of Measurements
1	Svantek	Svan 957	Type 1 Logging Sound Level Meter with 1/3 Octave Band Filters	20615	Current (Last Calibration: 15/12/09)
2	Svantek	Svan 957	Type 1 Logging Sound Level Meter with Octave Band Filters	20614	Current (Last Calibration: 15/12/09)
3	ARL	Ngara	Type 1 Environmental Noise Logger	87805e	Current (Last Calibration: 8/6/10)
4	ARL	Ngara	Type 1 Environmental Noise Logger	87805f	Current (Last Calibration: 8/6/10)
5	ARL	EL215	Type 2 Environmental Noise Logger	194694	Current (Last Calibration: 12/3/10)
6	Rion	NL32	Type 1 Logging Sound Level Meter with 1/3 Octave Band Filters	161683	Current (Last Calibration: 12/7/10. Previous calibration was current to 15/7/10)

The calibration of each Sound Level Meter and Environmental Noise Logger was field-checked before and after each set of measurements using a laboratory calibrated Rion NC 74 Portable Sound Level Calibrator (Serial No. 34262051, last calibrated 9/7/2010). The instruments were found to be reading correctly at the time of all checks.

All distance measurements along the road corridor were performed using a "Trumeter Measuremeter 5500" measuring wheel (Serial No. 158181).

4.4 Traffic Data

Traffic volumes, speeds, and the vehicle classes passing through each intersection during the measurement periods were logged by an NZTA contractor, using pneumatic tube counting equipment. The counting tubes were located at positions close to each intersection. Checks were performed to ensure that noise from vehicles passing over the counting tubes was not significantly influencing the noise levels at the noise measurement locations.

The traffic monitoring was performed for each individual lane on SH1 Great King Street North (at both the Duke Street and the Dundas Street intersections), and as combined two-way counts for Dundas Street and Duke Street.

Raw data from the traffic monitoring was provided to AECOM in a spreadsheet.

Analysis of the traffic volumes carried by the individual lanes on SH1 Great King Street North showed that the traffic was approximately evenly distributed between the two lanes at both intersections. This indicated that the side of SH1 Great King Street North on which the noise measurements were performed would not have had any significant influence on the noise measurement results.

4.5 Meteorological Conditions

At the beginning of the noise measurements at the Dundas Street intersection, the road surface was damp from overnight rain, but not saturated. The road surface dried over the course of the measurement period, and the traffic lanes were completely dry by around midday. The dampness of the road surface at the beginning of the measurements did not appear to affect the level or character of the traffic noise at the intersection.

With the exception of some periods during the second set of 7-day measurements at Location C, all other measurements were performed under dry conditions with little to no wind.

Hourly weather observations for the duration of the two 7-day measurement periods were obtained from the NIWA weather station located at Musselburgh, approximately 5 km to the south of the Duke Street intersection. The hourly wind speed and rainfall data is graphed on the charts presented in Appendix C.

Winds during the two 7-day measurement periods at Location C ranged from light to moderate. Rain occurred between 11am and 12 noon on 5 August, between 12 noon and midnight on 7 August, and from 9pm on 8 August until 5pm on 9 August. It is possible that during these periods of rainfall, the traffic noise may have been elevated slightly by the wet roads, but no significant increase is apparent from the noise measurement results.

4.6 Normalisation of Results

To enable direct comparison between the various measurement results, measured at different distances from the road, in different measurement positions, with different traffic conditions, the results were normalised to a standard set of conditions. Unless stated otherwise, all results presented in this report have been normalised to the standard set of conditions. The following subsections outline the standard measurement conditions chosen, and the methods used to normalise the measurement results to the standard conditions:

4.6.1 Standard Conditions

For the purpose of this investigation, the measurement results were normalised to the following standard set of conditions:

Table 2 Standard Conditions Used for Normalisation of Measurement Results

Parameter	Standard Condition for Normalisation	Comment
Traffic Volume and %HV	**For comparison of the $L_{Aeq(24h)}$ noise levels:** 10,042 vehicles per day 6.7% heavy vehicles on SH1. **For comparison of short-term noise levels (1-minute and 15-minute periods):** The traffic noise measurements performed at the Duke Street intersection after the signalisation, and the traffic noise measurements performed at the Dundas Street intersection, were normalised to the traffic volumes counted at the Duke Street Intersection before the signalisation, during the corresponding time periods e.g. the traffic volume counted between 1:00pm and 1:15pm on the Tuesday of the measurement period after the signalisation would be normalised to the traffic volume counted between 1:00pm and 1:15pm on the Tuesday of the measurement period before the signalisation.	This is the 2009 AADT volume quoted in the *NZTA State Highway Traffic Data Booklet 2005 to 2009*, as measured at the SH1 Great King Street count site near Willowbank, just to the north of the Duke Street intersection. The relevant 15-minute traffic volumes and percentage heavy vehicles are tabulated in Appendix E. Traffic volume data in 1-minute periods is available on request. The concept of "corresponding time periods" has been used for normalisation of the traffic volumes as a means of accounting for day to day variation in traffic volume for each different period of the day. By normalising the traffic volumes, seasonal variations in traffic flow, e.g. due to the university holiday period, are also accounted for.

Parameter	Standard Condition for Normalisation	Comment
Traffic Speed	N/A	No normalisation for average traffic speed was undertaken. Differences in average traffic speed are a potential effect of the signalisation, and therefore it would not be valid to adjust the measured noise levels to compensate for these differences.
Distance from Edge of Traffic Lane	9m	This is the distance from the nearest edge of the nearest traffic lane to the façade of the Mercure Hotel, which is the location where the traffic noise levels are assessed in accordance with NZS 6806:2010.
Change of Road Surface Adjustment	N/A	No normalisation for change of road surface was undertaken. The road surface at the Duke Street intersection was the same before and after the signalisation. At both the Dundas Street and the Duke Street intersections, the major road surface on SH1 was asphaltic concrete through the intersection and on both the immediate approach and departure from the intersection. The road surface on Dundas Street appeared to be asphaltic concrete compared with chip seal at Duke Street. However, as traffic speeds on these streets are fairly low (reducing the influence of road surface type) and as the intersection noise contribution from these streets is minor compared to the contribution from SH1 Great King Street, no adjustment for road surface is considered warranted.
Façade Adjustment	Free-field.	All measurements were normalised to free-field conditions as required by NZS 6806:2010.

4.6.2 Adjustment for Traffic Volume and Percentage of Heavy Vehicles

The following formula was used to calculate the adjustment that was applied to the measured L_{Aeq} noise levels to account for differences in traffic volume and percentage of heavy vehicles. The formula has been derived from the UK "*Calculation of Road Traffic Noise*" (CRTN) calculation methodology [Ref (1)], based on an approximate average vehicle speed of 45 km/h (as measured):

$$Adj_{(Traffic)} = 10\log_{10}\left(\frac{q_0}{q}\right) + 10\log_{10}\left(1+\frac{5p_0}{45}\right) - 10\log_{10}\left(1+\frac{5p}{45}\right) \qquad \textbf{Equation 1}$$

Where

$Adj_{(Traffic)}$	is the adjustment applied to account for differences in traffic volume and percentage of heavy vehicles
q	is the traffic volume during the measurement period under consideration
q_0	is the traffic volume that was counted during the corresponding period[5] in the set of measurements performed at Duke Street Intersection before the signalisation
p	is the percentage of heavy vehicles during the measurement period under consideration
p_0	is the percentage of heavy vehicles that was counted during the corresponding period[5] in the set of measurements performed at Duke Street Intersection before the signalisation

The measured L_{AFmax} noise levels were not adjusted for traffic volume and percentage of heavy vehicles, since L_{AFmax} noise levels are typically due to individual vehicles and are therefore largely independent of traffic volume.

4.6.3 Distance from Edge of Traffic Lane

The following formula was used to calculate the adjustment that was applied to the measured L_{Aeq} noise levels to account for differences distance of each measurement location from the traffic lane:

$$Adj_{(Distance)} = 10\log_{10}\left(\frac{d}{d_0}\right) \qquad \textbf{Equation 2}$$

Where

$Adj_{(Distance)}$	is the adjustment applied to account for differences in distance from the edge of the nearest traffic lane between the various measurement locations
d	is the distance of the measurement location under consideration from the nearest edge of the nearest traffic lane
d_0	is 9m, which is the distance from the nearest edge of the nearest traffic lane for SH1 Great King Street North to the facade of the Mercure Hotel

Since the L_{AFmax} noise levels are typically due to individual vehicles, rather than the overall traffic flow, the following formula was used to calculate the distance adjustments for the L_{AFmax} noise levels:

$$Adj_{(Distance)} = 20\log_{10}\left(\frac{d}{d_0}\right) \qquad \textbf{Equation 3}$$

4.6.4 Façade Adjustment

The following adjustments were applied to account for the effects of sound reflections from building façades and other sound-reflecting surfaces near to the measurement locations:

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[5] See Table 2 for explanation of "corresponding period".

Table 3 Facade Adjustments

Measurement Location	Facade Adjustment Applied, dB	Comment
A	-2.5	This is the standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces.
B	0	There were walls behind and to the side of measurement Location B; however, these walls were at least 3 to 5m away from the measurement location, and therefore the contribution of sound reflections from these walls is expected to have been minimal. Short-term comparative noise measurements performed at various locations in the vicinity of Location B supported this, and therefore Location B has been treated as for a free-field location, with no façade adjustment.
C	0	Although there were some potentially noise-reflecting features in the vicinity of Location C (e.g. the tree and the Giltech Precision sign) there did not appear to be any effects on the noise levels at the measurement location. This was tested through comparison with simultaneous short term noise measurements performed at various positions in the vicinity of Location C.
D	0	Free-field measurement position.
E	0	Free-field measurement position.
F	-2.5	There was a fence approximately 1m behind the microphone position. An adjustment of -2.5 dB is the standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces.
G	0	Free-field measurement position.
H	0	Free-field measurement position.
I	-2.5	This is the standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces.
J	0	Free-field measurement position.
K	0	Free-field measurement position.
L	0	There were walls behind and to the side of measurement Location L; however, these walls were at least 5m away from the measurement location, and therefore the contribution of sound reflections from these walls is expected to have been minimal. Short-term comparative noise measurements performed at various locations in the vicinity of Location L supported this, and therefore Location L has been treated as for a free-field location, with no facade adjustment.
M	-2.5	This is the standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces.
N	-2.5	This is the standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces.
O	-1.5	The standard adjustment recommended by NZS 6806:2010 for measurement positions 1m from reflecting surfaces is -2.5 dB. However, due to physical constraints the microphone position at Location O was approximately 2.5m in front of the building facade, and 1m in front of a fence of a height just below microphone level. The measurement position was therefore considered to be in the zone affected by reflections from the building and the fence, but away from the position where a full 2.5 dB contribution from reflected noise would be received. A “semi-façade” correction of -1.5 dB has therefore been applied to account for this situation. This correction is an estimate of the actual facade effect and has not been taken from NZS 6806:2010. (Also see Note 1, below)
P	0	Free-field measurement position.

Note 1:

Annex B of ISO 1996-2:2007 "*Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels*" provides additional guidance on the effect of different microphone positions relative to reflecting surfaces which has been considered in the estimation of the façade effect for Location O. It is considered that the measurement uncertainty for this location would be greater. It is estimated that the uncertainty in the façade effect is approximately ± 1 dB.

4.6.5 Additional Adjustment at Location I

At Location I at the time of the measurements there was a row of closely-spaced parallel-parked cars between the traffic lane and the measurement location. It was considered that these cars provided a degree of shielding from the traffic noise at the measurement location. Some shielding of noise from traffic south of the measurement location was possibly also provided by a concrete pillar adjacent to the measurement location, to which the monitoring equipment was secured.

To establish the possible effect of the above factors, a short series of simultaneous noise measurements was performed at the same distance from the SH1 / Dundas Street intersection on the opposite side of the SH1 (the monitoring equipment could not simply be installed on the other side of the road due to a lack of a suitable place to secure the equipment).

Through comparison with the noise measurements performed on the opposite side of SH1, it was determined that the shielding effect of the cars and/or pillar was generally of the order of -2 to -3 dB. A +2.5 dB adjustment has therefore been applied to the noise levels measured at Location I to account for these shielding effects.

4.6.6 Overall Normalised Noise Levels

The overall normalised noise levels ($L_{(Norm)}$) were calculated by summing the various adjustments and the measured noise levels ($L_{(Measured)}$), as follows:

$$L_{(Norm)} = L_{(Measured)} + Adj_{(Traffic)} + Adj_{(Distance)} + Adj_{(Facade)} + \left(Adj_{(Location\_I)}\right) \quad \textbf{Equation 4}$$

4.7 Exclusion of Atypical Data

During some periods of the measurement, data was recorded that was clearly not typical of the traffic noise environment. This data presented itself as significant spikes in the measured noise levels, and would typically be characteristic of events such as:

- A passerby tampering with / yelling into the measurement equipment;
- An unusual spike in the short term traffic volume;
- The passing of an unusually noisy vehicle or group of vehicles;
- The passing of an emergency services vehicle with sirens operating;
- A vehicle parking close to the measurement equipment and the occupants leaving the vehicle noisily;
- A significant short-term noise event due activities at a business or residence near to the measurement location.

Where these spikes were of sufficient magnitude to influence the overall analysis, the atypical data was excluded from any averaging or analysis that was performed. Specifically, the following data was excluded:

Table 4 Data Excluded from Analysis of Noise Measurements

Measurement Location	Excluded Period	Reason
A	15 minutes from 15:30 to 15:45 on 30/06/2010	L_{AFmax} spikes approximately +25 dB higher than typical level. L_{Aeq} affected with approximately +10 dB increase compared to typical level.
B	15 minutes from 13:15 to 13:30 on 30/06/2010	L_{AFmax} spikes approximately +25 dB higher than typical level. L_{Aeq} affected with approximately +5 dB increase compared to typical level.
C	15 minutes from 12:45 to 13:00 on 30/06/2010	L_{AFmax} spikes approximately +20 dB higher than typical level. L_{Aeq} affected with approximately +8 dB increase compared to typical level.
C	30 minutes from 7:30 to 8:00 on 6/08/2010	Measured L_{Aeq} noise levels spike up to +20 dB higher than the typical range for this time of day. L_{AFmax} noise level also elevated.
D	15 minutes from 11:00 to 11:15 on 4/08/2010	L_{AFmax} spikes approximately +40 dB higher than typical level. L_{Aeq} affected with approximately +20 dB increase compared to typical level.

5.0 Results

In order to maintain brevity in this report it has been chosen not to include a full set of raw measurement results at the finest level of detail measured, as this amounts to a significant volume of data. A full set of raw measurement data is instead provided in electronic form with this report.

The key measurement results are from the SH1 / Duke Street Intersection and these are summarised and analysed Sections 5.1 to 5.4.

Graphs showing the raw (non-normalised) 15-minute L_{Aeq} and L_{AFmax} noise levels measured at each location, before and after the signalisation, are presented in Appendix D.

Graphs showing the counted traffic volumes in 15-minute periods are presented in Appendix E.

5.1 Overall Traffic Noise Levels at Duke Street Intersection Before and After Signalisation

To analyse the overall changes in noise level at the intersection, $L_{Aeq(24h)}$ noise levels were derived from the measurements performed over 7-day periods at Location C, before and after the signalisation. Table 5 presents the normalised $L_{Aeq(24h)}$ noise levels that were determined, and the normalised average L_{AFmax} noise levels for the same period[6]: Note, the normalised noise levels are typically around 1 dB(A) greater than the measured noise levels.

Table 5 $L_{Aeq(24h)}$ Traffic Noise Levels Measured at Corner of SH1 Great King Street North and Duke Street (Location C)

Day	Normalised $L_{Aeq(24h)}$, dB			Normalised Average L_{AFmax}, dB		
	Before	After	Change	Before	After	Change
Thursday	65.6	66.1	+0.5	77.0	82.1	+5.1
Friday	64.8	65.9	+1.1	77.1	82.2	+5.1
Saturday	65.7	67.2*	+1.5	75.8	81.4	+5.6
Sunday	65.3	66.1	+0.8	76.0	80.2	+4.2
Monday	65.3	66.1	+0.8	76.1	82.0	+5.9
Tuesday	65.1	65.5	+0.4	76.7	81.6	+5.0
Wednesday	64.9	66.2	+1.3	76.1	82.2	+6.1
Average	**65.2**	**66.2**	**+0.9**	**76.4**	**81.7**	**+5.3**

* This noise measurement is likely to have been affected by increased traffic noise levels due to rainfall. Excluding the Saturday measurements from the averaging result results in an average $L_{Aeq(24h)}$ before signalisation of 65.1dB and 66.0 dB after signalisation. Therefore, the resultant change remains at +0.9 dB

As can be seen from the table above, the noise levels measured after the signalisation are, on average, approximately +1 dB $L_{Aeq(24h)}$ higher than the noise levels that were measured before the signalisation. This indicates that the installation of traffic signals has resulted in a minor increase in the $L_{Aeq(24h)}$ noise levels at the intersection (note that a 3 dB change in noise level is typically described as being just-perceptible). Noting that a change of 1 dB is unlikely to be noticeable, and that the estimated measurement uncertainty is ± 3.8 dB with a confidence level of 95% (see Appendix for further detail), this measured difference in $L_{Aeq(24h)}$ noise level is not considered to be significant.

The noise level increase might possibly have been greater if the intersection was a junction of two major roads instead of one major road (SH1) and one minor road (Duke Street).

The measured $L_{Aeq(24h)}$ noise levels would not have triggered a requirement to consider noise mitigation in accordance with NZS 6808:2010, if it was applicable to the intersection upgrade, as the noise levels after the signalisation are less than 68 dB $L_{Aeq(24h)}$ and have not increased by more than +3 dB as a result of the

[6] The average L_{AFmax} noise levels presented in Table 5 are an average of the 15-minute L_{AFmax} Sound Pressure Levels over each 24-hour period.

signalisation[7]. Note that NZS 6808:2010 does not apply to the intersection upgrade as there is no change in the road alignment.

However, the average L_{AFmax} noise levels show a more significant increase of approximately +5 dB on average. This indicates that the regularity with which high noise events occur, and/or that the noise levels associated with those high noise events has increased as a result of the signalisation. This would most likely be due to the noise from heavy vehicles on SH1 having to accelerate away after stopping at red lights at Duke Street, resulting in periods with higher levels of instantaneous noise than occurred prior to the signalisation, when the traffic flow was uninterrupted at Duke Street. This could also be partially due to additional braking noise associated with the signals, particularly from heavy vehicles using Jacobs brakes, and from general brake squeal. However, given that the long term measurement position was on the departure side of the intersection, it is more likely that the L_{AFmax} noise levels would be controlled by noise from accelerating vehicles, since there would be little braking occurring on the departure side of the intersection, and braking noise from the far side of the intersection is not likley to be louder than the accelerating vehicle noise when observed on the departure side of the intersection).

Breaking this down into day, evening and night periods as shown in Table 6, it can be seen that the largest changes occurred during the evening and night periods. Since the proportion of the traffic volume which was comprised of heavy vehicles increased significantly during these periods compared with the daytime, this supports the supposition that the increase is primarily due to heavy vehicles influencing the L_{AFmax} noise levels.

Table 6 Breakdown of Average L_{AFmax} Noise Level Changes by Time of Day

	Normalised Average L_{AFmax}, dB		
	Before	After	Change
Day (7am to 6pm)	79.0	83.4	+4.4
Evening (6pm to 10pm)	77.0	82.2	+5.2
Night (10pm to 7am)	73.1	79.5	+6.4
Overall	**76.4**	**81.7**	**+5.3**

The increase in L_{AFmax} noise levels suggests that the L_{AFmax} noise levels should be considered where intersections are to be signalised and noise is likely to be an issue. This would be particularly relevant in instances such as this particular case, noting that the largest increases have been observed to occur at night, and that the World Health Organisation "*Guidelines for Community Noise*" [Ref (14)] correlate frequent L_{AFmax} noise levels over 60 dB(A) outside bedroom windows with increased sleep disturbance.

5.2 Variability of Short Duration L_{Aeq} and L_{AFmax} Traffic Noise Levels at Duke Street Intersection Before and After Signalisation

The variability of the short term noise levels before and after the signalisation was investigated, as a change in the variability of the short term noise levels would be an indicator of a change in the character of the noise, and could potentially correlate with change in the level of annoyance perceived at noise sensitive locations in the vicinity of the intersection.

The following tables present the standard deviations and inter-quartile ranges of the noise levels measured over the 7-day measurement periods at Location C before and after the signalisation. Data is presented in terms of both L_{Aeq} and L_{AFmax} at 1-minute and 15-minute measurement intervals.

[7] In accordance NZS 6806:2010 the requirement for mitigation assessment is not triggered by a road alteration unless the "do minimum" noise level for the altered road would be greater than 64 dB $L_{Aeq(24h)}$ and would increase by more than +3 dB $L_{Aeq(24h)}$, or the "do minimum" noise level for the altered road would be greater than 68 dB $L_{Aeq(24h)}$ and would increase by more than +1 dB $L_{Aeq(24h)}$.

Table 7 Standard Deviation of Noise Levels Measured at Location C Before and After Signalisation of the SH1 / Duke Street Intersection

	Standard Deviation of $L_{Aeq(1min)}$, dB			Standard Deviation of $L_{AFmax(1min)}$, dB		
	Before	After	Change	Before	After	Change
Day (7am to 6pm)	3.9	3.2	-0.7	4.1	4.2	+0.2
Evening (6pm to 10pm)	3.2	2.8	-0.4	3.8	4.0	+0.2
Night (10pm to 7am)	8.6	8.6	0.0	9.4	10.4	+1.0
Overall	**7.9**	**7.9**	**0.0**	**8.3**	**8.6**	**+0.2**
	Standard Deviation of $L_{Aeq(15min)}$, dB			Standard Deviation of $L_{AFmax(15min)}$, dB		
	Before	After	Change	Before	After	Change
Day (7am to 6pm)	2.8	1.7	-1.1	3.3	3.9	+0.6
Evening (6pm to 10pm)	1.7	1.9	+0.2	3.4	4.8	+1.4
Night (10pm to 7am)	3.3	3.9	+0.6	4.2	4.7	+0.5
Overall	**4.4**	**4.4**	**0.0**	**4.5**	**4.7**	**+0.2**

Table 8 Inter-Quartile Range of Noise Levels Measured at Location C Before and After Signalisation of the SH1 / Duke Street Intersection

	Inter-Quartile Range of $L_{Aeq(1min)}$, dB			Inter-Quartile Range of $L_{AFmax(1min)}$, dB		
	Before	After	Change	Before	After	Change
Day (7am to 6pm)	4.4	3.7	-0.6	5.2	5.5	+0.3
Evening (6pm to 10pm)	4.0	3.1	-0.9	4.7	3.9	-0.8
Night (10pm to 7am)	13.3	13.8	+0.6	12.9	14.3	+1.4
Overall	**8.0**	**7.7**	**-0.3**	**7.3**	**6.3**	**-1.0**
	Inter-Quartile Range of $L_{Aeq(15min)}$, dB			Inter-Quartile Range of $L_{AFmax(15min)}$, dB		
	Before	After	Change	Before	After	Change
Day (7am to 6pm)	2.3	1.9	-0.4	3.6	4.0	+0.4
Evening (6pm to 10pm)	1.8	1.9	+0.2	4.2	4.6	+0.4
Night (10pm to 7am)	5.0	4.9	-0.1	5.8	4.6	-1.2
Overall	**5.6**	**5.6**	**0.0**	**4.8**	**4.3**	**-0.5**

The tables show that the standard deviation and inter-quartile range of the measurement data did not change significantly between the measurements performed before the signalisation and after the signalisation. This indicates that the general variability of the noise levels at the intersection has not changed as a result of the signalisation.

As there are no apparent changes in the variability of the measured short traffic noise levels due to the signalisation, it is considered unlikely that changes in the variability of the traffic noise level would be a factor of any significant influence with respect to any changes in annoyance that may or may not have been perceived at the noise sensitive locations in the vicinity of the intersection.

5.3 One-Third Octave Band Spectrum Analysis

The following chart shows a comparison of the one-third octave band spectra averaged across each entire measurement period at Location C.

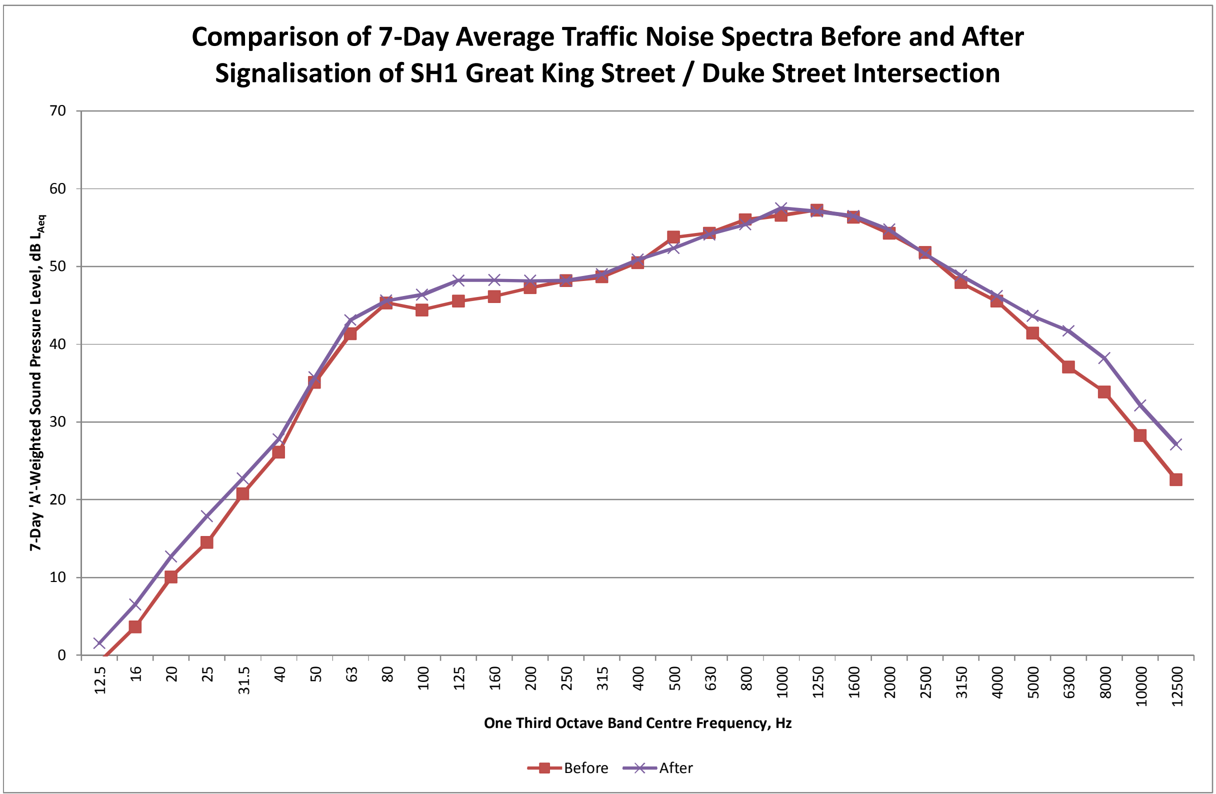

Figure 8 One-Third Octave Band Spectrum Analysis

The average spectrum determined from the measurements that were performed after signalisation of the intersection includes notably more sound energy at frequencies above 2500 Hz (up to +5 dB higher), and slightly more energy at frequencies below 250 Hz (up to +3 dB higher), than the average spectrum determined from the measurements that were performed before signalisation of the intersection.

However, the mid frequencies are relatively unchanged, with no statistically significant differences in the average noise level before and after the signalisation. As the mid frequencies dominate the overall noise level, the overall noise level is also relatively unchanged (approx +1 dB increase, as discussed earlier).

Although this indicates a possible change in the character of the noise in the vicinity of the intersection, it may or may not be significant in subjective terms. The measured differences in the average spectra may be simply a result of measurement uncertainties and variation between measurements due to differences in traffic conditions before and after, regardless of signalisation of the intersection.

In any case, the subjective impacts of changes in the character of any given noise source are difficult to assess, as different people have different perceptions of noise. Analysis of the subjective interpretation of any changes in the character of the traffic noise around the intersection would require further study, beyond the scope of this investigation.

5.4 Variation of Traffic Noise Level with Distance from Intersection Before and After Signalisation

Table 9 presents the normalised $L_{Aeq(3h)}$ noise levels that were measured at various distances along the State Highway from the intersection, between 12pm and 3pm on Wednesdays before and after the signalisation (30/6/2010 and 04/08/2010 respectively – see discussion of 'corresponding time periods' in Table 2, Section 4.6.1).

Table 9 Traffic Noise Levels at Various Distances from SH1 / Duke Street Intersection Before and After Signalisation

Distance Along SH1 from Duke Street Centreline (-ve = South, +ve = North)	Location	Normalised $L_{Aeq(3h)}$, dB			Normalised Average $L_{AFmax(15min)}$ for 3-Hour Period		
		Before	After	Change	Before	After	Change
-122	A	65.2	65.3	+0.1	78.3	82.0	+3.7
-53	B	65.2	65.3	+0.1	80.4	81.7	+1.3
-12*	G*	65.7*	65.0*	-0.7*	82.3*	86.6*	+4.3*
12	C	65.8	67.4	+1.6	78.4	86.4	+8.0
73	D	65.5	64.8	-0.7	79.1	81.0	+1.9
102	E	65.4	65.3	-0.1	76.8	79.2	+2.3

* The measurements at Location G were undertaken for a shorter duration than the 3-hour period used for the other locations. The noise levels measured at Location G are approximately +4 dB higher (for uninterrupted traffic flow) than the noise levels measured at Location C (on the opposite side of the intersection) as a result of additional tyre noise from vehicles driving over the traffic sensors that had been installed in the road adjacent to Location G as part of the signalisation (refer to Appendix F for a photograph of these sensors). These sensors had already been installed at the time of the "Before" measurements, and therefore both the "Before" and the "After" measurements have been affected by this additional noise source.

In light of this, the "Before" measurements presented above for Location G include a -4 dB adjustment, to provide equivalency to the true "Before" case, in which there would have been no traffic sensors installed in the road.

As Location A was sufficiently far from the intersection to be unaffected by the signalisation, the traffic noise levels at Location A can be considered as generally representative of the noise levels due to an uninterrupted traffic condition. Therefore, the noise levels measured at Location A before and after the signalisation have been used as a point of reference for determining the relative noise effect of the signalisation at various distances along the State Highway from the intersection.

Figure 9 shows a graph of the $L_{Aeq(3h)}$ noise levels relative to the noise levels at Location A, before and after the signalisation.

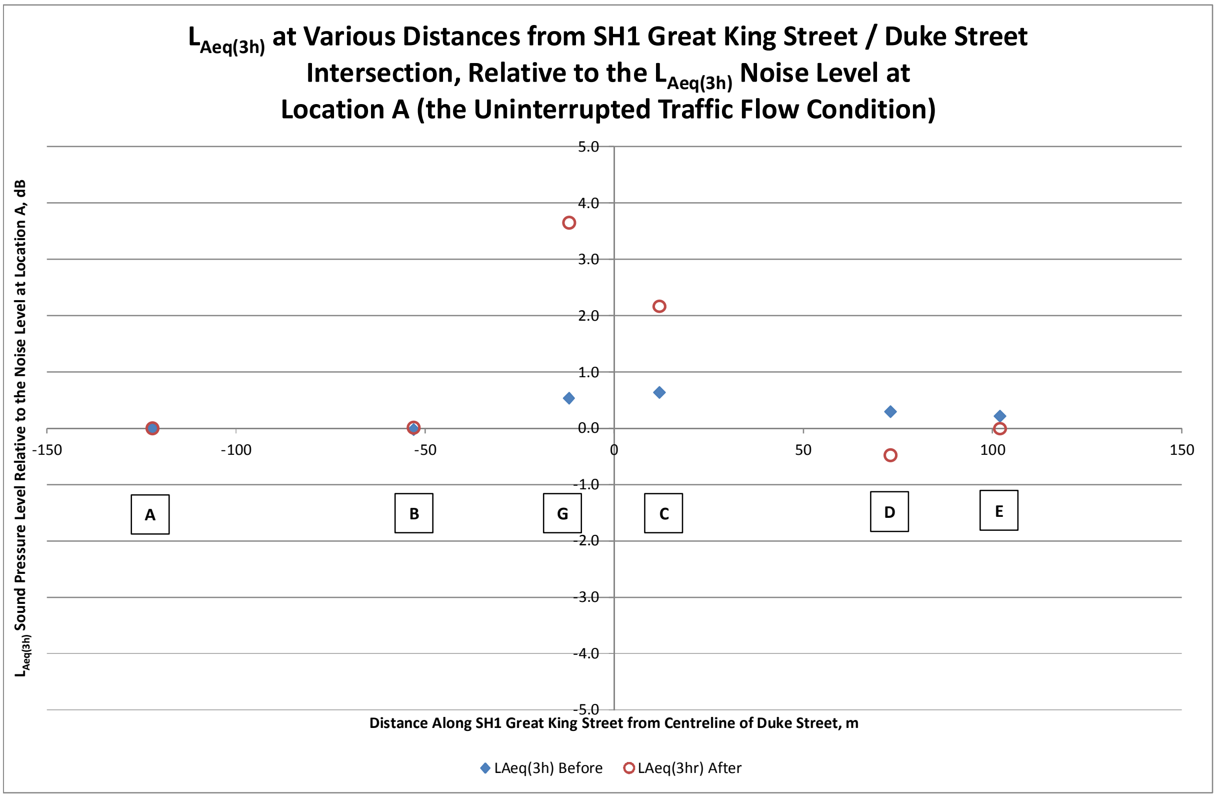

Figure 9 $L_{Aeq(3h)}$ **Noise Levels Relative to** $L_{Aeq(3h)}$ **Noise Level at Location A Before and After Signalisation**

As can be seen from the above graph, the measurements performed before the signalisation show no statistically significant variation with distance along the State Highway from the intersection except at Location G and C. At Location G and C, the noise levels are very slightly elevated relative to Location A due to a minor contribution of noise from Duke Street.

