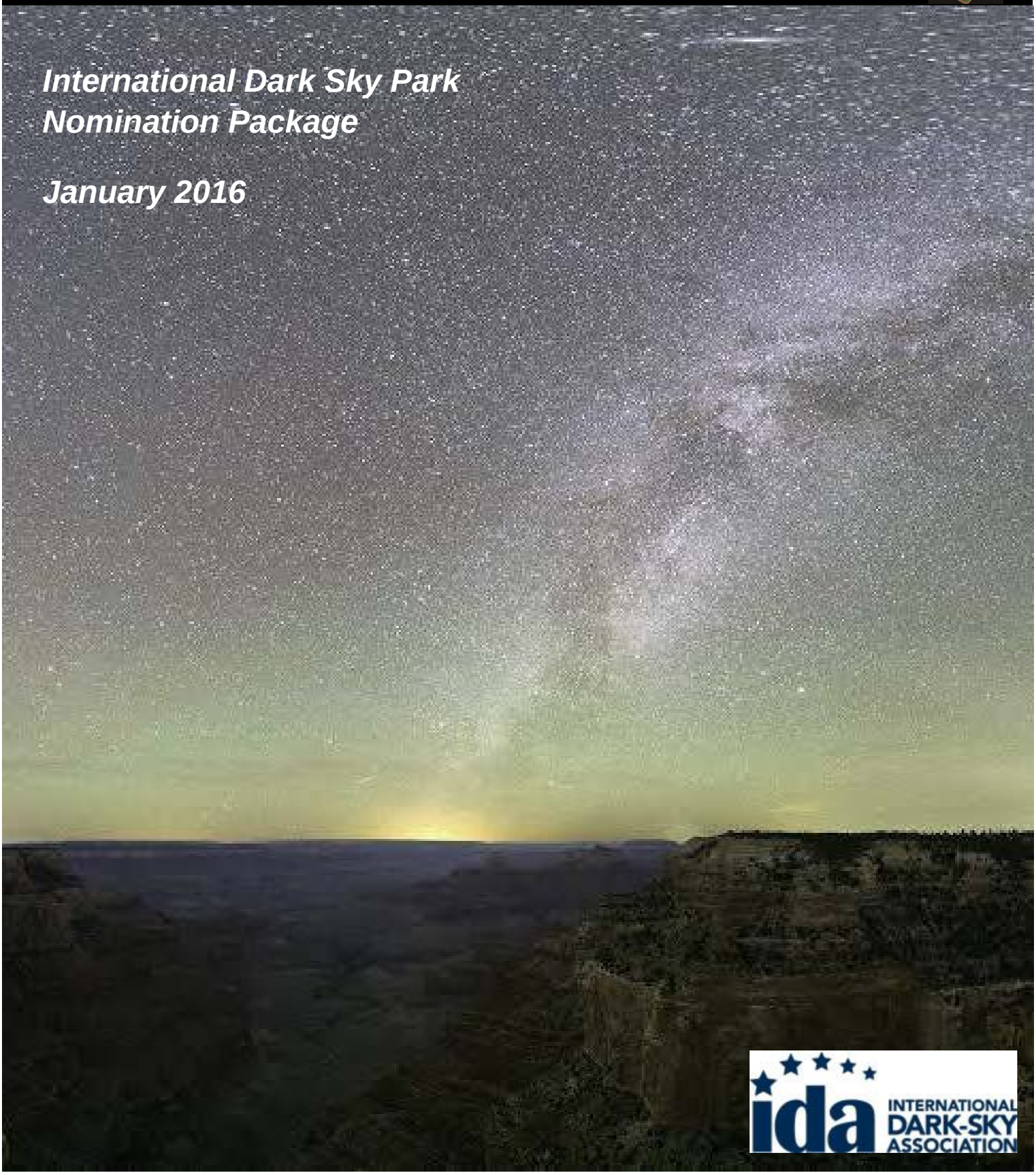
Grand Canyon

National Park Service
U.S. Department of the Interior

International Dark Sky Park Nomination Package

January 2016



View from Cape Royal looking south. Photo by Jeremy White, 2015.

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Table of Contents

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Grand Canyon International Dark Sky Park Summary

Grand Canyon is a spectacular asset that reflects the criteria desired for designation as a dark sky resource. Due to the remoteness, high elevation, distance from urbanization, dry air and clear skies, and status as a unit of the National Park Service (NPS), Grand Canyon National Park (GRCA) preserves, protects, and serves as a role model in conserving night skies.

All of the criteria addressed under the Gold Tier status requirements are met at Grand Canyon National Park. Based on GRCA's qualifications in each of the following categories designated by the International Dark-Sky Association (IDA), we feel the park should be considered for the Gold Tier designation.

1) *Philosophy: Nighttime environments that have negligible to minor impacts from light pollution and other artificial light disturbance, yet still display outstanding quality night skies and have superior nighttime landscapes.* Though a few small communities are scattered throughout the area, including Grand Canyon Village inside the park, GRCA displays outstanding quality night skies in nearly all points of the park with few visible light domes from those communities. The larger cities of Phoenix, Arizona, Las Vegas, Nevada, and Flagstaff, Arizona, create additional small light domes on the horizon, but with minimal effect on the outstanding quality of the night sky.

2) *Artificial Light and Skyglow: Typical observer is not distracted by glary light sources. Light domes are dim and are restricted to sky close to horizon.* Due to GRCA's remote location, few, if any, light sources are visible from most undeveloped places in the park.

3) *Observable Sky Phenomena: The full array of visible sky phenomena can be viewed.* The Milky Way is seen on every clear night throughout the year, as well as faint meteors and the zodiacal light from all locations around GRCA.

4) *Nocturnal Environment: The area is devoid of obvious lights that can cause wildlife disorientation. Artificial light levels are thought to be below the threshold for plant and animal impact. Ecological processes related to nocturnality are unaltered.* There is no lighting atop towers or buildings in undeveloped park areas. Again, due to the remoteness of nearly the entire park, GRCA preserves a dark sky devoid of any obvious light.

5) *Visual Limiting Magnitude: Equal or greater than 6.8 under clear skies and good seeing conditions.* The NPS Night Skies Team (NST) determined NELM data for Grand Canyon at 7.0–7.1.

