APPENDIX 9

ARROW LNG PLANT

Marine Ecology (Turtles) Technical Study - Curtis Island Baseline Light Monitoring 2012

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ARROW LNG PLANT

Marine Ecology (Turtles) Technical Study

CURTIS ISLAND BASELINE LIGHT MONITORING 2012

Prepared by

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For

Coffey Environments Australia Pty Ltd

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SUMMARY

Coffey Environments, on behalf of Arrow CSG (Australia) Pty Ltd (hereafter referred to as Arrow Energy), has engaged Pendoley Environmental to conduct an assessment on the potential impact of light emitted from the proposed Arrow LNG Plant ('the project') as a whole and particularly the plant flare stack on the nearby marine turtle rookeries at Curtis and Facing Islands.

The literature notes a number of cues used by hatchlings in sea-finding. These include but are not limited to: Beach slope; vision; light wavelength; light intensity; beach silhouettes; light directivity; trapping effect of light; moonlight, and; clouds. This information is critical to any impact assessment on Curtis and Facing Island hatchling emergences.

The literature on mature marine turtles suggest they use a range of orientation cues including a magnetic compass, wind borne odours, visual landmarks, aquatic chemical cues and solar or celestial navigation. Studies to date indicate that artificial night lighting on or near sea turtle nesting beaches may disrupt the nesting behaviour of females and on Floridian beaches exposed to urban lighting shielded by tall buildings or tall trees, nest placement was positively correlated with object elevation.

The current night time sky light visibility was surveyed at two sites on Facing Island (Settlement Beach and North Beach) and two on Curtis Island (Southend and Connor Bluff). Data was obtained using a novel technique developed for monitoring light emissions in remote settings. The methodology provides quantitative data that will facilitate management of the short- and long-term construction and operational lighting effects that may disorient marine turtles.

The results show that all four nesting beach sites were exposed to varying levels of sky glow from existing urban (Gladstone city, Tannum Sands) and industrial (Auckland Point Wharves, Barney Point Wharves and Coal Terminal, RG Tanna Coal Terminal, Boyne Smelter, Queensland Alumina) sources.

Once built, any artificial light used in the Arrow LNG Plant will, if not managed appropriately, emit glow into the sky that could be visible to marine turtles on Curtis and Facing Island nesting beaches. This includes all white (halogen, fluorescent, metal halide and LED) and orange (High Pressure Sodium and Low Pressure Sodium) light types. The level of glow visibility will vary along the length of the east coast beaches, depending on: how the lights are managed; the Wattage of the light fixture (intensity) and; a range of environmental factors.

One environmental factor is cloud cover, which can reflect artificial light back onto the beach. The level of reflected light will depend on the height of the cloud as high cloud illuminates the beach less than low cloud. On a clear night with no moon, the visibility of artificial light to marine turtles will be substantially greater than nights with a partial or full moon which provides natural illumination of the sky and reduces the relative visibility of artificial lights. Additionally, the visibility of light in the sky is directly correlated to the level of aerosols in the atmosphere (e.g., dust and salt spray) which reflects light back to the eye. Consequently, a high level of aerosols will increase the amount of sky glow visible.

Marine turtles utilising the section of beach close to the Southend settlement on Curtis Island and North Beach on Facing Island potentially have a direct line of sight to the Arrow LNG plant flare. The visibility of the flare itself will depend on dune and onshore topography between the beach and the

flare. Turtles on other sections of nesting beach, both adults and hatchlings, are unlikely to have direct visual contact with the flare itself as they will be shielded from the flame by the supratidal dune system, vegetation and hills. The flare will however produce a highly visible glow in the sky, particularly when it reflects off elevated atmospheric aerosols and clouds and this will be visible to turtles from all nesting sites on Facing and Curtis Island. The degree of visibility will vary depending on environmental factors discussed above.

The predicted impact of LNG plant light from the current regional industrial and urban sources, plus any incremental light glow from the project on hatchlings at each of the four survey sites, is summarised in the table below. Hatchlings from nests in front of tall dunes are likely to orient seaward as they move away from the tall dark horizon, while hatchlings exposed to light along the low horizon of a flat beach are likely to be misoriented and take a more circuitous route to the ocean. Biological orientation studies on the sea-finding behaviour of hatchlings on Curtis and Facing Islands beaches is recommended to either confirm or disprove this analysis. Furthermore a study of the dune elevation and topography along the beach could prove useful for predicting areas where hatchlings might be at greatest risk of misorientation. This study would also identify areas that may benefit from tree planting to enhance the horizon elevation.

Summary of the potential impacts of light on marine turtle hatchlings on Curtis and Facing Islands

Island	Beach/site	Land horizon or topography	Light source	Predicted hatchling behaviour
Curtis Island	Connor Bluff	Elevated horizon; tall primary dunes and vegetation	Gladstone area* glow behind tall dunes	Orient seaward away from tall dark horizon (dunes and trees)
				Orient along beach towards low horizon, light visible through breaks in the dunes
		Low horizon elevation ; flat looking south along beach	Southend settlement	Small point source lights similar in appearance to star, hatchlings very unlikely to be impacted by this light source
	Southend	Low horizon elevation; small primary dunes	Gladstone area* glow behind low primary dunes	May orient along beach or inland towards light glow low on their visual horizon. Response will depend on environmental conditions of moon phase and cloud cover and/or colour and spatial extent of glow along the horizon. The consequence of spending additional time in sea-finding is an increased risk of predation, dehydration and reduced fitness through consumption of energy reserves
		Low horizon elevation; flat looking south along beach	Southend settlement	Point source lights similar in appearance to stars, hatchlings unlikely to be impacted by this light source
Facing Island	Settlement Beach	Tall hills	Gladstone area* glow behind tall inland hills	Orient seaward away from tall dark horizon (hills and trees)
		Headland	Boyne Smelter	Orient towards smelter glow around headland at south west end of beach
	North Beach	Moderately tall dunes	Gladstone area* glow behind dunes	Orient along the beach or inland towards light glow low on their visual horizon, especially hatchlings further along the beach. Response will depend on environmental conditions of moon phase and cloud cover and/or colour and spatial extent of glow along the horizon. The consequence of spending additional time in sea-finding is an increased risk of predation, dehydration and reduced fitness through consumption of energy reserves
		Seaward	Large number of vessels moored offshore	Vessel lights may assist hatchlings to orient seaward, potential for entrapment in light spill around vessels
Curtis and Facing Island	All	Landward from the sea	Onshore	Hatchlings that have successfully reached the ocean may swim or be swept along the shore and crawl back onto land towards the inland light and glow. This is likely to occur in situations where hatchlings are unable to swim directly offshore and remain close to the beach as they attempt to swim offshore

*Includes lights from city, urban area, Auckland Point Wharves, Barney Point Wharf and Coal Terminal, Queensland Alumina and RG Tanna Coal Terminal.

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1 INTRODUCTION

1.1 Background

The Arrow LNG Plant is located within the Great Barrier Reef World Heritage Area (GBRWHA) and adjacent to the Great Barrier Reef Marine Park (GBRMP). The GBRMP extends around the Port of Gladstone, which encompasses Port Curtis and part of The Narrows (the narrow waterway between Curtis Island and the mainland).

Port Curtis is included in the list of nationally important wetlands in Queensland and areas in and around Port Curtis provide important habitat for a range of species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) and IUCN red list of threatened species (IUCN, 2010).

The marine and estuarine ecology impact assessment found marine turtles, listed as vulnerable or endangered under the EPBC Act, in waters of Port Curtis and along the east coast of Curtis Island, Facing Island and the mainland south of Port Curtis. Figure 1 shows the location of known turtle nesting sites along the east coast of Curtis Island, Facing Island and the mainland, and the number of females returning annually to each site. Port Curtis and its surrounding waters support 6 of the 7 known species of marine turtles in the world. The four marine turtle species most commonly found in and adjacent to the project area are:

- Flatback turtle (*Natator depressus*) - EPBC Act listed as 'Vulnerable'.
- Green turtle (*Chelonia mydas*) - EPBC Act listed as 'Vulnerable'.
- Hawksbill turtle (*Eretmochelys imbricata*) – EPBC Act listed as 'Vulnerable'
- Loggerhead turtle (*Caretta caretta*) - EPBC Act listed as 'Endangered

Flatback turtles are the most common species recorded nesting on Curtis and Facing Islands with rookery sizes ranging from 10–100 nesting females per year at Settlement Bay, Facing Island Eastern Beach, Pearl Ledge East Point and Pearl Ledge North Point and peaking at 100–500 per year at North Beach, Facing Island. Flatback numbers range form 10–100 per year on the beach adjacent to Connor Bluff on the north end of Southend Beach, Curtis Island (Figure 1). Green turtles have been recorded nesting on the south end of Southend Beach on Curtis Island in low numbers (Figure 1). Flatback turtles nest in the southern GBRWHA nest between early November and late January, peaking in late November and early December. Hatchlings emerge in early December through to late March with a peak in February. Green turtles nest December through January and hatchlings emerge in February and March. Very few hawksbill and loggerhead turtle species nest within the study area.

Impacts of light on marine turtle hatchlings and on nesting juveniles and adults are presented in Section 1.4.2. Potential impacts to marine turtles recognised in the environmental impact statement (EIS) relating to the proposed project, and the associated flare stack, on Curtis Island (Coffey Environments, 2012) include:

- Loss and disturbance of marine and estuarine habitat from project infrastructure.
- Injury or mortality from shipping activity or accidents, including boat strike.
- Displacement or mortality from the effects of underwater noise and lighting.

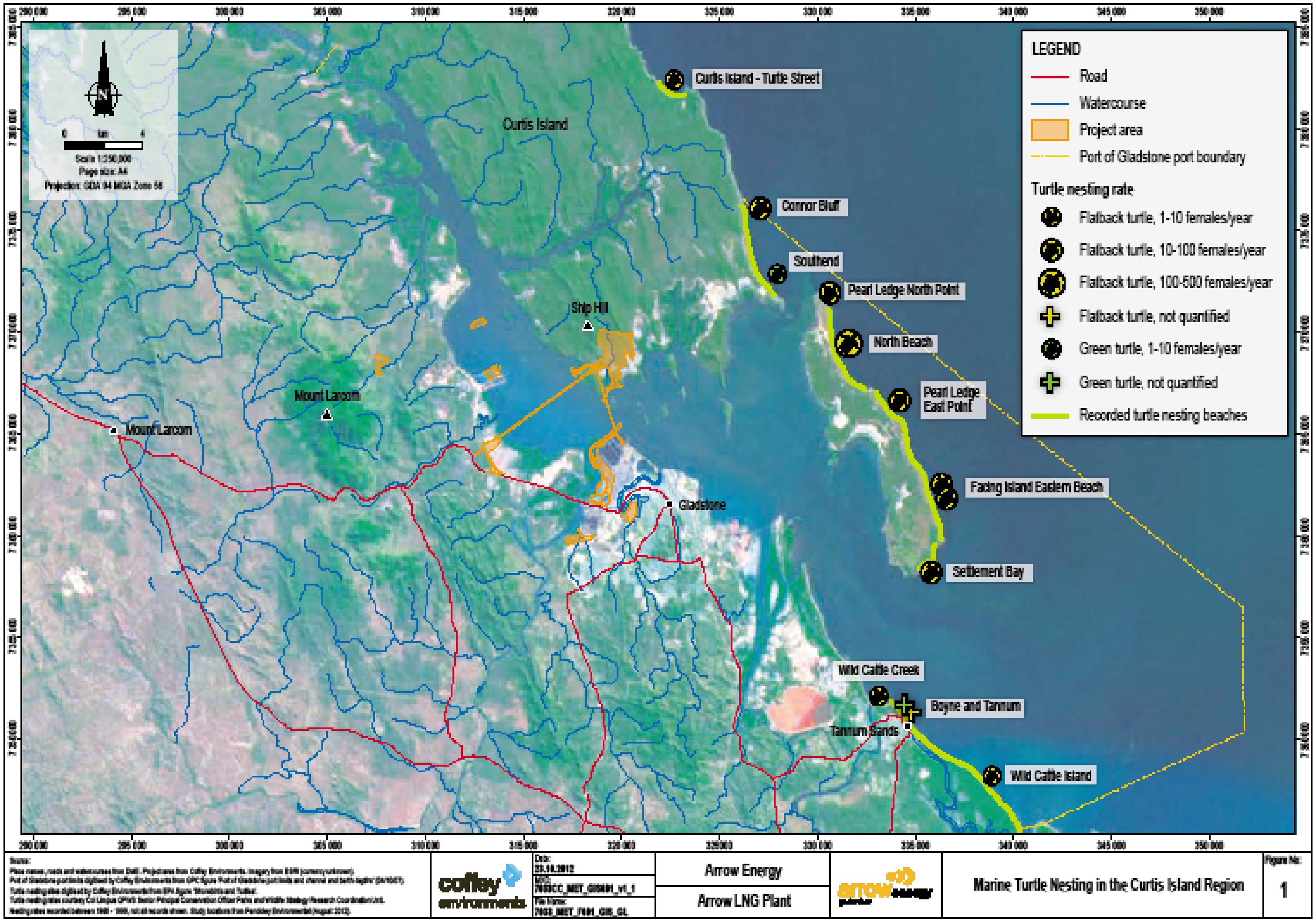


Figure 1: Marine Turtle Nesting in the Curtis Island Region (Source: Chapter 19, Coffey Environments, 2012)

1.2 Work completed to date

The Arrow LNG Plant, marine facility (e.g., MOF and LNG jetty and mainland launch site) lighting and particularly lighting from the flare were identified during the impact assessment process as potential impacts on marine turtles. Further investigation was therefore required to verify the adequacy of management measures proposed to protect turtles from the effects of lighting. Table 1 lists the management measures presented in the EIS (Coffey Environments, 2012).

Table 1: Proposed Management Measures for Lighting to Protect Marine Turtles

Implement measures to reduce the impacts of light from the LNG Arrow Plant and ancillary facilities including	
No.	**Commitment**
C17.16	Shield/direct the light source onto work areas where practical
C17.17	Use long-wavelength lights, where practical, including use of red, orange or yellow lights
C17.18	Lower the height of the light sources as far as practical
C17.19	Avoid routine planned maintenance flaring at night during sensitive turtle-reproductive periods (where practical)

The EIS recognised that lighting from the LNG and marine facilities would contribute to the numerous light sources in and around Port Curtis, particularly the Port of Gladstone facilities on the mainland and the other LNG plants being constructed on Curtis Island. This report also acknowledged the potential visibility of the flare and associated glow, including turtle nesting beaches north of Southend on the east coast of Curtis Island and on the beaches at the northern end of Facing Island. Based on Shell's international experience, Arrow Energy has proposed commitment C17.19 (Table 1) to manage potential impacts on turtles coming ashore to nest and in particular, when the hatchlings emerge and go to sea.

This Marine Ecology (Turtle) Technical Study determines the effectiveness of commitment C17.19 in managing potential impacts on marine turtles utilising the beaches north of Southend and on the northern end of Facing Island in addition to other commitments in reducing potential impacts on turtles from LNG Plant and marine facility lighting.

Coffey Environments, on behalf of Arrow Energy, requested Subject Matter Experts (SME) from Pendoley Environmental to conduct a Marine Ecology (Turtles) Technical Study, presented here, of the potential for light from the proposed project, and the associated flare stack, on Curtis Island to impact on nearby marine turtle rookeries at Curtis and Facing Islands.

Two technical studies, completed for the Arrow LNG Plant EIS (Coffey Environments, 2012), are relevant to, and inform, this Marine Ecology (Turtles) Technical Study: the Marine and Estuarine Ecology Impact Assessment (EIS Appendix 12, Coffey Environments 2011); and the Landscape and Visual Impact Assessment (EIS Appendix 17, AECOM, 2011). The main outcomes of both studies are presented in the Arrow LNG Plant EIS 2012 in Chapter 19 (Marine and Estuarine Ecology) and Chapter 23 (Landscape and Visual Amenity). A Literature Review, the results of a dedicated Baseline Light Study at Curtis Island, and specialist in-house turtle expertise were also used to inform the Marine Ecology (Turtles) Technical Study, presented here.

The Lighting Baseline Assessment (Coffey Environments 2012, Chapter 23, Section 23.3.4) findings pertinent to this marine turtle impact assessment are summarised in Table 2.

