The Biological Basis for the Canadian Guideline for Outdoor Lighting 6.

Canadian Guidelines for Outdoor Lighting (CGOL)

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Abstract

Lighting technologies have reduced the cost of outdoor lighting, so it is becoming less expensive to use brighter lights in more remote locations. Currently, industry lighting guidelines only place "lower limits" on illumination and luminance, which leads to the current exponential growth in brightness and extent of outdoor lighting (Kyba 2020).

During the last two decades a century of research on light at night has been re-focused from its impact on astronomy to its wider ecological impact and how it affects human health. Using animal sensitivity to artificial light, and modern work on human vision, there is sufficient information to support a lighting guideline that can provide light for human activity after dark, while minimizing its impact on animals and the ecological balance. This paper distills the generally available information in the research literature, including the preceding five papers in this series, into a coherent and practical guideline and specification for outdoor lighting with low ecological impact.

The effectiveness of these guidelines on human vision has been tested. Although these guidelines are based on extensive study of the research on biology and behaviour, their biological effectiveness on reducing the impact on the ecosystem requires long-term observations.

Critical Attributes Of Light

Scotobiology provides a new set of rules that define "upper limits" on the attributes of outdoor luminance and illuminance (Dick 2012, Dick 2013). These Canadian Guidelines for Outdoor Lighting (CGOL) do not recommend specific luminaires or lighting technologies. Lighting products continually enter the market, and are retired, as technologies evolve with surprising rapidity. To list hardware specifications or specific lighting products would soon render these guidelines obsolete. Consequently, these guidelines provide limits on the resulting luminance and illuminance. Lighting professionals can then work back from these requirements to select compatible luminaires.

In the previous set of five papers (Dick 2020a, Dick 2020b, Dick 2020c, Dick 2021a, Dick 2021b) we have presented the four critical attributes of Artificial Light At Night (ALAN): brightness (luminance and illuminance), extent (shielding), spectrum (colour) and timing (scheduling). Table 1 shows the interdependence of these attributes. This paper integrates this information and proposes a balance between them for use in areas where the ecology is a priority in-and-around illuminated areas (target areas).

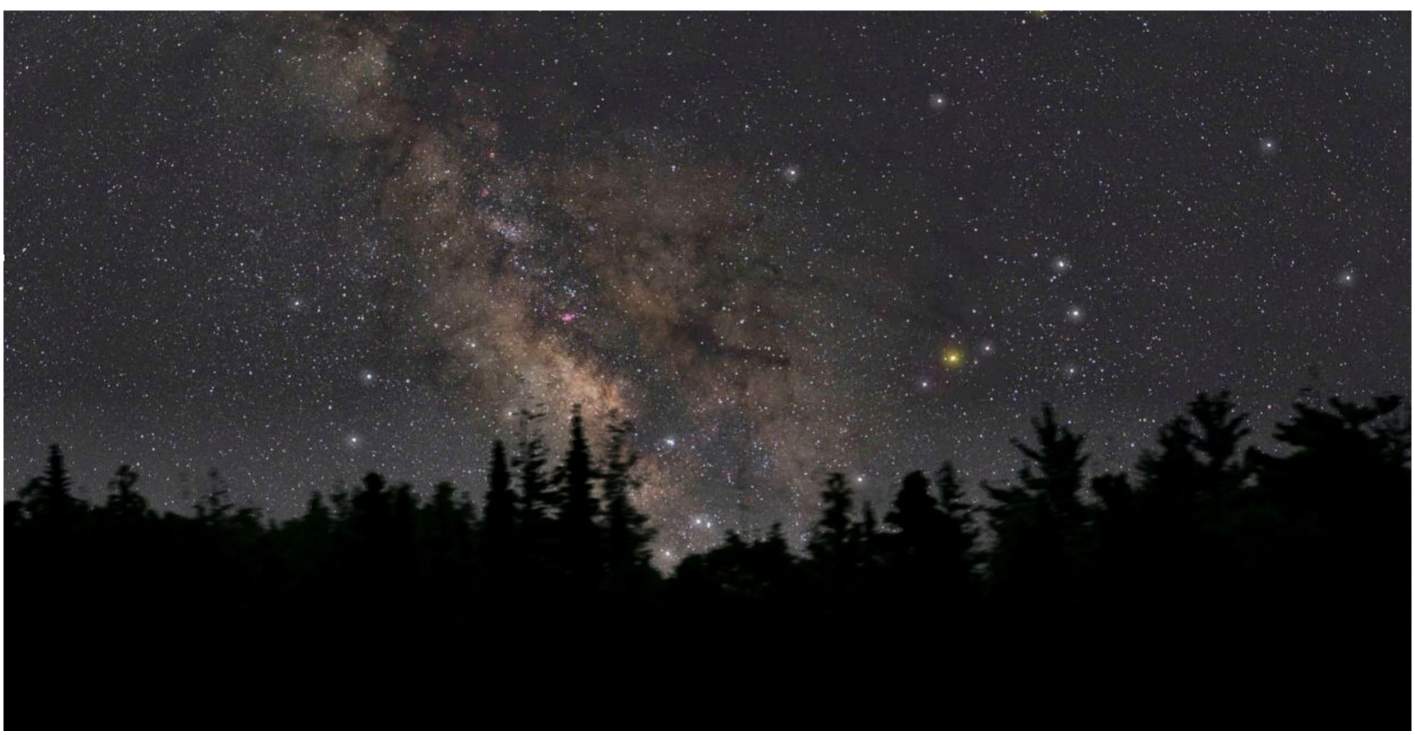

Figure 1 — Sky over Bruce Peninsula Dark-Sky Preserve. Under only starlight, the trees form a dark silhouette against the horizon.

