APPENDIX **K**

NOISE & VIBRATION

(SLR Report)

Ref: 610.17428-R03-v3.0
August 2018

YARRABEE SOLAR PROJECT

Environmental Impact Statement - Appendix K
Noise & Vibration

Prepared for:

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Reach Solar énergy (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
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610.17428-R02-v2.0	18 July 2018	Peter Runcie	Alex Campbell	Suzanne Jolly
610.17428-R02-v1.0	29 June 2018	Peter Runcie	Alex Campbell	Peter Georgiou

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1 Introduction

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Reach Solar énergy (Reach Solar) to prepare a noise and vibration impact assessment for the proposed Yarrabee Solar Project.

This report addresses the Secretary's Environmental Assessment Requirements (SEARs) relevant to the Project (State Significant Development 9237), as contained in the letter from the Department of Planning and Environment dated 20 April 2018.

This report presents the study methodology, assessment criteria, assessment of noise emissions and noise mitigation recommendations, where applicable, in relation to the following specific areas of acoustic significance:

- Potential noise and vibration emissions during the construction stage; and
- Operational noise emissions from servicing vehicle movements and the transformer (circuit breaker).

A glossary of acoustic terminology is included as **Attachment A**.

2 Project Description, Site and Surrounds

2.1 Proposed Project Description

Reach Solar is proposing the development of a 900 MWac solar project (the Project) to be located approximately 23 kilometres (km) southwest of Narrandera in Western NSW. The Project is proposed to connect to the 330 kilovolt (kV) Wagga to Darlington Point Transmission Line.

The solar project would occupy 2,600 hectares (ha) within a 3,000 ha Project site. The Project is expected to include solar photovoltaic (PV) modules and single axis tracking system, inverter stations, a new substation, potential energy storage, grid connection, security perimeter fencing, designated buffer zones for confirmed environmentally and culturally sensitive areas, internal access roads, underground cabling and a main office and maintenance building.

The Project comprises the construction of a 900 MWac photovoltaic (PV) solar plant to be developed in stages. The number of stages to be constructed is dependent on factors including:

- the contractual obligations for the purchase of electricity by one or more third parties;
- the capacity of the high voltage transmission network to which the Project will be connected for the export of generated electricity; and
- the future schedule for upgrading the high voltage transmission network.

The complete Project will consist of approximately 222 inverter stations distributed throughout the solar power plant area. The preliminary design consists of 2 SMA 2.5 MVA inverters per inverter station, a total of 444 inverters.

The substation and transformer is comprised of the 33 kV collector substation, step-up transformer and 330 kV switchyard. The design team has confirmed that the anticipated substation transformer would be rated at 300MW/352MVA.

The site and surrounding land is predominantly rural in nature and use with sparsely located agricultural residences.

- **Figure 1** shows the site in relation to surrounding townships and State Highways.
- **Figure 2** shows an indicative layout diagram for the Project.