At Location G, the relative increase in noise level following signalisation is approximately +3.1 dB. This increase is primarily as a result of the traffic sensors installed in the road adjacent to that location, as previously noted. At Location C, the relative increase is approximately +1.5 dB, and most likely due to additional noise generated by vehicles accelerating away from the intersection after having stopped at a red light. This is a slightly greater increase than observed in the $L_{Aeq(24h)}$ noise levels at Location C, possibly due to the lights being triggered by vehicles on Duke Street more frequently during the daytime than at night, meaning fewer vehicles accelerating away from the intersection at night, limiting the change in the $L_{Aeq(24h)}$ noise level.

Figure 10 presents a similar graph to Figure 9, showing the average L_{AFmax} noise levels. Figure 10 shows trend in the L_{AFmax} noise levels which is similar to that discussed in relation to Figure 9 for the $L_{Aeq(3h)}$ noise levels. The relative increases at Location G and C are +4.6 dB and +4.3 dB respectively. Note that the estimated measurement uncertainty is ± 3.8 dB with a confidence level of 95%.

Figure 10 **Average L_{AFmax} Noise Levels Relative to Average L_{AFmax} Noise Level at Location A Before and After Signalisation**

The above results are broadly consistent with the magnitude of the noise level increases determined from the longer term noise level measurements performed at Location C.

Overall, these results indicate that the noise effects of the signalisation are fairly localised, to within approximately 50m of the intersection.

6.0 Investigation of Potential Prediction Methods

The following sections present the methodology and findings of investigations into three potential methods that could be used to predict the change in noise levels due to signalisation of an intersection. The predictions presented in this section were performed following completion of the noise measurements at the Duke Street and Dundas Street intersection, to enable comparison of the predictions given by each method with the measured noise levels before and after signalisation.

6.1 Method 1: Prediction by Comparison

For this prediction method, noise levels were measured at the similar, but already signalised, SH1 / Dundas Street intersection, and were then normalised as per the methodology presented in Section 4.6.

Location I was then used as a reference location (as it was considered that it would approximate the noise level of an uninterrupted traffic flow), and the difference between the noise level at Location I and each of the other locations in the vicinity of the SH1 / Dundas Street intersection (J, K, L, M, O) was calculated.

The predicted noise levels for the equivalent locations at SH1 / Duke Street intersection after signalisation were then calculated by adding the above differences to the normalised noise level measured at Location A before the signalisation.

For the purpose of the investigation presented here, $L_{Aeq(3h)}$ and average L_{AFmax} noise levels have been used, but $L_{Aeq(24h)}$ noise levels could also be used in practice if additional measurement data were to be collected.

Table 10 and Table 11 present a summary of the prediction process:

Table 10 Prediction of $L_{Aeq(3h)}$ Signalised Noise Levels at SH1 / Duke Street Intersection Using "Prediction by Comparison" Method

SH1 / Dundas Street Intersection Measurement Location*	Equivalent Location at SH1 / Duke Street Intersection*	Normalised $L_{Aeq(3h)}$ Traffic Noise Level Measured at SH1 / Dundas Street Intersection, dB	Difference between Noise Level at SH1 / Dundas Street Intersection Measurement Location and Location I, dB	Normalised $L_{Aeq(3h)}$ Traffic Noise Level at Location A Before Signalisation, dB	Predicted $L_{Aeq(3h)}$ Traffic Noise Level at Duke Street After Signalisation, dB
I (-107m)	A (-122m)	65.3	0.0	65.2	65.2
J (-60m)	B (-53m)	65.0	-0.3		64.9
K (-12m)	G (-12m)	66.3	+1.0		66.2
O (12m)	C (12m)	67.3	+2.0		67.2
L (62m)	D (73m)	66.4	+1.1		66.4
M (110m)	E (102m)	65.8	+0.5		65.8

Table 11 Prediction of L_{AFmax} Signalised Noise Levels at SH1 / Duke Street Intersection Using "Prediction by Comparison" Method

SH1 / Dundas Street Intersection Measurement Location*	Equivalent Location at SH1 / Duke Street Intersection*	Normalised L_{AFmax} Traffic Noise Level Measured at SH1 / Dundas Street Intersection, dB	Difference between Noise Level at SH1 / Dundas Street Intersection Measurement Location and Location I, dB	Normalised L_{AFmax} Traffic Noise Level at Location A Before Signalisation, dB	Predicted L_{AFmax} Traffic Noise Level at Duke Street After Signalisation, dB
I (-107m)	A (-122m)	82.1	0.0	78.3	78.3
J (-60m)	B (-53m)	82.2	0.1		78.4
K (-12m)	G (-12m)	81.5	-0.7		77.6
O (12m)	C (12m)	85.7	2.0		80.3
L (62m)	D (73m)	82.4	1.1		79.4
M (110m)	E (102m)	80.7	0.5		78.8

* The numbers shown in brackets are the distances of the measurement positions along the State Highway from the centreline of the intersecting road. Negative numbers indicate a distance in the direction south of the intersection; positive numbers indicate a distance in the direction north of the intersection.

Table 12 and Table 13 present the $L_{Aeq(3h)}$ and average L_{AFmax} noise levels measured in the vicinity of the SH1 / Duke Street intersection after installation of the traffic signals, compared with the $L_{Aeq(3h)}$ noise levels predicted for the signalised SH1 / Duke Street intersection based on the noise levels measured at the already signalised SH1 / Dundas Street intersection.

Table 12 Comparison of Predicted and Measured $L_{Aeq(3h)}$ Noise Levels

Assessment Location at SH1 / Duke Street Intersection	Predicted $L_{Aeq(3h)}$ Noise Level for Signalised Intersection, dB	Measured $L_{Aeq(3h)}$ Noise Level with Signalised Intersection, dB	Difference between Measured and Predicted Noise Level, dB
A	65.2	65.3	+0.1
B	64.9	65.3	+0.4
G	66.2	69.0	+2.8
C	67.2	67.4	+0.2
D	66.4	64.8	-1.6
E	65.8	65.3	-0.5

Table 13 Comparison of Predicted and Measured L_{AFmax} Noise Levels

Assessment Location at SH1 / Duke Street Intersection	Predicted L_{AFmax} Noise Level for Signalised Intersection, dB	Measured L_{AFmax} Noise Level with Signalised Intersection, dB	Difference between Measured and Predicted Noise Level, dB
A	78.3	82.0	+3.7
B	78.4	81.7	+3.3
G	77.6	86.6	+9.0
C	80.3	85.4	+5.1
D	79.4	81.0	+1.6
E	78.8	79.2	+0.4

As can be seen from the tables above, the predicted L_{Aeq} noise levels for locations A, B, C, and E are in good agreement with the measured noise levels, noting the estimated uncertainties in the measured noise levels (see Appendix G).

The predicted L_{AFmax} noise levels agree comparatively poorly with the measured L_{AFmax} noise levels, under-predicting at all locations. This is partially due to the measured L_{AFmax} noise level at Location A, which was used as the reference / control point for the predictions, increasing from before signalisation to after signalisation. Either this point was also affected by the signalisation, or the difference is due to natural variability in L_{AFmax} noise levels from period to period..

In the case of both the L_{Aeq} and L_{AFmax} predictions, the noise levels predicted for Location G are considerably less than the noise level measured, and in the case of the L_{Aeq}, the noise level predicted for Location D is 1.6 dB higher than measured.

The discrepancy with Location G is almost certainly attributable to the additional tyre noise generated by vehicles driving over the traffic sensors in the road at the SH1 / Duke Street intersection. Although traffic sensors were also present in the equivalent location at the SH1 / Dundas Street intersection, the joints around the traffic sensors appeared to be smoother than at the SH1 / Duke Street intersection, and generated less additional tyre noise. This difference is possibly a factor related to quality of installation, or may simply by due to the joints around the sensors at the SH1 / Dundas Street intersection having bedded in over time. Other possible contributing factors could have included more screening due to parked cars at the Dundas Street position, and more reflection of sound from the build façade behind at the Duke Street position. Nevertheless, the traffic sensors are a potential source of error that should be considered for future predictions.

It is considered that the discrepancy at Location D probably arises due to a combination of factors:

1) Location L at the SH1 / Dundas Street intersection is approximately 11m closer to the intersection than Location D at the SH1 / Duke Street intersection. This places Location D further than Location L from the zone where vehicles on SH1 would be accelerating away from the intersection, reducing the exposure of Location D to noise from accelerating vehicles.

2) To the north of the SH1 / Duke Street intersection, most vehicles that have had to accelerate away from a red light begin to reduce their level of acceleration at a point around Location D in preparation for negotiating the next junction to the north. In comparison, many of the heavy vehicles that have had to accelerate away from a red light on SH1 at the SH1 / Dundas Street intersection are still accelerating at Location L.

3) As Dundas Street is slightly busier than Duke Street, there is more traffic flow on SH1 Great King Street to the north of the SH1 / Dundas Street intersection during red light periods on SH1 Great King Street, due to more traffic turning from Dundas Street onto SH1 than is the case with traffic turning from Duke Street onto SH1. The means that the noise levels to the north of the SH1 / Duke Street intersection tend to be comparatively lower during red light periods on SH1, than is the case to the north of the SH1 / Dundas Street intersection.

Despite the above discrepancies, it is overall considered that this method of prediction would be an acceptable approach to estimating the likely changes in L_{Aeq} noise levels due to signalising an intersection; however, care needs to be taken in ensuring that the intersections are entirely similar, and careful consideration needs to be given to the possible effects of any differences. In practice, a similar intersection may not always exist, which would eliminate the possibility of using this approach. The use of this method for L_{AFmax} predictions does not appear to be particularly reliable and is not recommended.

The cost of performing the measurements required to use this method of prediction may be another deterrent for its use in practice, as predictions using a desktop prediction model are likely to cost less. For this method of prediction to be cost effective in practice, consideration may need to be given to whether the noise from the intersections could be characterised with fewer measurement locations than used here.

6.2 Method 2: Application of the Traffic Signal Adjustments Recommended by RLS90

The German RLS90 "*Guidelines for Noise Protection at Roads*" recommends that the adjustments presented in Table 14 be applied to its predicted noise levels to account for the noise arising from signalised intersections. It is however unknown whether these adjustments are intended to reflect actual increases in noise level due to the traffic signals, or if the adjustments are to account for altered human perception of the sound i.e. increased annoyance due to a change in the character of the sound at the intersection. As the adjustments are intended to be applied to the L_{Aeq} noise levels, predictions of the L_{AFmax} noise levels are not able to be undertaken using this method.

Table 14 Adjustments Applied to Predicted Noise Levels to Account for Noise Effects due to Traffic Signals under RLS90

Distance from Intersection	Adjustment Applied
0 m to 40 m	+3 dB
40 m to 70 m	+2 dB
70 m to 100 m	+1 dB
Over 100 m	0 dB

Predictions of the noise levels that would occur in the vicinity of the SH1 / Duke Street Intersection after signalisation were performed by applying the above adjustments to the noise levels measured at the intersection prior to it having traffic signals installed. The following table presents a summary of the predictions and compares the predicted noise levels with the actual noise levels measured after the signalisation:

Table 15 Predicted Noise Levels using RLS90 Adjustment and Measured Noise Levels after Signalisation

Location*	Measured $L_{Aeq(3h)}$ Noise Level Before Signalisation, dB	Adjustment Applied in Accordance with RLS90, dB	Predicted $L_{Aeq(3h)}$ Noise Level with Traffic Signals Installed, dB	Measured $L_{Aeq(3h)}$ Noise Level with Traffic Signals Installed, dB	Difference between Measured Noise Level with Traffic Signals and Predicted, dB
A (-121m)	65.2	0	65.2	65.3	+0.1
B (-53m)	65.2	+2	67.2	65.3	-1.9
G (-12m)	65.7**	+3	68.7	69.0	+0.3
C (12m)	64.8	+3	67.8	67.4	-1.4
D (73m)	65.5	+1	66.5	64.8	-1.7
E (102m)	65.4	0	65.4	65.3	-0.1

* The numbers shown in brackets are the distances of the measurement positions along the State Highway from the centreline of the intersecting road. Negative numbers indicate a distance in the direction south of the intersection; positive numbers indicate a distance in the direction north of the intersection.

** Measured noise level adjusted as noted in Section 5.4.

As would be expected, predicted noise levels at the locations further than 100m from the intersection are in good agreement with the measured noise levels. However, at the locations where adjustments were applied in accordance with RLS90 the noise levels are over-predicted by 1 to 2 dB, except at Location G, where there was a significant increase in noise due to the traffic sensors that had been installed in the road.

The discrepancies on the south side of the intersection may be due to the fact that SH1 Great King Street North is one-way, and therefore not subject to significant numbers of vehicles accelerating south of the intersection, whereas the corrections are most likely to be intended for the general case of two-way traffic, where there would be traffic accelerating away from the intersection in both directions.

Additionally, all of the discrepancies may have been smaller had the intersection been a junction of two major roads, rather than the junction of one major road and one minor road.

As mentioned earlier, it is also possible that the adjustments of the RLS-90 guidelines, are designed to account for the change in character of the traffic flow and typical increase in noise annoyance associated with signalised intersections compared with freely flowing traffic rather than an actual difference in noise level. This could also explain the over-prediction observed.

6.3 Method 3: Prediction using the FHWA TNM Methodology

The FHWA TNM is a traffic noise modelling methodology widely used in the U.S.A. Like the CRTN methodology commonly used in New Zealand, it considers a range of parameters including road geometry and gradient, terrain, traffic volume and composition, traffic speed, road surface type, screening and barrier effects, and receptor distances.

The FHWA TNM calculation methodology attempts to take account of intersection and traffic signal effects through the way that it models traffic flows where a traffic signal is entered into the model.

For locations where a traffic signal is input into the model, the TNM uses a predetermined deceleration / acceleration profile to modify the modelled speed of traffic approaching and departing the intersection. The acceleration / deceleration profile is speed dependent, and based on research conducted by the FHWA.

In the model, the acceleration / deceleration profile used is determined based on the normal cruising speed of the traffic flow and the constrained speed of the traffic flow. (Note: For traffic lights the constrained speed of the traffic flow is 0 km/h, since traffic would stop completely at a red light. For an intersection such as a roundabout where traffic does not necessary have to stop, the constrained traffic flow might not be zero).

In addition to the speed adjustment, the TNM applies a higher emission level to vehicles accelerating above a certain rate, as calculated from the predetermined deceleration / acceleration profile.

Additionally, the TNM accounts for the percentage of the traffic flow actually affected by the traffic signals, since a reasonable proportion of the traffic may cruise through the intersection without having to slow or stop for a red light.

For the purpose of this investigation, the FHWA TNM calculation methodology was implemented using the “TNM Version 2.5” software developed by the FHWA. This is the current version of the software at the time of writing.

A model of the un-signalised SH1 / Duke Street intersection was generated, and then calibrated (by adding a calibration adjustment to the noise levels predicted by the model) so that the noise levels that were measured in the vicinity of the intersection before the traffic signals were installed matched the noise levels predicted by the model for the un-signalised intersection . The calibrated model of the un-signalised situation was then modified to include the traffic signals at the SH1 / Duke Street intersection and re-run to calculate the predicted noise levels with the traffic signals installed.

After some initial modelling, it was found that the model was significantly over-calculating the noise contribution from Duke Street. This is a common issue with many noise modelling methodologies where roads with low traffic volumes and low average speeds are involved (the average speed measured on Duke Street was only 26 km/h). As it was known from the noise measurements that Duke Street contributed very little to the noise levels in practice, Duke Street was removed from the model for the final modelling runs. This provided a much closer representation of the noise levels measured adjacent to SH1 Great King Street.

In practice, if baseline noise measurements were not available for an intersection that was being modelled, caution would need to be applied when modelling the noise levels using the TNM model if either of the intersecting roads have low traffic volumes or low average speed.

The parameters presented in Table 16 were used in the final model:

Table 16 Parameters Used in FHWA TNM Model of SH1 / Duke Street Intersection

Parameter	Modelled Value
	SH1 Great King Street North
Traffic Volume (Hourly) Note 1	663
Percentage Medium Vehicles Note 2	3%
Percentage Heavy Vehicles Note 3	4%
Percentage Buses Note 4	-
Percentage Motorcycles Note 4	-
Road Surface Note 5	TNM Default
Traffic Cruising Speed Note 6	45 km/h
Traffic Constrained Speed	0
Percentage of Vehicles Affected by the Traffic Signals Note 7	8%
Calculated Calibration Adjustment Note 8	+2.7 dB
Other	All predictions were performed for free-field positions, 9m from edge of traffic lane, as per the parameters used in the normalisation of the traffic noise measurements.

Note 1: This is the average hourly traffic volume measured during the period in which the $L_{Aeq(3h)}$ traffic noise measurements were performed before the signalisation.

Note 2: Determined from vehicle classification data gathered as part of the traffic monitoring. Under the TNM, medium vehicles are classed as vehicles with two axles and a mass between 4,500kg and 12,000kg. For the modelling this has been related to TNZ 1999 Class 3.

Note 3: Determined from vehicle classification data gathered as part of the traffic monitoring. Under the TNM, heavy vehicles are classed as vehicles with three or more axles and a mass generally over 12,000kg. For the modelling this has been related to TNZ 1999 Classes 4 to 13.

Note 4: The FHWA TNM includes separate equations for buses and motorcycles. However, the TNZ 1999 vehicle classification system (as used for the traffic counting performed for this investigation) groups motorcycles into Class 1 along with cars, and buses generally into Class 3 and 4. Therefore, no specific data is available with respect to the percentage of the traffic volume comprised by these types of vehicles. However, as the volumes of these types of vehicles are expected to be relatively low, the grouping of these vehicles into the other classifications is not expected to have any significant effect on the outcome of the modelling.

Note 5: The TNM calculation only offers four options for the road surface type but the default surface type is recommended in the TNM manual for most calculations. The default road surface is based on an "average of dense graded asphaltic concrete and Portland cement concrete".

Note 6: Based on the average traffic speed measured during the traffic count before signalisation of the intersection.

Note 7: The traffic lights at the SH1 / Duke Street intersection are biased to remain green on SH1 unless a change is triggered by waiting traffic on Duke Street. The signal sequence at the time of the "after signal installation" noise measurements allowed a 5 second green period for Duke Street each time a light change was triggered by vehicles waiting on Duke Street. The light change typically occurred around 1 minute after the traffic sensor registered waiting traffic. Based on the traffic monitoring data from Duke Street for the time of day during which the noise measurements were performed it is likely that a light change would have been triggered approximately every minute. Therefore, for every 60 seconds of free flowing traffic on SH1, there would be approximately 5 seconds worth of traffic affected by the lights. Assuming approximately even time distribution of traffic on SH1 during the period under consideration, the percentage of vehicles affected is then 5/60 * 100 = 8%.

Note 8: The calibration adjustment was calculated as the average difference between the noise levels measured before the signalisation, and the noise levels predicted by the TNM model for the 'before signalisation 'scenario.

Table 17 presents a summary of the modelling results, compared with the normalised measured noise levels.

Table 17 Comparison of Measured and Predicted Noise Levels using the Calibrated FHWA TNM Model

Location*	Normalised $L_{Aeq(3h)}$ Noise Levels Before Signalisation, dB			Normalised $L_{Aeq(3h)}$ Noise Levels After Signalisation, dB		
	Calculated Using Calibrated TNM	Measured	Difference	Predicted Using Calibrated TNM	Measured	Difference
A (-121m)	65.6	65.2	-0.4	65.0	65.3	+0.3
B (-53m)	65.6	65.2	-0.4	65.8	65.3	-0.5
G (-12m)	65.6	65.7	+0.1	66.7	69.0	+2.3
C (12m)	65.6	65.8	+0.2	67.0	67.4	+0.4
D (73m)	65.3	65.5	+0.2	65.9	64.8	-1.1
E (102m)	65.1	65.4	+0.3	65.0	65.3	+0.3

As can be seen from the above table, the TNM model of the intersection before signalisation was calibrated to within ± 0.5 dB of the measured values. Noting the tolerance of the calibrated model of the intersection before the signalisation, the noise levels predicted for the case with the traffic signals installed agree reasonably well with the noise levels measured with the traffic signals installed, except at Location G and Location D.

The model under-predicted the measured noise level at Location G by 2.3 dB. As discussed in previous sections, Location G registered a significant increase in noise level when the traffic signals were installed as a result of additional noise from the new traffic sensors on SH1 Great King Street to the south of the intersection. The TNM model clearly does not account for this, which seems reasonable given that the additional noise appears to be particular to this installation since the same level of noise was not measured due to the traffic sensors at the Dundas Street intersection.

For Location D, the model over-predicted the measured noise level by 1.1 dB. It is considered most likely that this would be due mainly to differences between the acceleration-distance profile assumed by the TNM model for vehicles accelerating away from a red light, and the actual profile.

As previously noted, vehicles that have had to accelerate away from a red light at Duke Street begin to reduce their level of acceleration at a point around Location D (in preparation for negotiating the next junction to the north). Under the acceleration-distance profile used in TNM, vehicles are modelled as continuing to accelerate until a point further along the road than Location D.

For an intersection where the above issues with Location D and G do not exist, it is possible that TNM could be used to provide a reasonable prediction of the noise level changes resulting from signalisation.

7.0 Conclusion

A comprehensive set of noise measurements has been performed in the vicinity of the SH1 Great King Street North / Duke Street intersection north of Dunedin, before and after traffic signals were installed at the intersection. This was undertaken with a view to evaluating the change in noise levels, and providing data for possible NZTA future policy development work on noise effects associated with traffic signals.

Comparison of the noise levels measured before and after the signalisation shows that the overall $L_{Aeq(24h)}$ noise level increased by approximately +1 dB on average and the average L_{AFmax} noise levels increased by +5 dB(A). The measurement uncertainty has been estimated to be ± 3.8 dB(A) with a confidence level of 95%. This suggests that the change in L_{AFmax} noise level is statistically significant, but the change in $L_{Aeq(24h)}$ noise level may not be i.e. the difference in measured $L_{Aeq(24h)}$ noise level may be due largely to measurement uncertainties.

The change in $L_{Aeq(24h)}$ noise level is a relatively small change that would not trigger a requirement to consider noise mitigation under NZS 6806:2010, if it was applicable. (Note that the signalisation is not classified as an altered road in accordance with NZS 6806:2010 since there is no change in alignment; therefore the criteria prescribed by NZS 6806:2010 are used as a benchmark only). The change in L_{AFmax} noise level is likely to be noticeable, and could potentially affect noise amenity at noise sensitive locations in the vicinity of the intersection.

The change observed in $L_{Aeq(24h)}$ noise level is somewhat less than the differences typically reported in the literature for similar studies. This discrepancy could possibly be a result of the SH1 / Duke Street intersection being the junction of one major road and one minor road, rather than two major roads, and may also be contributed to by the fact that SH1 Great King Street carries only one-way traffic.

Although the overall change in $L_{Aeq(24h)}$ noise level at the SH1 / Duke Street intersection was relatively minor, a larger increase in noise was measured near to the traffic sensors that were installed on SH1 Great King Street North as part of the signalisation.

Noise measurements performed near to the traffic sensors at the similar SH1 / Dundas Street intersection did not reflect the elevated levels of noise measured near to the sensors at SH1 / Duke Street. This suggests that the elevated noise levels measured near to the traffic sensors at the SH1 / Duke Street intersection are related to the particular installation at SH1 / Duke Street. Variations in installation method or quality of installation may have a significant bearing on the noise levels generated by traffic sensors. The potential impacts of variability in these factors should therefore be considered when assessing the noise effects of intersection signalisation where traffic sensors are to be installed near to noise sensitive locations.

Overall, the noise level changes of the signalisation were found to be limited to within about 50m of the intersection. For intersections in higher speed zones, greater traffic volumes on the cross streets, and without the other nearby junctions that exist in the case of SH1 / Duke Street, it is possible that the noise effect may extend further from the intersection.

Three potential methods of predicting the traffic noise at signalised intersections were briefly investigated using the noise levels measured at the SH1 / Duke Street intersection as a basis.

The first method was based on comparison to a similar existing signalised intersection, with noise levels measured at different distances form the intersection. This method appeared produce reasonably reliable L_{Aeq} predictions, but required extensive field measurements to characterise the subject intersection and the comparison intersection, and as such may be costly to implement in practice.

The second method was to apply the RLS90 traffic signal corrections to the noise levels from the existing intersection (pre-signals). This was found to over-predict the measured noise levels by 1 to 2 dB(A) in general.

The FHWA TNM calculation methodology was the third method investigated. It differs from the CRTN traffic noise modelling methodology adopted by the NZTA in that it incorporates specific procedures to account for the effects of traffic signals. This method appears promising as a method for predicting the noise level changes due to intersection signalisations; however, the based on the investigations performed here, the TNM methodology needs to be applied with caution where low traffic volumes or low average traffic speeds are present on one or more of the roads at the intersection.

8.0 References

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Appendix A

Acoustic Nomenclature

Appendix A Acoustic Nomenclature

Acum	The unit of measurement for acoustic Sharpness. 1 acum is the sharpness of a 60 dB narrow-band noise, one critical band wide with a centre frequency of 1 kHz.
Asper	The unit of measurement for acoustic Roughness. 1 asper is the roughness of a 60 dB, 1 kHz signal with 100% modulation at 70 Hz.
Critical Band	In human hearing, a tone at a given frequency can be masked by sound at other frequencies within a narrow bandwidth of the tone frequency. This bandwidth is called the Critical Bandwidth. Critical Bandwidth varies with frequency but is usually between 1/6- and 1/3-octave. For analytical convenience the frequency range from 20 Hz to 16 kHz is divided into 24 defined Critical Bands. The Critical bands are approximated by 1/3-octave bands above 500 Hz and by 100 Hz wide bands at lower frequencies.
dB	Decibels or 'A'-weighted Decibels, the units of Sound Pressure Level and Sound Power Level. 'A'-weighting adjusts the levels of frequencies within the sound spectrum to better reflect the sensitivity of the human ear to different frequencies. [Unit: dB]
$L_{Aeq,T}$	The Equivalent Continuous A-Weighted Sound Pressure Level measured over the period T. The Equivalent Continuous A-Weighted Sound Press Level is the constant value of A-Weighted Sound Pressure Level for a given period that would be equivalent in sound energy to the time-varying A-Weighted Sound Pressure Level measured over the same period. [Unit: dB]
$L_{AFmax,T}$	The maximum value of A-Weighted Sound Pressure Level measured using an 'F' time weighting during the period T. [Unit: dB]
Loudness	The attribute of auditory sensation which describes a listener's ranking of sound in terms of audibility. Usually quantified in terms of Loudness Level.
Loudness Level	A logarithmic measure of Loudness. [Unit: Phon]
Phon	The unit of Loudness Level. The Loudness Level of a sound or noise is expressed as *n* Phons when it is judged by binaural listeners, having standard auditory response, to be equal in loudness to a pure tone of frequency 1000 Hz, having the form of a plane progressive wave, coming from directly in front of the listener, at a Sound Pressure Level of *n* dB.
Roughness (Psycho-acoustics)	A measure of the modulation amplitude and frequency modulation of a sound where the modulation is in the range from 15 to 300 Hz. Maximum roughness occurs around 70 Hz. [Unit: Asper]
Sharpness (Psycho-acoustics)	A comparative measure of the high-frequency content in a signal. For example, white noise has more high-frequency level than pink noise and a higher sharpness value, making it more unpleasant to listen to. [Unit: Acum]
Sound Power Level	A measure of the total sound energy radiated by a source, per unit time. Mathematically, it is ten times the logarithm to the base ten of the ratio of the sound power (W) of the source to the reference sound power; where the reference sound power is $1x10^{-12}$ W. [Unit: dB]

Sound Pressure Level	A measure of the magnitude of a sound wave. Mathematically, it is twenty times the logarithm to the base ten of the ratio of the root mean square sound pressure at a point in a sound field, to the reference sound pressure; where sound pressure is defined as the alternating component of the pressure (Pa) at the point, and the reference sound pressure is $2x10^{-5}$ Pa. [Unit: dB]
Spectral Characteristics	Characteristics relating to the frequency content of a sound.
Temporal Characteristics	Characteristics relating to how the level and frequency content of the sound varies over time.

Appendix B

Details of Noise Measurement Locations

<table>
<tr><th>Measurement Location Reference</th><th colspan="2">Details:</th></tr>
<tr><td rowspan="8">A

(Adjacent to SH1 Great King Street, south of Duke Street Intersection)</td><td>Distance along SH1 Great King Street from Centreline of Duke Street:</td><td>121 m south</td></tr>
<tr><td>Distance from Edge of Nearest Traffic Lane:</td><td>6.4 m</td></tr>
<tr><td>Measurement Position Type:</td><td>Façade (fence behind microphone)</td></tr>
<tr><td>Measurement Period(s):</td><td>9:52am 30/6/10 to 4:53pm 30/6/10
(before signalisation)
9:18am 4/8/10 to 4:05pm 4/8/10
(after signalisation)</td></tr>
<tr><td>Instrumentation Used
(Refer to Section 4.3 for details)</td><td>Instrument 3 (before signalisation)
Instrument 4 (after signalisation)</td></tr>
<tr><td>Other Notes:</td><td>Opposite Otago University Child Care Association. During the daytime, noise from the playground is audible during lulls in the traffic.

Approximately 15m north of zebra crossing. Occasional interruptions in normal traffic flow due to pedestrians on crossing.</td></tr>
<tr><td colspan="2">Photographs of measurement location:</td></tr>
<tr><td colspan="2">
View of measurement position

Looking north along SH1 Great King Street

Looking south along SH1 Great King Street</td></tr>
</table>

Measurement Location Reference	Details:	
B (Adjacent to SH1 Great King Street, south of Duke Street Intersection)	Distance along SH1 Great King Street from Centreline of Duke Street:	53 m south
	Distance from Edge of Nearest Traffic Lane:	8 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	9:58am 30/6/10 to 4:48pm 30/6/10 (before signalisation) 9:08am 4/8/10 to 4:11pm 4/8/10 (after signalisation)
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 5
	Other Notes:	There is an automotive workshop behind the measurement location. Noise from inside the workshop occasionally dominated the noise at the measurement location, but is not considered to have significantly influenced the overall noise levels.
	Photographs of measurement location:	
	 View towards SH1 Great King Street	 Looking south along SH1 Great King Street
	 View from kerb of SH1 Great King Street	

<table>
<tr><th>Measurement Location Reference</th><th colspan="2">Details:</th></tr>
<tr><td rowspan="8">C

(Northwest corner of SH1 Great King Street / Duke Street Intersection)</td><td>Distance along SH1 Great King Street from Centreline of Duke Street:</td><td>12 m north</td></tr>
<tr><td>Distance from Edge of Nearest Traffic Lane:</td><td>10 m</td></tr>
<tr><td>Measurement Position Type:</td><td>Free-field (sound reflection from adjacent Giltech Precision sign did not appear to be significant)</td></tr>
<tr><td>Measurement Period(s):</td><td>1:03pm 30/6/10 to 10:55am 8/7/10
(before signalisation)
10:21am 4/8/10 to 9:49am 12/8/10
(after signalisation)</td></tr>
<tr><td>Instrumentation Used
(Refer to Section 4.3 for details)</td><td>Instrument 1</td></tr>
<tr><td>Other Notes:</td><td>Some periods during the afternoon of 30/6 were affected by noise from roadwork on the footpaths around the intersection.</td></tr>
<tr><td colspan="2">Photographs of measurement location:</td></tr>
<tr><td>
View towards intersection</td><td>

View of logger from corner of intersection</td></tr>
</table>

<table>
<tr><th>Measurement Location Reference</th><th colspan="2">Details:</th></tr>
<tr><td rowspan="9">D

(Adjacent to SH1 Great King Street, north of Duke Street Intersection)</td><td>Distance along SH1 Great King Street from Centreline of Duke Street:</td><td>73 m north</td></tr>
<tr><td>Distance from Edge of Nearest Traffic Lane:</td><td>7 m</td></tr>
<tr><td>Measurement Position Type:</td><td>Free-field</td></tr>
<tr><td>Measurement Period(s):</td><td>10:31am 30/6/10 to 5:06pm 30/6/10
(before signalisation)
9:41am 4/8/10 to 4:39pm 4/8/10
(after signalisation)</td></tr>
<tr><td>Instrumentation Used
(Refer to Section 4.3 for details)</td><td>Instrument 2</td></tr>
<tr><td>Other Notes:</td><td>Many vehicles stop accelerating around this position or prior to it, and begin to slow for the next junction to the north soon after.</td></tr>
<tr><td colspan="2">Photographs of measurement location:</td></tr>
<tr><td>
Logger position</td><td>
Looking south along SH1 Great King Street</td></tr>
<tr><td>
Looking north along SH1 Great King Street</td><td></td></tr>
</table>

Measurement Location Reference	Details:	
E (Adjacent to SH1 Great King Street, north of Duke Street Intersection)	Distance along SH1 Great King Street from Centreline of Duke Street:	102 m north
	Distance from Edge of Nearest Traffic Lane:	5 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	10:50am 30/6/10 to 5:01pm 30/6/10 (before signalisation) 9:50am 4/8/10 to 4:34pm 4/8/10 (after signalisation)
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 3 (before signalisation) Instrument 4 (after signalisation)
	Other Notes:	At this position some vehicles are decelerating to negotiate the next junction to the north.

