BEFORE	the Independent Hearing Panel appointed by the Hamilton City Council
UNDER	the Resource Management Act 1991
And	
IN THE MATTER OF	Proposed Plan Change 5 – Peacocke Structure Plan
BY	Hamilton City Council

STATEMENT OF EVIDENCE OF SUSAN MARIE MANDER

On behalf of the

DIRECTOR-GENERAL OF CONSERVATION / TE TUMUAKI AHUREI

SUBMISSION 38 FS013

LIGHTING

Dated: 16 September 2022

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1. INTRODUCTION

1.1. My full name is Susan Marie Mander. I have worked at Massey University (MU) since 2010, and I currently hold the position of Lecturer. My expertise is in Illumination Engineering, and I lead the university's research and teaching in this area. I worked as a consulting electrical engineer before joining MU.

1.2. I hold the following qualifications:

a) Bachelor of Engineering (Honours) in Electrical & Electronics Engineering, University of Auckland, 1996.

   Certificate in Illumination Engineering, Auckland University of Technology, 1999.

b) Master of Engineering in Environmental Technology and Sustainable Energy, Massey University, 2014. My thesis was on LED lighting products.

1.3. I have the following memberships:

a) Fellow of the Illuminating Engineering Society of Australia and New Zealand (FIES).

b) Member of the Institute of Electrical and Electronics Engineers (MIEEE).

1.4. I am the Academic Lead for the lighting major of MU's Graduate Certificate in Science and Technology. In this role, I teach fundamental aspects of lighting across four courses entitled *Light and Lighting, Lamps and Luminaires, Interior Lighting Design, Energy Efficient Lighting and Exterior Lighting Design.*

1.5. I am also the Academic Lead for MU's lighting laboratory, which is used for teaching, research, and commercial product development. I have completed over twenty confidential commercial projects for clients.

1.6. I am currently undertaking a PhD in Engineering at MU. My research focuses on measuring exterior lighting at night.

1.7. In 2021 I prepared two reports on the effects of road lighting in ecologically sensitive areas for Waka Kotahi. One of these reports focused on measuring and mitigating the impact of road lighting on the NZ long-tailed bat (Mander, 2021)[1].

1.8. I have also written journal and conference papers on lighting, including one on measuring "blue" wavelengths (Mander & Chitty, 2019)[2].

1.9. I was a member of the expert reference group for *Blue Light Aotearoa* (Royal Society Te Apārangi, 2018)[3].

1.10. As a consulting electrical engineer, I designed lighting for exterior applications, including roadways, sports fields, and facades. I also prepared lighting assessments for clients, including assessments of outdoor signage.

1.11. I am presenting this evidence as an expert for the Director-General of Conservation / Te Tumuaki Ahurei (Director-General) in relation to lighting matters arising out of proposed Plan Change 5 – Peacock Structure Plan.

1.12. I participated in online facilitated expert conferencing for Plan Change 5 on 24 August 2022 and I am a signatory to the "Joint Witness Statement Planning & Bats, 24 August 2022."

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1 Mander, S.M. (2021). *Measuring and mitigating the ecological effects of road lighting: A case study of the NZ long-tailed bat (Chalinolobus tuberculatus). Report to NZTA Waka Kotahi*. Massey University.

2 Mander, S.M., & Chitty, C.H. (2019). The measurement blues. *Instrumentation & Measurement Magazine. 22(2), 17-20*.

3 Royal Society Te Apārangi. (2018). *Blue light Aotearoa*. Wellington, New Zealand: Royal Society Te Apārangi.

2. CODE OF CONDUCT

2.1. I confirm I have read the code of conduct for expert witnesses as contained in the Environment Court's Practice Note 2014. I have complied with the practice note when preparing my written statement of evidence and will do so when I give oral evidence before the Hearing Panel.

2.2. The data, information, facts and assumptions I have considered in forming my opinions are set out in my evidence to follow. The reasons for the opinions expressed are also set out in the evidence.

2.3. Unless I state otherwise, this evidence is within my sphere of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

3. SCOPE

3.1. I have been asked to provide expert evidence in relation to the lighting effects of Proposed Plan Change 5 – Peacocke Structure Plan.

3.2. In preparing this evidence, I have read and considered the following documents:

a) Proposed Plan Change 5 to the Operative Hamilton City District Plan (Peacocke Structure Plan) – Chapter 25.6 Lighting and Glare, and Rule 25.10.5.7;

b) Plan Change 5: Peacocke Structure Plan Section 32 Report Notification Version July 2021;

c) Submission and further submission of the Director-General;

d) Section 42A Hearing Report (dated 2 September 2022);

e) Statement of evidence (dated 2 September 2022) prepared for the Hamilton City Council by Mr John Kinross Mckensey (Lighting);

f) Joint Witness Statements:

   i. Planning & Bats 24 August 2022;

g) Statements of evidence (dated 16 September 2022) prepared for the Director-General by:
   i. Ms Moira Pryde (Bat Ecology);
   ii. Dr Kerry Borkin (Bat Ecology and Effects of Development);
   iii. Dr Ilse Corkery (Biodiversity Offsetting); and
   iv. Mr Jesse Gooding (Planning).

h) Appendix J: Mueller H, Davidson-Watts I, Kessels G. 2021. Peacocke Structure Area Plan Change Long-tailed bat report For Hamilton City Council. Document name: 4sight_Psp_Bat_Report_Final_June 2021. Appendix J of the "*Plan Change 5 – Peacocke Structure Plan - Assessment of Environmental Effects (2021)"*.

i) Appendix Q: Mckensey, J. Peacocke Structure Area Plan Change Bat Sensitive Lighting Rules for Hamilton City Council. Appendix Q of the "*Plan Change 5 – Peacocke Structure Plan - Assessment of Environmental Effects (2021)"*.

j) Additional referenced material used in this evidence is attached in a consolidated list as Appendix 1 but is referenced throughout the document as appropriate.

4. EXECUTIVE SUMMARY

4.1. Lighting is known to affect bats (ILP, 2018[4]; EUROBATS, 2018[5]). I have reviewed the statement of evidence prepared by ecologist Dr Kerry Borkin and I note that she has confirmed that the New Zealand long-tailed bat may be considered sensitive to light.[6]

[4] Institution of Lighting Professionals. (2018). *Bats and artificial lighting in the UK*.

[5] Voigt CC, Azam C, Dekker J, Ferguson J, Fritze M, Gazaryan S, Hölker F, Jones G, Leader N, Lewanzik D, Limpens HJGA, Mathews F, Rydell J, Schofield H, Spoelstra K, Zagmajster M. 2018. Guidelines for consideration of bats in lighting projects. EUROBATS Publication Series No. 8. UNEP/EUROBATS Secretariat, Bonn, Germany, 62 pp

[6] Statement of Evidence of Dr Kerry Mare Borkin dated 16 September 2022, paragraph 12.1.