6) *Bortle Sky Class: 1–3.* The NPS NST determined a Bortle class of 2–3 for GRCA night skies, based on measurements from multiple nights and locations.

7) *Sky Quality:* Five locations important to the visitor experience, two at North Rim and three at South Rim, were selected for all-sky photometry and data of good quality was successfully collected at each site by the NPS NST. A reconnaissance of other sites along paved roads was also conducted at both areas; two additional sites were identified at North Rim as potentially important. The results indicate that the night sky quality at all of these sites is excellent (Sky Quality Index of 97.8–98.9) and has remained stable at least since 2007 (the last all-sky photometry trip to the park).

Stanley, Randy <randy_stanley@nps.gov>

Formal nomination of Grand Canyon NP as International Dark Sky Park

1 message

Stanley, Randy <randy_stanley@nps.gov> Thu, Jan 14, 2016 at 11:14 AM
To: John Barentine <john@darksky.org>
Cc: David Uberuaga <dave_uberuaga@nps.gov>, Jane Rodgers <jane_rodgers@nps.gov>, Nathan Ament <nathan_ament@nps.gov>, David Vana-Miller <david_vana-miller@nps.gov>

Hi John,

As an IDA member in good standing, I am sending this message to formally nominate Grand Canyon National Park (GRCA) as an International Dark Sky Park (IDSP). Although it's possible you may receive GRCA IDSP nomination requests from other IDA members, it is my privilege to support this nomination for a number of reasons.

It goes without saying that GRCA is recognized worldwide for its unique, awe-inspiring views. The canyon not only offers a beautiful landscape but also forms a dramatic backdrop for a vibrant, ever-changing view of the cosmos. Because GRCA is such a unique location with an expectation for visitors to engage in sightseeing and wonderment, it is hard to imagine a more ideal location to engage the public in appreciation of naturally dark night skies.

I hope you will give GRCA's expected IDSP application full consideration. I believe IDA's efforts to recognize special places like GRCA is a critical step for helping us engage with communities and gain public support for night sky protection.

Thank you for your efforts.

Sincerely,

Randy, P.E., PMP, INCE Bd.Cert.
–

National Park Service | Intermountain Region

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Section 1

Description of Grand Canyon's Night Sky Resources

Location and Description of the Park

Grand Canyon NP was first set aside as a park "for the benefit and enjoyment of the people" on February 26, 1919 (40 Stat 1175, Grand Canyon National Park Establishment Act). Public Law 93-620, the Grand Canyon Enlargement Act, made major changes in the park boundary in 1975. Summarizing the park's significance, the Act states GRCA is a "natural feature of national and international significance." It established the 1,215,735-acre GRCA from a mixture of state and federal lands which included the former national park, Grand Canyon and Marble Canyon national monuments, portions of Lake Mead National Recreation Area, and US Forest Service, Bureau of Land Management, and Tribal lands. The park consists of publicly owned lands with no major private in-holdings.

GRCA is located in northwestern Arizona in the Colorado Plateau Physiographic Province. The park encompasses the canyon and portions of the plateaus to the north and south along 277 miles of Colorado River, starting at the confluence of the Colorado and Paria rivers near Lees Ferry in northern Arizona. GRCA is situated in one of the largest undeveloped areas in the United States. To the south of the park entrance is the town of Tusayan, Arizona, with a land area of 144 acres. Tusayan was incorporated in 2010 but with a population of 573 at the time of the 2010 census. GRCA is the number one tourist attraction in Arizona, and the park generates significant economic activity for the region. Visitors (over 5 million in 2015) to the park are estimated to bring in more than $420 million to local economies, supporting over 10,000 jobs (NPS 2010).

Public Access to Night Skies

The park is open continuously, allowing for night sky viewing at any time and location in the park. Overnight parking is allowed in certain locations (due to potential changes in policy, visitors should check with park staff when planning a night sky visit to the park). Accommodations are available at several concessioner-run hotels, park campgrounds, and by backcountry permit for areas outside of day-use only locations. There is a nominal entry fee to the park ($30 per car at the time of this writing).

Ecology and Geology

Geologically, the park can be divided into eight soil-based Land Resource Units, defined by combined soil, elevation, temperature, and precipitation characteristics. These characteristics, in turn, influence the vegetation types in the analysis area. Major vegetation types in GRCA and surrounding landscapes range from hot, low-elevation deserts to cool, high-elevation spruce-fir forest. These vegetation types represent a diversity of biotic communities and encompass nearly all the North American life zones, due in large part to the dramatic topographic zonation of the canyon itself, which spans an average of 5,000 vertical feet (1,524 m) from the Colorado River to the rims. The topographic diversity creates immense habitat and species diversity, making GRCA a microcosm of the North American biodiversity found from Mexico to Canada.

The Land Resource Units provide an indication of geologic diversity at a rough scale. In the canyon's mile-high (1.6 km) walls, the Colorado River has exposed a cross-section of the earth's crust that represents about 2 billion years of geologic history. More than 40 exposed layers have

been identified. Immediately above the Colorado River are Precambrian rocks, and directly above these sit Cambrian Tapeats Sandstone, Bright Angel Shale, and Muav Limestone. The wide and striking Redwall Limestone and Supai Group form sharp bands near the summits of many of the canyon's formations. More recent sandstone and limestone layers climb the upper reaches of the canyon walls to meet the North and South rims.

Major vegetation types of the Grand Canyon region, along with their dominant species and life zone characteristics, include the following:

Spruce-Fir Forest: The spruce-fir boreal forest, dominated by Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and blue spruce (*Picea pungens*), occurs above about 8,200 feet (2,499 m) in elevation and covers a little more than 1% of the park. This habitat type is cool and moist, with dense tree cover, high plant diversity, and rare fires. With the high shade occurrence here, both grazing and exotic plants are rare in the spruce-fir forest. No endemic plant species are known to occur in the spruce-fir forest in the park. Rare wildlife found in this vegetation zone include the tiger salamander (*Ambystoma tigrinum*) and little brown bat (*Myotis lucifugus*).

