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ERAMURRA SOLAR SALT PROJECT: BENCHMARK ARTIFICIAL LIGHT MONITORING AND MODELLING

Prepared by

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For

Leichhardt Salt Pty Ltd

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ARTIFICIAL LIGHT ASSESSMENT SERVICES

PENDOLEY ENVIRONMENTAL

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ACRONYMS

CPE	Cape Preston East
DSLR	Digital single-lens reflex
E	East
EPA	Environmental Protection Authority
GPS	Global Positioning System
N	North
nm	Nanometres
OGV	Ocean-going Vessel
PENV	Pendoley Environmental
S	South
SRTM	Shuttle Radar Topography Mission
TSV	Transhipment Vessel
Vmag/arcsec^2	Visual magnitudes per square arc second
W/m^2/sr	Watt per steradian per square metre (unit of radiance)
WA	Western Australia
WOS	Whole of Sky

1 INTRODUCTION

1.1 Project Description

Leichhardt Salt Pty Ltd (Leichhardt) is the Proponent for the Eramurra Solar Salt Project (the Project), a proposed solar salt operation in the Pilbara region of Western Australia (WA). The Project is targeting production of 4.2 million tonnes per annum of high-grade salt from seawater using a series of evaporation and crystallisation ponds. The Project will be located to the east of Citic Pacific's Sino Iron Project at Cape Preston, WA, and will require the development of concentrator and crystallisation ponds, construction of a processing facility, and construction of an export facility (Cape Preston East; CPE).

Although the CPE export facility will be constructed in conjunction with the Project, key elements of the facility have already been referred and approved under the *Environmental Protection Act 1986* and determined to be 'not a controlled action if undertaken in a particular manner' under the *Environment Protection and Biodiversity Conservation Act 1999* (EPA 2020). The key elements already assessed are understood to include a trestle jetty at CPE, attended by a Transhipment Vessel (TSV), navigation markers, and Ocean-Going Vessels (OGVs), located at anchorages within a designated transhipment area to the north of South West Regnard and North East Regnard Islands.

1.2 Scope

In response to Leichhardt's draft Environmental Scoping Document (14th March 2022) for the Project, the Environmental Protection Authority (EPA) has requested a pre-construction light survey be undertaken, to address impacts to marine fauna. In particular, Leichhardt has been requested to:

"*Undertake a baseline light survey to identify the current light environment and undertake a light spill study to consider the direction and intensity of the expected light sources to determine whether the Proposal will attract turtle hatchlings or otherwise alter their behaviour. The light spill study will consider cumulative lighting impacts on the turtle population of the North West Shelf.*"

Leichhardt engaged Pendoley Environmental (PENV) to undertake artificial light monitoring to capture the pre-construction (or 'benchmark') lighting environment at known marine turtle nesting beaches in the vicinity of the Project's disturbance footprint, and light modelling to predict the visibility of future Project light emissions (including CPE) from the same beaches. Project facilities modelled for this purpose include:

- Project Facilities (i.e. associated with the Eramurra Solar Salt Project):
  - Pump station infrastructure
  - Operations and workshop buildings
  - Wash plant
  - Salt stockpile (stackers, dozer, loaders, trucks)
  - Power station
  - Crystalliser harvesters

- Wet salt haulage truck

Additionally, while the CPE facility does not form part of the Project being assessed, it has been included in the modelling to provide a cumulative understanding of light emissions that will be visible post-construction of the Project. Facilities modelled as part of CPE include:

- Export Facilities:
  - Operations, workshop, and logistic buildings
  - Power station
  - Salt stockpile (stacker, dozer, conveyors, hoppers)
  - Salt trucks
  - Outload jetty
  - Shiploader boom
- Vessels:
  - TSVs
  - OGVs

Construction of the Project will also require dredging of the CPE Port for shipping access to the trestle jetty, however, lighting associated with dredging has not been included in this assessment as dredging is planned to occur outside of the turtle nesting and hatching season over the months of April to July.

Outputs from the modelling may be used to undertake an impact assessment of Project lighting on marine turtle behaviour, and consider cumulative lighting impacts on the marine turtle population of the North West Shelf, however this has not been addressed by this report due to insufficient information on the marine turtle populations nesting at the Regnard Islands.