4.2. Lighting has many qualities that can affect an environment in various ways. In my evidence I address key lighting issues under the titles: *brightness*, *trespass*, *spectral* composition, and *duration*. I also provide evidence on the effects of *flicker* and *lighting for human safety*.

4.3. Careful planning is essential to provide responsible lighting and minimise its impact in ecologically sensitive areas. My evidence includes recommendations and suggestions on how best to plan for responsible lighting to minimise the effect on ecologically sensitive areas.

5. STANDARDS AND GUIDELINES FOR RESPONSIBLE OUTDOOR LIGHTING

5.1. The Illuminating Engineering Society of North America (IESNA) and the International Dark-Sky Association (IDA) agree that for a *responsible outdoor lighting* scheme, "all light should have a clear purpose", with consideration for the local environment (IDA, 2020).[7] In addition, light must be aimed to avoid spill into other areas; no brighter than needed; be dimmed or switched off when not needed; and of a warm colour temperature where possible. These five principles are summarised in Figure 1.

[7] International Dark-Sky Association. (2020) *Joining forces to protect the night from light pollution.* https://www.darksky.org/joining-forces-to-protect-the-night-from-light-pollution/

Figure 1 – Five principles for responsible outdoor lighting (IDA, 2020)

5.2. In 2020, the Australian Government produced *National light pollution guidelines for wildlife* (Australian Government, 2020)[8]. To my knowledge, these are not yet referred to in any New Zealand lighting standards; however, they provide a useful guide. The Australian guidelines refer to best practice lighting design, which is summarised in Figure 2.

Best practice lighting design incorporates the following design principles.

1. **Start with natural darkness and only add light for specific purposes.**
2. **Use adaptive light controls to manage light timing, intensity and colour.**
3. **Light only the object or area intended – keep lights close to the ground, directed and shielded to avoid light spill.**
4. **Use the lowest intensity lighting appropriate for the task.**
5. **Use non-reflective, dark-coloured surfaces.**
6. **Use lights with reduced or filtered blue, violet and ultra-violet wavelengths.**

Figure 2 – Best practice lighting design (Australian Government, 2020, p. 9)

[8] Australian Government. (2020). *National light pollution guidelines for wildlife.* https://www.environment.gov.au/system/files/resources/2eb379de-931b-4547-8bcc-f96c73065f54/files/national-light-pollution-guidelines-wildlife.pdf

5.3. To my knowledge, there are currently two key documents regarding lighting considerations for bats:

a) Voigt, C. C., Azam, C., Dekker, J., Ferguson, J., Fritze, M., Gazaryan, S., Hölker, F., Jones, G., Leader, N., Lewanzik, D., Limpens, H. J. G. A., Mathews, F., Rydell, J., Schofield, H., Spoelstra, H., & Zagmajster, M. (2018). EUROBATS: Guidelines for consideration of bats in lighting projects. https://eurobats.org/sites/default/files/documents/publications/publication_series/WEB_DIN_A4_EUROBATS_08_ENGL_NVK_28022019.pdf

This document considers European bats and provides general lighting guidelines while acknowledging that different species of bats may have different tolerances to light. For consistency with other experts, I will refer to this document as "EUROBATS".

b) The Institution of Lighting Professionals. (2018). *Bats and artificial lighting in the UK*. https://cdn.bats.org.uk/pdf/Resources/ilp-guidance-note-8-bats-and-artificial-lighting-compressed.pdf?mtime=20181113114229

This document was jointly prepared by the Institution of Lighting Professionals and the Bat Conservation Trust and considers bats in the UK. For brevity, I will refer to this document as "ILP".

5.4. While neither EUROBATS (2018) nor ILP (2018) mention long-tailed bats[9], I consider that they provide valuable guidelines in the absence of other species-specific literature.

[9] I understand that this is because long-tailed bats are only found in New Zealand. See Statement of Evidence of Dr Kerry Mare Borkin dated 16 September 2022, paragraph 6.1.

6. BRIGHTNESS

6.1. The amount of light in an environment can be measured using a variety of units and instruments. Units used in the standard AS/NZS 4282:2019 *Control of the obtrusive effects of outdoor lighting* include illuminance, luminous intensity and luminance (SA/NZS, 2019)[10]. These units are shown in Figure 3 and explained in the paragraphs that follow.

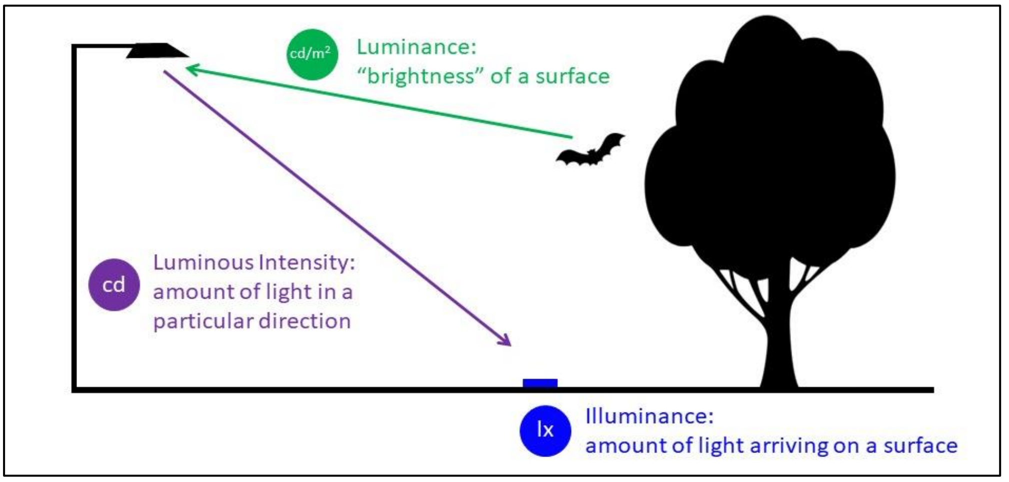

Figure 3 – Common lighting units

Illuminance (lux) levels

6.2. Illuminance can be described as the amount of light arriving on a surface, and is measured in lux (lx). Illuminance is inversely proportional to distance squared – in other words it attenuates as you move away from the light source. This relationship is expressed pictorially in Figure 4. The location of the light source is needed to calculate the illuminance at a point, as illuminance is related to the distance between the light source and the measuring point.