Mixed-Conifer Forest: Mixed-conifer forest occurs between 7,200 (2,195 m) and 8,500 feet (2,591 m) in elevation and is dominated by Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and ponderosa pine (*Pinus ponderosa*). This forest type covers about 3% of the park and is characterized by a mixed-severity fire regime, with normal fire return intervals of 10–20 years. High moisture availability and warm daytime temperatures create high productivity and high tree density in this forest type. Both grazing and exotic species are rare in this habitat. There are no known endemic plant species in the mixed-conifer forest of the park. Representative wildlife in the mixed-conifer forest are generalist and widespread species, including birds such as the Stellar's jay (*Cyanocitta stelleri*), and mammals such as the porcupine (*Erethizon dorsatum*), long-tailed vole (*Microtus longicaudus*), and mule deer (*Odocoileus hemionus*).

Montane-Subalpine Grassland: Dominated by herbaceous plants, forbs, and grasses, these small meadows cover about 3,000–5,000 acres (1,214–2,023 ha) on the North Rim. Cool temperatures and high soil moisture exclude woody species from meadows, which are critical habitat for some species. Species richness is moderate, with exotics representing less than 10% of species. This vegetation type is rare in the southwestern US and has recently suffered from increasingly intense bison grazing in the park. No endemic plant species are known to occur in the park's montane-subalpine grassland. Representative wildlife in the zone include habitat-generalist birds such as the broad-tailed hummingbird (*Selasphorus platycerus*), brown creeper (*Certhia americana*), and evening grosbeak (*Coccothraustes vespertinus*).

Ponderosa Pine Forest: Ponderosa pine forest encompasses woodlands, thicker forest, and savannahs, encompassing about 5% of the park and occupying elevations between 6,500 and 7,500 feet (2,286 m). The understory is characterized by shrubs, white fir, and Douglas-fir. Mixed-severity fires are common and exotic species rare. In contrast to much of the Southwest's ponderosa pine forest, neither logging nor fire suppression were major historical factors in the park's ponderosa pine forests, so vegetation composition patterns today are largely the result of site-specific fire history. The Grand Canyon goldenbush (*Ericameria arizonica*) is an endemic to the park's ponderosa pine forest. A diversity of wildlife, including widespread birds, mammals, and reptiles, inhabit this forest type. A few examples of

representative species are the mountain chickadee (*Parus gambeli*), northern flicker (*Colaptes auratus*), Western bluebird (*Sialia mexicana*), Abert's squirrel (*Sciurus aberti*), coyote (*Canis latrans*), elk (*Cervus canadensis*), Great Basin gopher snake (*Pituophis melanoleucus*), and mountain short-horned lizard (*Phrynosoma douglassi*).

Pinyon-Juniper Woodlands: About a quarter of the park falls in the pinyon-juniper biotic community, including both woodlands and savannahs below 6,561 feet (2,000 m) in elevation. This vegetation type is dominated by single-needle pinyon (*Pinus monophylla*), two-needle pinyon (*Pinus edulis*), and juniper (*Juniperus sp.*). Pinyon-juniper woodlands are characterized by multi-aged stands, forming a mosaic influenced by drought, insects, and disease, and vary widely in stem density. Fire and invasive species are generally of low importance in this vegetation type. Special status plants in the pinyon-juniper zone include the Grand Canyon goldenbush, sentry milk-vetch (*Astragalus cremnophylax var. cremnophylax*), North Rim milk-vetch (*Astragalus septentriorema*), and Grand Canyon catchfly (*Silene rectiramea*). The diversity of common vertebrates in this life zone include the common raven (*Corvus corax*), pinyon jay (*Gymnorhynus cyanocephalus*), Say's phoebe (*Sayornis saya*), desert cottontail (*Sylvilagus audubonii*), gray fox (*Urocyon cinereoargenteus*), plateau lizard (*Sceloporus undulatus*), and Sonoran gopher snake (*Pituophis melanoleucus*).

Shrub-Steppe: The shrub-steppe community, covering less than 5% of the park just above the rims, is dominated by big sagebrush (*Artemisia tridentata*) and Bigelow sagebrush (*Artemisia bigelovii*). Soil depth, temperature, and occasional fires dictate relative species occurrence within this community. The endemic Grand Canyon goldenbush is the only special status plant occurring in the shrub-steppe zone. Representative vertebrates again include many wide-ranging, habitat generalist species, similar to those found in the pinyon-juniper and montane shrublands.

Montane Shrublands and Interior Chaparral: Montane shrubland and interior chaparral is one of the primary vegetation types in GRCA, occupying nearly a quarter of the park area. Dominant plants include scrub oak (*Quercus turbinella*) and manzanita (*Arctostaphylos pungens*) in the warmer chaparral regions and Gambel oak (*Quercus gambelii*), three-leaf sumac (*Rhus trilobata*), snowberry (*Symphoricarpos oreophilus*), and mountain mahogany (*Cercocarpus ledifolius*) in the cooler montane shrubland. Fires are infrequent but key to regeneration and plant cover patterns. This habitat zone contains known populations of both the endemic Grand Canyon goldenbush and the Roaring Springs prickle poppy (*Argemone arizonica*). In addition to many of the same vertebrates found in the pinyon-juniper community, this zone also includes lower-elevation species such as the mourning dove (*Zenaida macroura*), plain titmouse (*Parus inornatus*), desert cottontail (*Sylvilagus audubonii*), desert woodrat (*Neotoma lepida*), white-tailed antelope squirrel (*Ammospermophi leucurus*), Great Basin gopher snake, and desert striped whipsnake (*Masticophis faeniatus*).

Desertscrub: Desertscrub vegetation, occurring throughout a wide band between 1,200 and 6,000 feet (1,829 m) in elevation, is the most widespread community in the park, occupying more than 500,000 acres (202,343 ha). Plants derive from all four major North American deserts: the Mojave, Sonoran, Chihuahuan, and cold Great Basin. A principle characteristic of desertscrub is the presence of young, undeveloped soils in dry environments. Dominant plants in warmer zones include creosote (*Larrea tridentata*), bursage (*Ambrosia dumosa*), honey mesquite (*Prosopis glandulosa*), cholla (*Cylindropuntia spp.*), and ocotillo

(*Fouqueria spendens*). In the cooler desertscrub, blackbrush (*Coleogyne ramosissima*), shadscale (*Atriplex spp.*), and Mormon tea (*Ephedra spp.*) dominate. Endemic plants of the desertscrub include the Roaring Springs prickle poppy, and McDougall's yellowtops (*Flaveria macdougallii*) Common vertebrates include many of those found in the montane shrublands and interior chaparral.