Table 2: Regional baseline light sources in the Port Curtis region, where 'level' refers to elevation and not intensity (extracted from Section 23.3.4, Coffey 2012)

Source	"White" lights[1]	"Orange"[2] and other[3] lights
RG Tanna Coal Terminal	White flood-type lighting Large scale, elevated	Orange street lighting Low level
Auckland Point Wharves	Bright white lighting Low level	
Barney Point Wharf and Coal Terminal	Bright white lighting Low level	
Queensland Alumina Limited Plant		Orange street lighting Numerous low level scattered
NRG Power Station		Orange street lighting Low level Red navigation lights on cooling tower
Rio Tinto Yarwun Alumina Refinery		Orange street lighting Numerous low level scattered
Clinker Wharf and Cement Australia at Fisherman's Landing		Orange street lighting Numerous scattered, illuminated wharf cranes
Gladstone shipping channel		Red, green, blue, navigation lights and white channel shipping lights[3] Intermittent blue red and white flashing navigation lights
Gladstone CBD	White urban lighting Throughout	Orange street lighting Throughout
Southend Curtis Island	White urban lighting Incidental	
Islands	White urban lighting Incidental	

Pendoley Environmental Notes on Arrow LNG Plant EIS Light Types; [1] "white" industrial lights typically include halogen, metal halide and fluorescent, [2] "orange" lights are High Pressure Sodium, [3] "navigation" lights are typically filtered unfiltered incandescent lamps (white) or filtered incandescent lamps (red and green, these inefficient light sources are being phased out in favour of coloured LED lights.

1.3 Project Description Changes

The elevated flare is a 115-m-high lattice structure housing several flare stacks (pipes). The flare will be used during start-up, shut-down, upset conditions and emergency conditions of the LNG plant to safely vent inventory in the LNG trains and associated process units. The original design has been revised with the flare now comprising four flare stacks instead of five for the ultimate four train development. The flare comprises a warm wet flare stack, two cold dry stream flare stacks and a flare stack for LNG storage and loading relief. The flare will be gas-assisted during turndown operations to suppress smoke generation.

There will be no continuous flaring. Scheduled routine maintenance on elements of the LNG plant (not requiring full plant shutdown) may be conducted whilst the plant is operational (e.g., the maintenance on one of the two main refrigerant compressor string in the train) and this can be done without flaring. Flaring will be triggered by unscheduled plant upsets occurring as a result of equipment malfunction and/or process upset (excursion outside the normal operating envelope) and/or an emergency e.g., a gas leak. Scheduled shutdowns will also require flaring.

Up to 20 plant upsets are anticipated each year during operations, with four of these upsets assumed to result in flaring. Under plant upset conditions, the affected part of the plant will be automatically or manually isolated, minimising the amount of gas that needs to be flared to approximately 20% of the capacity of the affected LNG train. Flaring under upset conditions is estimated to continue for up to two hours duration.

Each of the four LNG trains will be taken out of service for a shutdown once every eighteen months. Intermittent flaring will occur over approximately a two day period in preparation for a shutdown and intermittent flaring will occur again for approximately three days at start up. Scheduled shutdowns (where possible) will be planned during the southern hemisphere winter months to align with the period of lowest global demand for LNG.

In summary, scheduled flaring can be controlled and will be addressed in the proposed flaring strategy (the product of commitment C17.19, Table 1), which aims to avoid scheduled flaring during the turtle nesting season. Unscheduled flaring may occur at any time as the LNG plant's safety systems activate to protect the facility and workers from the consequences of trips and emergency events.

1.4 Literature Review

1.4.1 Measuring Light

Published quantitative literature on light pollution and methods for its measurement is limited. While astronomers recognised this as a potential impediment to observations of the night sky as early as the 1960s (Walker, 1970; Reigel, 1973; Cinzano, 2000), only a few methods have since been developed. Published methods, used with varying success, include: direct visual observations (Berry 1976, Moore, 2001); computer modelling (Pike 1976); ground based spectrophotometry (Cinzano, 2004); aerial based hyperspectral sensors (Barducci *et al,.* 2006); image resolution device (Kranicz *et. al,.* 2008); stellar photometer and telescope (Clark, 1999); and hand held Sky Quality Meter in conjunction with a Digital Single Lens Reflex Photography (Kollath, 2010). Also, Chalkias *et al.* (2006) described a detailed model that mapped the sky glow dome around Athens, Greece. However, they noted that their methodology was time consuming and iterative as well as demanding a large amount of computational power. Despite this research, there are currently no standardised methods for measuring light pollution (Narisada and Schreuder, 2004). Commonly-used methods focus almost exclusively on site selection for telescopes or spot meter monitoring for light spill beyond a fixed boundary.

None of the methods outlined above have been shown to meet the range of criteria required for routine wildlife biology monitoring. These fundamental requirements are: rapid and reliable target-specific light sources or sky regions; functional operation within a remote field setting; quantification of light within identifiable regions of the visible spectrum; detection of very low light levels such as sky glow from distant sources; the generation of an output that can be rapidly processed using standard computer equipment; and software that will provide data in an easily understood format. A promising new instrumental method based around Charge Coupled Device (CCD) technology has emerged in recent years (Duriscoe *et. al*., 2007; Rabaza *et. al,*. 2010). It is this technology on which the Sky Cam Light Monitoring program is based.

The short wavelength (blue) region of the spectrum was targeted for the Sky Cam Light Monitoring program for two reasons. First, because turtles are highly sensitive to short wavelength light (Pendoley, 2005) and second, this region of the spectrum is poorly quantified by commercial light measuring instruments (Pendoley, 2010). When measuring light in the night sky, the natural moon phase is a major source of light variability. As such, observations used for data processing are taken during the new moon phase so as to avoid ambient light generated by a full moon (Moore, 2001; Chalkias *et. al.,* 2006). Other factors affecting the amount of direct and scattered light visible in the sky at any particular point in time include the presence of clouds, pollutants, airborne particulates and humidity (Moore, 2001; Mizon, 2002).

1.4.2 Impact of Light on Hatchling Marine Turtles

1.4.2.1 Hatchling Orientation under Natural Light Conditions

Hatchlings emerging from the nest immediately crawl towards the sea. While the bulk of hatchlings emerge at night, when the sand temperature drops below daytime highs, it is not uncommon for emergences during the day time following rain storms or in the cool hours of the mornings or afternoons (Lohmann *et al.*, 1996). The sea-finding ability of hatchlings is maintained regardless of the time of day, the weather conditions, or the location of the nest relative to the ocean (Mrosovsky, 1972).

The sea-finding process is directed by several cues further discussed within this section (Table 3); light brightness, shape and form of the beach environment and, to a lesser extent, beach slope (Lohmann *et al.*, 1996; Tuxbury and Salmon, 2005). Hatchlings crawl away from the dimmer landward horizon, toward the brighter seaward horizon (Mrosovsky and Carr, 1967; Tuxbury and Salmon, 2005). They also crawl away from the higher dune towards the lower seaward horizon (Limpus, 1971; Salmon *et al.*, 1992; Van Rhijn and Van Gorkom, 1983; Witherington, 1992a). Beach slope is considered a secondary cue relative to vision and is not addressed any further here (Lohmann *et al.*, 1996; Salmon *et al.*, 1992).

Table 3: Summary of cues used by marine turtle hatchlings during sea-finding following their emergence from the nest.

Cue	Behavioural observations
Beach slope	Beach slope (geotaxis) is not considered a major cue in sea finding
Vision	Hatchlings use visual cues to find the ocean
Light wavelength	Short wavelength light is highly attractive to hatchlings Long wavelength light is *relatively* less attractive to hatchlings
Light intensity	High intensity light is more attractive than low intensity light High intensity *long* wavelength light may be more attractive than low intensity *short* wavelength light
Beach silhouettes (Shape and form)	Hatchlings move away from tall dark vegetated horizons and they move towards low light flat horizons
Light directivity	Hatchlings integrate light over a broad area (~180°). They often ignore bright point sources of light Broad sky glow is more attractive than a single bright point source of light
Trapping effect of light	Hatchlings that enter a bright pool of light may be trapped within the spill of light and are unable to crawl away from the light spill area
Moon light	Bright moonlight may override the effects of artificial light
Clouds	Artificial light reflected off clouds creates a broad area of sky glow that may be attractive to hatchlings

The response of hatchlings of *Natator depressus* (flatback*), Eretmochelys imbricata* (hawksbill) and *Chelonia mydas* (green) was tested under controlled light conditions in Western Australia (WA) (Pendoley, 2005) and found similar behavioural responses to green, hawksbill and olive ridley hatchlings tested in Florida (Witherington, 1992). While the WA sample sizes were small the results of choice experiments involving two colours (blue and green), suggested green and hawksbill turtle hatchlings select the shorter wavelength (blue) over the long wavelength light (green) more frequently. Flatback hatchlings responded differently and did not show a strong ability to discriminate between wavelengths in the blue to green range. However, when offered a choice between green and longer wavelengths in the yellow-red range, green light was selected more often.

Sensitivity to the direction of light has also been proposed as an orientation factor when hatchlings are required to integrate the effects of celestial light sources during sea-finding (Lohmann *et al.*, 1996). Since the sun or moon may rise behind the dunes on some nesting beaches, hatchlings attracted to these point sources of light would fail to reach the ocean. Hatchlings orientate themselves by integrating light across a horizontally broad (180° for green, olive ridley and loggerhead turtles) and vertically narrow (a "few degrees" for green and olive ridleys, and 10° - 30° for loggerheads) "cone of acceptance" (Lohmann *et al.*, 1996; Mrosovsky, 1978b). This integration ensures that irradiance (light reaching a hatchling) has greater importance than radiance (light emanating from a light source). Figure 2 demonstrates the difference in visibility between a bright point source of light (less attractive to a hatchling) and a broad area of horizon glow (most attractive to a hatchling).

Figure 2: The top image shows the similarities between single point sources of light (along the horizon) and stars (upper half of image). The bottom image shows what a broad area horizon glow may look like from the beach. Images were made looking south from Settlement Beach on Facing Island (top) and looking west from Southend towards Gladstone.

Form or shape vision studies have shown that loggerhead and green turtle hatchlings also respond to shape cues during sea-finding (Limpus, 1971; Salmon *et al.*, 1992). Hatchlings crawl away from a higher vegetated dune silhouette and toward the lower and flatter horizon over the ocean (Mrosovsky and Shettleworth, 1968; Salmon *et al.*, 1992; Van Rhijn and Van Gorkom, 1983). On a natural beach this behaviour would direct the hatchlings away from dunes and vegetation and towards the more open horizon over the ocean.

The relative importance of shape and silhouette in sea-finding may vary relative to the lunar cycle. The high levels of ambient light during the full moon illuminate the sky completely, so that the horizon over the ocean may not be the brightest. In this case hatchlings may rely more heavily on shape and silhouette cues to find the ocean. The literature suggests that horizon elevation is the most important cue in hatchling sea-finding. Undulating landform has not been studied specifically however hatchlings probably respond to tall trees and elevated dunes in the same way as any elevated horizon and orient awry from it. The elevated dark horizon is thought to be equally important as a lower light horizon as a sea-finding cue. The degree to which shape and form influence hatchling sea-finding is thought to be a graded response that corresponds with differing magnitudes of co-occurring visual stimuli (Tuxbury and Salmon, 2005). Artificial light is a competitive visual stimulus that hatchlings must integrate with the natural light intensity, wavelength, directivity, and horizon cues.

1.4.2.1 Hatchling Orientation under Artificial Light Conditions

The orientation or sea-finding ability of hatchlings can be affected by the presence of artificial lighting on beaches (Salmon, 2003; Tuxbury and Salmon, 2005; Verheijn, 1985; Witherington and Martin, 1996) and flares (Pendoley, 2000). Artificial lighting may adversely affect hatchling sea-finding behaviour in two ways; disorientation, where hatchlings crawl on circuitous paths; or misorientation, where they move landward, possibly attracted to artificial lights (Salmon, 2005; Witherington and Martin, 1996) The consequences of this disruption to sea-finding are mortality resulting from increased exposure to predation, dehydration and exhaustion (Salmon, 2005; Witherington and Martin, 1996).

Tuxbury and Salmon (2005) investigated the competitive interactions between artificial lighting and natural cues during sea-finding. They postulate disorientation will occur when artificial lighting and natural cues are perceived as similar in relative magnitude. For example, the impact of artificial light on hatchling sea-finding is often reduced by the presence of light from a full moon and enhanced in the absence of a full moon. Field experiments appear to support this model (Pendoley, 2000; Salmon and Witherington, 1995; Tuxbury and Salmon, 2005). Tuxbury and Salmon (2005) conclude that protection of nesting beaches may be enhanced by combining light management with increasing dune silhouette darkness and/or elevation.

A range of commercial light types have been tested with marine turtle hatchlings to determine which lights are least disruptive to hatchling sea-finding (Tuxbury, 2001; Witherington, 1991; Witherington and Martin, 1996). Lights emitting large proportions of short wavelength light (e.g. metal halide, halogen, fluorescent, mercury vapour) are not recommended while low pressure sodium vapour is the most highly recommended. High pressure sodium (HPS) vapour is an acceptable alternative after low pressure sodium (LPS) light. This recommendation is based on studies that show that both green and loggerhead turtles are only weakly attracted to yellow LPS and has therefore been suggested as a good lighting alternative for green turtle nesting beaches (Witherington and Bjorndal, 1991a, b; Witherington and Martin, 1996).

The empirical finding that yellow light causes an aversion response (loggerhead turtle experiments), or only a weak attraction (green turtle experiments), in hatchlings has been explored further as a management tool. The majority of light experiments to date have used yellow LPS lights, as they are the only lights commercially available that completely exclude the blue spectral bands. They are monochromatic, emitting only yellow wavelengths (580-590 nm), which is the wavelength range noted for causing an aversion response in loggerhead hatchlings (Witherington, 1989; Witherington and Bjorndal, 1991a). Fluorescent-based yellow bug lights have also been tested and, although they emit small amounts of the shorter (blue) wavelengths, they primarily emit the longer wavelengths, and so also tend not to attract hatchlings (Dickerson and Nelson, 1988; Witherington, 1989, 1991).

Field experiments with flatback turtle hatchlings investigating the effect of unshielded lights, glow, and light elevation have been carried out as part of the Gorgon project. The study results showed that under field conditions flatback hatchlings were attracted to unshielded 250 watt (W) high pressure sodium vapour, metal halide and fluorescent lights over a distance of ~200 m (Pendoley, 2005a). Follow-up experiments in 2006 and 2007 investigated the effect of artificial light glow on flatback hatchlings (Pendoley-Environmental, 2007; Pendoley, 2006). These results showed that flatback hatchling orientation is influenced by the glow from commercial luminaires (high pressure sodium vapour, metal halide and fluorescent) when they are situated low on the horizon relative to a hatchling. Misorientation was also related to light intensity. Hatchlings that were exposed to 500 W high pressure sodium vapour oriented in a more seaward direction. Those exposed to 1000W and 1300W of the same luminaire type and all intensities of fluorescent and metal halide sources did not (Pendoley-Environmental, 2007).

The 2007 study also investigated the response of flatback hatchlings to horizon elevation. When light glow was elevated to 12° behind a tall dune the hatchlings appeared to ignore the light cues and responded by moving away from the tall dark horizon created by the dune. Trials with the light positioned low on the beach at an elevation of 1° caused hatchling orientation to be less significantly directed towards the ocean. The lack of a tall silhouette may have forced the hatchlings to rely on light cues alone, reducing their ability to find the ocean. These results confirm the findings of Limpus (1971) who investigated the influence of horizon topography on loggerhead hatchlings in Queensland. He noted that flatback and green hatchlings appear to behave the same way as the loggerheads during arena trials although he presented no data to support this comment.

The observed behaviour of the flatback hatchlings at Barrow Island also supported the findings of Salmon *et al.* (1992) who concluded green and loggerhead hatchlings primarily respond to light and silhouette stimuli at eye level with precedence being given to the silhouette cue. They also showed that when relative differences in light intensity are low hatchlings didn't show significant orientation to these light cues.

