GUIDANCE FOR OUTDOOR LIGHTING
DEATH VALLEY NATIONAL PARK

Including OUTDOOR LIGHTING GUIDELINES, RECOMMENDED OUTDOOR LIGHTING APPLICATIONS, AND STANDARDS FOR THE PROTECTION OF THE NATURAL PHOTOPIC ENVIRONMENT

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Sources:
NPS Night Sky Team Outdoor Lighting White Paper (DRAFT)
NPS Night Sky Team Draft Lighting Zones for Parks
NPS Management Policies (2006)
IENSA Lighting for Exterior Environments (RP-33)
International Dark Sky Association/Illuminating Engineering Society Model Lighting Ordinance (MLO)
Yosemite National Park Outdoor Lighting Guidelines and Standards
Parks Canada Best Practices and Specifications for Outdoor Lighting

INTRODUCTION

Death Valley National Park preserves an area of the Mojave Desert with remarkable natural resources. Visitors experience nature on a grand scale, and one of the most profound experiences is at night, when the landscape is faintly illuminated by the distant suns punctuating the dark night sky. This night sky is a diminishing resource that the National Park Service seeks to preserve. Fortunately, through the application of the carefully considered lighting techniques and technology contained in these Guidelines, the safety, security and way finding of Park visitors and staff can be addressed without any significant impact on Death Valley's night sky.

Good lighting design and application requires the synthesis of several human and environmental factors— what visual tasks are to be performed, expectations for lighting, psychology of security, ocular adaptation level, fixture efficacy, lamp efficacy, fixture placement, ambient illumination level, spectrum, and lighting controls (i.e. switches, timers, and dimmers) to name a few. Additionally there are environmental consequences of artificial outdoor lighting related to direct glare, angular distribution, atmospheric scattering, color, duration, and intensity. Unfortunately most of the knowledge base and recommended practices for outdoor lighting were developed in urban and suburban environments. These practices apply to an ambient environment that is significantly brighter and much more frequently occupied by humans at night than a national park. Also, standards for protection of the natural environment are higher within parks, including

maintaining levels of luminance and illuminance within the range of natural variability in areas that are protected.

Fundamental differences between a park and more urban environments are many. First, visitors and employees expectation for outdoor illumination includes an understanding that all of the conveniences widely available in cities will not be found in parks. For example, visitors expect to need a flashlight while camping or walking at night from their car or campsite to the toilet. Second, parks are a dark environment, and thus typically require less light to provide commensurate visibility because of the dark adaptation of the human eye. In parks, you are commonly transitioning between lit and unlit areas, whereas in cities you experience a mostly uninterrupted series of lit environments. To maximize visibility, sharp contrasts in illumination should be avoided, and light should be "feathered" between zones. Lastly, in parks there are far more environmental concerns, in number and in sensitivity. An errant light can impact a stargazer's night vision a quarter mile away in the dark environment of a park, and what is a disappointment to visitors can be a matter of survival for wildlife.

Although it is preferable for government agencies to utilize widely adopted standards in lieu of inventing their own, the Recommended Practices issued by the Illuminating Engineering Society of North America (IESNA) fit the agency so poorly that specialized guidelines are necessary. Only a small fraction of the published IESNA guidance addresses lighting in dark ambient environment, and those that do seldom incorporate the latest research on light pollution and wildlife impact. Nor are they derived from a set of assumptions remotely similar to the NPS Organic Act. Finally, IESNA guidance does not address light "warranting"- assessing whether a light is necessary in the first place.

LIGHT POLLUTION

A natural lightscape is one that is free of light pollution. Spilled light or wasted light are phrases that describe the misuse of outdoor lighting, especially in a natural or protected environment such as a national park. The term *light pollution* has commonly been used to emphasize the concept that anthropogenic light in the naturally dark environment is indeed a pollutant, not just a nuisance. There are many good reasons to eliminate light pollution in national parks, including:

1. The preservation of natural lightscapes (the intensity and distribution of light on the landscape at night) will keep the nocturnal photopic environment within the range of natural variability. Excursions outside this natural range may result in a modification to natural ecosystem function, especially to systems involving the behavior and survival of nocturnal animals. The natural night sky is therefore one of the physical resources under which natural ecosystems have evolved.

2. The scenery of national park areas does not just include the daytime hours. A natural starry sky absent of anthropogenic light is one of their key scenic resources, especially large wilderness parks remote from major cities.

3. The history and culture of many civilizations are steeped in interpretations of night sky observations, whether for scientific, religious, or time-keeping purposes. As such, the natural night sky may be a very important cultural resource, especially in areas where evidence of aboriginal cultures is present.

4. The recreational value of dark night skies is important to campers and backpackers, allowing the experience of having a campfire or sleeping under the stars.

5. Night sky quality is an important wilderness value, contributing to the ability to experience a feeling of solitude in a landscape free from signs of human occupation and technology.