Photographs of measurement location:

Logger position

Looking south along SH1 Great King Street

Looking north along SH1 Great King Street

Measurement Location Reference	Details:	
F (Duke Street, west of SH1 Great King Street)	Distance along Duke Street from Centreline of SH1 Great King Street:	63 m west
	Distance from Edge of Nearest Traffic Lane:	5 m
	Measurement Position Type:	Façade (Fence approximately 1m behind microphone)
	Measurement Period(s):	3:42pm 30/6/10 to 4:04pm 30/6/10 (before signalisation) n/a (after signalisation)
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 6
	Other Notes:	The noise levels at this position were mostly dominated by traffic noise from vehicles on SH1 Great King Street (and George Street (further to the west) to some degree).
	Photographs of measurement location:	
	 Measurement position	 Looking west along Duke Street
	 Looking east along Duke Street towards SH1 Great King Street	

Measurement Location Reference	Details:	
G (Southwest corner of SH1 Great King Street / Duke Street Intersection)	Distance along SH1 Great King Street from Centreline of Duke Street:	12 m south
	Distance from Edge of Nearest Traffic Lane:	10 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	4:06pm 30/6/10 to 4:21pm 30/6/10 (before signalisation) 10:32am 4/8/10 to 12:39pm 4/8/10 (after signalisation)
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 6
	Other Notes:	Noise from vehicle tyres travelling over traffic sensor joints in road surface appeared to elevate the noise levels at this location. Noise from trucks was less affected by the traffic sensor joints than noise from light vehicles.
	Photographs of measurement location:	
		
	Looking south along SH1 Great King Street	Looking north towards intersection

Measurement Location Reference	Details:	
H (Duke Street, east of SH1 Great King Street)	Distance along Duke Street from Centreline of SH1 Great King Street:	53 m east
	Distance from Edge of Nearest Traffic Lane:	3 m
	Measurement Position Type:	Free-field (approx 3m out from façade of building behind measurement position)
	Measurement Period(s):	4:24pm 30/6/10 to 4:39pm 30/6/10 (before signalisation) 3:51pm 4/8/10 to 4:21pm 4/8/10 (after signalisation)
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 6
	Other Notes:	The noise levels at this position were mostly dominated by traffic noise from vehicles on SH1 Great King Street (and SH1 Cumberland Street to some degree).
	Photographs of measurement location:	

Looking east along Duke Street

Looking west along Duke Street towards SH1 Great King Street

Measurement Location Reference	Details:	
I (Adjacent to SH1 Great King Street, south of Dundas Street Intersection)	Distance along SH1 Great King Street from Centreline of Dundas Street:	107 m south
	Distance from Edge of Nearest Traffic Lane:	7 m
	Measurement Position Type:	Façade
	Measurement Period(s):	10:03am 29/6/10 to 2:21pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 4
	Other Notes:	Row of parked cars between measurement position and traffic lane.
	Photographs of measurement location:	
		
	Logger position	Looking south along SH1 Great King Street

Measurement Location Reference	Details:	
	Distance along SH1 Great King Street from Centreline of Dundas Street:	60 m south
	Distance from Edge of Nearest Traffic Lane:	11 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	9:44am 29/6/10 to 3:43pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 5
	Other Notes:	None.
J (Adjacent to SH1 Great King Street, south of Dundas Street Intersection)	Photographs of measurement location:	
		
	Logger position	View towards SH1 Great King Street

Measurement Location Reference	Details:	
K (Southeast corner of SH1 Great King Street / Dundas Street Intersection)	Distance along SH1 Great King Street from Centreline of Dundas Street:	12 m south
	Distance from Edge of Nearest Traffic Lane:	6.6 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	9:55am 29/6/10 to 3:47pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 1
	Other Notes:	None.
	Photographs of measurement location:	
		
	Logger position	View towards intersection

Measurement Location Reference	Details:	
L (Adjacent to SH1 Great King Street north of Dundas Street Intersection)	Distance along SH1 Great King Street from Centreline of Dundas Street:	62 m north
	Distance from Edge of Nearest Traffic Lane:	6.4 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	10:36am 29/6/10 to 4:16pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 3
	Other Notes:	None.
	Photographs of measurement location:	

Logger position

Looking south along SH1 Great King Street

Looking north along SH1 Great King Street

Measurement Location Reference	**Details:**	
	Distance along SH1 Great King Street from Centreline of Dundas Street:	110 m north
	Distance from Edge of Nearest Traffic Lane:	6.4 m
	Measurement Position Type:	Façade
	Measurement Period(s):	10:29am 29/6/10 to 2:08pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 2
	Other Notes:	None.
M (Adjacent to SH1 Great King Street north of Dundas Street Intersection)	Photographs of measurement location:	

Looking south along SH1 Great King Street

Looking north along SH1 Great King Street

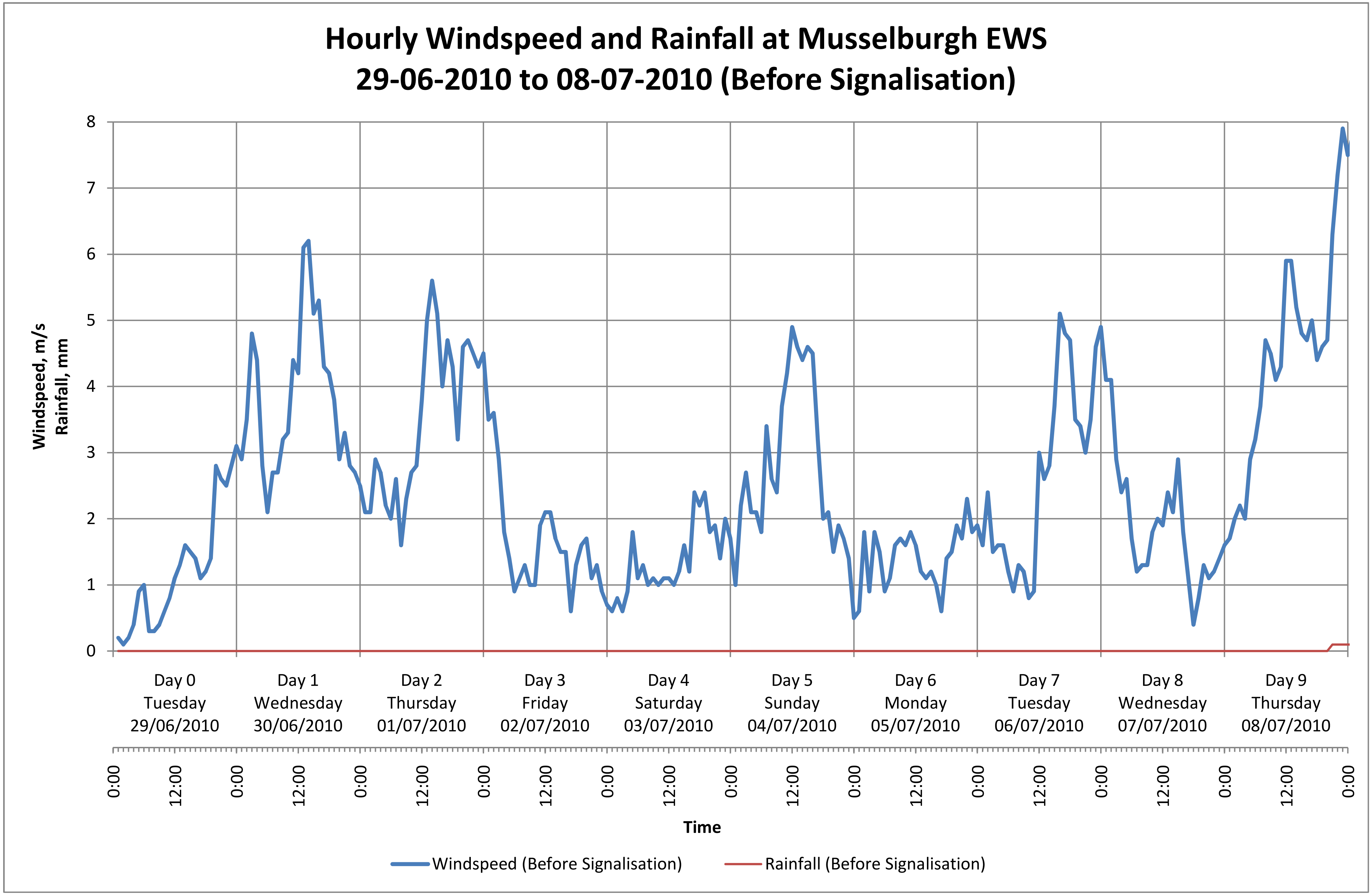
Measurement Location Reference	**Details:**	
N (Adjacent to Dundas Street, west of SH1 Great King Street)	Distance along Dundas Street from Centreline of SH1 Great King Street:	57 m west
	Distance from Edge of Nearest Traffic Lane:	6 m
	Measurement Position Type:	Façade (Fence approximately 1m behind microphone position)
	Measurement Period(s):	2:52pm 29/6/10 to 3:37pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 6
	Other Notes:	Noise levels at this locations mostly dominated by traffic noise from SH1 Great King Street.
	Photographs of measurement location:	
		
	Looking east along Dundas Street towards SH1 Great King Street	Looking west along Dundas Street

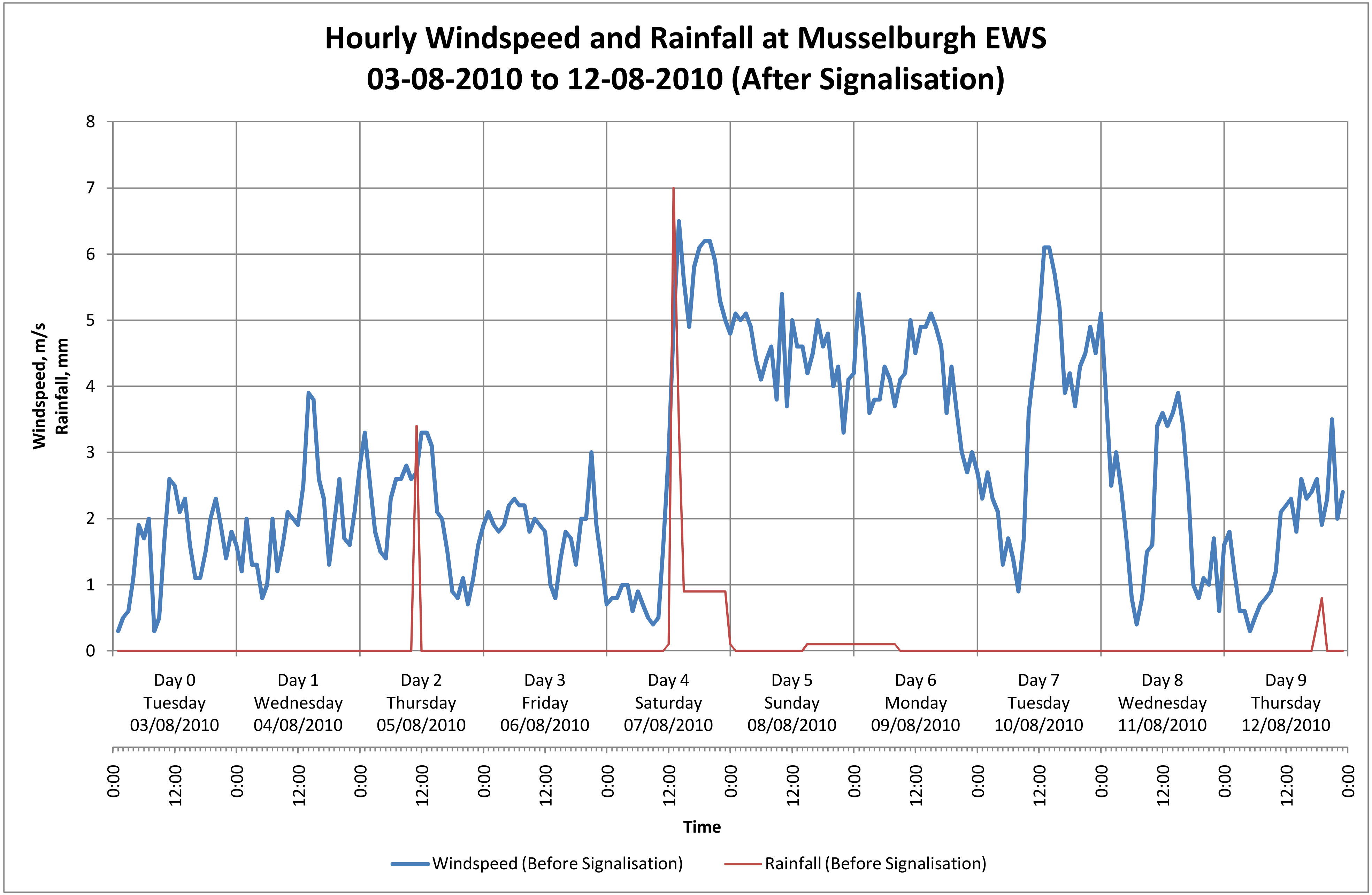
Measurement Location Reference	Details:	
	Distance along SH1 Great King Street from Centreline of Dundas Street:	12 m north
	Distance from Edge of Nearest Traffic Lane:	6.6 m
	Measurement Position Type:	Semi-façade (some noise reflection from ~1.5m high wall behind microphone position)
	Measurement Period(s):	10:47am 29/6/10 to 1:47pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 6
	Other Notes:	None.
O (Northeast corner of SH1 Great King Street / Dundas Street Intersection)	Photographs of measurement location:  Looking south along SH1 Great King Street	

Measurement Location Reference	Details:	
P (Adjacent to Dundas Street, east of SH1 Great King Street)	Distance along Dundas Street from Centreline of SH1 Great King Street:	50 m east
	Distance from Edge of Nearest Traffic Lane:	8 m
	Measurement Position Type:	Free-field
	Measurement Period(s):	2:27pm 29/6/10 to 3:58pm 29/6/10
	Instrumentation Used (Refer to Section 4.3 for details)	Instrument 4
	Other Notes:	Quiet periods at this location mostly dominated by traffic noise from SH1 Great King Street and SH1 Cumberland Street.
	Photographs of measurement location:	
		
	Measurement position	Looking west along Dundas Street towards SH1 Great King Street

Appendix C

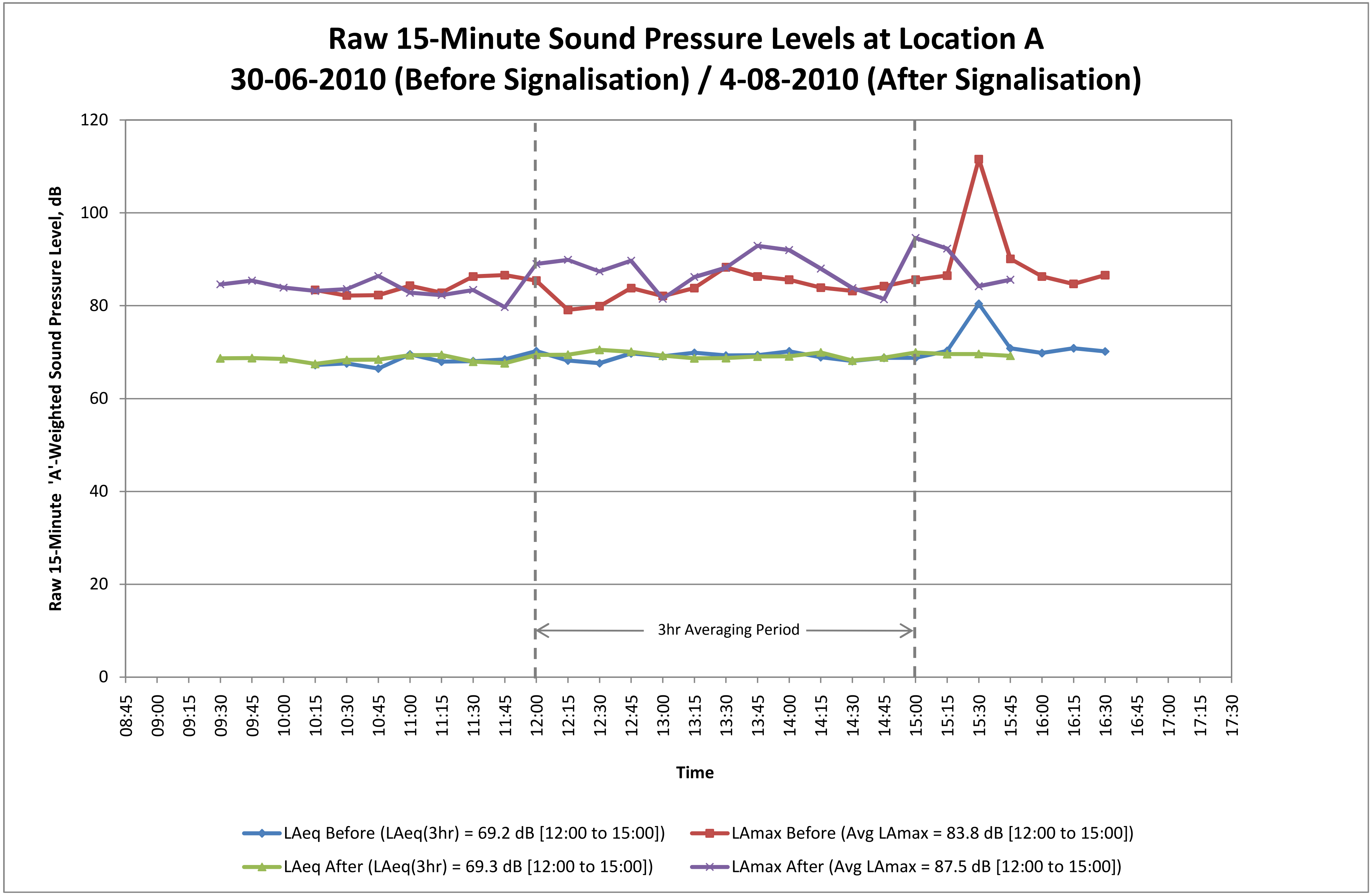
Meteorological Data


Hourly Windspeed and Rainfall at Musselburgh EWS
29-06-2010 to 08-07-2010 (Before Signalisation)
Windspeed, m/s
Rainfall, mm
0
1
2
3
4
5
6
7
8
Day 0
Tuesday
29/06/2010
Day 1
Wednesday
30/06/2010
Day 2
Thursday
01/07/2010
Day 3
Friday
02/07/2010
Day 4
Saturday
03/07/2010
Day 5
Sunday
04/07/2010
Day 6
Monday
05/07/2010
Day 7
Tuesday
06/07/2010
Day 8
Wednesday
07/07/2010
Day 9
Thursday
08/07/2010
0:00
12:00
Time
Windspeed (Before Signalisation)
Rainfall (Before Signalisation)

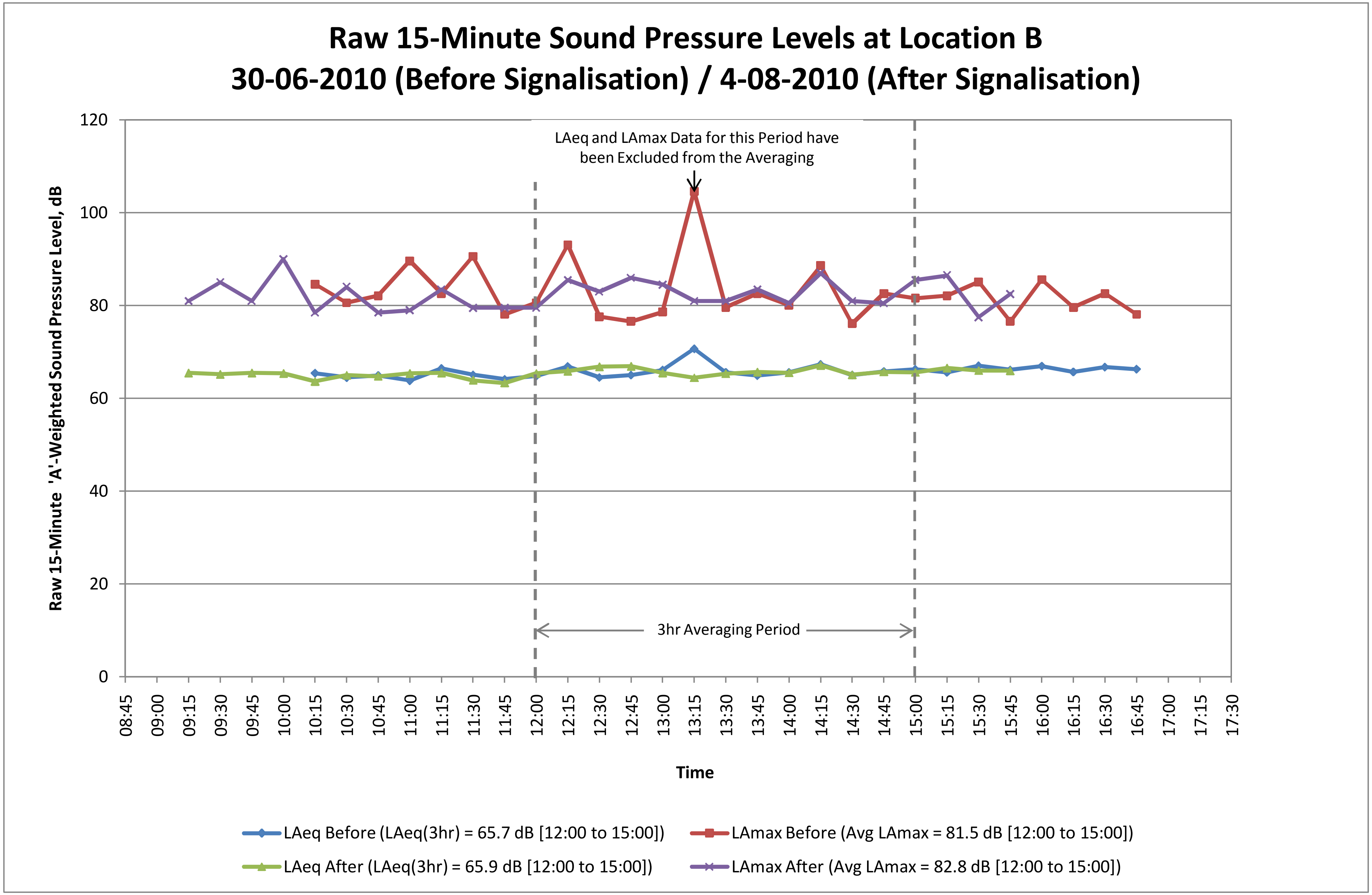

Hourly Windspeed and Rainfall at Musselburgh EWS
03-08-2010 to 12-08-2010 (After Signalisation)
Windspeed, m/s
Rainfall, mm
0
1
2
3
4
5
6
7
8
Day 0 Tuesday 03/08/2010
Day 1 Wednesday 04/08/2010
Day 2 Thursday 05/08/2010
Day 3 Friday 06/08/2010
Day 4 Saturday 07/08/2010
Day 5 Sunday 08/08/2010
Day 6 Monday 09/08/2010
Day 7 Tuesday 10/08/2010
Day 8 Wednesday 11/08/2010
Day 9 Thursday 12/08/2010
0:00
12:00
Time
Windspeed (Before Signalisation)
Rainfall (Before Signalisation)

Appendix D

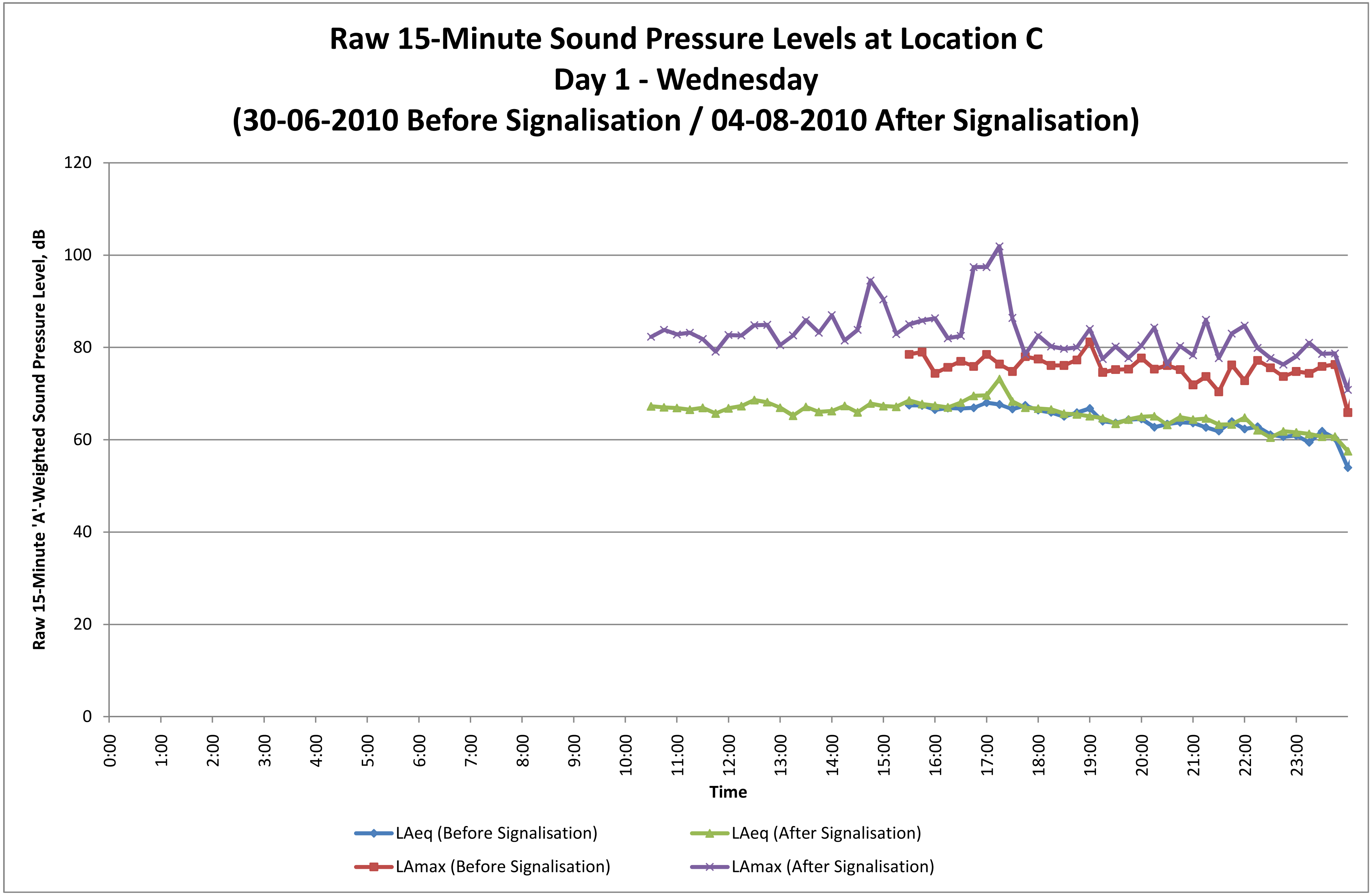
Noise Measurement Results (Raw)

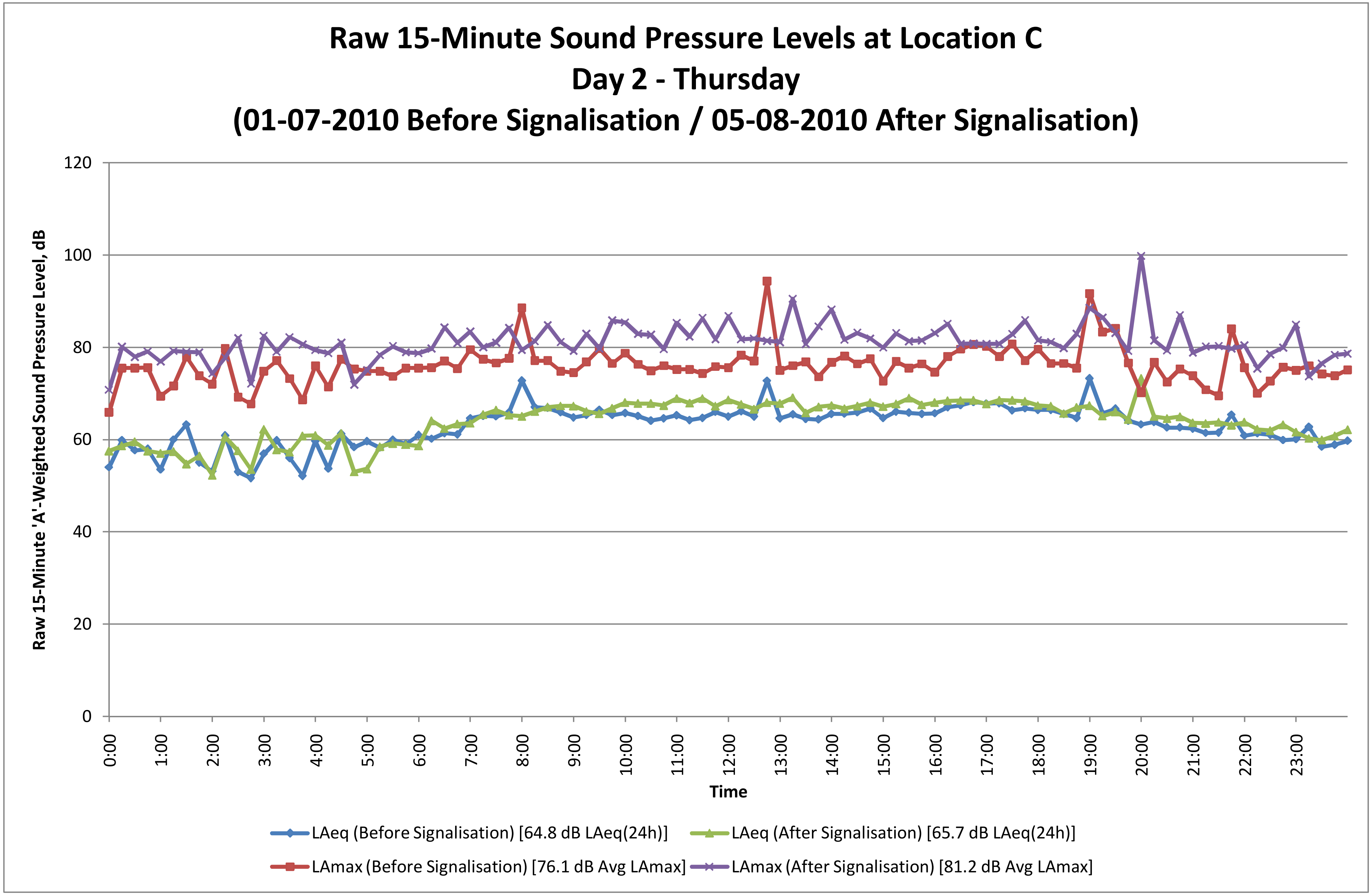


Raw 15-Minute Sound Pressure Levels at Location A
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
3hr Averaging Period
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(3hr) = 69.2 dB [12:00 to 15:00])
LAmax Before (Avg LAmax = 83.8 dB [12:00 to 15:00])
LAeq After (LAeq(3hr) = 69.3 dB [12:00 to 15:00])
LAmax After (Avg LAmax = 87.5 dB [12:00 to 15:00])

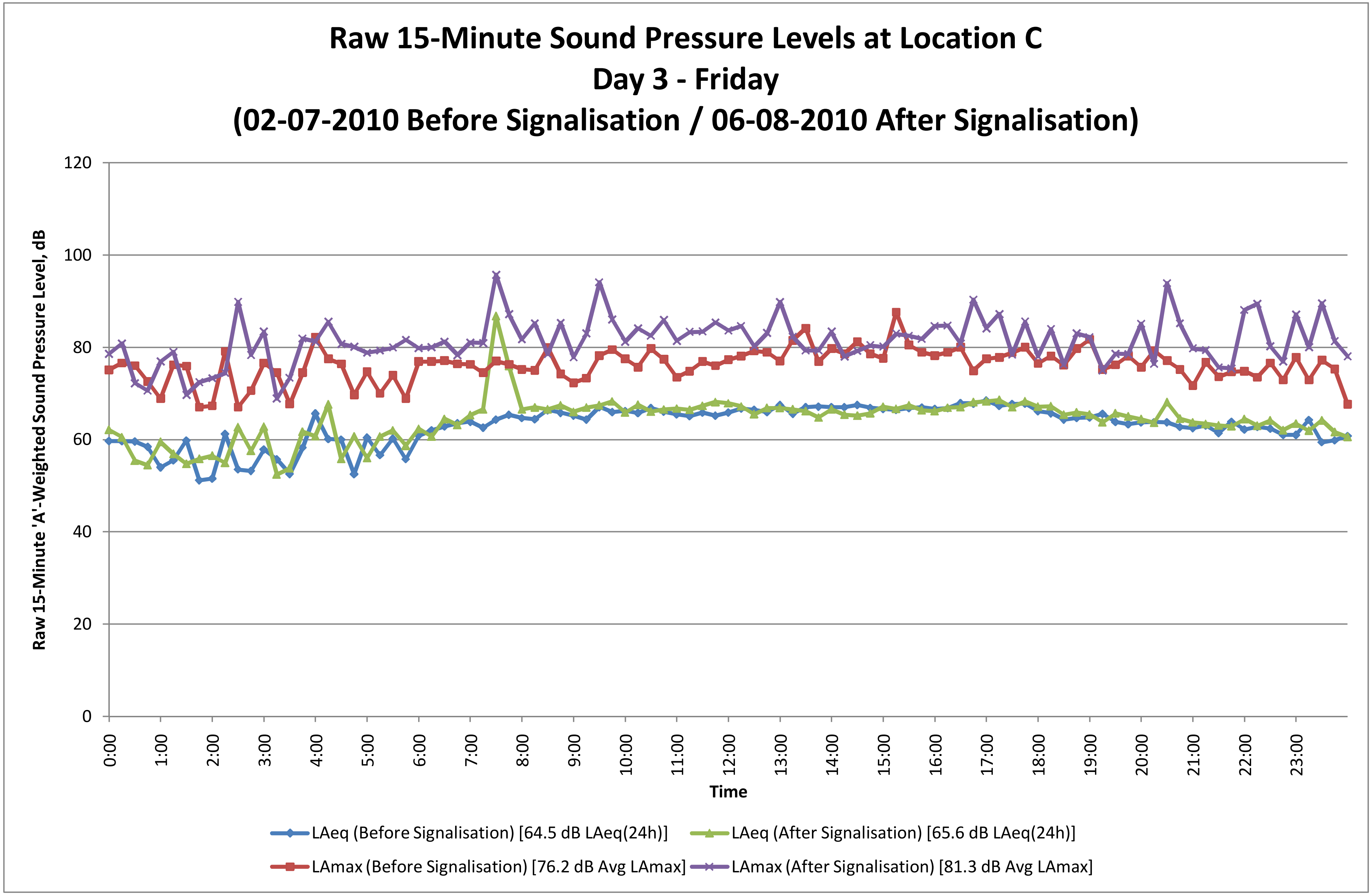


Raw 15-Minute Sound Pressure Levels at Location B
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
LAeq and LAmax Data for this Period have been Excluded from the Averaging
3hr Averaging Period
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(3hr) = 65.7 dB [12:00 to 15:00])
LAmax Before (Avg LAmax = 81.5 dB [12:00 to 15:00])
LAeq After (LAeq(3hr) = 65.9 dB [12:00 to 15:00])
LAmax After (Avg LAmax = 82.8 dB [12:00 to 15:00])