2 METHODOLOGY

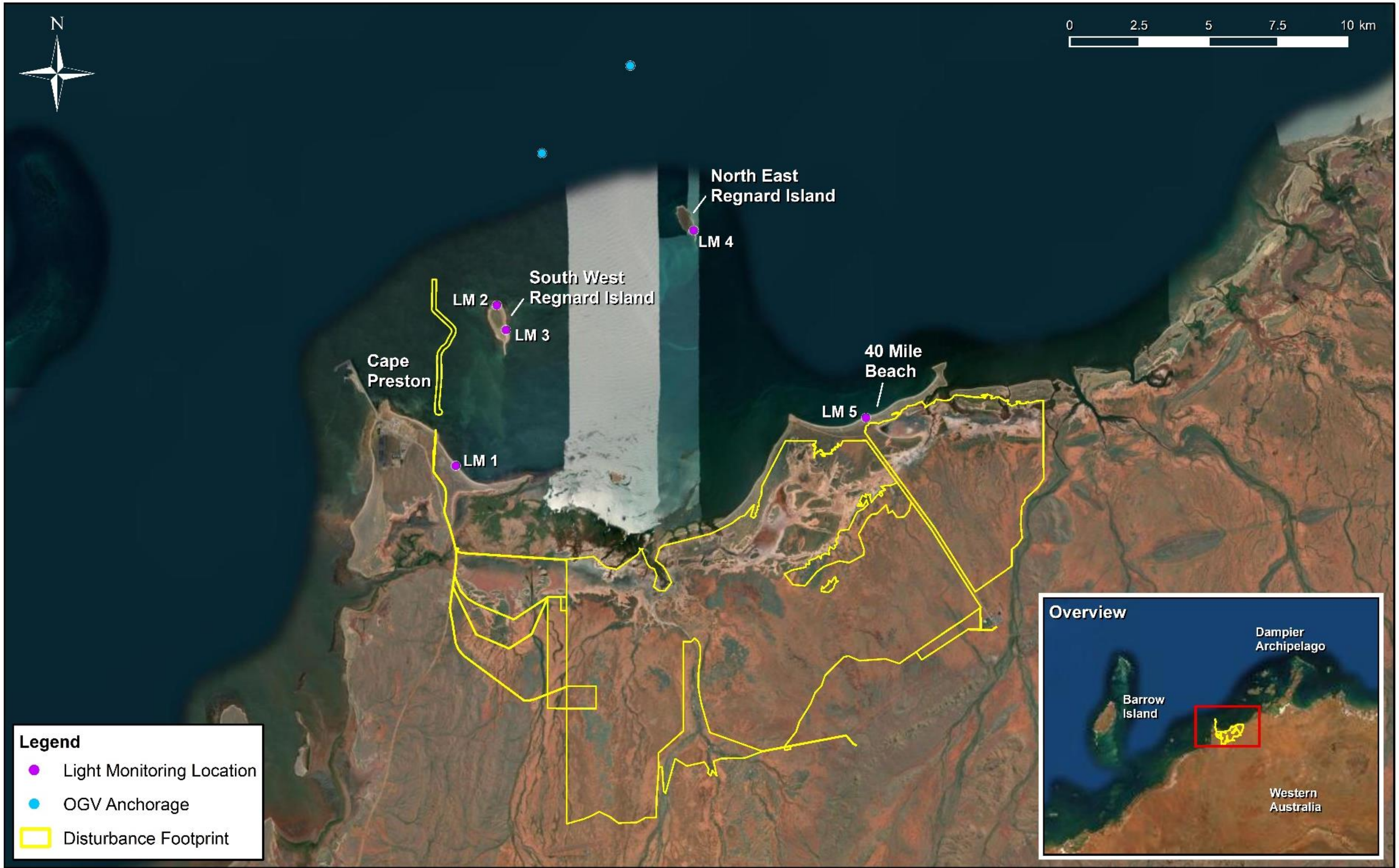
2.1 Light Monitoring

Monitoring was undertaken at three island and two mainland locations to capture the existing lighting environment at known turtle nesting beaches in proximity to the Project's disturbance footprint (**Table 1** and **Figure 1**). Monitoring was undertaken by two PENV personnel between 27th June and 1st July 2022, coinciding with a new moon period (29th June 2022). Island locations were accessed via vessel mobilising from Dampier each day, and mainland locations were accessed via four-wheel drive vehicle. Mainland locations (LM1 and LM5; **Figure 1**) could not be accessed directly via vessel because:

- LM1: The nearshore reef platform made it difficult to manoeuvre the vessel close to shore in strong winds.
- LM5: Restrictions imposed prevented access to port waters.

Table 1: Monitoring locations and coordinates.

Location	Latitude	Longitude
LM1: Mainland Cape Preston	-20.85500	116.22985
LM2: South West Regnard Island (N)	-20.80304	116.24437
LM3: South West Regnard Island (E)	-20.81084	116.24743
LM4: North East Regnard Island (S)	-20.77854	116.31259
LM5: 40-Mile Beach	-20.83994	116.37197



J10601 Eramurra Artificial Light Monitoring

Figure 1: Eramurra disturbance footprint and light monitoring locations. OGV, Ocean-Going Vessel.

Drawn: B. Moore
Date: 01/08/2022
Drawing File Ref: J10601-1185-A
Coordinate System: GDA 1994 MGA Zone 50

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2.1.1 Data Capture

Artificial light data was captured at each survey location using a Sky42 light monitoring camera. The camera features a calibrated Canon EOS 700D DSLR combined with a fish-eye lens and custom-built hardware to acquire low-light images of the entire night sky. The cameras are built into a weatherproof housing with a protective lid that automatically opens during image capture and closes between capture intervals.

Sky42 light monitoring cameras were deployed on tripods (~60 cm high) on areas of sandy beach suitable for turtle nesting and were programmed to capture one long-exposure image every 10 minutes between sunset and sunrise. At North East Regnard and South West Regnard Islands, cameras were deployed between old marine turtle body pits (**Figure 2**). At mainland locations, there was no visible historic nesting activity and therefore cameras were deployed above the spring high tide mark. Cameras were deployed overnight at all locations and images were downloaded each day.

Weather conditions for the survey were favourable for light monitoring on every night of the field campaign, however, winds were strong during the day and made for long transit times on the vessel and difficulty in undertaking shore transfers, particularly at the 40-Mile Beach boat ramp.

Figure 2: Light monitoring camera deployment on North East Regnard Island between old body pits.

2.1.2 Data Analysis

All suitable images were processed using specialised software to determine 'whole-of-sky' (WOS) and 'horizon' sky brightness. WOS is the mean value of light (including direct light and sky glow, natural and artificial) in the entire image, and horizon brightness is the mean value of light within the 60 – 90° outer band, considered most relevant to marine turtle vision (**Figure 3**). All images have been quantified in units of visual magnitudes per square arc second (Vmag), a common unit used to measure astronomical sky brightness that represents light intensity on an inverse logarithmic scale.

Note that the colour coding used in the processed imagery represents the scale of intensity of light and is not representative of the colour of light as perceived by a human or turtle eye, or a Sky42 camera.

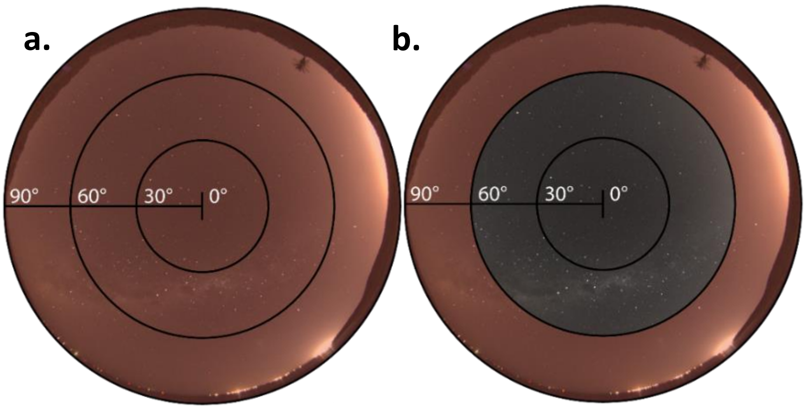

Figure 3: Measurement of mean pixel values; a. Whole-of-sky brightness (full image); b. Horizon brightness (60 – 90°). Shaded areas denote the region of the sky being measured.