Figure 1 Site Location Map

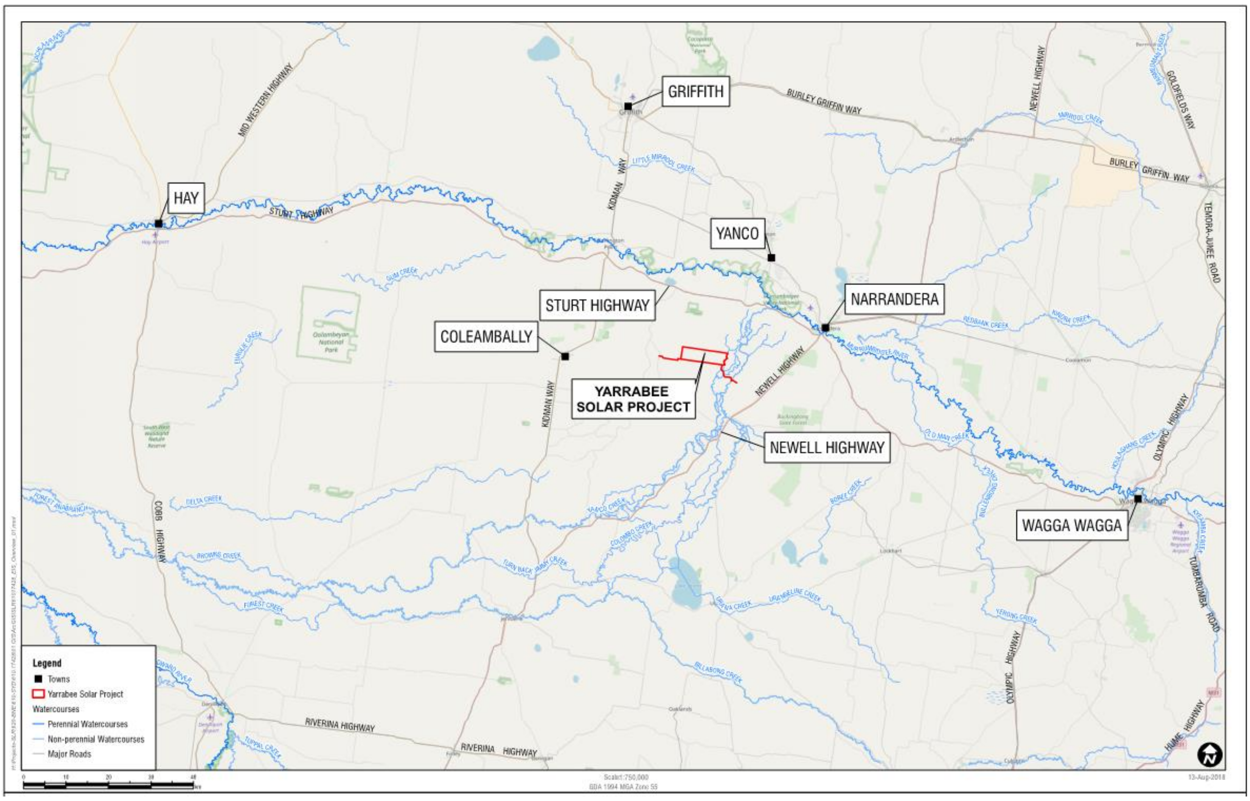
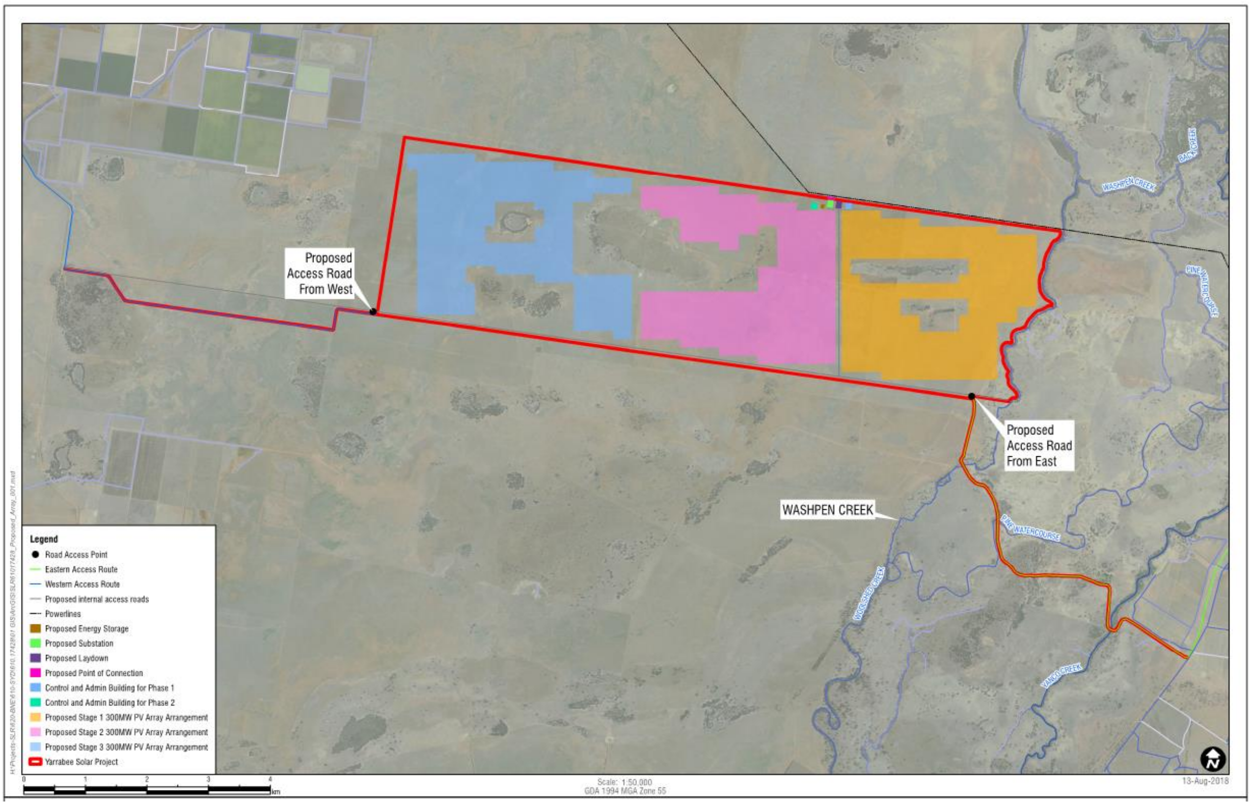