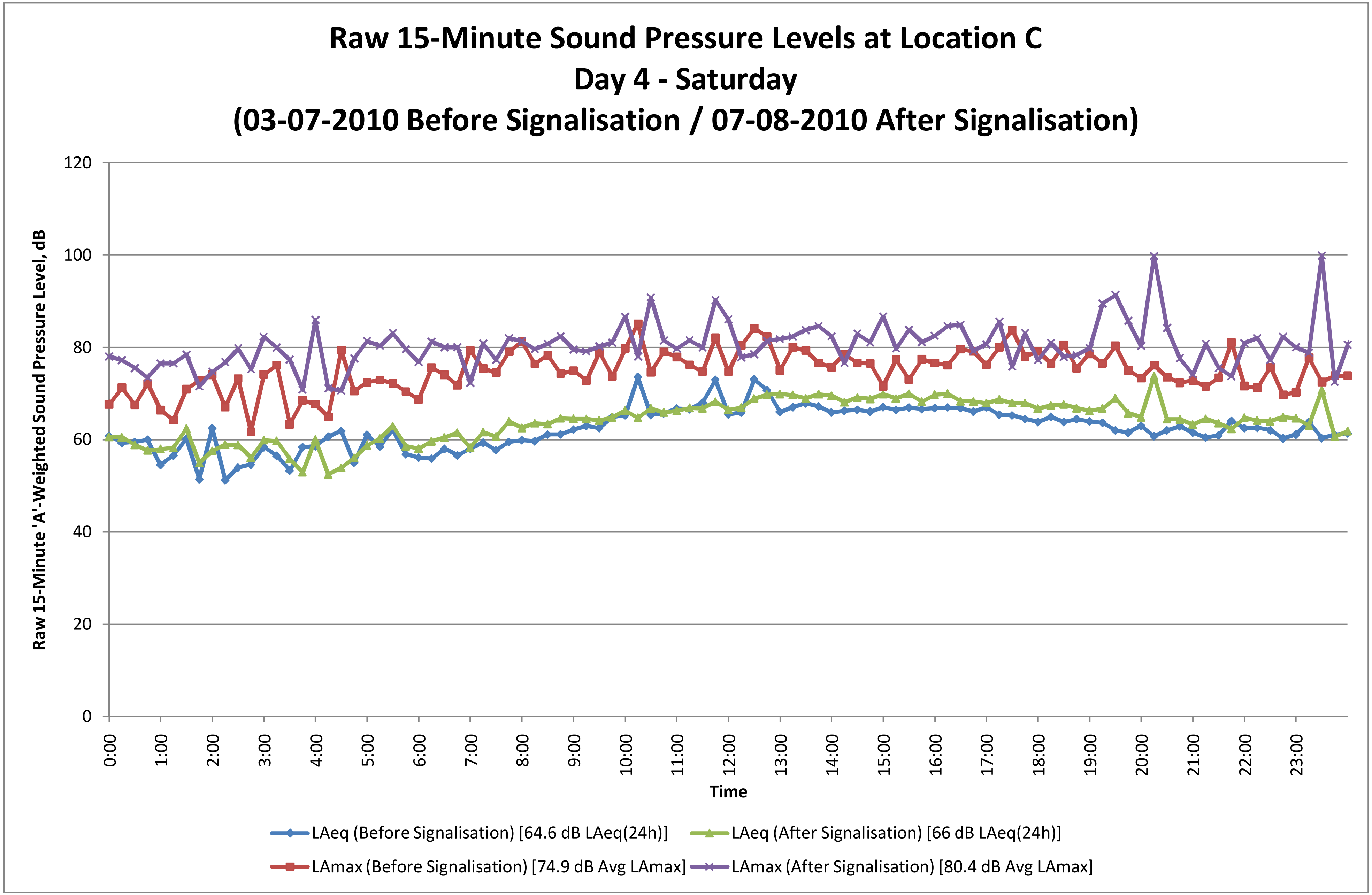

Raw 15-Minute Sound Pressure Levels at Location C
Day 1 - Wednesday
(30-06-2010 Before Signalisation / 04-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation)
LAeq (After Signalisation)
LAmax (Before Signalisation)
LAmax (After Signalisation)

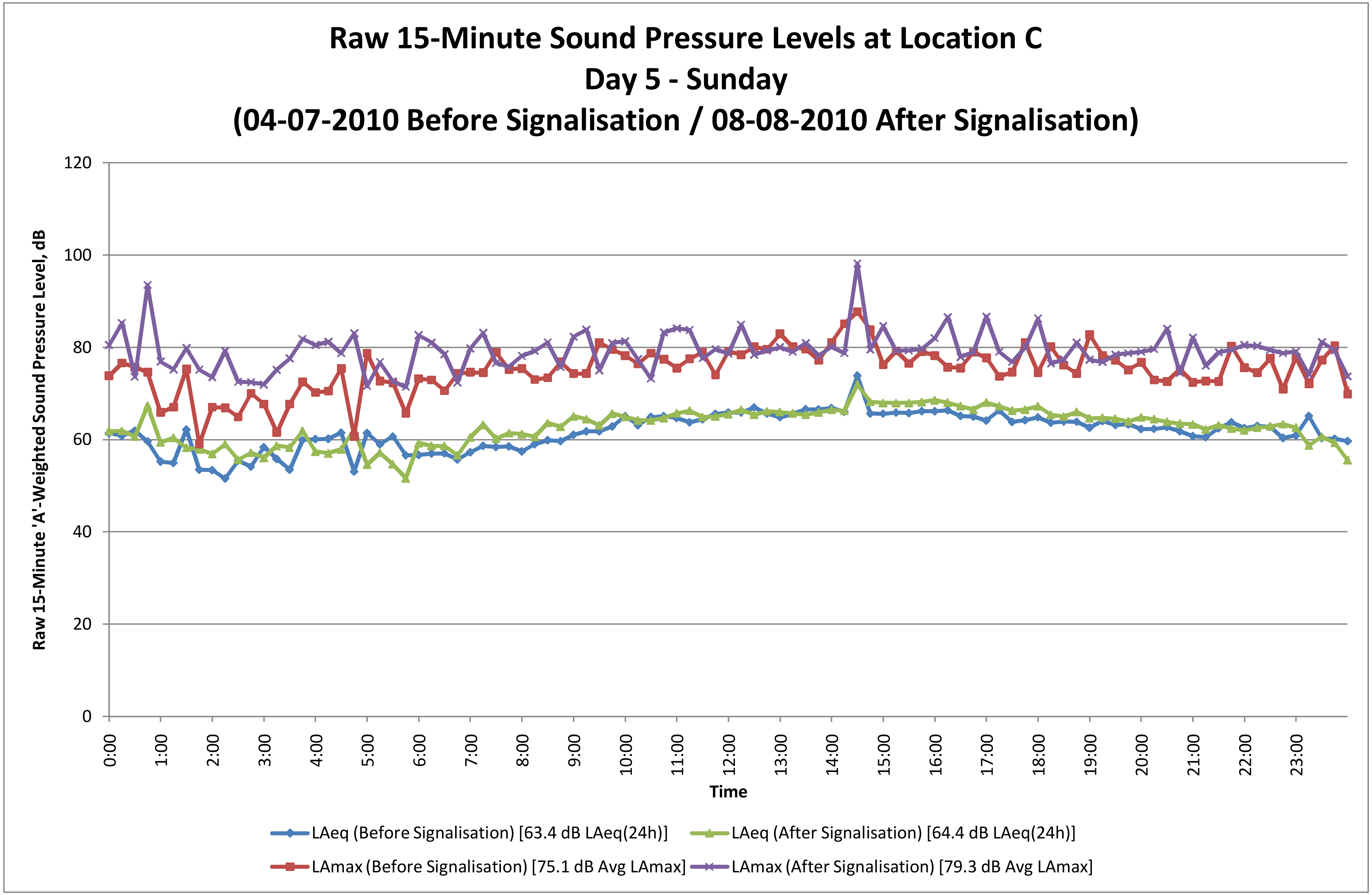


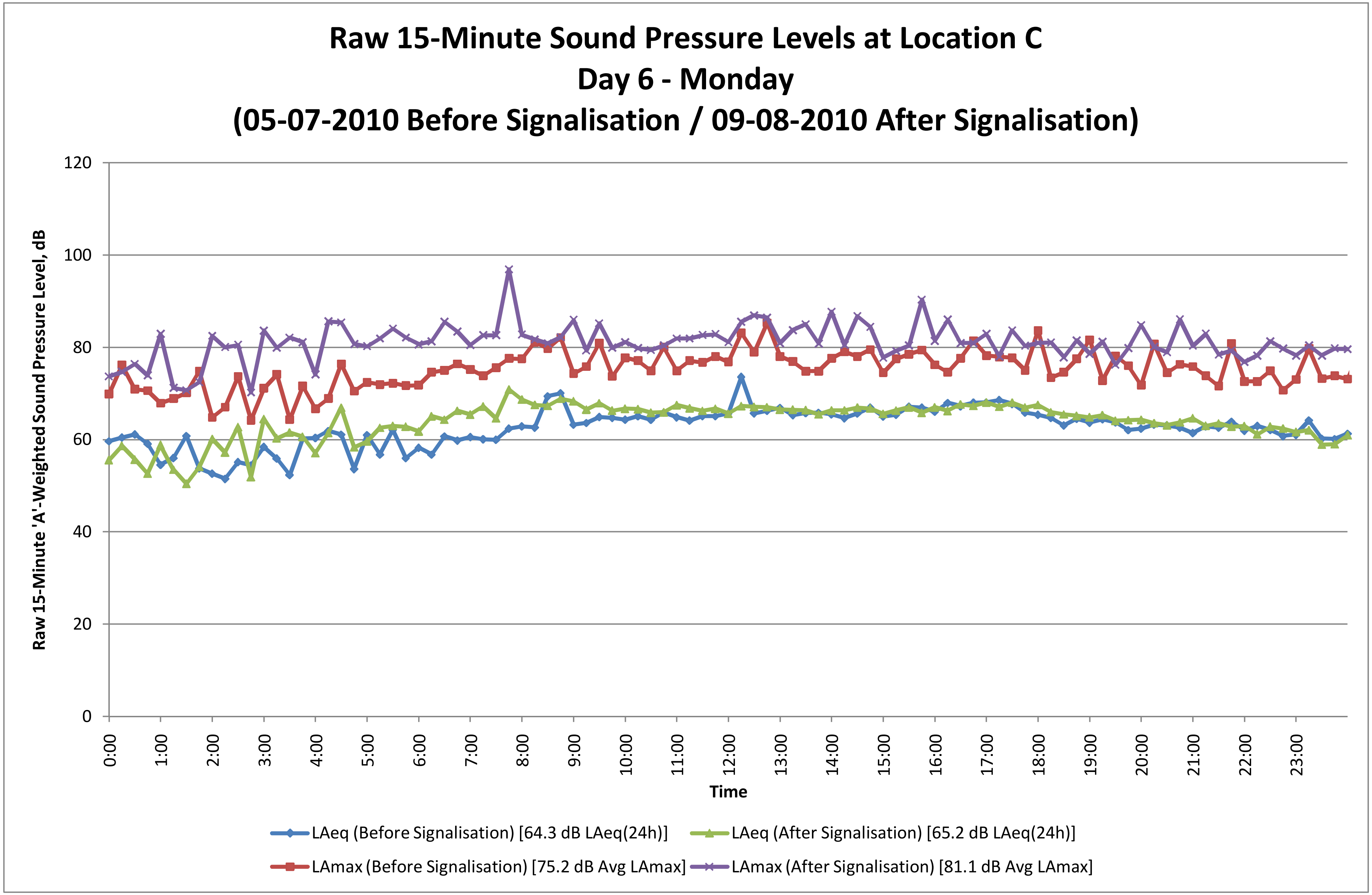
Raw 15-Minute Sound Pressure Levels at Location C
Day 2 - Thursday
(01-07-2010 Before Signalisation / 05-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.8 dB LAeq(24h)]
LAeq (After Signalisation) [65.7 dB LAeq(24h)]
LAmax (Before Signalisation) [76.1 dB Avg LAmax]
LAmax (After Signalisation) [81.2 dB Avg LAmax]



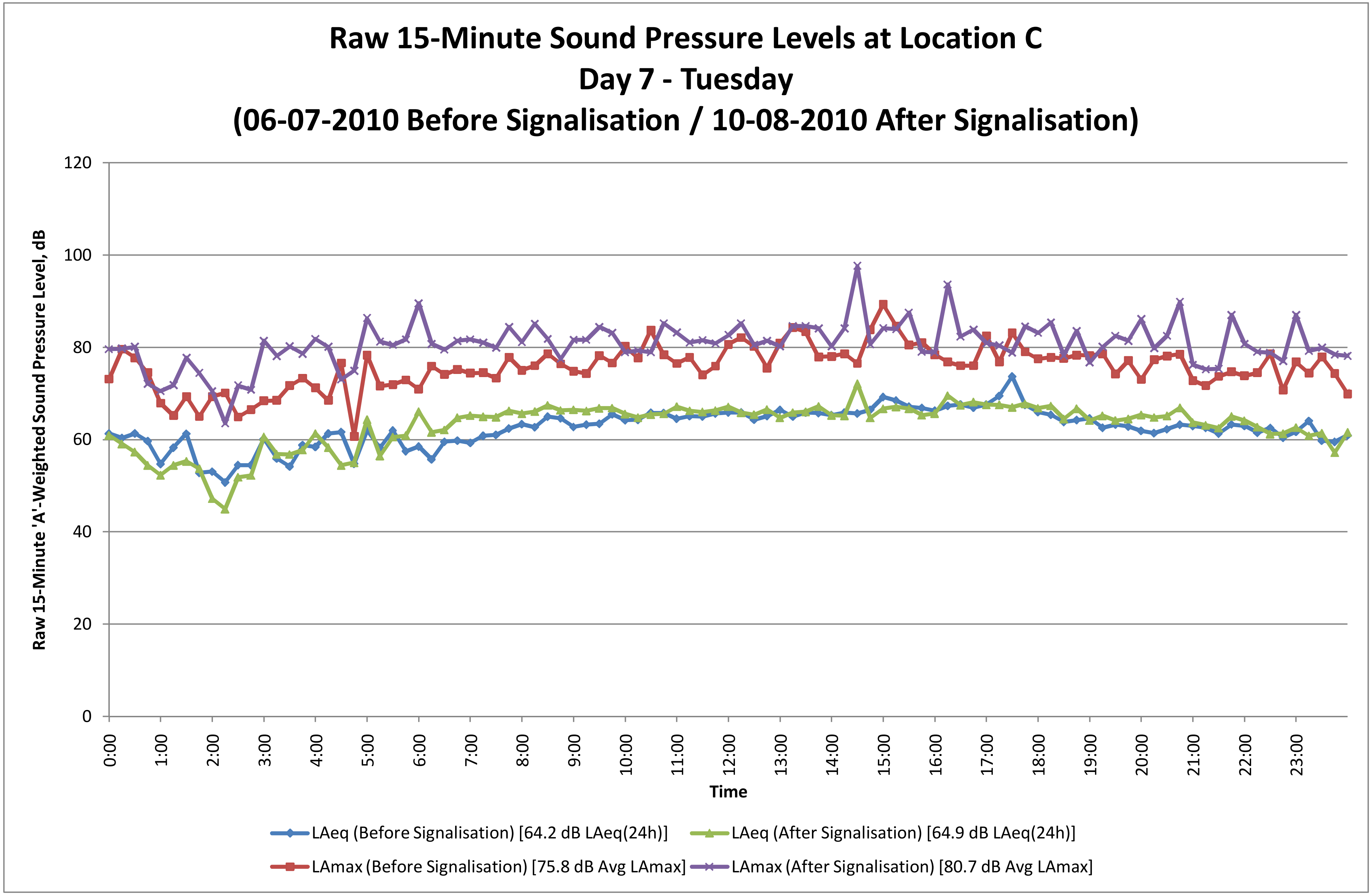
Raw 15-Minute Sound Pressure Levels at Location C
Day 3 - Friday
(02-07-2010 Before Signalisation / 06-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.5 dB LAeq(24h)]
LAeq (After Signalisation) [65.6 dB LAeq(24h)]
LAmax (Before Signalisation) [76.2 dB Avg LAmax]
LAmax (After Signalisation) [81.3 dB Avg LAmax]

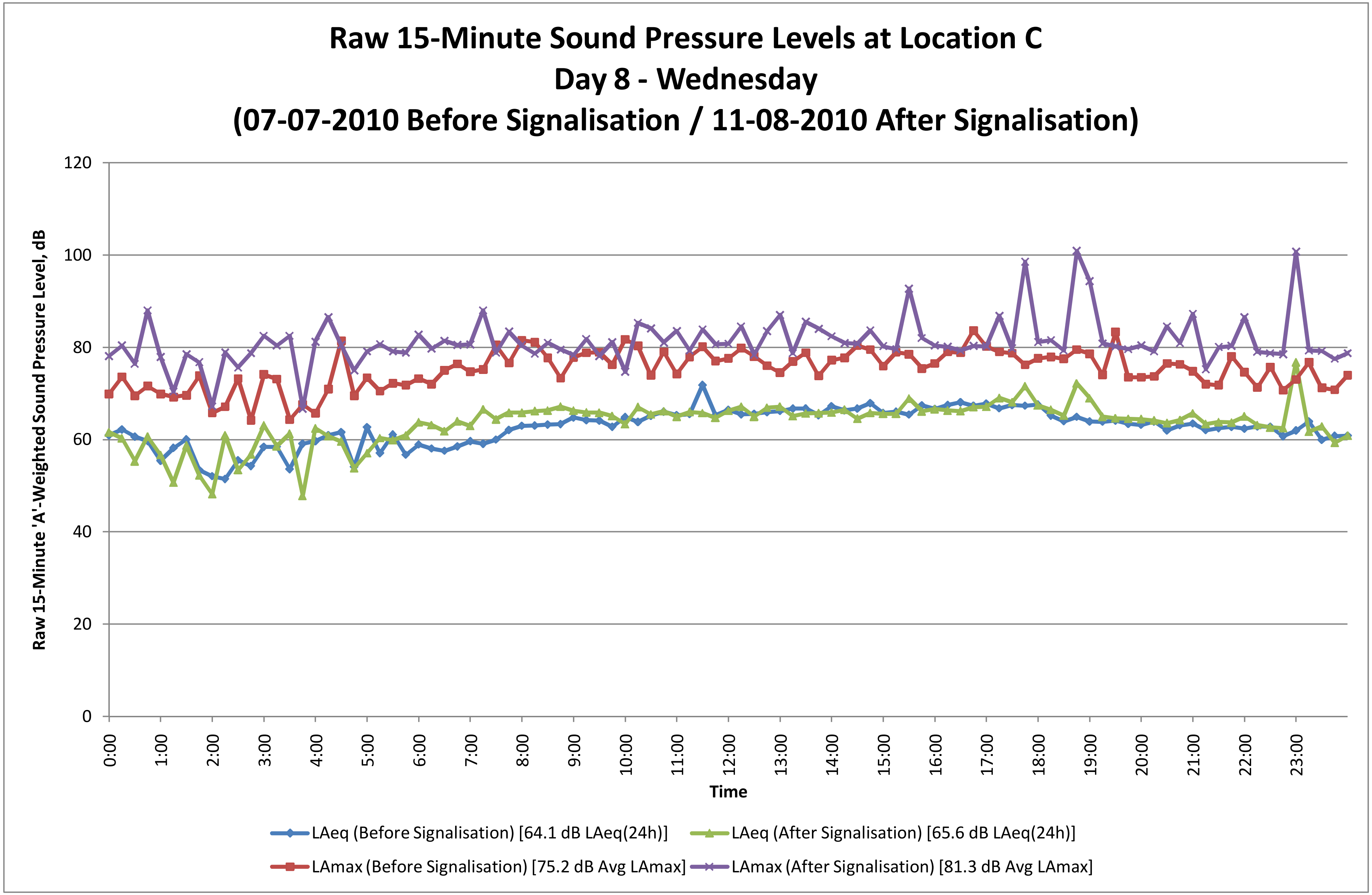

Raw 15-Minute Sound Pressure Levels at Location C
Day 4 - Saturday
(03-07-2010 Before Signalisation / 07-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.6 dB LAeq(24h)]
LAeq (After Signalisation) [66 dB LAeq(24h)]
LAmax (Before Signalisation) [74.9 dB Avg LAmax]
LAmax (After Signalisation) [80.4 dB Avg LAmax]


Raw 15-Minute Sound Pressure Levels at Location C
Day 5 - Sunday
(04-07-2010 Before Signalisation / 08-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [63.4 dB LAeq(24h)]
LAeq (After Signalisation) [64.4 dB LAeq(24h)]
LAmax (Before Signalisation) [75.1 dB Avg LAmax]
LAmax (After Signalisation) [79.3 dB Avg LAmax]

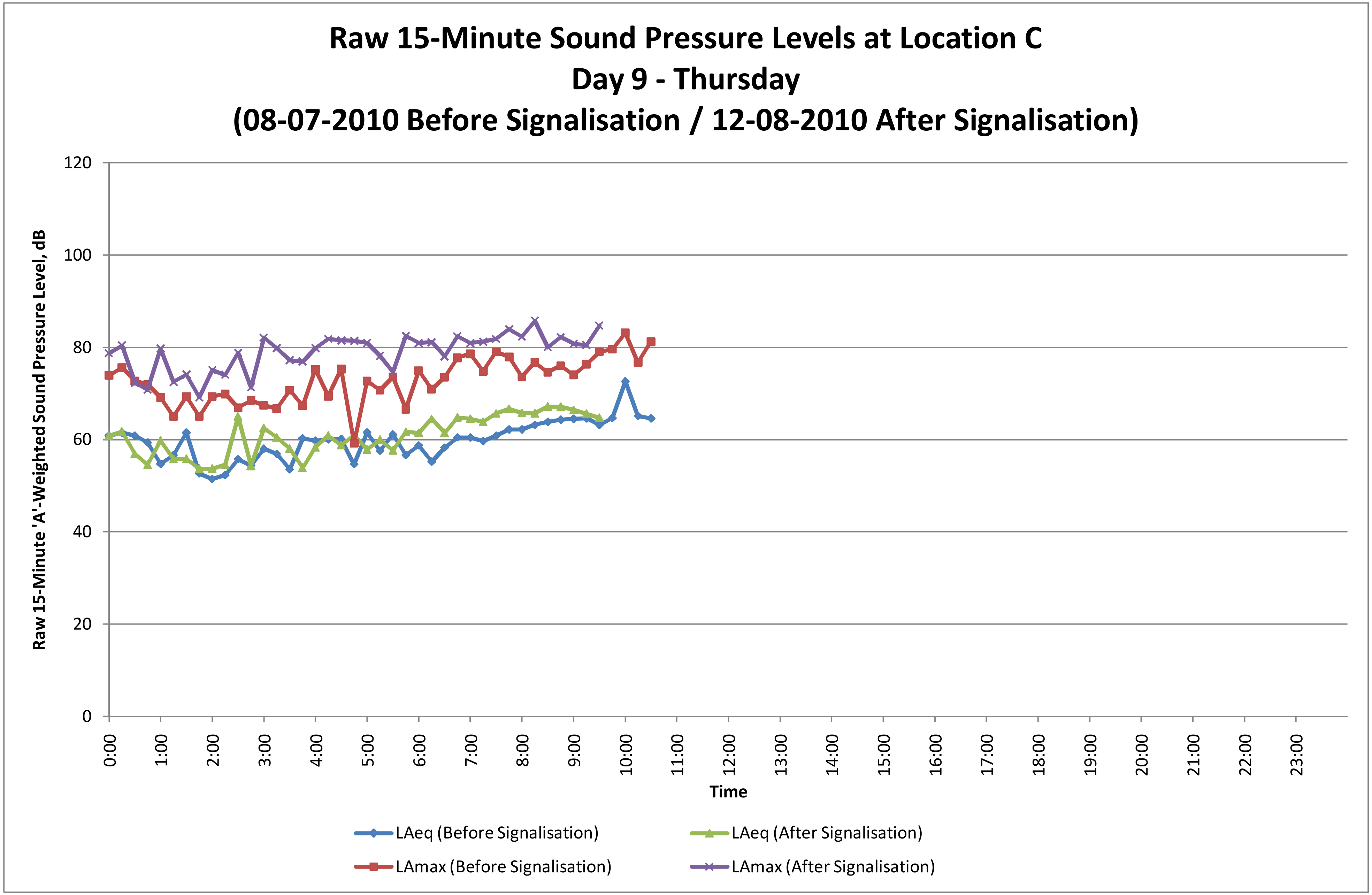


Raw 15-Minute Sound Pressure Levels at Location C
Day 6 - Monday
(05-07-2010 Before Signalisation / 09-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.3 dB LAeq(24h)]
LAeq (After Signalisation) [65.2 dB LAeq(24h)]
LAmax (Before Signalisation) [75.2 dB Avg LAmax]
LAmax (After Signalisation) [81.1 dB Avg LAmax]

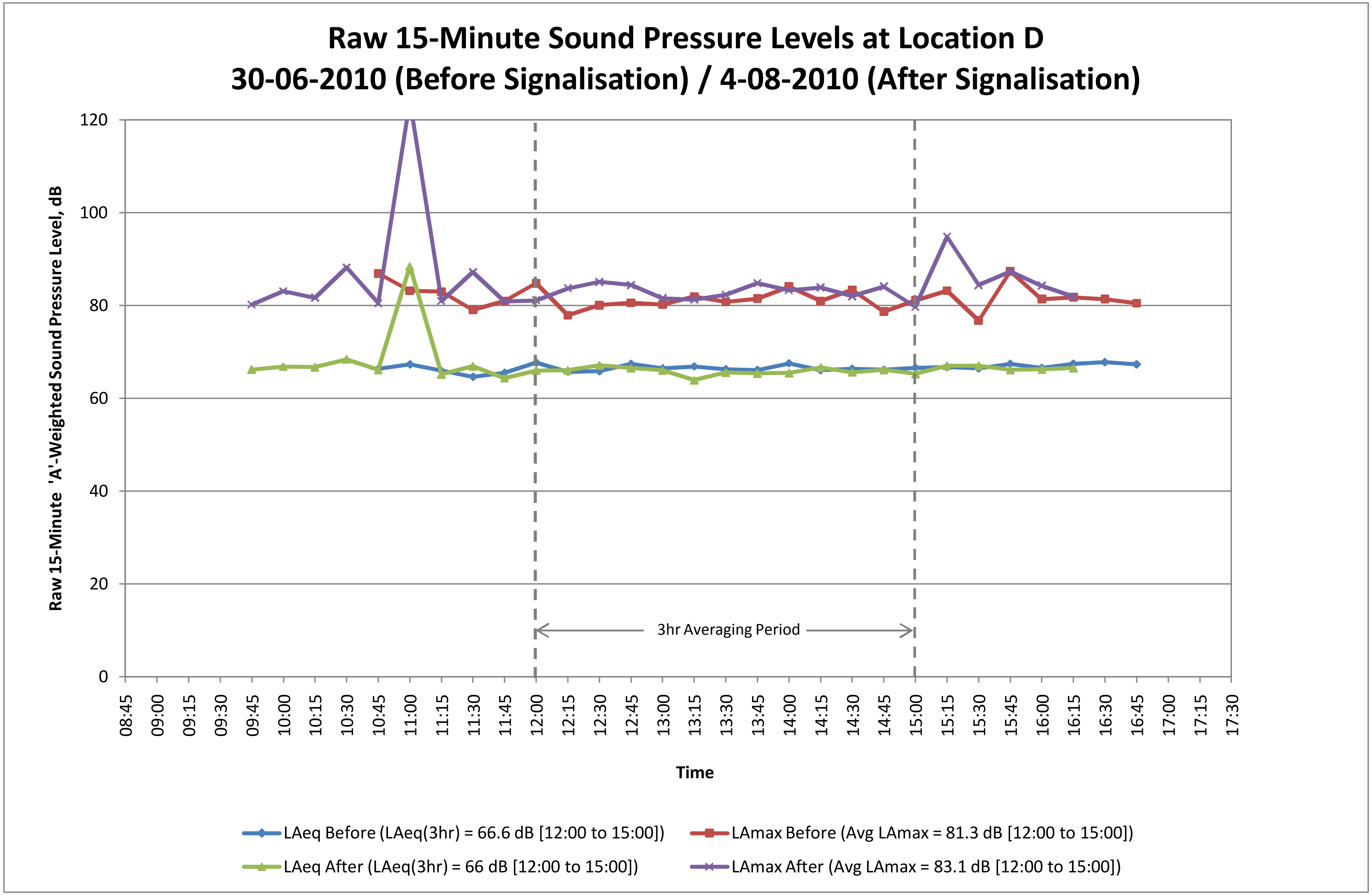

Raw 15-Minute Sound Pressure Levels at Location C
Day 7 - Tuesday
(06-07-2010 Before Signalisation / 10-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.2 dB LAeq(24h)]
LAeq (After Signalisation) [64.9 dB LAeq(24h)]
LAmax (Before Signalisation) [75.8 dB Avg LAmax]
LAmax (After Signalisation) [80.7 dB Avg LAmax]



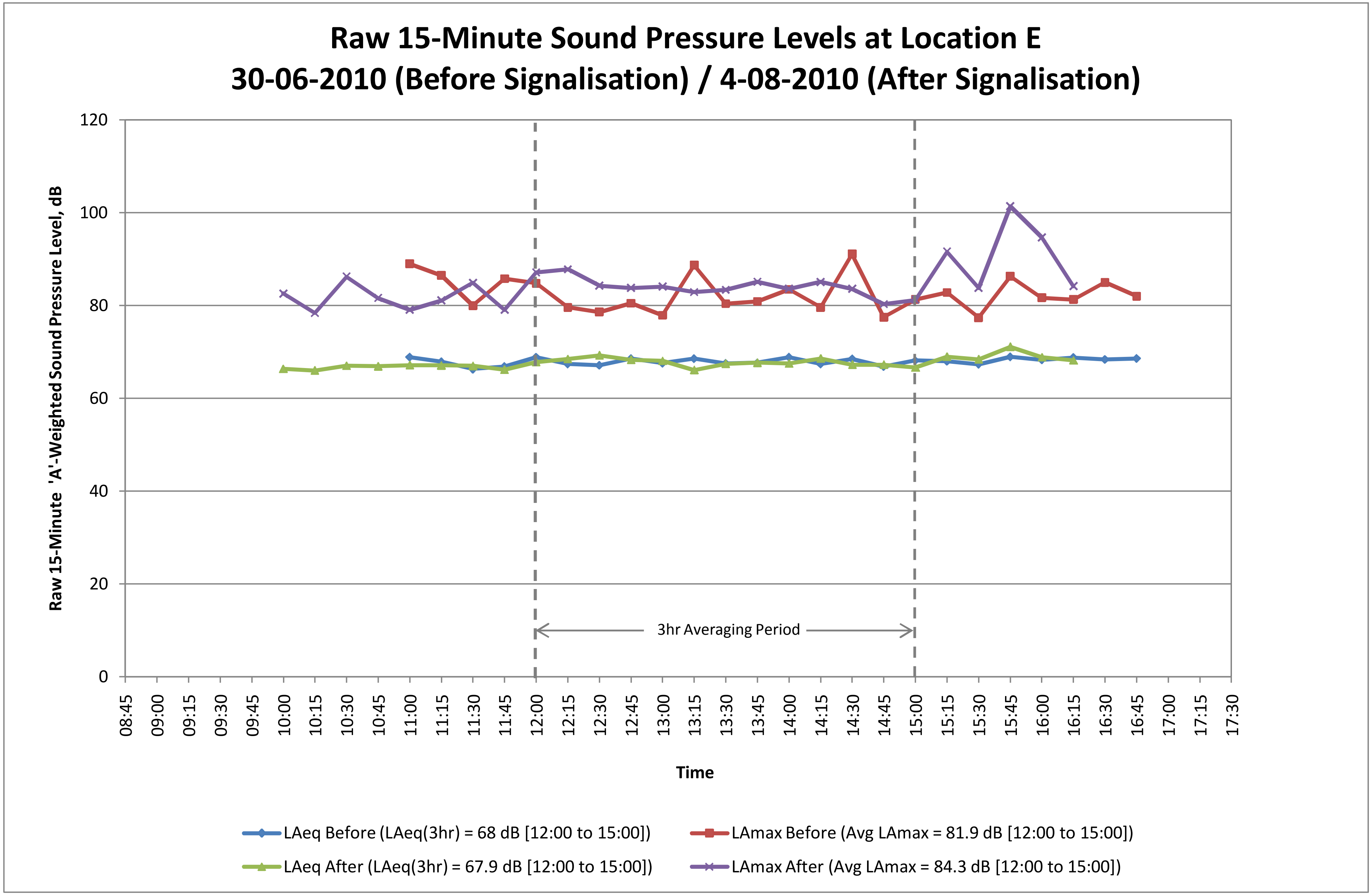
Raw 15-Minute Sound Pressure Levels at Location C
Day 8 - Wednesday
(07-07-2010 Before Signalisation / 11-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation) [64.1 dB LAeq(24h)]
LAeq (After Signalisation) [65.6 dB LAeq(24h)]
LAmax (Before Signalisation) [75.2 dB Avg LAmax]
LAmax (After Signalisation) [81.3 dB Avg LAmax]



