SOUND MEASUREMENTS

for

CITY OF MEDINA – SR520

Submitted to:

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CONTENTS

1. INTRODUCTION

This report presents measurements and evaluation of sound levels measured in the City of Medina, in the vicinity of the newly opened SR-520 Bridge Replacement and HOV Project and in other areas of the City. The scope of the report is to present sound levels measured at residential parkland properties in Medina, near and remote to SR-520; to evaluate measured and derived sound levels with respect to Federal Highway Administration (FHWA) and Washington State Department of Transportation (WSDOT) noise criteria; and to provide a discussion of sound levels from traffic passing over expansion joints near the eastern approach to the Bridge.

2. SOUND LEVEL DESCRIPTORS

Sound is measured as sound level in units of decibels, dB. Environmental sound is often measured as A-weighted sound level in dBA. The A-weighting is a specific weighting filter in a sound level meter that corresponds to human hearing sensitivity at the various sound frequencies. People normally experience sound levels between about 30 and 90 dBA, depending on their activity. For example, a loud nearby vehicle, radio or power tool may produce 80 to 90 dBA, normal conversation is about 50 to 60 dBA, and a bedroom or quiet office is about 30 to 40 dBA.

Each 10-dB increase in sound level corresponds to a tenfold increase of sound energy, but is judged by a listener as only a doubling of loudness. The smallest changes in sound level considered clearly noticeable are about 3 to 5 dBA.

Sound levels from two or more sources are combined using logarithms, not by adding the levels. When two levels are combined, the louder level predominates, and the combined level is the louder level plus 0 to 3 dBA. Some examples: 50 dBA combined with 50 dBA is 53 dBA, and 50 dBA combined with 40 dBA results in 50.4 dBA.

The smallest, just noticeable increase in the level of a source of steady noise is about 3 dBA, while a 5-dBA increase is clearly perceptible, and a 10 dBA increase causes a doubling of perceived loudness. For example, 70 dBA is judged to be twice as loud as 60 dBA and four times as loud as 50 dBA. Table 2-1 summarizes how increases in perceived loudness correlate with dBA sound level increases.

TABLE 2-1 Perceived changes in loudness based on increases in sound levels	
Sound Level Increase (dBA)	**Judged Loudness Increase**
0 – 2	Imperceptible
3	Just Perceptible
5	Moderate Increase
10	Twice as Loud
20	Four Times as Loud

Because sound levels fluctuate over time, several sound-level descriptors are used to characterize the sound. In this report, the following descriptors are used:

Leq — **Equivalent sound level, Leq**, is the most commonly used descriptor for measuring fluctuating sound. The Leq is the level of a constant sound that, over a given time period, contains the same amount of sound energy as the measured fluctuating sound.

Lmax — **Maximum sound level, Lmax**, is the highest instantaneous sound level for a given sound source, event or time period.

Frequency — **Frequency**, expressed in Hertz (Hz), is a measure of the rate of oscillations of a sound, roughly correlating with musical pitch.

Sound Spectrum — For a sound comprising energy over a range of frequencies, the spectrum quantifies the distribution of sound energy by frequency. Often the spectrum is shown in frequency bands with widths of one octave or one-third of one octave.

Lmin — **Minimum Sound Levels, Lmin,** is the lowest instantaneous sound level for a given sound source, event or time period.

3. NOISE CRITERIA

3.1 Federal Highway Administration and Washington State Department of Transportation

Federal Highway Administration (FHWA) criteria are contained in Title 23 of the Code of Federal Regulations Part 772, **Procedures for Abatement of Highway Traffic Noise and Construction Noise**, (23 CFR 772) and its interpretation by WSDOT (**Washington State Department of Transportation Traffic Noise Policy and Procedures**, 2011).

The WSDOT uses noise "design levels" based on Noise Abatement Criteria contained in 23 CFR 772. In this document, the FHWA has adopted noise impact terminology based on peak-hour Leq for specified land uses, and also identifies impacts as substantial increases over existing sound levels. The FHWA Noise Abatement Criterion for residential land use is an exterior peak-hour Leq of 67 dBA. The FHWA regulations define impacts as those levels that approach or exceed the specified abatement criteria. A sound level is considered to approach the 67 dBA criterion if it is within 1 dBA, according to WSDOT interpretation of the regulation. The FHWA Noise Abatement Criteria are listed in Table 3-1.

TABLE 3-1
FHWA NOISE ABATEMENT CRITERIA
HOURLY A-WEIGHTED SOUND LEVEL, DECIBELS (dBA)

Activity Category	Leq	Description of Activity Category
A	57 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 (Exterior)	Developed lands, properties, or activities not included in categories A or B above.
D	--	Undeveloped lands.
E	52 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

Source: 23 CFR 772

The FHWA policies regarding noise abatement contained in Title 23 CFR 772 are the following:

(a) In determining and abating traffic noise impacts, primary consideration is to be given to exterior areas. Abatement will usually be necessary only where frequent human use occurs

and a lowered noise level would be of benefit.

(b) In those situations where there are no exterior activities to be affected by the traffic noise, or where the exterior activities are far from or physically shielded from the roadway in a manner that prevents an impact on exterior activities, the interior criterion shall be used as the basis of determining noise impacts.

The **Washington State Department of Transportation Traffic Noise Policy and Procedures** (2011) consider an increase of more than 10 dBA over existing sound levels a substantial increase and a traffic noise impact.

3.2 City of Medina

Sound levels in the City of Medina are regulated by Chapter 8.06, *Noise*, of the Medina Municipal Code. The City has adopted by reference Chapters 12.86 through 12.100 of the King County Code (as revised by King County in June 2011). The King County noise limits do not apply to traffic on a State Highway. However, this report will refer to some of the provisions of the King County Code as a term of comparison.

4. MEASURED SOUND LEVELS

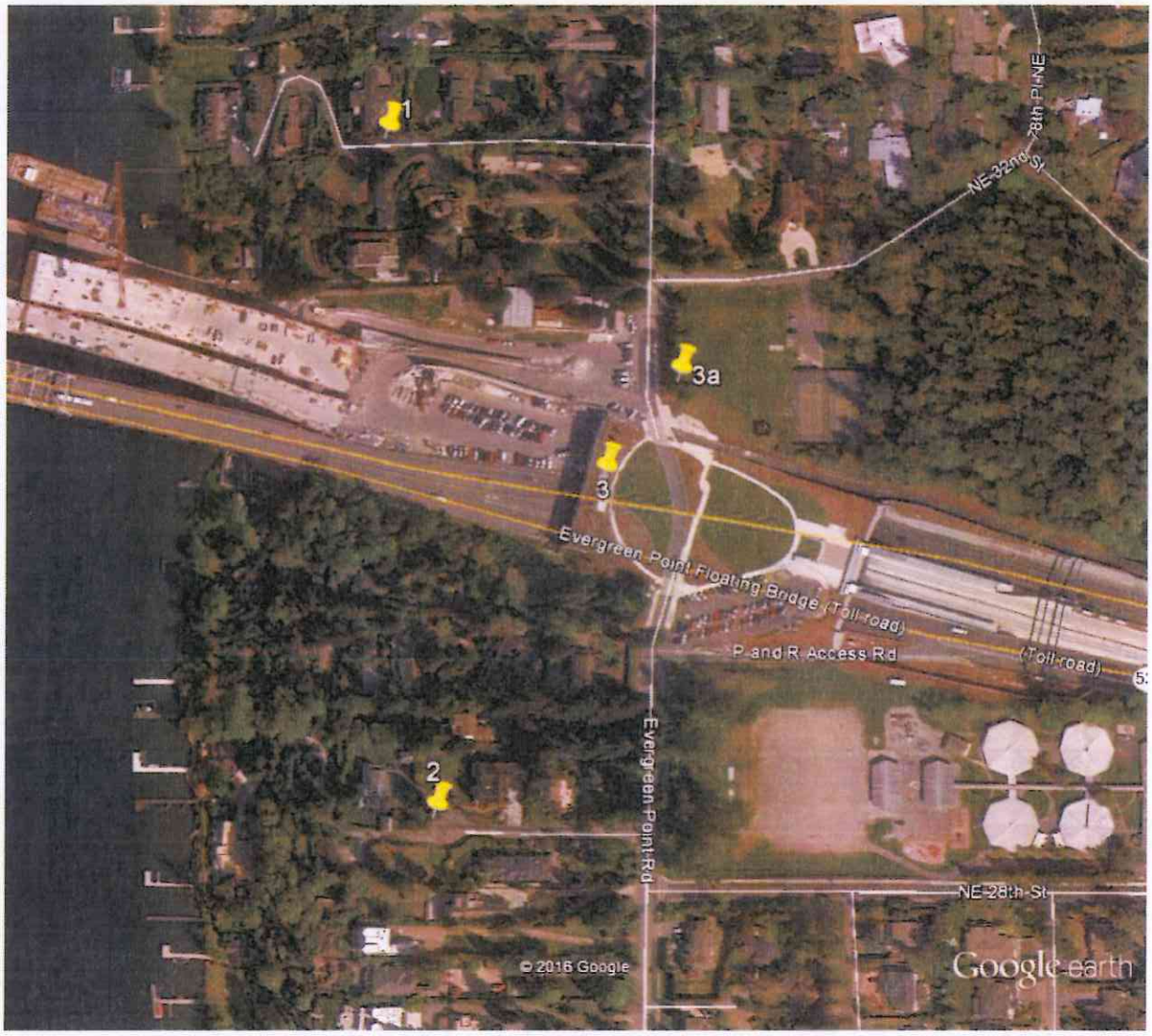
4.1 Measurement Locations and Methodology