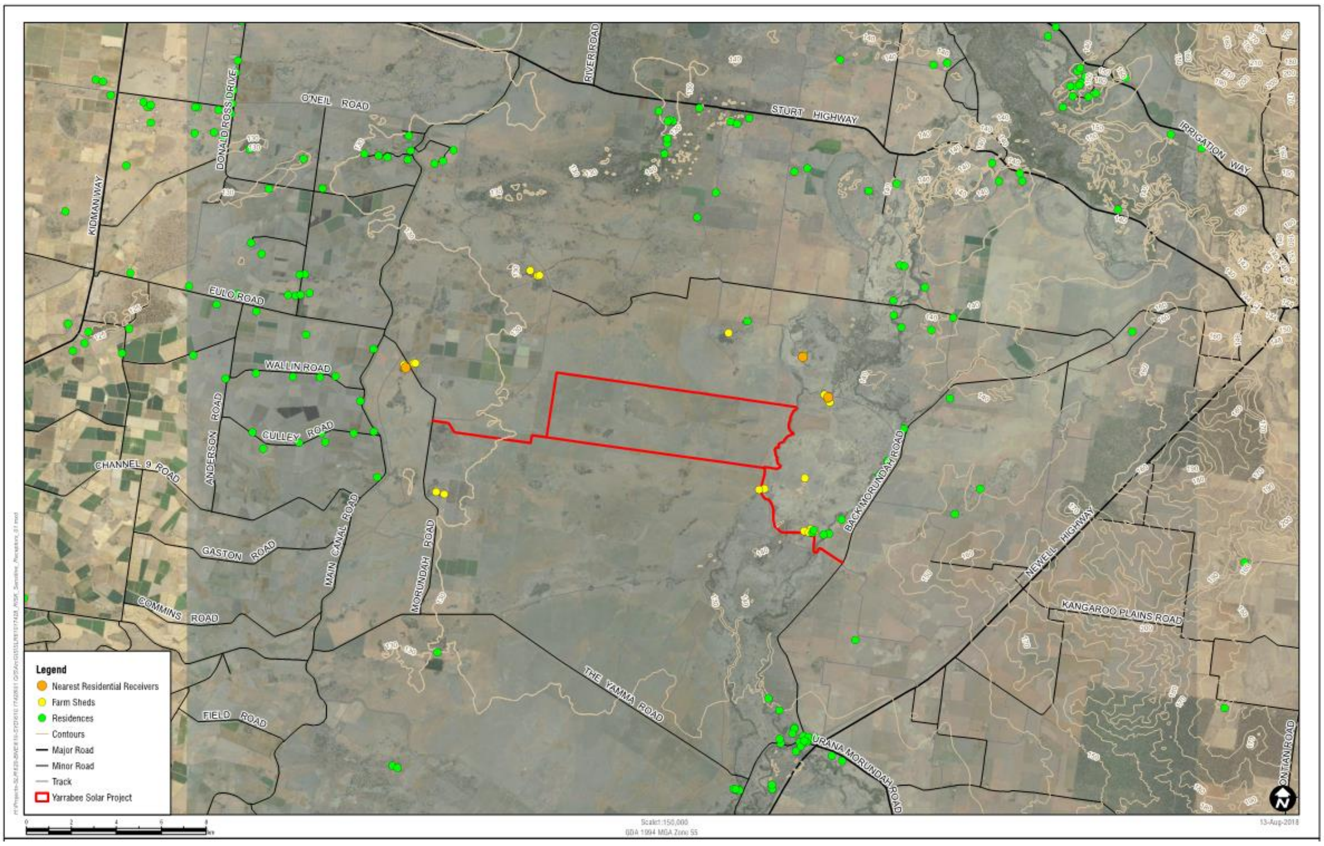
Figure 2 Indicative Site Layout for the Project



2.2 Noise Sensitive Receptors

Noise sensitive receivers surrounding the Project site are shown in **Figure 3**.

Figure 3 Surrounding Noise Sensitive Receivers to Project Site



The closest and potentially most impacted residential noise sensitive receivers identified in the vicinity of the Project site boundary are listed in **Table 1**.

Table 1 Nearest Noise Sensitive Receptors

Address	Approximate distance from nearest project site boundary (m)
2354 Back Morundah Road (house)	1200 m
2354 Back Morundah Road (house)	970 m
2354 Back Morundah Road (house)	1050 m
1714 Back Morundah Road (house)	1500 m
1714 Back Morundah Road (house)	1350 m

The nearest noise sensitive receiver to the proposed project office and substation location is approximately 2,600 m to the north.