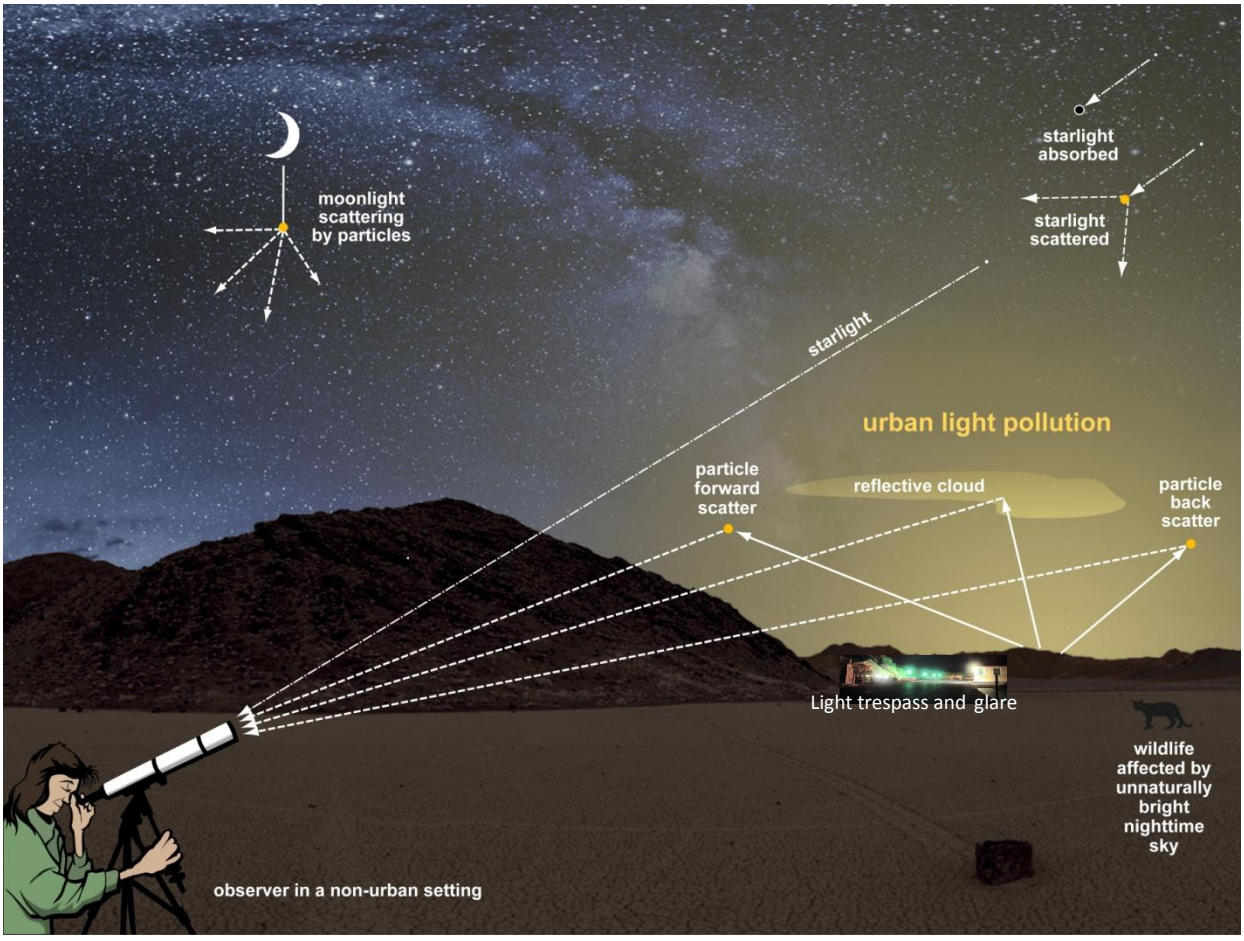

Figure 1. Illustration of anthropogenic light or light pollution in the natural environment.

GUIDING PRINCIPLES

-- **Providing for visitor safety in commonly used developed areas will be achieved while protecting the natural environment from light pollution.** Decisions on lighting necessary for employee and visitor safety must be made by considering factors such as the expectation of permanent artificial lighting, existing safety hazards (such as tripping, falling, criminal activity, and wildlife), type of tasks performed, frequency of those tasks or use level, and available alternatives. In some cases, modification of the built environment, relocation of tasks, alteration of work schedules, or issuing flashlights can be done in lieu of installing permanent outdoor lighting.

-- **Outdoor lighting zones** will be delineated in Death Valley National Park management plans, with each zone having varying degrees of visitor expectations for natural darkness/outdoor lighting, varying degrees of nighttime use and activity, and/or varying degrees of cultural/natural sensitivity.

-- **Energy efficiency should be a goal for all outdoor lighting**, as it lessens the park's carbon footprint.

-- **Long term sustainability in the operation and maintenance of outdoor lighting solutions should be maximized.** The total lifecycle cost should be weighed in a sustainability assessment.

-- **Outdoor lighting will be sensitive to the impact upon wildlife.** The addition of artificial light into a park setting will alter nocturnal habitat, and the impact may reach beyond the bounds of the developed area. Parameters of direct light intensity, scattered light intensity, light color, light timing and duration are all important considerations for wildlife.

-- **The darker the ambient environment, the more careful lighting choices must be.** A good example is a park entrance station, which is sometimes isolated from other developments and surrounded by natural darkness. Excessive outdoor lighting intensity here will unnecessarily impact the surrounding areas.

-- **Cultural and Historic Resources will be supported, not degraded, by outdoor lighting.** The use of period light fixtures represents a special challenge, as these are generally more decorative and less efficient than their modern equivalents. Successfully preserving the cultural and historical integrity may require additional expense and creative solutions, as well as tolerating lower task area illumination typical of decorative fixtures.

-- **Protecting the naturally dark surroundings of many park environments is an essential factor in outdoor lighting design.** Because of the human eye's reliance on contrast for vision, a dark ambient environment often enables the use of lower illumination levels to achieve the same visual effect. Additionally, in parks both visitors and employees are often transitioning from lit areas to unlit areas, so this transition must be addressed. For example,

it would be counterproductive to brightly illuminate a visitor center walkway, only to terminate the light at the edge of a dark parking lot. By gradually tapering lighting levels between use areas and zone, the dark-adaptation ability of the human eye is promoted. To implement such a design strategy, there can be no minimum illumination standards.

-- **External threats to the natural lightscape within the parks will be addressed, primarily by setting a leadership example for surrounding communities.** NPS management policies put a positive responsibility upon superintendents to partner with these communities to protect the natural environment of parks. Part of this effort is to provide examples of outdoor lighting Best Practices for the public to see. This requires that outdoor lighting in parks be held to a high standard, that the existing lights incorporate these principles, and that park facility lighting is interpreted to visitors and the surrounding community. The solution can only be leadership in sustainability through example.

OUTDOOR LIGHTING ZONES

Concepts

Outdoor lighting is appropriate only in certain areas of the park. A description of these areas in reference to the earth's surface as a portion of the land area of Death Valley National Park is a necessary planning, design, and operational tool. The resulting land may be portrayed as a GIS layer, generally representing the Development Zone or an area where facilities exist. These facilities include public areas (such as visitor centers, concession facilities, and campgrounds), staff residential areas, and administrative areas such as sewage treatment plants and fire stations. They may also include private inholdings or public lands leased to private individuals. The area should be limited to those portions of the Park that are commonly used at night and for which a need for outdoor lighting genuinely exists.

The prevention of light as a pollutant or unwanted entity in the natural environment is most easily addressed in a manner similar to other, time-honored zoning strategies within parks. Examples include limiting motorized vehicles to established and maintained roads to prevent soil erosion and vegetation damage, regulating overnight wilderness visitation to protect solitude, and protecting wetland and riparian areas from hydrologic modification by development or human waste. The definition of outdoor lighting zones within Death Valley National Park thus becomes the crux of an environmental protection strategy for natural lightscapes.

The primary purpose of delineating lighting zones is to protect the natural lightscape to the greatest extent practical. Higher intensity zones should be kept as small as possible or omitted in favor of zones that are more restrictive of outdoor lighting. With the advent of solar lighting, LED lighting, and other new technologies there is increasing threat that

artificial lighting will be promulgated to all areas of a park, fragmenting the natural lightscape and depriving visitors of experiencing a starry night sky.

Proper delineation of zones also helps park visitors and residents transition between zones effectively. The human eye is slow to adapt to different lighting levels, especially in darker ambient environments often found in parks. Thus, zones should be delineated with common travel routes, activities, and visitor expectations in mind. Higher intensity zones should be kept as small as possible and restricted to just those areas where needed, but should not be so fragmented into islands that a visitor or employees is constantly transitioning between different lighting levels.

The zoning process should also be cognizant of proximity to sensitive habitats. For example, a sensitive wetland designated as within the naturally dark zone may not be protected if it is adjacent to a high intensity outdoor lighting. In some cases, especially if terrain and vegetation is not adequately sheltering sensitive areas, a buffer zone with an intermediate lighting level may be required. In some cases, brighter corridors of light may act as barrier to wildlife. For example, a bridge that is illuminated with light that spills over the edges or into the surrounding environment may impede fish migrating at night in the waters below.