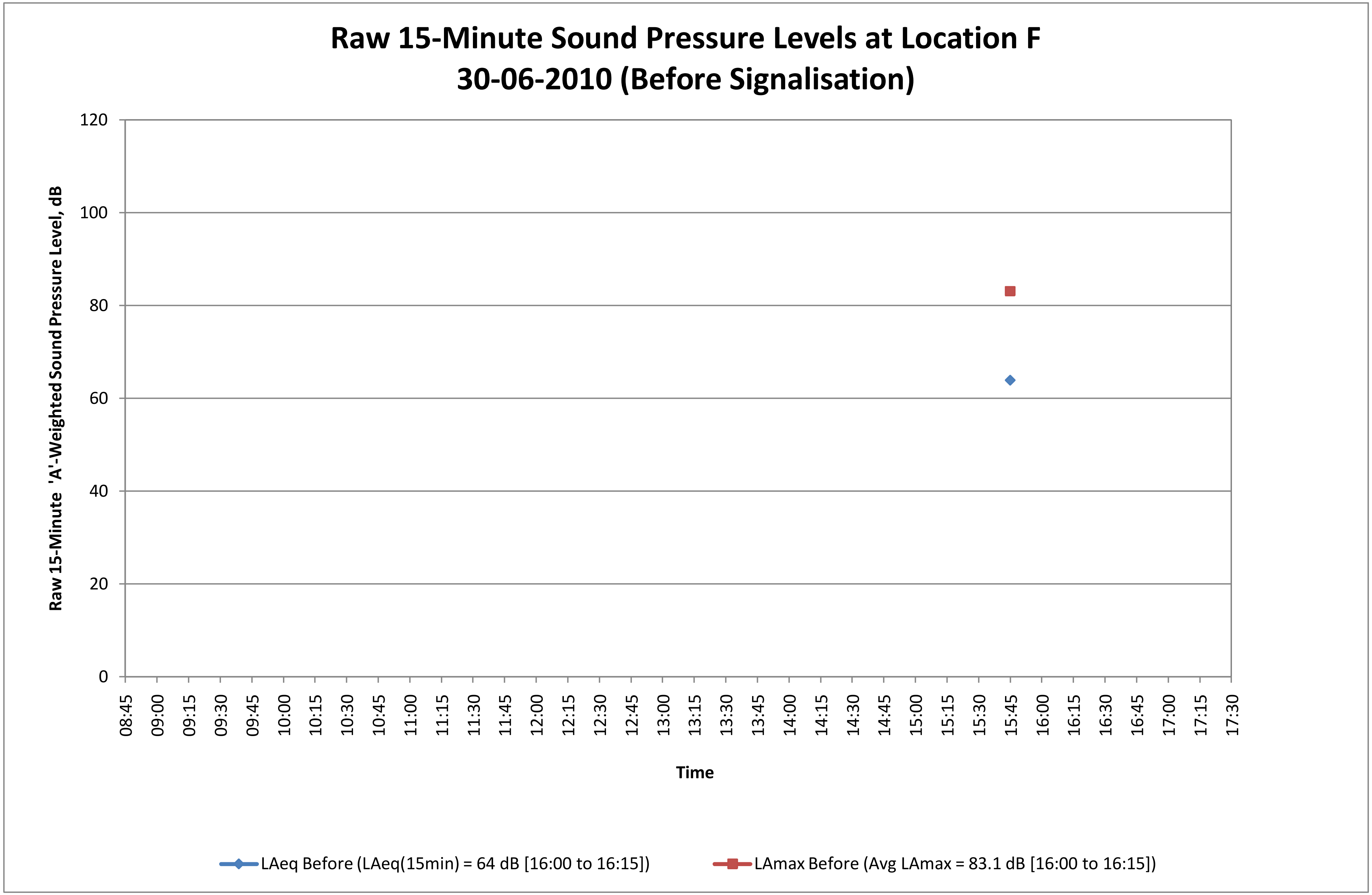
Raw 15-Minute Sound Pressure Levels at Location C
Day 9 - Thursday
(08-07-2010 Before Signalisation / 12-08-2010 After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
LAeq (Before Signalisation)
LAeq (After Signalisation)
LAmax (Before Signalisation)
LAmax (After Signalisation)



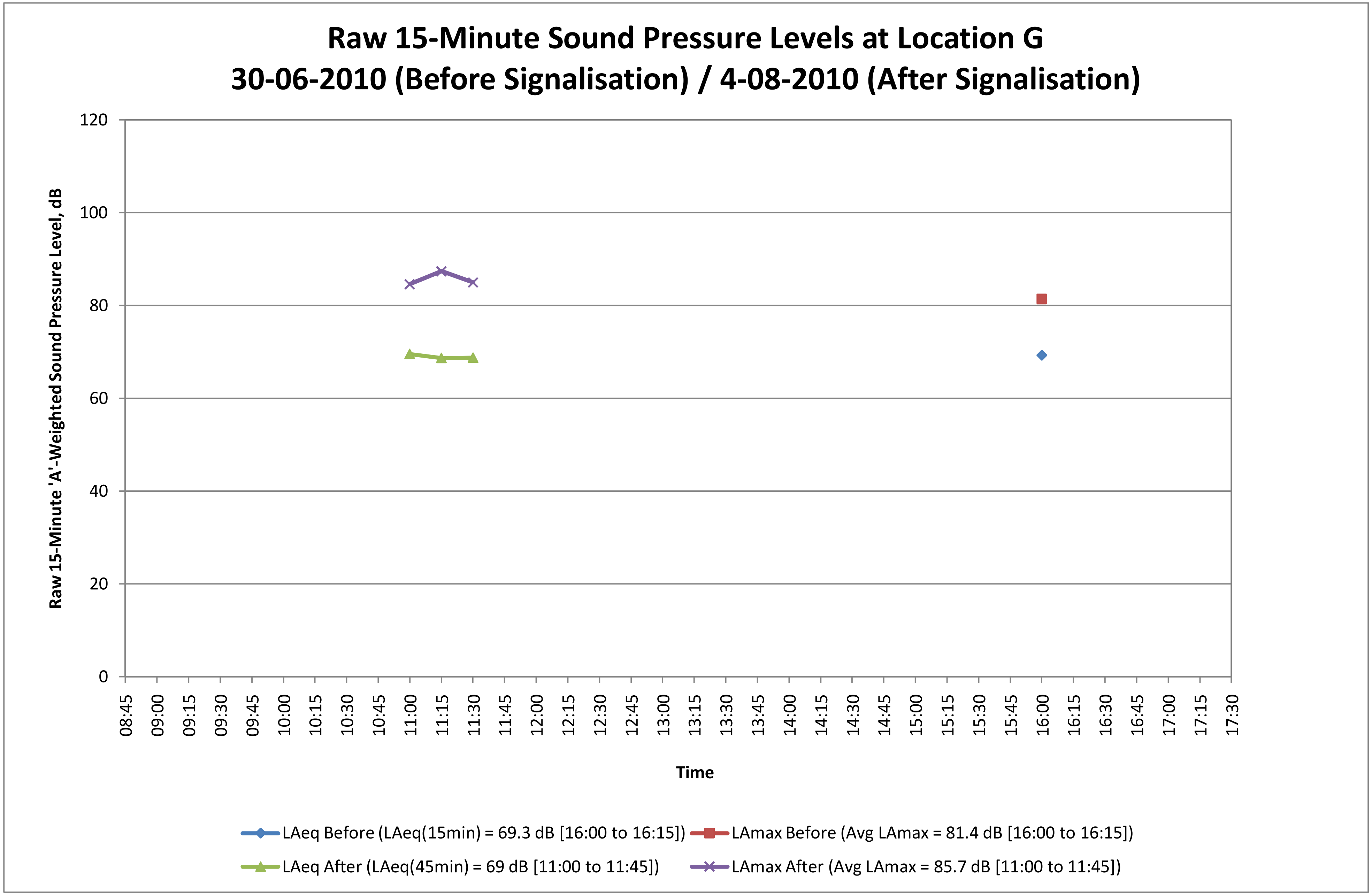
Raw 15-Minute Sound Pressure Levels at Location D
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
3hr Averaging Period
Time
LAeq Before (LAeq(3hr) = 66.6 dB [12:00 to 15:00])
LAmax Before (Avg LAmax = 81.3 dB [12:00 to 15:00])
LAeq After (LAeq(3hr) = 66 dB [12:00 to 15:00])
LAmax After (Avg LAmax = 83.1 dB [12:00 to 15:00])



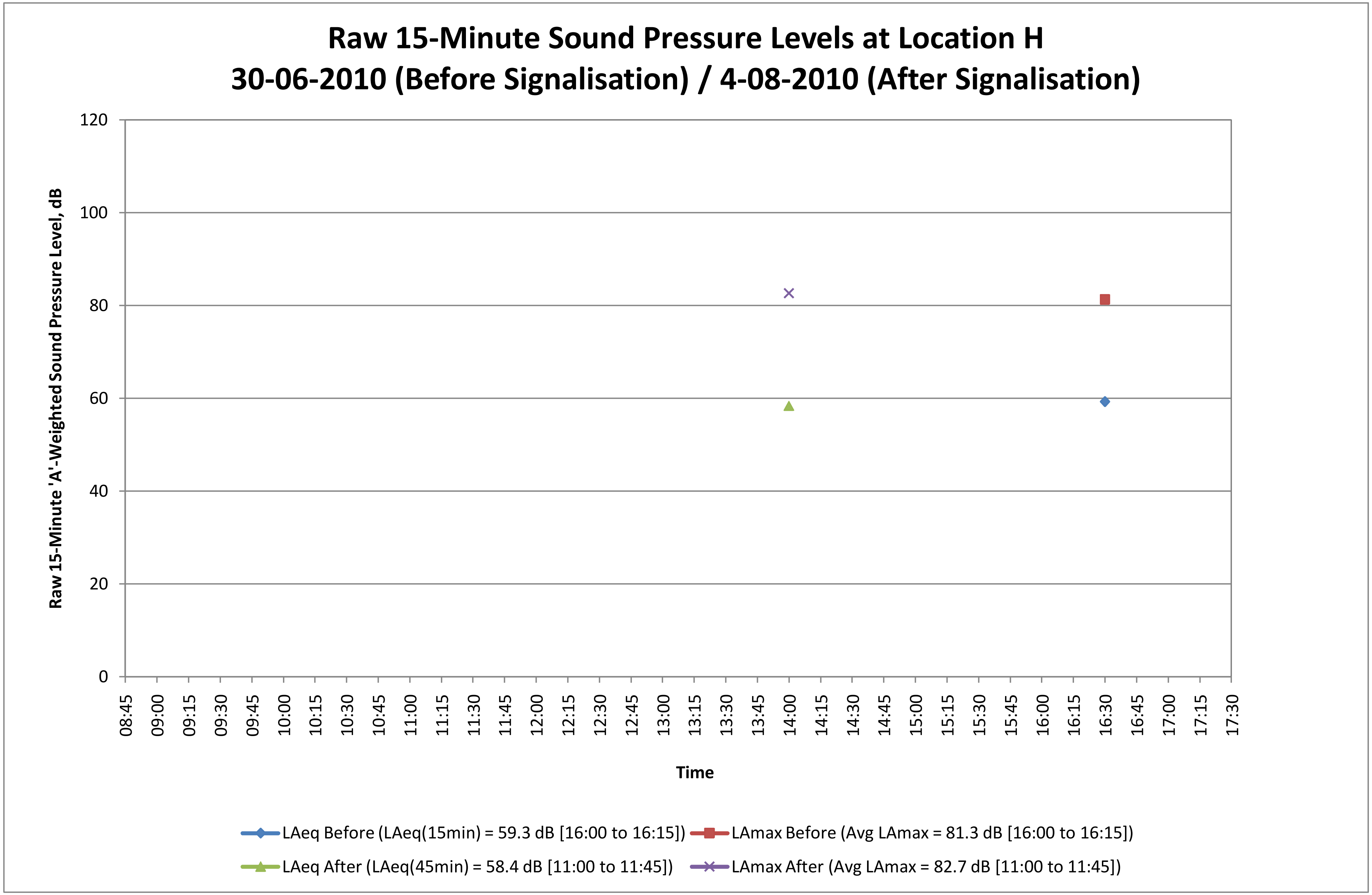
Raw 15-Minute Sound Pressure Levels at Location E
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
3hr Averaging Period
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(3hr) = 68 dB [12:00 to 15:00])
LAmax Before (Avg LAmax = 81.9 dB [12:00 to 15:00])
LAeq After (LAeq(3hr) = 67.9 dB [12:00 to 15:00])
LAmax After (Avg LAmax = 84.3 dB [12:00 to 15:00])



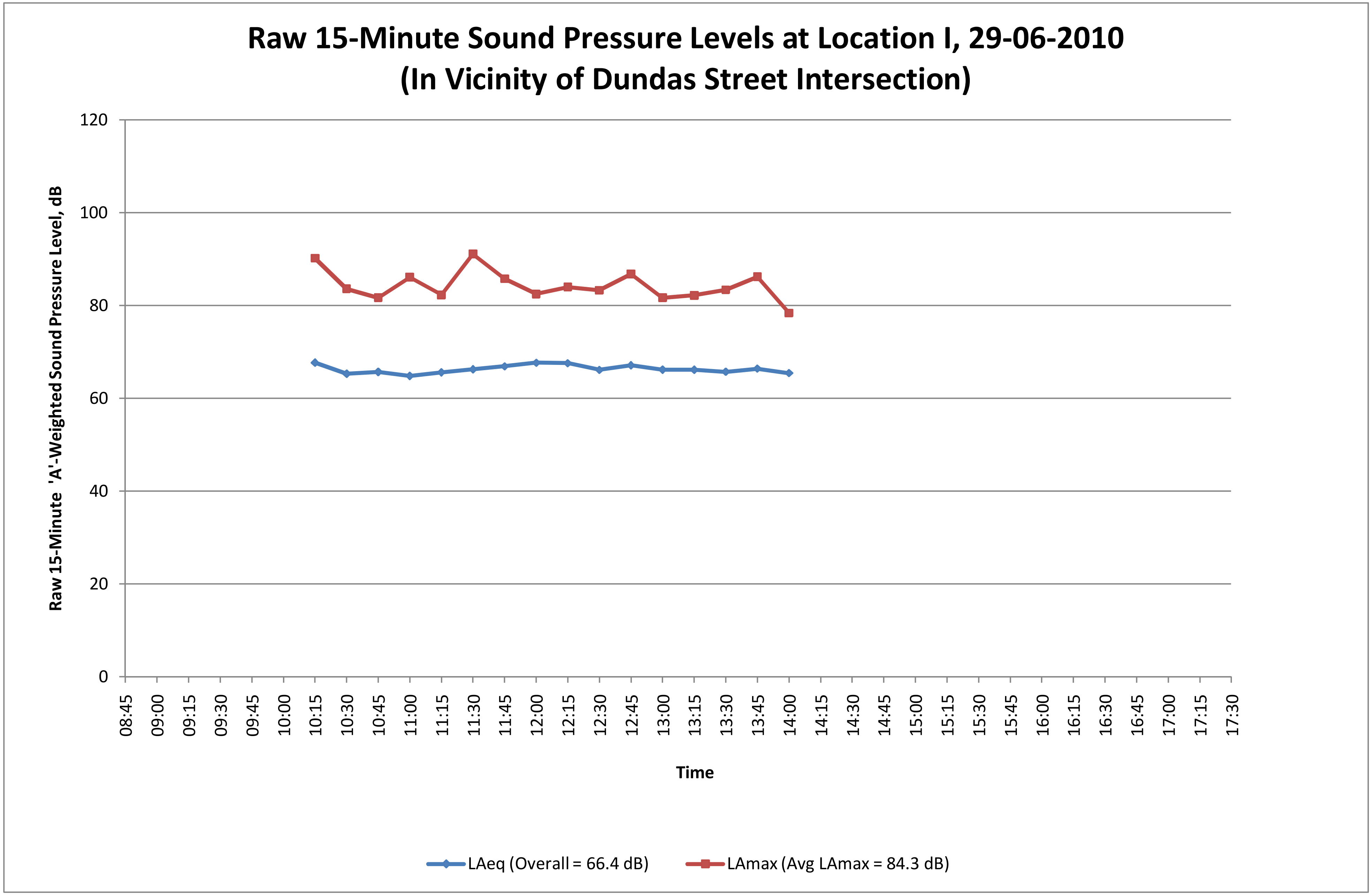
Raw 15-Minute Sound Pressure Levels at Location F
30-06-2010 (Before Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(15min) = 64 dB [16:00 to 16:15])
LAmax Before (Avg LAmax = 83.1 dB [16:00 to 16:15])



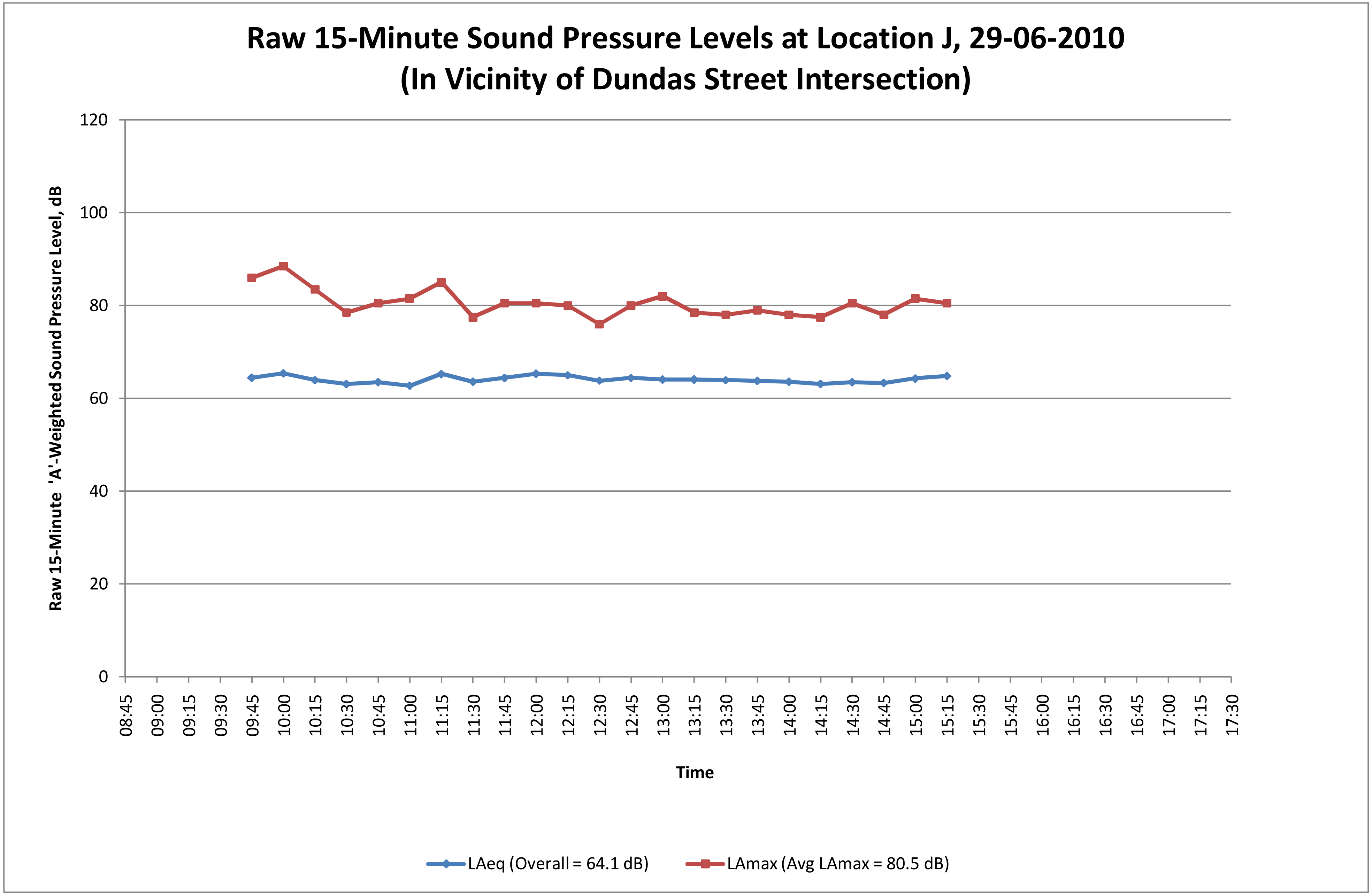
Raw 15-Minute Sound Pressure Levels at Location G
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(15min) = 69.3 dB [16:00 to 16:15])
LAmax Before (Avg LAmax = 81.4 dB [16:00 to 16:15])
LAeq After (LAeq(45min) = 69 dB [11:00 to 11:45])
LAmax After (Avg LAmax = 85.7 dB [11:00 to 11:45])



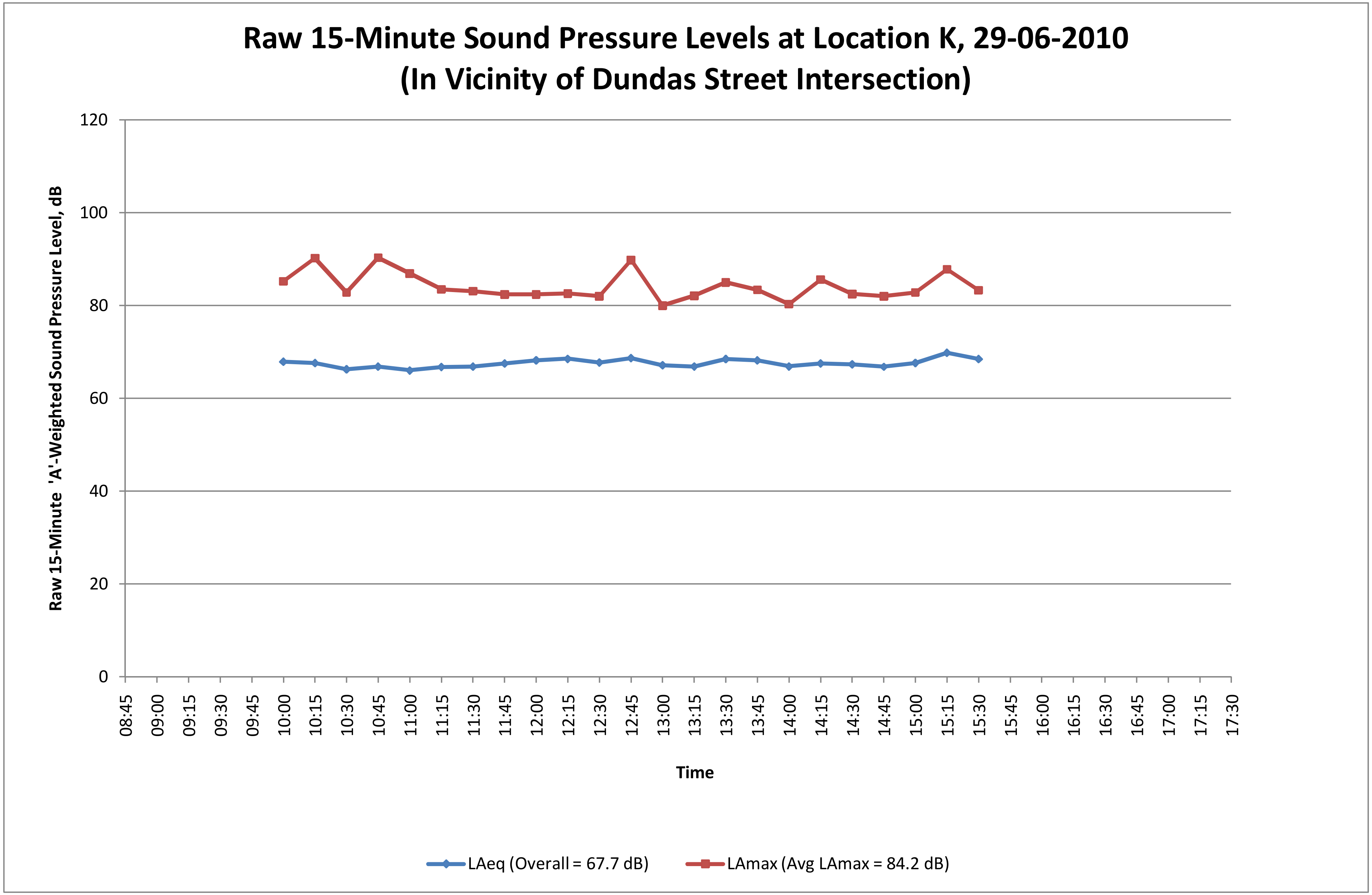
Raw 15-Minute Sound Pressure Levels at Location H
30-06-2010 (Before Signalisation) / 4-08-2010 (After Signalisation)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq Before (LAeq(15min) = 59.3 dB [16:00 to 16:15])
LAmax Before (Avg LAmax = 81.3 dB [16:00 to 16:15])
LAeq After (LAeq(45min) = 58.4 dB [11:00 to 11:45])
LAmax After (Avg LAmax = 82.7 dB [11:00 to 11:45])

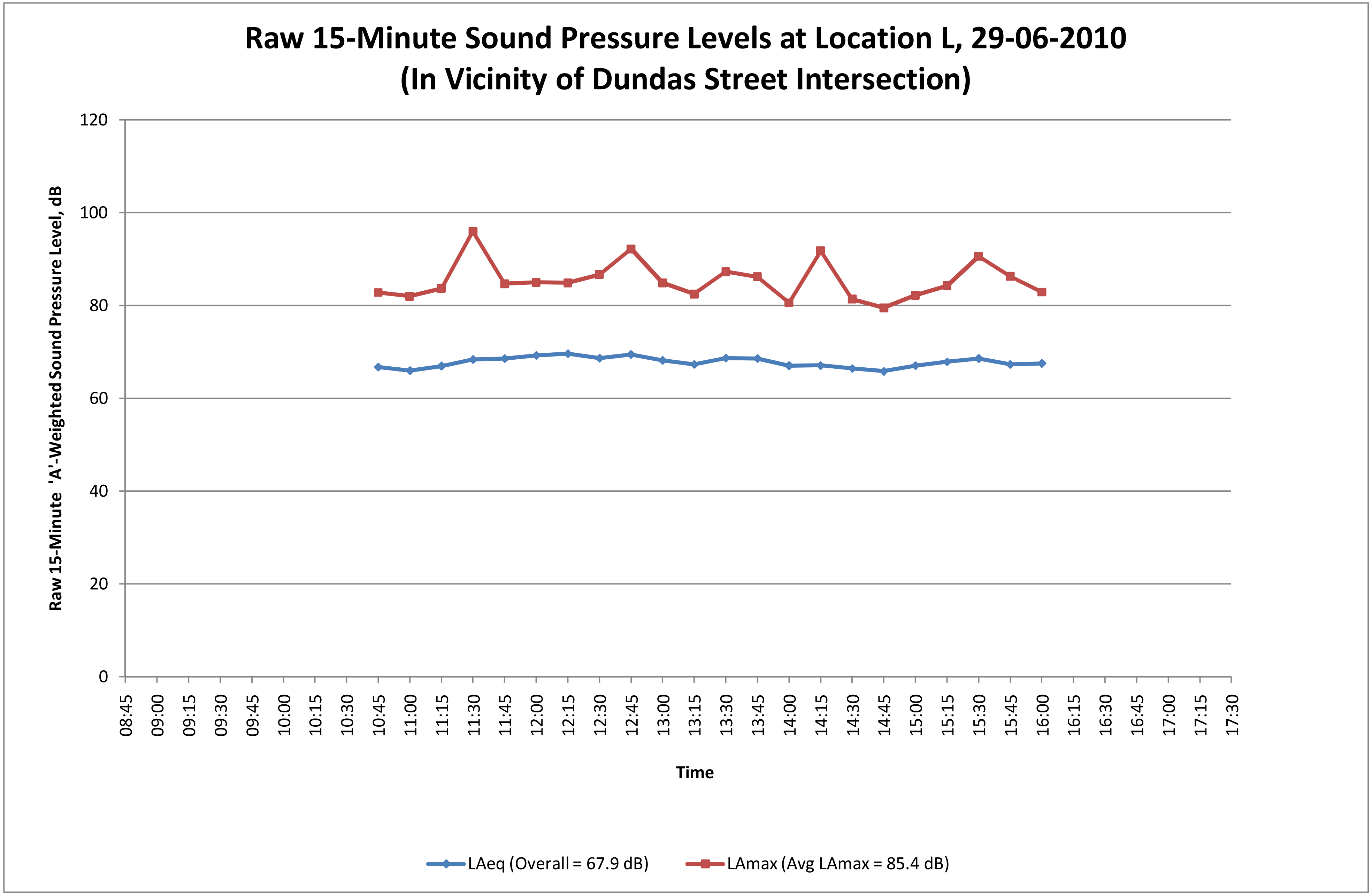


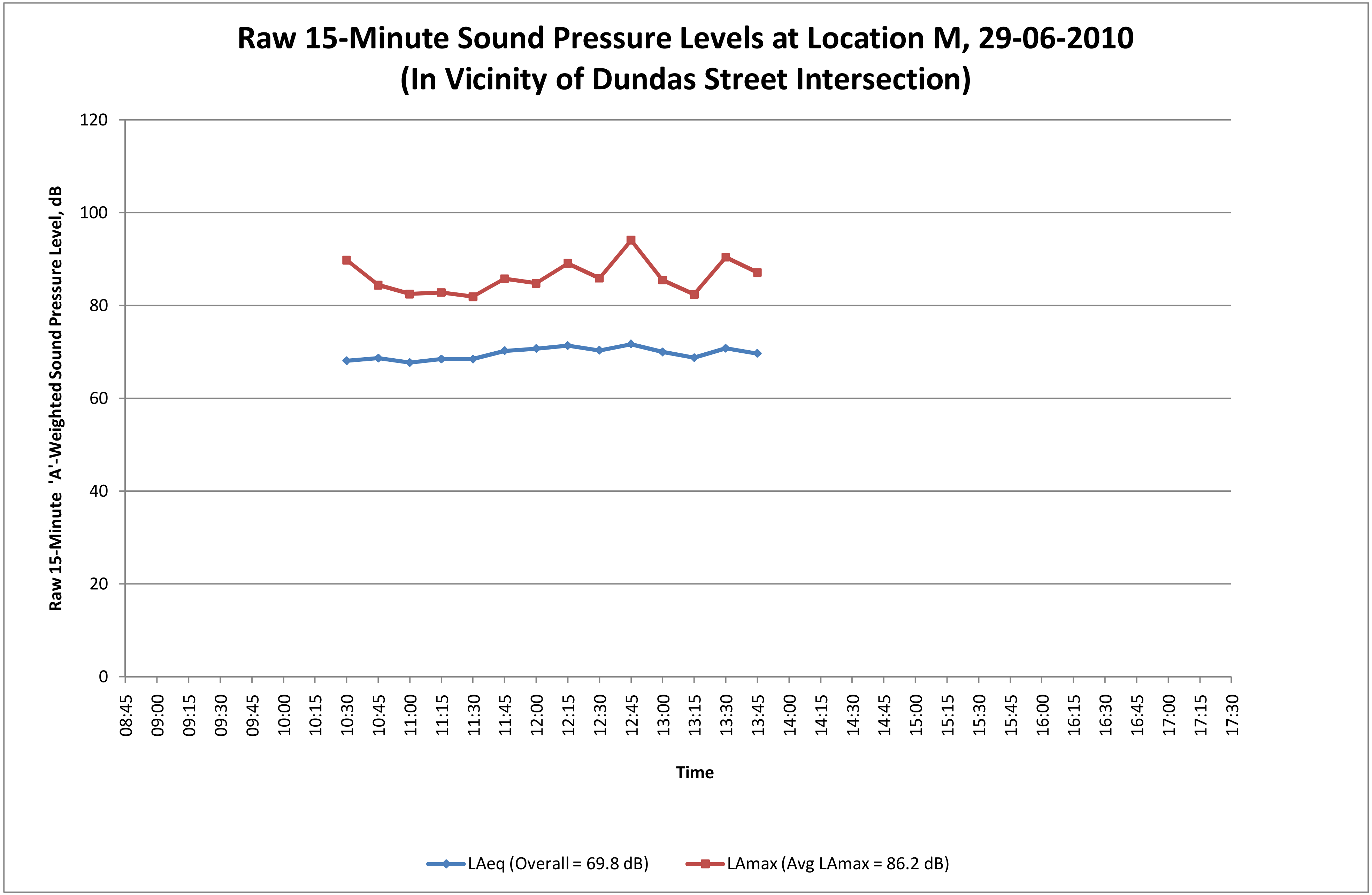
Raw 15-Minute Sound Pressure Levels at Location I, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 66.4 dB)
LAmax (Avg LAmax = 84.3 dB)