3 Assessment Criteria

3.1 Secretary's Environmental Assessment Requirements (SEARs)

The Project SEARs require an Environmental Impact Statement to be prepared for the project addressing the following requirements in relation to noise:

1. An assessment of the construction noise impacts of the development in accordance with the NSW Interim Construction Noise Guideline (ICNG) – including a draft noise management plan if the assessment shows construction noise is likely to exceed applicable criteria; and
2. An assessment of operational noise impacts in accordance with the NSW Noise Policy for Industry 2017 (NPfI).

3.2 Construction Noise - NSW Interim Construction Noise Guideline (ICNG)

The ICNG sets out ways to manage the impacts of construction noise on residences and other sensitive land uses. The guideline provides an approach for determining construction-related Noise Management Levels (NMLs) for residential and other noise sensitive receivers based on the Rating Background Noise (RBL) environment and the proposed times of construction work.

- NMLs are established as: $L_{Aeq(15minute)}$ noise levels refer **Table 2**.
- RBLs are established as: $L_{A90(15minute)}$ noise levels refer **Table 2**.

The NMLs are non-mandatory criteria to identify where feasible and reasonable noise mitigation measures are likely to be required in order to reduce and control noise levels.

NMLs for the Project were determined assuming:

- a daytime RBL value of 35 dBA; and
- a night-time RBL value of 30 dBA.

These are the minimum RBLs for establishing assessment criteria that are able to be achieved with reasonable and feasible best practice (refer to the NPfI methodology[1]).

The adopted RBLs are supported by SLR’s extensive experience undertaking noise measurements in similar rural environments with few surrounding noise sources.

The construction NMLs for the Project, and how they are to be applied, are detailed in **Table 2**.

The nearest sensitive receivers to the Project are all residential receivers. For these, ICNG NMLs apply at the property boundary that is most exposed to 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.

[1] NPfI Table 2.1 (page 10).

Table 2 Determination of NMLs for Residential Receivers Surrounding the Project Site

Time of Day	NML $L_{Aeq(15minute)}$	How to Apply
Standard hours Monday to Friday 7:00 am to 6:00 pm Saturday 8:00 am to 1:00 pm No work on Sundays or public holidays	RBL + 10 dBA **45 dBA** (35 dB LA90 + 10 dBA)	The noise affected level represents the point above which there may be some community reaction to noise. Where the predicted or measured $L_{Aeq(15minute)}$ is greater than the noise affected level, the proponent should apply all feasible and reasonable work practises 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 dBA**	The Highly Noise Affected (HNA) 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 restructuring 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	RBL + 5 dBA **35 dBA** (30 dB LA90 + 5 dBA)	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 practises have been applied and noise is more than 5 dBA above the noise affected level, the proponent should negotiate with the community.

Note 1 The RBL is the overall single-figure background noise level measured in each relevant assessment period (during or outside the recommended standard hours). The term RBL is described in detail in the NSW *Noise Policy for Industry (NPfI)*

3.3 Construction Vibration

As indicated above, the nearest sensitive receiver is over 900 m from the closest site boundary. Given the extensive setback distance from works to surrounding receivers – and a lack of significant vibration generating equipment – vibration would not expected to be a concern and has not been addressed further in this report.

3.4 Operational Noise – NSW Noise Policy for Industry (NPfI)

The New South Wales *Noise Policy for Industry* 2017 (NPfI) provides a framework and processes for deriving noise criteria for sources of industrial noise. It aims to ensure that noise is kept to acceptable levels in balance with the social and economic value of industry in NSW. Implementation is achieved by ensuring that:

- Noise from any single source does not intrude greatly above the prevailing background noise level. This is known as the *intrusive* noise criterion.
- The background noise level does not exceed the level appropriate for the particular locality and land use. This is known as the *amenity* criterion.

In order to satisfy the above requirements, separate intrusive and amenity noise criteria are determined, of which the lower is normally adopted as the project-specific noise level. The intrusiveness noise levels are not intended to be used directly as regulatory limits. They are used in combination with the amenity noise level to assess the potential impact of noise, assess reasonable and feasible mitigation options and subsequently determine achievable noise requirements.

As outlined in **Section 3.2**, in lieu of noise survey data, NPfI minimum-recommended RBLs have been adopted for the purposes of this assessment. The resulting NPfI intrusive and amenity criteria are presented in **Table 3**.