When in doubt, the protection of the natural lightscape should predominate. In conformance with NPS Management Policy 4.10— Natural Lightscapes, the installation and use of artificial outdoor lighting should be used only when and where necessarily dictated by safety, and should not be driven by convenience. Mitigations should be employed to the maximum practical extent. These guidelines direct park management to design park lighting to mitigate light pollution and to preserve the natural darkness as much as possible.

Lighting zones within development have been identified and discussed in the International Dark Sky Association/Illuminating Engineering Society's Model Lighting Ordinance (MLO). While intended for larger communities and a larger spectrum of facilities than those typically found in parks, the MLO addresses many of the engineering specifications of outdoor lighting from the standpoint of environmental protection as well as utility to humans. The full text is available at http://docs.darksky.org/MLO/MLO_FINAL_June2011.pdf. It should be noted, however, an additional zone between the MLO zone 0 and the Naturally Dark Zone has been added for parks (called zone 00), and lighting zones 2-4 are not discussed as they are considered inappropriate for Death Valley National Park. Also, light pollution protection standards for environmental illuminance and luminance for the Naturally Dark Zone and others are not included in the MLO.

Zones

Naturally Dark Zone (NDZ). There is an expectation of a natural lighting regimen and the *absence* of artificial light sources. No permanent light fixtures are allowed in this zone. Humans are provided the best opportunity for dark adaptation and experiencing of natural

lightscapes. Nocturnal habitat is afforded maximum protection. This is the default zone, and should cover the vast majority of land area of Death Valley National Park.

Examples may include: Wilderness areas, backcountry areas, sensitive wildlife habitats, lakeshore or riparian areas, stargazing sites, primitive campgrounds, and frontcountry areas with dispersed use and no facilities.

Lighting Zone 00 (LZ00). There is a minimal expectation of artificial lighting. Permanent artificial light fixtures exist only where critical for safety or mandated by codes and are generally isolated. There is a negligible to minor impact to human dark adaptation and experiencing of natural lightscapes. There is a presumed minimal impact to nocturnal habitat. Human activities in this zone at night are darkness oriented.

Examples may include: Developed campgrounds, restrooms in campgrounds or isolated areas, residence areas located adjacent to sensitive habitats, parking areas with limited nighttime use, interpretive kiosks, entrance stations closed at night, outdoor amphitheaters, rustic cabins, and administrative facilities with infrequent nighttime activity.

Lighting Zone 0 (LZ0). Expectation for artificial lighting is moderate to low. Lighting is frequently non-uniform, discontinuous/used only in specific areas, and may often be limited to specific times. There is a minimal to moderate impact to human dark adaptation and the experiencing of natural lightscapes. There is a presumed moderate impact to nocturnal habitat. Activities in this zone may occasionally require artificial light, though lighting is at a low relative brightness.

Examples may include: High use entrance stations, maintenance yards, administrative facilities with moderate nighttime activity, visitor centers, residence areas removed from visitor use areas and sensitive habitat, lodges, stores, restrooms (non-campground), outdoor dining areas, museums, high security areas, and high asset buildings.

Lighting Zone 1 (LZ1). There is an expectation for artificial lighting. Lighting is of low brightness relative to mundane lighting in an urban or suburban setting but may appear bright in a park setting. Lighting is typically continuous, but may be of low to moderate uniformity or limited to specific times of the night. There is a moderate to major impact to human dark adaptation and the experiencing of natural lightscapes. There is a presumed major impact to nocturnal habitat. Artificial light color rendition is frequently important, and white light is more frequently prescribed. Activities in this zone regularly require artificial light, though illumination levels may fall below IES illumination standards. Most parks do not have the visitor use intensity or administrative use intensity to warrant this zone. There are no areas in Death Valley National Park requiring this classification.

Special zones for sensitive wildlife habitat and cultural/historical landscapes:
Park Lighting Zones may have an alternate set of technical guidance related to two special circumstances— 1) conformance with historic character and preservation of cultural landscapes, and 2) enhancing protection of nocturnal habitat. The latter is especially important in sensitive biomes (such as beaches and wetlands) or when listed species known to be sensitive to artificial light are adjacent. Zoning guidance will refer to these as LZx—H or LZx—W respectively. These special modifications are options atop LZ 0 and 1, and should generally not be necessary for LZ00.

Lighting in historic landscapes has a greater need to have the appearance of the fixture conform to architectural and design standards, which makes optimization of light distribution and shielding more difficult. Thus, shielding requirements shall be relaxed in this zone. Architectural lighting shall be allowed only in LZ1-H. Mitigation within this zone can be accomplished by other means such as limiting total lumen output and restrictions on operations (e.g. curfew). These considerations are important within the Scotty's Castle historic district.

Lighting in wildlife sensitive areas should have a more stringent requirement for lighting controls (such as the use of timers and motion sensors) and lamp color. Amber colored light with a narrow spectrum of emission is preferred as a general wildlife-friendly light source, though certain specie concerns may dictate the use of other lamp colors.

Synopsis of Lighting Zones

Lighting Zone	Purpose	Continuity of Illumination	Allowances
NDZ	An area where **no permanent lighting is allowed** to provide best possible protection of natural lightscapes. Artificial light limited to only where needed for human travel.	**None.**	Only small portable lighting allowed for human travel through this zone- flashlights, headlights, etc. **This is the default lighting zone for undeveloped areas in parks.**
LZ00	To provide an **absolute minimal level of lighting** for human safety, minimal disruption of natural character.	**No continuity of lighting.** Permanent lighting is utilized only at critical safety areas, and unlit areas predominate.	Lighting restricted to specific applications (i.e. egress lighting, steps). Preference for non-white light with strict glare control.
LZ0	To provide a **reasonably low level of lighting for basic human safety and basic park operations**, with minimal disruption of natural character.	**Lighting is largely discontinuous**, and within the zone there are substantial unlit areas. Some high use corridors may have continuous lighting.	Lighting is used for a variety of safety and operational needs. **This is the default lighting zone for developed areas in parks.**
LZ1	To provide a **modest level of lighting to meet visitor expectations safety concerns, and park operational needs** in busy park environments.	**Lighting is largely continuous** along corridors and somewhat uniform.	Most lighting applications permitted, but at illumination levels well below typical suburban or residential practices.
LZ2	**For parks in urban areas** and with a high ambient illumination level, but without juxtaposition to natural areas.	**Lighting is mostly continuous** and designed to blend with surrounding urban environment.	Best lighting practices are used throughout and lighting is exemplary of night-sky friendly principles. This zone is only warranted within and adjacent to urban environments.

Table 1. General characteristics of each zone are summarized in this table.