Desert Grasslands: Desert grasslands are not common in Grand Canyon, and result from disturbance to desert shrublands. They can occur on flats or gentle slopes at 3,500–5,500 feet (1,067–1,676 m) in elevation. These habitats contain both warm and cool desert species. No endemic plants are known from the desert grasslands. Vertebrates ranging into this zone are common and widespread species known from other habitats, including many warm, lower-elevation species.

Riparian: Although they occupy only 1.4% of the total area of the park, riparian habitats are extremely important centers of species diversity as well as resources for wildlife species that use all other habitat types. In the Greater Grand Canyon Landscape, riparian areas include hydro-riparian areas, with year-round access to water, and xeroriparian habitats, where water presence is intermittent. In spite of their rarity, riparian areas support about 29% of the park's rare and endemic species, as well as up to ten times more birds than are found in surrounding desert habitats. A volatile water table and high potential for pollution threaten riparian areas and the diversity of species dependent upon them. In addition, riparian areas are subject to nonnative species invasion, including abundant tamarisk (*Tamarix ramosissima*) in the Colorado River corridor itself and Russian thistle (*Salsola tragus*) and annual bromes (*Bromus rubens, B. diandrus, B. tectorum*) in ephemeral xeroriparian sites. The riparian zone, so important to the overall diversity of the region, includes populations of three endemic plant species, the Kaibab suncup (*Chylismia confertiflora, syn. Camissonia confertiflora*), and McDougall's yellowtops (*Flaveria macdougallii*),. Special status wildlife in the Colorado River corridor include the humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), flannelmouth sucker (*Catostomus latipinnis*), and Kanab and Niobrara ambersnails (*Oxyloma haydeni kanabensis and Oxyloma haydeni*). Many more widespread species inhabit riparian areas in the park, including both species common in other habitats and riparian specialists, such as the great blue heron (*Ardea herodias*), canyon wren (*Catherpes mexicanus*), ringtail (*Bassariscus astutus*), beaver (*Castor canadensis*), and canyon tree frog (*Hyla arenicolor*).

History and Culture

The park's archeological record documents more than 12,000 years of human use and occupation. GRCA preserves thousands of archeological sites, but to date, only about 6% of park lands have been inventoried; many more sites remain unrecorded. Eleven American Indian tribes retain important connections to Grand Canyon, with some considering the canyon their original homeland and place of origin. These federally recognized Traditionally Associated Tribes include the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Las Vegas Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian Tribe of Utah, San Juan Southern Paiute Tribe, Yavapai-Apache Nation, and Zuni Tribe. The great significance of Grand Canyon's cultural heritage lies in the richness and diversity of the cultural groups found here and the varied lifeways people pursued to adapt to what many regard as a severe climatic and physiographic environment. Unique cultural adaptations made by diverse cultural groups over

millennia—such as establishing travel routes from river to rim, farming at 8,000 feet (2,438 m), and using varied microenvironments seasonally across the region—nurtured life in the rugged, remote Grand Canyon. These same adaptive strategies are found in neighboring tribes' historic and present-day land use.

The first European accounts of Grand Canyon came in 1540 with a Spanish expedition to find the fabled Seven Cities of Gold. The most famous explorer to visit the canyon, however, came in 1869 when John Wesley Powell surveyed the inner canyon. Settlers in the 19th century began mining operations near and in the canyon but often found that tourism was more profitable. In 1901, the Grand Canyon Railway was established to move tourists to the South Rim; shortly afterward Grand Canyon Village grew into being, including the centerpiece El Tovar Hotel in 1905. The first federal protection of the canyon came in 1893 when it was designated a Forest Reserve and later a National Monument. Grand Canyon National Park was created in 1919, three years after the creation of the NPS.

Today the park attracts over 5 million visitors, one of the most visited national parks in the system. For many visitors Grand Canyon is their first experience on the Colorado Plateau, their first experience of life away from cities and infrastructure, and their first experience of the American Southwest.

Weather, Climate, and Visibility

Temperatures at the canyon bottom can range from highs above 90ºF (32ºC) in summer to lows in the 30s (-1–4ºC) in winter. The bottom of the canyon varies in elevation as the Colorado River cuts through the park in a general east to west direction. The elevation of the river at Lee's Ferry, near the northeastern boundary of the park is 3,106 feet (947 m) while the elevation of the river at Diamond Creek, near the western boundary is 1,343 feet (409 m). The elevation is approximately 7,000 feet (2,134 m) at Grand Canyon Village on the South Rim. On the North Rim, 1,000 feet (305 m) higher in elevation than the South Rim, temperatures can range from highs in the 70s (21–26ºC) in summer to sub-zero (-18ºC) lows in winter. The North Rim's boreal forests receive on average 2.1 inches (5.3 cm) of precipitation per month, whereas an average of only 0.71 inches (1.8 cm) per month reaches the inner canyon (Figure 1). The region is generally arid, with most moisture arriving in the form of dramatic summer thunderstorms and winter snowfall. Variability is therefore high across both season and location, leading to notably diverse microclimates and sub-habitats. The entire region receives considerable amounts of solar energy, a product of both many clear days, high visibility, and high elevation (Figure 2).