Table 1 – Relationship between light attributes and perceived light pollution.

Attribute	Glare	Light Trespass	Sky Glow	Circadian Rhythm
Brightness (Dick 2020b)	X	X	X	X
Shielding (Dick 2020c)	X	X	X	
Spectrum (Dick 2020d)	X	X	X	X
Schedule (Dick 2021)		X		X

Figure 2 — Sky glow of town from 15 km away. A town with only 5,000 people can appear brighter than a city of a million if its lighting is not shielded and commercial lighting is not curfewed.

Glare

The most obvious impact of light pollution is glare that comes from the luminance of the light fixture, and even the light emitted by the illuminated surface. These are affected by brightness, shielding, and the spectrum of the light.

Some glare is necessary if the lamp is to be seen (marker lighting) or a surface is to be illuminated. But excessive luminance can create so much glare that it can compromise or cripple vision (Dick 2020b). We can reduce glare using several techniques.

Scattered light in our eyes, eyeglasses, and windows will be perceived as a veiling glow across the field of view, reducing the contrast of the scene. In extreme cases, "excessive" glare will contract our iris to let less light into our eyes and will bleach our rod cells, blinding us from seeing into the periphery of the illuminated area. All these can be reduced through reduced brightness, shielding, and colour of the light.

If reducing the amount of emitted light will reduce these effects, how much light do we need? The brightness required for visibility was discussed in the first and second papers of the series (Dick 2020a, Dick 2020b) and the uniformity, to reduce the concentrated luminance of a surface near the lamp, was discussed in the third paper (Dick 2020c).

Figure 3 shows that there is still significant glare beyond the illuminated area with FCO and to a lesser extent with ShCO shielding. To augment the fixture shield, trees and bushes around the target area can provide additional containment. However, for this to be practical, the luminaire must not be mounted above the surrounding trees.

The perception of glare is a function of wavelength (Dick 2020d). We unconsciously perceive blue spectral components as being 5× to 10× brighter than yellow-orange, or amber light. Therefore to reduce the visual impact of glare, the blue-light components must be filtered and removed.

Removing the blue-spectral components has a second benefit. Dust and aerosols in the low atmosphere scatter the glaring light and uplight, contributing to artificial sky glow. This brightens the urban sky and appears as a glow over distant urban centres. The process is wavelength dependent (Rayleigh scattering or 1/ wavelength), so sky glow can be reduced with longer-wavelength amber light that will scatter less.

This has a third effect. Short-wavelength light scatters close to the source, reducing its impact at greater distances. Thus the

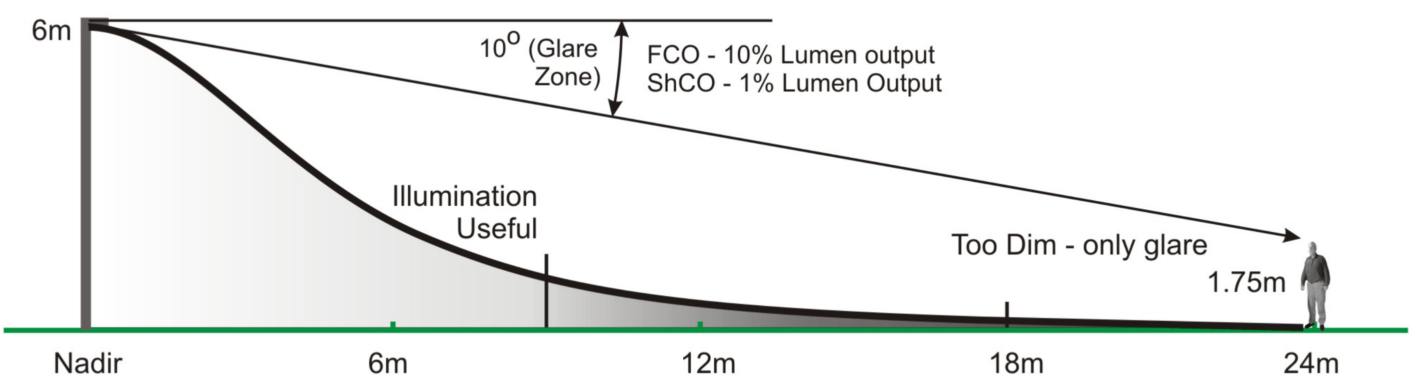

Figure 3 — Illumination and glare with distance. The range of useful illumination is quite limited, and beyond that range the luminaire creates only glare. The only ways to reduce glare is to reduce the lumen output of the luminaire, mount it on a short pole or use more aggressive shielding—ShCO instead of FCO. Since the illumination at distance is so low, the shielding will not reduce visibility in the periphery.