[10] Standards Australia & Standards New Zealand. (2019). *AS/NZS 4282:2019 Control of the obtrusive effects of outdoor lighting*. https://www.standards.govt.nz/

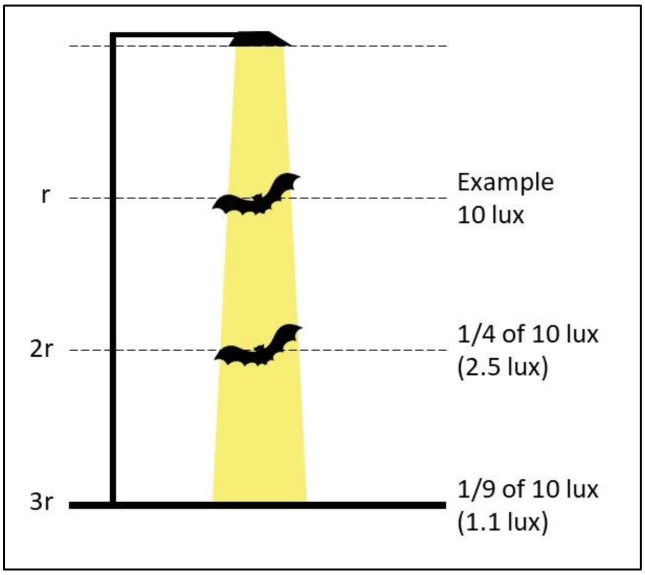

Figure 4 – Pictorial representation of the inverse square law of illuminance

6.3. For reference, Kyba *et al.* (2017) recorded a value of 0.26 lux (horizontal) for a "supermoon" in a temperate climate (Vienna, Austria) and suggest that values of 0.05 to 0.1 lux are typical during the summer period in a temperate climate[11].

6.4. ILP (2018) does not provide illuminance limits but instead advises to "avoid lighting on key habitats and features altogether" (p. 15); this includes "no illumination of any roost entrances and associated flightpaths, nor on habitats and features used by large numbers of bats, by rare species or by highly light-averse species" (p. 15). The document also recommends to "set dark habitat buffers and acceptable lux limits with ecologist guidance" (p. 15).

6.5. ILP (2018) notes that "… especially for vertical calculation planes, very low levels of light (<0.5 lux) may occur even at considerable distances from the source if there is little intervening attenuation", and "… where 'complete darkness' on a feature or buffer is required, it may be appropriate to consider this to be where illuminance is below 0.2 lux on the horizontal plane and below 0.4 lux on the vertical plane" (p. 22). In

[11] Kyba, C. C. M., Mohar, A., & Posch, T. (2017). How bright is moonlight? *Astronomy and Geophysics*, *58*(1), 1.31-31.32. https://doi.org/10.1093/astrogeo/atx025

my opinion, these comments are a statement of lighting thresholds for 'complete darkness', not a recommendation for acceptable *additional* light levels. I observe that Appendix Q of the Plan Change 5 supporting documents holds a different view and has interpreted this requirement as an *added* illuminance of 0.3 lux (presumably 0.3 lux is used as the average of 0.2 lux and 0.4 lux)[12].

6.6. EUROBATS (2018) states that "light levels as low as typical full moon levels, i.e. around 0.1 lx, are known to alter the flight activity of bats" (p. 8). The guidelines by EUROBATS (2018) recommend this threshold at the boundary of protected areas, key feeding areas, roost entrances, exits and emergence corridors. The measurements must be taken 1.5 m above ground or next to the roost entrance or exit. In all cases, vertical illuminance values are required. It is unclear whether EUROBATS (2018) refers to *added* illuminance or *threshold* illuminance, as terminology varies in the document. For example, page 34 states that "illuminance levels caused by distant lights must be below 0.1 lx…"; this could be interpreted as *added* illuminance. However, it also says that "… structures used by bats for commuting must be kept unlit, with light levels below 0.1 lx"; this indicates *threshold* illuminance. I observe that neither Appendix J nor Appendix Q of the Plan Change 5 supporting documents refer to EUROBATS (2018) for illuminance values. Appendix J of the Plan Change 5 supporting documents refers to a 0.1 lux threshold but chooses to use 0.3 lux instead[13]. It is not clear why this choice was made.

6.7. The Weston Lea interim decision states that "… 0.1 lux standard should be achieved within 3 metres of the boundary of the BPA on all boundaries whether they are residential or within the public areas" (paragraph 64)[14]. I do not know the history of that decision. While the value of 0.1 lux is in-keeping with EUROBATS (2018), I do not know why a 3-metre distance was used, and it is not mentioned in EUROBATS (2018) or ILP (2018).

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12 Appendix Q, Proposed Plan Change 5, Supporting Documentation.

13 Appendix J, Proposed Plan Change 5, Supporting Documentation.

14 Interim decision Weston Lea and Director-General of Conservation v Hamilton City Council [2020] NZENVC 189

Luminous Intensity

6.8. Luminous intensity can be used to indicate the amount of light in a particular direction, and is measured in candelas (cd). Luminous intensity does not change with distance from the source, as it is the distribution of light emitted from a luminaire. Light sources distribute luminous intensity in different ways, as illustrated in Figure 5. Careful luminaire selection is required for each application (e.g. road lighting) to ensure that light reaches its intended location with minimal disturbance to the surrounding environment. As some applications typically use higher values than others (e.g. road lighting versus residential lighting), luminous intensity may be more relevant in some circumstances than others.

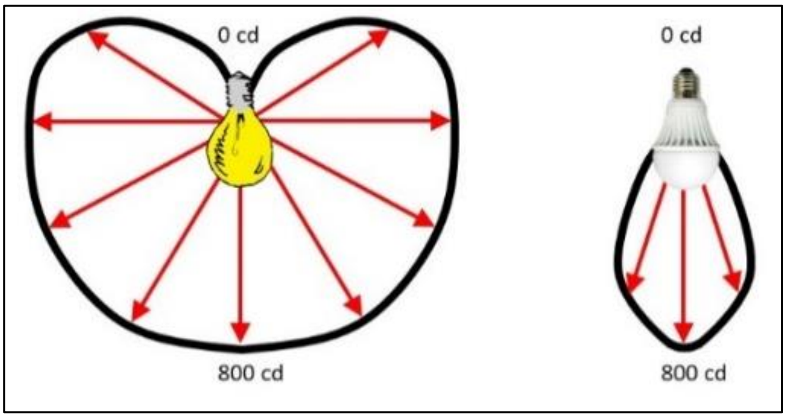

Figure 5 – Pictorial representation of luminous intensity for two different light sources

6.9. While the term "intensity" is used in EUROBATS (2018), the authors use this word to refer to illuminance, which is misleading, as luminous intensity is a metric in its own right. In my opinion, this is an important consideration as a light source may produce a low illuminance value on a boundary but still be perceived as a "bright" light source in the field of view. ILP (2018) *does* refer to luminous intensity, by stating "additionally, glare (extremely high contrast between a source of light and the surrounding darkness – linked to the intensity of a luminaire) may affect bats over a greater distance than the target area directly illuminated by a luminaire and must also be considered on your site" (p. 17).