BRC Acoustics conducted measurements of sound levels at six locations selected in collaboration with City of Medina representatives. The locations, shown in Figures 4-1 and 4-2, were as follows:

Location 1	South of residence at 3223 Evergreen Point Road. Sound levels were monitored continuously for 24 hours starting at 1 p.m. on Tuesday, May 31, 2016. The monitoring was conducted using a Bruel & Kjaer 2238 Logging Integrating Sound Level Meter.
Location 2	East of residence at 7550 NE 28th Place. Sound levels were monitored continuously for 24 hours starting at 1 p.m. on Tuesday, May 31, 2016. The monitoring was conducted using a Bruel & Kjaer 2238 Logging Integrating Sound Level Meter. During retrieval of the sound monitor at the end of the measurement, residential maintenance activities using power tools were observed at the neighboring residence. The measurement data suggest that the measurements during the 12 and 1 p.m. hours on June 1 were affected.

Location 3	Bench on Evergreen Point Lid. Daytime measurements of traffic noise were not possible at this location due to construction activities. A 32-minute measurement was conducted starting at 8:58 p.m. on Tuesday, May 31, 2016 using a Bruel & Kjaer 2250 Real-Time Spectrum Analyzer. Evening traffic on SR-520 was traveling at the speed limit. The measurement was paused during extraneous events such as aircraft flyovers and local traffic.
Location 3a	Fairweather Park, 45 feet east of the Evergreen Point Rd. centerline. A 26-minute measurement was conducted starting at 1:26 p.m. on Tuesday, May 31, 2016.using a Bruel & Kjaer 2250 Real-Time Spectrum Analyzer. Afternoon traffic on SR-520 was proceeding at the speed limit. The measurement was paused during extraneous events such as aircraft flyovers and local traffic.
Location 4	Northeast corner of 77th Ave. NE and NE 16th St. A 27-minute measurement was conducted starting at 11:35 a.m. on Wednesday, June 1, 2016.using a Bruel & Kjaer 2250 Real-Time Spectrum Analyzer. The measurement was paused during extraneous events such as aircraft flyovers and local traffic. This location was selected as a reference. Sound from traffic on SR-520 was not audible at this location.
Location 5	Dock at Viewpoint Park. A 20-minute measurement was conducted starting at 12:41 p.m. on Wednesday, June 1, 2016.using a Bruel & Kjaer 2250 Real-Time Spectrum Analyzer. The measurement was paused during extraneous events such as aircraft flyovers and local traffic and was stopped short of the intended 30 minutes due to landscaping work at the neighboring residence. This location was selected as a reference. Sound from traffic on SR-520 was not audible at this location. The location experienced noise from distant watercraft and waves on Lake Washington and distant traffic on Interstate 90.

All measurement instruments conform to the specifications of ANSI S1.4 for Type I instruments.



			16.054
			Figure 4-1
	Date	Name	
Drafted	06-10-16	IP	**City of Medina - SR-520**
Checked			Sound Measurement Locations 1-3
			BRC Acoustics & Audiovisual Design

			16.054
			Figure 4-2
	Date	Name	
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Checked			Sound Measurement Locations 4-5
			BRC Acoustics & Audiovisual Design

The weather conditions during the measurements were clear, with daytime temperatures in the upper 70s and nighttime temperatures in the low 50s to mid-60s degrees Fahrenheit and wind from the northwest at 0-7 mph. The measured conditions are in the range recommended by Washington Administrative Code (WAC) 173-58 for sound-level measurements.

4.2 General Results of Sound Measurements

4.2.1 Results of long-term sound monitoring

The results of the 24- to 25-hour noise monitoring at Locations 1 and 2 are presented in Figures A-1 and A-2, as graphs of the hourly A-weighted Leq, Lmax, and Lmin sound levels.

General features of the measured hourly sound levels are summarized in Table 4-1. The results in Table 4-1 were derived by omitting sound levels during hours that appeared compromised by extraneous, local events such as construction or residential maintenance.

TABLE 4-1
RESULTS OF LONG-TERM SOUND MONITORING

Descriptor	MONITORING LOCATION	
	1	2
Overall daytime Leq, dBA	60	58
Overall daytime Lmax, dBA	78	79
Overall nighttime Leq, dBA	43	44
Overall nighttime Lmax, dBA	63	65
Peak-hour Leq, dBA	58	57

4.2.2 Results of short-term, attended sound measurements

Table 4-2 shows the short-term measurement results.

TABLE 4-2
MEASURED SOUND LEVELS AT SHORT–TERM MEASUREMENT LOCATIONS

Location	3	3a	4	5
Date and Time of Measurement	5/31/2016 8:59 - 9:30 p.m.	5/31/2016 1:26 - 1:53 p.m.	6/1/2016 11:35 – 12:03 p.m.	6/1/2016 12:21 – 12:41 p.m.
Measured Leq (dBA)	63	50	41	58
Measured Lmax (dBA)	80	59	58	70

4.2.3 Evaluation of general measurement results

The Leq sound levels shown in Figures A-1 and A-2 and summarized in Tables 4-1 and 4-2 are below the FHWA Noise-Abatement Criterion of 67 dBA.

WSDOT prepared a memorandum dated April 29, 2016, reporting sound-level measurements conducted on April 19 and 20 at several locations in Medina and on the bridge deck. The sound levels reported by WSDOT were 15-minute, daytime Leq sound levels.

Location A in the WSDOT report (3223 Evergreen Point Road) coincides with BRC's measurement Location 1. The 15-minute Leq reported by WSDOT (59 dBA) is in agreement within 1 dBA with the measurement by BRC Acoustics (60 dBA).

4.3 Measurements Pertaining to Expansion-Joint Noise

4.3.1 Results of the measurements in 1-second and 10-second intervals

The measurements discussed in Sections 4.2 were conducted in 10-second intervals at Location 2 and 1-second intervals at all other locations. The short-term measurements at Locations 3 to 5 also included sound spectra in one-third-octave bands Furthermore, the short-term measurements allow a breakdown into increments of 100 milliseconds (or 1/10 of one second) The overall results reported in Section 4.2 were derived from the 1-second or 10-second sound levels.