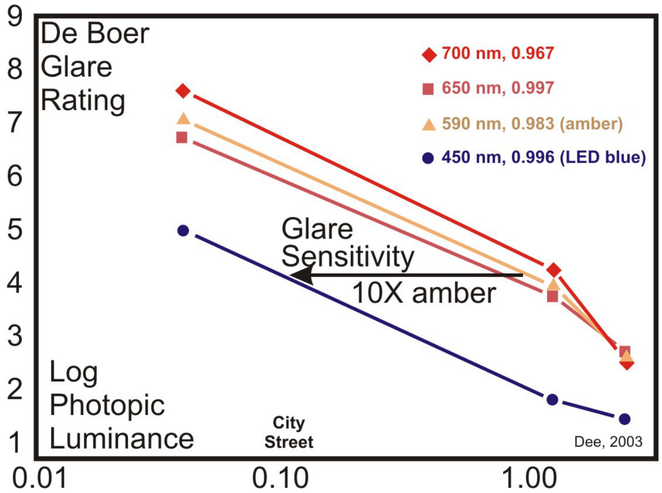

Figure 4 — Subjective assessment of glare of different colours of light. Using the de Boer scale for glare, blue light must be about 1/5 to 1/10 the brightness of amber for it to be perceived with the same degree of glare. (From Van Derlofske and Bullough 2004.)

scattered light will "redden" with distance. Although amber light will be scattered to a lesser degree and will therefore shine farther (Luginbuhl 2013), less amber light scatters back to the ground. Also, our scotopic vision is less sensitive to these long wavelengths than to blue wavelengths—so we will perceive less sky glow.

Marker Lights

The luminance of a lamp can be used to mark a course to help in navigation and situation awareness (a curve in a road). Illuminating the ground may not be sufficient for this purpose because of the poor visibility of a horizontal surface along hilly terrain viewed at a low angle at a distance, so an unshielded marker light may be preferred. However since they are not meant to illuminate the ground, much lower luminance lamps can be used.

The planet Venus (1 cd/m^2) appears quite prominent in the bright twilight sky, and appears "brilliant" in a dark sky, so the luminance of a marker light should be less than 1 cd/m^2. Since a fainter lamp will still be prominent against a dark line of trees, we prefer a lamp with about 0.1 cd/m^2. This corresponds to about a 50 mw[1] directional LED that can be powered by two AA batteries for about 1000 hours!

Bug Rating

Selecting a commercial luminaire that will reduce glare has become much easier with the "BUG Rating". The name stands for Backlight (illuminates the mounting wall behind the luminaire), Up-light (shines directly into the sky) and Glare (light that shines directly into our eyes and creates light trespass) so luminaires should have B=U=G=0. This may not eliminate all of the glare, but it will be much better than lights B, U or G ≠ 0.

Backlight can help identify a building, but if the fixture is properly shielded (no glare) there is sufficient light scattered from the ground to illuminate a nearby wall.

Light Trespass

The impact of glare and light trespass is subjective. Some people may tolerate light trespass but others may be very sensitive to it. So to simplify—these Guidelines focused on the biological and behavioural limits discussed in previous papers in order to remove "personal preferences."

Light trespass refers to light that shines where it is not wanted. It has a relatively local impact, which differentiates it from glare. It is affected by all four attributes of light: brightness, shielding, spectrum, and scheduling.

Illumination may be desirable in the early evening, but not late at night, when it could shine into bedrooms or may impact wildlife activity or biology (circadian rhythm). Shielding is an obvious solution but it can be made less objectionable later at night if the light is dimmed or the colour shifted to longer wavelengths (filtered).

Light trespass can be characterized by the luminance of the lamp and the surrounding illuminated surface (vertical wall or horizontal ground) as viewed from beyond the edge of the target area, or property. These are subject to the albedo of the illuminated surfaces.

Non-uniform illumination will exacerbate light trespass by producing over-bright patches—above the ecological threshold, that makes it difficult to see into the periphery. A small bright patch can have a greater impact than a larger area of lower illumination - below the threshold. For example, the mounting surface of a wall pack light fixture can be over 200× brighter than the threshold due to its close proximity to the mounting wall. A reflecting wall's high albedo and height will cause it to impact a wide area—"as far as the eye can see."

The illuminance at property boundaries should be below the ecological thresholds (0.02 lux or the illuminance produced by the crescent moon (Dick 2020b)) irrespective of the limits for human activity, since we should not encourage human activity beyond the activity area if it makes hazards accessible and will impact the natural landscape.