6.10. When considering luminous intensity in areas where bats are present and the effects of lighting that need to be mitigated, neither EUROBATS (2018) nor ILP (2018) give threshold values. However, guidance can be found in AS/NZS 4282 (2019), which gives a table of pre-curfew and curfew limits (curfew is noted as between 11 pm and 6 am). For "intrinsically dark" environmentally sensitive areas (Zone A0), "as close to zero as practicable without impacting safety considerations" (p. 25) is required for a vertical plane at the property boundary at pre-curfew and 0 cd is required for curfew. Zone A1 ("dark" environmental zones) has limits on of 2,500 cd (pre-curfew, new installations) and 500 cd (curfew). Auckland Council's Unitary Plan also provides luminous intensity limits, which are given in Figure 6 (Auckland Council, 2022)[15]. For example, an "Open Space – Conservation Zone" area (Lighting category 1 - intrinsically dark), has limits of 2,500 cd (pre-curfew) and 0 cd (curfew). In my opinion, luminous intensity is an important metric that should be included in areas where bats are present and the effects of lighting need to be mitigated.

Table E24.6.1.5 Pre-curfew luminous intensity limits

Intentionally illuminated area		**Pre-curfew luminous intensity limit for each lighting category**			
Size of area (based on the controlling dimension)	**Controlling dimension (refer to Note 1)**	**Lighting category 1**	**Lighting category 2**	**Lighting category 3**	**Lighting category 4**
Large	>75m	2,500 cd	7,500 cd	10,000 cd	25,000 cd
Medium	≥25m ≤75m	2,500 cd	7,500 cd	10,000 cd	25,000 cd
Small	<25m	2,500 cd	2,500 cd	7,500 cd	25,000 cd

Note 1

The controlling dimension is the maximum dimension from any light source to the furthest point of the intentionally illuminated area in the direction of maximum intensity.

Table E24.6.6 Curfew luminous intensity limits

Curfew luminous intensity limit for each lighting category			
Lighting category 1	**Lighting category 2**	**Lighting category 3**	**Lighting category 4**
0 cd	500 cd	1,000 cd	2,500 cd

Figure 6 – Luminous intensity limits for Auckland Unitary Plan (Auckland Council, 2022)

15 Auckland Council. (2022). *Auckland unitary plan operative in part.* https://unitaryplan.aucklandcouncil.govt.nz/pages/plan/Book.aspx?exhibit=AucklandUnitaryPlan_Print

Luminance

6.11. Luminance indicates how bright a luminaire is in the field of view. It is the luminous intensity in the direction of view divided by the area of the source in view. Luminance is measured in candelas per square metre (cd/m^2). The contrast of a high luminance object against a low luminance background can cause glare.

6.12. Neither EUROBATS (2018) nor ILP (2018) give luminance recommendations; however, luminance limits for surfaces (such as building facades) are given in AS/NZS 4282:2019. For Zones A0 and A1, the limit for maximum average luminance is 0.1 cd/m^2. The proposed update to AS/NZS 4282:2019 includes values for internally-lit signage of 0.1 cd/m^2 and 50 cd/m^2 for A0 and A1 respectively. Auckland Council's Unitary Plan also provides luminance limits, which are given in Figure 7 (Auckland Council, 2022). The value for an "Open Space – Conservation Zone" area (Lighting category 1 - intrinsically dark) is 0 cd/m^2. In my opinion, luminance is an important metric that should be included in areas where bats are present and the effects of lighting need to be mitigated.

(9) The average surface luminance measured in candelas per square metre (cd/m^2) for an intentionally artificially lit building façade shall not exceed any one of the following:

(a) 0 cd/m^2 in lighting category 1;

(b) 5 cd/m^2 in lighting category 2;

(c) 10 cd/m^2 in lighting category 3; or

(d) 25 cd/m^2 in lighting category 4.

Figure 7 – Luminance limits for Auckland Unitary Plan (Auckland Council, 2022)

Illuminance, Luminous Intensity and Luminance - Demonstrating Compliance

6.13. It is usual for exterior lighting installations to be designed using computer software such as AGi32[16]. For example, obtrusive lighting standard AS/NZS 4282:2019 requires that "conformance to the limiting values specified… shall be assessed on the basis of calculations" (p. 15). Similarly, road lighting standard AS/NZS 1158.2:2020 is dedicated to "computer procedures of the calculation of light technical parameters for Category V and Category P lighting"[17]. In my experience, on-site measurements are not routine but can be carried out if necessary.

6.14. Section 5 of lighting Standard AS/NZS 4282:2019 notes that measuring illuminance on site is complicated by many factors. These include the accuracy, linearity, cosine response and spectral response of the meter being used. It is my opinion that such measurements need to be made by a specialist illumination engineer with a calibrated illuminance meter that has a suitable range and spectral sensitivity. Owing to the low light levels involved, I recommend that illuminance meters are able to measure down to 0.01 lux. IANZ-calibrated meters with this sensitivity are available for hire in New Zealand (Techrentals, 2022)[18].

6.15. Luminous intensity is not measured on site, as it is a lab-based measurement. Luminous intensity data is provided in luminaire datasheets and photometric files that are used by computer software.

6.16. Like illuminance, luminance can be measured on site using a specialised meter. Similar to paragraph 6.14 above, I recommend that luminance meters are also able to measure down to low light levels – in this case 0.01 cd/m^2. IANZ-calibrated meters with this sensitivity are available for hire in New Zealand (Techrentals, 2022).

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16 Lighting Analysts. (2022). *The Lighting Industry's Premier Calculation Tool.* https://lightinganalysts.com/software-products/agi32/overview/

17 Standards Australia & Standards New Zealand. (2020). *AS/NZS 1158.2 Lighting for roads and public spaces: Computer procedures for the calculation of light technical parameters for Category V and Category P lighting*. https://www.standards.govt.nz/

18 Techrentals. (2022). *Light measurement equipment.* https://www.techrentals.co.nz/category/31/light-measurement

7. TRESPASS

7.1. Electric light sources can cause pollution by emitting light beyond the intended design area. This includes brightening of the sky ("skyglow") and local light trespass (also known as spill light). These items will be discussed in the following paragraphs. Figure 8 gives an example of light distribution from a luminaire, and shows that:

- illuminance attenuates over distance (shown as yellow gradient shading) (see paragraph 6.2)
- obstructions (e.g. light absorbent walls) can reduce illuminance values (see paragraph 7.4)
- reflected light can cause skyglow (see paragraph 7.3)
- direct light can encroach into bat habitats (this indicates that, while the illuminance value at the bat habitat may be low, bats may still be affected through glare) (see paragraphs 6.8 – 6.12).