Example of Suitable Applications within zones

Lighting Zone	LZ00	LZ0	LZ1	LZ2
Exemption for Temporary Lighting	OK	OK	OK	OK
Doorway / Egress Lighting	OK	OK	OK	OK
Stairway Lighting	OK	OK	OK	OK
Pathway Guidance Markers	OK	OK	OK	OK
Emergency, Phone, or Alarm Lighting	OK	OK	OK	OK
Kiosk lighting	OK	OK	OK	OK
Roadway Guidance Markers	OK	OK	OK	OK
Pathway Lighting		Minimal	OK	OK
Area and Parking Lot Lighting		Minimal	OK	OK
Outdoor Work Areas		Minimal	OK	OK
Storage Areas			OK	OK
Roadway Lighting			Intersections and Pedestrian Crossings Only	OK
Marina or Boat ramp			OK	OK
Concession and Storefront			OK	OK
Architectural and Monument Lighting			Discouraged unless specific historic / cultural needs	OK

Table 2. Example list of suitable lighting applications by zone.

Comparison of Zones

NPS Zones	***NDZ***	***LZ00***	***LZ0***	***LZ1***	***LZ2***		
Model Lighting Ordinance 2011	**—**	**LZ0**		**LZ1**	**LZ2**	**LZ3**	**LZ4**
IES RP-33-99	**—**	**—**	**—**	**E1**	**E2**	**E3**	**E4**

Table 3. Comparison between three systems of environmental lighting zones.

An example of defined lighting zones for the Stovepipe Wells area is given in Figure 2. These are suggested, and may be adjusted according to management's needs.

Figure 2. Proposed lighting zones for Stovepipe Wells development area.

Luminance and Illuminance Standards by Zone

Protection of the natural environment in parks is high priority. At night, anthropogenic light has the potential to stray beyond its intended use and pollute the environment. Measurement of luminance and illuminance levels at the edge of the development or a lighting zone boundary will determine the amount of light that is escaping into the natural environment. Standards or maximum allowable values for different lighting zones are proposed below to allow protection of the environment by evaluating the success or failure of outdoor lighting developments in preventing light pollution. It should be noted that the Luminance standards given in these tables are approximate and in development.

The Naturally Dark Zone includes wilderness areas or any areas park managers wish to remain as close to pristine as possible. Light from the night sky is present, even with the moon below the horizon, but is of an extremely low intensity compared to indoor spaces and many lit outdoor spaces in today's built environment. Vertical illuminance and sky luminance from the natural sky are shown in Table 4. Note the units for both are milli-, or 10^{-3}, indicated as such by the preceding "m."

Light in the natural environment on a moonless night (natural ambient light)		
	Illuminance (mLux)	**Luminance (mCd/m^2)**
Minimum	0.3	0.2
Maximum	0.6	0.8
Average	0.4	0.3

Table 4. Natural (pristine) levels of vertical illuminance and sky luminance of the moonless night sky under clear atmospheric conditions

Unshielded lights will be highly visible in this environment, even if they are of low intensity (equivalent to 40 watt incandescent or less). For this reason light trespass should be eliminated by shielding (zero uplight in the BUG rating system for luminaires). Features of the land and development will also be visible as they are illuminated by outdoor lights, even if they are fully shielded. Ideally the contrast between an illuminated development and the natural landscape on a clear moonless night will be small enough that, although the development is visible, its appearance does not seriously impair the natural lightscape. Illuminance will decrease with distance from the development rapidly according to the inverse square law, but luminance will not. However, as the observer moves away, the illuminated area's angular size will eventually become small enough to be negligible in most cases. Therefore, if a development is immediately adjacent to the naturally dark zone, some mitigating measures will be necessary to achieve environmental protection, such as using considerably lower illuminance levels at the development or screening the illuminated areas with hardscape objects, such as walls or berms. Evergreen trees or bushes are an option, but have a greater potential to be removed in the future.

Standards for total ambient light on clear moonless nights are proposed in Table 5, and apply at the zone boundary. Presumably, areas within the Naturally Dark Zone will experience lower levels than these with increasing distance from the boundary, as no outdoor lights should exist within this zone. These standards should not be exceeded. A lighting curfew is proposed to allow some illuminated outdoor activities in the evening hours, but providing protection for the environment for most of the night. Therefore a higher threshold is proposed for the evening hours, while the night standard is considered to fully protect the natural lightscape. The standard for luminance applies to the average over an area of 0.5 degrees in diameter. Areas less than 0.5 degrees across may be illuminated to any level, providing the illuminance standard is met.

Maximum anthropogenic light at the boundary of the Naturally Dark Zone (NDZ)		
Time of Night	**Vertical Illuminance (mLux)**	**Luminance (mCd/m^2)**
Before curfew	10	1000
Night (after curfew)	1	5

Table 5. Proposed standards for vertical illuminance and luminance of objects on the land at the boundary of LZ 00 and the Naturally Dark Zone.

Figure 3 shows the wilderness boundary around the Stovepipe Wells development. The distance from the gas station to the boundary to the east is 1560 meters.

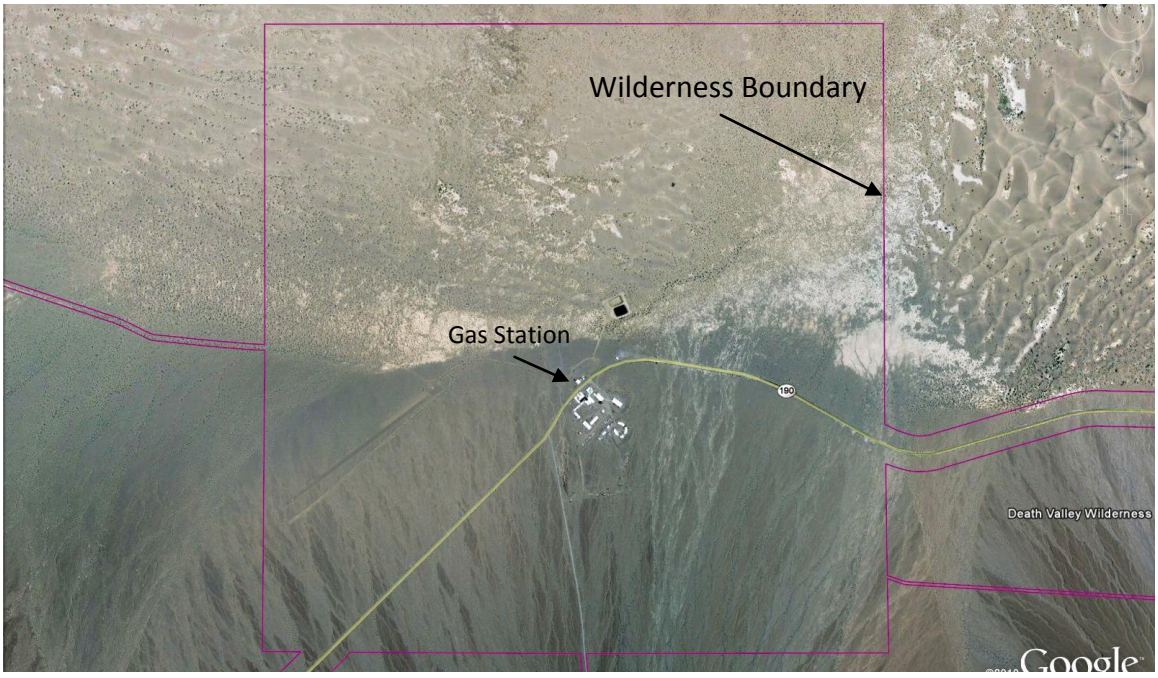

Figure 3. Wilderness boundary drawn around Stovepipe Wells development as a square exclusion 2 miles wide on each side.