The luminance of the lamp or illuminated surface, as viewed from the edge of the target area, should be less than that the bright star Sirius (0.1 cd/m^2). Sirius is a "white" light source. However using an amber light source allows a brighter limit (up to 2.5× — Dick 2020d) that will still be less than this threshold. Alternatively, the luminaire may be mounted away from the wall, to reduce the illumination from the backlight.

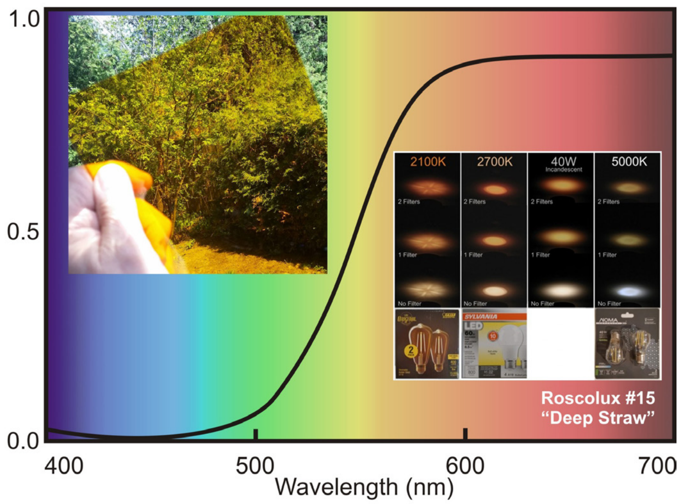

Figure 5 — Filtering offending lights may be the least expensive solution for some applications. Roscolux "Deep Straw" #15 photographic film is a very inexpensive way to render some white lamps amber-compliant. (Available from www.bhphotovideo.com, and from www.csbg.ca/BLOG.HTM, accessed 2020 June 5).

In addition to shielding the luminaire (Dick 2020c), trees and bushes bordering the area should be used to block the light scattered from the ground. This requires the luminaire to be mounted below the height of surrounding trees and bushes (typically 6 meters). Vegetation has a typical broadband albedo of 10-20%, so plants will help absorb scattered light – preventing it from shining beyond the target area.

Where possible, surfaces that are illuminated for safety (railings, steps, etc.) should have a high albedo (painted yellow or white). This will reduce the amount of light that is used for visibility to less than 20% compared to a dark brown surface.

This shows that there are a range of options for reducing light trespass that involve luminaire shielding, natural vegetative shielding, light spectrum and surface albedo control (paint). These can be balanced off to suit local circumstances.

Sky Glow

Sky glow is the symbol of distant light pollution—forming a dome of light above brightly lit areas. It is the combined effect of glare and light trespass, so by properly managing these sky glow will be minimized. However the benefits of careful shielding can be undermined if excessively bright lights are used, even if shielded because of the light that reflects off illuminated surfaces, or if some bright and unshielded lights are allowed to remain.

Circadian Rhythm

Unlike glare, light trespass and sky glow, which can be cut immediately with a light switch, the disruption of our circadian rhythm has more lasting effects that may not become evident for years or decades when we have grown into our senior years. The circadian rhythm schedules our many biological processes that retain our health and vitality; and is affected by the spectrum of the light, the light brightness, and timing the light.

ALAN will provide mis-cues and will alter our natural circadian rhythm. However we can take advantage of the natural biological and behavioural plasticity of animals to extend the early twilight later into the evening (Dick 2021b). However, this plasticity must not be used as an excuse to over-extend twilight for aesthetics or perceived safety when there is minimal human activity.

The circadian rhythm of most animals and plants is very sensitive to the perceived end of twilight, so ALAN should be dimmed below the biological threshold of 0.02lux during times of limited human activity. If more light is deemed necessary, then ALAN should be restricted with shields so as to minimize the extent of the contaminated area and limited to an amber spectrum to reduce its biological impact.

Facility managers should not assume light is required at night without records of when people are mobile. Typically most people do not drive or walk about after the late evening or during the night (Dick 2021b), and this has also been observed in rural areas and parks.

General records indicate that pedestrian and vehicle traffic are low two hours after sunset between mid-spring to mid-autumn and about 22:30 in winter—subject to the local schedule of activities. Readily available sunset and sunrise detectors and timers are available to turn lights on and off at the appropriate times. And, some luminaires have built-in and programmable timers that control the luminaires to reduce electricity use and their ecological impact.