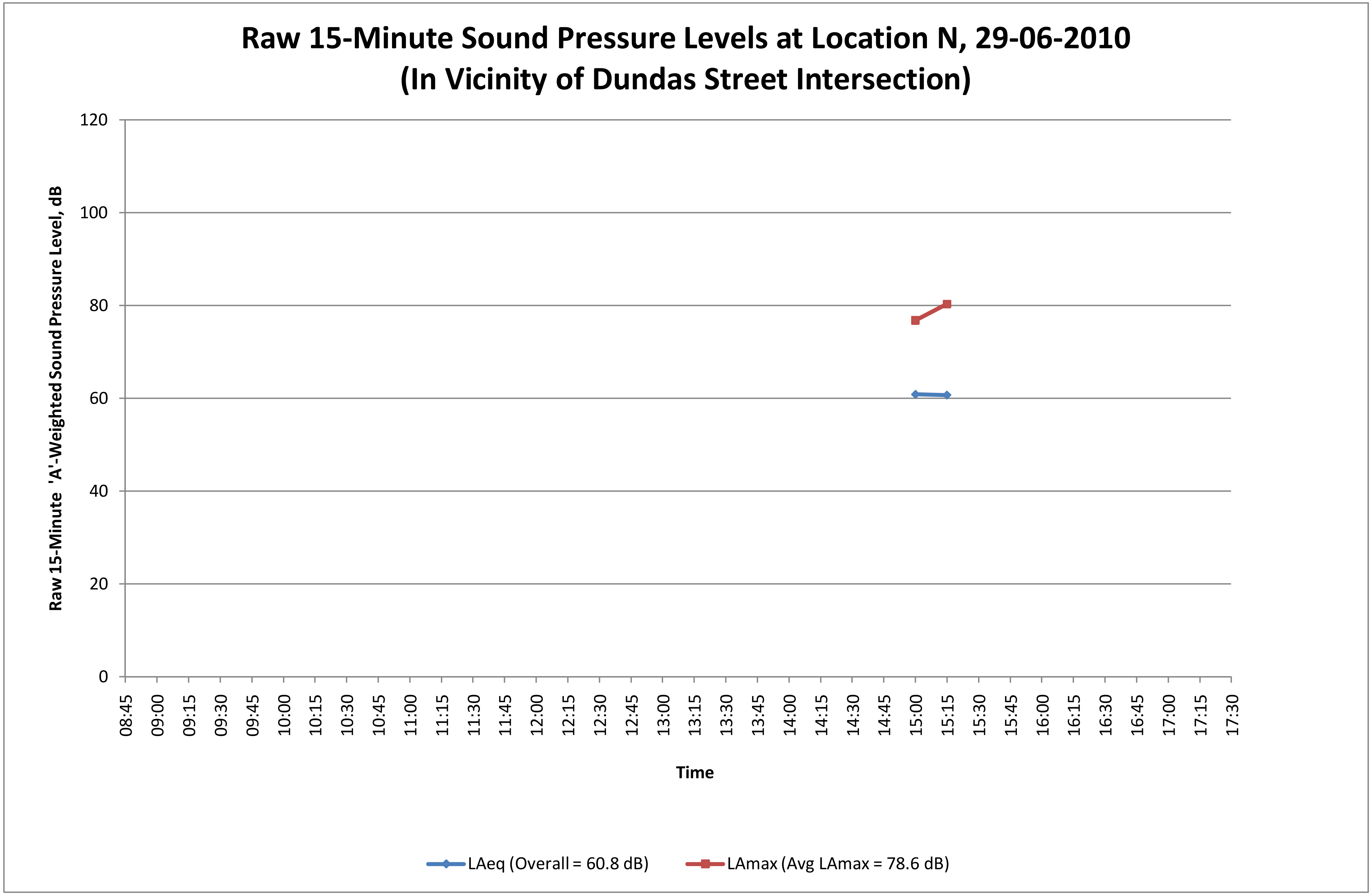
Raw 15-Minute Sound Pressure Levels at Location J, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 64.1 dB)
LAmax (Avg LAmax = 80.5 dB)


Raw 15-Minute Sound Pressure Levels at Location K, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 67.7 dB)
LAmax (Avg LAmax = 84.2 dB)

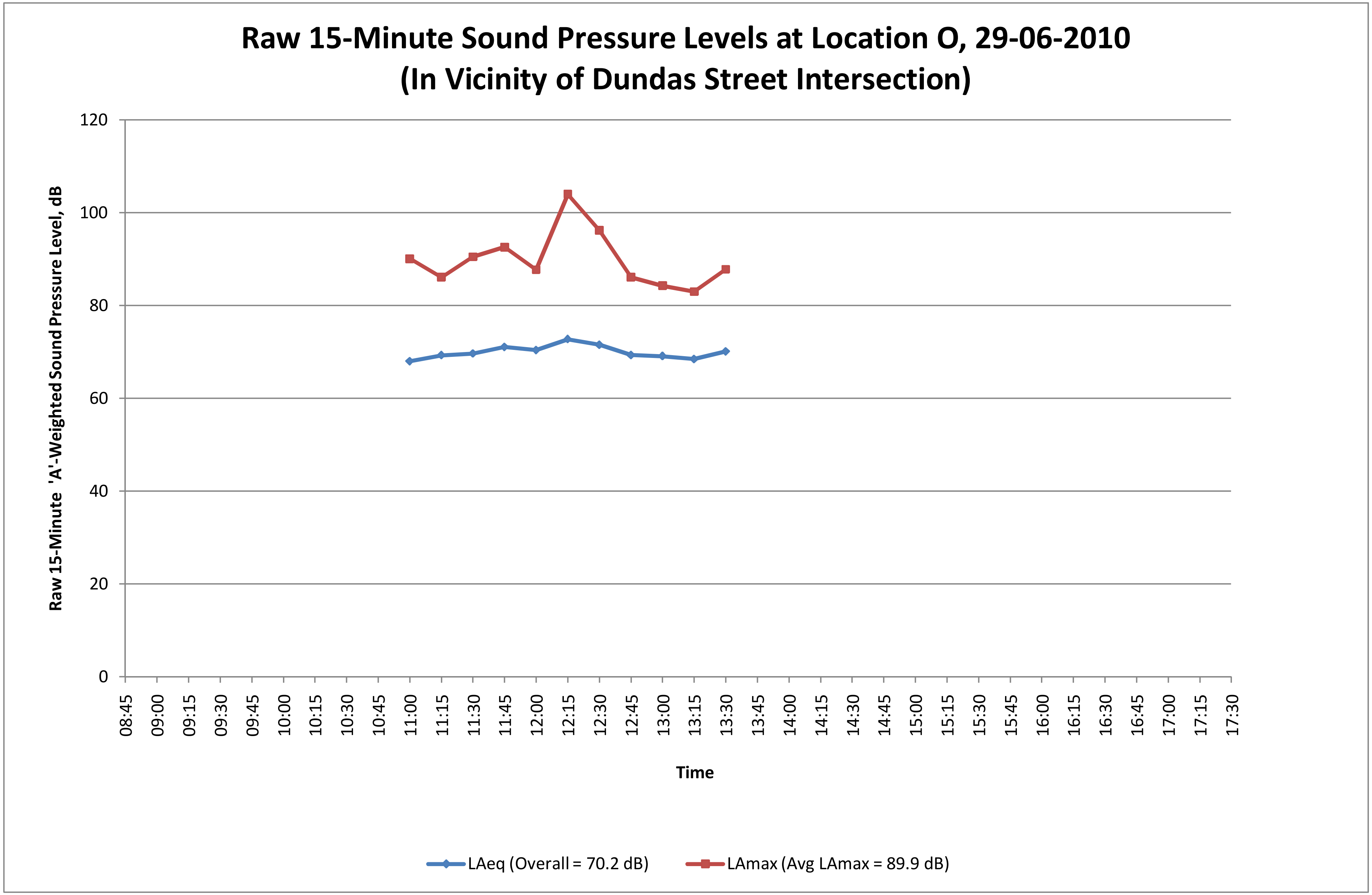

Raw 15-Minute Sound Pressure Levels at Location L, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 67.9 dB)
LAmax (Avg LAmax = 85.4 dB)

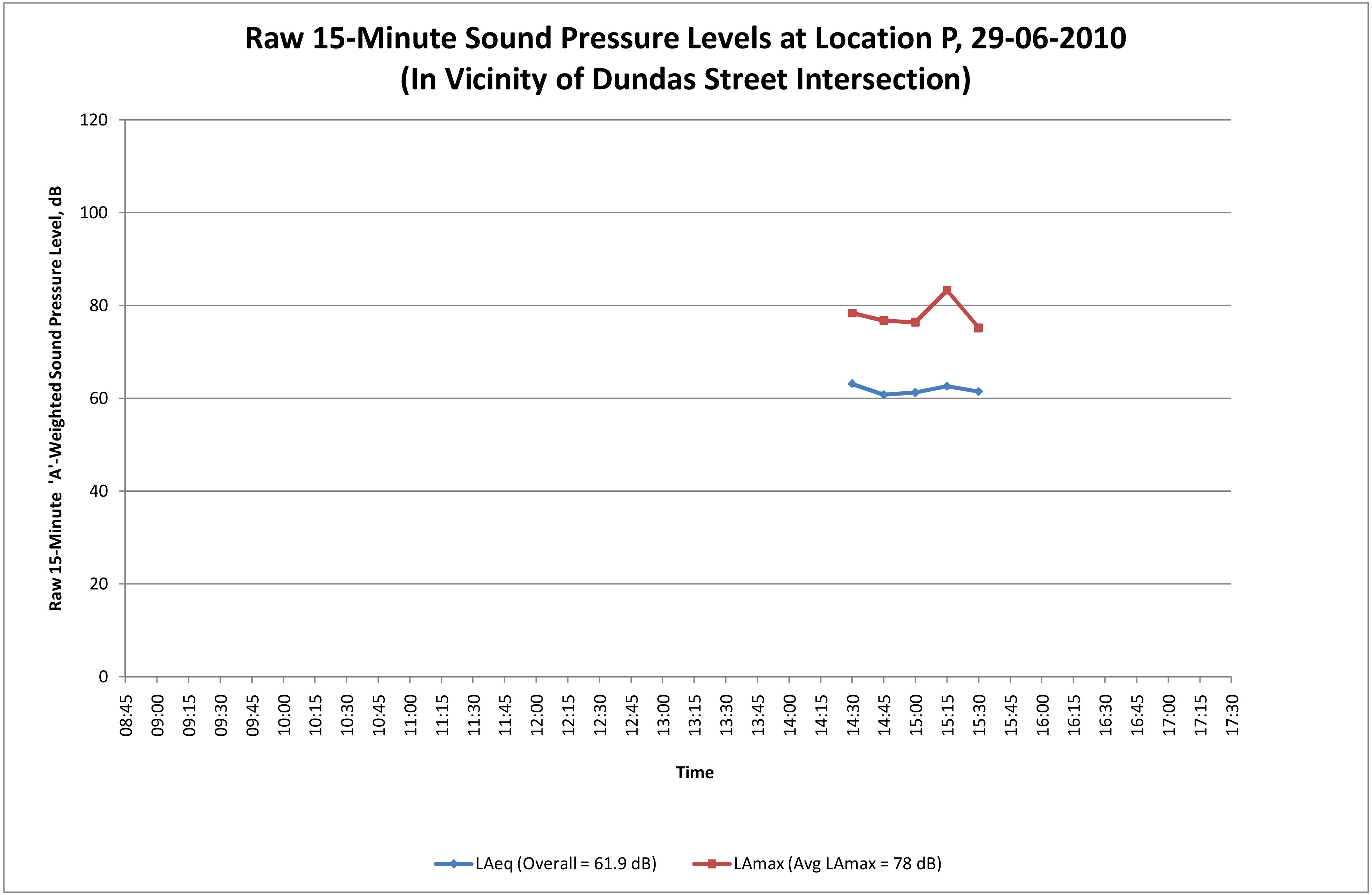


Raw 15-Minute Sound Pressure Levels at Location M, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
0
20
40
60
80
100
120
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 69.8 dB)
LAmax (Avg LAmax = 86.2 dB)



Raw 15-Minute Sound Pressure Levels at Location N, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 60.8 dB)
LAmax (Avg LAmax = 78.6 dB)


Raw 15-Minute Sound Pressure Levels at Location O, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 70.2 dB)
LAmax (Avg LAmax = 89.9 dB)



Raw 15-Minute Sound Pressure Levels at Location P, 29-06-2010
(In Vicinity of Dundas Street Intersection)
Raw 15-Minute 'A'-Weighted Sound Pressure Level, dB
120
100
80
60
40
20
0
08:45
09:00
09:15
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
14:30
14:45
15:00
15:15
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
Time
LAeq (Overall = 61.9 dB)
LAmax (Avg LAmax = 78 dB)

Appendix E

Traffic Volume Data

Appendix E Traffic Volume Data

Table D1 and Figure D1 summarise the 24hr traffic volumes counted on SH1 Great King Street North, north of Duke Street, during the noise measurement period before and after the signalisation.

On the following page, Table D2 and Figure D2 summarise the traffic volumes counted on Duke Street, west of SH1 Great King Street North during the noise measurement period before and after the signalised.

The summaries are followed by more detailed daily 15-minute graphs of the traffic volumes.

The final two graphs that are provided show the traffic volumes counted on SH1 Great King Street near Dundas Street, and on Dundas Street, during the noise measurement period at Dundas Street.

Table D1 Traffic Volumes on SH1 Great King Street North, North of Duke Street, Before and After Signalisation

Day	Before Signalisation			After Signalisation		
	Date	24hr Volume	%HV	Date	24hr Volume	%HV
Wednesday	30/06/2010	9388	6.3%	4/08/2010	-	-
Thursday	1/07/2010	9345	6.0%	5/08/2010	10127	5.7%
Friday	2/07/2010	10324	5.6%	6/08/2010	10570	5.6%
Saturday	3/07/2010	8695	3.3%	7/08/2010	8594	3.0%
Sunday	4/07/2010	7223	3.2%	8/08/2010	7529	2.8%
Monday	5/07/2010	8829	6.8%	9/08/2010	9103	5.8%
Tuesday	6/07/2010	9021	6.5%	10/08/2010	9617	5.7%
Wednesday	7/07/2010	9309	6.3%	11/08/2010	9862	5.7%
Thursday	8/07/2010	9518	6.3%	12/08/2010	9928	5.4%

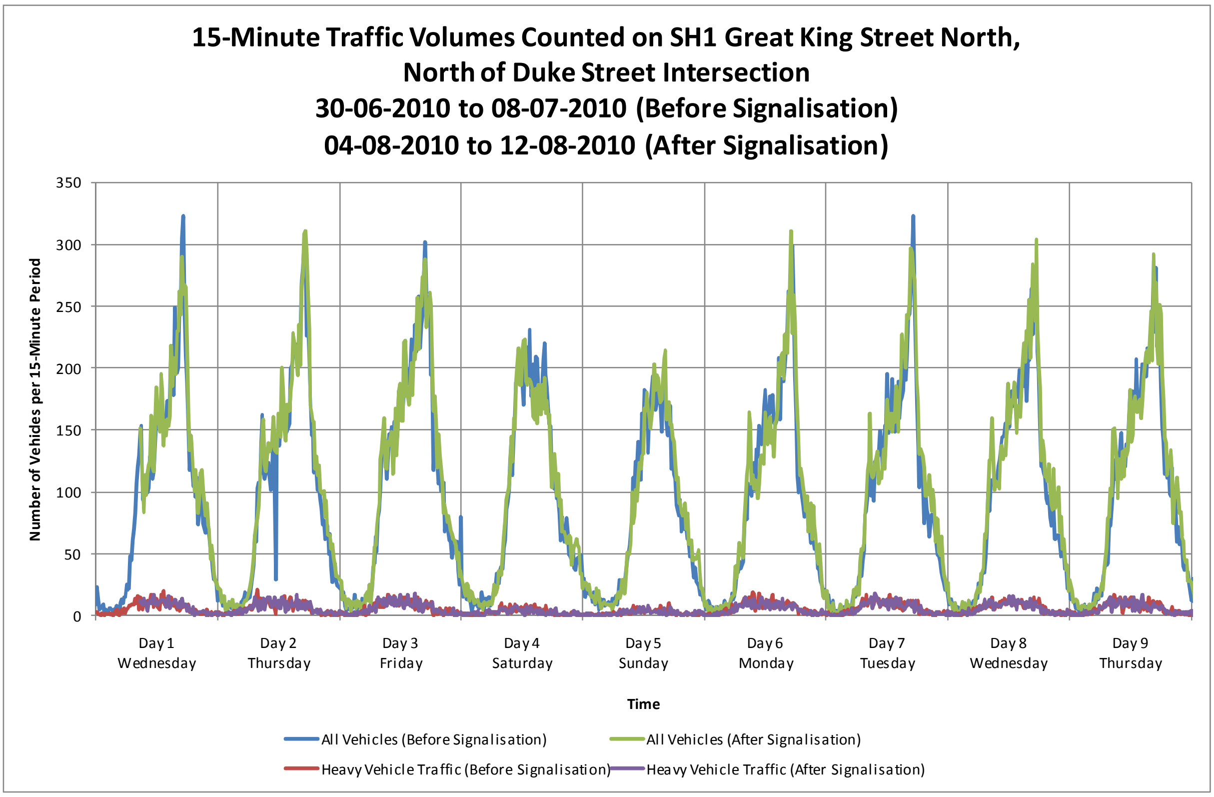


Figure D1 Traffic Volumes on SH1 Great King Street North, North of Duke Street, Before and After Signalisation

TableD2 Traffic Volumes on Duke Street, West of SH1 Great King Street North, Before and After Signalisation

Day	Before Signalisation			After Signalisation		
	Date	24hr Volume	%HV	Date	24hr Volume	%HV
Wednesday	30/06/2010	2351	25.0%	4/08/2010	-	-
Thursday	1/07/2010	2483	13.4%	5/08/2010	2125	2.8%
Friday	2/07/2010	2630	5.6%	6/08/2010	2158	3.3%
Saturday	3/07/2010	2062	4.6%	7/08/2010	2021	3.3%
Sunday	4/07/2010	1686	2.1%	8/08/2010	1533	1.4%
Monday	5/07/2010	2147	3.8%	9/08/2010	1887	3.4%
Tuesday	6/07/2010	2161	4.5%	10/08/2010	2044	3.8%
Wednesday	7/07/2010	2225	3.6%	11/08/2010	1929	3.5%
Thursday	8/07/2010	2416	3.9%	12/08/2010	2112	3.0%

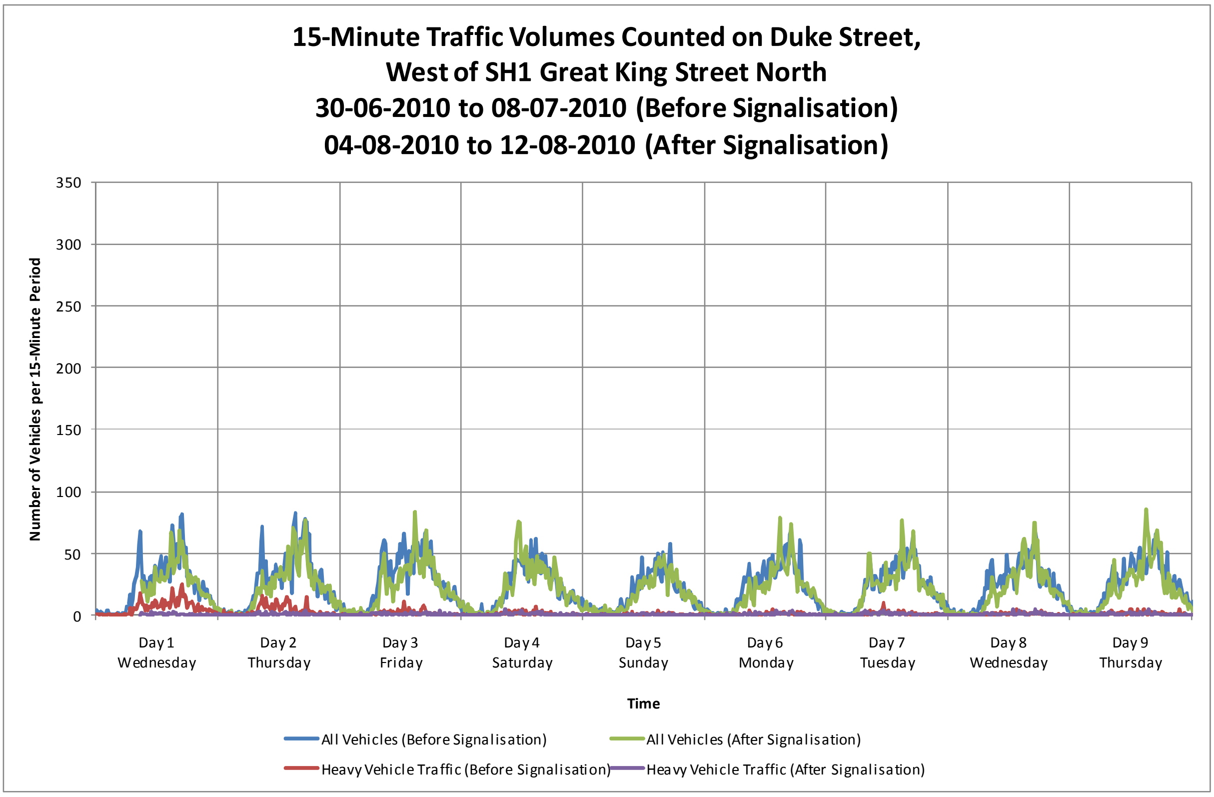
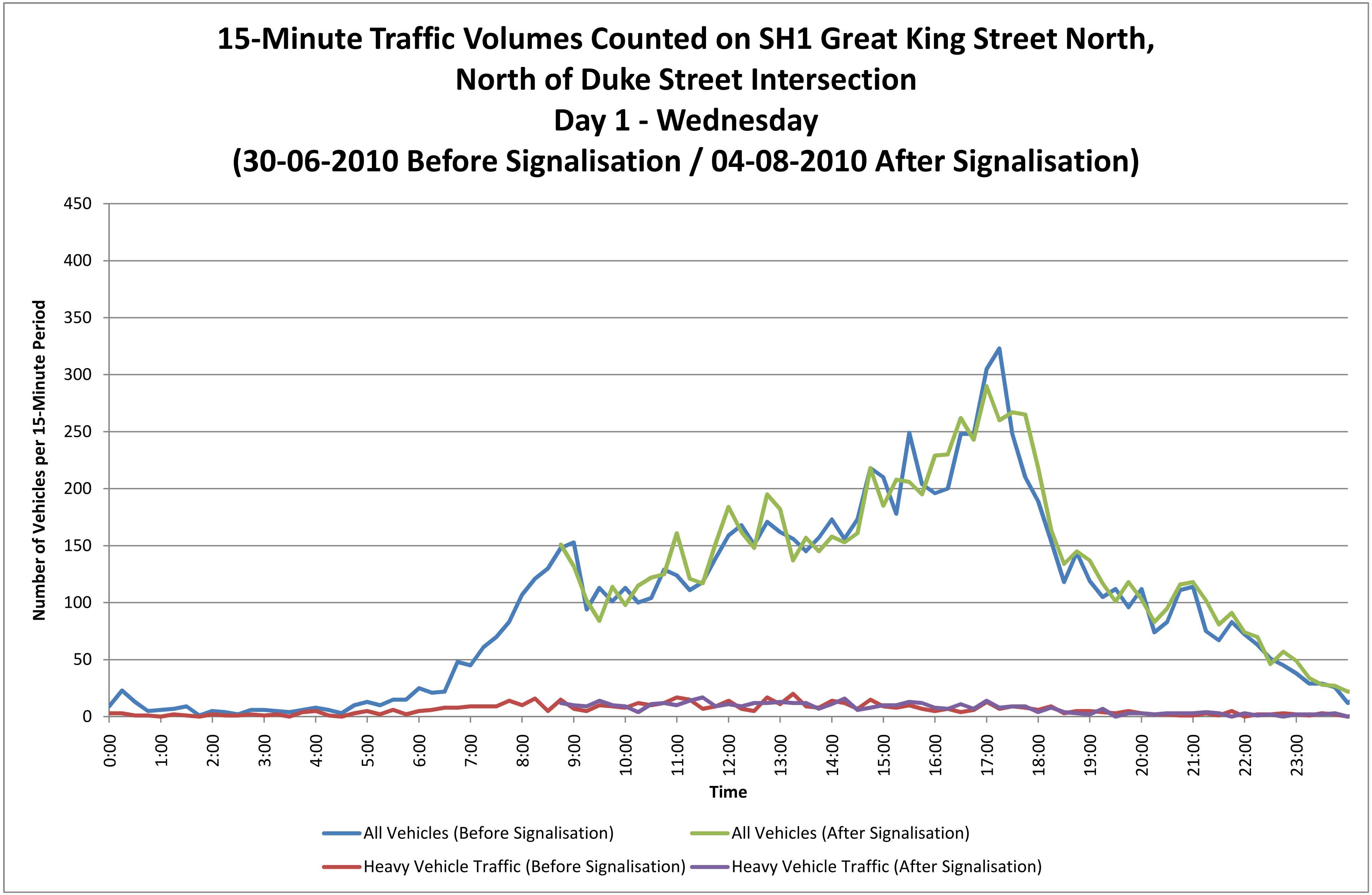
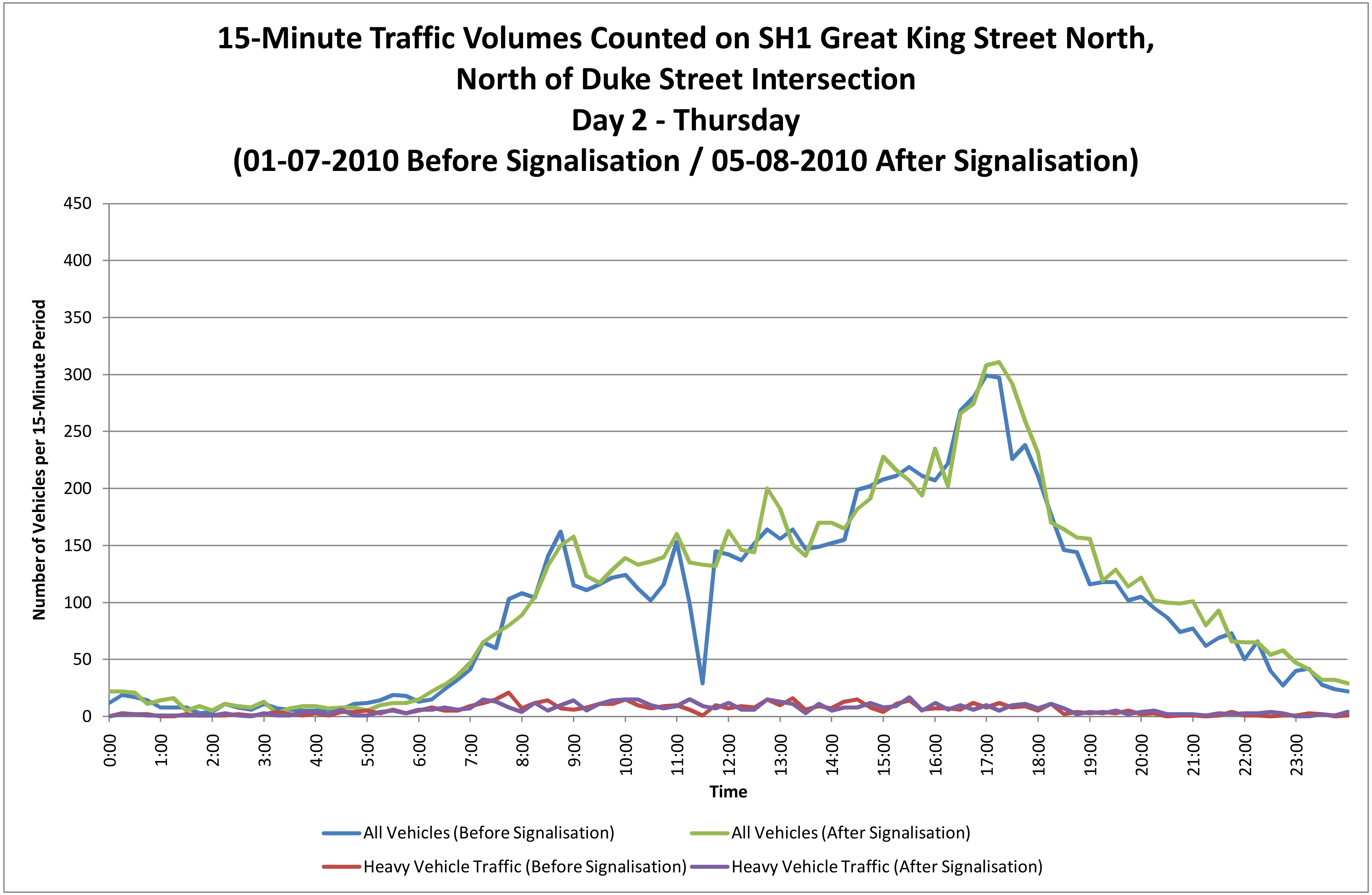


Figure D2 Traffic Volumes on Duke Street, West of SH1 Great King Street North, Before and After Signalisation