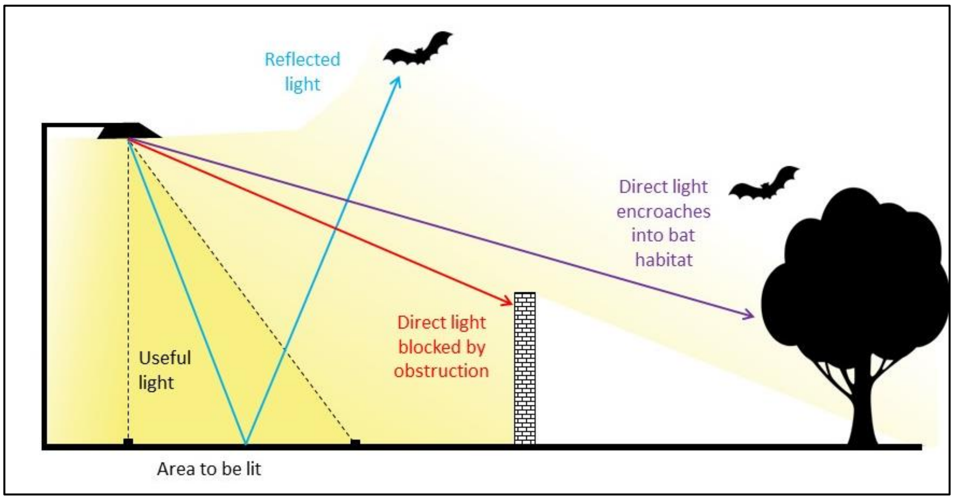

Figure 8 – Example of light distribution from a luminaire (not to scale)

7.2. The draft update to standard AS/NZS 4282:2019 states that "the most effective way to avoid impacts on the environment is to keep naturally dark places dark (i.e. avoid light spill into unmodified bushland, waterways and coastal habitats) and minimize artificial sky glow" (SA/SNZ, 2022, Section 2.4.5).

7.3. Skyglow is produced through a combination of direct light and indirect reflections (ILP, 2021)[19]. It is a product of the luminaire, its installation, and "the atmospheric conditions (humidity, aerosols, clouds, haze, atmospheric pollution, etc.)" (ILP, 2021, p. 5). IDA (2020) recommends that outdoor light should "use shielding and careful aiming to target the direction of the light beam so that it points downward and does not spill beyond where it is needed". ILP (2018) and EUROBATS (2018) agree that fixed luminaires should not emit any light upwards and have no upward tilt. The use of light-absorbent materials is also recommended to reduce surface reflections.

7.4. Local light trespass can be reduced using low-reflectance screens and/or buffer planting (ILP, 2018; EUROBATS, 2018).

7.5. Low mounting heights can also reduce light trespass (ILP, 2018; EUROBATS, 2018). ILP (2018) suggests that "taller buildings may be best located toward the centre of the site or sufficiently set back from key habitats to minimise light spill" (p. 19). The document also considers that "internal luminaires can be recessed where installed in proximity to windows to reduce glare and light spill" (ILP, 2018, p. 18). Glazing treatments are also suggested (ILP, 2018, p. 20).

[19] Institution of Lighting Professionals. (2021). *The reduction of obtrusive light*. https://theilp.org.uk/publication/guidance-note-1-for-the-reduction-of-obtrusive-light-2021/

7.6. The draft update to standard AS/NZS 4282:2019 states that "the obtrusive effects of the lighting system may be significantly influenced by… the topography of the area surrounding the lighting installation. Residential developments at a lower level than that of the lighting installation are more likely to be subjected to a direct view of the luminaires" (Section 2.3b). In my opinion, the same could be said of bat habitat, as illustrated in Figure 9. Therefore, metrics such as luminous intensity may have more relevance depending on the ground level.

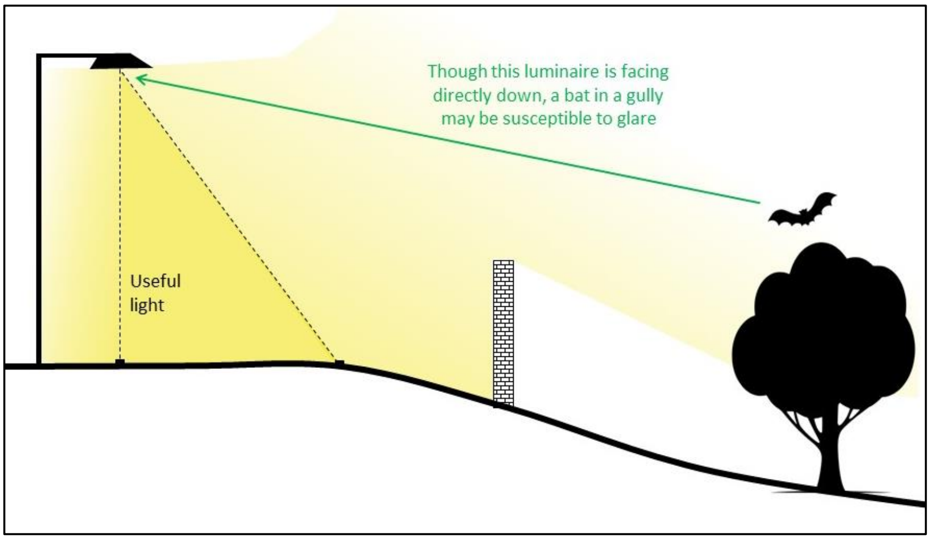

Figure 9 – Example of light distribution in a sloping topography (not to scale)

7.7. Vehicle headlamps can also cause light pollution. Paragraphs 13.2 and 13.4 in the statement of evidence prepared by ecologist Dr Kerry Borkin indicate that long-tailed bats may be affected by this. In my opinion, vehicle lighting is an important consideration that should be included in areas where bats are present and the effects of lighting need to be mitigated.

8. SPECTRAL COMPOSITION

Spectral composition - Theory

8.1. The human visual spectrum is between approximately 380 nm and 780 nm, with peak sensitivity in well-lit "photopic" conditions of 555 nm

(Julian, 2015)[20].

8.2. Wildlife has different wavelength sensitivity to humans, and this varies between species (Longcore et al., 2018)[21]. For example, some bats are known to be sensitive to UV radiation (Zhao et al., 2009)[22].

8.3. Light Emitting Diode (LED) light sources are becoming the dominant light source in the world (Zissis et al., 2021)[23]. As LEDs are inherently monochromatic sources, "white" light is typically produced using a short-wavelength "pump" LED that is coated in a phosphor. These light sources are often called "phosphor-converted LEDs" (pcLED), though I will refer to them simply as "LED" throughout my evidence. This method of light generation gives the LED spectrum two characteristic peaks – a short-wavelength peak from the pump at approximately 450 nm and a second peak from the phosphor. Data from MU's photometric laboratory illustrates these peaks in Figure 10. This data is commonly referred to as a "spectral power distribution" (SPD).

