

UNSW Science and Engineering Building
Secretary's Environmental Assessment Requirements
Noise and Vibration Impact Assessment

Report Number 610.16372-R1

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Brookfield Multiplex Australasia
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1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Brookfield Multiplex Australasia (Brookfield) to provide acoustic and vibration services for the construction and operation of the University of New South Wales (UNSW) Science and Engineering Building (SEB).

The first stage of the project is to satisfy the Secretary's Environmental Assessment Requirements (SEARs). The SEARs General Requirements are that an Environmental Impact Statement (EIS) is prepared which meets the minimum form and content requirements in Clauses 6 and 7 of Schedule 2 in the *Environmental Planning and Assessment Regulation 2000*.

This report has been prepared in order to satisfy the following specific component of the EIS:

"7. Noise and Vibration

Identify and provide a quantitative assessment of the main noise and vibration generating sources during construction and operation. Outline measures to minimise and mitigate the potential noise impacts on surrounding occupiers of land, including residences in Willis and Norton Street, Kingsford.

→*Relevant Policies and Guidelines:*

- *NSW Industrial Noise Policy (EPA)*
- *Interim Construction Noise Guideline (DECC)*
- *Assessing Vibration: A Technical Guideline 2006"*

The purpose of the SEARs is to safeguard the amenity of neighbouring off-site premises, however this report also considers the operational and construction noise impacts to the University itself.

The results of environmental noise logging (on the University within grounds) are also presented.

Specific acoustic terminology is contained within this report. An explanation of common terms is included as **Appendix A**.

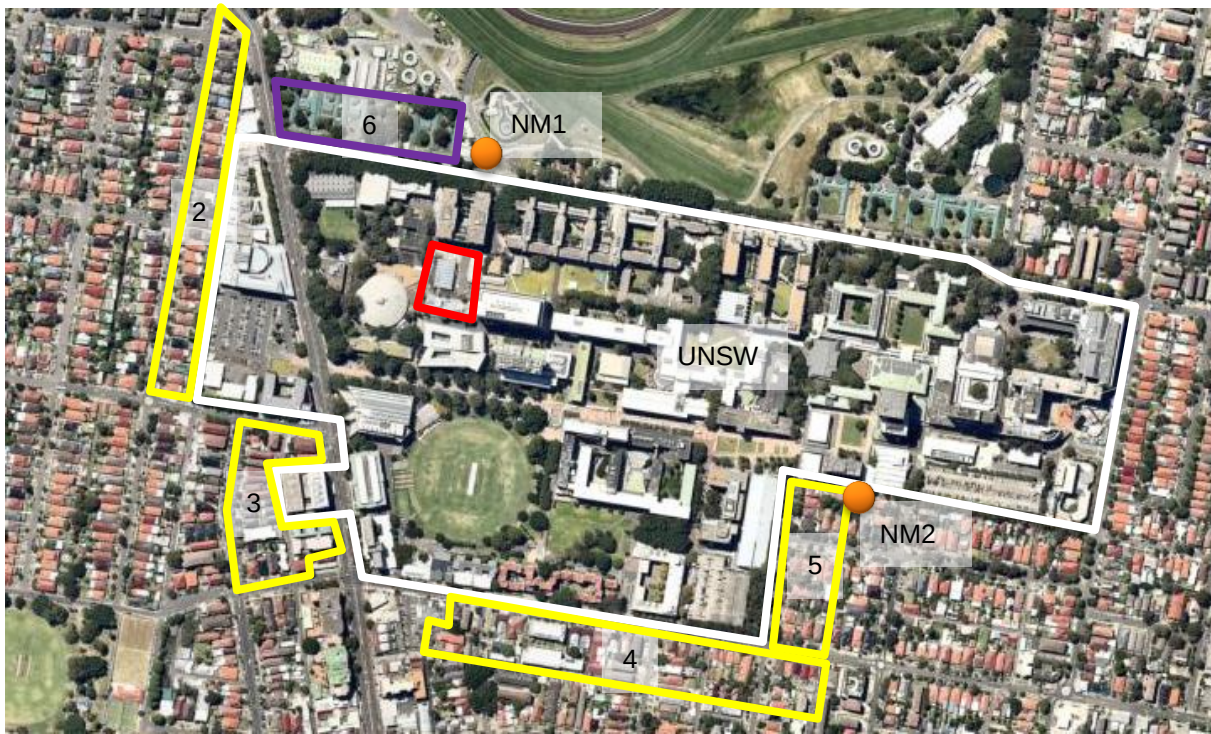
2 PROJECT DESCRIPTION

2.1 Site and Surrounds

The proposed site of the UNSW SEB is at the lower campus of UNSW near International Road and Union Road. The proposed location of the SEB within the UNSW campus and the nearby sensitive receivers outside of the campus are shown in **Figure 1**, supplemented with **Table 1**.

A detailed map of the Kensington campus is provided in **Appendix B**. An aerial photograph indicating the various receivers within the UNSW campus in close proximity to the SEB site is shown in **Figure 2** supplemented with **Table 2**.

Figure 1 Project Site and Sensitive Receivers external to the UNSW Campus



Aerial photography courtesy of Nearmap – image captured 24 February 2016.

Table 1 Sensitive Receivers External to UNSW

Location Identifier	Receiver	Receiver Type	Distance/Direction from SEB
1	SEB Site	-	-
2	Doncaster Avenue Residents	Residential	250 m W
3	Anzac Parade/Houston Lane Residents		200 m SW
4	Barker Street Residents		320 m S
5	Willis Street and Norton Street Residents		430 m SE
6	Randwick Stables	Active Recreation	110 m N

Figure 2 Project Site and Sensitive Receivers within UNSW Campus

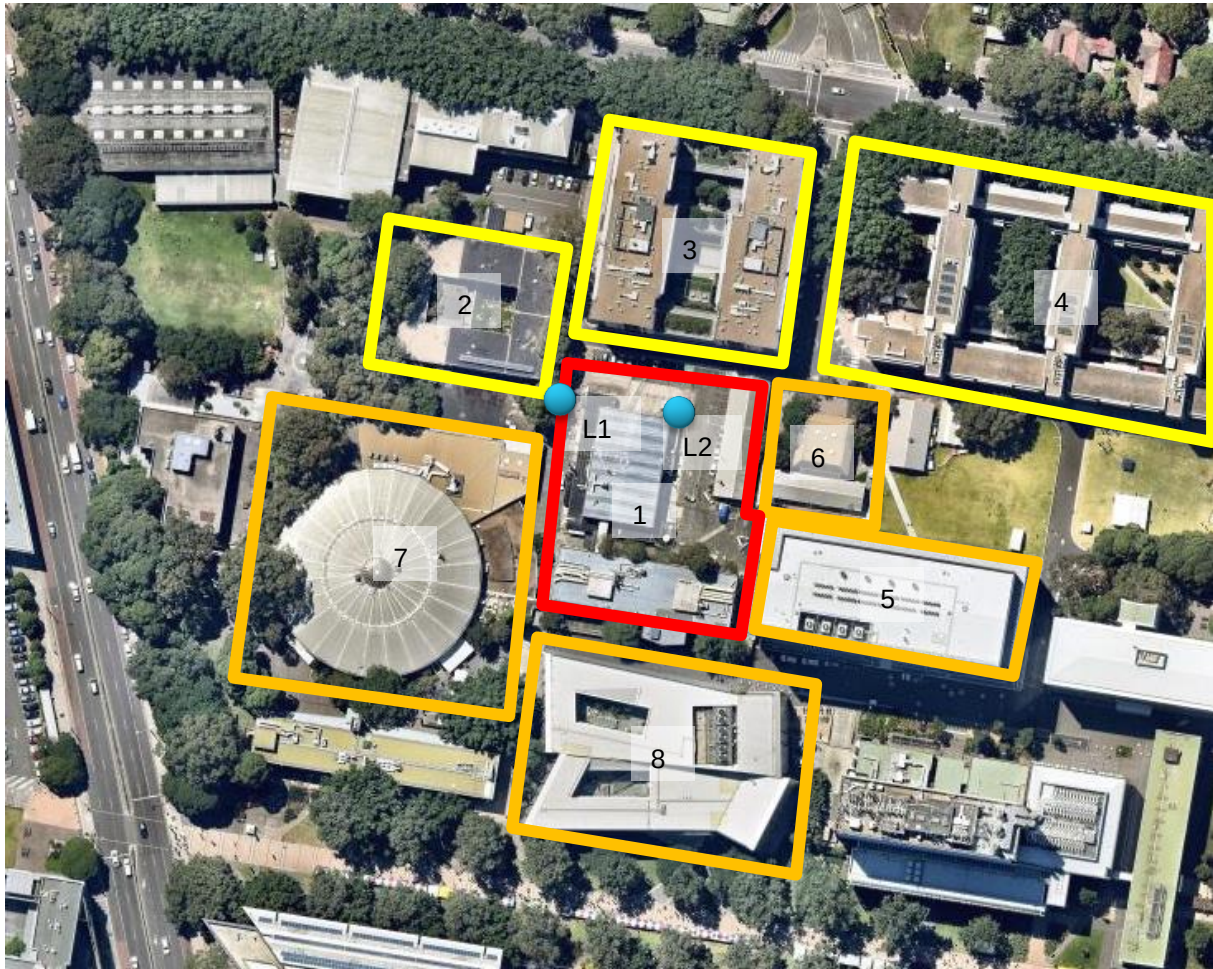


Table 2 Sensitive Receivers within UNSW Campus

Location Identifier	Receiver	Receiver Type	Distance/Direction from SEB
1	SEB Site	-	-
2	International House Ltd.	Residential	12 m NW
3	University Terraces	Residential / Commercial	12 m N
4	University Village	Residential	30 m NE
5	Materials Science & Engineering Building	Educational	5 m E
6 ¹	Io Myers Studio	Educational	5 m NE
7	Roundhouse	Educational	10 m W
8	Law Building	Educational	15 m S

Note 1: The Io Myers Studio and Studio 1 are to be relocated into the Northern Basement Component of the SEB Building.