2.2 Light Modelling

Currently, there are no standard commercial models for landscape scale modelling of artificial light emissions (Commonwealth of Australia 2020). Recognising the gap and the growing need to respond to both local and national regulatory concerns over artificial light impacts on wildlife and on dark sky conservation values required to meet the International Dark Sky Association Dark Sky Park certification requirements, PENV has developed a landscape-scale model of artificial light.

The ILLUMINA model is used as the base model for the work, selected for its ability to represent light across large areas and distances, and across the entire visible spectrum, including biologically meaningful light from 350 – 700 nm (Aube et al. 2005). ILLUMINA accounts for both line-of-sight light visibility and sky glow derived from atmospheric scattering of light. The model also addresses the attenuation of light over landscape scale distances and, consequently, the areal extent of glow across the sky can be modelled.

2.2.1 Inputs

The following general parameters were used as inputs into the model:

- Topography and reflectance: NASA Shuttle Radar Topography Mission (SRTM) digital elevation data (1 arc-second resolution).
- GPS coordinates for the observer viewpoints (**Table 1**).
- Weather conditions: all scenarios are considered free of any influencing atmospheric or weather conditions (sun, moon, rain or cloud).
- A detailed lighting inventory (light types, positions, heights, intensity) for the Project and CPE infrastructure and vessels, including OGVs and TSVs, based on information provided by Leichhardt. A summary of the lighting inventory is provided in **Appendix A**.

2.2.2 Outputs

All-sky modelled image: A projected all-sky modelled image 'as viewed' from each of the five monitoring locations was produced and combined additively with benchmark camera imagery to illustrate the predicted visible increase in brightness across the horizon and sky due to direct light and sky glow.

Direct light is defined as lighting that has line of sight visibility from the monitoring location, and sky glow is defined as light that is scattered or reflected into the area surrounding a direct light source.

2.2.3 Model Assumptions

The lighting inventory was assembled under the following assumptions:

- Only external lighting has been considered in the model (i.e. omits internal lighting that may be reflected externally).
- All modelled lighting is considered to have a completely spherical emission (i.e. light is emitted equally in all directions), with no shielding applied.
- Where manufacturer specifications on luminaire spectra were not available, PENV generated their own spectral power curves based on what is typical for the type/colour temperature of the luminaire.
- OGV lighting was merged and then divided evenly into three main areas on the vessel (front/middle/rear), as opposed to being placed in individual positions. Due to the distance of the OGVs from observer viewpoints (~6 km from the nearest site), it is not expected this simplification would meaningfully impact the results.
- Two OGVs are included: one at each of the anchorages north of the Regnard Islands (**Figure 1**).
- Two TSVs are included: one at berth at the end of the proposed trestle jetty, and one at the westernmost OGV anchorage.

2.2.4 Model Limitations

While the underlying science of light behaviour is well known, the methods required to measure and model light intensity and sky glow on a landscape scale are still in the research and development phase, and consequently, are constrained by the following limitations:

- Model results have not yet been definitively ground-truthed for large-scale projects (Linares et al. 2018, 2020), however, the technical approach outlined within this report is considered current with the most recent literature, subject matter expert input, and best practice.
- The precision of the model outputs is directly related to the level of input detail. Much of the lighting design is still conceptual and may be changed prior to construction.
- The model has converted units of absolute radiance ($W/m^2/sr$) to units of photometric luminance ($Vmag/arcsec^2$). Where absolute radiance represents light equally across the whole visible spectrum, visual magnitudes represent only the human visual (green) band of the spectrum and may not fully represent light as perceived by marine turtles or seabirds.

3 RESULTS AND DISCUSSION

3.1 Benchmark Light Monitoring

Artificial light data was successfully captured at all monitoring locations during the field campaign. A single clear image was selected from each monitoring location for analysis and processed results are shown in **Figures 4a** – **8a**.

Citic Pacific's Sino Iron Facility at Cape Preston, situated adjacent to the proposed CPE port facility, was the largest existing source of sky brightness on the horizon and was visible from all survey locations (**Figures 4a** – **8a**). Lighting from industry on the Burrup Peninsula and the Karratha townsite was also visible from all survey locations, however, the extent of sky glow visible from these sources was comparatively much smaller due to their distance from the monitoring locations. Direct light from vessels anchored to the northwest of South West Regnard Island was also visible (**Figure 5a**).

3.2 Light Modelling

The majority of lighting associated with Project facilities will consist of 5000 – 6000K (cool white) LEDs that range in height from 1 to 29 m. The majority of lighting at the CPE facilities is 2200K (orange) LED, with Amber LEDs on the outload jetty, and ranges in height from 1 to 27 m. Lighting on the OGVs is predominately fluorescent and High Pressure Sodium, with LED lighting ranging from 3500K (warm white) – 5000K (cool white). See **Appendix A** for a detailed light inventory for each source.

The modelling predicts that light emissions from the Project and CPE facilities will be visible from all monitored locations at varying intensities, with the CPE facilities either partially or directly overlapping with the bearing of the Sino Iron Facility (**Figures 4** – **8**).

At LM1 (mainland Cape Preston), the modelling indicates there will be a substantial increase in sky brightness (WOS: 170 %; horizon: 320 %), primarily due to the proximity of the site to the proposed CPE facility (**Table 2** and **Figure 4**). The height of the proposed CPE light sources (up to 40 m) and the low dune profile at LM1 indicates an observer at this location will have direct visibility of the bright CPE lighting (**Figure 4**). Lighting from the Project facilities and OGV anchorages will also be visible from LM1, however, this will primarily be comprised of sky glow, with the topography providing some shielding of direct light. Both the Project and OGV anchorage lighting will appear similar in size and intensity to the Burrup Peninsula and Karratha townsite lighting, located ~60 km from LM1.