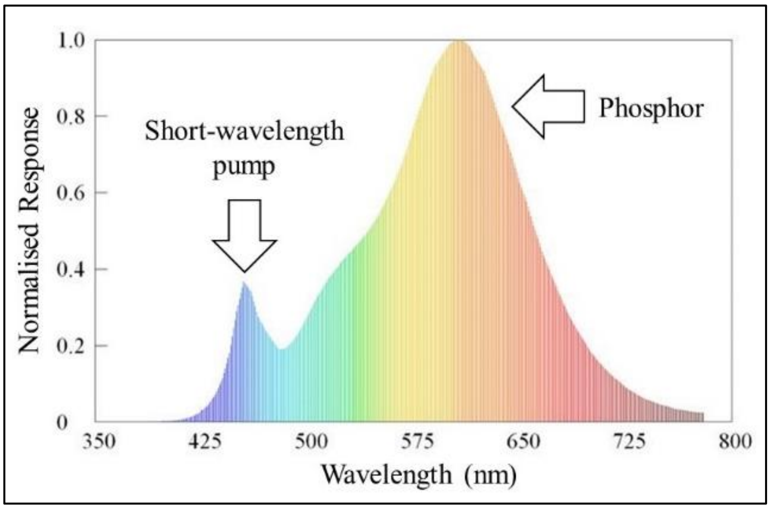

Figure 10 – Normalised SPD of 2700 K LED

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20 Julian, W. A. (2015). Lighting: Basic Concepts (6th (rev.) ed.). University of Sydney.

21 Longcore, T., Rodríguez, A., Witherington, B., Penniman, J. F., Herf, L., & Herf, M. (2018). Rapid assessment of lamp spectrum to quantify ecological effects of light at night. *Journal of Experimental Zoology Part A: Ecological and Integrative Physiology*, *329*(8-9), 511-521. https://doi.org/10.1002/jez.2184

22 Zhao, H., Rossiter, S. J., Teeling, E. C., Li, C., Cotton, J. A., & Zhang, S. (2009). The evolution of color vision in nocturnal mammals. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(22), 8980-8985. https://doi.org/10.1073/pnas.0813201106

23 Zissis, G., Bertoldi, P., & Serrenho, T. (2021). *Update on the status of LED-lighting word market since 2018*. https://publications.jrc.ec.europa.eu/repository/handle/JRC122760

8.4. While some older light sources (such as Mercury Vapour lamps) emit UV radiation, “white” LED light sources do not usually emit wavelengths in the UV range (below 380 nm) (van Bommel, 2015)[24].

8.5. The colour of light sources can be denoted in several ways. For a “white” light source, it is common to refer to a light source’s colour appearance in terms of its Correlated Colour Temperature (CCT). CCT is measured in kelvin; a low CCT (e.g. 2700 K) has a “warm” yellow-white colour, and a high CCT (e.g. 6500 K) has a “cool” blue-white colour. In white LEDs, a higher short-wavelength peak generally indicates a higher CCT (i.e. more “blue” light). However, as CCT is an aggregate number, it can mask the peaks in a spectrum. For example, the two light sources illustrated in Figure 11 both have a CCT of ~2700 K; however, they have noticeably different spectra. I have previously written a journal paper on this phenomenon (Mander & Chitty, 2019).

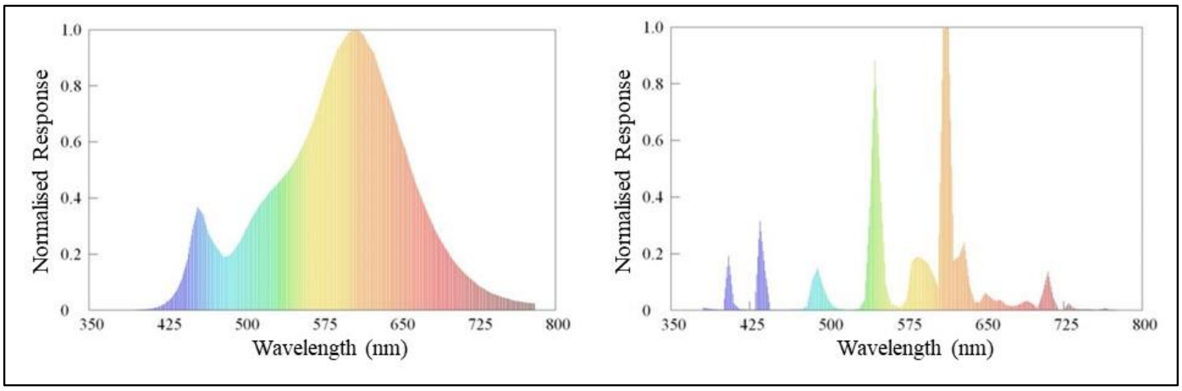

Figure 11 – Normalised SPDs of ~2700 K LED (left) and ~2700 K compact fluorescent (right)

8.6. Short (“blue”) wavelengths are known to affect humans and wildlife. For example, a paper by Hatori et al. (2017)[25] discusses the effects of “blue” light on the human circadian system (wake/sleep cycle), and comments that “misalignment of circadian rhythmicity is observed in numerous

24 van Bommel, W. (2015). Road lighting: Fundamentals, technology and application. Springer International Publishing. https://doi.org/10.1007/978-3-319-11466-8

25 Hatori, M., Gronfier, C., Van Gelder, R. N., Bernstein, P. S., Carreras, J., Panda, S., Marks, F., Sliney, D., Hunt, C. E., Hirota, T., Furukawa, T., & Tsubota, K. (2017). Global rise of potential health hazards caused by blue light-induced circadian disruption in modern aging societies. *npj Aging and Mechanisms of Disease*, *3*(1), Article 9. https://doi.org/10.1038/s41514-017-0010-2

conditions, including aging, and is thought to be involved in the development of age-related disorders, such as depression, diabetes, hypertension, obesity, and cancer" (p. 1). A study by the Royal Society Te Apārangi (2018) noted that "blue" light "may affect plant growth, pollination, reproduction, migration, predation, and communication" (p. 3)[26].

8.7. Short ("blue") wavelengths are known to affect night-sky pollution (skyglow) more than other wavelengths, as they scatter more in the atmosphere (Spoelstra, 2014)[27]. This phenomenon means that there can be significant effects over a wide area of many kilometres (Bará, 2016)[28].

8.8. Another important colour quality of a light source is its Colour Rendering Index (CRI), which indicates how well an object's true colours are replicated. In other words, a coloured object will be perceived as a different colour (or devoid of colour) if the illuminating light does not include the correct wavelengths. CRI has a maximum value of 100. The road lighting technical specification SA/SNZ 1158.6:2015 requires a minimum CRI of 70.