In LZ 00, there is a minimal expectation of anthropogenic outdoor light, especially in the late night hours. An example may be a developed campground, where most people would plan

on taking a flashlight or headlamp with them when venturing out from beyond their immediate campsite, but would expect some sort of guidance and egress light on the rest room or kitchen building. After hours, though, a primitive experience is expected, where viewing the night sky would be minimally disturbed by outdoor light and those who sleep outdoors would expect it to be dark. Standards for both before and after curfew are proposed in Table 6. These are for the ambient environment only, not for task areas such as at building egress points. Task areas in LZ 00 are very small; no general area lighting such as parking lots would be expected. Note that light shining through windows from indoor spaces may need to be controlled in this zone to meet the proposed standards. The standards are for permanently installed lights and not for temporary lighting such as camper's lanterns, although a curfew may also apply to temporary lighting.

Maximum anthropogenic light for LZ 00 (illuminance at the boundary with LZ0), not including task areas			
		Illuminance (mLux)	
Time of Night	**Luminance(mCd/m^2)**	**Horizontal**	**Vertical**
Evening	500	500	1000
Night	20	50	200

Table 6. Proposed standards for maximum luminance, horizontal illuminance, and vertical illuminance in LZ 00 at the boundary of Zone 00 with Zone 0, not including task areas (such as building egress points). The luminance standard given is approximate and in development.

In LZ 0, a moderate amount of outdoor light is expected and may be required for human safety, because of a pattern of high human occupancy, especially in the evening hours. Examples would include permanent structures such as visitor centers, stores, gas stations, maintenance yards and administrative facilities commonly used at night. Note in Table 8 the units are now in normal units, not milli-. As in Table 6, these standards apply to ambient areas away from specific task areas.

Maximum anthropogenic light for zone LZ 0 (illuminance at the boundary with LZ1), not including task areas			
		Illuminance (mLux)	
Time of Night	**Luminance(mCd/m^2)**	**Horizontal**	**Vertical**
Evening	20000	1000	5000
Night	1000	100	500

Table 7. Proposed standards for maximum luminance, horizontal illuminance, and vertical illuminance in LZ 0. Illuminance is at the boundary of Zone 0 with Zone 1. The luminance standard given is approximate and in development.

OUTDOOR LIGHTING GUIDELINES

All exterior lighting in Death Valley National Park shall be designed to eliminate light trespass, minimize glare, and use an intensity, color, and duration that will preserve the natural darkness as much as possible.

NPS Management Policies direct parks to use artificial light on an "only as needed" basis and to minimize impact whenever possible. The mitigation of outdoor lighting impacts upon the environment is best accomplished by addressing six parameters of lighting in a step-wise fashion.

1) Warranting- Light only WHERE you need it

2) Controls- Light only WHEN you need it

3) Shielding- Direct light DOWNWARD

4) Spectrum- Select LAMPS that minimize negative impacts

5) Intensity- Use the minimum AMOUNT of light necessary

6) Efficiency- Select the most energy EFFICACIOUS lamp and fixture

If this assessment can be made at the onset of projects or as part of a holistic inventory, as opposed to a last minute modification, the results will be far better and more inline with the agency's mission. When these six points are carefully addressed, they result in "lightscape friendly" outdoor lighting. Merely shielding a light does not necessarily constitute lightscape, wildlife, or night-sky friendliness; especially if that light is unnecessary in the first place. Even when a light is necessary, the incorporation of a timer, motion sensor, or switch can greatly reduce its impact.

When designing lighting, use only the minimum necessary amount and ensure that it is shielded from the sky and from being seen from beyond the immediate area of use. Do not use lighting when it is not required, and discontinue current wasteful uses. When designing interior lighting, use low light levels, dimming and shielding to prevent stray light from affecting exterior areas.

Warranting

Is a permanent outdoor light necessary at all? There are two high priority lighting tasks that are potentially present in every development: guidance to and illumination of walkways at building egress points, and the illumination of stairs or other uneven ground in the

immediate vicinity of buildings on defined pedestrian paths. A choice to not install permanent outdoor lighting at these points may be made, but is difficult to defend, especially if the building houses essential services frequently needed at night, such as a Ranger Station, rest room, or lodging. Beyond these two tasks, especially in LZ 00, the decision to not install permanent lighting is often a valid one. Even if a light is installed, intelligent controls (like a timer or presence detector or even a manual switch that is accessible to all) can turn the light off when it is not required, such as after 11PM or when a public facility is closed.

Dusk to dawn lighting for "security" purposes is rarely warranted in parks. Assets such as vehicles or equipment that are stored outdoors may not necessarily be protected from theft or vandalism by bright illumination at night. There is evidence that this type of illumination deters "opportunistic" crime (a potential criminal comes across an opportunity for theft or vandalism by accident; the crime is not pre-meditated), but does not deter the more careful planning of theft by a determined criminal. The question then becomes "Is the environmental impact of dusk to dawn bright outdoor light worth the expected benefit of prevention of opportunistic crime?" If an asset of very high value must be kept outdoors, an infrared camera surveillance system or a network of presence detectors might be a better choice for security at night than dusk to dawn area lighting.

Many park visitors will feel more "secure" when area illumination is provided between their parked vehicle and a building such as a restaurant or lodge. There is even a feeling among the population that such lighting is expected and required to help them assess dangers and protect or defend themselves from attack either from other people or large wild animals. This type of lighting may be provided in LZ 1, where one would expect a large number of people out at night walking between vehicles or other destinations and buildings that are frequented at night (the Mall in Yosemite Valley, Lodgepole Market Center, or Furnace Creek Ranch Plaza area might be examples in national parks). However, in LZ 0 and LZ 00, this level of modification to the natural environment should not be expected. Once again, the park manager must decide whether the environmental impact warrant the benefits in these situations, and make every effort to eliminate light trespass and glare from a permanent installation.

Outdoor general area illumination is rarely required in parks. Notable exceptions include maintenance yards or fire stations where equipment and materials must be examined and worked on at night (such as preparing snow plow equipment in the pre-dawn hours), walkways or plazas open to the public in LZ 1, outdoor sports fields, and monuments (such as the Washington Monument in the National Capital Parks or Mt. Rushmore). Any other type of outdoor area lighting is mostly for convenience, not safety or security.

An argument for dusk to dawn outdoor lighting is often made in the name of safety of employees. While in some situations an employee will be required to venture out at night and retrieve materials or find a vehicle in a large parking lot, it is not unreasonable to require employees to carry their own illumination device and should be trained to do so.

The small extra effort this takes easily outweighs the environmental impact of permanent dusk to dawn area lighting.