At South West Regnard Island, the visibility of Project lighting will be influenced by the height of the primary dune, which will determine the amount of natural shielding provided from a viewpoint on the beach. At the northern extent of the island (LM2), introduction of the CPE lighting will increase the amount of glow visible on the same bearing as the existing Sino Iron Facility. The tall dune between the beach and the port, however, naturally shields any direct light emissions from the CPE facilities (**Figure 5**). Similarly, lighting from Project facilities will be almost entirely shielded at this location. The OGV anchorages are not shielded by any topography and are the largest contributor to increased sky brightness visible at this location (WOS: 65 %; horizon: 138 %; **Table 2**).

At the eastern beach of South West Regnard Island (LM3), the primary dune profile is much lower than at LM2. While the contribution of sky glow from all of the Project light sources will therefore be more visible (**Figure 6**), direct light from the anchorages is not visible, resulting in a lower overall increase in sky brightness (WOS: 22 %; horizon: 33 %; **Table 2**). CPE lighting will provide the greatest source of sky glow on the same bearing as the Sino Iron Facility, however, the low dune will provide shielding from direct light. The Project facilities and OGV vessels at anchor will emit glow of similar intensity and size as observed for the Burrup Peninsula and Karratha townsite at this location.

North East Regnard Island (LM4) and 40-Mile beach (LM5) are situated the furthest from the Project and are predicted to remain the darkest following construction (**Table 2**). This is both due to the attenuation of light with distance from the Project, and the natural shielding provided by the tall primary dunes at each location (**Figures 7** and **8**). At LM4, the addition of Project lighting will result in a marginal increase in sky glow at the top of the dune behind the beach (WOS: 13 %; horizon: 18 %), while the Burrup Peninsula and Karratha townsite will remain the most visible light source at this location (**Figure 7**). At LM5, addition of the Project and CPE infrastructure will result in a marginal increase in direct light and sky glow on the existing bearing of the Sino Iron Facility (WOS: 15 %; horizon: 17 %; **Figure 8**). OGV vessel lighting emissions are predicted to be negligible at both LM4 and LM5.

Table 2: Comparison of benchmark and benchmark + modelled (cumulative) sky brightness values (Vmag/arcsec^2). Note that the scale is inverse logarithmic, brightness increases with decreasing Vmag/arcsec^2 values.

Location	WOS (0 – 90°) (Vmag/arcsec^2)			Horizon (60 – 90°) (Vmag/arcsec^2)		
	Benchmark	Benchmark + Modelled	Change	Benchmark	Benchmark + Modelled	Change
LM1	20.89	19.82	170 %	20.52	18.94	327 %
LM2	21.19	20.64	65 %	20.98	20.03	138 %
LM3	21.07	20.85	22 %	20.85	20.52	34 %
LM4	21.22	21.08	13 %	21.09	20.91	18 %
LM5	21.36	21.20	15 %	21.26	21.08	17 %

While PENV only undertook modelling of the cumulative contribution of light sources from both the Project and CPE facilities, the relative contribution of these sources separately to horizon sky brightness has been estimated and outlined in **Appendix B: Table B1**. The results from this analysis confirm that the CPE facilities are the greatest contributor to horizon brightness at mainland Cape Preston and South West Regnard Island (LM1: 302 %; LM2: 135 %; LM3: 25 %). Once light emissions from Project facilities are added to the CPE facilities, horizon brightness increases by a further 6 % at LM1, 1 % at LM2, and 7 % at LM3. At North East Regnard Island and 40-Mile beach, there is a greater increase in brightness from the Project facilities (LM4: 11 %, LM5: 9%) than from the CPE facilities (LM4: 7 %, LM5: 8%).