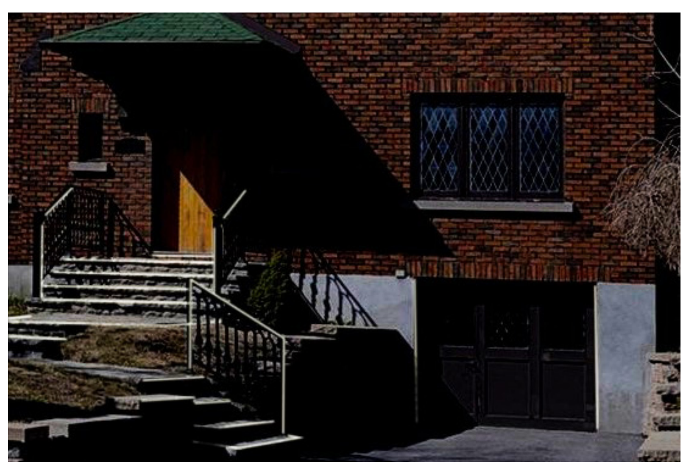

Figure 6 — Reflective paint to highlight hazards and features. Some hazards are identified by the irregular shadows they cast. However at night these shadows can be indistinct—even with flashlights. Highlighting these features with reflective pain (white or yellow) will make them more visible with less artificial light—even under moonlight. (Simulated image)

Most species are sensitive to short wavelength light at night, so the spectrum of ALAN should avoid blue-light components (<500 nm). This spectral limit is typical of consumer "bug lights" available from retail stores. If changing lamps or light fixtures is not convenient, then inexpensive filter sheets can be mounted inside the luminaire to absorb the blue light before it leaves the fixture (www.bhphotovideo.com—Roscolux #15 Deep Straw film, or equivalent).

Figure 7 — Glare from unshielded lighting. This example shows across-channel glare from light fixtures that remain on throughout the night—even when owners are not home.

Guidelines And Specifications

Guidelines provide general principles that support a vision of the future, and reflect the values that are important to society. Currently, our society aspires to protect the natural environment as much as possible given our predilection for late-night outdoor activity. As society evolves, these values may change, however, the ephemeral nature of a value system should not prevent us from trying to improve our current situation.

Some gidelines are a "narrative" and may be too general to be used to design a lighting system and select hardware, which requires more specific information. Specifications are "specific" and are used to engineer the ALAN. Scotobiology provides the limits for these specifications that are unequivocal and measurable. Specifications define the lighting requirements—not the technology. Therefore they do not include a list of compliant hardware. To do so would soon render the document obsolete.

The tables in the next section define the brightness for a range of typical applications of outdoor lighting. Urban areas have considerable co-lateral lighting that undermines the visibility that would be provided by these Guidelines. Therefore they may not be practical for some urban locations. However where practical and permissible, urban officials will benefit from adopting these guidelines to replace older lighting that conformed to earlier and disruptive urban "Best Practice." Application of these Guidelines can be used to help work toward a more sustainable future.

Canadian Guidelines For Outdoor Lighting (CGOL)

Human activity is generally centred near built structures and activity centres (referred to here as buildings) and transportation routes (pathways, roadways, and parking lots). We differentiate roads from parking areas and pathways because parking areas have greater potential for conflict between vehicles and pedestrians.

In the following tables, N/A = not applicable, and curfew refers to when the lights are turned off, or dimmed to produce less than 1-lux illumination. It defaults to about two hours after sunset when buildings or services are closed.

Lamp power is not given because it depends on the lamp efficacy, which depends on the technology used. The required fixture-brightness (lumens) is approximately the illumination level (lux) multiplied by the area to be illuminated (m^2). This assumes uniform illumination. As a point of reference, 2-lux is approximately the illumination of twilight under a clear sky 20 minutes after sunset.

Buildings

These guidelines refer to different building types and uses in park settings: administration and offices, kiosks, services, and retail outlets. Offices are generally closed and not available to the public after office hours, which usually end before sunset, except in winter. Public buildings (information kiosks, showers, toilets) will be needed throughout the night and may require both marker lighting and illumination to safely guide visitors to and from the building.

Indoor illumination (200-1000-lux) bleaches (blinds) our night vision, so upon exit, a period of approximately 10-20 seconds is needed to initially adjust to the night. Therefore a period (distance) of transition back into the night is needed for pedestrians to reach pathways, parking lots, or other facilities. Illumination levels need to be about 2-lux—high enough for the use of our cone vision but not so high as to prevent the recovery of our rod vision.

Pedestrians walk between buildings. Observation and anecdotal reports indicate that pedestrian activity (persons / minute) is typically much less than 1 person / minute after dark—when artificial light is used. This is significantly less than the urban traffic on which the industry guidelines are based (IES RP-08). Therefore only the lowest illumination levels should be used.

Retail outlets may be stores or vending machines. Stores are generally closed in the late evening so their internal lighting should be turned off or significantly dimmed. However, vending machines will likely be visited throughout the night. These machines should be enclosed to prevent their internal lighting from affecting the area around them. This will also protect the machine from the weather.

Shielding and mounting-height limits ensure the light and glare is contained within the target area. In all cases, FCO or ShCO shielding and amber light shall be used. Where no visitors are allowed after dark, outdoor lighting should be turned off or dimmed so as not to attract and encourage visitors. The dimmed brightness will protect our scotopic vision and permit our ability to read posted information (about 1-lux).