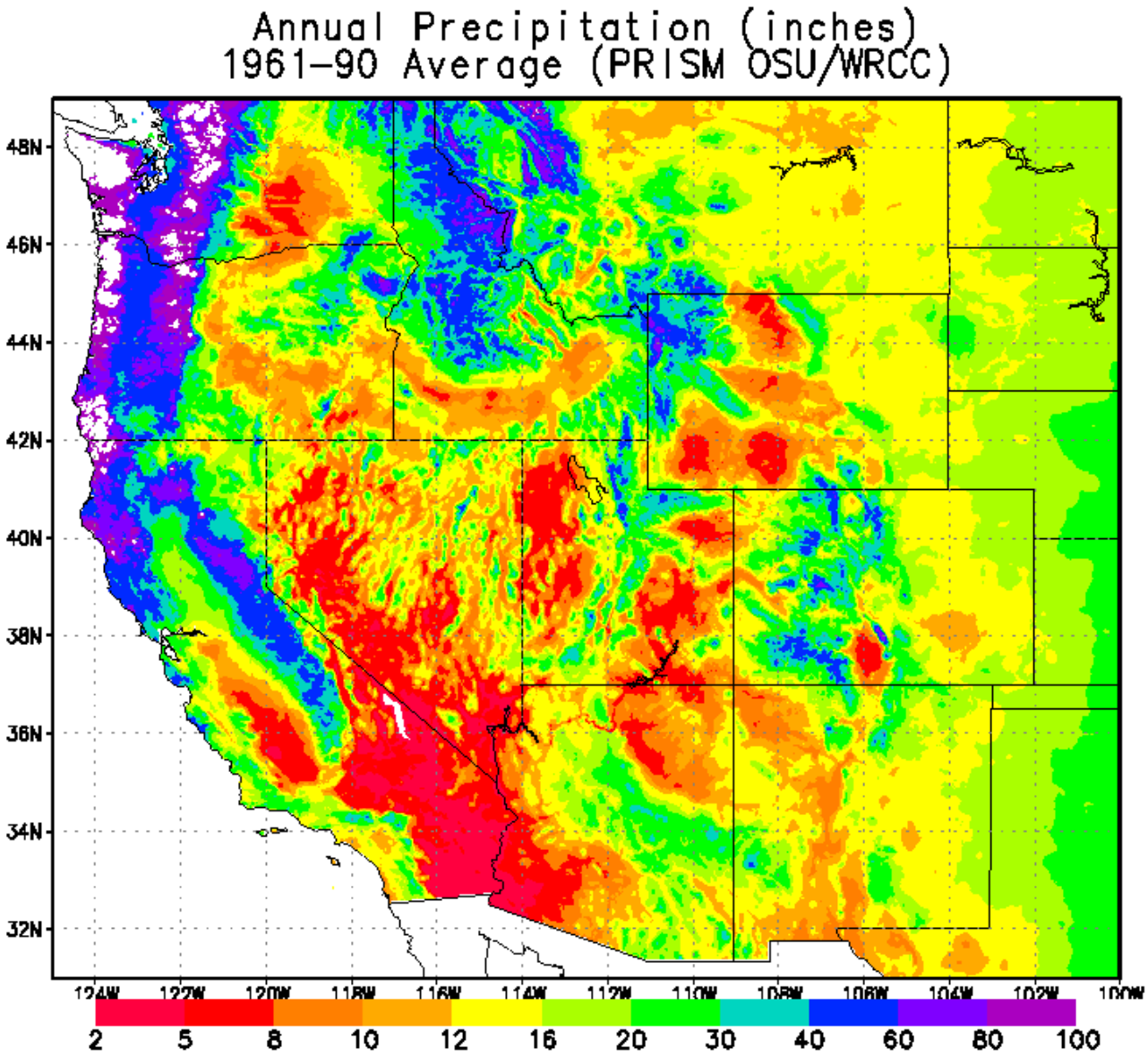

Figure 1. Average annual precipitation in inches as measured by the PRISM satellite. Data from the Western Regional Climate Center: http://www.wrcc.dri.edu/images/west.gif. Grand Canyon National Park is located in north-northwest Arizona with the inner canyon visible in the image as the thin strip of red running east-west.