The potential for light to cause conflicting orientation cues in hatchling orientation on the beach and in the surf zone was explored by Lorne and Salmon (2007). They tested the effects of long (two hour) and short (two minute) light exposure to beach-based hatchlings on their subsequent ability to carry out successful orientation both on the beach and at sea. The presence of waves in nearshore waters was critical for successful offshore orientation. When waves were present all hatchlings swam offshore regardless of whether they had been able to locate the sea whilst under the influence of artificial light ashore. However, when waves were absent, the ability to swim offshore depended on the hatchlings completing a successful seaward orientation crawl. Hatchlings tested after a prolonged exposure to light were unable to locate the ocean and were only able to swim offshore if waves were present. Lorne and Salmon (2007) concluded that orientation toward artificial light sources compromised the ability of hatchlings to respond to natural orientation cues both on land and at sea.

1.4.3 Impact of Artificial Light on Nesting Juveniles and Adults

1.4.3.1 Onshore

Studies to date indicate that artificial night lighting on or near marine turtle nesting beaches may disrupt the nesting behaviour of females (Salmon, 2005; Salmon *et al.*, 1995). Nesting densities are typically lower at beaches exposed to artificial night light, although this may not be the only, or even primary cause (Salmon *et al.*, 1995). Furthermore, on beaches exposed to urban lighting shielded by tall buildings or tall trees, nest placement was positively correlated with object elevation. Higher density nesting occurred in the shadow of the buildings or trees than in the lit areas between the buildings or trees. To date there does not appear to be any available data determining whether choosing nest sites to avoid lighting affects reproductive success at the individual turtle level (Salmon, 2005). However, Witherington and Martin (1996) suggest that light-mediated variations in adult female turtle nesting behaviours, such as the location of beach emergence, nest construction, and whether (and at what stage) nesting is abandoned, may affect success of egg deposition, hatchling production and seaward return of adults.

Evidence for the deterrent effect of artificial light on adult female turtles emerging to nest has been summarised by Witherington and Martin (1996). Studies of green and loggerhead turtle nesting beaches in Florida suggest that the light from beach developments, roadways, and piers may have contributed to the decline in nesting effort in these areas. Limited empirical data are available on the impacts of light on adult emergence, however a study by Witherington (1992a) suggested that green and loggerhead female turtles nest in significantly lower numbers on beach sections exposed to mercury vapour light than on dark beach sections. In similar experiments with LPS vapour lights nesting turtles did not show the same tendency to avoid the illuminated sections of beach (Witherington, 1992a).

The only published experimental field study relating to the effect of lights on adult green marine turtles was conducted by Ehrenfild and Carr (1967) in Costa Rica. They concluded that adult green turtles use vision to find the ocean following nesting. Their experiments showed blind-folded adult green turtles found the ocean by chance only. Use of red and blue filtered glasses on the turtles also significantly reduced seaward orientation scores while animals wearing green and neutral density filters were able to find the ocean as well as control animals wearing clear glasses. They interpreted this result to mean that the adults displayed an 'apparent brightness preference related to retinal spectral sensitivity rather than true colour preference'. That is the adults were more influenced by the brightness of the light reaching their eyes than by the colour (or wavelength) of the light.

A second study investigating indirect light management techniques near loggerhead turtle nesting beaches in Florida found that light from filtered HPS street lights did not have a significant impact on the location or density of nests. There was also no observed difference in nesting patterns in beach sections exposed to filtered lighting versus sections of dark beach (Pennell, 2000; Salmon, 2005).

Despite the apparent evidence that nesting female marine turtles may be deterred from hauling out onto artificially lit beaches, the fact that many do nest along developed coastlines around the world suggests that, at least for some turtles, the urge to nest overrides any deterrent effect the artificial light may have. The apparent lack of an attraction to light is best demonstrated by the behaviour of female turtles following nesting. With very few exceptions (e.g. Witherington, 1992a), they return directly to the ocean after nesting and do not appear to be attracted to artificial lights on or near their nesting beaches. It is possible the relative importance of light as a cue for sea-finding is not as great in adults as it is in hatchlings.

1.4.3.2 Offshore

A review by Luschi *et al.* (2003) confirmed that little is known of the orientation mechanisms used by juvenile and adult turtles to navigate at sea, although it is recognised that they may differ substantially from those used by turtle hatchlings embarking on their first offshore migration (Avens and Lohmann, 2003). Mature marine turtles may use a range of orientation cues including a magnetic compass (Balazs, 1994; Luschi *et al.*, 1996), wind borne odours (Luschi *et al.*, 2001), visual landmarks (Luschi *et al.*, 1996), aquatic chemical cues (Grassman *et al.*, 1984) and solar or celestial navigation. Studies with juvenile loggerhead turtles have shown that they are able to use at least two directional cues (visual and magnetic) independently or simultaneously depending on the time of day or weather conditions (Avens and Lohmann, 2003).

None of the literature reviewed suggest light cues influence juvenile or adult migration movements while at sea, although this is likely to be a reflection of the difficulties in observing and testings these animals at sea, rather than direct knowledge. However a single study by the US Minerals Management Service (Kebodeaux, 1994) found that adult turtles observed near oil production platforms in the Gulf of Mexico were feeding on animals attracted to the platform lights. It is not clear from this report whether the turtles were attracted to the light or to the food source that was attracted to the light. Anecdotal information from the Harriet A oil production platform, located 6.5 km north east of Varanus Island, in Western Australia, indicates that flatback turtles are frequently observed around the Harriet A production platform during the day. This platform is the site of a gas flare and is not staffed at night (K Pendoley pers. obs.).

1.4.4 Key Findings from the Literature

Hatchlings

- *The natural sea-finding ability of hatchlings is maintained regardless of the time of day, the weather conditions or the location of the nest relative to the ocean.*
- *Brightness is recognised as an important cue for hatchlings as they attempt to orient toward the ocean as they crawl away from the dimmer landward horizon, toward the brighter seaward horizon.*
- *Brightness is a function of light intensity, wavelength and hatchling spectral sensitivity.*
- *Artificial lighting can affect hatchling sea-finding behaviour in two ways; disorientation, where hatchlings crawl on circuitous paths; or misorientation, where they move landward, possibly attracted to artificial lights.*
- *Flatback hatchlings were shown to be attracted to unshielded 250W high pressure sodium vapour, metal halide and fluorescent lights over a distance of ~ 200 m.*
- *It was also found that orientation toward artificial light sources offshore compromised the ability of hatchlings to respond to natural orientation cues both on land and at sea.*
- *Studies have concluded and recommended that in light management, low pressure sodium vapour lights be used over lights emitting large proportions of short wavelength (e.g. metal halide, halogen, fluorescent, mercury vapour).*
- *Although it has been shown that under certain conditions, filtered lighting may be attractive to green and loggerhead turtle hatchlings, it is still recognised as a useful management tool in situations where there were no other practicable options.*

Juvenile and Adult Turtles

- *Mature marine turtles may use a range of orientation cues including a magnetic compass, wind borne odours, visual landmarks, aquatic chemical cues and solar or celestial navigation.*
- *Studies to date indicate that artificial night lighting on or near marine turtle nesting beaches may disrupt the nesting behaviour of females.*

- *On beaches exposed to urban lighting shielded by tall buildings or tall trees, nest placement was positively correlated with object elevation.*
- *In Florida lighted beach developments, roadways, and piers may have contributed to the decline in nesting effort in these areas - green and loggerhead female turtles nest in significantly lower numbers on beach sections exposed to mercury vapour light than on dark beach sections but not with LPS vapour lights.*
- *Many turtles do nest along developed coastlines around the world suggesting that, at least for some turtles, the urge to nest overrides any deterrent effect the artificial light may have.*
- *After nesting females tend to return directly to the ocean and do not appear to be attracted to artificial lights on or near their nesting beaches. It is possible the relative importance of light as a cue for sea-finding is not as great in adults as it is in hatchlings.*
- *None of the literature reviewed suggest light cues influence juvenile or adult migration or movements while at sea. However a single study found that adult turtles observed near oil production platforms were feeding on animals attracted to the platform lights. It is not clear from this report whether the turtles were attracted to the light or to the food source that was attracted to the light.*

1.5 Objectives and Scope of Work

The objective of this work is to provide additional technical information to that contained in the Environmental Impact Statement (EIS) on surrounding project light impacts on marine turtles utilising Curtis and Facing Island. The brief describes the additional marine turtle information required by Arrow Energy to respond to submissions on the project released for public review on 16 April 2012. The brief for Marine Ecology (Turtles) Technical Study focussed on the effect of project lighting, specifically flaring, on marine turtles utilising Port Curtis and the beaches north of Southend and on Facing Island. The thirteen (13) specific questions raised within the brief to be addressed by this study are outlined in Table 4.

Table 4: Questions Addressed within this Report

Number	Question
1	Are marine turtle species found in Port Curtis and along the east coast of Curtis Island likely to be affected by project lighting?
2	What background lighting conditions exist at the turtle nesting sites north of Southend and at the northern end of Facing Island i.e., prior to any project development?
3	What specific intensity (luminosity) and wavelength/spectrum of light are the nominated marine turtle species most sensitive to? Do the light sources at the LNG Plant fit within the spectrum, wavelength and intensity of light to which the nominated marine turtle species are susceptible?
4	Will marine turtles utilising beaches north of Southend and on Facing Island have line of sight to the flare?
5	Will marine turtles utilising beaches north of Southend and on Facing Island have line of sight to the glow created by LNG Plant lighting?
6	The beaches north of Southend are backed by a high foredune and established (back) dune system that is vegetated. If turtles will not be in line of sight of project lighting, are turtles utilising the nesting sites north of Southend and on the northern end of Facing Island likely to be affected by project lighting?
7	What specific behaviour is affected by light – breeding, nesting or hatching?
8	What time of year is the most sensitive for the species which nest on the east coast of Curtis Island and Facing Island?
9	What are the potential risks to marine turtles if flaring occurs during the sensitive periods for the nominated species e.g., during hatching?
10	Are the management measures expressed as commitments adequate to address potential impacts on marine turtles?
11	Is additional mitigation required to address potential impacts on marine turtles?
12	How effective are the mitigation and management measures likely to be; specifically, will the proposed flaring strategy reduce impacts on the nominated marine turtle species?
13	Will there be any residual impacts to turtles following adoption of the mitigation and management measures and if so, how significant will they be?

This technical study will form part of the supplementary report to the EIS and the information provided within in it will assist in specifically addressing questions raised in submissions on the EIS. The project scope is therefore:

- Conduct a field survey of the current night time light visibility in the Gladstone region, using innovative light monitoring (Sky-42) technology. The fieldwork scope included the collection of light data from marine turtle nesting beaches at Curtis (on Southend and Connor Bluff beaches) and Facing Island (on Settlement Beach and North Beach) and will establish a "baseline" against which future light emissions associated with project activities can be measured;
- The results will identify the current sources of sky glow at the monitoring sites, quantify the area of sky exposed to this light and permit comparisons between locations and time.
- These data are to be used to address the questions listed in section 3.2.3 of the Turtle Brief (Table 4)

1.6 Acknowledgements

The Sky Cam Light Monitoring project was initiated as a collaborative scientific research program between Dr Kellie Pendoley (Pendoley Environmental) and Mr Arie Verveer (Perth Observatory, DEC). The data processing was done by Mr Benjamin Goodsell and Mr Jeremy Savage. Mr Robert Ryan assembled and programmed the Sky-42 instrument, participated in the field work as the instrument technician and contributed to technical improvements in the methodology. Ms Lucy Thomas (Coffey Environments) assisted in the field program.

2 METHODS

2.1 Camera and Ancillary Equipment

The Sky-42 instrumentation and software used for this project follows a proof of concept study for recording and quantifying light in the field using a modified Santa Barbara Group Charge Coupled Device (CCD) camera and techniques borrowed from astronomy. The purpose of measuring anthropogenic (man-made) light on the horizon is to determine the extent of disorientation it causes to turtle hatchlings.

The Sky-42 images were taken with a Canon CCD camera using a fish eye lens and housed in a weather proof case. Sky-42 contains a 10 megapixel colour CCD chip (Figure 3). The large size of the CCD chip can easily capture the entire 360° horizon in a single shot (a significant advancement over earlier systems).

The camera runs customised firmware which allows the user to interface with the camera by the means of a computer script. The script is loaded on a memory card in the camera and contains instructions for the camera related to the periodicity of image collection, exposure time and various other settings. Sky-42 contains no physical filter, instead the Red, Green and Blue (RGB) waveband values of each pixel are used to develop a digital filter. In this report we use only the Blue waveband values to mimic the blue filter response. The construction of a digital filter which more accurately simulates the standard astronomical blue filter is the subject of research initiatives by Pendoley Environmental.

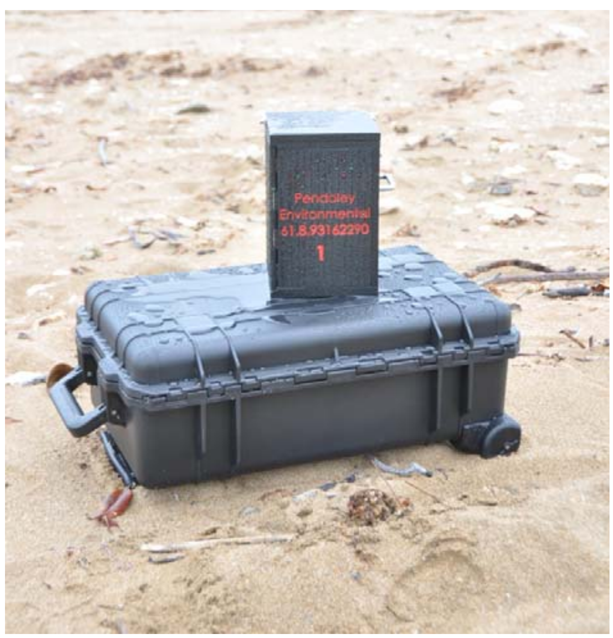


Figure 3: The Sky-42 camera set up on the beach.

The camera can be operated manually *in situ* or can be scheduled to automatically take pictures at a given interval throughout the night. Sky-42 is set to take pictures at an exposure time of 64 seconds at intervals of fifteen minutes. Each image is characterised by the reversal of normally accepted East and West due to the image capturing the sky looking outward away from the earth instead of inwardly towards it.

The camera is deployed around dusk. Notes on GPS location, weather conditions (most importantly cloud cover and wind speed) and bearings to light sources are recorded for use in the data analysis. The camera is collected the following morning around dawn after taking images overnight.

The presence of the moon interferes with the collection of data by introducing a glow around the horizon which cannot be resolved from the light emitted by artificial sources during post processing. Therefore it is important to make observations during the New Moon phase of the month to avoid this problem. In addition, cloud cover can amplify any ambient light and rain or condensation formation can obscure the view of the sky. Both effects are capable of degrading an image, rendering it unsuitable for analysis and their contribution is more difficult to predict than moon phases.

In order to minimise the impact of rain, condensation or blowing sand, on the lens, the Sky-42 instrument housing has been designed with a lid operated by micro controllers (Figure 4). The lid is normally closed and automatically opens only for the duration of image acquisition. The instrument contains a memory card which stores and pre-processes the images as well as running the script for automatic camera operation and is powered by 8 AA batteries which are sufficient to last the equipment from sunset to sunrise for 1- 2 days. The Sky-42 has an integrated GPS (location), magnetometer (compass bearings) and inclinometer (levelling of the unit) to facilitate field set up and reduce alignment error and thereby improving post processing of the images. The increased sensitivity of the instrument (relative to earlier versions) permits shorter exposure times which improve the accuracy of the results.

2.2 Software and the Star Catalogue

Stellarium 0.11.0, a freeware planetarium simulator developed by Fabien Chéreau *et al.* (2011), can obtain astrometrical data of the stars visible at any given time. This is used for aligning the images to obtain bearings of artificial light sources, and in calculating the volume of atmosphere passed through by the starlight. Known star magnitudes were obtained from the Yale Bright Star Catalogue which is the most accurate for sources visible from Earth.

The Instrument runs customized software, written in-house, which allows the user to program its operations (e.g. periodicity of image collection and exposure time). The scheduling script for controlling the camera triggering was coded by Mr Rob Ryan to interface with the camera control. The processing script is developed in the Python programming language by Mr Jeremy Savage and Mr Arwin Kahlon and interfaces with MaxIm DL and Stellarium via the freeware AutoIt (multiple authors, www.autoitscript.com).