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 1 - Wednesday
(30-06-2010 Before Signalisation / 04-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
0
50
100
150
200
250
300
350
400
450
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 2 - Thursday
(01-07-2010 Before Signalisation / 05-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
0
50
100
150
200
250
300
350
400
450
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
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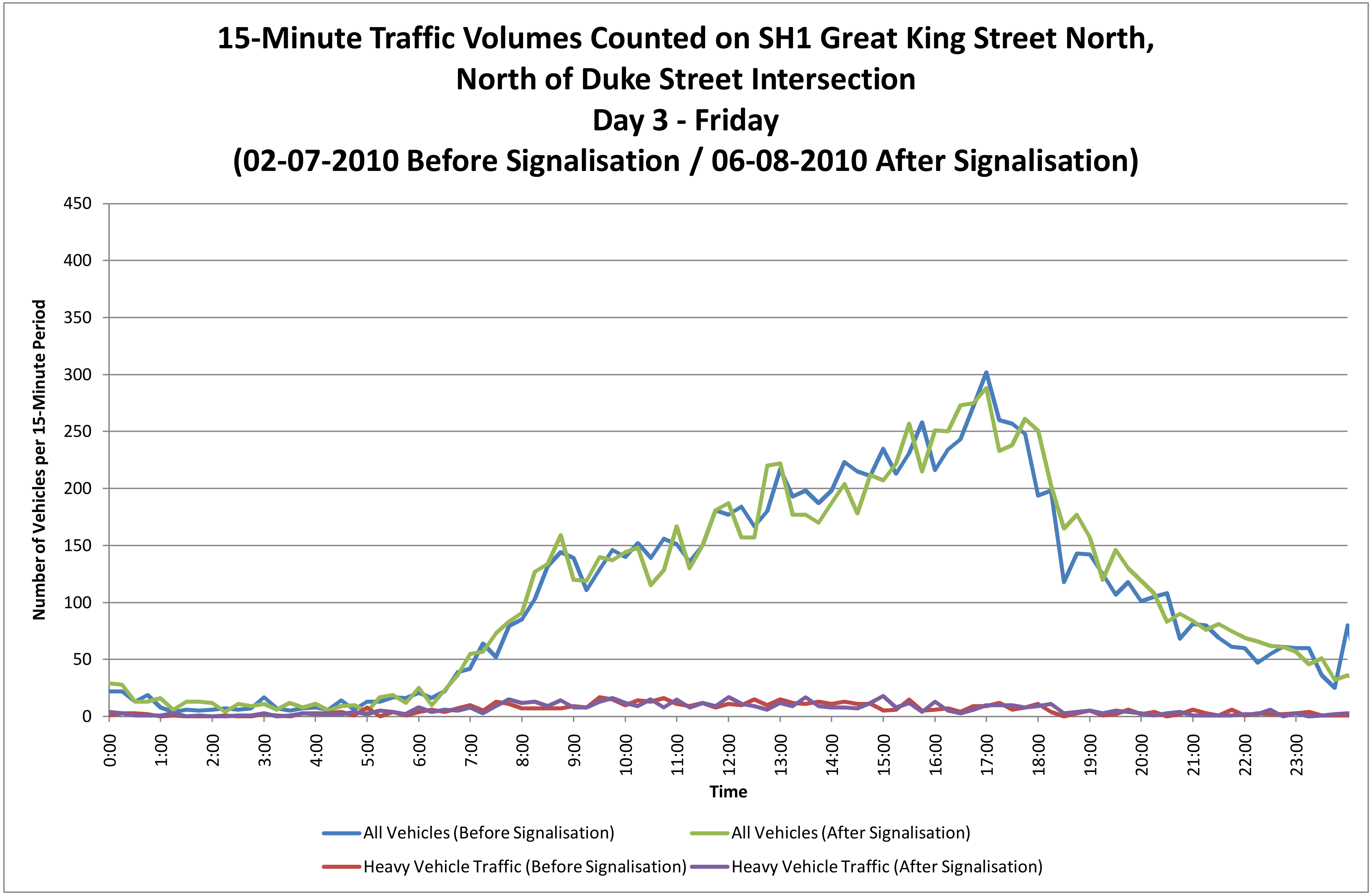
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 3 - Friday
(02-07-2010 Before Signalisation / 06-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
0
50
100
150
200
250
300
350
400
450
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
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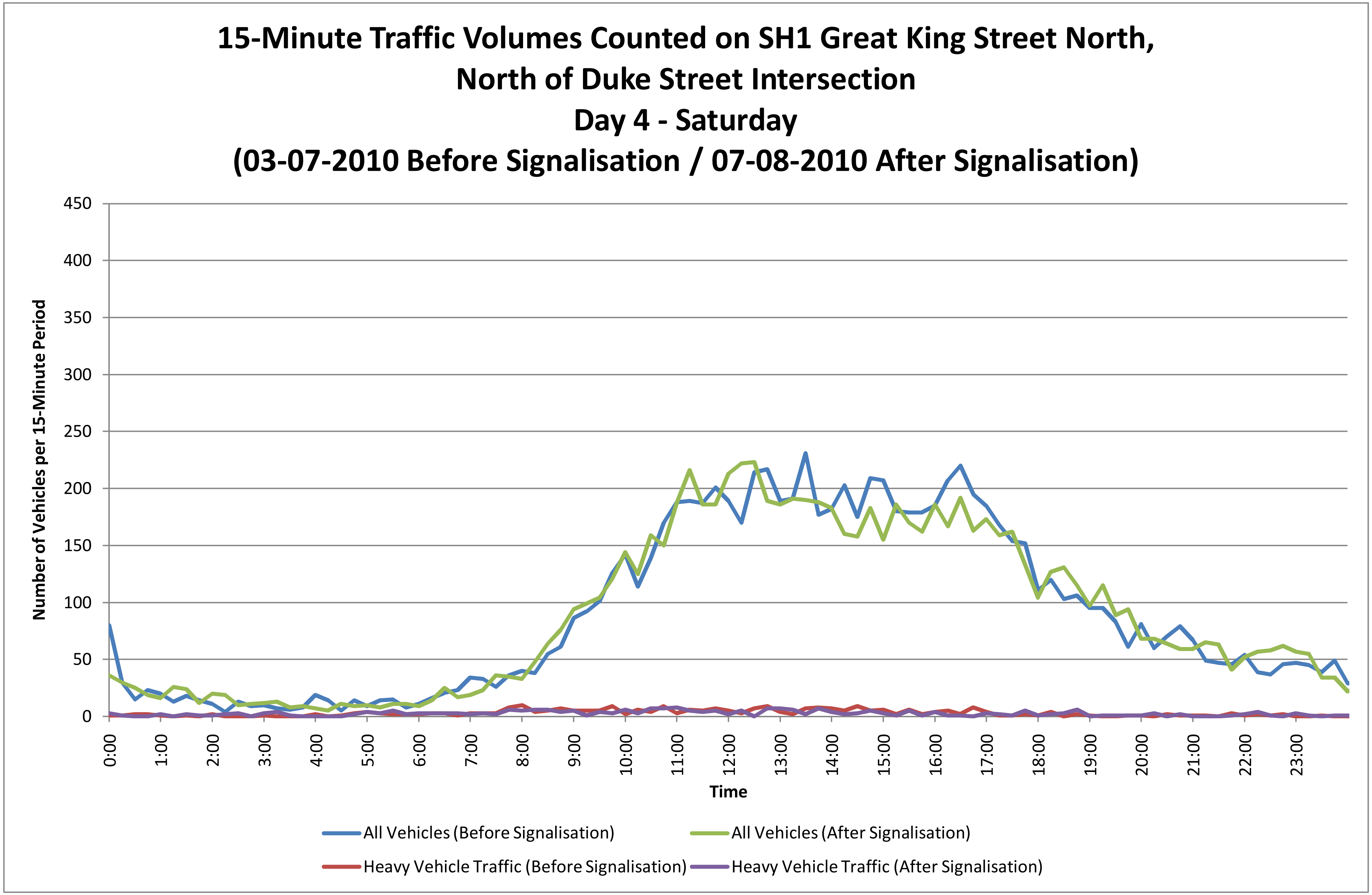
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 4 - Saturday
(03-07-2010 Before Signalisation / 07-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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13:00
14:00
15:00
16:00
17:00
18:00
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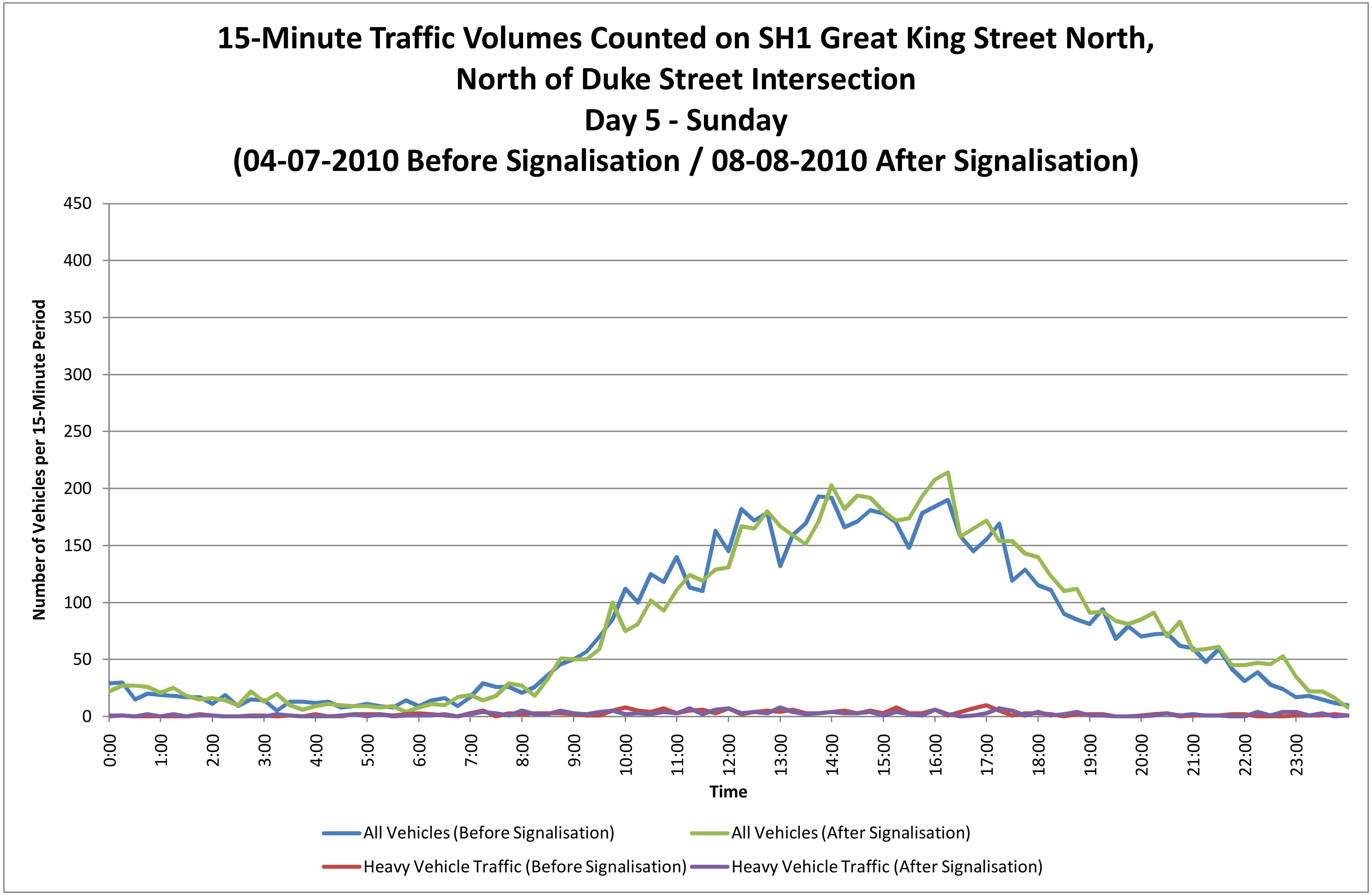
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 5 - Sunday
(04-07-2010 Before Signalisation / 08-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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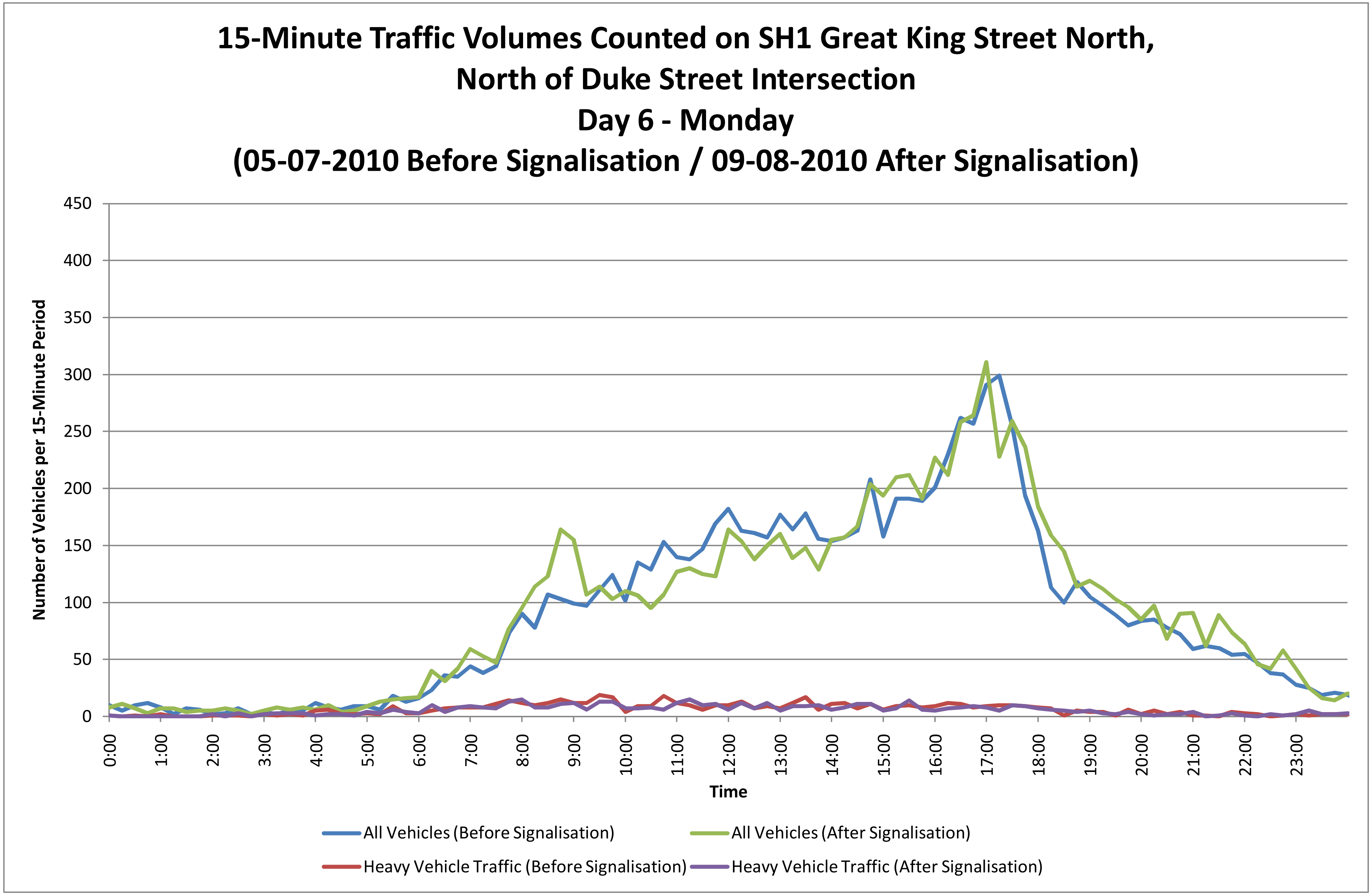
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)


15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 6 - Monday
(05-07-2010 Before Signalisation / 09-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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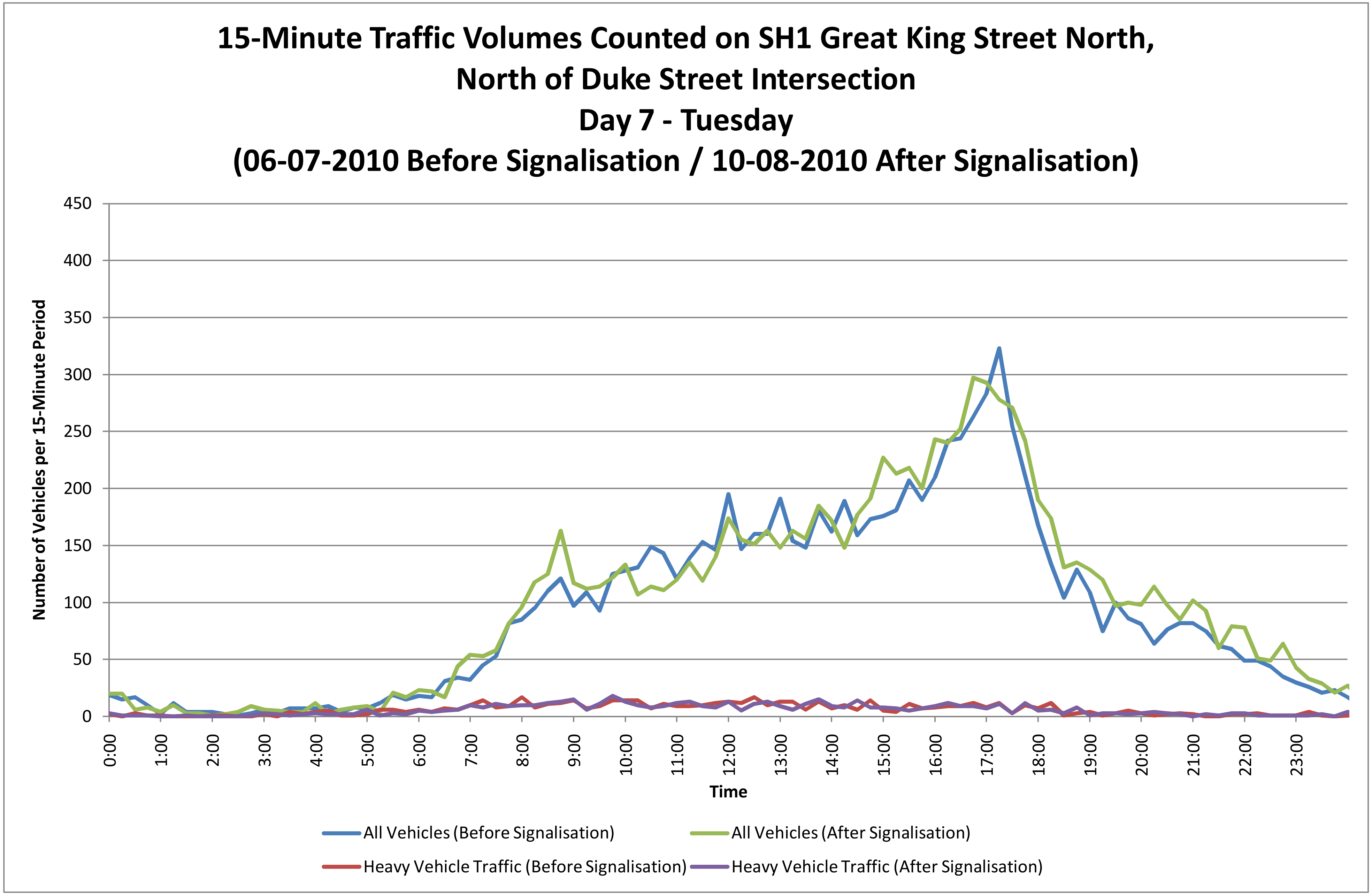
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)


15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 7 - Tuesday
(06-07-2010 Before Signalisation / 10-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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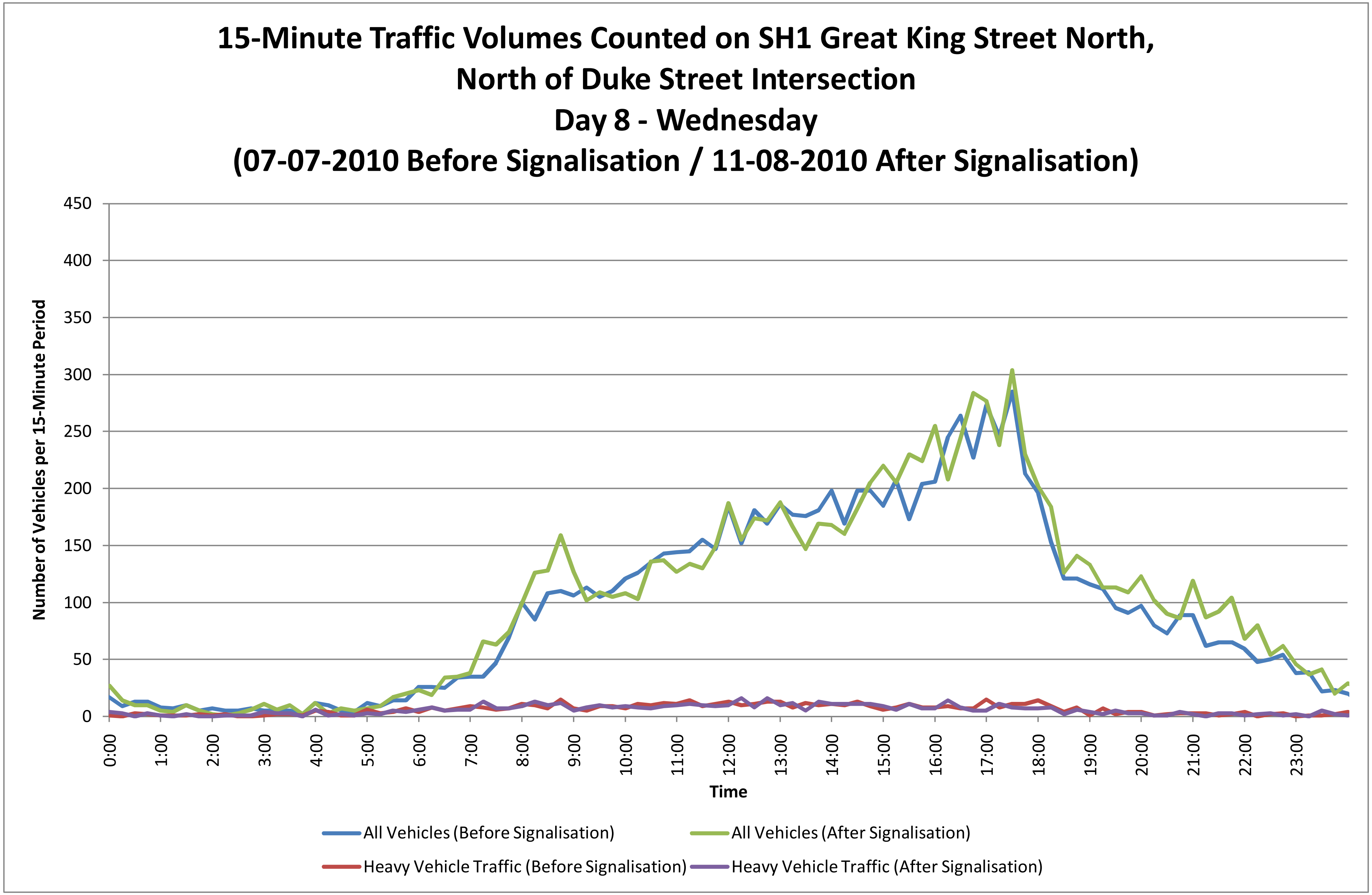
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 8 - Wednesday
(07-07-2010 Before Signalisation / 11-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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12:00
13:00
14:00
15:00
16:00
17:00
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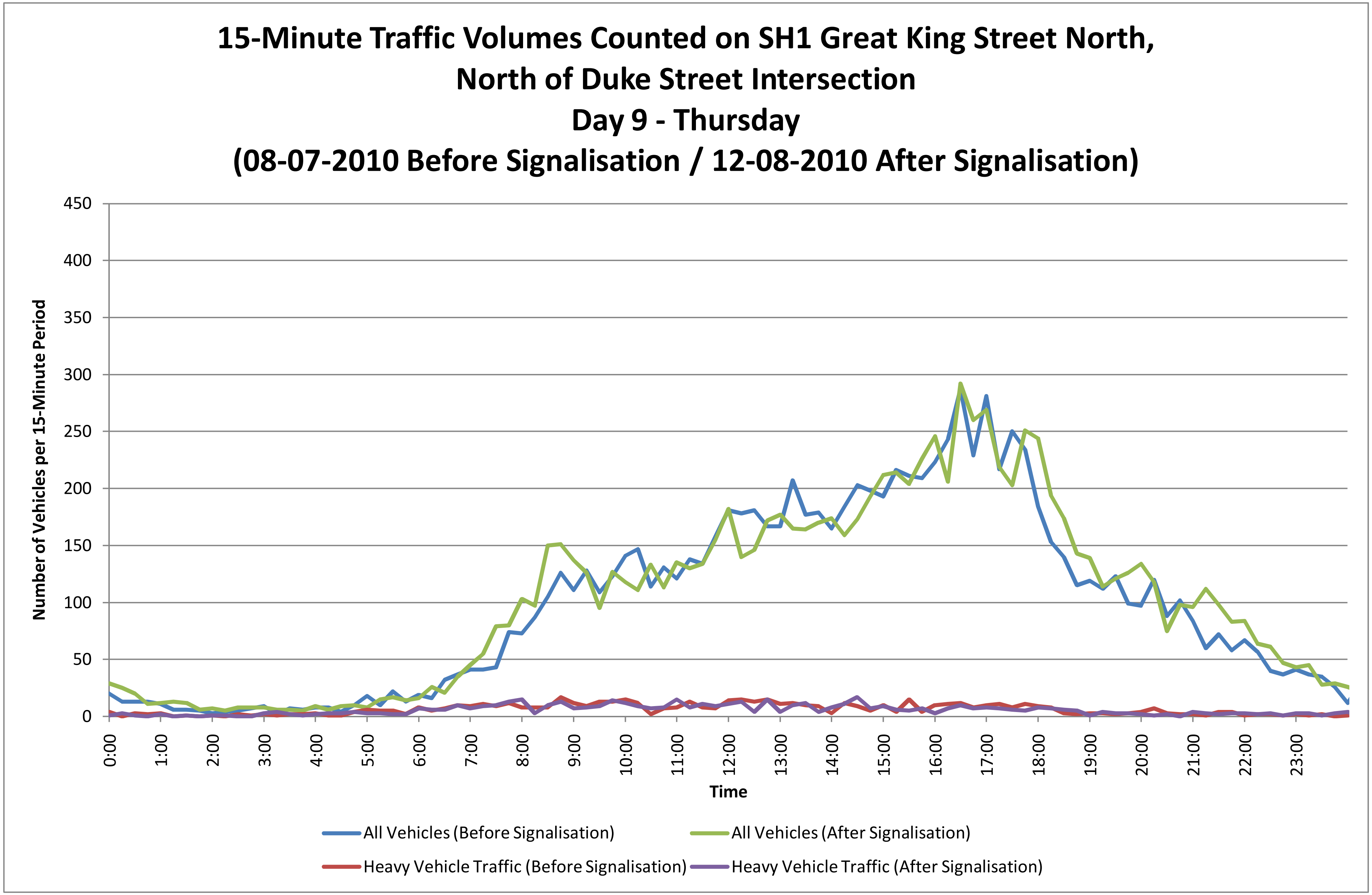
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on SH1 Great King Street North,
North of Duke Street Intersection
Day 9 - Thursday
(08-07-2010 Before Signalisation / 12-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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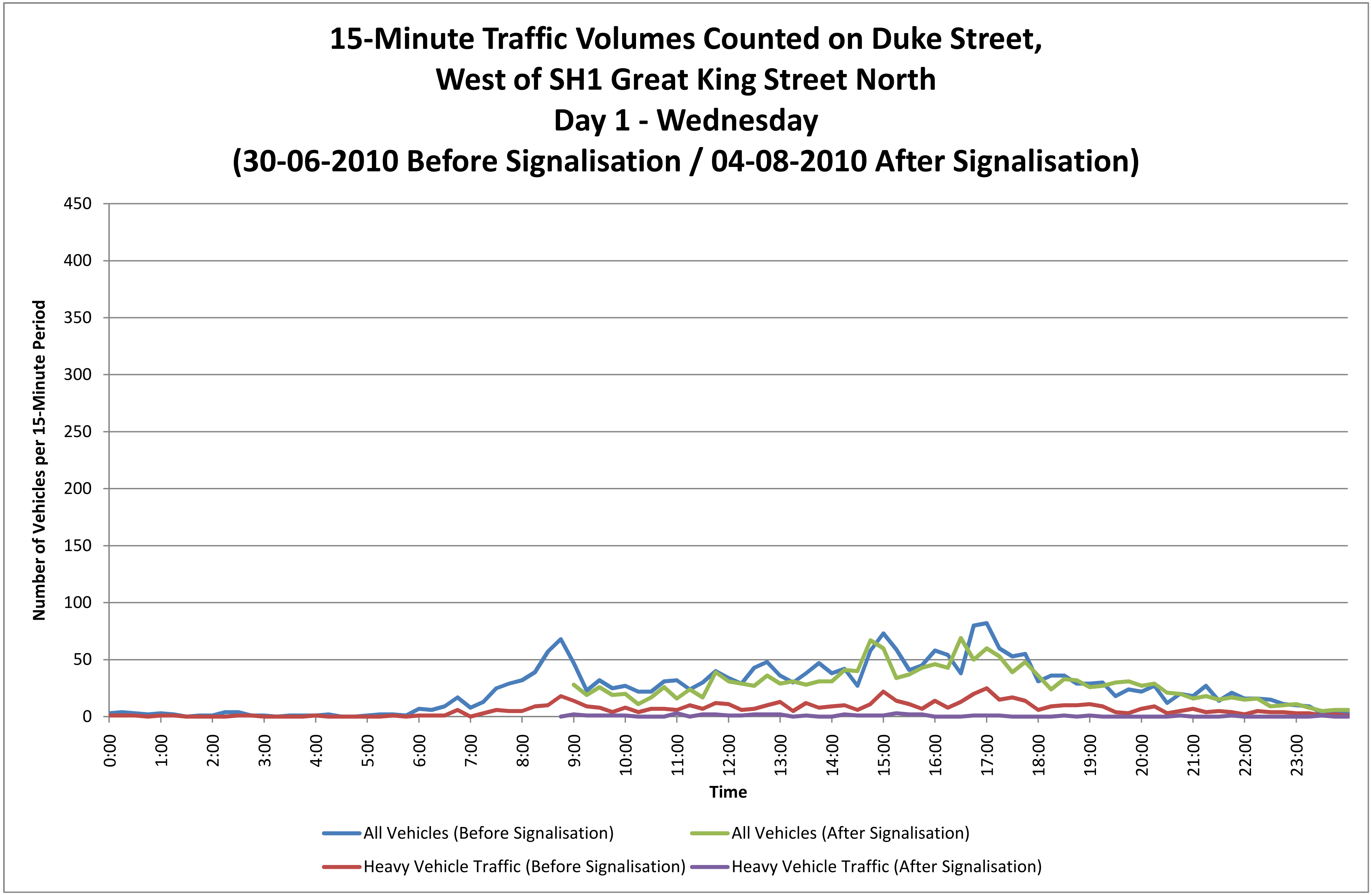
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)


15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 1 - Wednesday
(30-06-2010 Before Signalisation / 04-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
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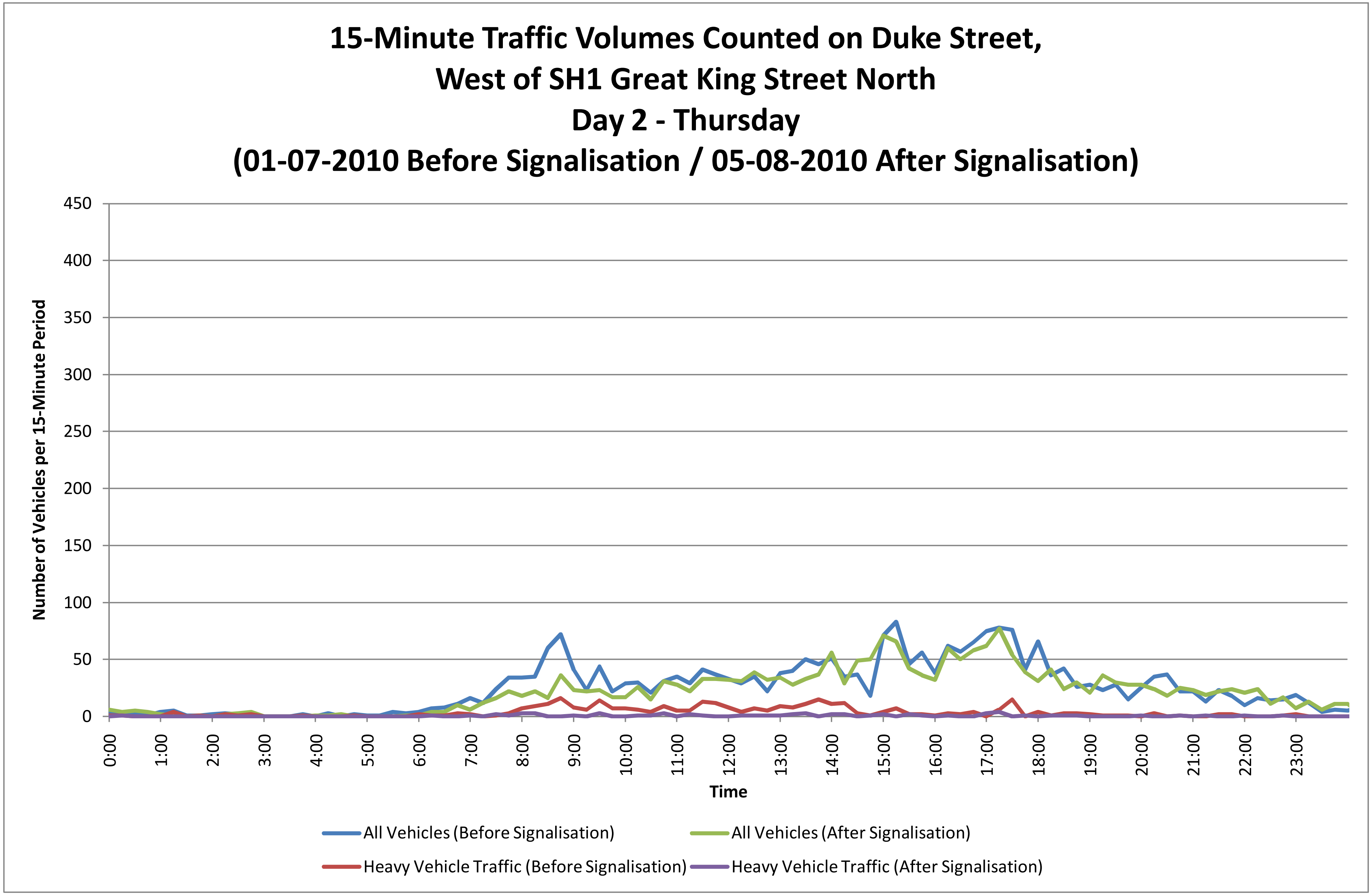
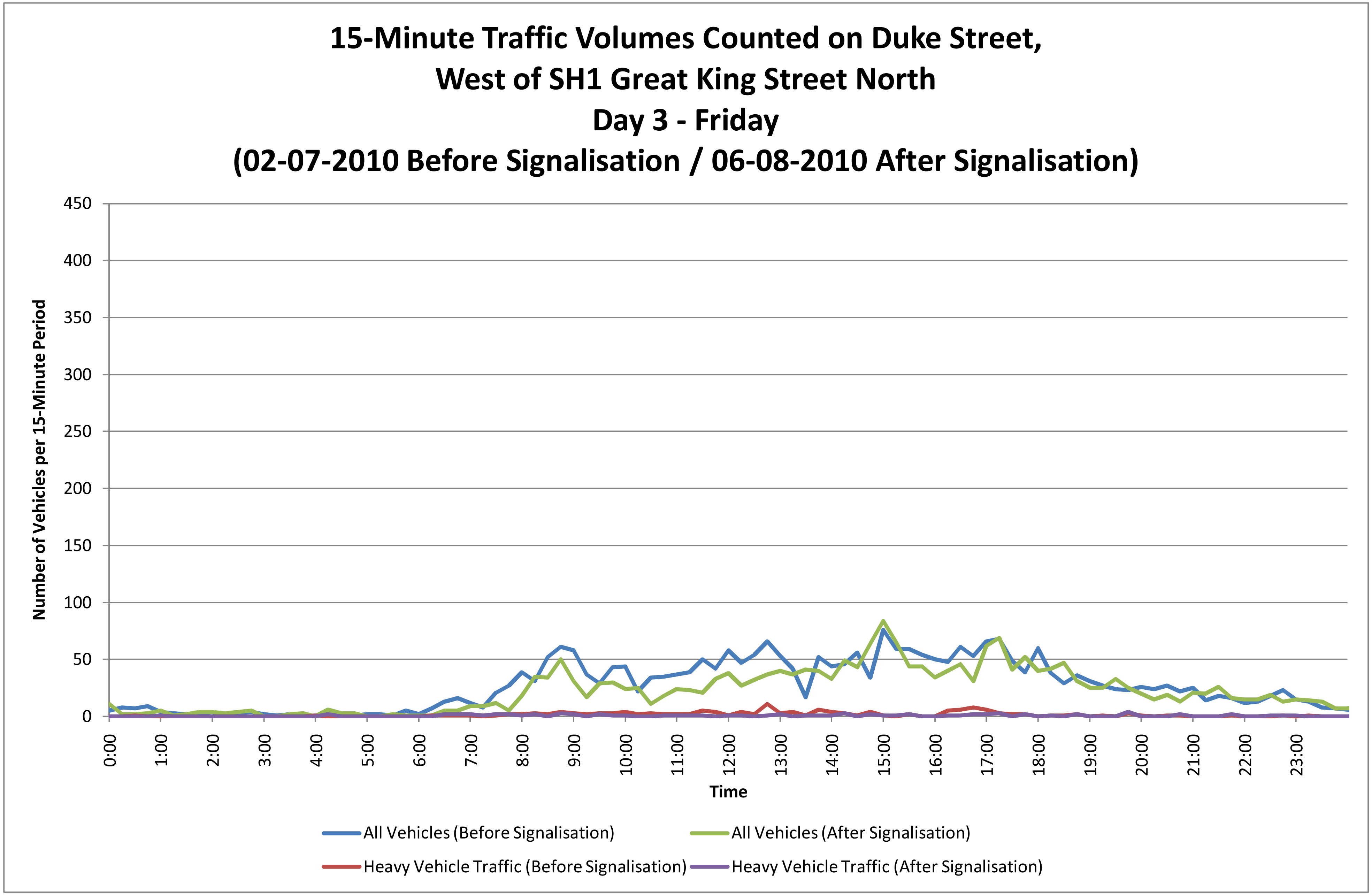
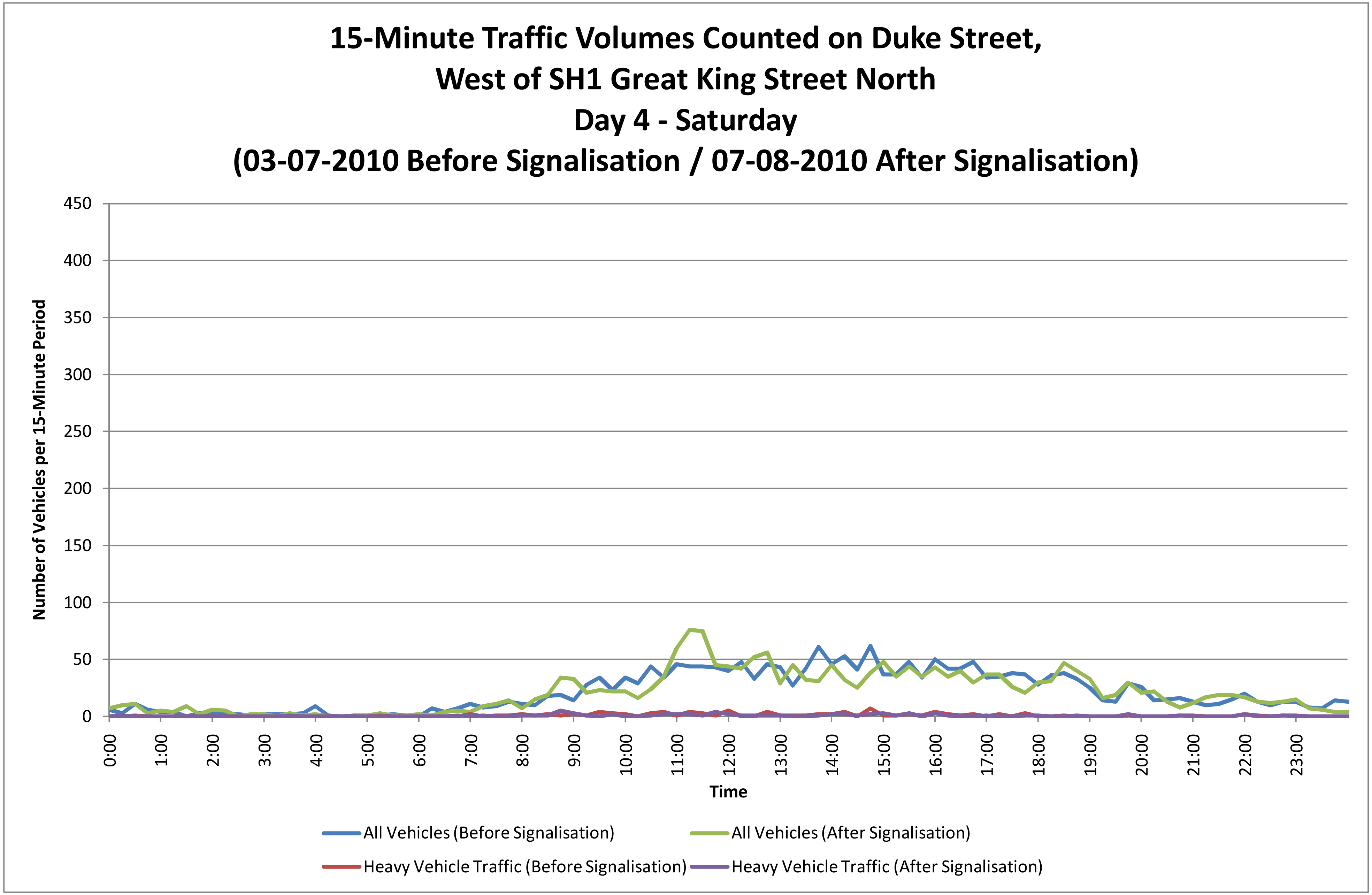
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 2 - Thursday
(01-07-2010 Before Signalisation / 05-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
0
50
100
150
200
250
300
350
400
450
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 3 - Friday
(02-07-2010 Before Signalisation / 06-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)