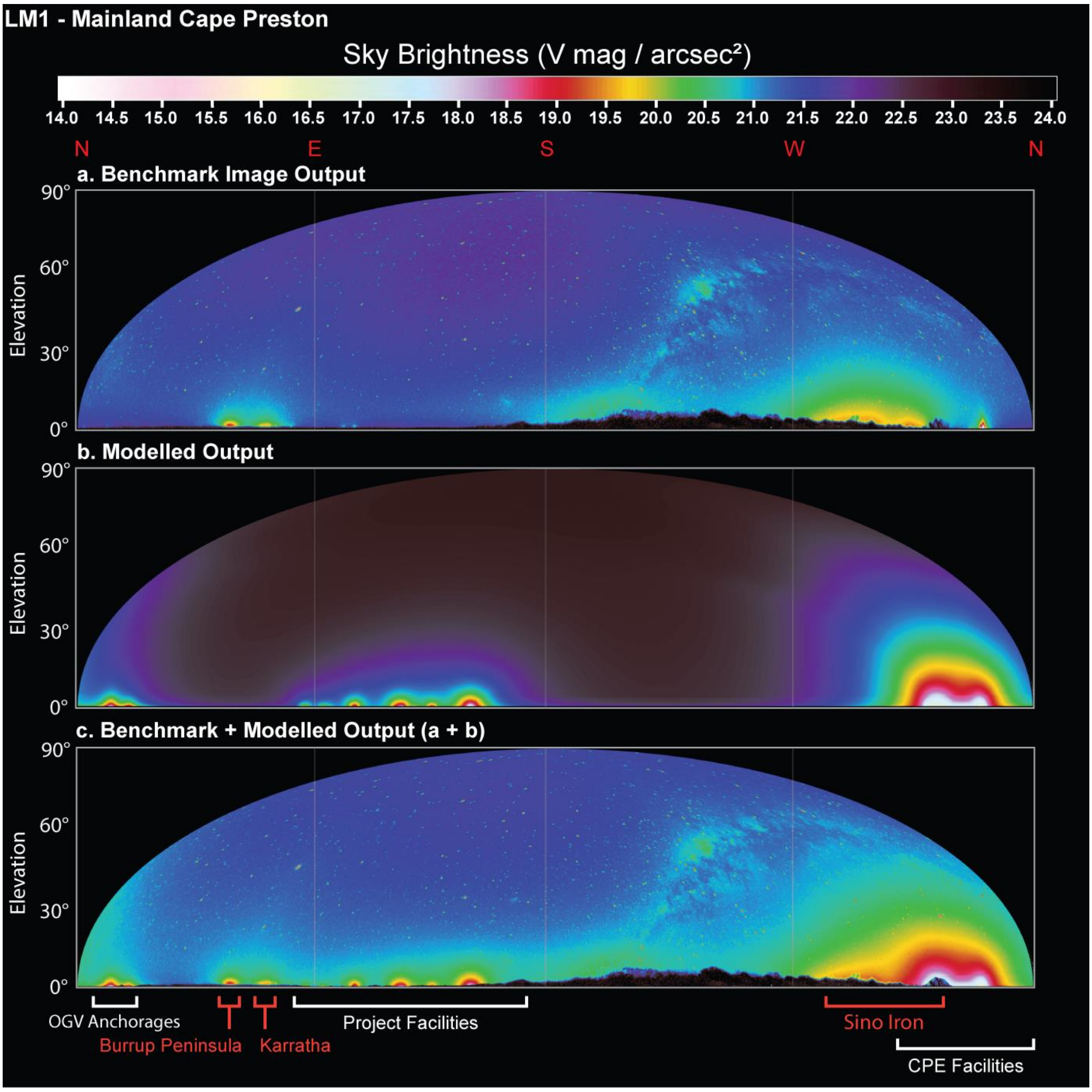

Figure 4: Artificial light modelling results for LM1 (mainland Cape Preston): a. Benchmark all-sky processed image recorded during the light survey; b. Modelled brightness based on light design provided by Leichhardt; c. Benchmark monitoring image + modelled brightness. Red labels = existing light sources, white labels = new light sources associated with the Project.

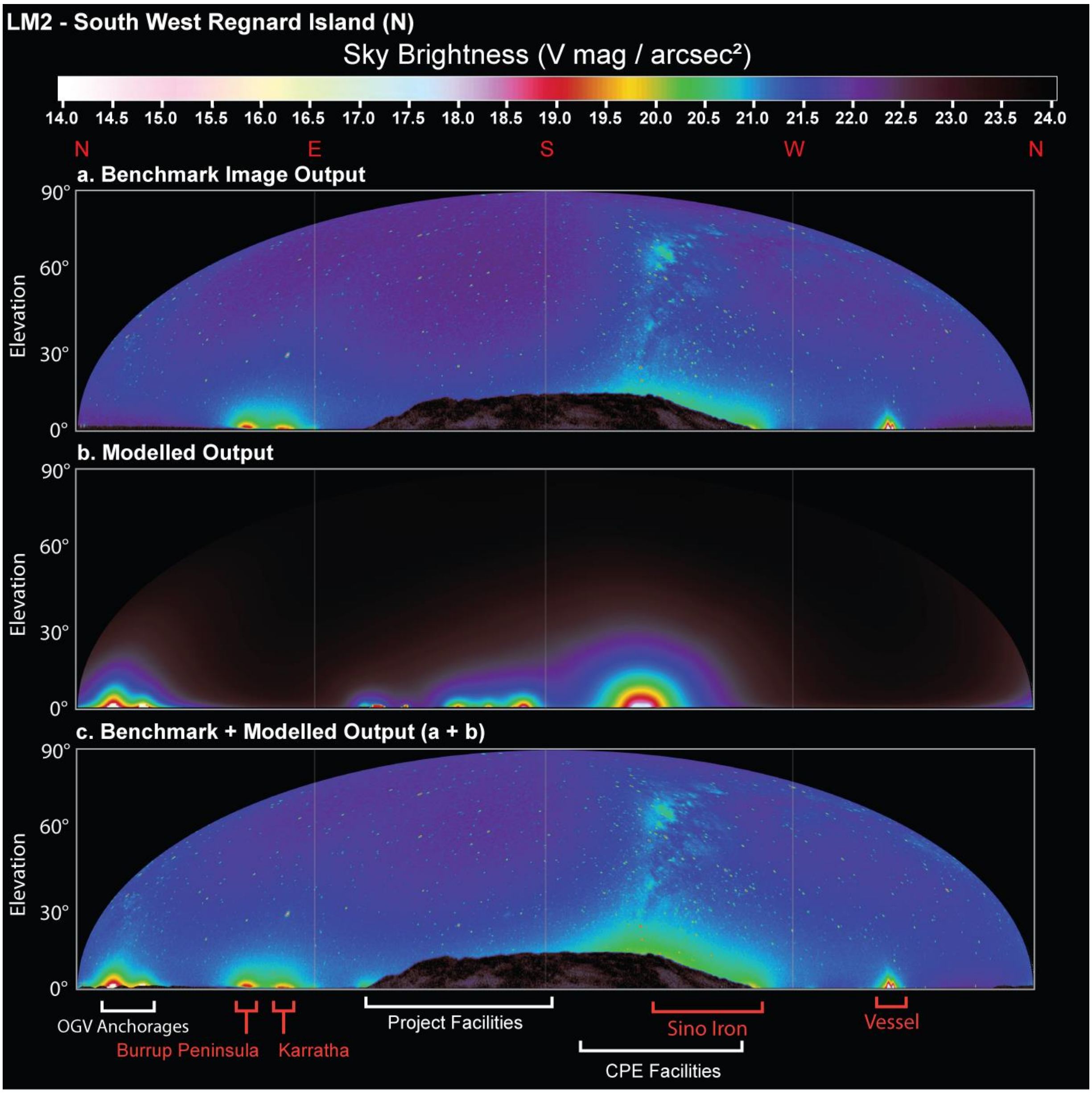

Figure 5: Artificial light modelling results for LM2 (South West Regnard Island [N]): a. Benchmark all-sky processed image recorded during the light survey; b. Modelled brightness based on light design provided by Leichhardt; c. Benchmark monitoring image + modelled brightness. Red labels = existing light sources, white labels = new light sources associated with the Project.