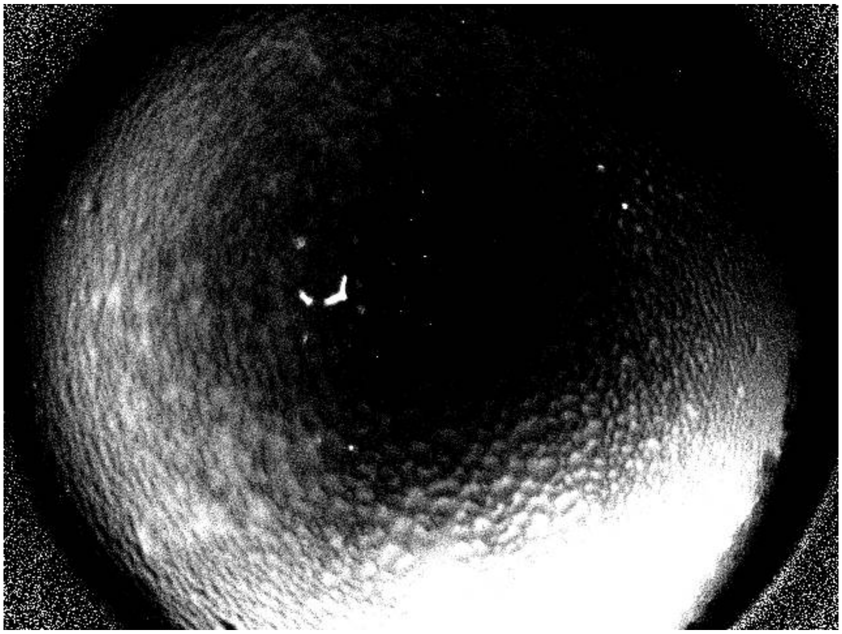


Figure 4: Image from the SBIG All Sky Camera showing the effect of water condensation on the camera dome.

Condensation is less of an issue with Sky-42, utilised within this study, due to the electronically controlled lid.

2.3 Field Locations

Images were taken at two sites on Facing Island and two on Curtis Island (Figure 5) during the new moon phase in July 2012 (Table 4). The observing conditions were not ideal with cloud occurring on 3 of the 5 observing nights during the survey. The site at North Beach on Facing Island was surveyed on two nights (July 17th and 19th) because of rain reducing the number of useable images on the night of July 17th. The angle of elevation of the dunes adjacent to the survey site was also recorded using a hand held digital inclinometer (Leica Disto D3a).

Table 5: Dates and locations of the five observing nights

Date	Location (Island, Beach)
16 July 2012	Facing Island, Settlement Beach
17 July 2012	Facing Island, North Beach
18 July 2012	Curtis Island, Southend
19 July 2012	Facing Island, North Beach
20 July 2012	Curtis Island, Connor Bluff

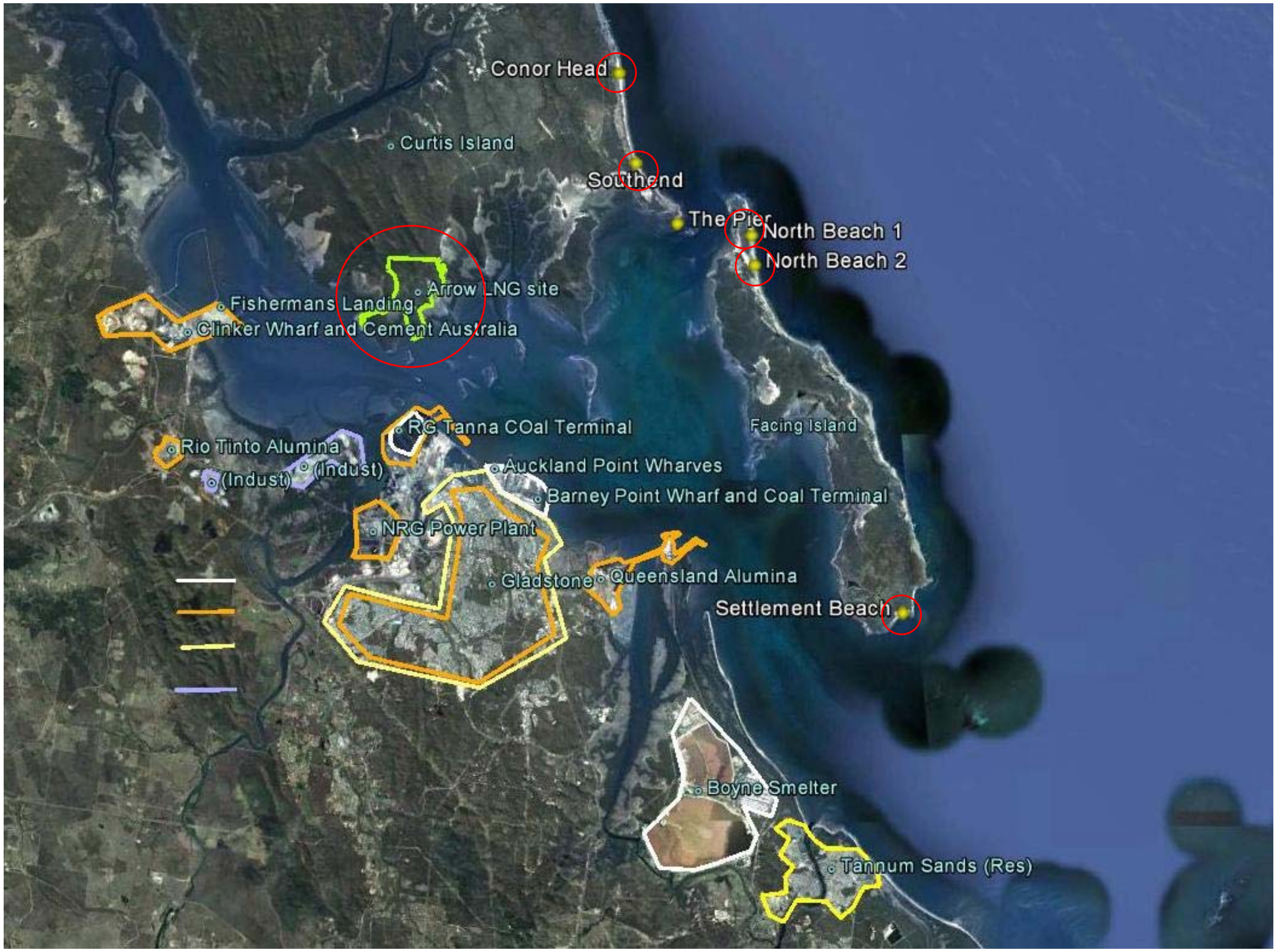


Figure 5: Light monitoring sites on Curtis and Facing Islands (yellow spots, circled in red), industrial light sources on the mainland (lavender outline), urban light sources (yellow outline), Gladstone port (orange outline) and the proposed Arrow LNG Plant site (green outline, red circle).

2.4 Image Processing

Technical details for the image processing are provided in Appendix 1 and as such have been summarised here. The geometric bearing of the raw image is first established using standard "Stellarium" software. It is important to restate that the image compass is "inverted" relative to the conventional perspective as the view is looking up at the sky, rather than down as with a map.

Small sections in the raw images are searched to locate specific stars with less than a 2.5 apparent blue magnitude which are listed in the Yale Bright Star Catalogue (total of 68 stars). The flux (i.e. light emission) for each star and the background sky surrounding it is then calculated and the results are used as the reference for the anthropogenic light on the image horizon. All light sources are therefore calibrated against Standard Star light intensities and the data output is given in units of apparent magnitude (see Appendix 1 for formulas).

The analysed raw images are subsequently converted into an isophote plot of the sky. An isophote plot is analogous to a topographical map where the contours represent levels of apparent magnitude (light intensity) rather than elevation. This replicates the light as it appears to an observer on the beach while also providing a quantitative indication of intensity using a colour scale. Red represents the brightest lights – often saturated while dark green represents the dimmest end of the light scale – very faint sky glow. White areas of the isophote represent the darkness of deep space.

The quantitative results (Section 3.0) are presented for each identifiable light source within an image on each survey night at each location. The amount of light calculated for each light source is an average of the area of light in the image for each of the four magnitude bands from each usable image on that night and for that location. The size of this value is a representation of the area of the sky illuminated by the light glow while the standard deviation gives an indication of how much fluctuation there was in the light emissions over the night. The standard deviation may represent a range of different sources of variation in the light source; i.e. it may represent transient sources such as switching on/off lights on vessels, switching of lights from onshore sources, vehicle headlights etc. The variation is also strongly influenced by changes in atmospheric conditions, i.e. atmospheric dust, sea spray, mist, rain and cloud cover. Reflection from cloud cover, its height and movement typically exerts the greatest influence on the amount of light received at the observation sites.

3 RESULTS

3.1 Site Details

The location of the five survey sites are shown in Table 6 below along with the measured dune elevation immediately behind the camera site.

Table 6: GPS location, dune elevation angles and dominant weather conditions at the five survey sites

Date	Location (Island, Beach)	Latitude (South)	Longitude (East)	Primary dune elevation (degrees) from sand	% images affected by cloud
16 July 2012	Facing Island, Settlement Beach	-23.874425	151.385441	7° - 12° (from base of dune)	> 50%
17 July 2012	Facing Island, North Beach 1	-23.765498	151.337483	20° (from base of dune)	100%
18 July 2012	Curtis Island, Southend	-23.744566	151.300873	25° (2.7m behind camera) 6° (15m south of camera)	> 50%
19 July 2012	Facing Island, North Beach 2	-23.774023	151.338485	19° (8m behind camera) 5° (10m south of camera)	0%
20 July 2012	Curtis Island, Connor Bluff	-23.718631	151.295626	No Data	0%

3.2 Sample Raw Images and Average Isophotes

Qualitative (image) results in the form of both raw images (Figures 6 to 10) and processed isophote images (Figures 11 to 15) provide a way to visually represent the light that hatchlings see from the beach. The images can be used with mapping or GIS software to identify light sources by backtracking on compass bearings to specific light sources in the image.

The highest proportion of the sky affected by glow was seen at Settlement Beach and North Beach 1 on Facing Island while the clear sky over North Beach site 2 is consistent with the least amount of sky glow recorded during the entire survey. The images in Figure 66 and 11 show a band of sky glow visible from Settlement Beach at the south end of Facing Island, that is dominated by light from Tannum Sands and Boyne Smelter 8 km to the south, and from the mainland "Gladstone area" (encompassing Gladstone city/Auckland Point Wharves/Barney Point Wharves and Coal Terminal, and the RG Tanna Coal Terminal), 12 km to the west. The influence of cloud on sky illumination is demonstrated in the bottom image with a much greater proportion of the sky illuminated by glow reflecting from the clouds compared to when cloud cover was absent earlier in the night (top image).

Data was collected on two separate nights at North Beaches 1 and 2 and on Facing Island (Figures 7, 9, 12 and 14). The glow from the Gladstone area, 9-11 km south-southwest through to west-southwest, dominated the entire south to west horizon quadrant. The different industrial light types are discernible within the glow reflected from the clouds. For example the orange coloured High Pressure Sodium lights at the Queensland Alumina site can be seen along the southern horizon in Figure 7 (bottom, cloud covered) while the white lights from the city of Gladstone and the adjacent wharves appear as a white coloured glow in the western quadrant of the this image. The large numbers of vessels moored east of Facing Island are clearly observed from the two North Beach locations.

Of the five survey sites, the two study sites on Curtis Island, Southend and Connor Bluff, measured less sky glow than Settlement Beach and North Beach 1, but more than North Beach 2.

The two Southend study sites on Curtis Island are located on either end of this 4.8 km long beach, Southend (Figures 8 and 10) and Connor Bluff (Figures 13 and 15). The Southend site is 1.45 km from the South End settlement while the Connor Bluff location is situated 4.4 km north of the settlement area. Light from the Southend settlement was indistinguishable from star light at both locations. The Gladstone area (city, wharves and coal terminals, 9 -13 km away), RG Tanna coal terminal (10 – 12 km away) and Queensland Alumina (10 – 15 km away) dominated the southern sky at both of the Curtis Island survey locations.

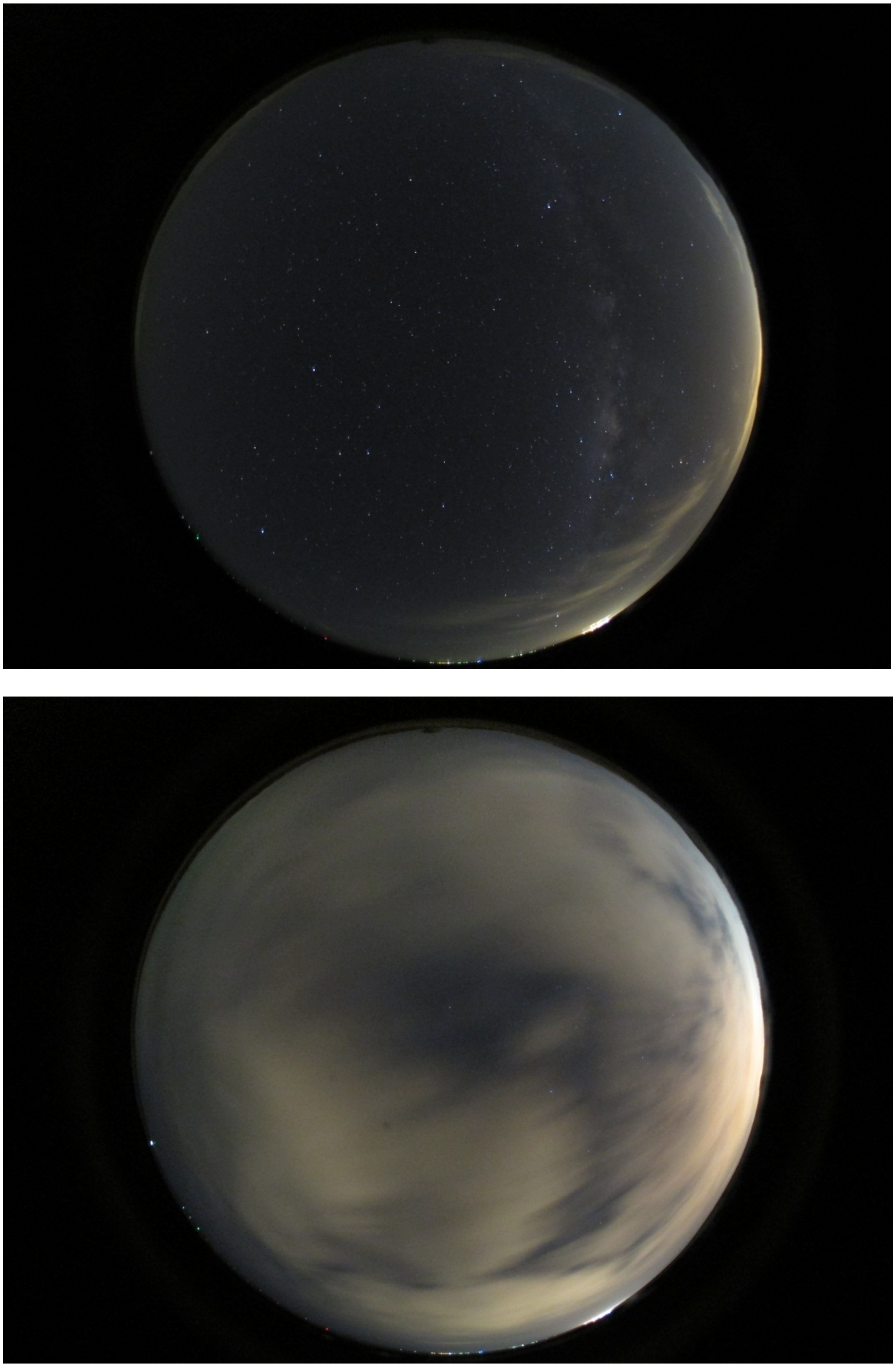


Figure 6: Representative images from Facing Island, Settlement Beach, without cloud cover (top) and with cloud cover (bottom) (Image codes 2590 and 2611).