15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 4 - Saturday
(03-07-2010 Before Signalisation / 07-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
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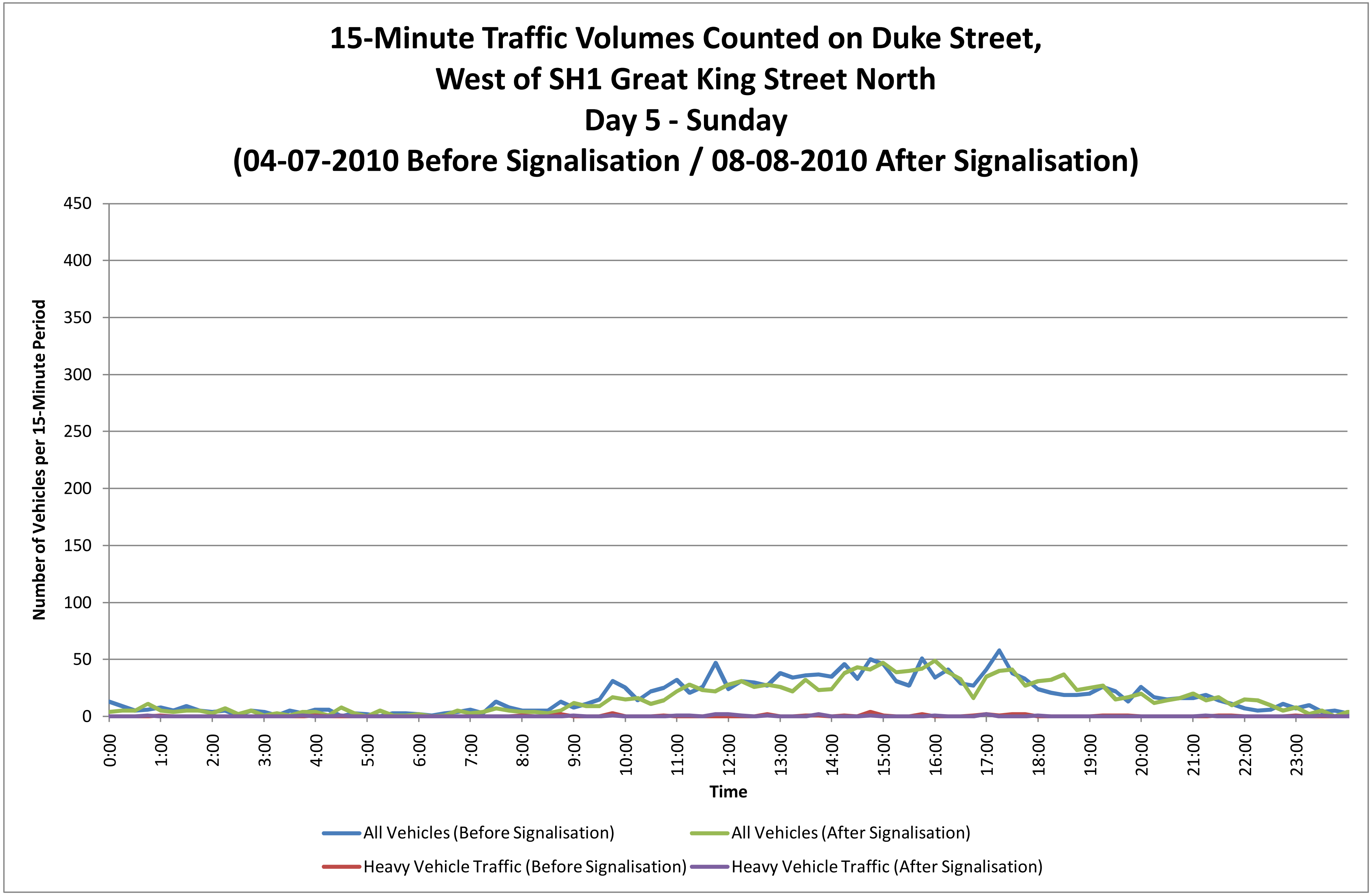
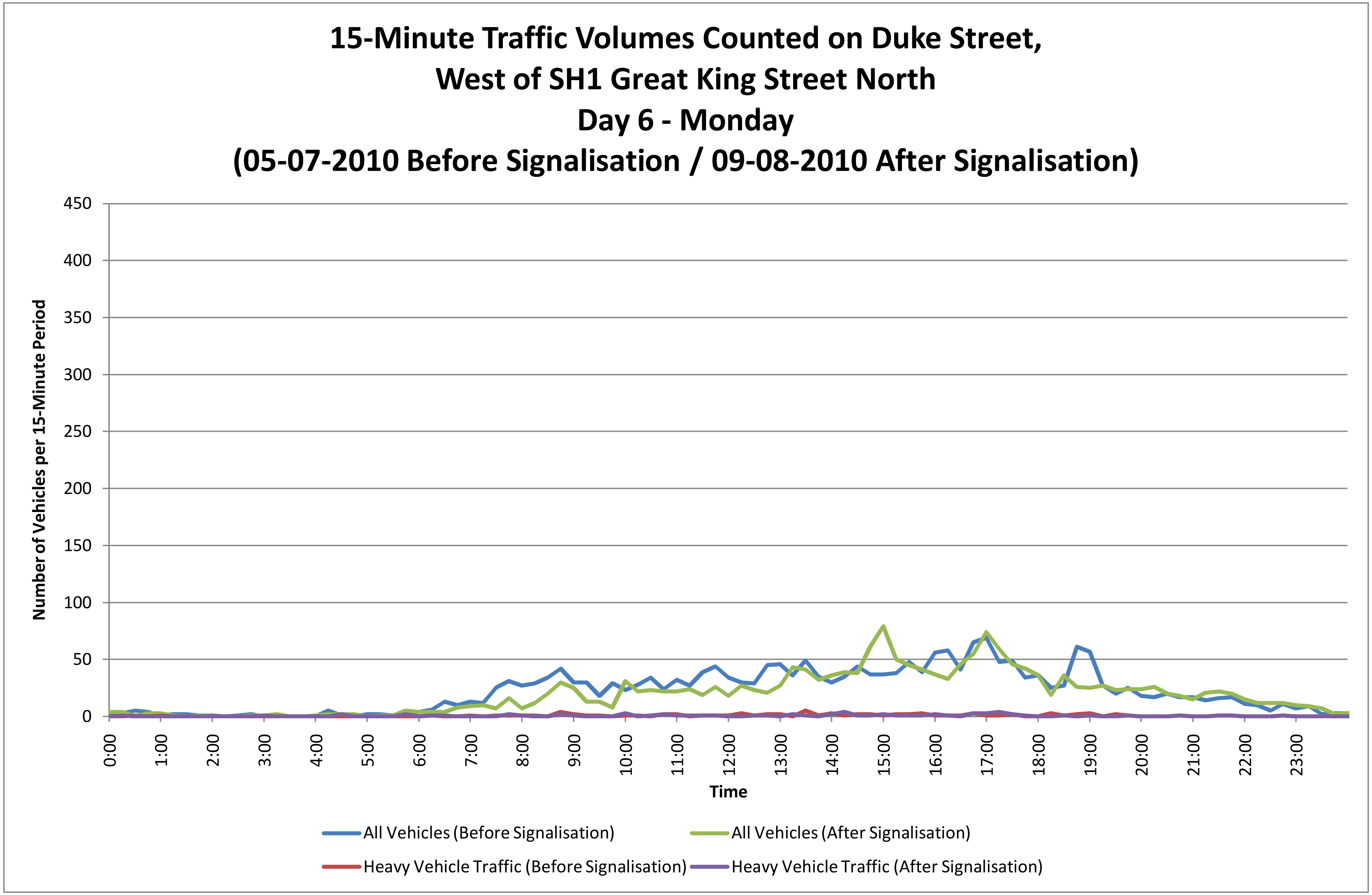
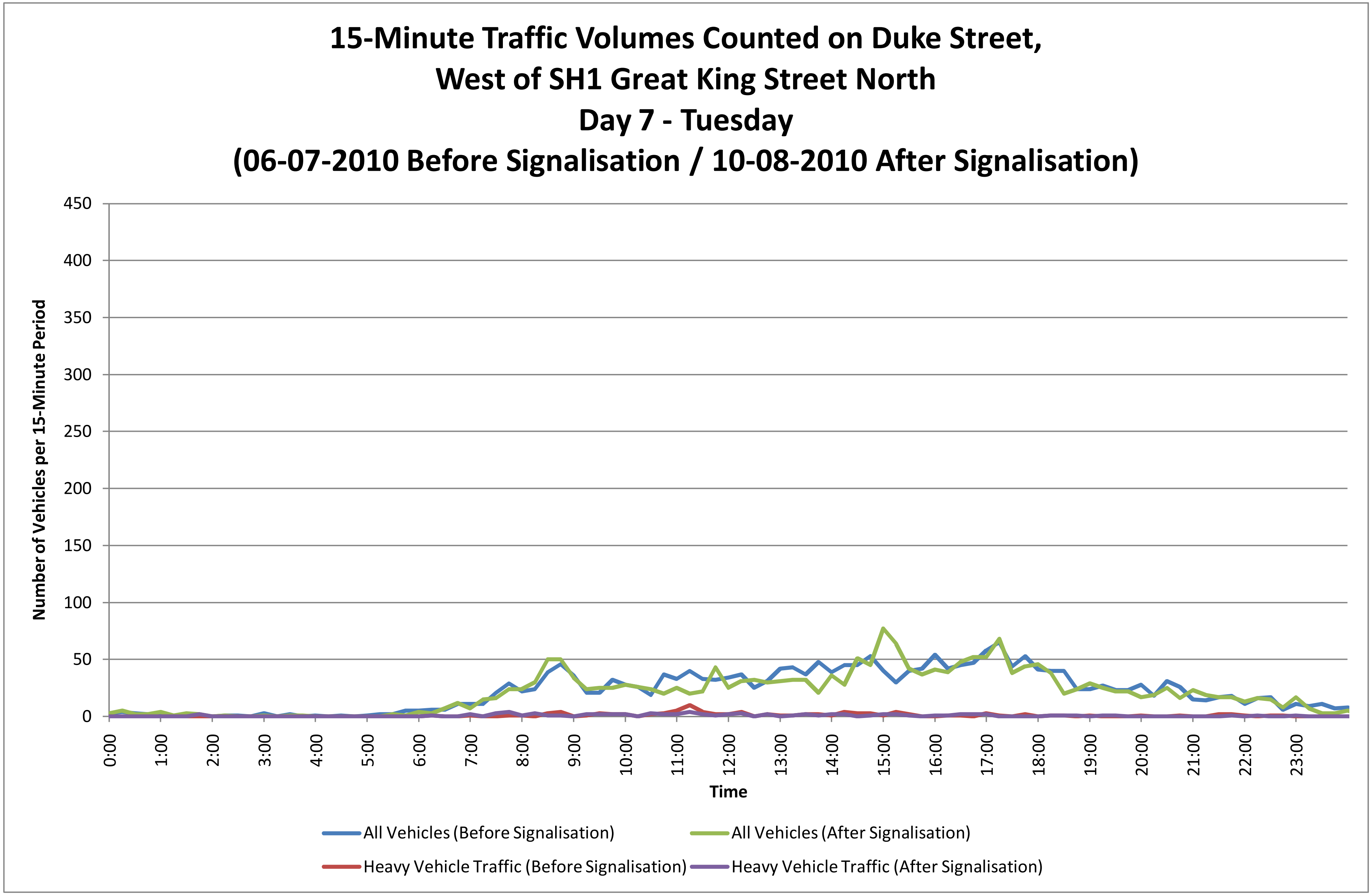
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)

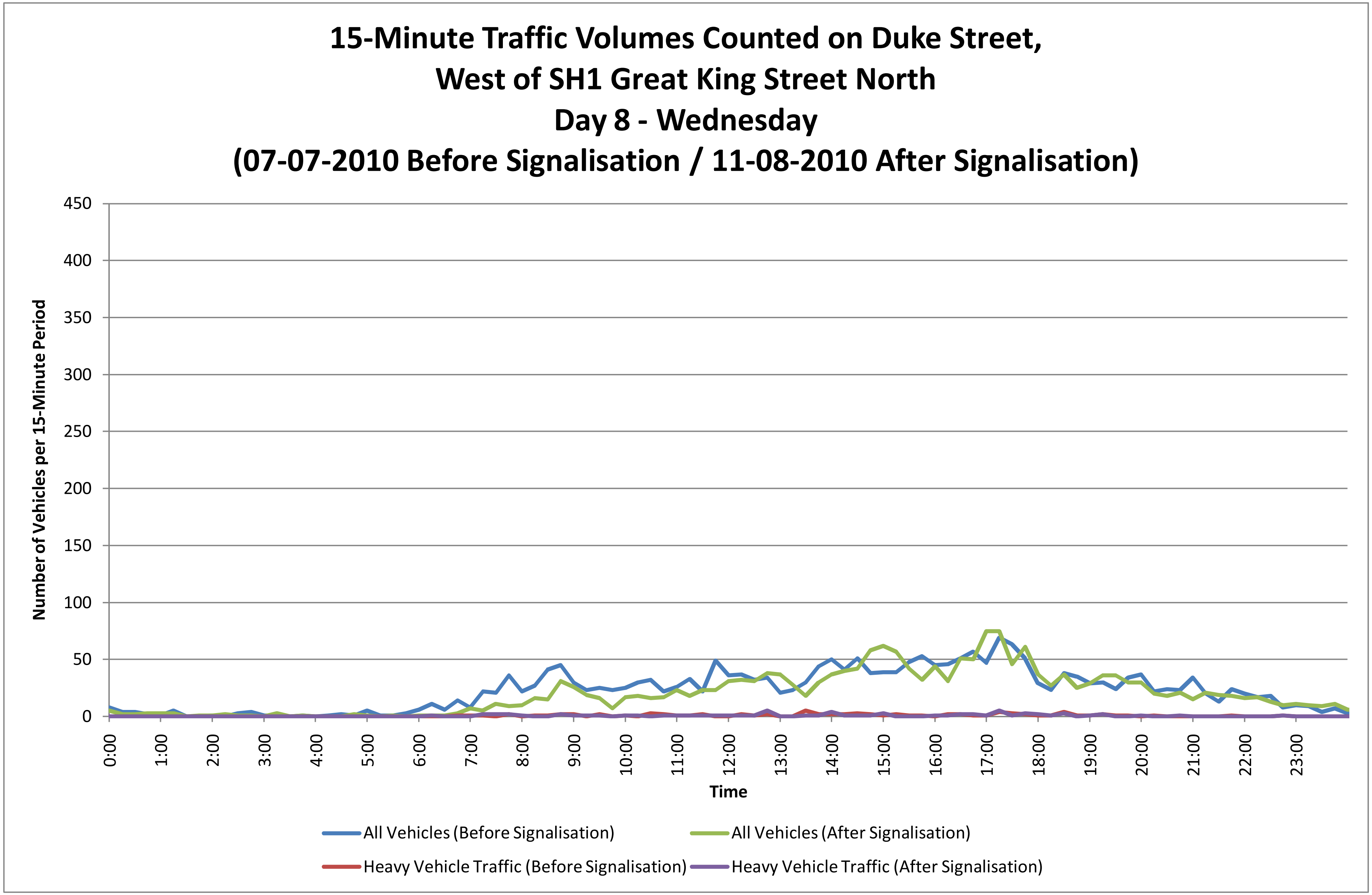

15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 5 - Sunday
(04-07-2010 Before Signalisation / 08-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



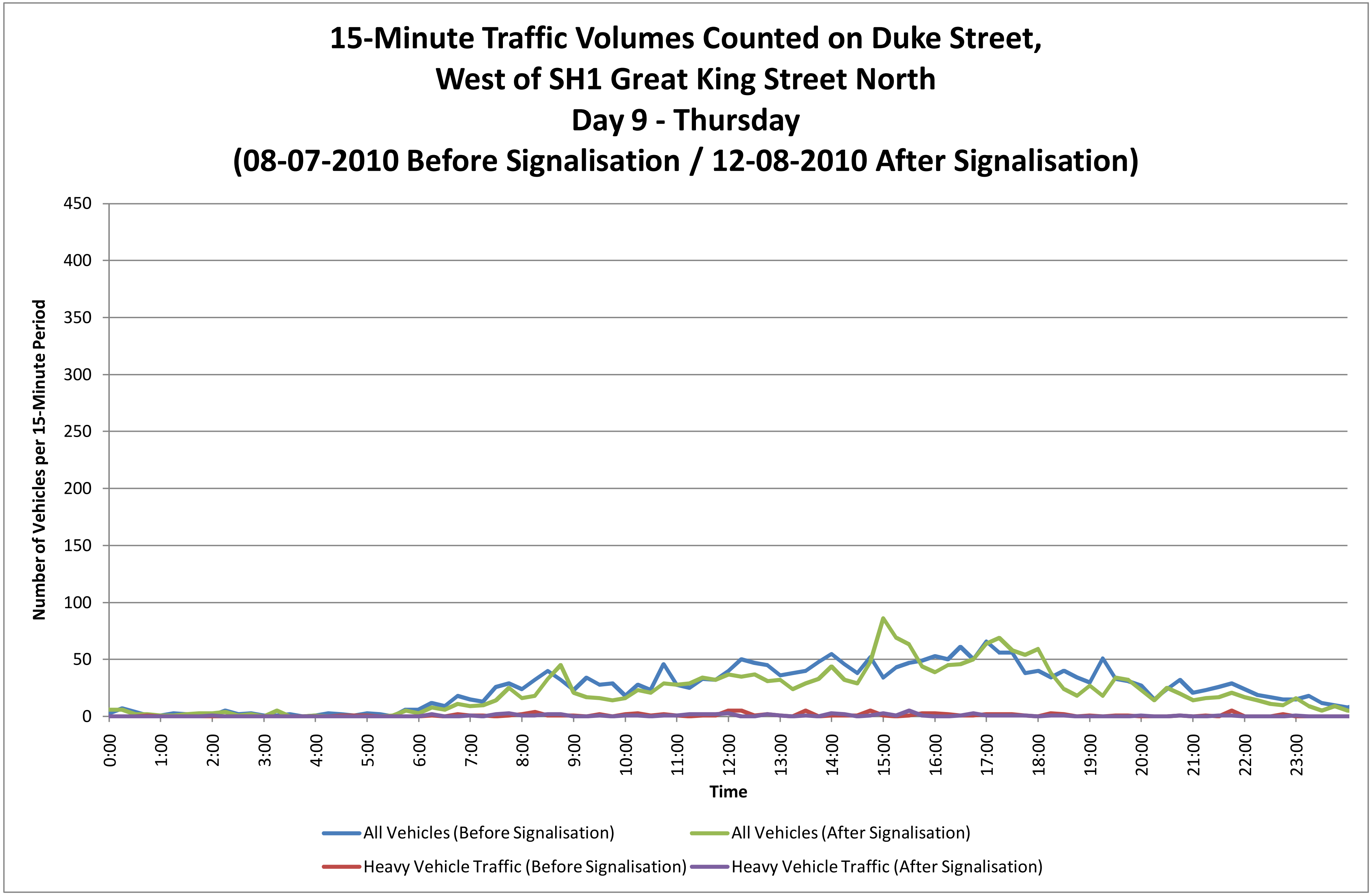
15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 6 - Monday
(05-07-2010 Before Signalisation / 09-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



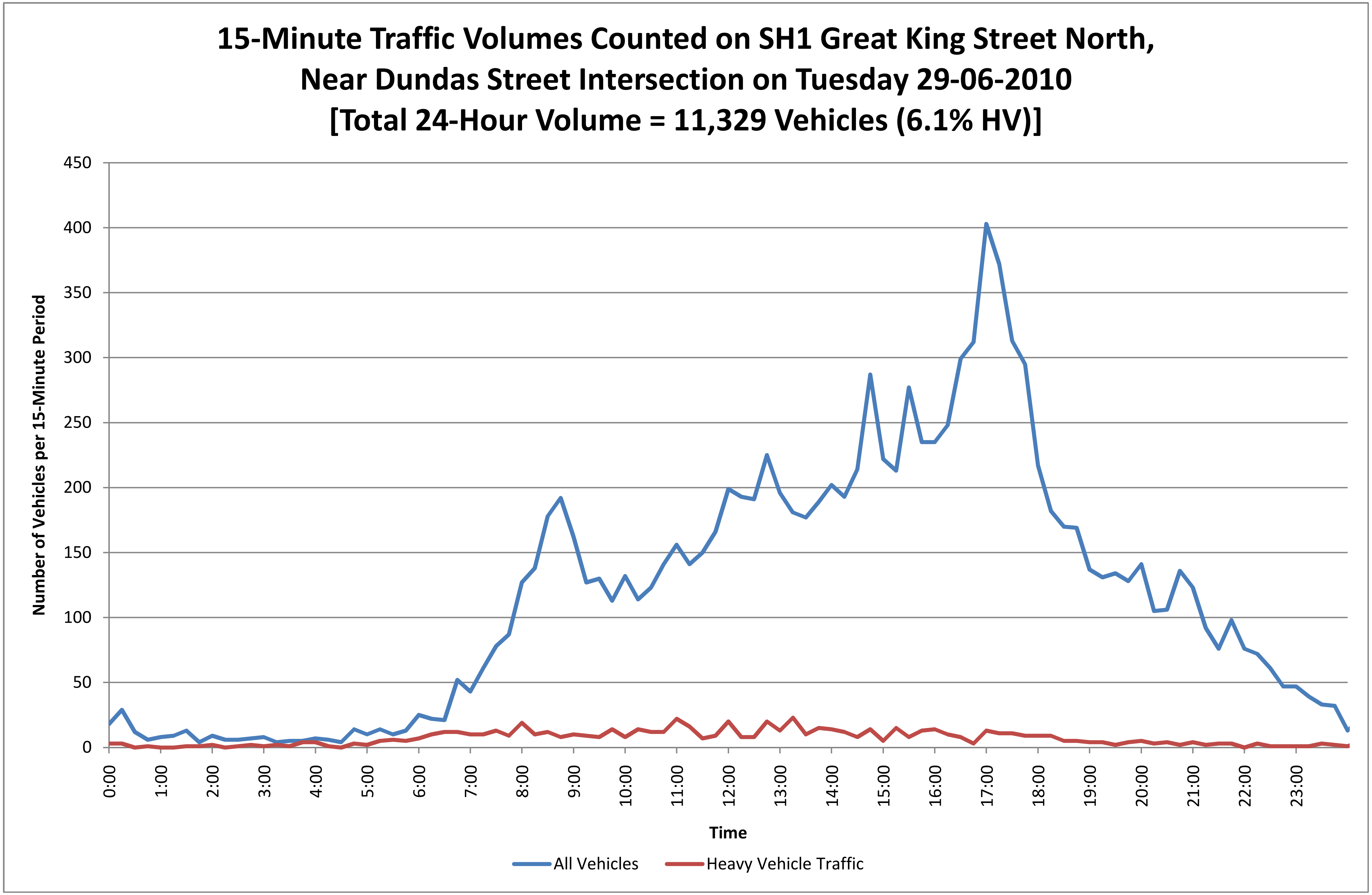
15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 7 - Tuesday
(06-07-2010 Before Signalisation / 10-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 8 - Wednesday
(07-07-2010 Before Signalisation / 11-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)



15-Minute Traffic Volumes Counted on Duke Street,
West of SH1 Great King Street North
Day 9 - Thursday
(08-07-2010 Before Signalisation / 12-08-2010 After Signalisation)
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles (Before Signalisation)
All Vehicles (After Signalisation)
Heavy Vehicle Traffic (Before Signalisation)
Heavy Vehicle Traffic (After Signalisation)


15-Minute Traffic Volumes Counted on SH1 Great King Street North,
Near Dundas Street Intersection on Tuesday 29-06-2010
[Total 24-Hour Volume = 11,329 Vehicles (6.1% HV)]
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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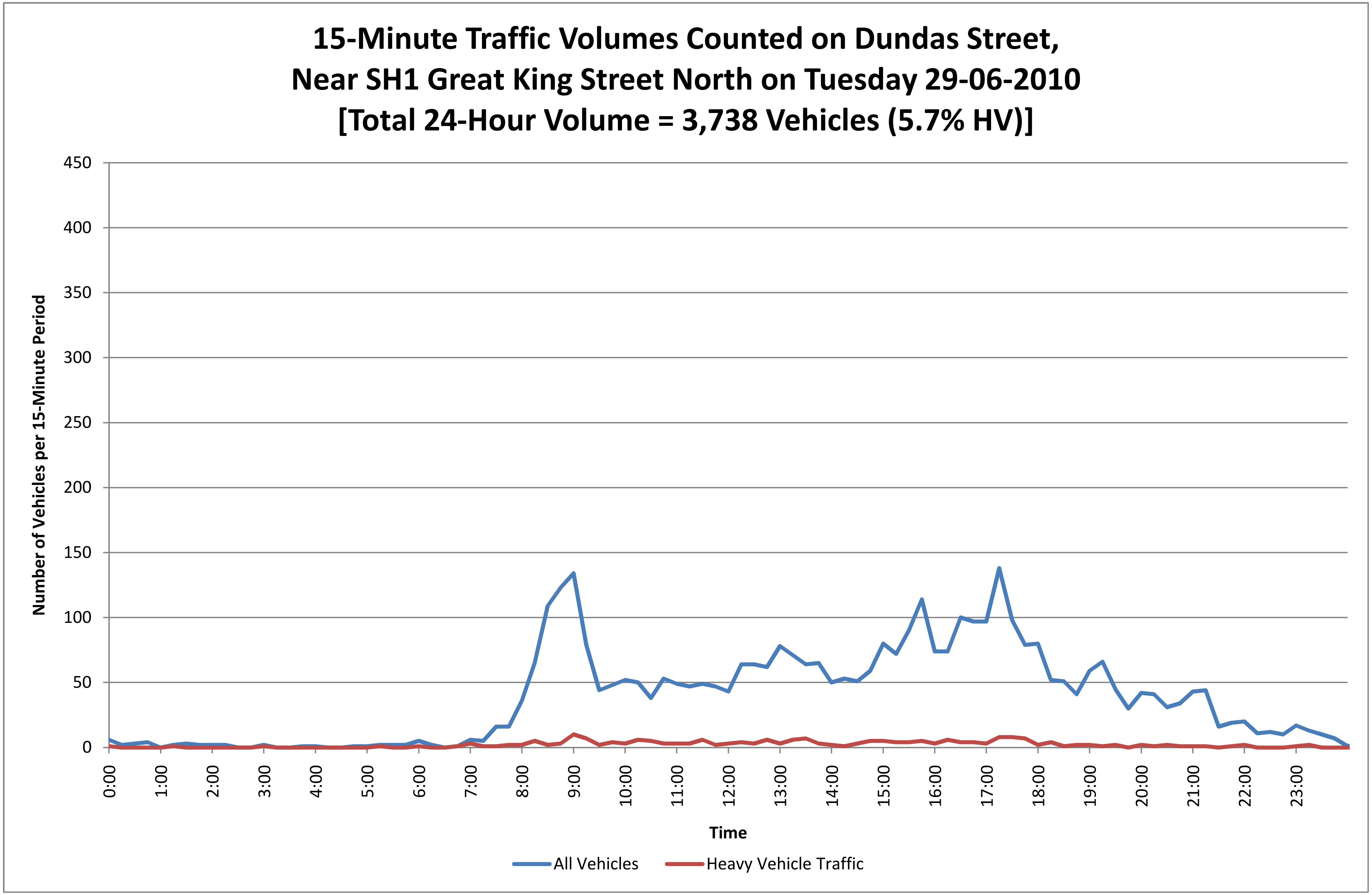
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time
All Vehicles
Heavy Vehicle Traffic



15-Minute Traffic Volumes Counted on Dundas Street,
Near SH1 Great King Street North on Tuesday 29-06-2010
[Total 24-Hour Volume = 3,738 Vehicles (5.7% HV)]
Number of Vehicles per 15-Minute Period
450
400
350
300
250
200
150
100
50
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
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19:00
20:00
21:00
22:00
23:00
Time
All Vehicles
Heavy Vehicle Traffic

Appendix F

Photograph of Traffic Sensors on SH1 at Duke Street Intersection

Appendix F Photograph of Traffic Sensors on SH1 at Duke Street Intersection

Figure F1 Photograph of Traffic Sensors on SH1 at Duke Street Intersection

Appendix G

Uncertainty Estimate

Appendix G Uncertainty Estimate

Measurement uncertainty in this investigation has been estimated to be ± 3.8 dB with a confidence level of 95%. The following table presents details of the uncertainty estimate:

Source of Uncertainty	Magnitude of Uncertainty (half width)	Conversion to dB	Uncertainty Distribution	Standard Uncertainty, dB	Notes
Source					
Traffic volume and %HV	8% variation in traffic volume and 1% variation in HV	0.6	Rectangular	0.3	N1
Traffic speed	4% variation in mean traffic speed	0.2	Rectangular	0.1	N2
Road surface	± 1.0 dB	1.0	Rectangular	0.6	N3
Transmission path					
Weather	-	0.0	Rectangular	0.0	N4
Ground	-	0.0	Rectangular	0.0	N5
Topography	-	0.0	Rectangular	0.0	N6
Receiver					
Position	10% of distance from road	0.4	Rectangular	0.2	N7
Instrumentation	± 1.9 dB	1.9	Rectangular	1.1	N8
Background noise influence	± 1.0 dB	1.0	Rectangular	0.6	N9
Reflective surfaces	± 1.5 dB	1.5	Rectangular	0.9	N10
Screening due to parked cars	± 1.5 dB	1.5	Rectangular	0.9	N11
Combined uncertainty				**1.9**	
Expanded uncertainty (95% confidence)				**3.8**	

Notes:

N1. Although variation in traffic volume has been accounted for in normalisation of the results, the normalisation is based on theoretical relationships and therefore still subject to uncertainty, since the theory-based normalisation adjustment may or may not accurately reflect the real effects.

N2. Variation in traffic speeds between the 'before' and 'after' measurements is a source of uncertainty as it is not known how much of the variation is due to the signals and how much is due to typical day to day variation.

N3. No change in road surface type. Road dry in both sets of 3hr 'before' and 'after' measurements. Uncertainty value accounts for limited periods of rainfall during longer term measurements at Location C.

N4. Differences in weather conditions would have negligible effect on noise propagation since all measurement locations were close to the road.

N5. No difference between 'before' and 'after' measurements.

N6. No difference between 'before' and 'after' measurements.

N7. Same position used for before and after measurements. The estimated uncertainty accounts for uncertainty in the distance measurement used for normalisation, and the uncertainty due to the traffic volume not being split exactly between the two lanes (and therefore changing hte effective source distance).

N8. Type 1 sound level meters used except Location

N9. Estimated.

N10. Estimated based on ISO 1996-2 Annex B.

N11. Estimated from measurements.