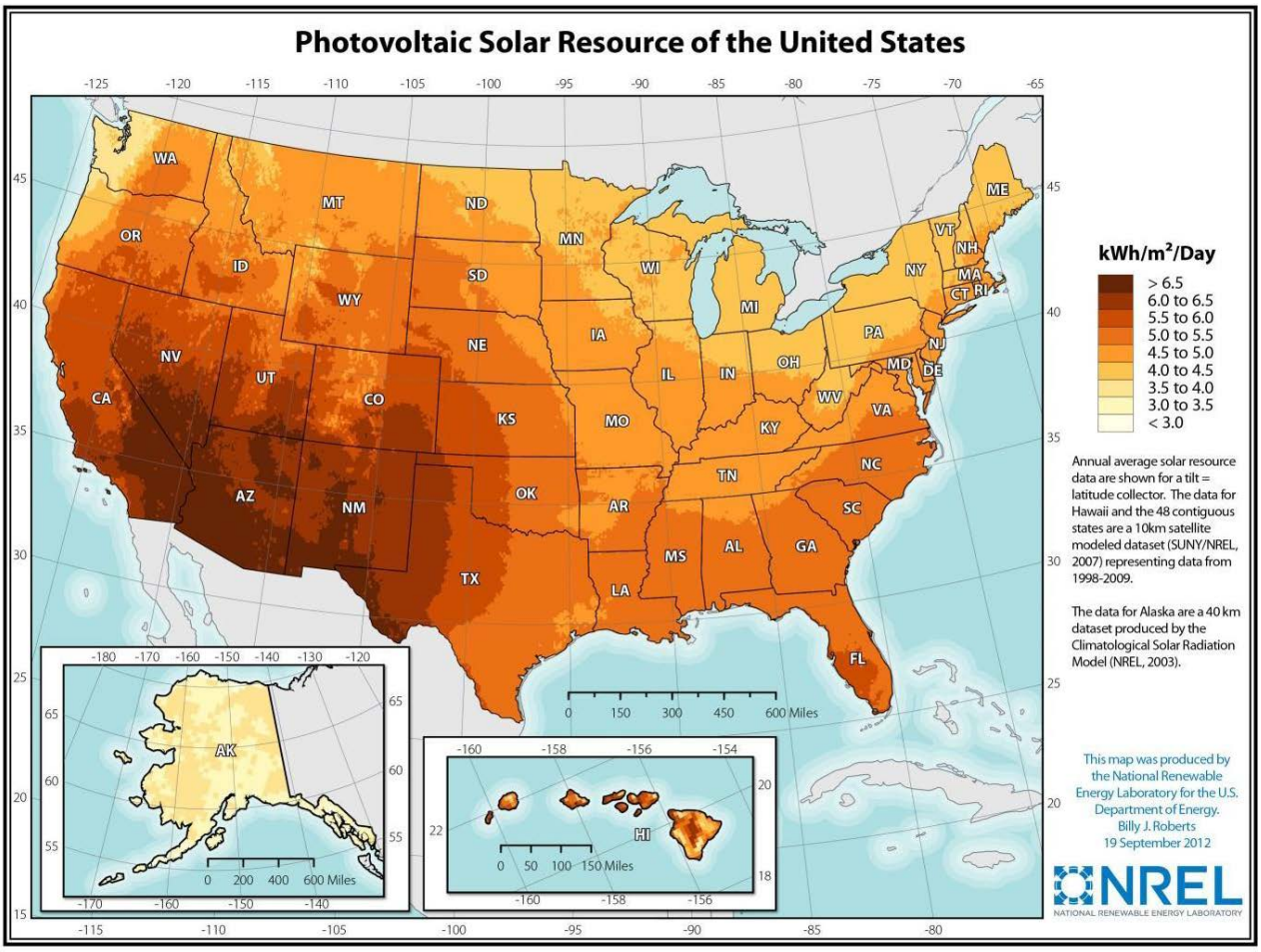

Figure 2. Photovoltaic solar resources in the United States from 1998 to 2009 provided by the National Renewable Energy Laboratory (http://www.nrel.gov/gis/solar.html). Most of GRCA is in the second highest solar intensity zone (6.0 to 6.5 kWh/m2/day).

Grand Canyon is a Class I area under the Clean Air Act, requiring that the park receives the highest level of air-quality protection. Consequently, Grand Canyon participates in the NPS comprehensive air resources management program, which is designed to assess air pollution impacts and protect air quality related resources (Figures 3 and 4). A webcam is maintained on the roof of the Yavapai Geology Museum to assess daytime visibility; view it at: http://www.nature.nps.gov/air/WebCams/parks/grcacam/grcacam.cfm The Grand Canyon is in a region with some of the most pristine visibility conditions, only bested by areas further North in the Colorado Plateau (Figure 5).

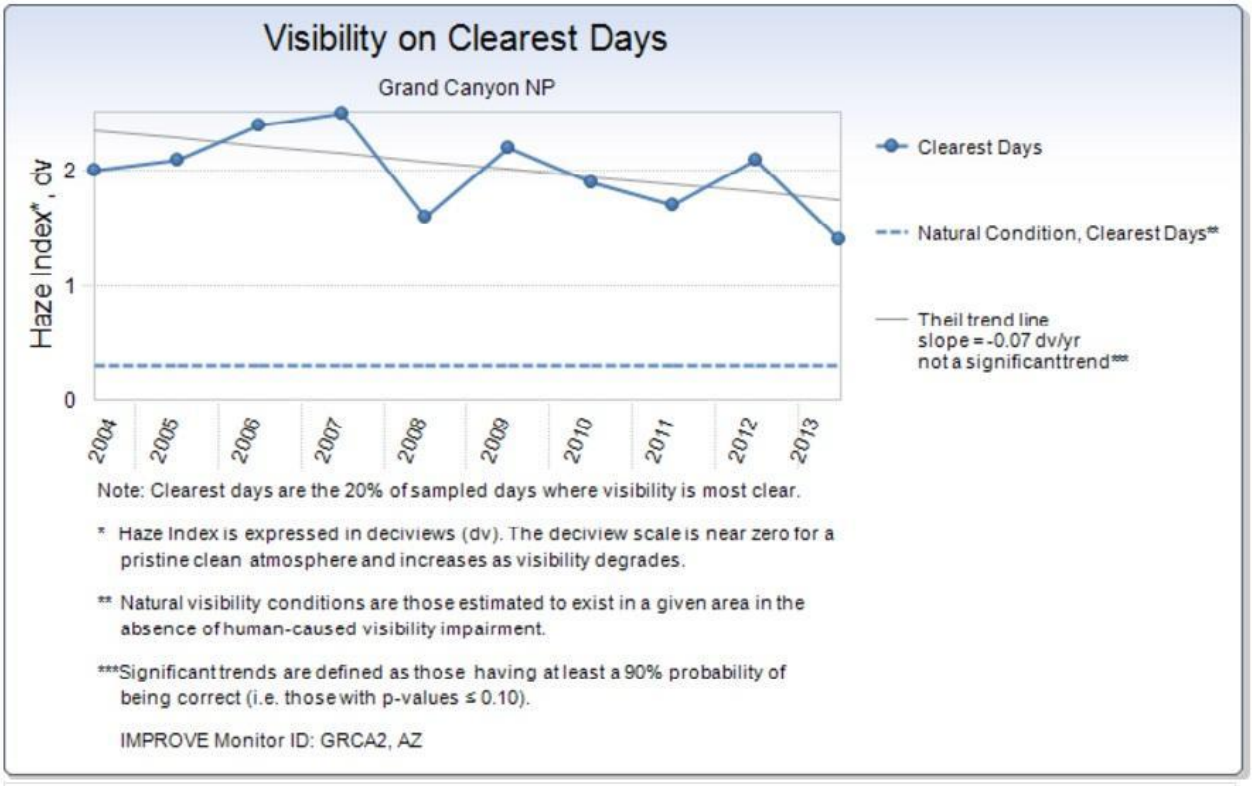

Figure 3. Visibility data from 2004 to 2013 as measured in GRCA at the IMPROVE (Interagency Monitoring of Protected Visual Environments) site. Data indicate a slight, non-significant, improvement in clear day haze reduction. (Data from http://www.nature.nps.gov/air/maps/AirAtlas/visibility.cfm)