Lighting Controls

Controls that automatically dim or switch outdoor lights may be used to mitigate environmental impacts and conserve energy. An outdoor light curfew, similar to a noise curfew in campgrounds, should be employed, where light is reduced or eliminated, where feasible, following a reasonable time after dark (11 PM local time or two hours after sunset, whichever is later). Natural illumination levels are approximately 0.1% that of full sunlight just after sunset (100 lux) and 100X that of a full moon. At that time, typical indoor illumination (approximately 200 lux) is higher than the outdoor levels. After about 30 minutes, the natural illumination level due to dusk is about that of a full moon (0.3 lux).

If indoor lighting, especially for offices and stores, shines through windows it may have an impact on the areas outside. It may also produce glare that will prevent dark adaptation for people and animals. This has no effect until after sunset, at which time the sky illuminates the ground to a lower level. Window coverings should be used to prevent continued spillage of the indoor light through the windows.

Timing circuits should turn off all exterior lighting fixtures at the beginning of the lighting curfew except guidance lighting. A photoswitch can be combined with timing circuit to turn light fixtures off within a certain amount of time after sunset. Manually activated switches should also be available to turn off exterior lighting.

In areas with high volume of pedestrian traffic and where limited activity continues after dark that requires illumination, motion detectors should control light fixtures. Automatic timers should be used to turn them off after a reasonable period of time.
On a technical note, only Light Emitting Diodes (LEDs), compact fluorescent and incandescent lamps can be switched on for short periods of time. High Intensity Discharge (HID) lamps (Low Pressure Sodium and High Pressure Sodium) require several minutes to heat up before they will reach full brightness.

Shielding

Every permanent outdoor light within a park should not emit light above the horizontal. More correctly, every light should not emit light above the contour of the land surface, since lights installed (particularly on poles) on hilltop or sloped locations may easily unintentionally emit light miles into the landscape at lower elevations even if they are full cutoff fixtures installed horizontally. These situations may require the installation of custom shielding on individual luminaires. In addition, luminaires designed to be full cutoff should never be deliberately aimed upward when installed in an attempt to increase their range of horizontal coverage. As a rule of thumb, an outdoor light should not be expected to illuminate land at a distance horizontally of more than three times its mounting height. If a

pole 20 feet high is used, for example, do not expect this light to “throw” horizontally more than 60 feet from the base of the pole.

Death Valley National Park management will strive to correct unshielded or poorly shielded lights. Previous examples from the Stovepipe Wells development revealed glare and light trespass produced by unshielded pole mounted lights, bare CFL lamps, and incandescent landscape flood lighting aimed near the horizontal or upward. These have been replaced with a retrofit of the external lighting facilities in 2012.

Figure 4a-b. Before/after: Unshielded bare bulbs were removed during retrofit at Stovepipe Wells.

Figure 5a-b. Unshielded wall mounted lights for building egress were replaced by canopy mounted lights at Stovepipe Wells motel units.

Figure 6. Before: Unshielded pole mounted lamp at Stovepipe Wells, designed to illuminate a large area. Below: Old pole mount replacements do not reach beyond recommended 3:1 height to lit area.

Figure 7 a-b. Before: Unshielded yellow CFL lamps at Stovepipe Wells motel. Below: After lights have been removed and replaced by lights under canopy.

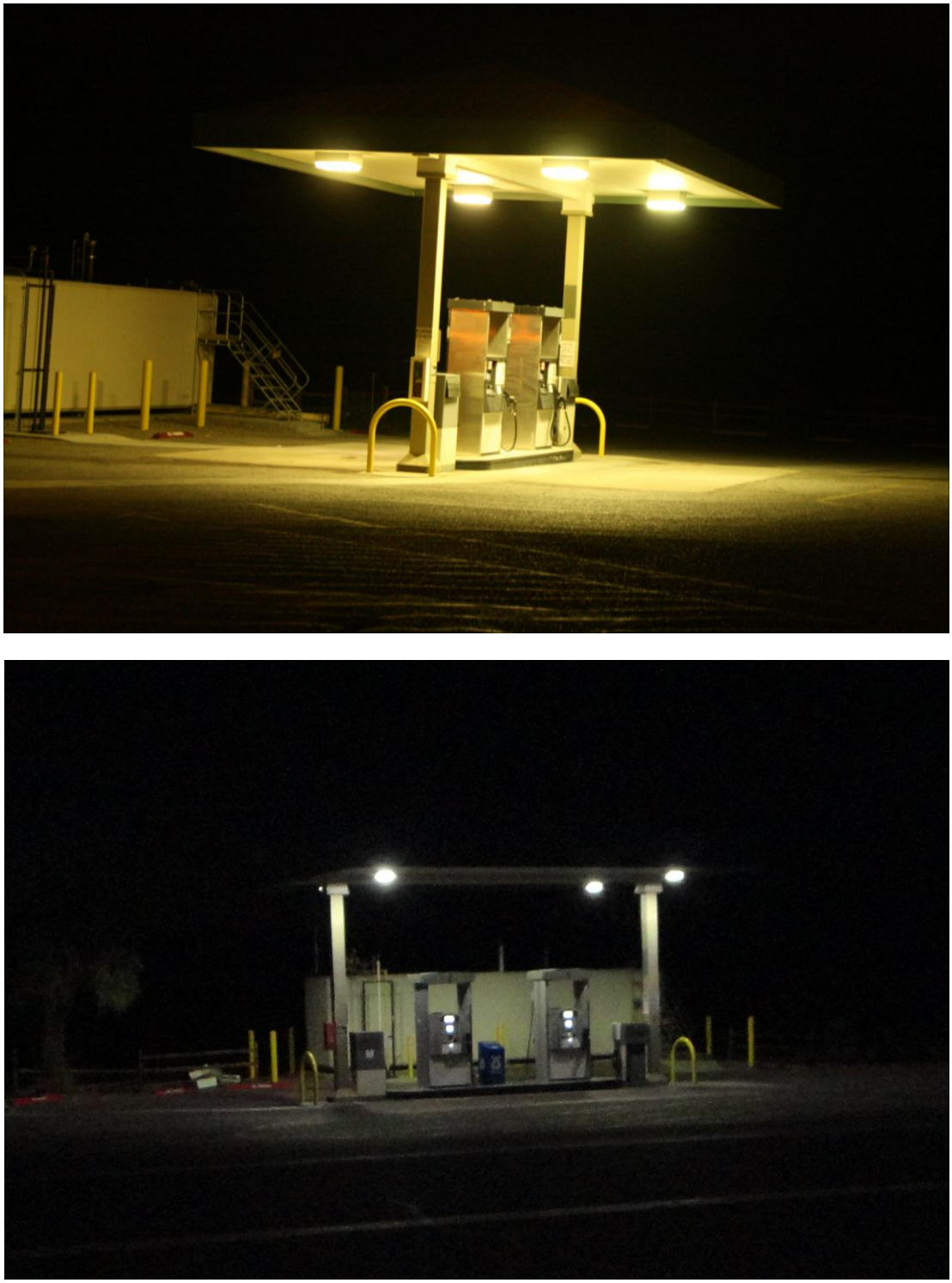

Figure 8. Stovepipe Wells Gas pump canopy before and after retrofit.