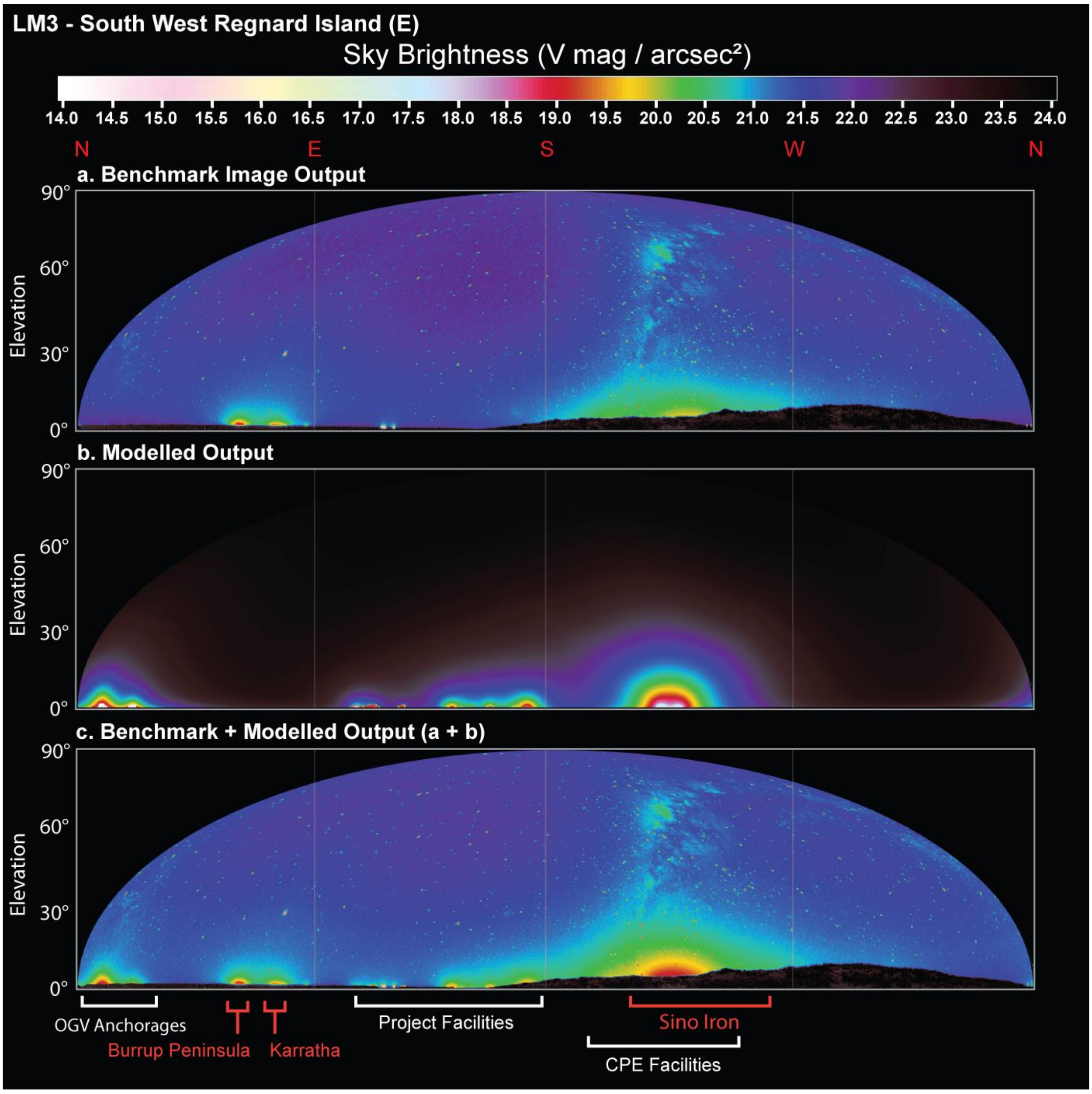

Figure 6: Artificial light modelling results for LM3 (South West Regnard Island [E]): a. Benchmark all-sky processed image recorded during the light survey; b. Modelled brightness based on light design provided by Leichhardt; c. Benchmark monitoring image + modelled brightness. Red labels = existing light sources, white labels = new light sources associated with the Project.