*Table 2 – Building Illumination Guidelines (Maximum Values)**

Area	Type	Light/Lamp	Level (lux)	Height	Curfew
Office Buildings	FCO ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	Yes
Public Bldgs.	Marker, FCO ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	No
Retail Outlets	FCO, ShCO	Amber Incandescent, LED or Filtered	~2 lux	2.5 m	Yes

** Curtains should block indoor lighting within 30-minutes of sunset.*

Parking Lots

Parking lots have both pedestrians and vehicles. Due to potential inattention of motorists and the vulnerability of pedestrians, it is necessary to augment the relatively directional car headlights with more isotropic illumination.

The illumination shall be in the low mesopic region so pedestrians can use both their sensitive scotopic vision and photopic vision when around vehicles. The lighting for these lots should be turned off after the associated office buildings have closed or other night activities have ended and traffic is minimal.

Although Table 2 refers to buildings that are accessible to pedestrians, Table 3 refers to areas where the pedestrians may have parked their cars. No extra lighting may be needed in small lots because there will be fewer pedestrians and fewer cars than in large lots. And in small lots, cars will typically be parked around the perimeter reducing the need for pedestrians to cross the open lanes.

In larger parking lots, light fixtures should be mounted on poles near the perimeter and shine light in toward the centre with shielding against backlight beyond the lot perimeter. The mounting height must be limited to that of adjacent trees (typically 6 metres) to help contain scattered light to the parking area.

Table 3 – Parking Lot Illumination Guidelines (Maximum Values)

Parking Area	Type	Light/Lamp	Level (lux)	Height	Curfew
For < 10 cars	N/A	None	N/A	N/A	N/A
For > 10 cars	FCO, ShCO	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	Yes

Roadways

In the second paper of this series (Dick 2020b) we presented various aspects of roadway illumination and luminance. The IESNA Handbook and RP-08 provide guidance for urban illumination but are based on higher traffic densities than are typical of rural areas and parks. However, users can significantly reduce their ecological impact by taking advantage of shielding, spectrum and dimming, described here, when adapting these documents to rural and semi-rural areas.

Roadway illumination provides three functions: visibility of the road surface, situation awareness (for navigation) and to avoid unexpected hazards (visibility of pedestrians and animals). Rural roads may be illuminated in built-up areas (hamlets, villages and towns). These guidelines refer only to the rural communities and park facilities. However, roadway lighting should comply with the City Right-of-Way Lighting Policies where they exist and may be adopted for urban residential areas.

Typical park settings can have much lower traffic densities than urban areas, but during twilight when people are returning to their vehicles and tents, dark adaptation is inhibited by a relatively bright sky, yet the low albedo of trees and bushes is too low to help silhouette pedestrians against the background. Therefore some additional illumination may be needed.

Most rural and semi-rural roads only have marker lighting at intersections. However, glare from these unshielded lights along a dark road will significantly reduce visibility of roadside hazards, so it is recommended that they be shielded, or removed and replaced with roadside equipment, retro reflective signs, and turnoffs designed with car headlights in mind. For example, bushes and trees may be planted near intersections, with suitable setbacks, to provide visual cues for approaching motorists. Car headlights can illuminate this vegetation to improve situation awareness without the added glare from a streetlight; they will also shield against light that shines beyond the roadway.

In Table 4 we refer to roadways with low traffic speeds and vehicle densities. These would be typical of towns, villages, hamlets, parks, and in low-rise urban residential areas.

Table 4 – Rural Roadway Illumination Guidelines (Maximum Values)

Roadways	Type	Light	Level (lux)	Height	Curfew
Rural Local	None	N/A	N/A	N/A	N/A
Rural Collectors	Marker	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	No
Rural Highways	Signs, Marker	LPS, HPS or Amber CFL, LED, or Filtered	~3	6 m	No

Pathways

Pathways are for pedestrians with speeds at a walking pace, however if the pathway has been graded and smoothed, human powered aids can be expected (wheel chairs, skate boards, bicycles, etc.). If these are permitted then landscaping should ensure good sight lines. IESNA recommends illumination levels of about 2 lux for walkways and bikeways, in residential areas with low traffic volumes and speeds.

Less travelled pathways do not require illumination throughout the night. However, main pathways may provide navigation cues at night, so they may be exempt from a lighting curfew.

Pathways are typically narrower than roads and the optics of overhead luminaires will be unable to limit the extent of the illumination to the path. Therefore the mounting height should be closer to the ground. To avoid glare as the pedestrians pass by, the lamps should be FCO and mounted on approximately 1-metre-high bollards.

The illuminations in Table 5 are based on the need to follow the path and see obstacles on the ground. Although 1-lux is the ground illumination, a pedestrian with printed instructions will be able to hold his or her map closer to the light source, so it will appear easy to read.

This illumination assumes an asphalt (dark) surface, so a more reflective surface will require lower illumination. For example, white crushed stone is easily followed with only a full Moon (0.1 lux)—assuming the path is not under a tree canopy.

Table 5 presents the illumination of three types of pathways. Most paths are rarely used, or the public may not be encouraged to use them at night. (There may be limited navigation cues or hazards that should be avoided.) Paths may also remain un-lit due to the cost and risk of running high voltage power along the path. To help delineate these paths, a (passive) reflective surface or light-coloured edging should be used.