Table 3 NPfI Assessment Criteria (Rural Amenity Area)

Intrusive $L_{Aeq(15min)}$ – RBL +5dB			Amenity (Rural) $L_{Aeq(period)}$		
Day	Evening	Night	Day	Evening	Night
40	35	35	50	45	40

3.4.1 Modifying Factors

Modifying factors are to be applied to the predicted noise levels if the source noise, at the receiver, is low frequency, tonal or intermittent in nature. **Table 4** lists the relevant modifying factors found in the NPfI.

Table 4 Modifying Factors from NPfI Table C1

Factor	Correction - dB
Tonal Noise	5
Low Frequency Noise	2 - 5
Intermittent	5

3.4.2 NPfI Assessment of Prevailing Weather Conditions

NPfI - *Fact Sheet D: Accounting for noise-enhancing weather conditions,* states:

Two options are available to a proponent to consider meteorological effects:

1. *Adopt the noise-enhancing meteorological conditions for all assessment periods for noise impact assessment purposes without an assessment of how often these conditions occur - a conservative approach that considers source-to-receiver wind vectors for all receivers and F-class temperature inversions with wind speeds up to 2 m/s at night.*

   Or

2. *Determine the significance of noise enhancing conditions.*

Noise emissions from the proposed development have been assessed in accordance with NPfI Option 1 using 'worst-case' meteorological conditions in the assessment. Compliance under 'worst-case' conditions ensures that compliance can be expected throughout the range of all possible meteorological conditions.

4 Noise Assessment

4.1 Construction Noise

4.1.1 Working Hours

Where possible, the majority of construction works would be undertaken in accordance with the ICNG during the standard daytime working hours of:

- 7.00 am to 6.00 pm Monday to Friday
- 8.00 am to 1.00 pm Saturdays

Limited works may be conducted outside of these hours provided they are managed so as to generate noise levels below the relevant ICNG noise management levels.

4.1.2 Source Location

Consistent with the requirements of the ICNG, this assessment adopts a 'realistic worst-case' noise impact assessment scenario based on the expected construction works occurring within any 15-minute period. The adopted scenario assumes that the works are located at the Project site boundary nearest to a particular receiver.

In reality, the potential construction noise impacts at any particular location will vary greatly depending on a number of factors, including the following:

- The position of the works within the site and distance to the nearest sensitive receiver;
- The overall duration of the works;
- The number if plant items operating simultaneously;
- The time at which the works are undertaken; and
- The character of the noise.

Noise levels at surrounding sensitive receivers would likely be significantly lower than the adopted worst-case scenario when the construction works move to a more distant location within the Proejct site or when fewer than the assumed numbers of plant items are operating.

4.1.3 Calculation Methodology

Calculations were undertaken based on the CONCAWE methodology for the calculation of noise propagation and attenuation.

Meteorological conditions were set to 'worst-case' in accordance with the NPfI guidance outlined in **Section 3.4.2**, i.e. this assumes that the prevailing wind blows directly from the source to the receiver.

4.1.4 Noise Sources

The activities likely to be required to construct the project would involve conventional construction equipment such as earth moving equipment, solar PV tracking system piling plant and cranes.

Noise sources likely to be associated with the construction works are summarised in **Table 5**.

Table 5 Construction Noise Sources – Sound Power Levels

Noise Source (expected number of plant)	Sound Power Level per Item (dBA)
Excavator (5)	105 dBA
Piling (10)	115 dBA
Trucks (4)	110 dBA
Grader (1)	107 dBA
Crane / telehandlers (2)	100 dBA

To determine potential worst-case impacts, the above noise sources were modelled assuming five items of plant operating at the same time and at the same location close to the site boundary. No account was made for site hoarding or other mitigation in the initial calculations to ensure a conservative assessment.

4.1.5 Results

The construction noise levels (without additional mitigation such as boundary or local screening) at the most exposed receiver (some 970 m from the site boundary) are predicted to be approximately 45 dB L_{Aeq}. This noise level is representative of the worst-case potential impact and demonstrates that construction noise levels are expected to meet the ICNG construction standard hours noise management levels at all surrounding residential receivers.

For most construction activities and at receivers further afield it is expected that the construction noise levels would be significantly lower than predicted at the most-exposed receiver.

4.1.6 Construction Noise Control Measures

In order to minimise potential noise impacts on nearby sensitive receivers, it is understood that the majority of construction works are proposed to be undertaken during the ICNG standard daytime construction hours (i.e. 7.00 am to 6.00 pm Monday to Friday and 8.00 am to 1.00 pm on Saturdays).