Before an outdoor light is installed and maintained, its effect on the surrounding environment must be analyzed. Protection of natural lightscapes is an integral part of outdoor lighting, and the facility manager has the same responsibility to assess the impact

of any outdoor light on the surrounding environment as to ensure the application performs to its intended specifications in the task area. Ambient illuminance levels within and at the margins of the development should be predicted based upon individual luminaire photometrics. They may also be measured after installation to ensure the standards for environmental protection given in a previous section are met.

The potential for light trespass is the easiest contributor to light pollution to estimate or measure. Light trespass is measured as vertical illumination at the boundary of the intended area of use, or at the lighting zone boundary. Illuminance follows the inverse square law for radiant energy. If the intensity in candela in known at a viewing angle close to the horizontal from a given light source, the vertical illuminance in lux at any distance (in meters) from the light source can be easily predicted using the following equation.

$E = I / d^2$

Luminance of objects and surfaces is more difficult to predict, since it depends on many factors, including the intensity of the light source, proximity to the light source, albedo or reflectance of the surface, and the angles of both the illumination source and the observer to the surface. As a rule, bright sources should not be placed immediately adjacent to light colored reflective surfaces (such as a wall sconce containing a high intensity lamp with little or no offset from the vertical wall surface). Also, luminance meters are expensive and may not be readily available. Common sense must prevail when designing and installing outdoor lights mounted on vertical surfaces or close to horizontal surfaces. Remember that snow is an excellent reflector as well.

Spectrum

Various light sources (lamps) have different color content. Humans and animals are affected by the color of light. Blue light (short wavelengths) affects their low level scotopic vision whereas red light (long wavelengths) is seen well by their photopic vision. The use of long wavelength light allows animals to see without degrading their sensitive scotopic vision. Specifically, insects and birds are affected more by white than red lights.

The color tint of white light is measured in Kelvins (K), a scale in which warm-toned white light has smaller values (1800-3000K) and cold-toned light has larger values (5000K and higher). Between 3000 and 5000K, light is said to be “neutral” in tone. The common incandescent lamp is 2700K.

Traditional incandescent lighting is about 2700K, a warm toned light considered normal for residential and hospitality lighting in North America. For reasons of consistency and appearance, light sources should be 2700-3000K with a minimum CRI of 70. Amber or yellow light sources are preferable, both to limit attraction by insects and to reduce sky glow. Light sources should be chosen for energy efficiency, long life and low maintenance. Because some locations in the Park experience extremes of temperature, elevation and exposure, light sources must be suitable for all expected operating conditions. The following light sources are acceptable:

--LED 2700K "warm" white lamps, yellow, or amber colored, 1, 3, or 7 watt. LED's superior life, energy efficiency, instant starting and low temperature performance are superior but some capabilities of the source are limited. Use with caution in hot climates. Use amber LEDs in most environmentally sensitive areas.

--Compact fluorescent, 9 watt, twin tube and 13 watt double twin tube or Edison base spiral 3, 7, 10, 13 or 26 watt (2700K only or yellow "bug lamps"). Because of low starting temperature and low cost components, this light source can be used for many basic outdoor lighting applications.

--Halogen IR, 20 watt, 12 volt MR16 lamp. Uses are generally limited to temporary (presence detector activated) lighting applications. Because of their low luminous efficacy they should not be used in continuous duty applications.

--Ceramic metal halide lamps, 20 watts, T4.5 and 39 watt, T6, 3000K only. In general, these are the most powerful light source to be used outdoors, but warm up and restrike time preclude use where frequent switching or power quality issues are present.

Illuminance for Lighting Tasks

Most engineers and architects observe recommendations of the Illuminating Engineering Society (IES) when designing lighting. However, because of the Park's extremely low ambient light levels, many IES recommendations do not directly apply and need to be adjusted to be appropriate. Criteria expressed in this report were developed to meet the spirit of IES Recommended Practice RP-33-99, Lighting for Exterior Environments, but certain tasks are interpreted to require lower illuminance levels in the dark surroundings of parks. Additional research conducted in Yosemite and other parks confirms this interpretation. Parks Canada has produced a "best practices" document that indicates much lower illuminance levels than IES RP-33 and requires a curfew or turning off lights that are not in active use.

The illuminance levels listed in table 8 are recommendations to accomplish the task at the task area. The task area should be kept as small as possible with no direct light spill into the surrounding areas. The use of full cutoff fixtures or recessed lights under canopies may accomplish this objective. Exceptions are parking area lighting, the lighting of plazas and grounds, and outdoor sports fields. These should be kept to a minimum within parks. Sports fields, such as the volleyball court in Cow Creek, are considered temporary lighting and have no maximum or average recommended illuminance, although shielded fixtures are recommended. Alternatively, trees or other screening may be used to block escaped light.

Area lighting for parking lots, while generally accepted practice in urban environments, must be evaluated carefully in parks. The amphitheater at Mesquite Springs Campground has no illumination and visitors are asked to bring their own light for evening programs. Tripping hazards or steps should be illuminated with low recessed bollards, but primarily only guidance lighting should be used in these areas, and these could be temporary for the program purposes only.

Specific Recommendations for Death Valley

As Death Valley NP has high quality dark ambient skies, multiple lighting zones may not be desirable or necessary. All task areas that need to be lit should be kept to a minimum. Light levels for ingress/egress to buildings and illuminating walking paths should be minimal. The goal for light levels for these tasks is less than 10 lux, but could be much less with good uniformity (2-5 lux) and should be as low as practicable. Even where fixtures are in place, lights can be turned off if not required, and would be controlled by switches when needed for occasional use. Most lighting will fall into zones LZ0 or LZ1. LZ2 light levels are not recommended on Death Valley NP lands. Many of the lights currently above this level can be mitigated by replacing bulbs with lower watt levels. A light curfew should be considered in certain areas where appropriate. Park staff will work with partners but it is acknowledged that the park does not have control or authority over private inholdings within its boundaries.

Recommended horizontal illuminance at task areas

Lighting Situation	Illumination criteria Uniformity expressed as average to minimum ratio; light levels in lux.	Application Notes
Streets, roads and drives	0.5 avg. lux LZ 00, 0	Restricted to high pedestrian conflict areas adjacent parking lots
Parking lots – high activity	1.0 avg. lux @ 4:1 uniformity LZ 1	Uniformity is moderately important, close to buildings
Parking lots – medium activity	0.5 avg. lux @ 10:1 uniformity LZ 0	Uniformity is not critical, presence detector or timer only
Parking lots – low activity	none LZ 00	
Walkways and bikeways – high activity	2.0 avg. lux @ 8:1 uniformity LZ 1	Uniformity is important, example front of Stovepipe Wells restaurant
Walkways and bikeways – medium activity	0.5 avg. lux @ 12:1 uniformity LZ 0	Uniformity is not critical
Walkways and bikeways – low activity	Guidance and stair lighting only – 3-5 lux at stairs	Non uniform lighting acceptable
Steps – Public areas	3 lux minimum; all steps illuminated, use recessed bollard at 2 feet height LZ 0 and LZ 1	Provide illumination for every step, guidance + presence detector recommended for sensitive areas LZ 00
Building Exterior Entrance (active)	5avg. lux LZ00, 0 10 avg. lux LZ 1, max. 30 lux	Downlighting under canopy preferred, wall mounted lantern decorative only, not for ground illumination
Building Exterior Entrance (inactive)	0.2 avg. lux LZ 00, 0 10 avg. lux LZ 1	Guidance with presence sensor or manual switch activating light in LZ 00 and LZ 0 recommended
Plazas and grounds within a developed and active area	1.0 avg. lux LZ 0, 0.5 avg. lux LZ 00	Uniformity is not critical, outdoor dining recommend spot illuminance at tables
Bulletin and poster boards	10 lux LZ 0, tightly controlled for no light trespass	LED lamps in display case recommended
Storage Yards	None unless night use required; when needed, an average of 1.0 lux LZ 0	Full cut off floodlights and wallpacks recommended
Service Stations - driveway	1.0 max. lux LZ 0	Guidance lighting or reflective paint strips may be used instead, not uniform
Service Station - Pump Area	50 lux maximum LZ0, LZ 1	None currently in Death Valley National Park, not to be operated 24 hours, manual switch for employee fuel stations, presence detector for public