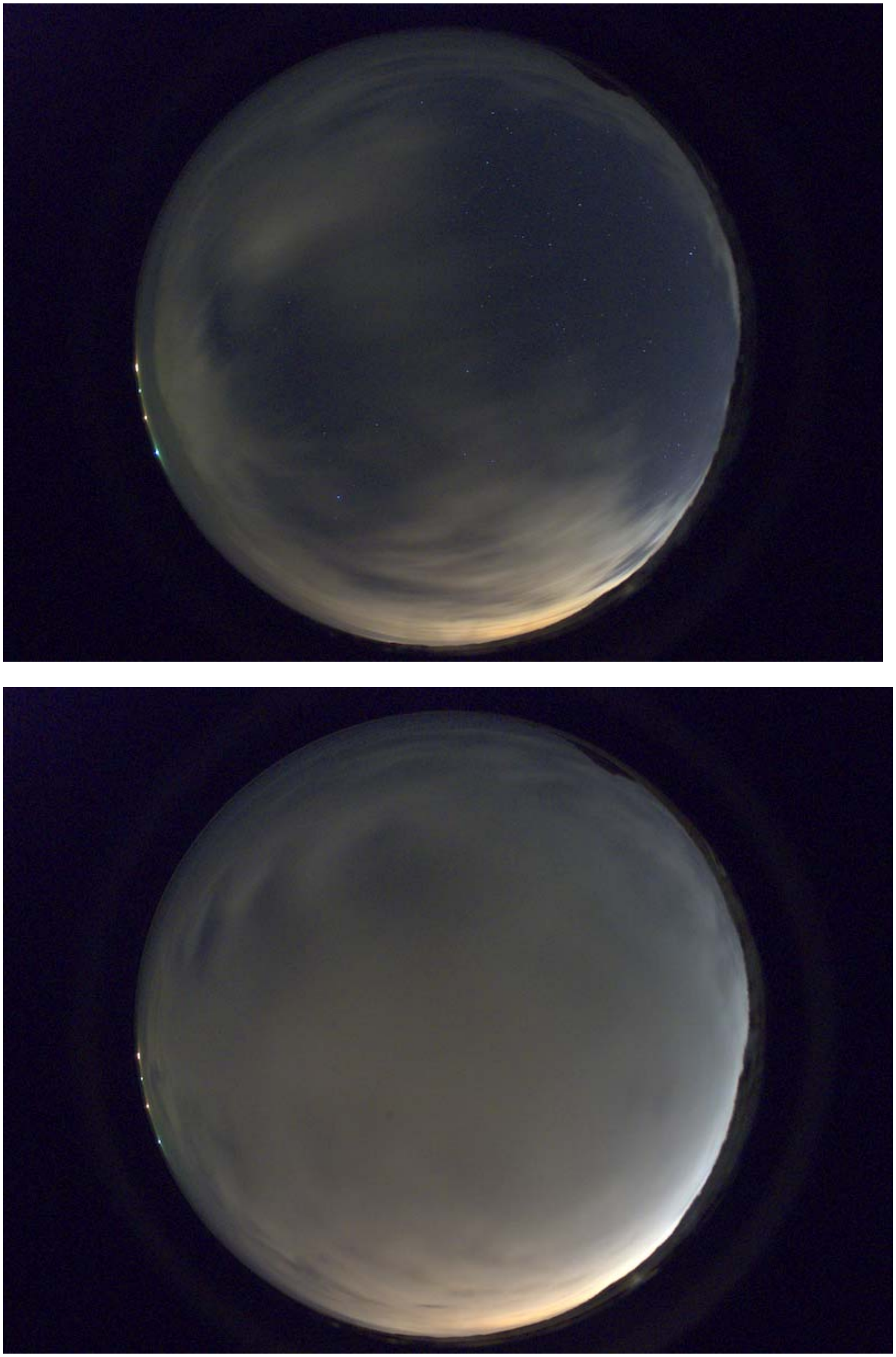


Figure 7: Representative images from Facing Island, North Beach 1 location, without cloud cover (top) and with cloud cover (bottom) (Image codes 2711 and 2668).

Figure 8: Representative images from Curtis Island, Southend location, without cloud cover (top) and with cloud cover (bottom) (Image codes 2821 and 2871)

Figure 9: Representative image from Facing Island, North Beach 2 location (Image code 2922)

Figure 10: Representative image from Curtis Island, Connor Bluff location (Image code 2977)

3.3 Processed Isophotes

A description of the Figures 11 to 15 (below) is presented in Section 3.2, 'Sample Raw Images and Average Isophotes'.

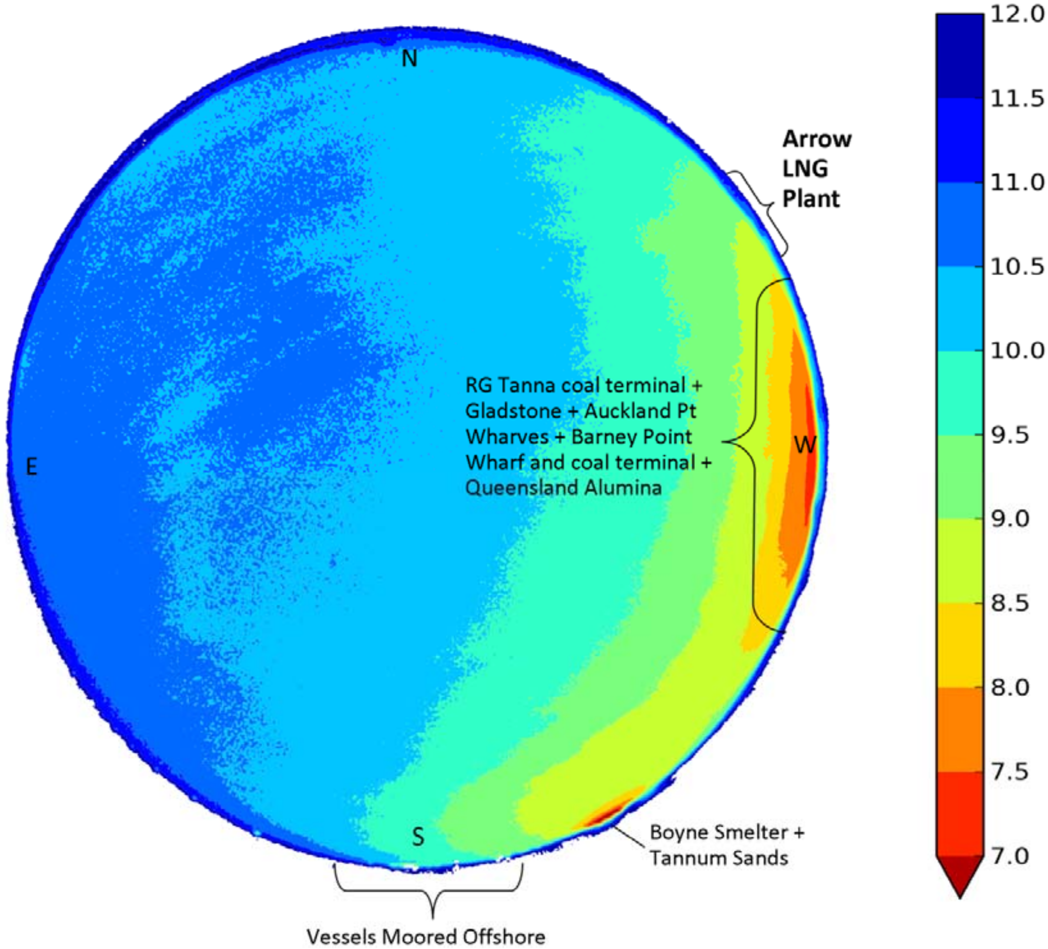


Figure 11: Facing Island, Settlement Beach Average Isophote (n=15 images)

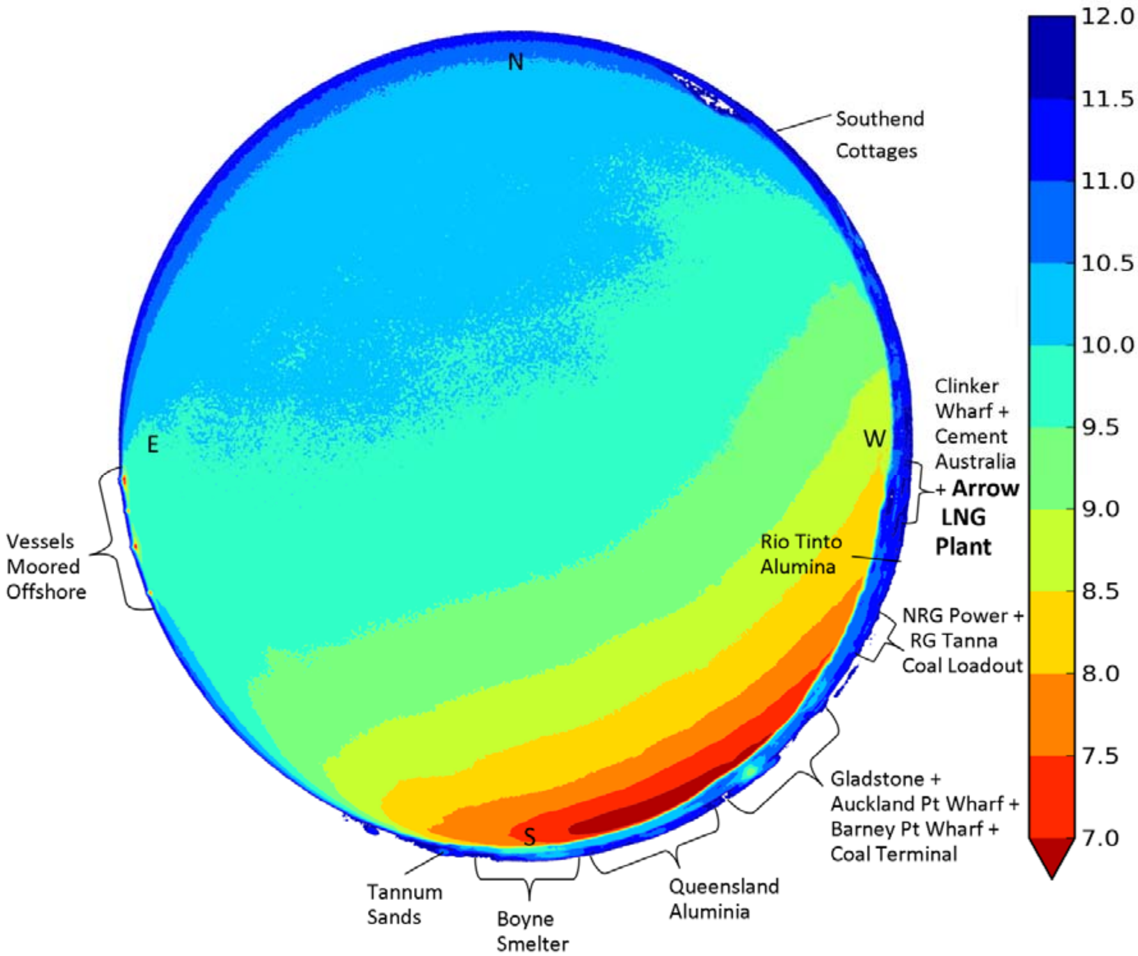


Figure 12 Facing Island, North Beach 1 Average Isophote (n=30 images)

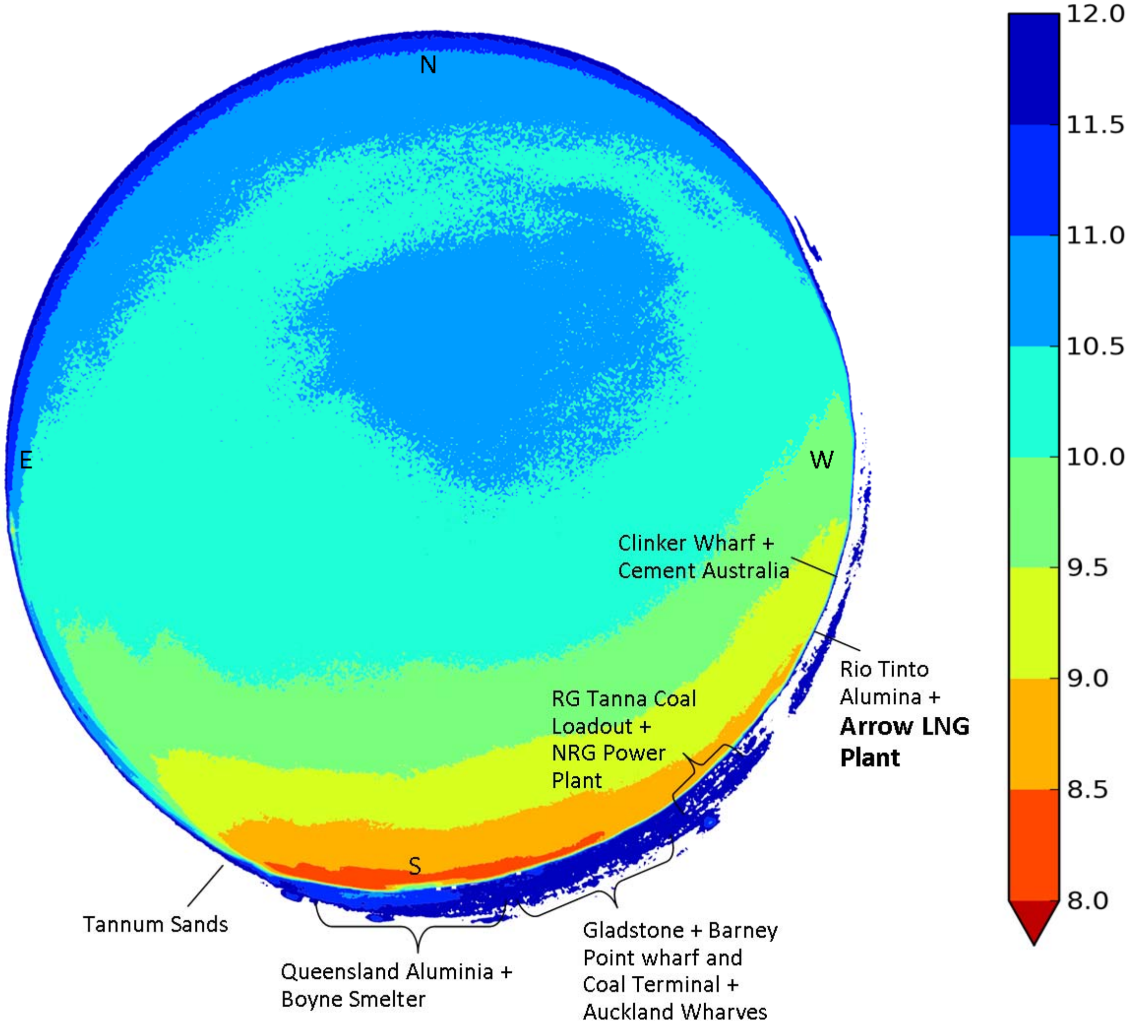


Figure 13: Curtis Island, Southend Average Isophote (n=66 images)

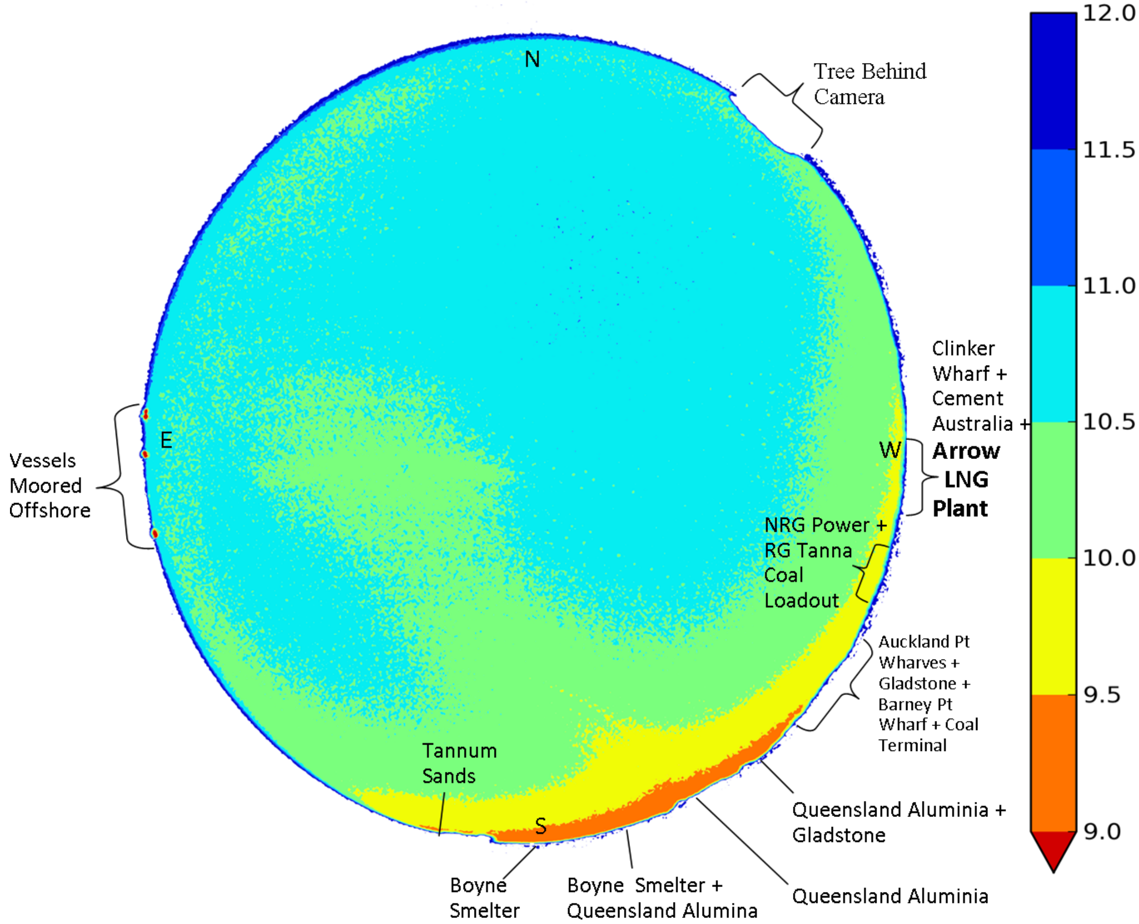


Figure 14: Facing Island, North Beach 2 Average Isophote (n=14 images)