The availability of sound-level histories in short time intervals and of spectral data facilitates additional analysis in an effort to characterize the sound levels from expansion-joint events. This additional analysis is presented in the following subsections of this report.

Table 4-3 summarizes sound-measurement results at measurement Locations 1, 2, 3, and 3a. These were measurement locations where sound from vehicle pass-bys over expansion joints was audible during daytime and evening conditions. The notes pertaining to Table 4-3 provide brief explanations of the derivation of table entries. The results are discussed in more detail in the subsections following Table 4-3.

TABLE 4-3
RESULTS DERIVED FROM 1-SECOND AND 10-SECOND MEASUREMENTS

#	Descriptor	MEASUREMENT LOCATION			
		1	2	3	3a
1	Overall Leq/Lmax, dBA	Daytime **60/78;** Nighttime **43/63**	Daytime **58/79;** Nighttime **44/65**	8:59 - 9:30 p.m. **63/80**	1:26 - 1:53 p.m. **50/59**
2	Peak-hour Leq, dBA	**58**	**57**	--	--
3	Lmax attributable to Expansion Joints, dBA	3 a.m.: **59** 3 p.m.: **64**	2 a.m.: **58** 3 p.m.: **62**	8:59 - 9:30 p.m.: **75**	1:26 - 1:53 p.m.: **57**
4	Leq during same measurement intervals as Line #3, dBA	3 a.m.: **42** 3 p.m.: **58**	2 a.m.: **44** 3 p.m.: **55**	**63**	**50**
5	Difference between expansion Lmax and overall Leq over same time interval, dBA	Nighttime **17** Daytime **6**	Nighttime **14** Daytime **7**	Evening **12**	Daytime **7**

Notes for Table 4-3:

Line #1 Overall Leq/Lmax derived from results in Figures A-1 and A-2 and in Tables 4-1 and 4-2. These sound levels include effects of extraneous sound sources, such as construction. Sound levels at Locations 1 and 2 also include aircraft flyovers.

Line #2 Peak-hour Leq derived from results in Figures A-1 and A-2, omitting high levels most probably associated with aircraft or construction

Line #3 Locations 1 and 2, nighttime: selected quietest nighttime hour and examined graphs of Lmax sound levels in 1-second or 10-second intervals (Figures B-2 and B-4). Selected Lmax of often-repeated peaks.

Locations 1 and 2, daytime: Selected peak hours of Line 2, examined graphs of Lmax sound levels in 1-second or 10-second intervals (Figures B-1 and B-3). Selected Lmax of often-repeated peaks.

Locations 3 and 3a: examined graphs of Lmax in 1-second intervals (Figures B-5 and B-6). Selected Lmax of often-repeated peaks.

Line #4 Leq measured during the same time intervals reported in Line #3

Line #5 Difference between Lines 3 and 4

Figures B-1 to B-5 show graphs of Lmax over 1-second intervals for total durations ranging from 2 minutes to one hour, as follows.

Figure B-1 shows one-second Lmax levels measured by the unattended sound monitor at Location 1 during the 3-p.m. hour. The measurements include contributions from other noise sources, such as aircraft flyovers, construction, and local events. The Lmax of 64 dBA attributable to traffic over expansion joints was estimated by examining events that repeated frequently and were short in duration. The hourly Leq for the 3-p.m. hour was measured as 58 dBA.

Figure B-2 shows one-second Lmax levels at Location 1 during the 3-a.m. hour. The hourly Leq for the 3-a.m. hour is 42 dBA and is considerably lower than the daytime Leq of 58 dBA. The estimated Lmax from pass-bys over expansion joints if 59 dBA. The lower Lmax during nighttime pass-bys suggests that the daytime Lmax of 64 dBA represents a high estimate, affected somewhat by continuous background noise present during daytime activities.

Figure B-3 shows 10-second Lmax sound levels measured by the unattended sound monitor at Location 2 during the 3 p.m. hour. The estimated Lmax from expansion-joint events was 62 dBA. The hourly Leq at Location 2 during the 3 p.m. hour was 55 dBA.

Figure B-4 shows one-second Lmax levels at Location 2 during the 2-a.m. hour, which was confirmed by the hourly data to represent one of the quietest nighttime conditions. The Lmax attributable to pass-bys over expansion joints was estimated as 58 dBA. The hourly Leq at Location 2 during the 2 a.m. hour was 44 dBA.

Figure B-5 shows one-second Lmax levels measured during the short-term readings at Location 3. The Figure shows the sound levels during a continuous measurement from 9:02 to 9:07 p.m. Since the instrument at Location 3 was paused for all extraneous events, the measurements in Figure B-5 are due to traffic only. The typical one-second Lmax from pass-bys over expansion joints is estimated as 75 dBA. The Leq over a 30-minute evening measurement at Location 3 was 63 dBA.

Figure B-6 shows one-second Lmax sound levels measured during the short-term, attended readings at Location 3a. The Figure shows a continuous two-minute time interval staring at 1:52 p.m. The estimated Lmax attributable to expansion-joint events was 57 dBA. The Leq from traffic over a 25-minute measurement at Location 3a was 50 dBA.

The measured sound levels shown in Figure B-1 to B-6 constitute Lines 3 and 4 of Table 4-3. The following observations pertain to the results shown in Figures B-1 to B-6 and in Lines 3 and 4 of Table 4-3:

- Lmax sound levels directly attributable to pass-bys over expansion joints as received at the residential locations (Locations 1 and 2) are below 67 dBA during both daytime and nighttime conditions. While the FHWA Noise-Abatement Criterion does not apply to Lmax sound levels, the comparison clearly demonstrates that traffic noise from the SR-520 Project does not approach the FHWA and WSDOT criteria requiring additional

sound mitigation.

- Line 5 shows the comparison between the Lmax from expansion-joint crossing and the underlying Leq during the same measurement conditions. The comparison shows that the Lmax from pass-bys over expansion joints exceed the underlying Leq by 6 to 7 dBA during the daytime and by 12 to 17 dBA during evening and nighttime conditions. As was shown in Table 2-1, sound-level differences of 6 to 7 dBA are clearly noticeable, and differences of 10 dBA and more are judged subjectively as more than a doubling of perceived loudness. This is consistent with the experience reported by residents in the adjacent community of the sound from expansion joints being particularly noticeable during the nighttime hours.

- The pavement on the SR-520 project leads to sound levels from tire-pavement interaction that are considerably lower than on the existing SR-520 Bridge pavement. The lowered sound levels from vehicles traveling over the new pavement on spans between expansion joints exacerbate the prominence of sounds from pass-bys over the expansion joints.

4.3.2 Time profile of sound from expansion-joint events

As stated previously, the Sound Analyzer used in the short-term sound measurements at Locations 3 and 3a recorded A-weighted sound levels in 100-ms intervals. Figure C-1 shows the profile of the A-weighted sound level over time for a typical expansion-joint event measured at Location 3. The graph in Figure C-1 spans a duration of one second.

Figure C-1 shows that the onset of the event is abrupt (a rise of almost 15 dBA over 0.2 seconds). The sound level stays within 6 dBA of the maximum level for less than 0.3 seconds, which is a short duration compared with the time interval between events, which was approximately 3 seconds during the daytime under free-flowing traffic conditions (Figure B-6). During the evening and nighttime, the maximum sound level is at least 12 dBA above the Leq measured between events (Table 4-3, Line 5).