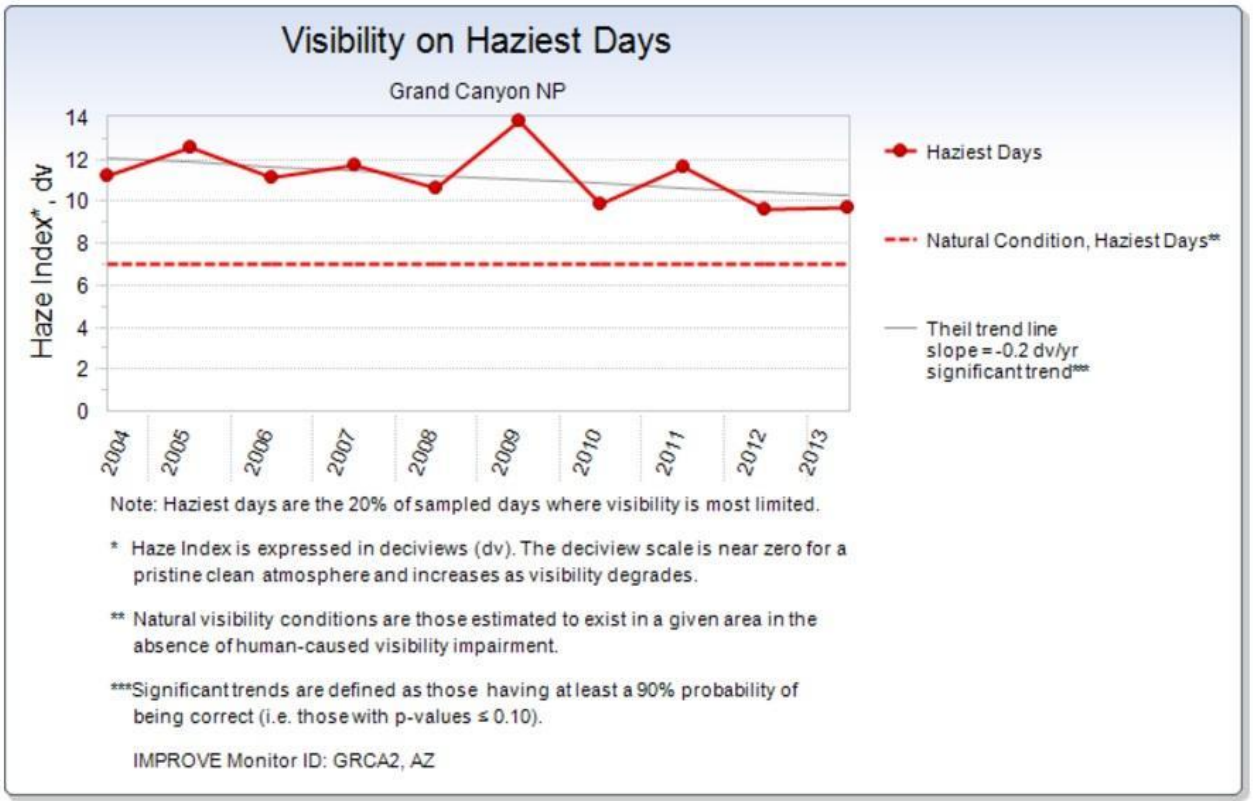

Figure 4. Visibility data from 2004 to 2013 as measured in GRCA at the IMPROVE (Interagency Monitoring of Protected Visual Environments) site. Data indicates a slight, statistically significant, improvement in hazy day haze reduction. (Data from: http://www.nature.nps.gov/air/maps/AirAtlas/visibility.cfm)

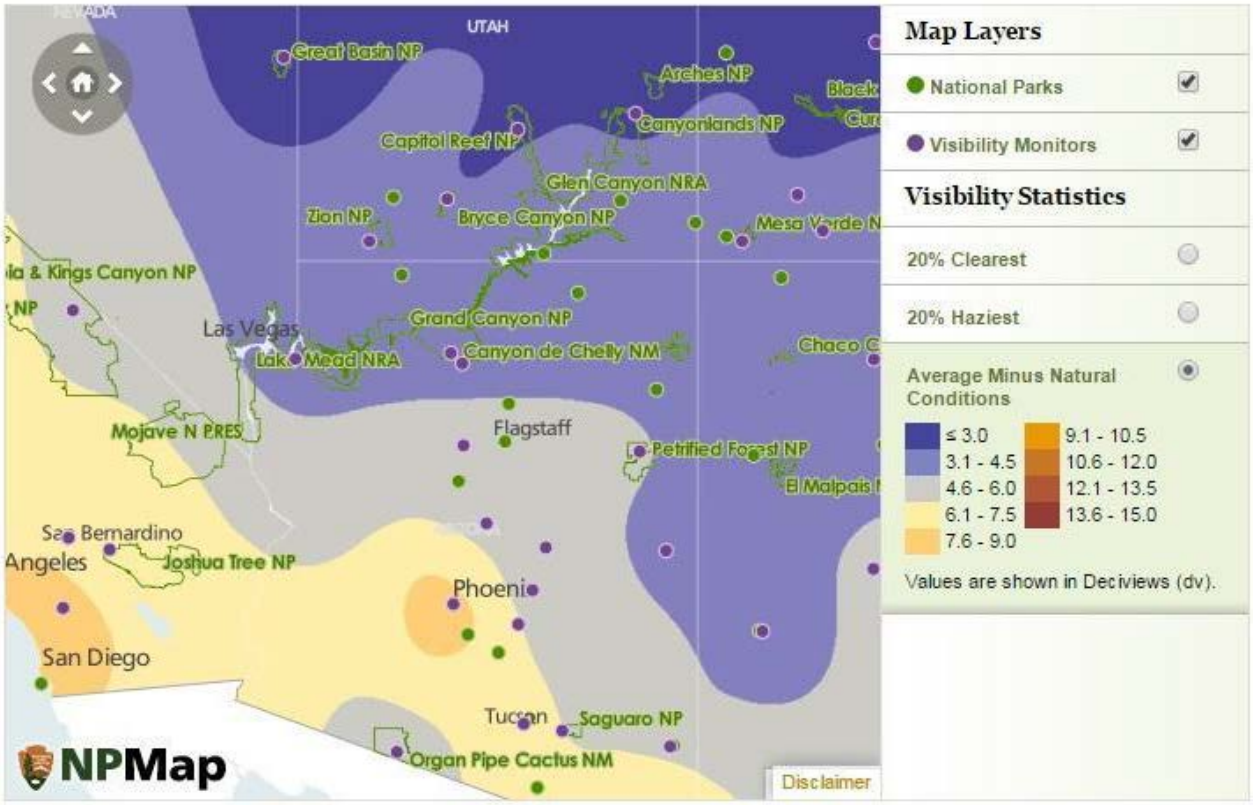

Figure 5. A regional visibility map showing the average minus the natural conditions in deciviews (dv). Areas of higher visibility are indicated in blue, areas with higher anthropogenic haze are indicated in tan, browns, and reds. Data viewer available at: http://www.nature.nps.gov/air/maps/AirAtlas/visibility.cfm

Isolation from Light Pollution

Light pollution limits the visibility of the Milky Way to the unaided eye, the visibility of nebulae and galaxies seen in telescopes, and raises the noise on charge coupled device (CCD) astrophotographs. Only observations of planets and double stars are unaffected. Low light pollution conditions, or dark skies, are one of the most important properties of a good astronomical observing site.