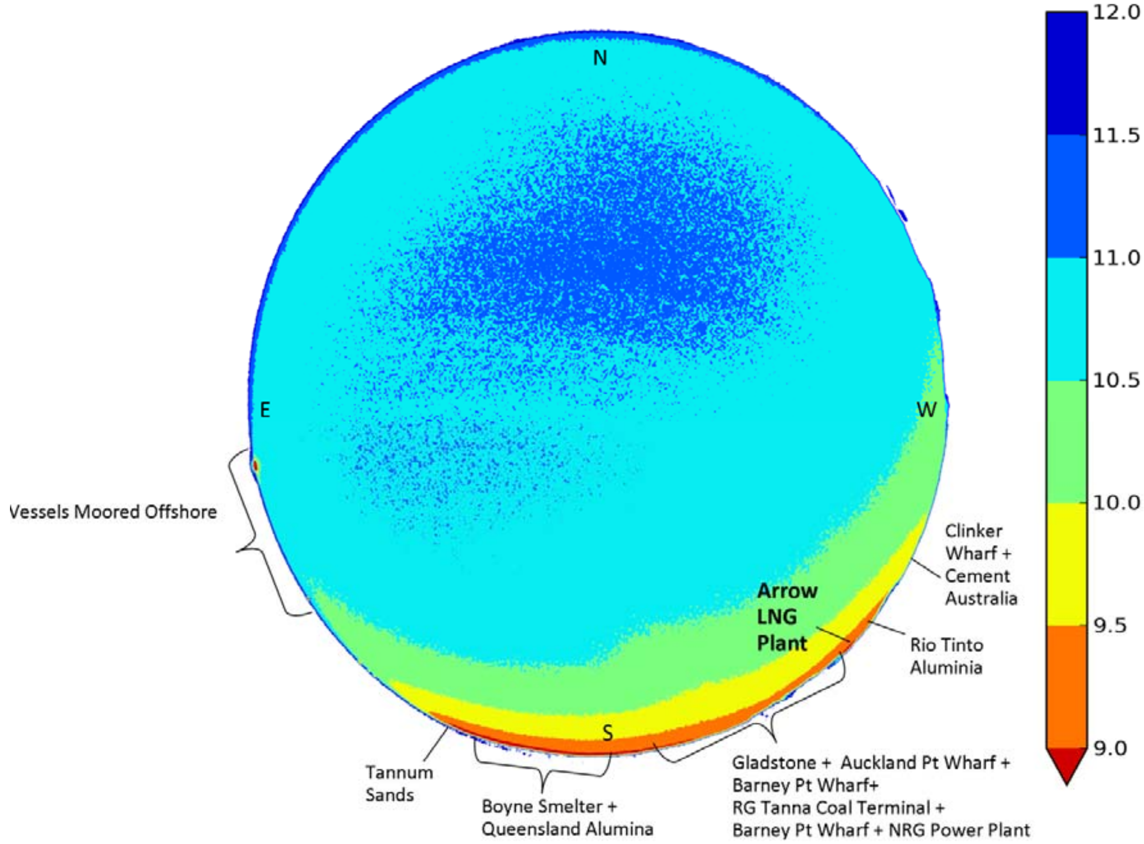


Figure 15: Curtis Island, Connor Bluff Average Isophote (n=45 images)

3.4 Quantified Data

Images collected in July 2012 from various locations on Curtis and Facing Islands provide a snapshot of the baseline light conditions present at that time. The quantitative results from all locations summarised in Table 6 form the baseline data set against which future monitoring programs will be compared. Table 6 below presents the glow area (arcminute^2) per magnitude for the 5 observation nights. The glow area was calculated from the average isophote, derived from each location set of overnight images. The *n* value is the number of images used to derive average isophote (excludes outliers). Results are presented as mean (± one standard deviation) with the standard deviation representative of the variability in light sources overnight.

The number of images used to derive each average isotope varied between 14 for North Beach 2 and 66 for Southend Beach (Table 7). The number of images that are used for analysis is dependent upon the effects of rain, dust, wind movement and instrument programming. The percentage of sky occupied by each band of light at each light monitoring location is plotted in Figure 16.

Table 7: Glow area (arcminute²) per magnitude for the 5 observation nights.

Date	Location (Island, Beach)	$A_{<7}$	$A_{<8}$	$A_{<9}$	$A_{<10}$	$A_{<11}$	$A_{<12}$	*n*
16 July 2012	Facing Island, Settlement Beach	961 (1019)	8782 (9353)	37831 (40166)	107926 (113626)	206554 (208493)	254126 (254275)	15
17 July 2012	Facing Island, North Beach 1	1935 (1131)	13631 (4714)	49792 (14050)	163528 (41700)	239284 (18109)	256017 (1858)	30
18 July 2012	Curtis Island, Southend		2442 (2269)	19012 (17519)	81321 (79035)	210541 (210059)	247291 (247113)	66
19 July 2012	Facing Island, North Beach 2		70 (5)	295 (17)	19255 (2515)	213493 (5802)	247094 (538)	14
20 July 2012	Curtis Island, Connor Bluff		45 (9)	675 (157)	15647 (2282)	169276 (19635)	249699 (1464)	45

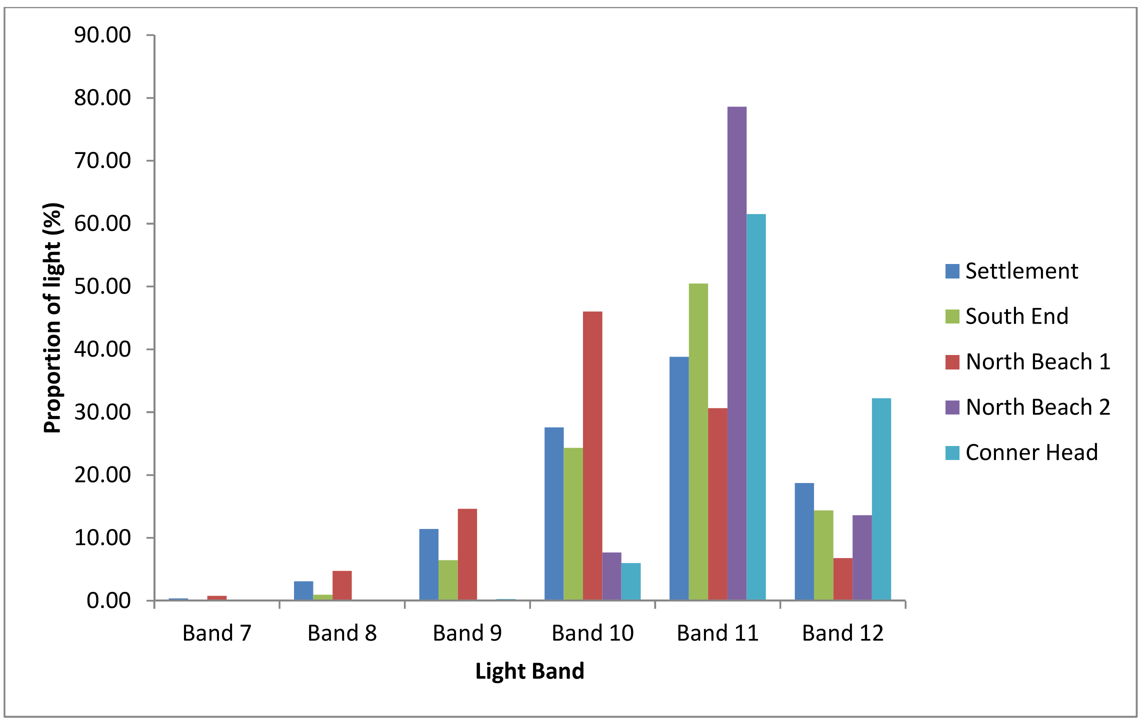


Figure 16: Percentage of the sky occupied by magnitude bands 7 to 12 in each Averaged Isophote image

4 DISCUSSION

As outlined in Section 2.2, the highest proportion of the sky affected by glow was seen at Settlement and North Beaches 1 and 2 on Facing Island. Both survey nights were characterised by >50% cloud cover and clearly demonstrate the effect that cloud has on illuminating the beach with reflected light. By comparison the clear sky over North Beach site 2 is consistent with the least amount of sky glow observed during the entire survey.

Marine turtle hatchlings are more susceptible to large scale and broad glow low on the horizon as opposed to small discrete point source lights (Witherington, 1992, Pendoley 2005). The total glow is represented by both the proportion of sky affected by glow and the level of brightness of the sky glow. As per the method of this research (Section 2.2), all of the colour areas under magnitude 12 ($A_{<12}$) are presented within the isophote figures (Figures 11 thru 15)

The effect of cloud can be observed in Figure 16 which presents the proportion of light emissions in each band for each survey site. Generally the clear nights (North Beach 2 and Connor Bluff) recorded little or no light in the brightest bands (bands 7, 8, 9) a minor amount in band 10, rising to a maximum for all surveys sites and intensity in band 11, before falling off in the dimmer bands to a moderate level in band 12 and minor levels in band 13. Cloudy nights (Settlement Beach, Southend and North Beach 1) in contrast recorded light, albeit minor levels, in the bright bands (bands 7, 8, 9), moderately high levels in bands 10 and 11 and minor levels in the dimmer bands 12 and 13.

4.1 Assessment of Light Impact on Hatchlings

The data captured by this study enable the effects of light pollution on marine turtle behaviour to be better understood. Biological studies on the orientation behaviour of hatchlings as they leave their nests on Curtis and Facing Islands and commence sea-finding were not undertaken. Therefore in the absence of biological data from Curtis and Facing Islands, any comments on the significance of the Gladstone night sky light and the predicted impact on marine turtle hatchlings are made using the behavioural observations from literature summarised in Table 3. Impacts of light on hatchlings, of both current and proposed operations are highlighted below in Sections 3.1.1 and 3.1.2.

4.1.1 Current Environment

The topography of the beaches on Curtis and Facing Islands is varied, ranging from 2-3 m tall dunes vegetated by short soft dune grass and interspersed with Casuarina trees down to regions of low flat bare dune blowouts. Hatchlings emerging onto these beaches from their nests will be subject to a range of cues, dominated by the glow from the Gladstone region. This glow is expected to be most visible to hatchlings under new moon conditions or when low cloud cover is significant. The influence of the glow will depend on its directivity (i.e. direction of visibility) and its elevation relative to the position of the hatchling on the beach. For beach locations in front of tall vegetated dunes on the western beaches of Facing and Curtis Islands it is reasonable to predict the sea-finding cue used by hatchlings would cause them to move away from the tall dune horizon and towards the ocean. The glow of Gladstone being behind the tall dunes and vegetation thus enhances the relative darkness of the fore dune. Beach locations in front of low dunes, where the elevation of the glow behind the beach is reduced, are likely to lead to some degree of misorientation in emerging hatchlings. The degree and duration of misorientation will depend on a range of factors, including light elevation, moon phase, cloud cover, time of emergence and the location of other lights both on shore and offshore (vessels).

Beach locations that are exposed to broad areas of glow that are visible from along the beach (as opposed to behind the dunes or from the ocean in front of the beach) are likely to be characterised by misorientation since the light will appear low on the horizon if the distance between the nest site and the light source is relatively large. Hatchling misorientation in this case could result in them crawling along the beach or back into the dunes, increasing their exposure to predators, reducing their energy reserves or preventing them reaching the ocean at all. Individual point sources of light are unlikely to impact hatchling orientation since they will appear as indistinguishable to stars over a long distance.

4.1.2 Proposed Development

The large variability in supratidal and dune topography makes predicting impacts of additional light sources associated with the LNG plant and flare for a whole beach difficult. Table 9 below summarises the potential impacts of light on marine turtle hatchlings on Curtis and Facing Islands.

The specific location of the emerging nest along the beach will impact on hatchling behaviour in conjunction with the other environmental variables that influence sea-finding (horizon elevation, moon phase, cloud cover etc.). Additionally, it is also common for hatchlings that have successfully reached the ocean to crawl back out of the ocean and up a beach towards artificial light. This behaviour cannot be discounted for the Curtis and Facing Islands beaches.

Biological orientation studies on the sea-finding behaviour of hatchlings on Curtis and Facing Islands beaches is recommended to either confirm or disprove this analysis. Furthermore a study of the dune elevation and topography along the beach could prove useful for predicting areas where hatchlings might be at greatest risk from misorientation and also identify areas that might benefit from tree planting to enhance the horizon elevation.

While this technical study has focussed almost exclusively on hatchlings it is also possible that young females newly recruited into the breeding population may avoid the island beaches that are brightly lit at night and instead are nesting elsewhere. In the absence of data on nesting adults it is not possible to reliably comment any further on this age class.

4.2 Marine Turtle Impact Assessment

Pendoley were engaged by Coffey Environments to complete a Marine Ecology (Turtles) technical study. As part of this study a number of specific questions have been addressed and these are detailed below:

4.2.1 Are marine turtle species found in Port Curtis and along the east coast of Curtis Island likely to be affected by project lighting?

Marine turtles nesting and hatching on both Curtis Island and on Facing Island (see Figure 1 for species usage of regional beaches) are likely to be exposed to project related lighting, in addition to the light that currently illuminates the night sky from regional urban and industrial sources. Information on marine turtle species, population number and nesting locations are outlined in Section 1.1.

4.2.2 What background lighting conditions exist at the turtle nesting sites north of Southend and at the northern end of Facing Island i.e., prior to any project development?

The current night sky, as seen from Curtis and Facing Island east facing beaches, is dominated by the glow from the area surrounding the city of Gladstone and including city and urban lighting, Auckland Point Wharves, Barney Point Wharf and Coal Terminal, RG Tanna Coal Terminal, NRG Power Plant and Rio Tinto Alumina. The different light sources can sometimes be resolved in the images, for example the glow from the white lights of Gladstone city is clearly distinguishable from the orange glow of the High Pressure Sodium lights at the Queensland Alumina (Figure 7). Beaches on the south end of Facing Island are also highly exposed to lights from the Gladstone area (urban and industrial sources, including the probability of industrial aerosols and particulates couple with atmospheric water vapour provide reflective medium to create the “glow” effect), furthermore they are also exposed to light from Boyne Smelter and the residential area at Tannum Sands.

4.2.3 What specific intensity (luminosity) and wavelength/spectrum of light are the nominated marine turtle species most sensitive to? Do the light sources at the LNG plant fit within the spectrum, wavelength and intensity of light to which the nominated marine turtle species are susceptible?

Hatchling marine turtles of all species use light as a cue in sea-finding. The literature indicates hatchlings use a combination of horizon elevation, light intensity, light wavelength, light directivity and light duration to successfully find the ocean. In broad terms hatchlings show preference for short wavelength (blue-green) light over long wavelength (yellow-red) light and high intensity light over low intensity light. However in the absence of any other light and under favourable environmental conditions their sea-finding may also be influenced by low intensity, long wavelength light, e.g. glow. Adult turtles returning to the ocean from a beach are less sensitive to light and are able to orient seaward despite the visibility of light.