2.2 Potential Noise to Nearby Receivers

2.2.1 Fixed Mechanical Plant

It is recognised that noise from mechanical services plant will, when operational, be incident on the University and indicative / preliminary criteria have been developed in order to control plant noise to University buildings (see **Section 3.1**).

Compliance with these criteria at the University's residential accommodation (approximately 12 m to the north, 12 m to the northwest and 30 m to the northeast respectively) will ensure compliance at off-site residences approximately 200 m to the southwest, as well as at the stables belonging to the Royal Randwick Racecourse, located approximately 110 m to the north.

Other teaching / educational buildings are closer to the site, at approximately 5 m to the east (the recently completed Material Sciences Building), 10 m to the west (the Roundhouse building) and 15 m to the south (the Law building).

2.2.2 Breakout Noise from Studio Spaces

It is proposed that the Io Myers Studio and Studio 1 are relocated into the Northern Basement Area of the SEB building, with the current building capacities and the proposed operations of the studio spaces to remain unchanged. If the building constructions were to remain unchanged, this relocation of the spaces would increase the existing noise impacts at International House Pty Ltd and University Terraces.

The University has existing controls regarding both the Io Myers Studio and Studio 1. The Io Myers Studio Conditions of Hire stipulate:

"Hirers shall carry out their activities in such a way as to avoid any interference, particularly by way of sound, with the normal activities of the nearby residential colleges. No performance or part of any performance may take place outside the theatre building."

A very similar Condition of Hire is also in place for Studio 1.

Indicative / preliminary criteria have been developed in order to control the potential breakout noise to the University's nearby residential accommodation (see **Section 3.2**). Compliance with these criteria at International House Pty Ltd (approximately 12 m to the north-west) and at University Terraces (approximately 12 m to the north) will ensure compliance at off-site residences in addition to other University buildings.

The building design should also consider the potential for breakout noise from the studio spaces to impact adjacent spaces within the SEB building. This is outside of the scope of this report, but this will be determined during the detailed design stage of the project.

2.2.3 Construction Noise and Vibration

During construction, noise and vibration will be incident on the University and indicative / preliminary criteria have been developed in order to control construction noise and vibration to University buildings (see **Section 3.3** and **Section 3.4** respectively).

Implementing feasible and reasonable mitigation measures to protect the amenity of the University buildings will also protect the amenity of off-site premises, such as those listed in **Table 1**.

2.3 Existing Noise Environment

2.3.1 Short-term Noise Survey

Short-term (15 minute) noise surveys were conducted at the High Street entrance to the Royal Randwick Racecourse and at the corner of Kennedy Street and Oval Lane, Kingsford (locations NM1 and NM2 respectively in **Figure 1**), on 5 May 2016, to obtain indicative environmental noise levels for the area.

The measurements are summarised in **Table 3**.

Table 3 Short Term Survey Measurement Details

Measurement Location Start Time	Measured Noise Levels (dBA re 20µPa)					Observations	Weather Conditions
	L _{Amax}	L _{A1}	L _{A10}	L _{Aeq}	L _{A90}		
NM1 3:45 pm	87	78	71	68	58	Car passbys 69 – 75 dBA Bus passbys 76 – 86 dBA Motorbikes 82 – 87 dBA	Sunny 23°C Calm
NM2 3:00 pm	78	64	57	55	48	Car passbys 56 – 64 dBA Bird Chirps 57 – 73 dBA Aeroplanes Overhead 61 – 67 dBA	Clear Skies Dry

The background (or underlying) noise on High Street at Location NM1 (of 58 L_{A90}) was primarily due to distant road traffic on Anzac Parade. The background noise at Location NM2 consisted of general environmental sounds (birds chirping etc.).

2.3.2 Long-term Noise Monitoring

In order to derive airborne noise goals for residential receiver locations, it is necessary to undertake background noise measurements in the absence of construction noise. Accordingly, a background noise survey was undertaken between 4 February 2016 and 8 February 2016 at locations L1 and L2 shown in **Figure 2**.

Instrumentation for the survey comprised two SVAN-957 environmental noise loggers (serial numbers 20675 and 23816 for locations L1 and L2 respectively). Instrument calibration was checked before and after the measurement survey, with the variation in calibrated levels not exceeding the acceptable variation of ±0.5 dBA (in accordance with AS 1055).

The acoustic instrumentation employed throughout the monitoring was designed to comply with the requirements of AS IEC 61672.1-2004 “*Electroacoustics-Sound Level Meters, Part 1: Specifications*” and carry current NATA or manufacturer calibration certificates.

The full, 7-day, graphical results of the survey are shown in **Appendix C**. The data obtained from the noise monitoring was subsequently processed in accordance with the procedures set out in the NSW INP and are presented in **Table 4**.

Table 4 Measured Ambient Noise Levels Corresponding to Defined INP Periods

Location	Measurement Descriptor	Measured Noise Level (dBA re 20 µPa)		
		Daytime ¹	Evening ¹	Night-time ¹
L1	L _{Aeq}	64	56	55
	RBL (Background)	53	52	51
L2	L _{Aeq}	58	56	55
	RBL (Background)	55	54	54

Note 1: INP Governing Periods – Day: 7:00 am to 6:00 pm Monday to Saturday, 8:00 am to 6:00 pm Sundays & Public Holidays, Evening: 6:00 pm to 10:00 pm, Night: 10:00 pm to 7:00 am Monday to Saturday, 10:00 pm to 8:00 am Sundays & Public Holidays.

It is clear, from the unwavering level of noise at both locations, particularly during the early hours of the morning, that the background noise level at the logging location was predominantly controlled by some local mechanical plant noise. SLR will conduct further noise monitoring during the building demolition phase to verify the measured noise levels, and subsequently verify the criteria outlined in **Section 3.1.5** and **Section 3.3.1**.

3 NOISE AND VIBRATION CRITERIA

3.1 Operational Noise Criteria – Mechanical Plant

“Industrial” noise emissions from on-site activities associated with the proposed development (such as on-site vehicle movements, air-conditioning equipment, exhaust fans and other mechanical plant) must be controlled to avoid them impacting upon the acoustic amenity of nearby premises which, in this case, are either nearby teaching areas or residential accommodation.

Responsibility for the control of noise emission in New South Wales is vested in Local Government and the Environmental Protection Authority (EPA).

The EPA oversees the NSW “*Industrial Noise Policy*” (INP, 2000) which provides a framework and process for deriving noise criteria designed to:

- Control the intrusive noise impacts for residents and other sensitive receivers in the short term; and
- Maintain noise level amenity for particular land uses for residents and sensitive receivers in other land uses

3.1.1 Assessing Intrusiveness

The intrusiveness criterion essentially requires that the equivalent continuous noise level (LAeq) of the source should be no more than 5 dB above the background noise level over any 15 minute period.

In situations where “industrial noise” from a site occurs in short bursts followed by much longer periods of relative quiet (which is unlikely to be the case here) the impact of the industrial noise must be assessed on the basis of the level of that noise against the background noise during the period that the activity occurs (if the LAeq level of the industrial noise was “averaged” over the whole day, evening or night period – it is possible that impact of the activity could potentially be under-estimated).

For steady-state noise sources (ie where the industrial noise is fairly uniform over the whole daytime, evening or night period - as is the case here) the intrusiveness criterion requires that the equivalent continuous noise level (LAeq) of the source should be no more than 5 dBA above the Rating Background Level (RBL). The RBL is established through environmental monitoring (see **Section 2.3**).

3.1.2 Assessing Amenity

The amenity criterion is based on land use and associated activities (and their sensitivity to noise emission). The cumulative effect of noise from industrial sources needs to be considered in assessing the impact. The criterion relates only to other industrial-type noise sources and does not include road, rail or community noise.

The existing noise level from industry is measured. If it approaches the criterion value, then noise levels from new industrial-type noise sources (including air-conditioning mechanical plant and vehicle movement) need to be controlled so that the cumulative effect does not significantly exceed the criterion. If, on the other hand, the existing level of industrial noise is below the criterion value, then noise levels from new industrial-type are controlled so that the cumulative effect approaches the criterion.

(For areas of high road traffic, there are further considerations that influence the selection of the noise criterion - but that is not the case here.)

3.1.3 Area Classification

3.1.3.1 Residential Accommodation

We have deemed this area to fall within the "Urban Area" classification. The INP characterises an urban area as, inter alia:

"an area with an acoustical environment that:

- is dominated by "urban hum" or industrial source noise*
- has through traffic with characteristically heavy and continuous traffic flows during peak periods*
- is near commercial districts or industrial districts*
- has any combination of the above."*

3.1.3.2 Educational Areas

The INP requires an internal LAeq(1 hour) noise level of no greater than 35 dBA, during the noisiest 1-hour period when the educational facility is in use.