Table 8. Recommended Lighting Levels

Efficiency

The energy efficiency of a light source is measured in lumens per watt and is called efficacy. Efficacy is important but must be weighed against maintenance and durability. With the exception of halogen lamps listed above, all recommended sources meet minimum expectations of efficacy. Evolving sources like LED are expected to become extremely efficacious in the future and projects should employ the most efficacious source that meets these Guidelines and project requirements. Note: in a limited number of genuinely historic applications, incandescent lighting is called for. The requirement to provide historically correct lighting must be approved by park management, but should be designed to meet standards for environmental protection for the surrounding zones.

RECOMMENDED DESIGNS

Outdoor lighting design requires careful consideration of purpose and need, location of landscape and hardscape objects, environmental sensitivity of the area, and the frequency and type of outdoor use by humans. All aspects of this art and science are well beyond the scope of this paper. Listed below are some types of hardware and typical applications in parks. Design will vary with lighting zone and the surrounding environment. The use of professional lighting engineers and/or computer modeling software is highly recommended.

A wide selection of full cutoff fixtures or luminaires for various mounting situations are commercially available. The lamp type and output lumens may be somewhat restricted, however, especially for park applications. The most common problem in locating a suitable fixture/lamp combination is that often the available lamp luminosities are simply too bright or the desired color is not available. Listed below are some suggested solutions available as of September 2011.

Wall Mounted Luminaires

Wall mounted lights are typically used in building egress applications. The best mounting position is directly above the door, but often the junction box is placed to the side of the doorway because of space limitations. The task areas include the ground in front of the door and the doorknob or deadbolt lock. A small “sconce” will often work with about a 200-500 lumen lamp. The Glare Buster GB1000 is an economical wall mount luminaire with some forward throw optics and a medium Edison base that will accept a variety of lamps. Care must be taken not to over-lamp wall mounted-downward pointing luminaires as the vertical wall surface will have a high luminance and produce light trespass from reflected light. A 10-watt CFL (520 lumens) should be considered the maximum in LZ 0.



Figure 9a,b,c. Fully shielded luminaires designed for wall mounting.

Figure 10. LED shoebox style used as wall mount building egress and patio lighting in Big Bend National Park.

Bollards

Bollards are typically used for pathway lighting. They can be on freestanding posts or incorporated into walls or stairway railings. A low mounting height is preferred, less than 36 inches, especially in areas that are wheelchair accessible. The task area is usually very small, in the immediate vicinity of the light. If the pathway is paved and free of tripping hazards, a large spacing between bollards may be used, in which case they serve as guidance light rather than for area illumination. Low wattage is called for, 7 watt CFL or 3 watt LED lamps will suffice in most cases. The light should be directed downward and only toward the path (avoid "mushroom" designs that have a 360 degree pattern).



Figure 11 a,b,c. Fully shielded free-standing bollards providing guidance and pathway lighting.

Under-canopy lighting

Placing luminaires under a built canopy provides the greatest opportunity for conservative and effective outdoor lighting. Canopies over motel units or restaurants are particularly useful. The luminaire can be effectively hidden from view during the day (especially if the luminaire is recessed) while providing glare-free area lighting for paths and doorways at night. Fixtures recessed into a soffit are preferred, but "shoebox" style lights can be relatively thin, especially if LEDs are used as lamps.


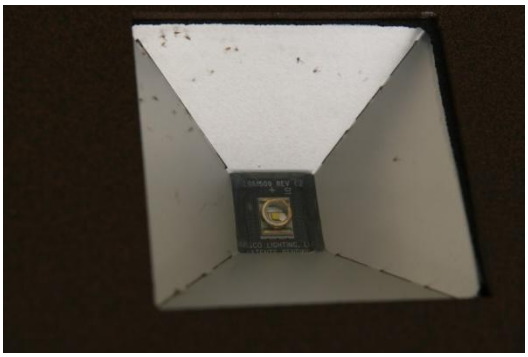

Figure 12 a-b. Under canopy fixture with wiring in soffit at Big Bend National Park, close-up shows deeply recessed single LED lamp.

Figure 14 a-b. Recessed under canopy lights at Stovepipe Wells (left) and Sequoia National Park (right).

The desired illuminance at the ground (2-5 lux in LZ 0) should be easy to achieve with this type of mounting and the proper lamp. Spacing away from the wall helps prevent "hot spots" of reflected light on the vertical wall surface.

Figure 15. Under canopy lighting at Stovepipe Wells motel.

Pole Mounted Luminaires

Often the only solution to area lighting in open areas is to mount a fixture on a pole. Mounting height will significantly affect lamp type, lighting pattern, and the potential environmental impact. Care must be taken to include the slope of the land in an assessment of light trespass; if the pole is place on a hilltop, even a full cutoff luminaire will create significant glare and light trespass over a wide area, and may require a custom made shield. Dusk to dawn area lighting (such as parking lots, plazas, and sports fields) is strongly discouraged. Such lights should be operated only when needed, controlled by timer, presence detector, or manual switch.

The vast majority of commercially available luminaires for pole mounting contain lamps that are too bright for most park applications. Even in LZ 1, a single source with a lumen output of more than 3000 is excessive. The 39 watt ceramic metal halide lamp recommended above produces about 2200 lumens. A 250 watt halogen lamp (commonly marketed at

hardware stores in a flood reflector as an outdoor illumination solution) produces about 3600 lumens. A 160 watt HPS lamp (typical in “cobra head” streetlights on 35 foot tall pole) produces about 18,000 lumens.

Beware of LED luminaires mounted on tall poles, often they produce excessive glare unless the cutoff angle is 60 degrees from nadir or less. Remember the 3:1 maximum ratio of horizontal distance to pole height. For LEDs this may be decreased to 2:1 to avoid glare. Any luminaire that has a significant amount of light emitted at 80-90 degrees from nadir should be avoided.

Pole lights with compact fluorescent or ceramic metal halide lamps are probably the most suitable for parks. Calculate the pole height carefully for the desired horizontal illuminance, and live with poor uniformity.