The images captured within this study recorded current light conditions only. Flare design for the Arrow LNG Plant is still in progress, however Figure 17 is an example of the light emission spectra for a flare collected from an LNG plant in North West Australia. The light is strongly concentrated in the orange and red range of the visible spectrum and can be considered representative of a typical flare emission. This long wavelength light is less attractive to hatchlings relative to short wavelength blue and green or white light and is most attractive to hatchlings in the absence of any other competing light sources (natural or manmade).

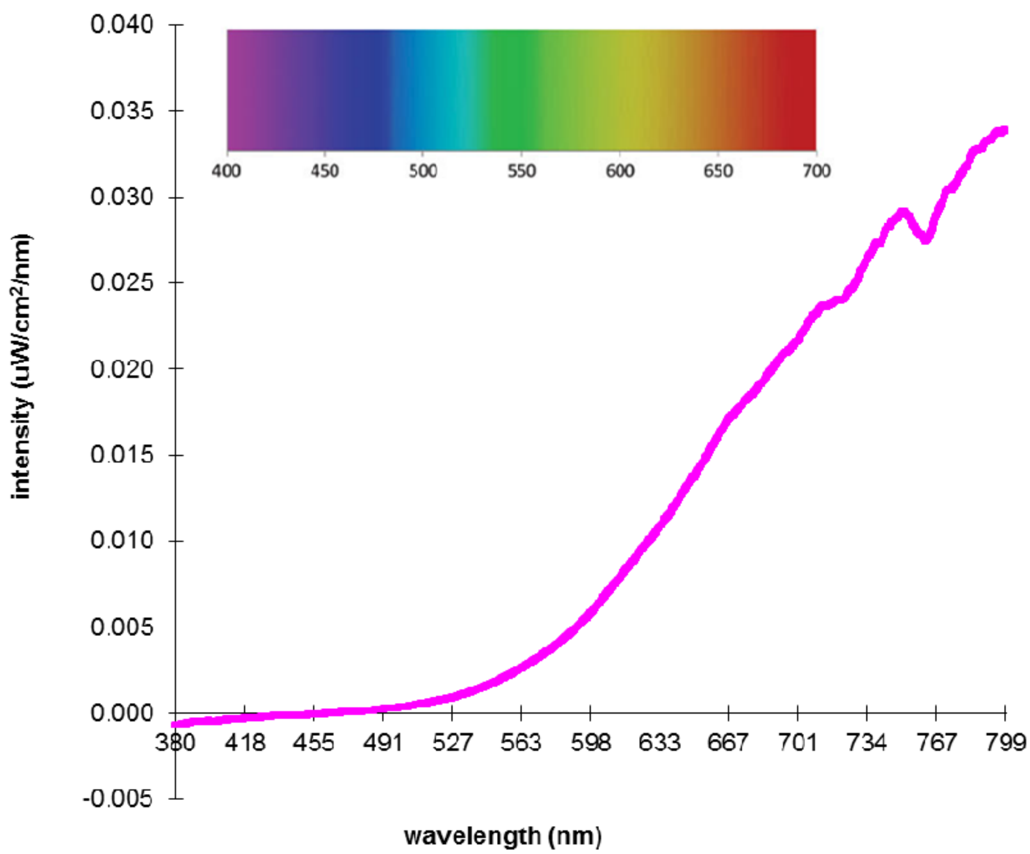


Figure 17: Representative spectral power distribution curve for an operating LNG gas flare showing the equivalent colour spectrum.

Any artificial light used in the Arrow LNG Plant will, if not managed appropriately, emit glow into the sky that could be visible to marine turtles on Curtis and Facing Island nesting beaches. This includes all white (halogen, fluorescent, metal halide and LED) and orange (High Pressure Sodium and Low Pressure Sodium) light types

The visibility of the glow will vary along the length of the east coast beaches and will depend on how the lights are managed, the wattage of the light fixture, the intensity of the light on the beach, and a range of environmental factors. For example, cloud cover will reflect artificial light back onto the beach. The amount of light will depend on the height of the cloud. Low cloud illuminates the beach more than high cloud. On a clear night with no moon, the visibility of artificial lights to marine turtles will be substantially greater than nights with a partial or full moon. Full moon phases provide natural illumination of the sky, reducing the relative visibility of artificial light. Also, the visibility of light in the sky is directly correlated with the level of aerosols in the atmosphere (e.g. dust and salt spray) reflecting light back to the eye and consequently a high level of aerosols will increase the amount of sky glow visible.

4.2.4 Will marine turtles utilising beaches north of Southend and on Facing Island have line of sight to the flare?

Marine turtles using the section of beach close to the Southend settlement on Curtis Island and North Beach on Facing Island potentially have a direct line of sight to the project's flare. The visibility of the flare itself will depend on dune and onshore topography between the beach and the flare. Turtles on the other sections of nesting beach, both adults and hatchlings, are unlikely to have direct visual contact with the flare itself as they will be shielded from the flame by the supratidal dune system, vegetation and hills.

The flare will however produce a highly visible glow in the sky, particularly when it reflects off elevated atmospheric aerosols and clouds and this will be visible to turtles from all nesting sites on Facing and Curtis Island. The degree of visibility and the impact of this on hatchling orientation will vary depending on the environmental factors discussed in Section 3.2.3 above.

4.2.5 Will marine turtles utilising beaches north of Southend and on Facing Island have line of sight to the glow created by LNG plant lighting?

The location of the project's site has been included in Figures 11 – 15 to show the expected visibility of the plant lights from the sites monitored for light emissions on Curtis Island and Facing Island nesting beaches. It is clear from these figures that the glow from the LNG plant lighting will merge with the glow from the existing industrial and urban sites on the mainland when viewed from North Beach on Facing Island and from Southend on Curtis Island. The LNG plant site will potentially create a new area of horizon glow when viewed from the north end of Southend Beach (see Connor Bluff site, Figure 15) and from Settlement Beach on Facing Island (see Figure 11). The turtles utilising the beaches on the east coast of Curtis and Facing Islands will have visibility of the glow created by the LNG plant site and depending on island topography, will have line of sight to the flare flame when in operation (see Sections 3.2.4 and 3.2.5 above).

4.3 Potential Effects of Lighting on Turtles:

4.3.1 What specific behaviour is affected by light – breeding, nesting or hatching?

The behaviours most influenced by light are sea-finding in hatchlings and beach selection in neophyte (novice) females making their first breeding migration and nesting attempt (see Section 1.2 and references therein).

4.3.2 What time of year is the most sensitive for the species which nest on the east coast of Curtis Island and Facing Island?

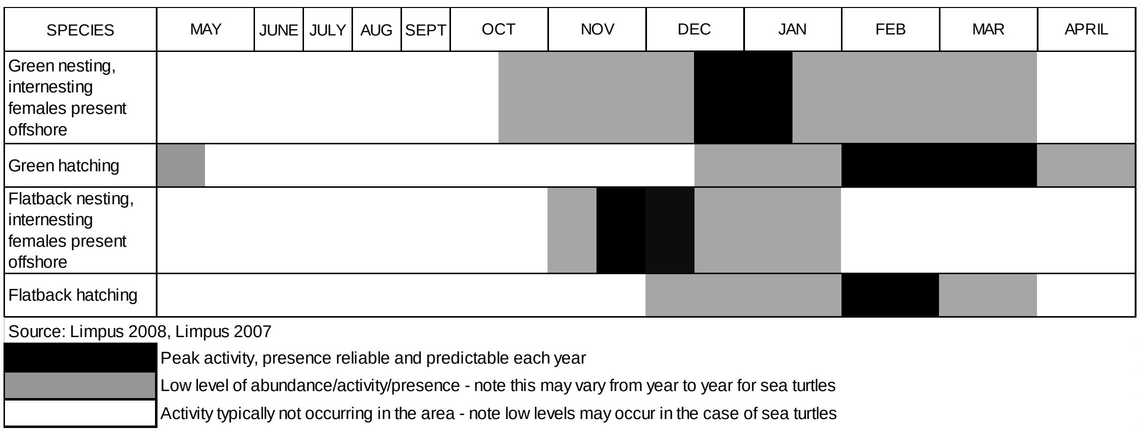
While Figure 1 indicated green turtles have been recorded nesting on the south end of Southend Beach on Curtis Island in low numbers, Table 8 below summarises the breeding schedule for green and flatback turtles in the southern GBRWHA. Green turtles nest between late October and late March, peaking between late December and early January. Hatchling emergence occurs between late December and early May with a peak in February and March (Limpus, 2008).

Figure 1 shows flatback turtles are the most common species recorded nesting on Curtis and Facing Island with rookery sizes ranging from 10 – 100 nesting females per year at Settlement Bay, Facing

Island Eastern Beach, Pearl Ledge East Point and Pearl Ledge North Point and peaking at 100- 500 per year at North Beach, Facing Island. Flatback numbers range form 10-100 per year on the beach adjacent to Connor Bluff on the north end of Southend Beach, Curtis Island. Flatback turtles nest in the southern GBRWHA nest between early November and late January, peaking in late November and early December. Hatchlings emerge in early December through to late March with a peak in February.

Greatest sensitivity is therefore during the peak flatback and green hatching (February and March). This is followed by the shoulder hatching periods (December and January, April to mid-May) and adult nesting period (mid-November to mid-January).

Table 8: Peak and shoulder nesting and hatching periods for green and flatback turtles in the southern GBR



4.3.3 What are the potential risks to marine turtles if flaring occurs during the sensitive periods for the nominated species e.g., during hatching?

Short term (e.g. hours) flaring is unlikely to have detectable impact on marine turtle nesting or hatchling orientation. Sky glow arising from extended flaring during the nesting season could potentially have an impact on neophyte nesting green or flatback females by causing them to avoid these beaches and choose to nest on other beaches in the area.

Studies by Limpus et al (2006) on GBR green turtle nesting fidelity have found that adult females do not show 100% fidelity to nesting beaches either within or between nesting seasons. They concluded that adjacent rookeries can be treated as the same breeding unit. Curtis and Facing Islands fall within the “Mainland and mainland islands” stock (breeding) unit which incorporates Fraser Island, Agnes Waters, Wreck Rock, Rules Beach, Moore Park and Woongarra Coast (Norman et al 1994a and 1994b) and consequently any neophyte females discouraged from nesting on Curtis or Facing Islands beaches are likely to move on and nest on another of these beaches within the region. Flatback turtles show similar within season and between season movement between nesting sites (unpublished data obs K Pendoley) and consequently a similar option to move onto another beach is available to neophyte flatback females.

It is possible the neophytes females may select a less successful nesting site (e.g. lower hatching and emergence rates) if they are forced to move to other nesting sites by light impacting on their potential rookery beaches. This may already be occurring as a result of existing light pollution of the nesting beaches and therefore additional light from flaring could cause a cumulative impact. It is not possible to assess this impact without detailed studies on the number of neophytes and the success rate of the various nesting beaches in the region. Curtis Island is an index beach for monitoring the population dynamics within the eastern Australian flatback stock (Limpus 2007) and it is possible any change in the annual size of the nesting female population will therefore be detected.

The impact of flaring during the hatching season will be on sea-finding as the hatchlings leave the nest. Impacts might include disorientation and misorientation leading to increased numbers of death through dehydration or predation, or reduced energy reserves available for the offshore migration through increased time wandering on the beach. The degree to which the light impacts hatchlings will be a function of the duration of flaring (i.e. hatchlings typically reach the ocean within minutes of emerging from the sand) and horizon elevation with hatchlings emerging onto the beach in front of tall dark dunes, such as those found at the south end of Southend Beach, expected to predominantly orient seaward.

As dune elevation decreases and the artificially illuminated horizon falls (relative to the hatchling position on the beach) the ability of the hatchlings to discriminate between the artificial light horizon and the ocean horizon also decreases and the hatchlings may no longer orient directly towards the ocean (K Pendoley unpublished data). On a beach this occurs when the supratidal zone flattens out behind the beach or when a light is visible at a distance along the beach appearing low in the hatchlings zone of visibility. Identification of actual zones at risk is difficult and complicated by the environmental factors discussed in Sections 3.2.4 and 3.2.5. However, predicted impacts on hatchling behaviour have been summarised and listed in Table 9 below.

Table 9: Summary of the potential impacts of light on marine turtle hatchlings on Curtis and Facing Islands.

Island	Beach/site	Land horizon or topography	Light source	Predicted hatchling behaviour
Curtis Island	Connor Bluff	Elevated horizon; tall primary dunes and vegetation	Gladstone area* glow behind tall dunes	Orient seaward away from tall dark horizon (dunes and trees)
				Orient along beach towards low horizon, light visible through breaks in the dunes
		Low horizon elevation; flat looking south along beach	Southend settlement	Small point source lights similar in appearance to star, hatchlings very unlikely to be impacted by this light source
	Southend	Low horizon elevation; small primary dunes	Gladstone area* glow behind low primary dunes	Orient along beach or inland towards light glow low on their visual horizon
		Low horizon elevation; flat looking south along beach	Southend settlement	Point source lights similar in appearance to stars, hatchlings unlikely to be impacted by this light source
Facing Island	Settlement Beach	Tall hills	Gladstone area* glow from behind tall inland hills	Orient seaward away from tall dark horizon (hills and trees)
		Headland	Boyne Smelter	Orient towards smelter glow around headland at south west end of beach
	North Beach	Moderately tall dunes	Gladstone area* glow behind dunes	Orient along the beach or inland towards light glow low on their visual horizon, especially hatchlings further along the beach
		Seaward	Large number of vessels moored offshore	Vessel lights may assist hatchlings to orient seaward, potential for entrapment in light spill around vessels
Curtis and Facing Island	All	Landward from the sea	Onshore	Hatchlings that have successfully reached the ocean may swim or be swept along the shore and crawl back out to the ocean towards the inland light and glow.

*includes lights from city, urban area, Auckland Point Wharves, Barney Point Wharf and Coal Terminal, Queensland Alumina and RG Tanna Coal Terminal.

4.3.4 Are the management measures expressed as commitments adequate to address potential impacts on marine turtles?

The management commitments listed in the Arrow LNG Plant EIS (Coffey Environments 2012) are summarised in Table 10 below (left hand column). Pendoley Environmental's comments and recommendations are listed in the right hand column.

Table 10: EIS Commitments and Pendoley Environmental Comments

	Coffey EIS Commitments	Marine Turtle Subject Matter Expert comment (Pendoley Environmental)
Chapter 19, Section 19.8, Table 19.12 ***Implement measures to reduce the impacts of light from the LNG Plant and ancillary facilities including:***		
C17.16	Shield/direct the light source onto work areas where practical	Agree, if the Plant aims to minimise all sources of sky glow the potential impacts on marine turtles will be equally minimised.
C17.17	Use long wavelength lights, where practical, including use of red, orange or yellow lights	Agree, Low Pressure Sodium light has least impact on turtles, followed by High Pressure Sodium. The Plant should avoid using metal halide, halogen, incandescent and fluorescent lights and if used they should be carefully managed so as to prevent light escaping into the overhead sky. The additional impact on marine turtles from using well managed (i.e. shielded and directed) short wavelength light is likely to be minor and undetectable over existing light impacts.
C17.18	Lower the height of the light sources as far as practical	Agree, this in addition to shielding will mitigate sky glow.
C17.19	Avoid routine planned maintenance flaring at night during sensitive turtle reproductive periods (where practical)	Agree. Give highest priority to avoid flaring during the peak flatback and green hatching (February and March). Secondary priority is to avoid flaring during the shoulder hatching periods (period (December and January, April to mid-May) and adult nesting period (mid-November to mid-January).
C19.01	Develop a construction management plan which contains specific mitigation measures, performance indicators and management action required to reduce impacts to the marine and estuarine ecological values.	Develop a light mitigation plan for construction and operation. Include specific light management measures outlined within this table, commitment to routine light audits, and hatchling monitoring to assess the impact of current and future light impacts on hatchlings emerging on both Curtis and Facing Island beaches.
Appendix 17, Section 6.1.7 ***Lighting Recommendations***		
a)	Limit construction to day light hours	Agree, particularly during the peak flatback and green hatching (February and March) period, the shoulder hatching periods (period (December and January, April to mid-May) and the adult nesting period (mid-November to mid-January) (Table 8).
b)	Minimise night time work	Agree, see Table 8 for schedule
c)	Use passive lighting measures, i.e. reflective tape and materials for road markers, signage, information signs etc.	Agree, good way to minimise sources of sky glow.
d)	Use LED studs in road and pathways	This is fine but only if the studs are not aimed upwards into the sky and the light type minimises white light.
e)	Use directional lighting to focus on specific work areas	Agree
f)	Limit hours worked in floodlit areas	During the breeding season, see point a) for schedule.
g)	Use automatic light sensors	Agree, reduces the time lights are on for
h)	Use high pressure sodium instead	Disagree. Low pressure sodium is less disruptive and produces

	of low pressure sodium for street lighting (improved colour rendition)	less sky glow than high pressure sodium light and should be considered in any non-explosive area.