Paragraph 12.87.130 of the King County Code (KCC) defines an impulsive sound as having the following characteristics: (1) the peak of the sound level is less than one second and short compared to the occurrence rate; (2) the onset is abrupt; (3) the decay is rapid; (4) the peak value exceeds the ambient level by more than 10 dBA.

The sound time profile shown in Figure C-1 displays all the characteristics of an impulsive sound with the exception of (3). It is therefore expected to elicit some of the same responses in a listener as an impulsive sound.

Paragraph 12.88.030 of the King County Code imposes a 5-dBA reduction in the noise limits for impulsive sounds, in recognition of the added annoyance produced by such sounds. Similar provisions appear in the Noise Codes of other agencies, such as the City of Seattle.

The provisions of KCC do not apply to traffic on public roads. Furthermore, the profile of the expansion-joint events only partially satisfies the definition of an impulsive sound. However, the reference to the treatment of impulsive sounds in the Noise Code is illustrative of the perceptual effect of sounds with the abrupt time profile shown in Figure C-1.

4.3.3 Spectral characteristics of sound from pass-bys over expansion joints

Figure D-1 shows two Lmax spectra in one-third octave bands. Both were measured over intervals of one second during the 9-p.m. hour at Location 3. One of the curves represents the spectrum of traffic between expansion-joint events. The other curve represents the spectrum during the expansion-joint event.

Figure D-1 shows that the spectrum of the expansion-joint event contains significantly higher components in the one-third octave bands centered on 500 to 1000 Hz. These components exceed those of standard traffic noise by up to 15 dB, which is more than a doubling of perceived loudness. The difference occurs in the mid-range frequency bands to which human hearing is most sensitive. This further explains the highly noticeable character of the sound from pass-bys over expansion joints.

5. SUMMARY AND CONCLUSIONS

Measured sound levels at locations in the vicinity of the SR-520 project and at other reference locations in the City of Medina were presented in Section 4 of this report. Hourly sound levels corresponding to FHWA and WSDOT criteria were presented in Section 4.2. Additional results aimed at characterizing the sound from traffic pass-bys over expansion joints were presented in Section 4.3.

The following conclusions can be drawn from the measured and derived sound levels presented in Section 4:

- Results reported in Sections 4.2 and 4.3 show that sound levels from traffic on SR-520, including traffic over expansion joints, are below the FHWA and WSDOT Noise-Abatement Criteria.

- Sound levels measured by BRC Acoustics on May 31 and June 1, 2016 are consistent with recent sound measurements by WSDOT, reported in the memorandum dated April 29, 2016.

- At locations within 600 feet of the SR-520 right-of way, maximum sound levels from pass-bys over expansion joints exceed ambient Leq sound levels by 6-7 dBA during the daytime and by 12 to 17 dBA during the night. The daytime sound-level differences are expected to be clearly noticeable, and the nighttime differences are typically judged as

more than a doubling of perceived loudness.

- The time profile of sound levels from expansion-joint events shows characteristics common with impulsive sounds, which are recognized as having a higher potential for annoyance than steady-state sounds or those with a more gradual onset.

- The highly noticeable character of sound from traffic traveling over expansion joints is consistent with the spectral make-up of the sound, as illustrated in Section 4.3.3 and Figure D-1.

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Figure A-1
Hourly Sound Levels
Location 1, May 31-June 1, 2016