Allowing for an outside-to-inside noise reduction of (at least) 10 dBA for a facade with openable windows, this requires the external LAeq(1 hour) levels incident on the adjacent educational buildings to be no greater than 45 dBA.

3.1.4 Preliminary Project Specific Noise Levels

Having defined the area classification, the processed results of the unattended noise monitoring have been used to generate project-specific noise criteria. For each INP defined time period, the lowest LAeq and LA90 measured at locations L1 and L2 have been used in order to provide the most conservative criteria.

In this case (since the noise from equipment is anticipated as being fairly steady) the project-specific noise levels, which are shown in bold in **Table 5**, are the lower of the intrusive and amenity criteria.

Where the noise source contains annoying characteristics (such as prominent tonal components, impulsiveness, intermittency, irregularity or dominant low-frequency content) adjustments are applied to the level of noise that is received at the assessment point before comparison with the criteria.

The Amenity criteria given in **Table 5** assumes the existing LAeq level of industrial type noise at the residential accommodation currently matches the ANL, so as to result in the most stringent criteria. These criteria should therefore be considered as preliminary and further testing should be conducted in order to verify the measured levels, and the developed criteria, during the detailed design stage of the project.

Table 5 Criteria for Noise Emissions to Nearby Residential Receivers

Time of Day		Noise Level (dBA re 20 µPa)				
		ANL ¹ (Period)	Measured RBL LA90(Period) ²	Measured LAeq(Period)	INP Criteria	
					Intrusive	Amenity
					LAeq(15minute) Criterion for New Sources	LAeq(Period) Criterion for New Sources ³
Location 1						
Day	7.00 am - 6.00 pm	60	53	58	58	52
Evening	6.00 pm - 10.00 pm	50	52	56	57	42
Night	10.00 pm - 7.00 am	45	51	55	56	37

Note 1: ANL: Acceptable Noise Level for an "Urban" area.

Note 2: RBL: Rating Background Level.

Note 3: Assuming existing noise levels are unlikely to decrease.

Note 4: Project Specific Criteria are shown in bold.

Note 5: The Amenity criteria given assumes the existing level of "industrial" noise (LAeq) at the residential accommodation currently matches the ANL, so as to result in the most conservative (ie most stringent) criteria.

3.1.5 Summary of Criteria for Mechanical Plant

The following criteria are proposed (subject to verification during the detailed design stage):

Closest Residential Accommodation

- Day LAeq(11 hour) 52 dBA (Externally)
- Evening LAeq(4 hour) 42 dBA (Externally)
- Night LAeq(9 hour) 37 dBA (Externally)

Closest Educational Buildings

While the existing educational buildings are in use: LAeq(1 hour) 45 dBA (Externally - openable glazing)

3.1.6 Discussion of Mechanical Plant Noise Criteria

Given the increased distance to the residential accommodation (approximately 12 m) compared to the adjacent educational areas (as close as 5 m), complying with the noise criterion at the nearby educational areas will also result in compliance at the residential accommodation during the daytime.

Mechanical plant usage would be scaled back considerably outside of the primary teaching hours with base systems continuing to operate for key laboratory services and the 'evening' oriented spaces such as the theatrical/studio spaces and plant associated with the adjoining Roundhouse.

Considering that the nearest off-site premises are approximately 110 m away, it is expected that compliance at the University will also result in compliance at off-site premises.

3.2 Operational Noise Criteria – Breakout Noise from Studio Spaces

When in operation, the breakout noise from the studio spaces must also be controlled to prevent impacts to the acoustic amenity of nearby premises. However, breakout noise from studio spaces would have different characteristics to "Industrial" noise, and consequently the noise criteria outlined in the INP are not immediately applicable. Breakout noise from these spaces is likely to occur for short periods of time (up to 3-4 hours) on an irregular basis during the daytime and evening periods, rather than on a continuous basis like mechanical plant noise.

SLR proposes that the INP Intrusiveness Criteria are adopted to ensure that the breakout noise impacts are adequately controlled, with the penalties outlined in the INP applied for low frequency noise and impulsive noise where applicable (depending on the nature of the specific usage of the spaces). This would be imposed in addition to the existing controls stipulated by the University.

Using information outlined within **Table 5**, the following criteria for breakout noise from the studio spaces are proposed (subject to verification during the detailed design stage):

Closest Residential Accommodation

- Day LAeq(15minute) 58 dBA (Externally)
- Evening LAeq(15minute) 57 dBA (Externally)
- Night LAeq(15minute) 56 dBA (Externally)

Closest Educational Buildings

While the existing educational buildings are in use: LAeq(1 hour) 45 dBA (Externally - openable glazing).

The criteria given should be considered as preliminary and further testing should be conducted during the detailed design stage of the project to verify the measured levels, and the developed criteria.

3.3 Construction Noise Criteria

The EPA's "*Interim Construction Noise Guideline*", 2009 (ICNG) presents procedures for dealing with the impacts of construction noise on residences and other sensitive land uses by presenting assessment approaches that are tailored to the scale of construction projects.

The main objectives of the ICNG are stated in Section 1.3 of the ICNG. The relevant items are presented below:

- Promote a clear understanding of ways to identify and minimise noise from construction works
- Focus on applying all 'feasible' and 'reasonable' work practices to minimise construction noise impacts.
- Encourage construction to be undertaken only during the recommended standard hours unless approval is given for works that cannot be undertaken during these hours.
- Streamline the assessment and approval stages and reduce time spent dealing with complaints at the project implementation stage.
- Provide flexibility in selecting site-specific feasible and reasonable work practices in order to minimise noise impacts.

Whilst it is recognised the guideline is non-mandatory, it is considered to be applicable to this project and has been adopted for the assessment of construction noise.

Guidance noise levels are given for airborne noise at sensitive land uses, including passive recreation, commercial and industrial premises. Guidance levels are also given for ground-borne noise and sleep disturbance. The assessment method involves predicting noise levels and comparing them with the guidance or management levels.

The 'management levels' will be referred to as 'Noise Management Levels' (NMLs). The NMLs have been reproduced from the guideline and are presented in **Table 6**.

Specific non-residential receivers in the vicinity of the proposed construction site, and their recommended 'management levels', are presented in **Table 7**.

Table 6 Guideline Management Levels for Construction Noise

Time of day	Management Level LAeq (15 min) ¹	How to apply
Recommended standard hours: Monday to Friday 7 am to 6 pm Saturday 8 am to 1 pm No work on Sundays or public holidays	Noise affected RBL + 10 dB	The noise affected level represents the point above which there may be some community reaction to noise. - Where the predicted or measured LAeq(15 min) is greater than the noise affected level, the proponent should apply all feasible and reasonable work practices to meet the noise affected level. - The proponent should also inform all potentially impacted residents of the nature of works to be carried out, the expected noise levels and duration, as well as contact details.
	Highly noise affected 75 dB(A)	The highly noise affected level represents the point above which there may be strong community reaction to noise. - Where noise is above this level, the relevant authority (consent, determining or regulatory) may require respite periods by restricting the hours that the very noisy activities can occur, taking into account: - times identified by the community when they are less sensitive to noise (such as before and after school for works near schools, or mid-morning or mid-afternoon for works near residences. - if the community is prepared to accept a longer period of construction in exchange for restrictions on construction times.
Outside recommended standard hours	Noise affected RBL + 5 dB	- A strong justification would typically be required for works outside the recommended standard hours. - The proponent should apply all feasible and reasonable work practices to meet the noise affected level. - Where all feasible and reasonable practices have been applied and noise is more than 5 dB(A) above the noise affected level, the proponent should negotiate with the community.

Note 1 The noise levels apply at the property boundary that is the most exposed to the construction noise, and at a height of 1.5 m above ground level. If the property boundary is more than 30 m from the residence, the location for measuring or predicting noise levels is at the most noise-affected point within 30 m of the residence. Noise levels may be higher at upper floors of the noise affected residence.

Table 7 Noise at Sensitive Land Uses (other than Residences) and Commercial and Industrial Premises

Land use	LAeq(15minute) Construction NML
Classrooms at schools and other educational institutions	Internal noise level 45 dBA
Hospital wards and operating theatres	Internal noise level 45 dBA
Places of worship	Internal noise level 45 dBA
Active recreation areas (characterised by sporting activities and activities which generate their own noise or focus for participants, making them less sensitive to external noise intrusion)	External noise level 65 dBA
Passive recreation areas (characterised by contemplative activities that generate little noise and where benefits are compromised by external noise intrusion, for example, reading, meditation)	External noise level 60 dBA
Offices, retail outlets	External noise level 70 dBA
Industrial premises	External noise level 75 dBA

3.3.1 Summary of Construction Noise Criteria

The NML is 45 dBA (internally) for the adjacent educational facilities, which translates to an external level (incident on the buildings) of 55 dBA.

The NML is 63 dBA for the nearby University accommodation during recommended standard hours. The NML is 56 dBA outside of the recommended standard hours, based on the measured night-time RBL.

For the stables to the north, the NML is taken as 65 dBA (see active recreation areas in **Table 7** above).