Table 5 – Pathway Illumination Guidelines (Maximum Values)

Pathways	Type	Light	Level (lux)	Height	Curfew*
Minor Paths	None	None	N/A	N/A	N/A
Illuminated Paths	FCO ShCO	Amber Incandescent, LED or Filtered	~1 lux	1 m	Yes
Main Pathways	FCO ShCO	Amber Incandescent, LED or Filtered	~1 lux	1 m	No

Shorelines

Built facilities and light fixtures should be set well back from the water to protect the sensitive aquatic and shoreline ecology. Shoreline lighting will also shine out across the water, scattering off the surface—creating glare and confusing waterway navigation.

There are three general applications for these guidelines: shoreline property, private dock and large dock or lock facilities.

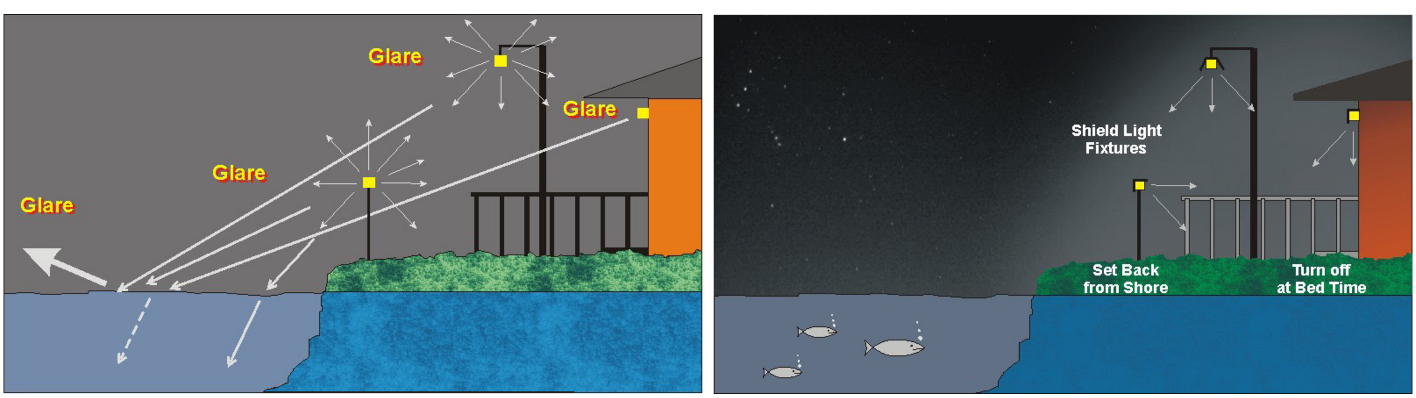

Figure 8 — Guidelines for shoreline lighting. Placement, shielding, brightness, and colour are critical for minimizing the impact of the ALAN on navigation of the waterway and on the biology of the ecosystem.

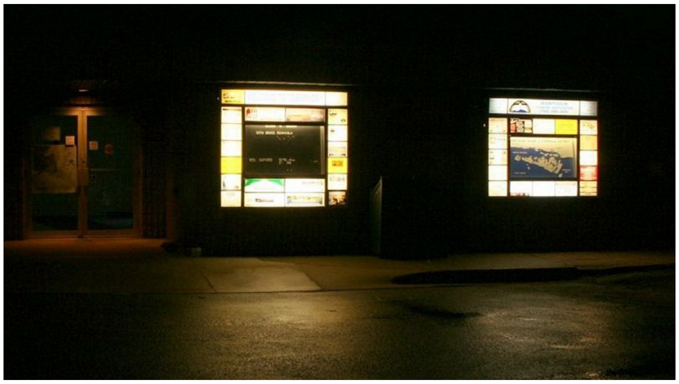

Figure 9 — Glare from backlit signs reduces visibility along roadway and makes doorway lighting ineffective. Notice that the non-white signs are more readable.

Some light may be needed at dock facilities where people will be entering or leaving boats at night. Significant glare undermines this visibility. This activity requires only enough light to see the boat gunwale, edge of the dock and the gap. White paint will help delineate these areas with minimal light and glare. Since it is inevitable that light will shine into the water, the illumination level must be as low as practical, shielded and curfewed.

In general, there should be no light fixtures within 10 metres of the shore. This setback will lower the angle the light will shine on the water and will reduce the light that penetrates the surface.

Where machinery is present, more light may be needed for safety and situation awareness. Luminaires should be mounted above the area so as not to interfere with this activity but flood lighting from the side shall not be used. Since dock activities do not generally extend throughout the night, a curfew should be in place when there is no activity. If there are boat departures and arrivals throughout the night motion detectors should be used. Otherwise these light fixtures may be exempt from the curfew.