Where it is necessary to undertake works outside of these hours, it is recommended that Australian Standard AS 2436-2010 *"Guide to Noise and Vibration Control on Construction, Demolition and Maintenance Sites"* is used to assist in mitigating construction noise emissions. Examples of strategies that could be implemented on the project are provided below:

Adoption of Universal Work Practices

- Regular reinforcement (such as at toolbox talks) of the need to minimise noise;
- Regular identification of noisy activities and adoption of improvement techniques;
- Avoiding the use of portable radios, public address systems or other methods of site communication that may unnecessarily impact upon nearby residents;
- Where possible, avoiding the use of equipment that generates impulsive noise;

- Minimising the need for vehicle reversing for example (particularly at night), by arranging for one-way site traffic routes;
- Use of broadband audible alarms on vehicles and elevating work platforms used on site;
- Minimising the movement of materials and plant and unnecessary metal-on-metal contact; and
- Minimising truck movements.

Plant and Equipment

- Choosing quieter plant and equipment based on the optimal power and size to most efficiently perform the required tasks;
- Selecting plant and equipment with low vibration generation characteristics; and
- Operating plant and equipment in the quietest and most efficient manner.

On Site Noise Mitigation

- Maximising the distance between noise activities and noise sensitive land uses; and
- Installing purpose built noise barriers, acoustic sheds and enclosures.

Work Scheduling

- Providing respite periods which could include restricting very noisy activities (e.g. piling) to the daytime, restricting the number of nights that after-hours work is conducted near residences or by determining any specific requirements;
- Scheduling work to coincide with non-sensitive periods;
- Planning deliveries and access to the site to occur quietly and efficiently and organising parking only within designated areas located away from the sensitive receivers;
- Optimising the number of deliveries to the site by amalgamating loads where possible and scheduling arrivals within designated hours; and
- Including contract conditions that include penalties for non-compliance with reasonable instructions by the principal to minimise noise or arrange suitable scheduling.

Source Noise Control Strategies

Approaches to controlling noise at the source include:

- Where reasonably practical, noisy plant or processes should be replaced by less noisy alternatives;
- Modify existing equipment: Engines and exhausts are typically the dominant noise sources on mobile plant such as cranes, graders, excavators, trucks, etc. In order to minimise noise emissions, residential grade mufflers should be fitted on all mobile plant utilised on site;
- Use of siting of equipment: Siting noisy equipment behind structures that act as barriers, or at the greatest distance from the noise-sensitive area; or orienting the equipment so that noise emissions are directed away from any sensitive areas, to achieve the maximum attenuation of noise; and
- Regular and effective maintenance.

Noise Barrier Control Strategies

Temporary noise barriers are recommended where feasible, between the noise sources and all nearby potentially affected noise sensitive receivers, wherever possible. Typically, 7 dBA to 15 dBA of attenuation can be achieved with a well-constructed barrier. Specific strategies include:

- Orientation of the noisy equipment whereby the least noisy side of the equipment is facing the closest receiver; and
- The positioning of any site huts/maintenance sheds adjacent to the noisy equipment, in the direction of the closest receiver.

4.2 Operational Noise

Details on the specific plant items associated with the proposal are not currently known at this stage of the project. It has therefore been necessary to make certain assumptions as to the type of equipment/activities.

The principal sources of industrial noise associated with the operation of the Project will likely consist of the following:

- Substation / transformers and inverters
- At this stage in the project exact details of the substation/transformers and inverters are unknown and would not be confirmed until detailed design. Sound power levels have been assumed based on SLR experience working on similar projects and with reference to the expected size of plant (**Section 2.1**).
    - The substation is located in proximity to the Project Office (between Stage 1 and Stage 2).
    - A worst-case scenario of 6 inverters (3 inverter stations) located in close proximity to the substation has been assumed. Beyond this distance the inverters will be sufficiently spread out over the site and further from other noise sources resulting in reduced noise levels at receivers.
- Maintenance activities
    - A limited number of up to 20 staff members will be on site to operate and maintain the solar plant equipment. Maintenance activities are expected to involve low noise generating manual hand tools, be infrequent and be conducted on an as-needs basis during daytime hours.
- Noise from the tracking mechanism on the solar panels is expected to be insignificant in comparison to that of the above identified sources.

In order to assess the potential worst-case impacts, a combined cumulative noise model was used to assess all of the above noise sources using the sound power levels listed in **Table 6**.

Table 6 Operational Noise Sources – Sound Power Levels

Noise Source	Sound Power Level (dBA)
Substation / Transformer	90 dBA [1]
Inverters	101 dBA [2]

Note 1 includes 5dB penalty for potential tonal noise

Note 2 includes 5dB penalty for potential tonal noise

4.2.1 Calculation Methodology

Calculations were undertaken based on the CONCAWE methodology for the calculation of noise propagation and attenuation.