For the closest off-site residential receivers (200 m to the south-west) the NML during recommended standard hours can be expected to be in the order of 68 dBA, assuming a daytime background noise similar to that measured at the stables of 58 dBA (see **Section 2.3.1** and **Table 6**). This assumption is considered to be conservative given the proximity of these receivers to Anzac Parade, which will have appreciably high levels of road traffic noise. In the hours outside of the standard hours but still during the daytime period (i.e 1:00 pm to 5:00 pm Saturday) the NML is 63 dBA.

For the off-site residential receivers at Willis Street and Norton Street (430 m to the south-east) the NML during standard construction hours is 58 dBA. In the hours outside of the standard hours but still during the daytime period (i.e 1:00 pm to 5:00 pm Saturday) the NML is 53 dBA.

Note, however, these criteria should be considered as preliminary and further testing will be conducted to verify the measured levels, and the developed criteria, during the detailed design stage.

3.4 Construction Vibration Criteria – Human Comfort

Humans are far more sensitive to vibration than is commonly realised. They can detect vibration levels which are well below those causing any risk of damage to a building or its contents.

The actual perception of motion or vibration may not, in itself, be disturbing or annoying. An individual's response to that perception, and whether the vibration is "normal" or "abnormal", depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as "normal" in a car, bus or train is considerably higher than what is perceived as "normal" in a shop, office or dwelling.

Human tactile perception of random motion, as distinct from human comfort considerations, was investigated by Diekmann and subsequently updated in German Standard DIN 4150 Part 2-1975. On this basis, the resulting degrees of perception for humans are suggested by the vibration level categories given in **Table 8**.

Table 8 suggests that people will just be able to feel floor vibration at levels of about 0.15 mm/s and that the motion becomes “noticeable” at a level of approximately 1 mm/s.

Table 8 Peak Vibration Levels and Human Perception of Motion

Approximate Vibration Level	Degree of Perception
0.10 mm/s	Not felt
0.15 mm/s	Threshold of perception
0.35 mm/s	Barely noticeable
1 mm/s	Noticeable
2.2 mm/s	Easily noticeable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having a frequency content in the range of 8 Hz to 80 Hz.

3.4.1 Human Comfort Criteria for Construction Vibration

British Standard 6472-2008 “*Guide to evaluation of human exposure to vibration in building*” nominates criteria for various categories of disturbance, the most stringent of which are the levels of building vibration associated with a “low probability of adverse comment” from occupants. The “low probability of adverse comment” level for residential buildings is:

0.4 to 0.8 m/s^{1.75} (16 hour daytime Vibration Dose Value)

0.2 to 0.4 m/s^{1.75} (8 hour night-time Vibration Dose Value)

BS 6472-2008 provides criteria for continuous, transient and intermittent (in the case of road traffic) events that are based on a Vibration Dose Value (VDV), rather than a continuous vibration level. The vibration dose value is dependent upon the level and duration of the short-term vibration event, as well as the number of events occurring during the daytime or night-time period.

The criteria presented in BS6472 supersede the EPA’s “*Assessing Vibration: A Technical Guideline*”. As outlined within “*Assessing Vibration: A Technical Guideline*”:

“As BS 6472-1992 is due to be revised, this guideline can be considered interim until the revision is published.”

3.4.2 Vibration Dose Limits

The permissible rms particle velocity levels corresponding to the vibration dose value vary according to the duration of exposure. **Table 9** shows the range of satisfactory vibration dose values for which various degrees of adverse comment may be expected in the buildings surrounding the project.

Table 9 Vibration Dose Values ($\text{m/s}^{1.75}$) above which Various Degrees of Adverse Comment May Be Expected in Residential Buildings, Offices and Workshops

Location	Low Probability of Adverse Comment	Adverse Comment Possible	Adverse Comment Probable
Offices 16 hour day	0.4 to 0.8	0.8 to 1.6	1.6 to 3.2
Workshops 16 hour day	0.8 to 1.6	1.6 to 3.2	3.2 to 6.4
Residential buildings 16 hour day	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6

Situations exist where motion magnitudes above the dose levels given in BS 6472 can be acceptable, particularly for temporary disturbances and infrequent events of short-term duration. An example is a construction or excavation project.

When short-term works such as piling, demolition or compaction give rise to impulsive vibrations, it should be borne in mind that undue restriction on vibration levels can significantly prolong these operations and result in greater annoyance.

In certain circumstances, the use of higher magnitudes of acceptability may be considered, eg for projects having social worth or broader community benefits or in view of the economic or practical feasibility of reducing vibration to the recommended levels. In such cases, best management practices should be employed to reduce levels as far as practical.

3.4.3 Effects on Building Contents

People can perceive floor vibration at levels well below those likely to cause damage to building contents or affect their operation. For most receivers, the controlling vibration criterion is therefore the human comfort criterion and separate objectives are not normally required in relation to the effect of construction vibration on building contents.

Some scientific equipment (eg electron microscopes and microelectronics manufacturing equipment) can require more stringent objectives than those applicable to human comfort. Where appropriate, objectives for the satisfactory operation of critical instruments or manufacturing processes should be sourced from manufacturer's data and /or other published objectives.

3.5 Effects of Vibration on Structures

The levels of vibration required to cause cosmetic damage to buildings tend to be at least an order of magnitude (ie, 10 times) higher than those at which people may consider the vibration to be intrusive.

In terms of the most recent relevant vibration damage objectives, Australian Standard AS 2187: Part 2-2006 *"Explosives - Storage and Use - Part 2: Use of Explosives"* recommends the frequency dependent guideline values and assessment methods given in BS 7385 Part 2-1993 *"Evaluation and measurement for vibration in buildings Part 2"* as they "are applicable to Australian conditions".

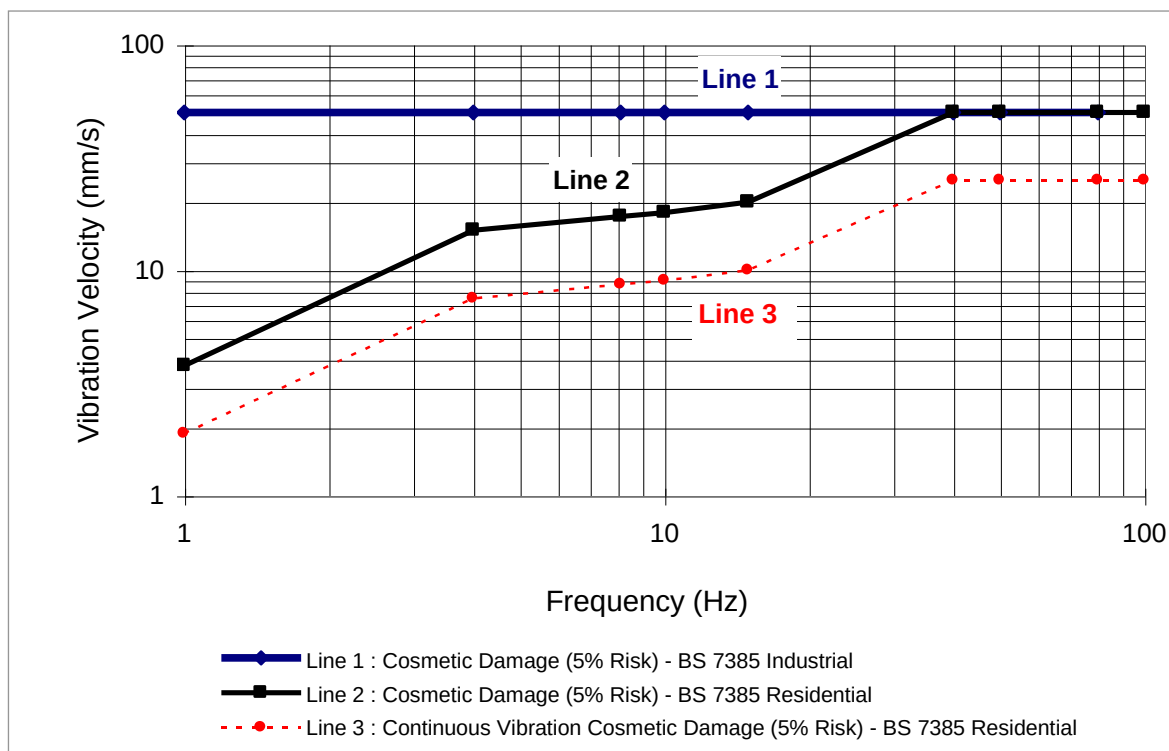
The British Standard sets guide values for building vibration based on the lowest vibration levels above which damage has been credibly demonstrated. These levels are judged to give a minimum risk of vibration induced damage, where minimal risk for a named effect is usually taken as a 95% probability of no effect.

The recommended limits (guide values) from BS7385 for transient vibration to ensure minimal risk of cosmetic damage to residential and industrial buildings are presented numerically in **Table 10** and graphically in **Figure 3**.