Table 6 - Shoreline Illumination Guidelines (Maximum Values)

Waterways	Type	Light	Level (lux)	Height	Curfew
General Areas	N/A	None	N/A	N/A	N/A
Dock Bollards	FCO ShCO	Amber Incan-descent, LED or Filtered	~1 lux	1m	Limited
Lock Facilities	FCO ShCO	Amber Incan-descent, CFL, LED or Filtered	~3 lux	6 m	Limited

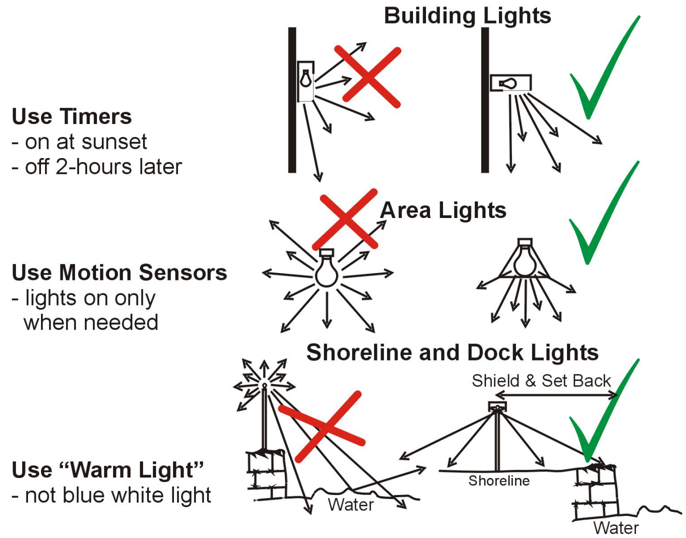

Figure 10 — Simple summary of techniques to reduce the impact of ALAN

Signage

Signs are used to augment situation awareness for navigation and provide information. There are three general types of signs. Those visible by reflecting incident light, those lit internally and signs illuminated with exterior lights. Retro reflecting signs are preferred since they are passive (scatter light when flashlights are present) and efficiently reflect dim incident light.

If signs are to be illuminated, the shielding, colour, brightness and scheduling of the light fixtures shall comply with the earlier sections of this guideline.

Managers should not use signs with white backgrounds and dark text or graphics because the expansive bright surface will cause glare. Signs should use high albedo (reflective) text and graphics on a dark background. They should also use contrasting colours instead of white and black.

Summary

In all cases the default lighting is for no illumination. However when deemed necessary by the manager, these guidelines and specifications should be used. In some cases lighting levels may need to be increased but with the knowledge that this will undermine the ecological integrity of the area, it will reduce visibility for people beyond the target area and will increase the cost of the project.

Additional and more detailed information is provided in the RASC-CGOL, and its Appendices. These are freely available from the RASC, CSbG Inc. and other sources.

Continues on page 124

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The six tables in this paper summarize most applications for ALAN in public areas based on pedestrian level activity (walking) and vehicle traffic. These limits minimize the impact on the ecosystem and they will help preserve our enjoyment and the aesthetics of the night environment. ✷

Endnotes

1 0.1 cd/m^2 = 0.1 x 4π lumens ~ 12 lumens or 0.012W. At 3V, this is 0.004A. 2 x AA = 4Ah, so a set of 2 AA batteries (for 3V) will operate for 1,000 hours.

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The August 2021 *Journal* deadline for submissions is 2021 June 1.

See the published schedule at

rasc.ca/sites/default/files/jrascschedule2021.pdf

The Planetarium: Linked to War

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As a youngster, I learned my way around the stars in a way I thought at the time was a little unusual. I learned the major stars and planets from someone who had no astronomy books, no telescope, and no apparent interest in the subject other than getting me oriented. And yet my father knew his way around the sky—and with good reason. As a pilot with the Royal Canadian Air Force in World War II, he was also tasked with learning the basics of navigation so that in an emergency, he would still be able to find his way. So, just how did one learn this skill during the war?

Finding One's Way

At the outbreak of the Second World War, flying was still in its infancy: aircraft flew low, slow and with only the most rudimentary of instruments, including those for navigation. Following roads and rivers was one sure way to find one's way around but traversing long distances, especially over trackless desert, forest, or ocean, was a problem. All this on top of the danger of putting an unskilled pilot at the unfamiliar controls of an aircraft. The seriousness of the situation was demonstrated when, in a 78–day period in 1934, a dozen pilots of the U.S. Army Air Corps were killed (1). Enter Edwin Link.

Link was fascinated by aviation and, in 1929, was prompted to build a flight simulator using knowledge and material gained from his father's Link Organ and Piano Company (2). The device looked like a small airplane and was fully equipped with the same type of instrumentation (Figure 1). Activating the flight controls caused the simulator to move in the same three axes as a real aircraft. Closing the opaque hood cut the trainee off from all external references forcing him to fly on instruments alone. This was helpful preparation for flying in conditions where visibility, in fog or low light for example, was poor. His course could be monitored by a trainer watching a "crab," a wheeled device connected to the simulator that crawled across a map thereby denoting the trainee's cross-