4.3.5 Is additional mitigation required to address potential impacts on marine turtles?

A range of light management actions are currently being used to minimise light from industrial and urban sources globally (Witherington and Martin, 1996; Gorgon ESE, 2005) and these are summarised below. Nationally these management practices have been implemented in industrial settings in Western Australia and have been established as good industry practice by the West Australian Environmental Protection Authority (EPA 2010). These options should be considered as part of the project's lighting management plan;

- Assess the necessity for **every** light in the Plant area
- Switch off unnecessary lighting (when not in use)
- Use LPS lights as a first choice light source
- Use HPS lights where LPS is not practical
- Avoid using any white lights, i.e. halogen, metal halide or fluorescent lights
- Replace short wavelength light with long wavelength light
- Minimise the number of lights
- Minimise the wattage of lights
- Exclude short wavelength light with filters
- Use reflective materials to delineate equipment or pathways
- Shield lights behind structures
- Position doors and windows on the side of buildings facing away from marine turtle nesting beaches
- Install and use window coverings on windows to reduce light emissions that contribute to sky glow
- Use white lights in contained areas where colour rendition in required
- Shield light fixtures to prevent sky glow Redirect lighting onto work areas
- Lower the height of light poles
- Recess lighting into structures
- Use timers
- Use motion-activated switches
- Use embedded road lighting Use personal light sources (hand or head torch) to navigate dark work areas
- Design elevated horizon or vegetation to screen rookery beaches from light sources.

4.3.6 How effective are the mitigation and management measures likely to be; specifically, will the proposed flaring strategy reduce impacts on the nominated marine turtle species?

Reducing flaring to the non-breeding season and minimising flaring during the breeding season will reduce the potential impacts on green and flatback nesting females and hatchlings.

The short duration of both scheduled flaring (2-3 days every 1.5 years) and unscheduled (train trips) flaring (up to 2 hours and possibly 4 times per year) are unlikely to have a detectable impact on the regional marine turtle flatback population. Regional beaches may be exposed to flaring events during the nesting season, however the low density of marine turtle nesting on regional beaches, the intermittent nature of flaring together with the relatively short duration of flaring will result in a low number of hatchling's potentially exposed to the flare light.

4.3.7 Will there be any residual impacts to turtles following adoption of the mitigation and management measures and if so, how significant will they be?

If a detailed and all-encompassing lighting management policy and plan is developed and implemented it is possible the residual impact of Plant lighting can be reduced to an absolute minimum reducing the sky glow and long term visibility of the Plant during the production phase. It is not possible to quantify the impact of light on hatchlings due to the complicated ecology of marine turtles and the environmental variables that contribute to how the hatchlings see and respond to light. Equally, residual impact is difficult to assess qualitatively without a light management plan (i.e., what sort of lights will be used, how will they be managed and monitored). However we can conclude that residual impacts would include the following;

- The incremental effect of the additional light from the flare will increase the region of horizon illuminated by light from some locations on Facing and Curtis Island Beaches.
- Unmanaged light emissions (similar to those used in regional urban and industrial sites) from the Arrow Plant are expected to incrementally increase the amount of light glow in the sky over the turtle nesting beaches. The residual impact will be a potential incremental increase in misorientation of hatchings on the nesting beaches.
- Because low and high pressure sodium lights are less attractive to green and flatback turtles relative to white lights, these lights are recommended for use in the Arrow LNG Plant where possible. Used in conjunction with light management measures, the amount of sky glow will be substantially reduced over unmanaged lights and consequently the residual impact from the Arrow LNG Plant on hatchlings will be similarly reduced.

5 REFERENCES

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APPENDIX 1: Image Processing Technical Details

APPENDIX 1

PRE-PROCESSING

To correct for instrument noise the following pre-processing steps are conducted. Each image is constructed from two parts; a "dark" and a "light" image. The dark image is taken with the shutter closed and captures fluctuations caused by the instrumentation such as thermal noise. The scheduler script automatically subtracts the dark image from the light to yield the "final" image.

The image then has to be flat-field corrected using a master flat image to account for inhomogeneity in pixel sensitivity. The master flat for the old SBIG camera was created by averaging forty flat-field images in a controlled environment by Arie Verveer at the Perth Observatory. Due to the unavailability of the specialised equipment, flat field correction has not been applied to Sky-42 yet. Once a master flat has been obtained the data can be re processed to give more accurate readings.

PROCESSING

The next step in processing the dark subtracted, flat-field corrected images is to determine the bearing of the image. Spatial and temporal data are fed to Stellarium to replicate a view of the night sky. The images are then manually aligned for each observing night. Note that the compass is "inverted" relative to the conventional (downward-looking) view.

This method is not ideal as it involves some manual input from the user and is thus susceptible to an incorrect alignment, especially if the user is unfamiliar with astronomy. A major alignment issue occurs if the camera is not pointed directly towards the zenith of the sky; as such, a bubble level and much care must be used in deploying the camera.

When the bearings in the image have been determined, the next step is to search small sections of the sky according to astrometrical data from Stellarium. Each section should contain one bright star. The stars targeted are those which are listed in the Yale Bright Star Catalogue with less than a 2.5 apparent blue magnitude. This amounts to 68 stars; some have been excluded if they are too close to one another and interfere with background flux calculations, for example Alnilam, Alnitak, and Mintaka of Orion's Belt.

The flux for each star and the background surrounding it is then calculated. This is a difficult aspect to automate because it must be a general method of deciding how many pixels contribute to the star flux. Such a method was achieved by integrating over successively more pixels, starting from the brightest, until the background flux (simply an average of the remaining pixels) flattens out, weighted towards a lower number of pixels. In theory this represents the point at which the pixels being added are from the background instead of the star, as the average of the dark sky is relatively constant.

These data are subsequently processed similarly to the method described by Rabaza, 2010. The fluxes determined in each section are first converted to a logarithmic scale by

$$m_B{}' = 2.5\log\left(\frac{\Phi/t}{A}\right) \tag{1}$$

where Φ is the flux per pixel of the source in consideration, t is the exposure time of the image, and A is the number of squared arcseconds in each pixel, an instrumental value measured during the calibration process.

Before these can be compared to apparent magnitudes as listed in star catalogues they must be standardised to known magnitude values. Equation 1 is offset from these magnitudes by both an instrumental factor, the zero-point constant C, and a factor related to the amount of air the light is required to pass through. The atmospheric conditions of each night are represented by an extinction coefficient K. The offset is the product of this constant and the equivalent volume of air the light is required to pass through, known as the airmass χ. Following the formula given by Rozenberg 1966, this is approximated as

$$\chi = \frac{1}{\cos z + 0.025e^{-11\cos z}} \tag{2}$$

where z is the zenithal distance and is directly related to altitude, which in turn is obtainable from Stellarium.

Factoring in the offset the relationship between the blue magnitude of a star listed in a catalogue, M_B, and that calculated with Equation 1 can be found by

$$M_B - m_B' = K\chi + C \tag{3}$$

Using Equation 3 for a sample of stars allows the determination of values of the atmospheric extinction coefficient and zero-point instrumental constant by linear regression. From the 68 brightest (in the blue range) stars searched, generally around 20 will be included in the sample. Only the stars found 20° above the horizon are used because their fluxes are less likely to be affected by light pollution. From this the magnitude of every individual pixel in the sky with a modified Equation (1) can be calculated,

$$m_B = C - 2.5\log\left(\frac{\Phi/t}{A}\right) \tag{4}$$

This effectively standardises the image by comparing the observed stars in the sky to the star catalogue and quantifies the brightness of unknown light sources, particularly the light pollution around the horizon.

Equation 4 is only dependent on the zero-point constant which is dependent on the camera alignment and should stay the same for every image taken by the camera. As a result the camera only needs to be calibrated once using a large dataset of clear sky images. This implies that images affected by cloud cover can now be processed provided the camera has been previously calibrated.

A Connected Component Labelling algorithm is used to identify regions in the image that are connected to the same light source. This then allows the counting of the number of pixels of each magnitude for each light source. Connected Component Labelling is very efficient and is significantly faster than the previously inefficient method of checking every pixel in the image, (i.e. 10 million pixels).

OUTPUT PRESENTATION

Qualitative results: Raw images and processed isophotes

It is important to also provide both a qualitative impression of the light conditions, especially large but less intense generic glows which can be graphically represented, as well as the calibrated quantitative data. The latter is useful for temporal comparisons and for correlating with hatchling disorientation observations. Ultimately these data will be the basis for placing light pollution limits.

The analysed images are presented in the form of an isophote. An isophote plot is analogous to a topographical map where the contours represent levels of apparent magnitude rather than elevation. This has the benefit of replicating the presence of light as it appears on the beach while also delivering a quantitative sense of intensity via the colour scale. Red represents the brightest lights – often saturated. For each of the light sources of interest, the number of adjacent pixels with intensity values greater than magnitude 'x' are found before converting them into units independent of instrumentation, similar to the formula for the SBIG All Sky Camera:

$$A_{<x} = \text{pixels less than magnitude x} \times \frac{174.5\ \text{arcsecond}^2}{\text{pixel}} \times \left(\frac{1\ \text{arcminute}}{60\ \text{arcsecond}}\right)^2 \quad (5)$$

to give area values in units of arcminute^2. To find the number of pixels less than a certain magnitude, the Connected Component Labelling algorithm is used which identifies regions in the image that are connected to the same light source, is used.

Quantitative results

Values are collected for each of the discrete light regions for these four magnitude bands over the night, after excluding outliers caused by atmospheric effects (clouds or rain), condensation formation, the presence of the Sun or Moon, or obvious changes in the source (lights turned on or off, vessels moving). The data are averaged and presented with a standard deviation to account for the variability in a discrete light source throughout the night.

The quantitative results (see Section 3.0) are presented for each identifiable light source within an image on each survey night at each location. The amount of light calculated for each light source is an average of the area of light in the image for each of the four magnitude bands from each usable image on that night and at that location. The magnitude of the value is a representation of the area of the sky illuminated by the light glow while the standard deviation gives an indication of how much fluctuation there was in the light emissions over the night. The standard deviation does not always represent the normal changes in the light source (i.e. switching on/off lights on the vessels/other work sites etc.) overnight; often it is a representation of how the changes in atmospheric conditions (i.e. cloud cover and movements) affect the light received at the observation sites (in this case the beaches).

Figure 1 shows the output of the CCL code, each different coloured area represents a source of different light intensity. The group of pixels within an area represents the spatial extent of that particular source. This method is used to measure the total area covered by a particular magnitude.

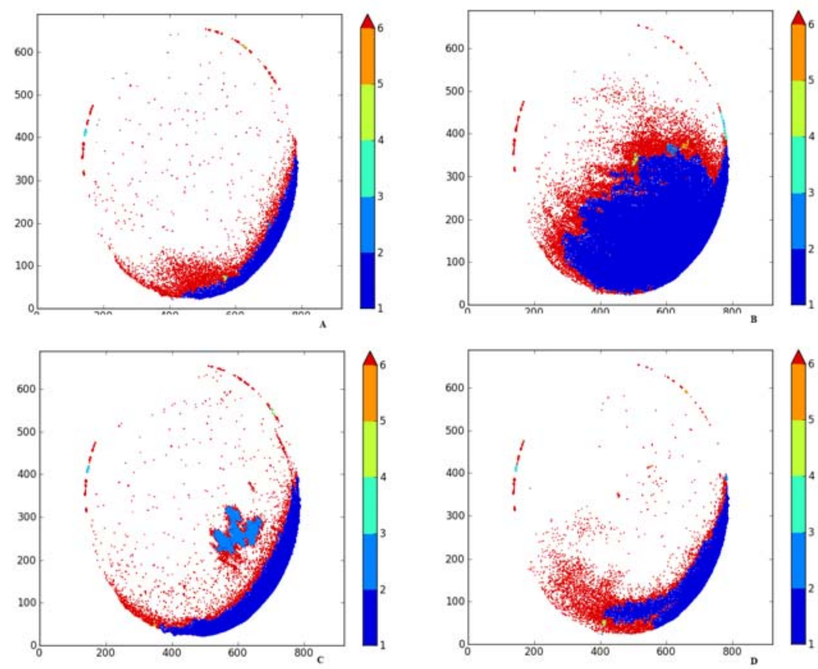

Figure 1: The output of the CCL algorithm. Each different colour "blob" represents a different magnitude source. The number of pixels of each colour are counted and used to find the area covered by that particular magnitude. The numbers on the scale represent labels to help colour different magnitudes and as such are not any physical units.

SOURCES OF UNCERTAINTY

The combination of multiple processing steps creates many potential sources of error that are difficult to quantify. All instrumentation comes with its own uncertainties which are reduced to an extent in the Sky-42 Camera by performing the dark subtraction. Digital cameras typically have limited sensitivity at low light intensities, especially in the case of the blackness of empty space and the signal is further diminished in coastal regions where atmospheric water vapour can be high. However, most target measurements used in the standardisation are of relatively high-intensity stars and artificial light sources, so this system, for practical reasons, is considered the most suitable that is currently available.

In general, the statistical uncertainties of pixel intensities are reduced by taking a 120 second exposure and averaging over this time as in Equations (1) and (4) giving a higher signal-to-noise ratio than short exposure times. On the other hand, a longer exposure time leads to star trails, causing the total flux of a star to be predictably spread out over more pixels. As the algorithm for determining flux considers a sector of the sky that encloses each star and its trail, it is able to account for these short trails.

This algorithm in itself does not produce as accurate results as it would if done carefully by hand, but it is also more efficient and consistent. It is also less susceptible to human error or bias. The flux values it returns are generally in agreement with those obtained manually, so when a value is clearly inconsistent with the rest it can be confidently discarded as an outlier before the regression step.

The blue wavelengths measured by the instrument are also especially susceptible to absorption of light by invisible atmospheric water vapour and other molecules present in the atmosphere (Horvath, 2003). Water vapour is a highly variable component of the entire depth of the atmosphere and to some extent, along with extinction from other molecules present in the atmosphere is modelled by Equations (2) and (3). The extinction of light from terrestrial sources is deemed a less significant factor as the volume of air passed through is much lower. Therefore the calculated coefficient is not included in Equation (4).

While the long exposure time may yield an accurate average for relatively constant light sources such as stars, it will be less accurate for potentially fluctuating artificial sources. A moving light or one that is switched on for only half of the exposure time will appear to have a proportion of its intensity in the image. This will give an underestimate of the light source for that image. However, the most intense light sources, in particular large glows from construction sites, are unlikely to be regularly switched on and off or fluctuate or accumulate in the time scale of minutes.

Errors in the location of the camera and time of image are manageable and are an insignificant contribution to the total error. The GPS readings are very precise and the time of image capture is automatically recorded in the file name. Inputting these parameters into Stellarium permits the extraction of accurate astrometrical data to align the image with the stars. A potentially more substantial source of error is levelling the camera base to the ground with a bubble level. However, so long as care is taken while setting up the camera and the zenith in the image approximates the normal to the Earth closely enough; the processing algorithm always finds the star within the section that it searches.

As this processing method relies on the use of stars visible in the image, both for establishing bearings in the image and standardising the magnitudes of light sources, any shielding of these stars may compromise the results. Specifically, heavy cloud cover that conceals most of the stars results in an incorrect standardisation. To circumvent this, Sky-42 will use clear images collected on one of the observing nights to calibrate the zero point constant. This method requires that at least one of the observing nights be clear.

All these uncertainties are difficult to quantify individually, so in order to attach a value to the final result, systematic errors must be eliminated wherever possible and multiplicative errors avoided. For example, collecting a large sample set to obtain an average and standard deviation. On an ideal observing night, about 20 stars are used to standardise each image, and up to 40 usable images make up the ideal data set.