Table 10 Transient Vibration Guide Values – Minimal Risk of Cosmetic Damage

Line	Type of Building	Peak Component Particle Velocity in Frequency Range of Predominant Pulse	
		4 Hz to 15 Hz	15 Hz and Above
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commercial type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above

Figure 3 Graph of Transient Vibration Guide Values for Cosmetic Damage



The standard states that the guide values in **Table 10** relate predominantly to transient vibration which does not give rise to resonant responses in structures, and to low-rise buildings. Where the dynamic loading caused by continuous vibration is such as to give rise to dynamic magnification due to resonance, especially at the lower frequencies where lower guide values apply, then the guide values in **Table 10** may need to be reduced by up to 50% - ie 7.5 mm/s at 4 Hz (as shown by Line 3 of **Figure 3** for Residential Buildings).

In the lower frequency region where strains associated with a given vibration velocity magnitude are higher, the guide values for building types corresponding to Line 2 are reduced. Below a frequency of 4 Hz where a high displacement is associated with the relatively low peak component particle velocity value, a maximum displacement of 0.6 mm (zero to peak) is recommended. This displacement is equivalent to a vibration velocity of 3.7 mm/s at 1 Hz.

The standard goes on to state that minor damage is possible at vibration magnitudes which are greater than twice those given in **Table 10** and major damage to a building structure may occur at values greater than 4 times the tabulated values.

Fatigue considerations are also addressed in the standard and it is concluded that unless calculations indicate that the magnitude and number of load reversals is significant (in respect of the fatigue life of building materials) then the guide values in **Table 10** should not be reduced for fatigue considerations.

It is noteworthy that, in addition to the guide values nominated in **Table 10**, the standard states that:

"Some data suggests that the probability of damage tends towards zero at 12.5 mm/s peak component particle velocity. This is not inconsistent with an extensive review of the case history information available in the UK."

Also that:

A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive."

3.5.1 German Standard DIN 4150: Part 3-1999

For continuous long-term vibration or repetitive vibration with the potential to cause fatigue effects, DIN 4150 provides the following Peak Particle Velocity (PPV) values as safe limits, below which even superficial cosmetic damage is not to be expected:

- 10 mm/s for commercial buildings and buildings of similar design.
- 5 mm/s for dwellings and buildings of similar design.
- 2.5 mm/s for buildings of great intrinsic value (eg heritage listed buildings).

For short-term vibration events (ie those unlikely to cause resonance or fatigue), DIN 4150 offers the criteria shown in **Table 11**. These are maximum levels measured in any direction at the foundation or in the horizontal axes in the plane of the uppermost floor.

Table 11 DIN 4150 Structural Damage - Safe Limits for Short-term Building Vibration

Group	Type of Structure	Peak Particle Velocity (mm/s)			
		At Foundation			Plane of Floor of Uppermost Storey
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz ¹	
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 at 10 Hz increasing to 40 at 50 Hz	40 at 50 Hz increasing to 50 at 100 Hz	40
2	Dwellings and buildings of similar design and/or use	5	5 at 10 Hz increasing to 15 at 50 Hz	15 at 50 Hz increasing to 20 at 100 Hz	15
3	Structures that because of their particular sensitivity to vibration, do not correspond to those listed in Lines 1 or 2 and have intrinsic value (eg buildings that are under a preservation order)	3	3 at 10 Hz increasing to 8 at 50 Hz	8 at 50 Hz increasing to 10 at 100 Hz	8

Note 1: For frequencies above 100 Hz the upper value in this column should be used.

As opposed to the “*minimal risk of cosmetic damage*” approach adopted in BS 7385 (95% probability of no effect), the “*safe limits*” given in DIN 4150 are the levels up to which no damage due to vibration effects has been observed for the particular class of building. “*Damage*” is defined by DIN 4150 to include even minor non-structural effects such as superficial cracking in cement render, the enlargement of cracks already present, and the separation of partitions or intermediate walls from load bearing walls.

4 OPERATIONAL NOISE ASSESSMENT

4.1 Mechanical Plant Noise

Typically large air conditioning equipment will have Sound Power Levels in the order of 100 dBA. Such plant may require some perimeter screening to satisfy the criteria at the residential accommodation to the north, depending upon the plant's location, and its operational load.

Although adjacent educational areas are closer, noise to these may be reduced by the shielding effect from the building's roof-top edge. Thus, the plant may similarly require some perimeter screening to satisfy the criterion at these locations.

Plant of less acoustic power is unlikely to be problematic with regard to noise to the environment.

Any tri-generation plant (the feasibility of which is currently being investigated) would likely require large-section, long attenuators to control breakout noise to the environment, and space for these should be allowed for in the early stages of the design.

4.2 Breakout Noise from Studio Spaces

The Io Myers Studio and Studio 1 both accommodate a wide variety of uses, ranging from a teaching space to hosting musical and dramatic performances. However, given that the proposed activities already occur within existing above-ground facilities (of lightweight construction) adjacent to the proposed site, it is envisaged that breakout noise can be controlled through conventional means such as the provision of upgraded glazing, absorptive panelling and insulation of the ceiling spaces.

Space for such measures should be allowed for in the early stages of the design, and must be developed during the design stages of the project, to ensure any breakout noise from the proposed spaces will meet the noise criteria.

The detailed design will also be required to consider the potential noise impacts on adjacent spaces within the SEB building as well as noise intrusion into the performing spaces, such that the performing spaces comply with the requirements of AS/NZS 2107: *Acoustics – Recommended design sound levels and reverberation times for building interiors*. However, these considerations are outside of the scope of this report.

5 CONSTRUCTION NOISE ASSESSMENT

The conceptual construction program is expected to last for a total period of approximately 22 months and comprises the major elements shown in **Table 12**.

Table 12 Proposed Construction Program

Activity	Equipment Used
1. Site establishment including the construction of access roads	Earthmoving equipment and paving machinery
2. General excavation work	Earthmoving equipment, trucks, rockbreakers, piling
3. Building shell construction	Trucks, concrete pumps, crane
4. Basic Fitout, including electrical and mechanical services	General construction, crane
5. Detailed Fitout, such as partitions, communications and security systems	Hand tools, cranes
6. Landscaping and Commissioning	Hand tools, trucks, crane

The construction hours for the project are outlined in **Table 13**.

Table 13 Project Construction Hours

Day	Hours Working
Monday to Friday	7:00 am to 6:00 pm
Saturday	8:00 am to 5:00 pm
Sunday	No work

To assess the impact of the construction of the proposed building, noise levels have been calculated (based on distance attenuation) at the following locations (detailed in **Figure 1**, **Figure 2**, **Table 1** and **Table 2**):

- Willis Street/Norton Street Residents
- Anzac Parade/Houston Lane Residents
- Randwick Stables
- International House Ltd.
- Materials Science and Engineering Building (MSEB)

The noise and vibration impacts of the demolition of the existing buildings are not covered in this report. SLR has prepared a separate Construction Noise and Vibration Management Plan for these works (SLR report 610.11518 CNVMP R1R2 dated 4 April 2016).

The noise levels calculated at the Willis Street/Norton Street Residents, the Anzac Parade/Houston Lane Residents and the Randwick Stables included a nominal 15 dBA reduction for shielding from intervening buildings.

Typical Equipment Sound Power Levels of the noisiest equipment likely to be used during the construction phase are shown in **Table 14**.

At the MSEB and the other educational facilities, the external noise level criterion of 55 dBA during use will be exceeded significantly (i.e in the order of 13 dB to 45 dB). On this basis, it is recommended that feasible and reasonable mitigation and management measures are implemented in order to reduce noise generation and impacts, these measures will be outlined in **Section 7**.

At International House, the receivers will be “Highly Noise Affected” during rockbreaking, and will be “Noise Affected” during all other construction activities except for the use of the compressor and general hand tools. Similarly, it is recommended that feasible and reasonable mitigation and management measures are implemented to reduce noise generation and impacts.

At the stables, the levels are expected to fall within the “noise affected” NML of 65 dBA (for “Active recreation areas (characterised by sporting activities and activities which generate their own noise or focus for participants, making them less sensitive to external noise intrusion)”). Further, the predicted noise levels are well below the general ambient daytime levels at that location (in the order of 57 LA90 to 67 LA10) and are likely to go mostly unnoticed.

At the nearest off-site residences near Anzac Parade / Houston Lane (200 m to the southwest), the noise levels are expected to fall within the “Noise Affected” NMLs of 68 dBA and 63 dBA (as detailed in **Section 3.3.1**). Further, the predicted noise levels are likely to be well below the ambient daytime levels at that location and are likely to go mostly unnoticed.

The noise levels are also expected to fall within the NMLs of 58 dBA and 53 dBA (as detailed in **Section 3.3.1**) at the Willis Street/Norton Street residents. Similarly, the predicted noise levels are likely to be well below the ambient daytime levels at that location and are likely to go mostly unnoticed.

Table 14 Typical Equipment Sound Power Levels and Predicted Noise Levels at the nearest Receivers

Operation/ Activity	Range of typical Maximum ¹ Sound Power Levels (dBA)	Willis Street Residents (430 m from SEB)	Houston Lane Residents (200 m from SEB)	Randwick Stables (110 m from SEB)	Internation al House Ltd (12 m from SEB)	MSEB (5 m from SEB)
		Receiver LAeq Noise Level in dBA ¹				
Concrete Mixers	107 to 112	28 to 33	35 to 40	40 to 45	74 to 79	82 to 87
Dump trucks on site	108	29	36	41	75	83
Excavators/Loaders	108 to 112	29 to 33	36 to 40	41 to 45	75 to 79	83 to 87
Rockbreaker	120	46 ²	53 ²	58 ²	92 ²	100 ²
Vibrating Roller	107	28	35	40	74	82
Bored piling rig	105	27	33	38	72	80
Compressor	94	15	22	27	61	69
Jackhammer - pneumatic	109	35 ²	42 ²	47 ²	81 ²	89 ²
Fixed Crane	104 to 108	25 to 29	32 to 36	37 to 41	71 to 75	79 to 83
Mobile Crane	100 to 110	21 to 31	28 to 38	33 to 43	67 to 77	75 to 85
General hand tools	93 to 98	14 to 19	21 to 26	26 to 31	60 to 65	68 to 73

Note 1: LAeq noise levels are typically 3 dB below maximum noise levels.