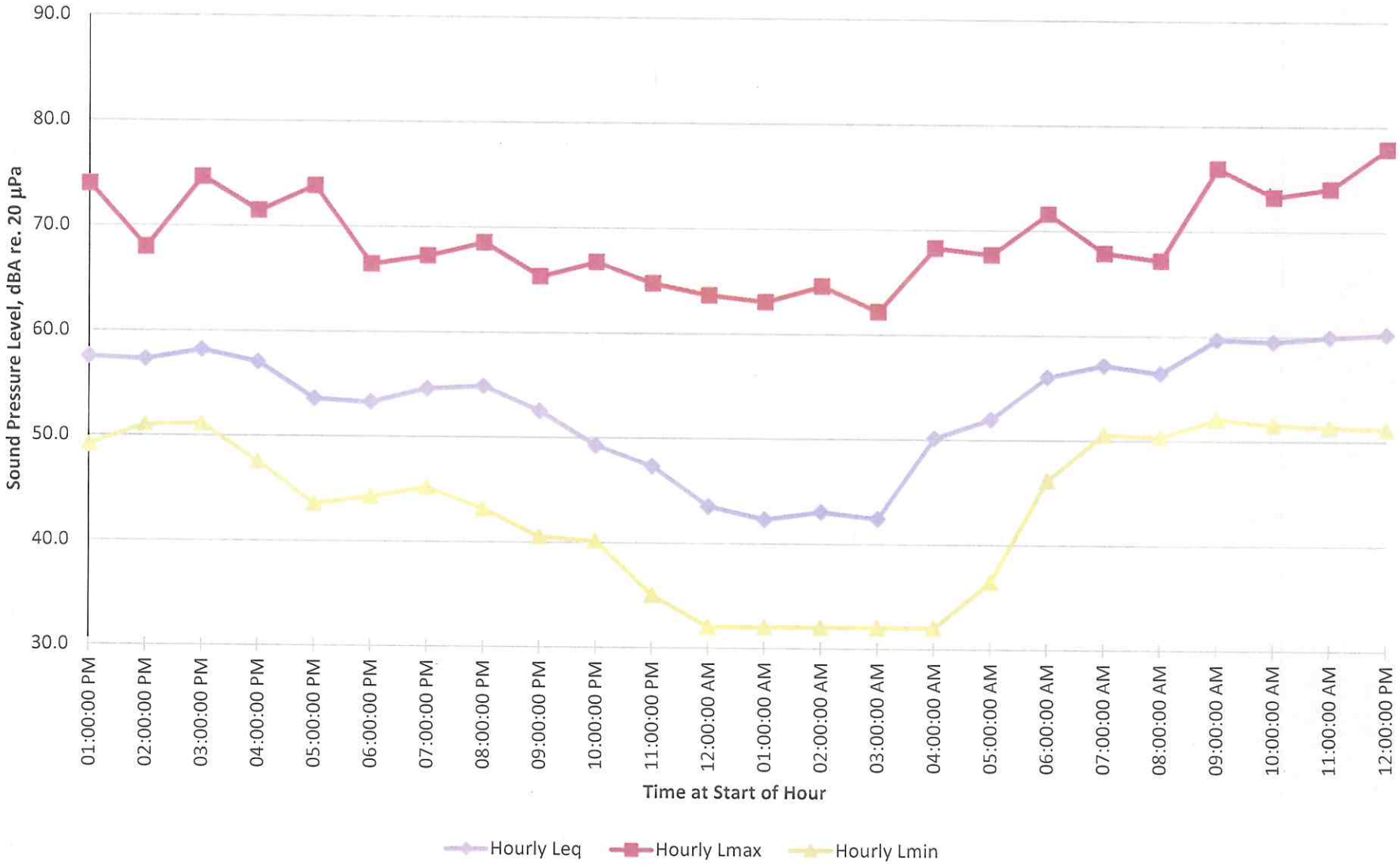

Figure A-2
Hourly Sound Levels
Location 2, May 31-June 1, 2016

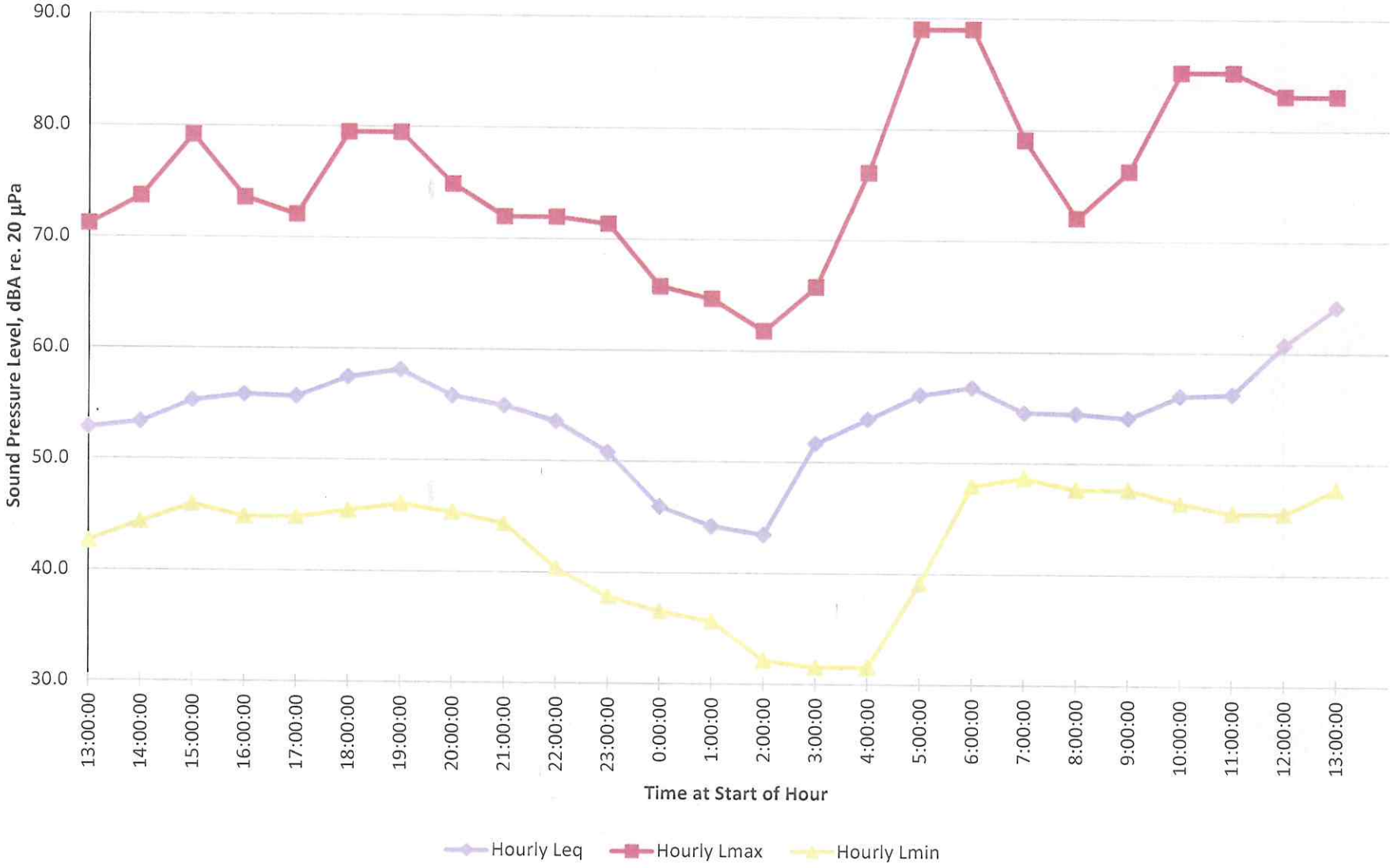

Figure B-1
Lmax Sound Levels in One-Second Intervals
Location 1, May 31, 2016, 3 p.m.

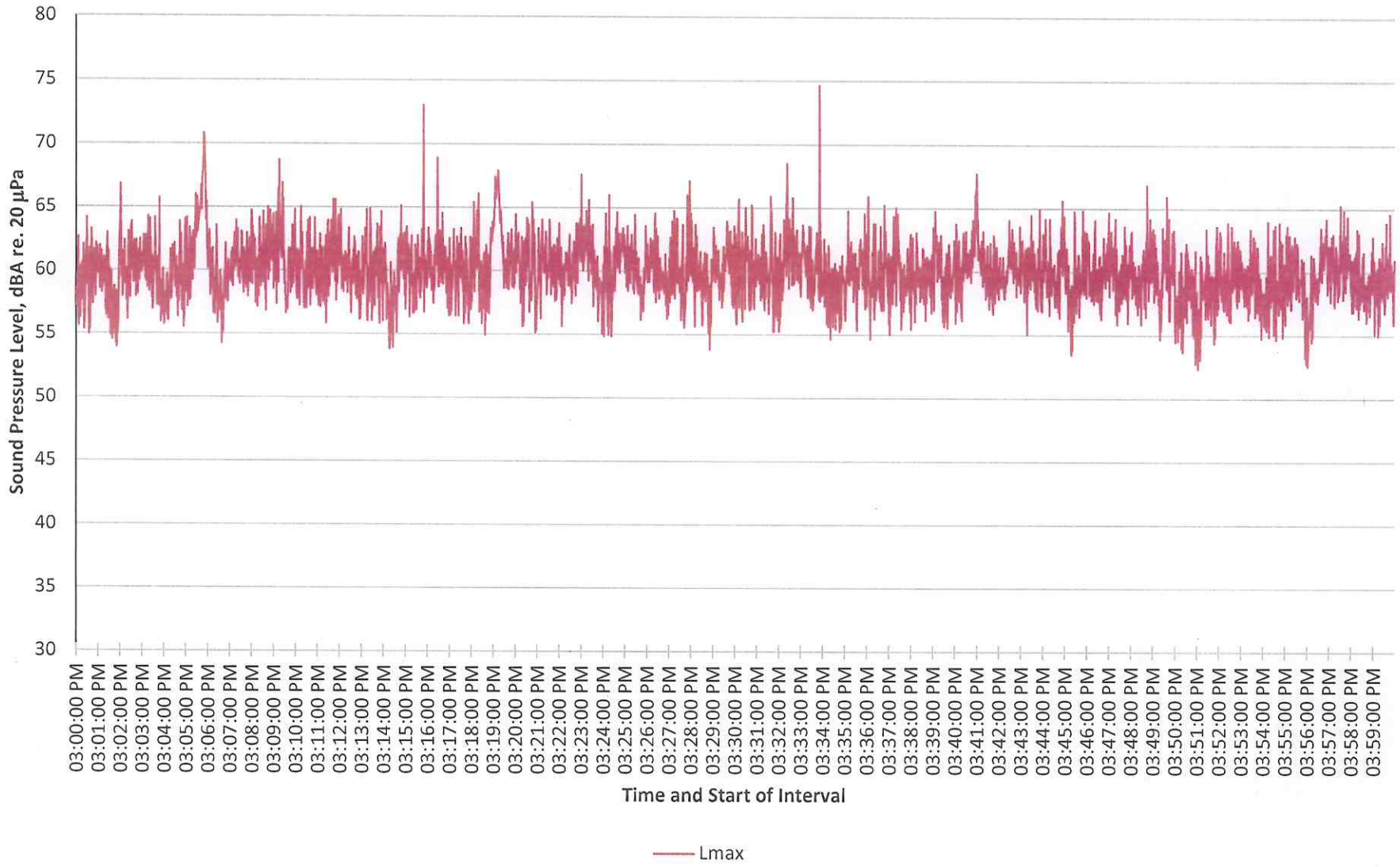

Figure B-2
Lmax Sound Levels in One-Second Intervals
Location 1, June 1, 2016, 3 a.m.