Meteorological conditions were set to 'worst-case' in accordance with the NPfI guidance outlined in **Section 3.4.2** i.e. this assumes that the prevailing wind blows directly from the source to the receiver.

4.2.2 Predicted Noise Levels

Operational noise levels have been predicted at the most exposed receiver to the proposed noise generating plant (located 2,600 m to the north). The noise levels include the cumulative impact of the above identified sources of industrial noise, summarised in **Table 7**.

Table 7 Predicted Operational Noise Levels at Most Exposed Receptor, dBA L_{Aeq}

Daytime			Evening/Night-time		
Predicted Level	Intrusive Criterion	Amenity Criterion	Predicted Level	Intrusive Criterion [1]	Amenity Criterion[1]
<25 dBA	40 dBA	50 dBA	<25 dBA	35 dBA	40 dBA

Note 1 The more pessimistic night-time period assessment criterion has been adopted as a conservative approach.

Table 7 shows that predicted noise levels (including the allowance for a potential tonal penalty) meet the NPfI intrusive and amenity criteria during daytime, evening and night-time periods.

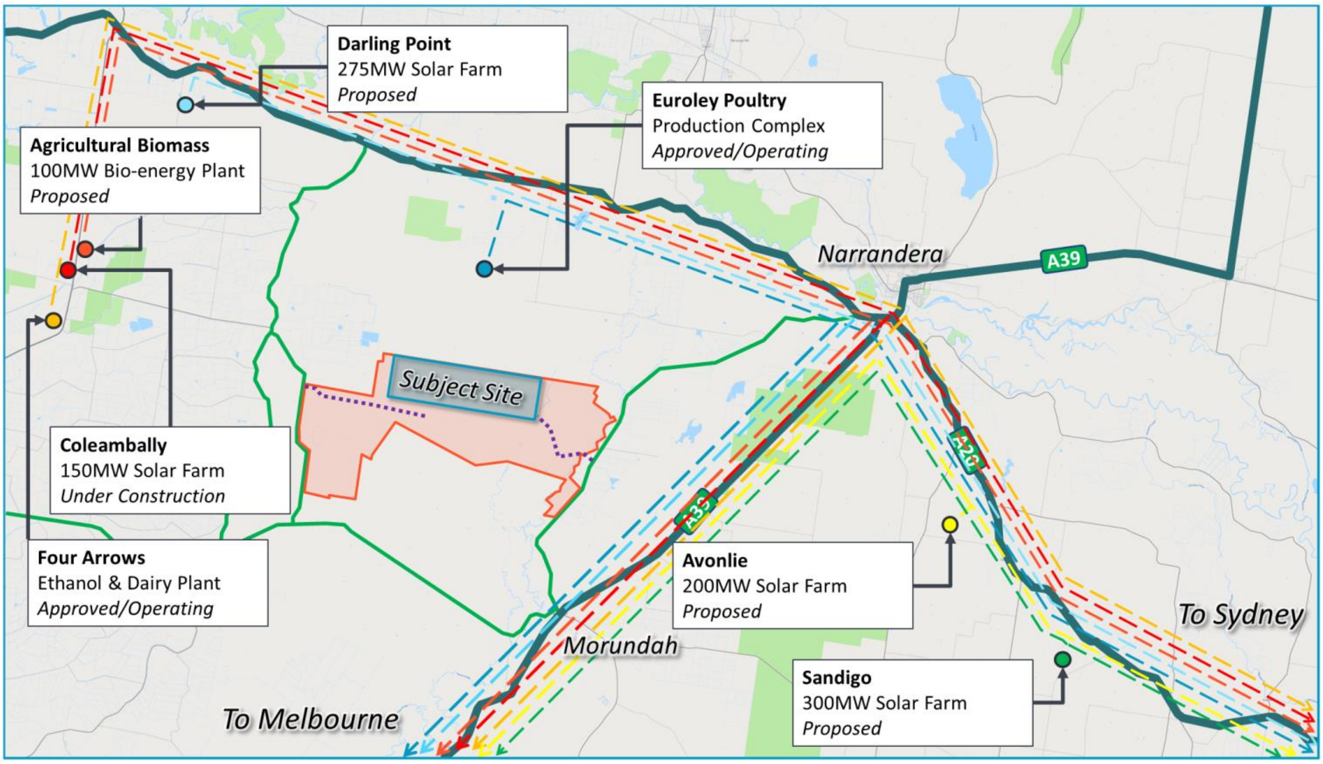
Assuming the assumed sound power levels are achieved from the transformer and inverter equipment (to be confirmed during the detailed design phase), compliance with NPfI is readily anticipated to be met at all surrounding noise sensitive receivers during daytime, evening and night-time periods.