Note 2: The resultant noise levels from the rockbreaker and jackhammer include a 5dB ‘impulsive’ noise penalty.

6 CONSTRUCTION VIBRATION ASSESSMENT

The major potential sources of construction vibration include driven piles, rockbreakers and vibratory rollers.

6.1 Safe Working Distances for Vibration Intensive Activities

Safe working distances for typical items of vibration intensive plant are listed in **Table 15**. These distances are indicative only and can vary depending on the particular item of plant and geotechnical conditions. Please note, the safe working distances apply to structural damage of typical buildings and typical geotechnical conditions. They do not address heritage structures, sensitive equipment or human comfort considerations.

Table 15 Indicative Safe Working Distances for Vibration Intensive Plant Items

Plant Item	Rating/Description	Safe Working Distance
		Cosmetic Damage (DIN 4150)
Impact Roller	10 to 12 tonne	5 m to 15 m
Vibratory Roller	< 50 kN (Typically 1-2 tonnes)	2 m
	< 100 kN (Typically 2-4 tonnes)	2 m
	< 200 kN (Typically 4-6 tonnes)	4 m
	< 300 kN (Typically 7-13 tonnes)	5 m
	> 300 kN (Typically 13-18 tonnes)	6 m
	> 300 kN (> 18 tonnes)	8 m
Vibratory Pile Driver	Sheet piles	1 m to 6 m
Small Hydraulic Hammer	(300 kg - 5 to 12t excavator)	1 m
Medium Hydraulic Hammer	(900 kg - 12 to 18t excavator)	2 m
Large Hydraulic Hammer	(1600 kg - 18 to 34t excavator)	6 m
Pile Boring	≤ 800 mm	2 m (nominal)
Ripping	-	2 m (nominal)
Jackhammer	Hand held	1 m (nominal)
Rocksaw	-	1 m (nominal)

6.2 Expected Vibration Impacts

There is no risk of damage to off-site buildings, or even to the closest University buildings, from rock breaking.

Vibratory rollers and large hydraulic hammers present no risk of damage to off-site buildings, but the University may wish to consider a noise and vibration management plan to minimise the risk of damage to the closest of their buildings and / or interference to the operation of nearby sensitive equipment.

Vibration may be perceptible for relatively short periods of time when construction activities are immediately adjacent to specific buildings.

7 RECOMMENDATIONS

7.1 Operational Noise – Mechanical Plant

Noise control measures must be developed during the design stages of the project to ensure noise from mechanical equipment will meet the noise criteria.

However, given the location of the proposed development in relation to teaching / educational areas to the east, northeast, west and south, and the residential accommodation to the north, it is likely that noise from mechanical services plant will be adequately controlled through conventional means such as attenuators, acoustic louvres, barriers, enclosures, and the careful location and orientation of the plant and of air inlets and outlets.

Given the distance and screening to the stables to the north (110 m), complying with the noise criteria at the University's residential accommodation will also result in compliance at these neighbouring premises.

The criteria given should be considered as preliminary and further testing should be conducted during the detailed design stage of the project to verify the measured levels, and the developed criteria.

7.2 Operational Noise – Breakout from Studio Spaces

Noise control measures must be developed during the design stages of the project to ensure breakout noise from the studio spaces will meet the noise criteria.

Considering that the proposed activities already occur within existing above-ground facilities (of lightweight construction) adjacent to the proposed site, it is envisaged that breakout noise can be controlled through conventional means such as the provision of upgraded glazing, absorptive panelling and insulation of the ceiling spaces. The facades will be designed in consideration of the requirements for both breakout noise emission as well as noise intrusion into the performing spaces, such that the performing spaces comply with the requirements of AS/NZS 2107: *Acoustics – Recommended design sound levels and reverberation times for building interiors*.

Given the distance and screening to the stables to the north (110 m), complying with the noise criteria at the University's residential accommodation will also result in compliance at these neighbouring premises.

7.3 Construction Noise and Vibration

7.3.1 Off-Site Locations

There is no need for any particular control measures in relation to off-site locations: noise and vibration both at the stables and at the residences on High Street are expected to be less than the "Noise Affected" Noise Management Level, and less than the respective ambient daytime noise levels in these locations.

There will clearly be no risk of vibration damage to off-site buildings.

7.3.2 University Premises

SLR recommends that the University consider implementing a Noise and Vibration Management Plan to minimise the disruption / interference to the operation of nearby vibration-sensitive equipment and the adjacent educational facilities.

A summary of the potential mitigation measures that may need to be implemented is provided in **Table 16**.

Table 16 Potential Noise and Vibration Mitigation Measures

Item	Description
Noise Monitoring	Carry out continuous noise monitoring for the duration of the construction period. The continuous noise monitoring would be supplemented by attended noise monitoring where required.
Noise Barriers	Install Noise Barriers around the perimeter of the construction site where possible and practicable.
Construction Hours	Carry out works only within the hours of 7:00 am to 6:00 pm Monday to Friday and 8:00 am to 5:00 pm on Saturday.
Deliveries	Carry out deliveries only within the standard construction hours.
Site Layout	Where possible, locate and orient plant and equipment to direct noise away from sensitive receivers.
Quietest Suitable Equipment	Select plant and equipment to minimise noise emission, where possible, whilst maintaining efficiency of function. Fit residential grade silencers and maintain all noise control equipment in good order.
Hammer Equipment	Maximise hammer penetration (and reduce blows) by using sharp hammer tips. Keep stocks of sharp profiles at site, and monitor the profiles in use.
Reversing Alarms	Minimise the reversing alarm noise emissions of mobile plant and trucks operating on site for a significant portion of the project, where possible, recognising the need to maintain occupational safety standards.
Vibration Buffer Zones	General safe working distances for impact rolling, rockbreaking and bored piling are described in Table 15 . Carry out monitoring to confirm these buffer zones at locations where buildings are closest.
Vibration Monitoring	Carry out vibration monitoring where vibration intensive activities (eg impact rolling, rockbreaking and bored piling) are required to be carried out within the established buffer zones, or where there is considered to be a risk that vibration levels may exceed the relevant structural damage criteria.
Truck Noise (off site)	Ensure mufflers are installed on all trucks regularly used for the project and ensure that any other noise control equipment is maintained in good working order. Trucking routes are to use main roads, where feasible.
Community Liaison	Implement a programme of community liaison and complaint response.
Training	Include a noise awareness component in the site induction training

8 CONCLUSION

This report addressed the Secretary's Environmental Assessment Requirements in terms of noise and vibration impacts due to operational and construction activity.

The results of environmental noise logging are presented, together with preliminary noise criteria for the development's own noise emissions to the environment from fixed plant and breakout noise from the relocated studio spaces.

Recommendations are given with regard to further noise logging during the design stages in order to verify these preliminary criteria.

Noise arising from the operational phase should not result in any significant or unacceptable impacts on the site or the surrounding premises.

Noise and vibration arising from the construction phase should not result in any significant or unacceptable impacts on the surrounding premises. However, the implementation of a Noise and Vibration Management Plan would minimise the disruption and the risk of structural damage to the closest of the University buildings.

1 Sound Level or Noise Level

The terms “sound” and “noise” are almost interchangeable, except that in common usage “noise” is often used to refer to unwanted sound.

Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or LP are commonly used to represent Sound Pressure Level. The symbol LA represents A-weighted Sound Pressure Level. The standard reference unit for Sound Pressure Levels expressed in decibels is 2×10^{-5} Pa.

2 “A” Weighted Sound Pressure Level

The overall level of a sound is usually expressed in terms of dBA, which is measured using a sound level meter with an “A-weighting” filter. This is an electronic filter having a frequency response corresponding approximately to that of human hearing.

People’s hearing is most sensitive to sounds at mid frequencies (500 Hz to 4000 Hz), and less sensitive at lower and higher frequencies. Thus, the level of a sound in dBA is a good measure of the loudness of that sound. Different sources having the same dBA level generally sound about equally loud.

A change of 1 dBA or 2 dBA in the level of a sound is difficult for most people to detect, whilst a 3 dBA to 5 dBA change corresponds to a small but noticeable change in loudness. A 10 dBA change corresponds to an approximate doubling or halving in loudness. The table below lists examples of typical noise levels

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130	Threshold of pain	Intolerable
120	Heavy rock concert	Extremely noisy
110	Grinding on steel	
100	Loud car horn at 3 m	Very noisy
90	Construction site with pneumatic hammering	Loud
80	Kerbside of busy street	
70	Loud radio or television	
60	Department store	Moderate to quiet
50	General Office	
40	Inside private office	Quiet to very quiet
30	Inside bedroom	
20	Recording studio	Almost silent

Other weightings (eg B, C and D) are less commonly used than A-weighting. Sound Levels measured without any weighting are referred to as “linear”, and the units are expressed as dB(lin) or dB.