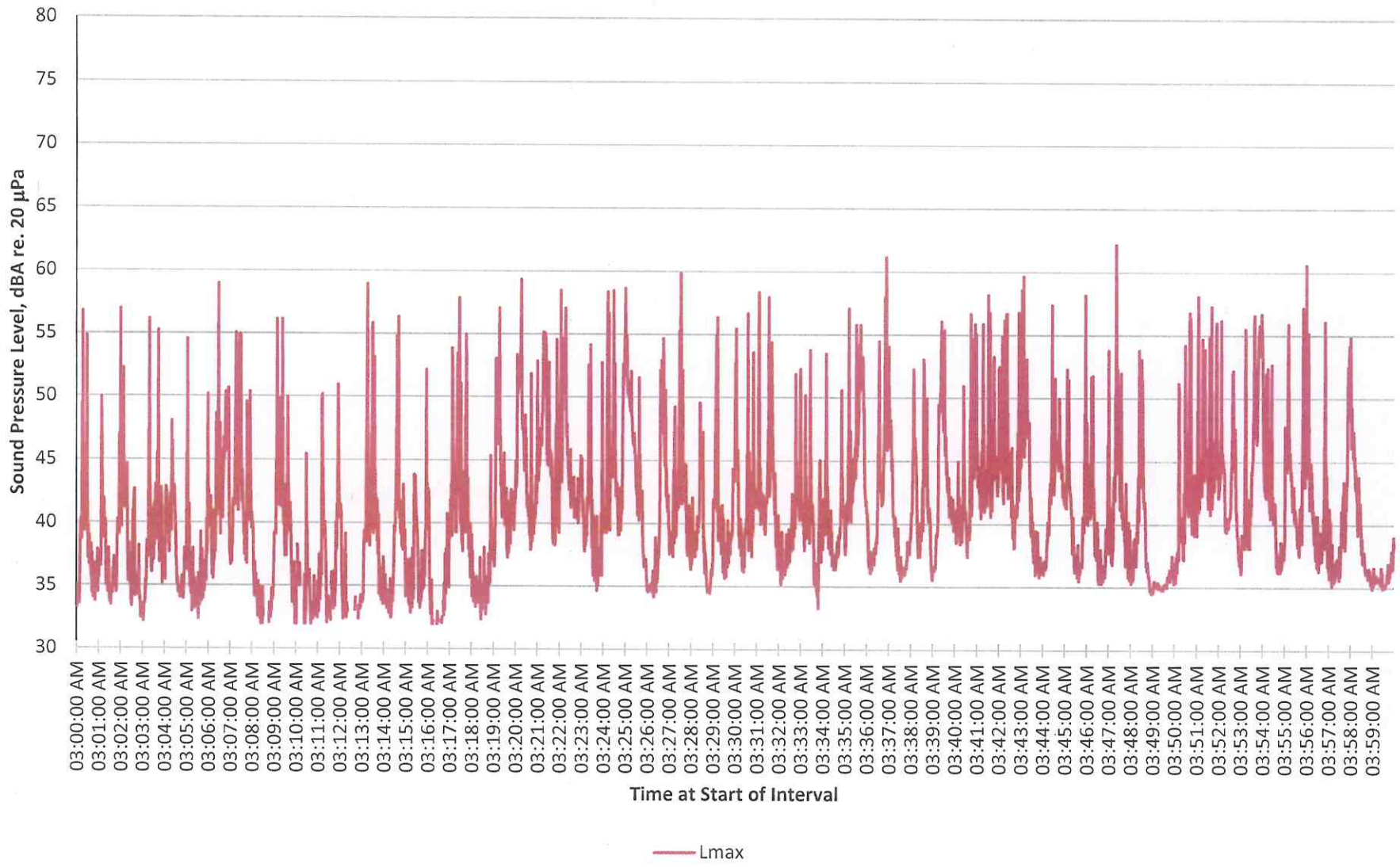

Figure B-3
Lmax Sound Levels in One-Second Intervals
Location 2, May 31, 2016, 3 p.m.

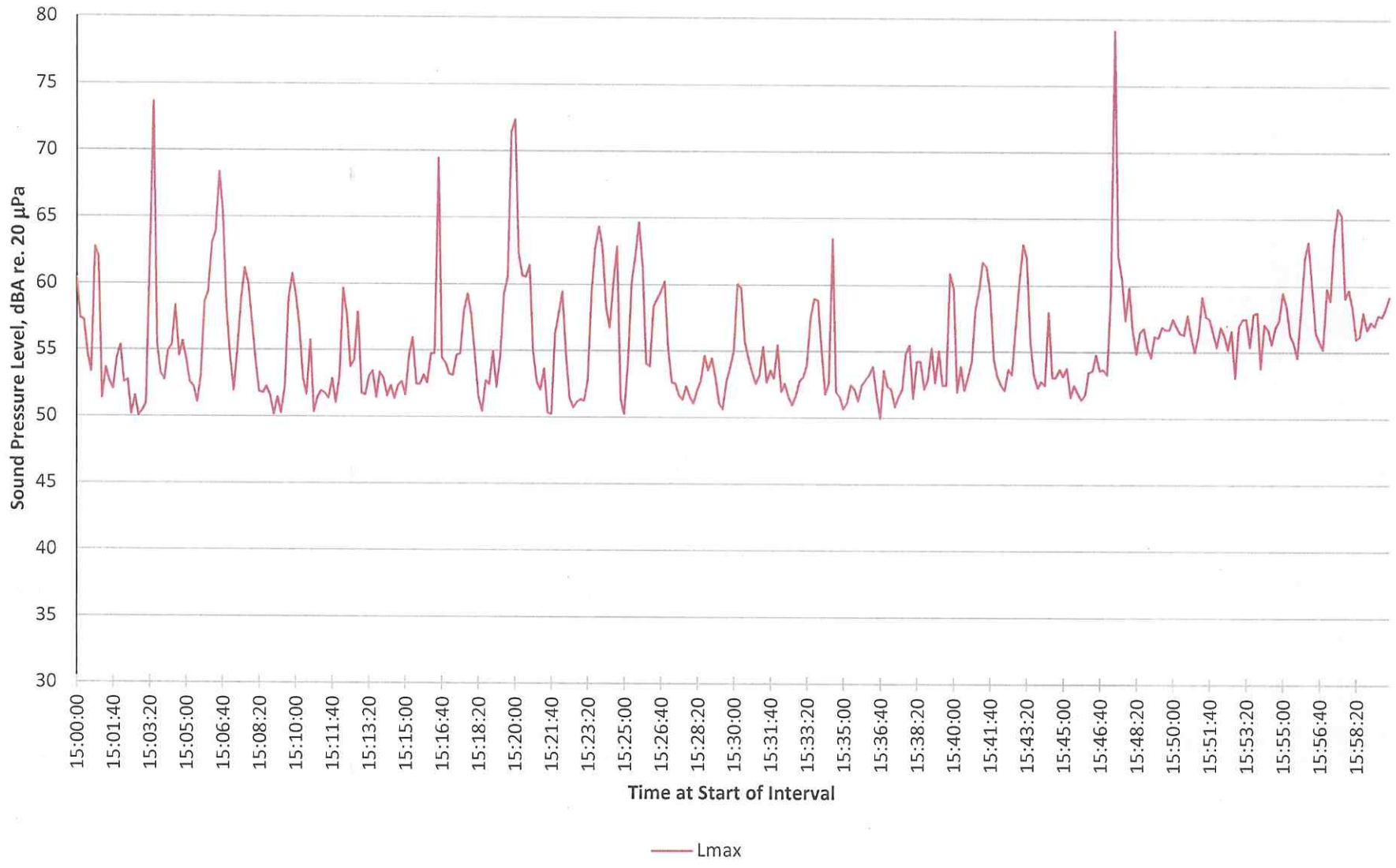

Figure B-4
Lmax Sound Levels in One-Second Intervals
Location 2, June 1, 2016, 2 a.m.