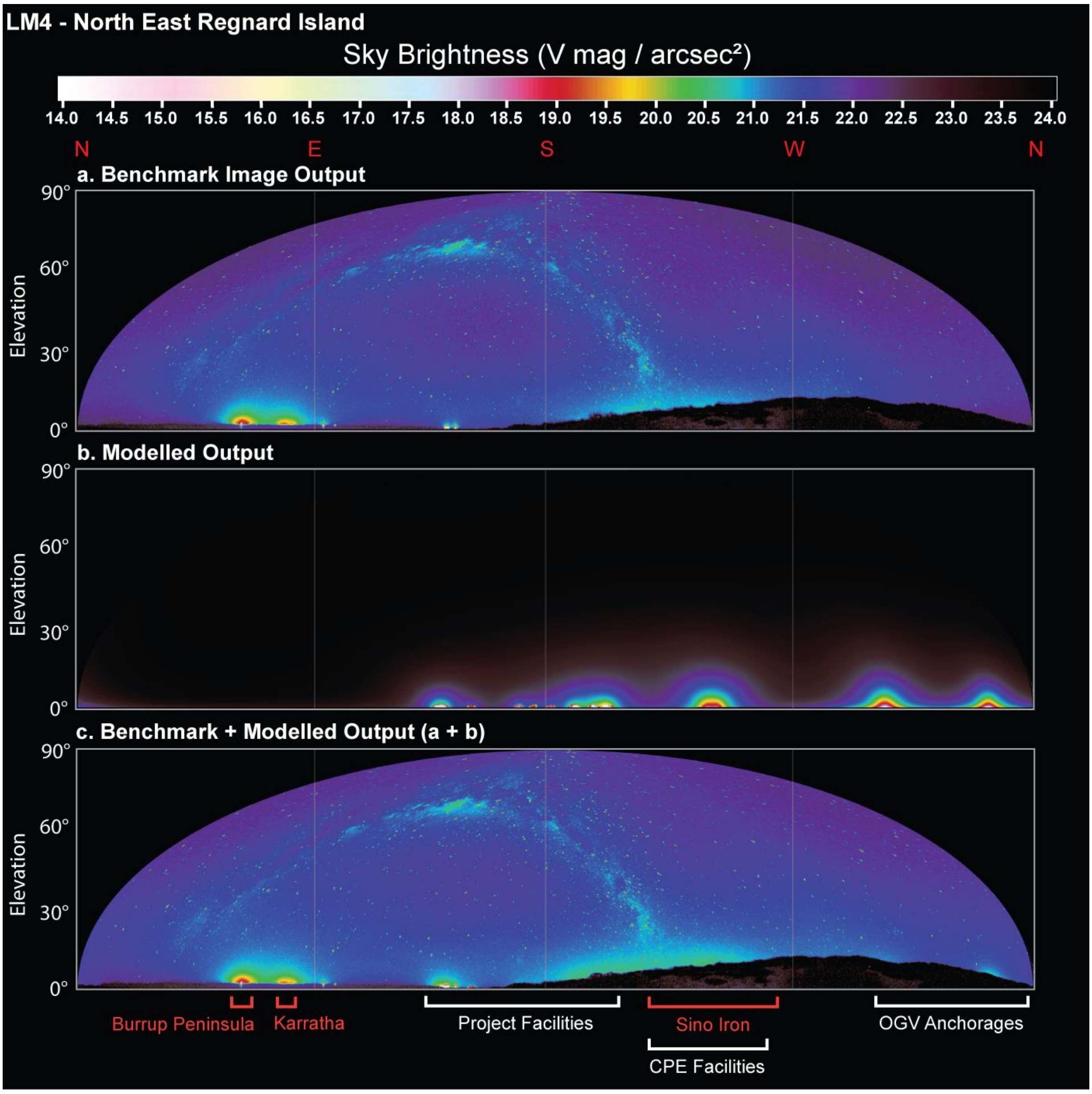

Figure 7: Artificial light modelling results for LM4 (North East Regnard Island): a. Benchmark all-sky processed image recorded during the light survey; b. Modelled brightness based on light design provided by Leichhardt; c. Benchmark monitoring image + modelled brightness. Red labels = existing light sources, white labels = new light sources associated with the Project.

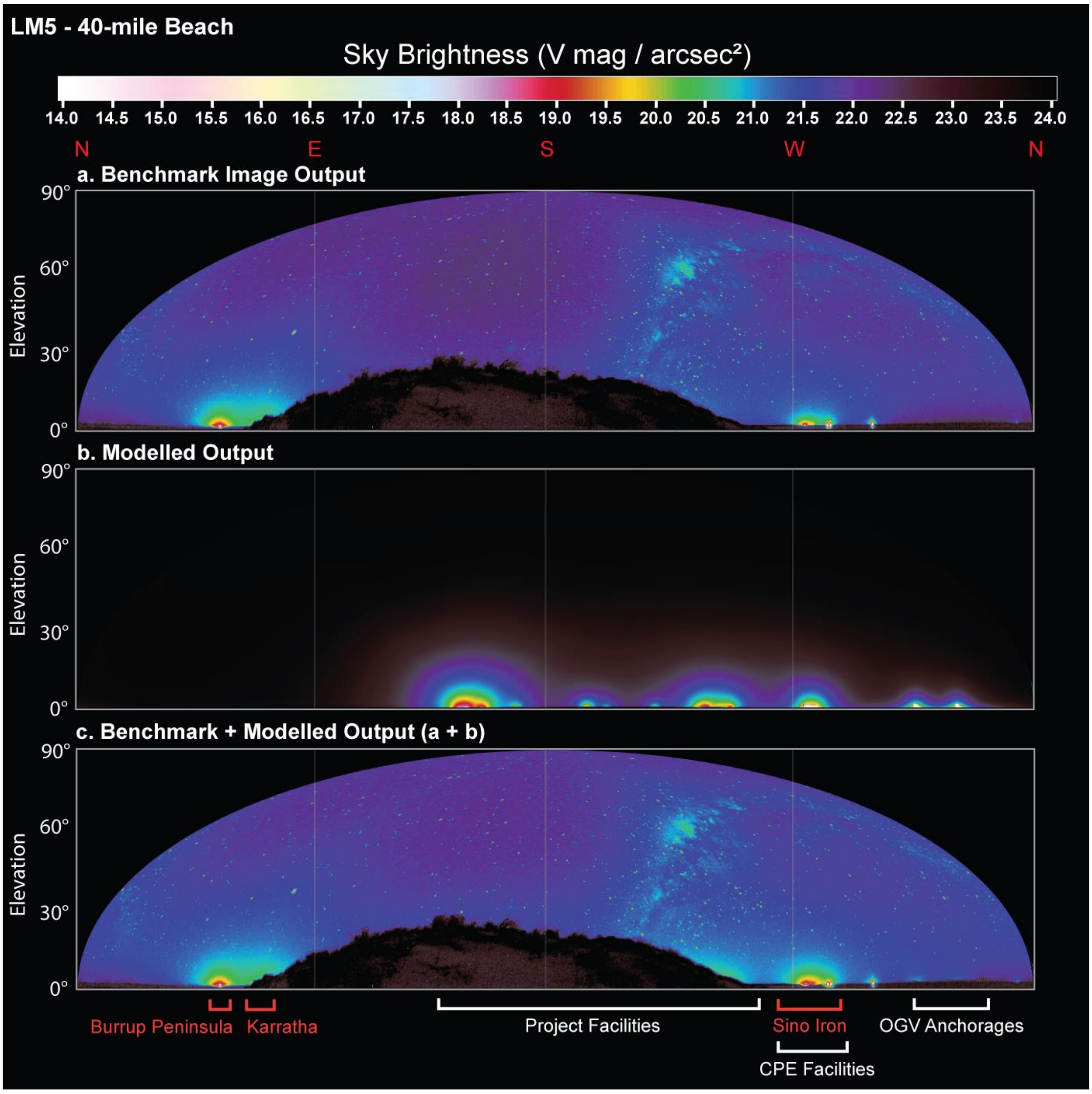

Figure 8: Artificial light modelling results for LM5 (40-Mile Beach): a. Benchmark all-sky processed image recorded during the light survey; b. Modelled brightness based on light design provided by Leichhardt; c. Benchmark monitoring image + modelled brightness. Red labels = existing light sources, white labels = new light sources associated with the Project.