8.9. When considering UV content in areas where bats are present and the effects of lighting need to be mitigated:

a) ILP (2018) requires that "all luminaires should lack UV elements when manufactured. Metal halide, fluorescent sources should not be used" (p. 18).

b) EUROBATS (2018) advises that bat-inhabited areas should "avoid lamps emitting wavelengths below 540 nm (blue and UV ranges)" (p. 39).

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[26] Royal Society Te Apārangi. (2018). *Blue Light Aotearoa*.

[27] Spoelstra, H. (2014). New device for monitoring the colors of the night. *Journal of Quantitative Spectroscopy and Radiative Transfer*, *139*, 82-89. https://doi.org/10.1016/j.jqsrt.2014.01.001

[28] Bará, S. (2016). Anthropogenic disruption of the night sky darkness in urban and rural areas. *Royal Society Open Science*, *3*(10). https://doi.org/10.1098/rsos.160541

c) The requirement for no UV can be met using LED light sources. The comment regarding “540 nm” will be addressed in paragraph 8.11.

8.10. When considering CCT in areas where bats are present and the effects of lighting need to be mitigated:

a) ILP (2018) requires that “a warm white spectrum (ideally <2700Kelvin) should be adopted to reduce blue light component” (p. 18).

b) EUROBATS (2018) advises that bat-inhabited areas should “avoid lamps… with a correlated colour temperature > 2700 K” (p. 39).

c) The requirement for CCTs of 2700 K and below can be met using LED light sources.

8.11. When considering SPD in areas where bats are present and the effects of lighting need to be mitigated:

a) ILP (2018) states that “luminaires should feature peak wavelengths higher than 500nm to avoid the component of light most disturbing to bats” (p. 18). I assume that this statement refers to the highest peak in the spectrum. This condition can be met using LED sources with a CCT of 2700 K or lower.

b) EUROBATS (2018) advises to “avoid lamps emitting wavelengths below 540 nm (blue and UV ranges)” (p. 39) for feeding areas and commuting routes. In addition, roosts are recommended to avoid wavelengths under 500 nm (p. 43). In my opinion, it is impractical to use light sources with *no* wavelengths below 500 nm or 540 nm, as this would reduce the CRI of the light sources to below the level discussed in SA/SNZ 1158.6:2015 (refer to paragraph 8.8 above). It would also exclude naturally occurring wavelengths that are part of the moonlight spectrum.

8.12. In my opinion, the preference for 2700 K or under (as noted in paragraph

8.10 above) should also be considered from a human-centric perspective.

a) Discomfort glare to motorists is affected by light spectrum, and short wavelengths (i.e. light sources with more "blue") are known to be problematic. (Van Bommel, 2015). On that basis, I consider that LEDs with warmer CCTs are preferable.

b) Short wavelengths at night are known to affect human circadian rhythms (refer to paragraph 8.6 above). Hence, I consider that LEDs with warmer CCTs are preferable.

c) It has been suggested that short wavelengths may be *beneficial* in aiding driver vision, resulting in lower light levels being needed (Boyce, 2014, 2018)[29]. However, while this comment favours "blue" light sources, no preference for a higher blue content is made in NZ road lighting design standards. The recently published standard AS/NZS1158.1.1:2022 for vehicular roads states that "no re-rating lumen multipliers, such as those based on either the changing sensitivity of the eye at low light levels or the enhanced receptiveness of the eye to white light, shall be used in Category V lighting" (p. 13)[30]. Standard AS/NZS 1158.3:2020 for pedestrian roads also makes no distinction between different CCT values of LED light sources[31]. The incumbent high-pressure sodium street lights had a much lower CCT of 2000 K (Van Bommel, 2015). Therefore, in my opinion, a 2700 K CCT LED light source is acceptable for human use in these circumstances.

[29] Boyce, P. R. (2008). Lighting for driver: roads, vehicles, signs, and signals. CRC Press. Boyce, P. R. (2014). Human factors in lighting. CRC Press.

[30] Standards Australia & Standards New Zealand. (2022). *AS/NZS 1158.1.1 Lighting for roads and public spaces: Vehicular traffic (category V) lighting - performance and design requirements*. https://www.standards.govt.nz/

[31] Standards Australia & Standards New Zealand. (2020). *AS/NZS 1158.3.1 Lighting for roads and public spaces: Pedestrian area (category P) lighting - performance and design requirements*. https://www.standards.govt.nz/

Spectral Composition – Demonstrating Compliance

8.13. SPD data, such as that shown in Figure 11, is often provided on a luminaire datasheet. Alternatively, information can be obtained using a spectrometer (portable and lab-based instruments are available). In my opinion, it is essential to restrict light source selection to a particular type (such as 2700 K LED), rather than specifying light sources by CCT alone.

9. FLICKER

Flicker - Theory

9.1. Some light sources flicker at high frequencies due to the power supply[32].

9.2. Research by Inger et al. (2014) indicates that wildlife detects flicker at different thresholds than humans, and some species may be affected[33]. Inger et al. (2014) highlight bats as a possible affected group.

9.3. In sample site measurements of road lighting in Auckland, I found that modern road lighting LED luminaires produce little flicker. However, I found high levels of flicker in other new lighting installations utilising LEDs, such as luminaires attached to building facades. I also found high flicker levels in lab-based testing of some new LED products. Therefore, I recommend that a flicker provision be included in Proposed Plan Change 5. Various flicker metrics are used, including percent flicker, flicker index, and Stroboscopic effect Visibility Measure (SVM). In each case, a lower value equates to less flicker, which is preferable. To the best of my knowledge, flicker standards do not specify an acceptable flicker threshold for wildlife.

Flicker – Demonstrating Compliance

9.4. Flicker data may be provided on a luminaire datasheet. Alternatively,

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[32] Poplawski, M., & Miller, N. J. (2011). Exploring flicker in solid-state lighting: What you might find, and how to deal with it. http://www.e3tnw.org/Documents/2011%20IES%20flicker%20paper%20poplawski-miller-FINAL.pdf

[33] Inger, R., Bennie, J., Davies, T. W., & Gaston, K. J. (2014). Potential biological and ecological effects of flickering artificial light. *PLoS ONE*, *9*(5), Article e98631. https://doi.org/10.1371/journal.pone.0098631

information can be obtained using a flicker meter.

10. DURATION

10.1. Lighting controls (such as movement sensors and dimming schemes) can be used to reduce illuminance during periods of inactivity.

10.2. ILP (2018) and EUROBATS (2018) recommend the use of motion sensors, with the former recommending short (1-minute) timers.