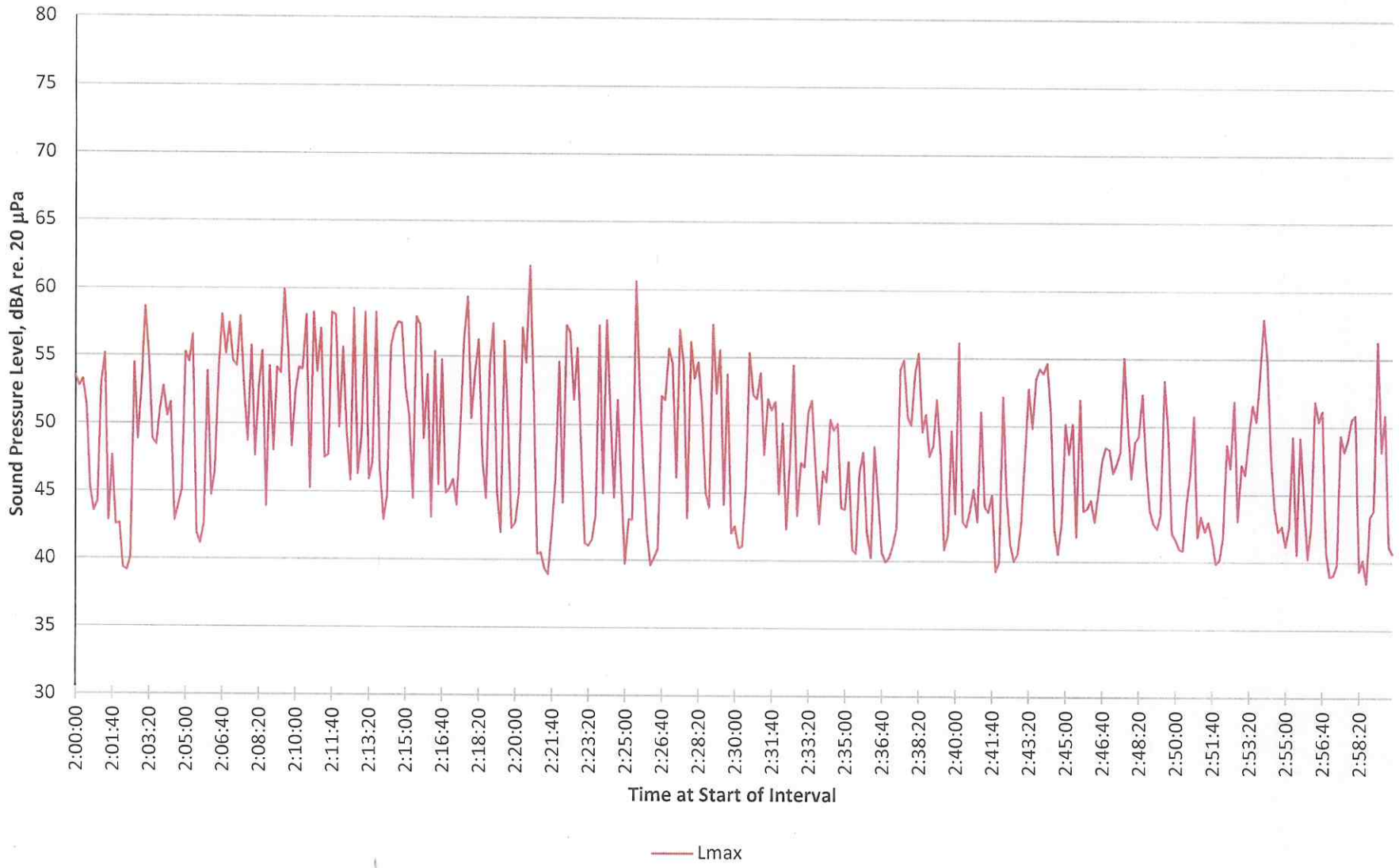

Figure B-5
Lmax Sound Levels in One-Second Intervals
Location 3, May 31, 2016

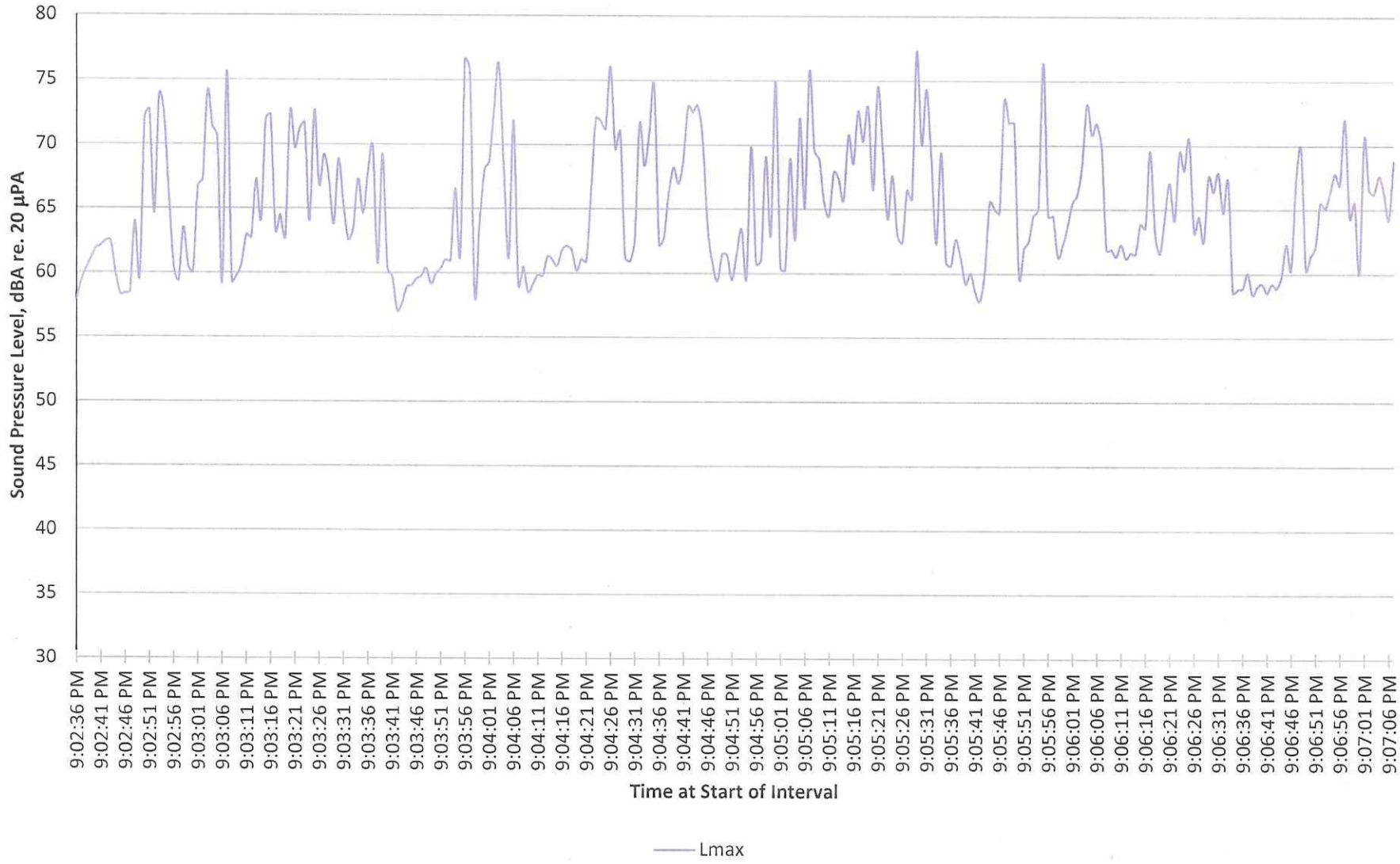

Figure B-6
Lmax Sound Levels in One-Second Intervals
Location 5, May 31, 2016