4.2.3 Cumulative Effects

In preparing the present assessment, a number of other developments that have the potential to result in cumulative impacts on surrounding receivers have been identified. These are shown in **Figure 4**.

Due to the extensive distance from the Project site to other nearby major projects (over 4.5 km from the closest Project boundary) there are no expected cumulative noise effects associated with the proposal.

Figure 4 Surrounding Projects of Significance and Development Status



5 Conclusion

SLR has conducted an assessment of the noise impacts associated with the proposed Yarrabee Solar Park project. This assessment has been carried out in accordance with NSW regulatory requirements identified in the SEARs issued for the development.

An assessment has been undertaken using plant and equipment representative of the likely construction methodologies against the guidelines of the ICNG. The assessment identifies that no adverse impacts are expected due to the separation of the site to the surrounding receivers.

An assessment has been undertaken of the operational noise associated with the Project. The assessment has shown that –without any mitigation – cumulative noise emissions from the development are expected to comply with the relevant NPfI noise emission criteria.

ATTACHMENT A

Acoustic Terminology

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	
80	Kerbside of busy street	Loud
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

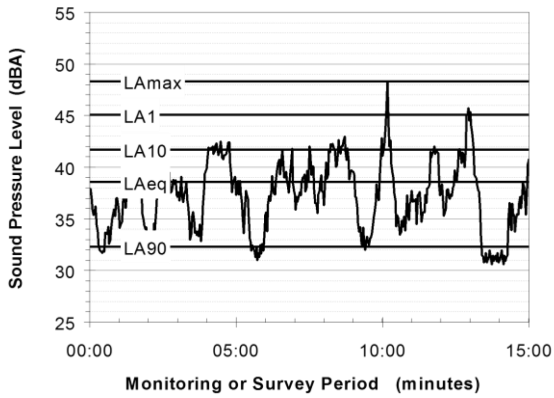
The Sound Power of a source is the rate at which it emits acoustic energy. As with Sound Pressure Levels, Sound Power Levels are expressed in decibel units (dB or dBA), but may be identified by the symbols SWL or LW, or by the reference unit 10^{-12} W.

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 LAN, where LAN is the A-weighted sound pressure level exceeded for N% of a given measurement period. For example, the LA1 is the noise level exceeded for 1% of the time, LA10 the noise 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:

LA1 The noise level exceeded for 1% of the 15 minute interval.

LA10 The noise level exceed for 10% of the 15 minute interval. This is commonly referred to as the average maximum noise level.

LA90 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.

LAeq 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' LA90 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 (LAeq, LA10, 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

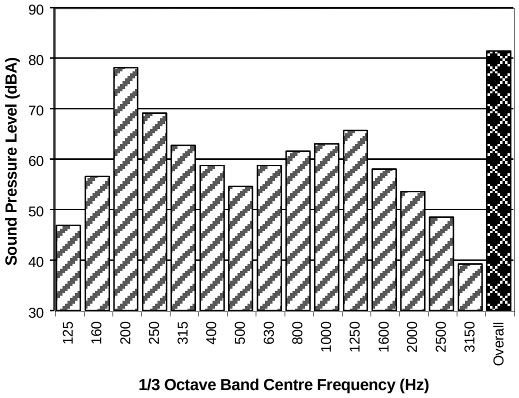
Frequency analysis is the process used to examine the tones (or frequency components) which make up the overall noise or vibration signal. This analysis was traditionally carried out using analogue electronic filters, but is now normally carried out using Fast Fourier Transform (FFT) analysers.

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/Vo), where Vo 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

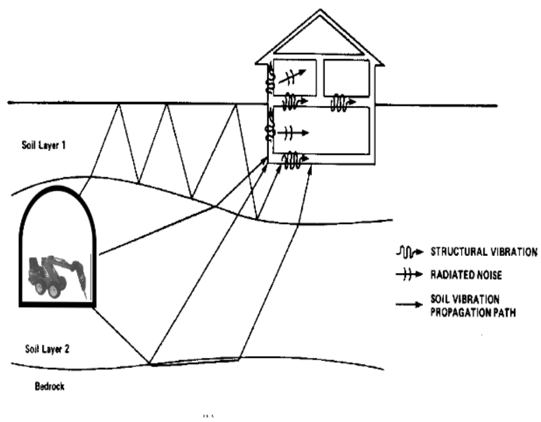
The term 'over-pressure' is used to describe the air pressure pulse emitted during blasting or similar events. The peak level of an event is normally measured using a microphone in the same manner as linear noise (ie unweighted), at frequencies both in and below the audible range.

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

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