10.3. EUROBATS (2018) suggests that *if lighting is necessary,* public lighting should be turned off “within 2 hours after sunset (civil twilight)” (p. 39) for feeding areas and commuting routes.

11. LIGHTING FOR HUMAN SAFETY

11.1. Research on the use of lighting to deter criminal acts has produced mixed results. As discussed in Boyce (2014), one study found that substance abuse increased when the lighting in an alley was increased. Conversely, a study on workplace homicide found that well-lit exteriors reduced the risk of murder. Boyce concludes that while lighting does not directly affect crime levels, it can indirectly affect crime through improved surveillance and “enhancing community confidence” (p. 471).

11.2. The link between lighting and the *perception* of safety has been more proven, and it is generally agreed that people feel safer under street lighting, particularly women and the elderly (Boyce, 2014).

11.3. Regarding the use of lighting for safety, ILP (2018) uses the example of “some industrial sites with 24-hour operation” (p. 16). However, the document notes that “in the public realm, while lighting can increase the perception of safety and security, measurable benefits can be subjective” (p. 16).

12. COMMENT ON SECTION 42A REPORT

12.1. Chapter 25.6 is entitled *lighting and glare*, but it does not include any glare metrics, such as luminous intensity (refer to paragraphs 6.8 - 6.10 above) and luminance (refer to paragraphs 6.11 - 6.12 above). In my opinion, these metrics are essential for all areas except perhaps where downward-facing security lights on motion sensors are used with short-duration timers.

12.2. Chapters 25.6.2.2a and 25.6.2.2b require the maintenance of “safety of adjoining properties” and “a safe public realm for the community”, respectively. I recommend that the safety needs of the community and their subsequent effects on lighting design are defined, as this is not included at present. Per paragraphs 11.1 - 11.3 above, research shows that light does not directly affect crime levels, though it can provide enhanced perceptions of safety.

12.3. Chapter 25.6.4.4 a) refers to added illuminance of 0.3 lux. This does not align with the values given in EUROBATS (2018) or ILP (2018) (see paragraphs 6.4 - 6.7 above). The advisory note does not explain why *added* illuminance has been used, nor why a threshold of 0.3 lux (and not another value) has been set. It is my opinion that these items need to be addressed.

12.4. Chapter 25.6.4.4 a) gives an illuminance threshold “at any height at the external boundary of the Significant Bat Habitat Area”. I agree with this requirement. However, this implies that calculations (and not measurements) are necessary for all circumstances, as illuminance meters cannot physically measure “at any height”. In my opinion, clarification is needed on when an illuminance meter may be used, as such meters are mentioned in Chapter 25.6.4.4 advisory note 2.

12.5. Chapter 25.6.4.4 c) sets out parameters for land adjoining a SBHA, including land immediately on the opposite side of the road which adjoins a SBHA. I agree that lighting controls are essential; however, in my opinion, *the five principles for responsible outdoor lighting* are best practice and should ideally be universal in Plan Change 5 rather than restricted to limited areas (refer to paragraph 5.1 above) (IDA, 2020).

12.6. Chapter 25.6.4.4c iii) requires that LED light sources be used. I agree that the light source should be specified (see paragraph 8.13 above).

12.7. Chapter 25.6.4.4c iii) sets out two different CCT values for residential use (2700 K and 3000 K). In my opinion, making such distinctions does not make sense. Appendix Q of the Plan Change 5 supporting documents suggests that this is due to poor availability of 2700 K luminaires, yet Chapter 25.6.4.4c iii) indicates that such luminaires are available for residential use. I therefore recommend a value of 2700 K for all lighting (see paragraphs 8.10 and 8.12 above). If that is not possible the second-best option in my opinion is to use the CCT values proposed in Chapter 25.6.4.4c iii) (refer to Figure 12).

iii. *Be white LED, a maximum colour temperature of;*

- *3000K on land with a residential use where separated from a SBHA by a public road with maximum 2700K lighting*
- *2700K for land with a residential use, directly abutting a SBHA*
- *2700K for all other uses (30.4)*

Figure 12 – Chapter 25.6.4.4c iii) Submitter changes

12.8. Chapter 25.6.4.4c iv) refers to using a motion sensor with a 5-minute timer for “security lighting”. It is my opinion that the term “security lighting” may need to be defined. I agree with the use of motion sensors in principle, though note that the need for a 5-minute duration deviates from ILP’s guidance of 1 minute (ILP, 2018). Paragraph 14.10 in the statement of evidence prepared by ecologist Dr Borkin indicates that allowing the lights to be on for more than 1 minute “will not minimise effects of lighting on long-tailed bats as much as is possible or practical”. On that basis, the 1-minute duration would be preferable.

12.9. Chapter 25.6.4.4 advisory note 2 states requirements for illuminance meters. The meter sensitivity ("100.1 lux") appears to be a typographical error, as paragraph 47 of Mr Mckensey's Evidence states a value of 0.1 lux[34]. I agree that calibrated meters are essential (refer to paragraph 6.14 above). In my opinion, the meter must have a lower limit of 0.01 lux, as a value of 0.1 lux is too close to the low light threshold.

12.10. Chapter 25.10.5.7 refers to illuminated signage in the Neighbourhood Centre Zone – Peacocke and Local Centre Zone – Peacocke. The maximum night time luminance value for this is 350 cd/m^2, which is significantly higher than the thresholds outlined in paragraph 6.12 above. It is not clear to me whether signage in the remainder of the Peacocke area is prohibited.

12.11. The Section 42A report makes no provision for the following items, which I consider essential:

a) low-reflectance surfaces (paragraphs 7.3 - 7.4 above);

b) light trespass from windows (paragraph 7.5 above);

c) shielding from headlamps (paragraph 7.6 above); and

d) flicker (paragraphs 9.1 - 9.3 above).

13. CONCLUSION

13.1. In my opinion, the amended plan provisions have made significant progress toward providing responsible lighting. However, I consider that further refinement is necessary to minimise the effects of lighting on the long-tailed bat.

13.2. In particular, I consider that:

a) the safety needs of the community and their subsequent effects on lighting design should be defined;

[34] Plan Change 5 – Peacocke Structure Plan, Supplementary Technical Report, John McKensey dated 29 August 2022; Statement of Evidence of John McKensey

b) illuminance thresholds should be based on sound evidence;

c) principles of responsible lighting should be applied across the whole area, and not only in areas adjacent to a SBHA;

d) 2700 K lighting should be consistently;

e) illuminance meters should be capable of reading at low light levels (0.01 lux); and

f) consideration should be made for luminous intensity, luminance, low-reflectance surfaces, light trespass from windows, shielding from headlamps, and flicker.

Susan Marie Mander

Dated 16 September 2022

APPENDIX 1: CONSOLIDATED LIST OF REFERENCES IN MS MANDER'S EVIDENCE

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