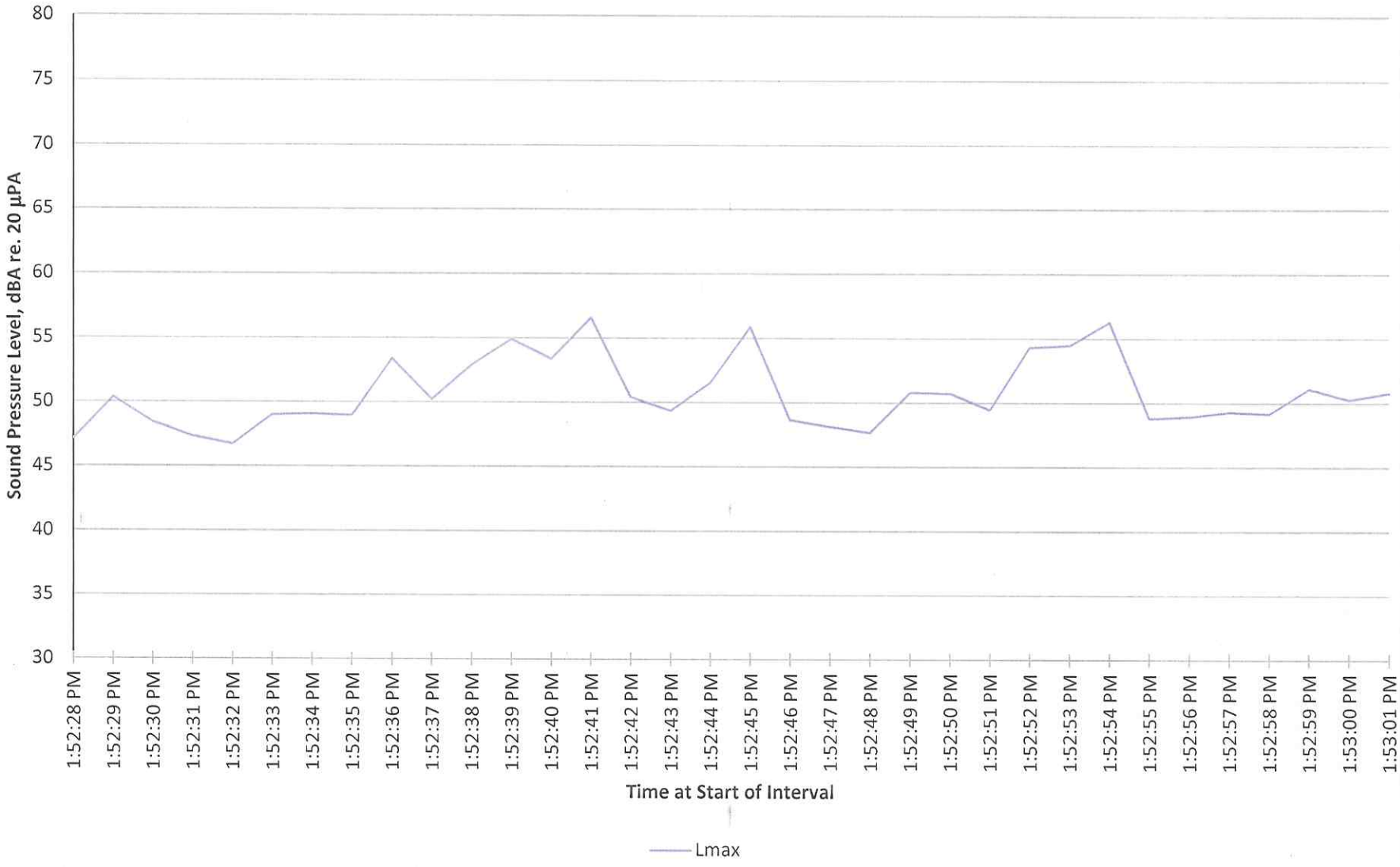

Figure C-1
Expansion Joint Event in 100-ms increments
Location 3, May 31, 2016, 9:05 p.m.

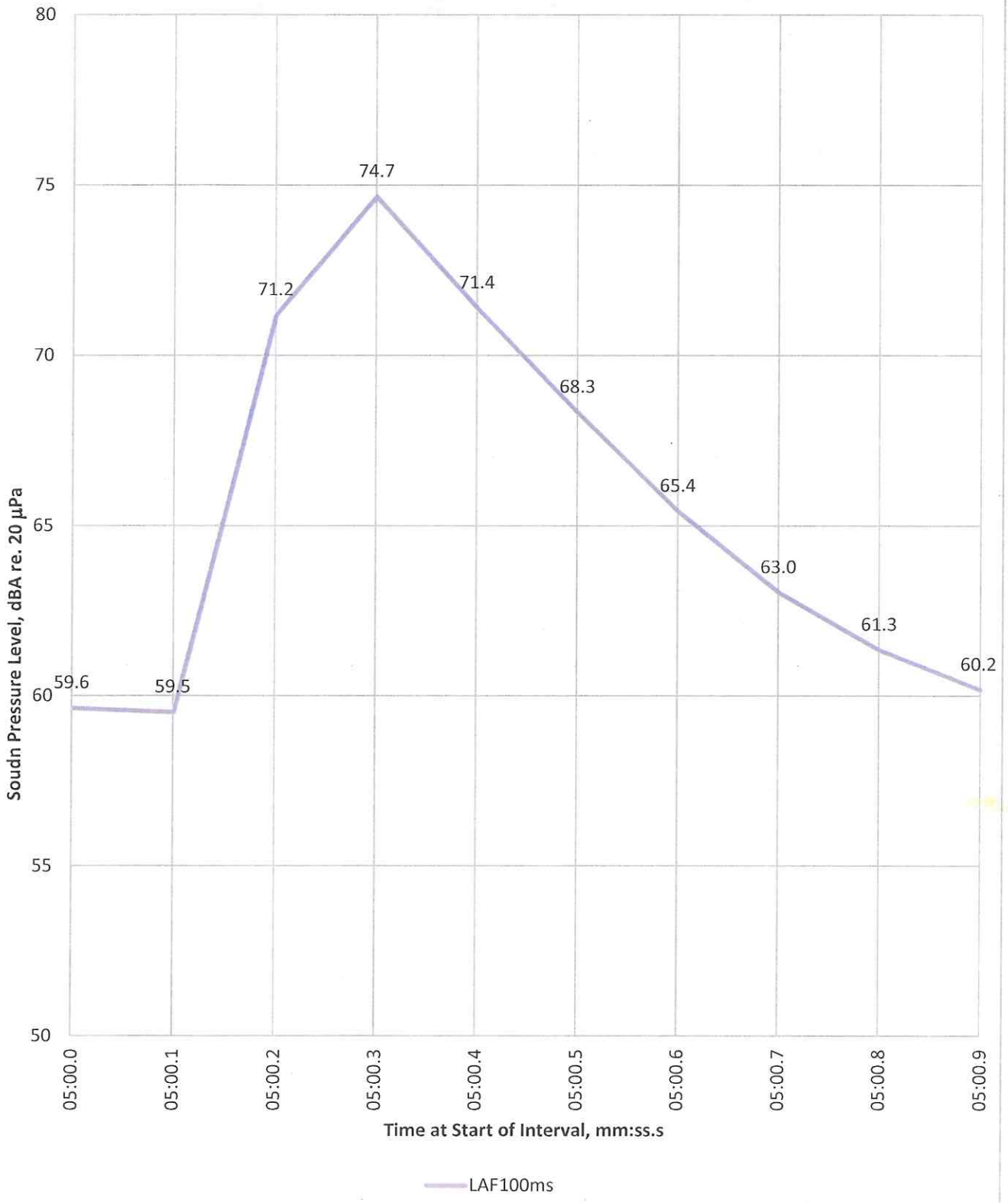

Figure D-1
Spectrum of Traffic Sound
Location 3, May 31, 2016