4 CONCLUSION

Artificial light monitoring in the vicinity of the proposed Eramurra Project undertaken in June 2022 identified several existing light sources visible from monitored beaches, including the Citic Pacific Sino Iron facility and associated vessels, industrial lighting on the Burrup Peninsula, and the Karratha townsite. These sources were included in light modelling undertaken by PENV to provide a cumulative understanding of light emissions following the addition of Project lighting associated with the Eramurra Solar Salt Project, and CPE facility lighting (including OGVs and TSVs).

Light modelling of Project facilities predicts that the greatest change in brightness will occur at the beach directly adjacent to CPE (LM1). The topography at this location provides minimal natural shielding of both direct light and sky glow from the port facilities, and the Project facilities and OGVs are also visible as sources of sky glow on the horizon. Sites at South West Regnard Island will also experience a notable increase in brightness, but to a lesser degree than LM1. At the northern end of South West Regnard Island (LM2) the increase in brightness is primarily due to the OGV anchorages, which are visible as direct and unshielded sources of light from the beach. On the eastern beach of South West Regnard Island (LM3), the increase in brightness is attributed to sky glow from the Project and CPE facilities. At sites situated further from the Project, such as North East Regnard Island and 40-Mile Beach, the cumulative change in brightness resulting from Project lighting will be minimal.

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Appendix A: Eramurra Solar Salt Project Lighting Inventory

Table A1: Landside Project Facilities Lighting Inventory

Light Location	Light Type	Power (lm)	Number	Height (m)
Operations building	5000K LED	6325	10	2.5
Workshop	5000K LED	6325	10	5
Wet salt inload hopper	2200K LED	13140	8	9
Wash plant	2200K LED	13140	20	9
Salt stockpiles stacker	Red Light	6000	1	29
Salt stockpiles stacker delivery	2200K LED	13140	6	26
Salt stockpile dozer	6000K LED	6000	4	29
Salt loading FEL	6000K LED	6000	4	4
Salt truck	6000K LED	6000	4	1
Salt truck loading area	HPS	30000	8	9
Power station	4000K LED	19685	8	10
Harvester 1	6000K LED	13140	2	2
Harvester 1	2200K LED	6000	4	11
Harvester 2	6000K LED	13140	2	2
Harvester 2	2200K LED	6000	4	11
Wet salt haulage trucks	6000K LED	6000	4	2

Table A2: Port Facilities Lighting Inventory

Light Location	Light Type	Power (lm)	Number	Height (m)
Operations building	5000k LED	5500	8	2.5
TSV workshop/logistics building	5000k LED	5500	8	5
LEIC workshop	5000k LED	5500	8	5
PPA building	5000k LED	5500	8	2.5
MSIC barrier lighting	5000k LED	5500	8	4
Port power station	2200K LED	13140	4	3
Product salt inload hopper	2200K LED	13140	8	4
Port landside conveyors and outload hopper	2200K LED	13140	12	11
Salt stockpile stacker	Red Light	6000	1	27
Salt stockpiles stacker delivery	2200K LED	13140	6	19
Salt stockpile dozer	6000K LED	10000	4	14
Salt truck	6000K LED	6000	4	1
Jetty head apron	2200K LED	13140	12	10
Conveyor walkway lighting and shiploader	2200K LED	13140	8	6
Shiploader boom	Red Light	6000	1	10
Outload jetty 1	Amber LED	6000	60	1
Pump station (intake)	2200K LED	13140	10	3
Pump station PSC1	2200K LED	13140	4	4.5
Pump station PSE1	2200K LED	13140	4	4.5
Pump station PSE3	2200K LED	13140	4	2.5
Pump station PSE5	2200K LED	13140	4	2.5
Pump station PSR1	2200K LED	13140	4	4.5
Pump station PSW1	2200K LED	13140	4	4.5
Pump station PSW4	2200K LED	13140	4	4.5
Pump station PSW5	2200K LED	13140	4	2.5
Pump station PSW7	2200K LED	13140	4	2.5
Pump station PSW8	2200K LED	13140	4	1.5
Pump station PSW9	2200K LED	13140	4	1.5

Table A4: OGV Lighting Inventory

Light Description	Light Type	Power (lm)	Number	Height (m)
Deck lighting	3500K LED	4800	4	20
Deck lighting	3500K LED	4800	3	25
Deck lighting	3500K LED	4800	5	30
Deck lighting	3500K LED	8500	1	30
Floodlights	3500K LED	23000	2	30
Walkway lighting	4000k LED	960	19	25
Walkway lighting	Fluorescent	4000	42	20
Floodlights	HPS	47000	12	20
Floodlights	HPS	47000	4	30

Table A3: TSV Lighting Inventory

Light Description	Light Type	Power (lm)	Number	Height (m)
Deck lighting	4000K LED	12151	2	6
Walkway lighting	4000K LED	4876	12	3
Floodlight	5000K LED	27000	21	12

Appendix B: Relative Contribution of Light Sources

Table B1: Relative contribution of CPE and Project light sources to horizon sky brightness from each monitoring site. * = Estimated values

Location	Horizon Brightness (60 – 90°)					Is light from the Project facilities directly visible from nesting habitat?	Is light from the Project facilities visible as sky glow from nesting habitat?
	Benchmark (Vmag/arcsec^2)	Benchmark + CPE* (Vmag/arcsec^2)	Change from benchmark due to addition of CPE	Benchmark + CPE + Project (Vmag/arcsec^2)	Change from benchmark + CPE due to addition of the Project		
LM1	20.52	19.01	+ 302%	18.94	+ 6%	Yes	Yes
LM2	20.98	20.05	+ 135%	20.03	+ 1%	No	Yes
LM3	20.85	20.6	+ 25%	20.52	+ 7%	Yes	Yes
LM4	21.09	21.02	+ 7%	20.91	+ 11%	Yes	Yes
LM5	21.26	21.17	+ 8%	21.08	+ 9%	No	Yes

Note the following limitations apply to the above table:

1. Results for the Benchmark + CPE scenario have been estimated from the Benchmark + CPE + Project scenario (i.e. predicted cumulative emissions). The Benchmark + CPE scenario has not been modelled as a separate scenario at this time.