3 Sound Power Level

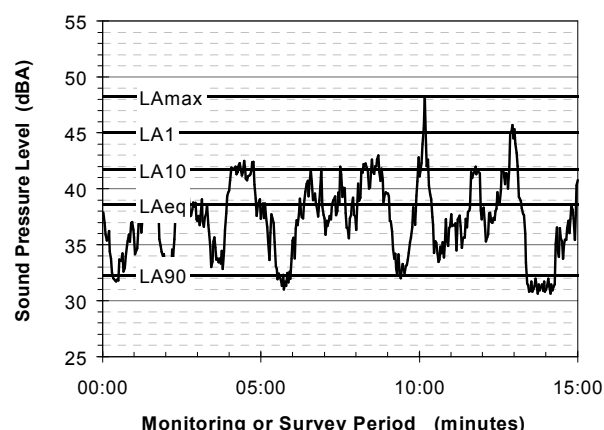
The Sound Power of a source is the rate at which it emits acoustic energy. As with Sound Pressure Levels, Sound Power Levels are expressed in decibel units (dB or dBA), but may be identified by the symbols SWL or Lw, or by the reference unit 10^{-12} W.

The relationship between Sound Power and Sound Pressure may be likened to an electric radiator, which is characterised by a power rating, but has an effect on the surrounding environment that can be measured in terms of a different parameter, temperature.

4 Statistical Noise Levels

Sounds that vary in level over time, such as road traffic noise and most community noise, are commonly described in terms of the statistical exceedance levels L_{AN} , where L_{AN} is the A-weighted sound pressure level exceeded for N% of a given measurement period. For example, the L_{A1} is the noise level exceeded for 1% of the time, L_{A10} the noise level exceeded for 10% of the time, and so on.

The following figure presents a hypothetical 15 minute noise survey, illustrating various common statistical indices of interest.



Of particular relevance, are:

- L_{A1} The noise level exceeded for 1% of the 15 minute interval.
- L_{A10} The noise level exceeded for 10% of the 15 minute interval. This is commonly referred to as the average maximum noise level.
- L_{A90} The noise level exceeded for 90% of the sample period. This noise level is described as the average minimum background sound level (in the absence of the source under consideration), or simply the background level.
- L_{Aeq} The A-weighted equivalent noise level (basically the average noise level). It is defined as the steady sound level that contains the same amount of acoustical energy as the corresponding time-varying sound.

When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given monitoring location for a particular time of day. A standardised method is available for determining these representative levels.

This method produces a level representing the “repeatable minimum” L_{A90} noise level over the daytime and night-time measurement periods, as required by the EPA. In addition the method produces mean or “average” levels representative of the other descriptors (L_{Aeq} , L_{A10} , etc).

5 Tonality

Tonal noise contains one or more prominent tones (ie distinct frequency components), and is normally regarded as more offensive than “broad band” noise.

6 Impulsiveness

An impulsive noise is characterised by one or more short sharp peaks in the time domain, such as occurs during hammering.

7 Frequency Analysis

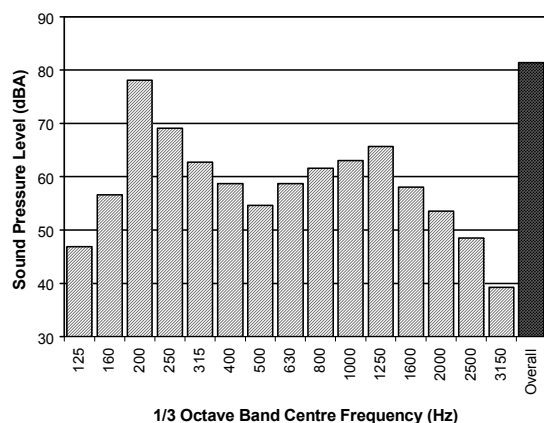
Frequency analysis is the process used to examine the tones (or frequency components) which make up the overall noise or vibration signal. This analysis was traditionally carried out using analogue electronic filters, but is now normally carried out using Fast Fourier Transform (FFT) analysers.

The units for frequency are Hertz (Hz), which represent the number of cycles per second.

Frequency analysis can be in:

- Octave bands (where the centre frequency and width of each band is double the previous band)
- 1/3 octave bands (3 bands in each octave band)
- Narrow band (where the spectrum is divided into 400 or more bands of equal width)

The following figure shows a 1/3 octave band frequency analysis where the noise is dominated by the 200 Hz band. Note that the indicated level of each individual band is less than the overall level, which is the logarithmic sum of the bands.



8 Vibration

Vibration may be defined as cyclic or transient motion. This motion can be measured in terms of its displacement, velocity or acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of "peak" velocity or "rms" velocity.

The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as "peak particle velocity", or PPV. The latter incorporates "root mean squared" averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse.

The common units for velocity are millimetres per second (mm/s). As with noise, decibel units can also be used, in which case the reference level should always be stated. A vibration level V , expressed in mm/s can be converted to decibels by the formula $20 \log (V/V_0)$, where V_0 is the reference level (10^{-9} m/s). Care is required in this regard, as other reference levels may be used by some organizations.

9 Human Perception of Vibration

People are able to "feel" vibration at levels lower than those required to cause even superficial damage to the most susceptible classes of building (even though they may not be disturbed by the motion). An individual's perception of motion or response to vibration depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as "normal" in a car, bus or train is considerably higher than what is perceived as "normal" in a shop, office or dwelling.

10 Over-Pressure

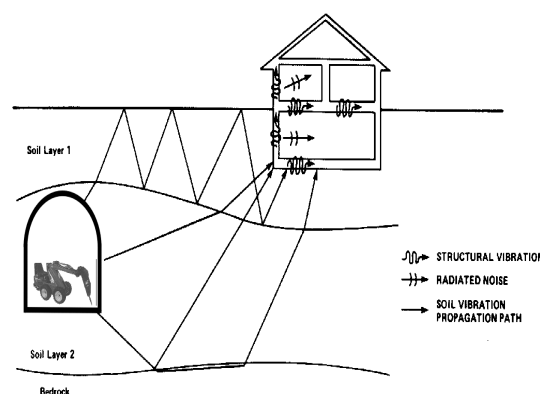
The term "over-pressure" is used to describe the air pressure pulse emitted during blasting or similar events. The peak level of an event is normally measured using a microphone in the same manner as linear noise (ie unweighted), at frequencies both in and below the audible range.

11 Ground-borne Noise, Structure-borne Noise and Regenerated Noise

Noise that propagates through a structure as vibration and is radiated by vibrating wall and floor surfaces is termed "structure-borne noise", "ground-borne noise" or "regenerated noise". This noise originates as vibration and propagates between the source and receiver through the ground and/or building structural elements, rather than through the air.

Typical sources of ground-borne or structure-borne noise include tunnelling works, underground railways, excavation plant (eg rockbreakers), and building services plant (eg fans, compressors and generators).

The following figure presents the various paths by which vibration and ground-borne noise may be transmitted between a source and receiver for construction activities occurring within a tunnel.



The term "regenerated noise" is also used in other instances where energy is converted to noise away from the primary source. One example would be a fan blowing air through a discharge grill. The fan is the energy source and primary noise source. Additional noise may be created by the aerodynamic effect of the discharge grill in the airstream. This secondary noise is referred to as regenerated noise.

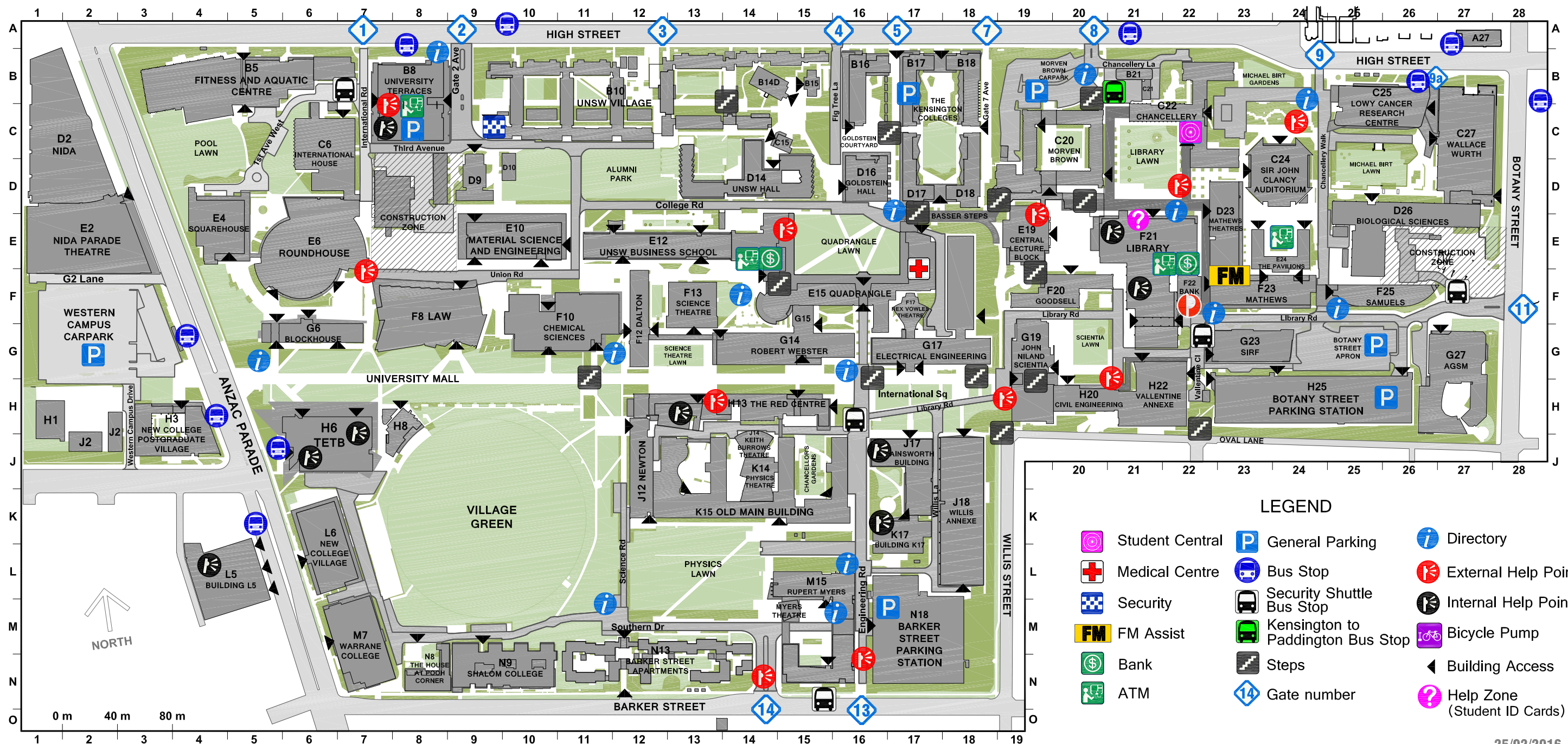
Appendix B

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Kensington Campus Map

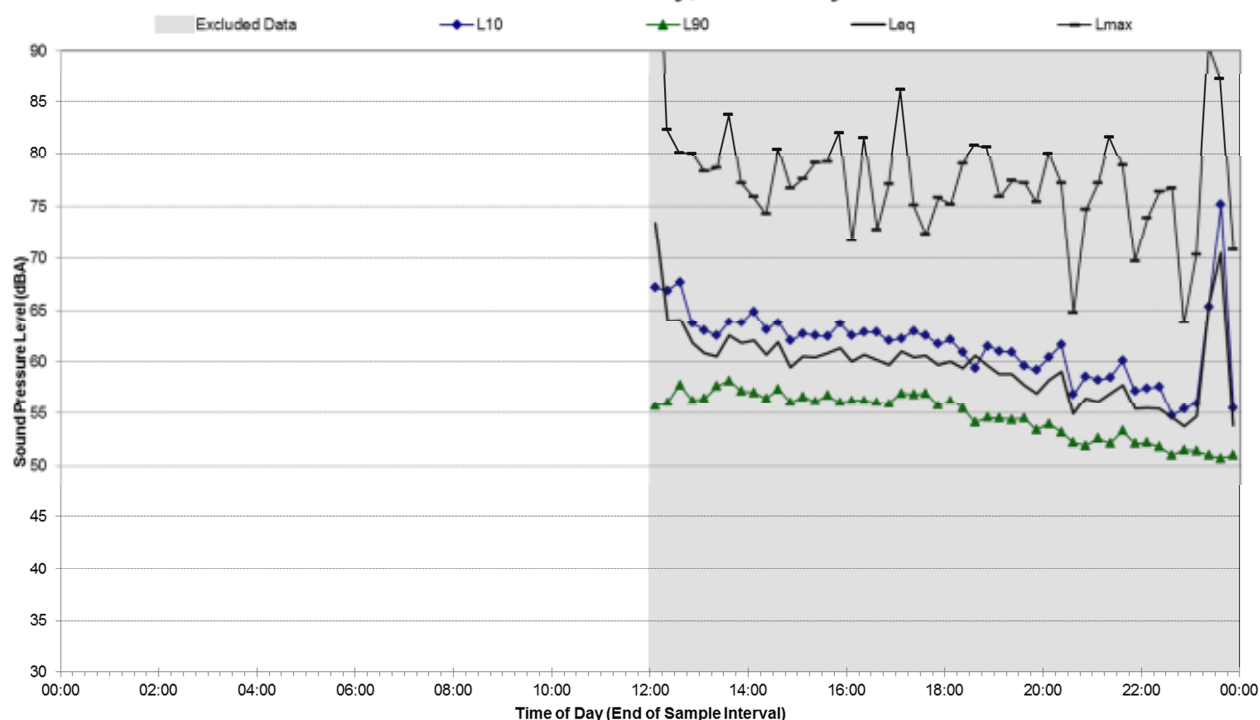
Kensington Campus



25/02/2016

Buildings		Material Science and Engineering		University Regiment		Faculty Offices		New South Global Theatre		Facilities Management		Religious Centre	
AGSM	G27	Mathews	E10	UNSW Business School	H1	Arts and Social Sciences	C20	Old Main Theatres (Room 112)	G14	FM Assist ID Cards & Parking	F23	Research Services	E4
Ainsworth Building	J17	Mathews Arcade	F23		E12	Built Environment	H13	Parade Theatres	K15	Foundation Studies Permits	F23	Security	M15
Biological Sciences	D26	Morven Brown	E24a			Engineering	K17	Physics Theatre	E2	Freehills Law Library	L5	Sports Association	B10
Blockhouse	G6	Newton	C20	Barker Apartments	N13	Law	F8	Red Centre Theatre	K14	Future Students Office	F8	Squash Courts	H8
Building D10	D10	NIDA	J12	Basser College	D17	Medicine	H13	Rex Vowels Theatre	H13	Graduate Research School	F20	Swimming Pool	B7
Building L5, 223 Anzac Parade	L5	Old Main	D2	Colombo House	B16	Science	C27	Ritchie Theatre	F17	Help Zone (Student ID Cards)	M15	The Learning Centre	B4
Chancellery	C22	Pavilions	K15	Creston College	A25	UNSW Business School	F12	Rupert Myers Theatre	G19	Human Resources	F21	University Health Services	C22
Chemical Sciences	F10	Quadrangle	E24	Fig Tree Hall	B18	Theatres	E12	Webster Theatres	M15	Institute of Languages	C22	UNSW Bookshop	E15
Civil Engineering	H20	Red Centre	E15	Goldstein College	B17	AGSM Theatres	G27	Science Theatre	G15	IT Service Desk	L5	UNSW International Student Centre	
Colombo House	B16	Robert Webster	H13	Goldstein Hall	D16	Allens Arthur Robinson	F8		F13	Kingsford Legal Centre	F8		H13
Computer Science	K17	Roundhouse	G14	International House	C6	Central Lecture Block	E19	Services		Learning & Teaching Unit @UNSW	F21	UNSW Residential Communities	B17
Dalton	F12	Rupert Myers	E6	New College	L6	Chemical Sciences Theatres	F10	Accommodation Services	C18	Library	F21	UNSW Scholarships	F21
Dangerous Goods Store	F17A	Sam Cracknell Pavilion	M15	New College Postgrad. Village	H3	Civil Engineering (Room G1)	H20	Admissions and Enrolments	C22	Lifestyle Clinic	A27	UNSW Fitness and Aquatic Centre	B5
Electrical Engineering	G17	Samuels	H8	Philip Baxter College	D18	Clancy Auditorium	C24	Alumni Association	C22	Mail Centre	F23	UNSW Student Central	C22
Golf House, 38 Botany Street	A27	SIRF	F25	Shalom College	N9	Colombo Theatres	B16	Arc @ UNSW	D17	Marketing Development	C22	Venues and Events	F23
John Goodsell	F20	Squarehouse	G23	Warrane College	M7	Fig Tree Theatre	B14d	Careers and Employment Office	E15	New South Innovations	M15		
John Niland Scientia	G19	Tyree Energy Technologies	E4	University Terraces	B8	Gonski Levy Theatre	F8	Cashier	C22	Nura Gili - Balnaves Place	G17	Childcare Centres	
Law	F8	Valentine Annexe	H6	UNSW Hall	D14	IO Myers Studio	D9	Chaplains	E4	Optometry Clinic	M15	Kangas House, 52 Barker St	O14
Library	F21	Wallace Wurth	H22	UNSW Village	B10	Keith Burrows Theatre	J14	Co-op program & Scholarship	F21	Physiotherapy Clinic	B8	House at Pooh Corner	N8
Lowy Cancer Research Centre	C25	Willis Annexe	C27	UNSW Residential Communities	B17	Law Theatres	F8	Counselling Service	E15	Post Office	F22	Tigger's Honeypot, 22 Botany St	BS22
			J18			Macauley Theatre	E15	Educational Support Service	F20	Print Centre	F23	Owl's House, 9 Kennedy St	KS9
						Mathews Theatres	D23	Equity and Disability Unit	F20				

Statistical Ambient Noise Levels Location One - Thursday, 4 February 2016



Statistical Ambient Noise Levels Location One - Friday, 5 February 2016