Figure 6 shows a small excerpt from the Light Pollution Atlas 2006 by David Lorenz. The background imagery is from Google Maps. A more sophisticated sky glow model is presented later in this report based on visible infrared imaging radiometer suite (VIIRS) satellite data.

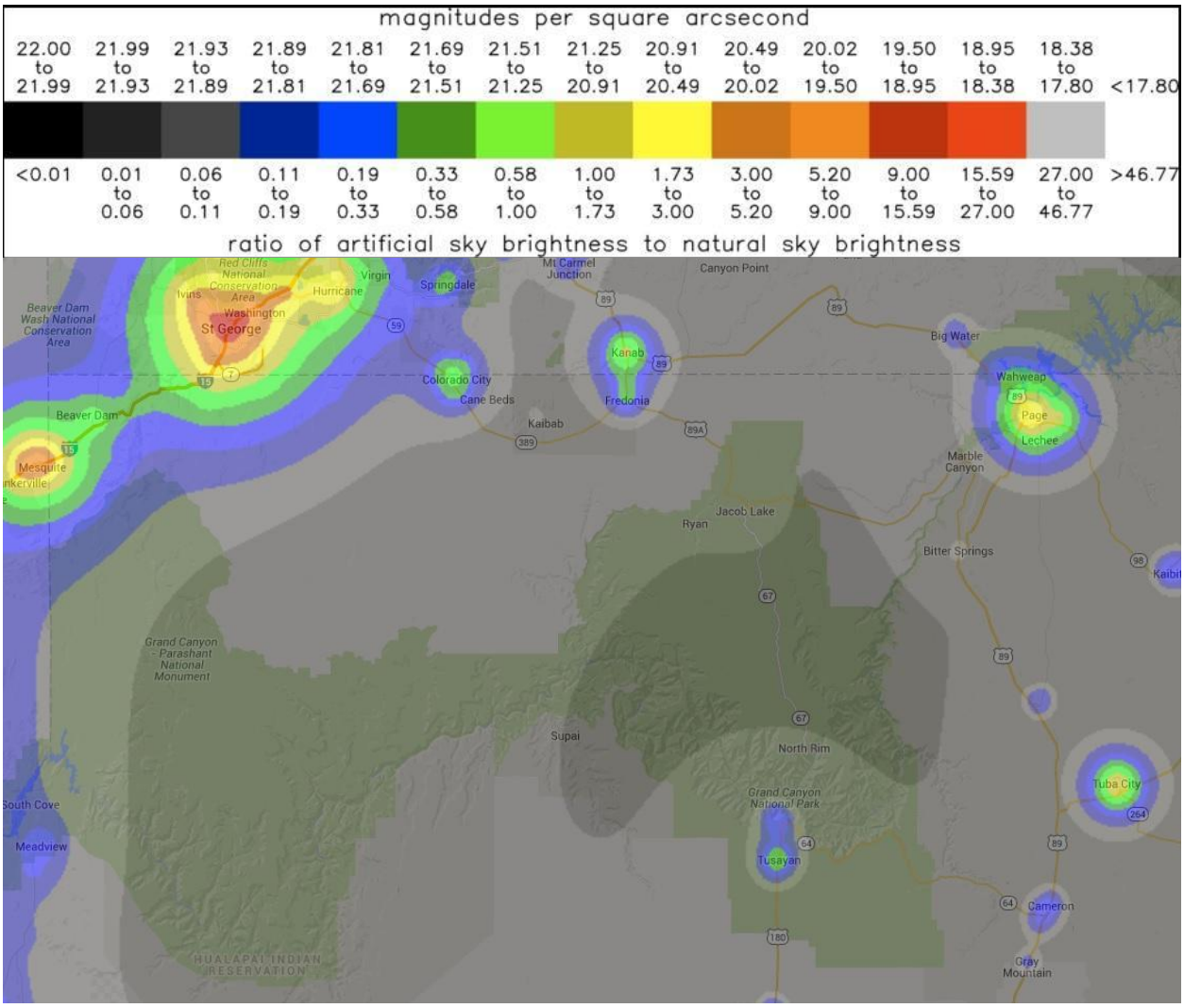

Figure 6. Ratio of artificial sky brightness to natural sky brightness and magnitudes per square arcsecond from David Lorenz's 2006 Light Pollution Atlas.

Grand Canyon National Park is isolated from cities and towns of significant size (Table 1). With the exception of the town of Tusayan, there are no nearby communities that significantly impact the night skies of the developed areas of the North and South rims. The western portion of the park is negatively impacted by the Las Vegas "light dome" but not to the extent that nearby Lake Mead National Recreational Area is impacted.

City/Town	Distance (miles)	Population (2010)	Direction
Tusayan	6	573	South
Havasupai	27	549	West
Valle	28	832	South
Cameron	41	885	Southeast
Bitter Springs	42	452	Northeast
Tuba City	50	8611	East
Williams	55	3000	South
Flagstaff	65	68,000	Southeast
Page	71	7,300	Northeast
Las Vegas	168	603,000	West
Phoenix	175	1,500,000	South

Table 1. Distances, populations, and orientation of cities and towns surrounding GRCA.

Assessment of Sky Quality at Grand Canyon

October 2015 Lightscape Evaluation Survey Summary of Results

Five locations important to the visitor experience, two on North Rim and three on South Rim, were selected for all-sky photometry, and data of good quality was successfully collected at each site. A reconnaissance of other sites along paved roads was also conducted at both areas; two additional sites were identified on the North Rim as potentially important.

The results indicate that the night sky quality at all of these sites is excellent and has remained stable at least since 2007 (the last all-sky photometry trip to the park). An examination of outdoor lighting in the Grand Canyon Village area between the Kolb Studio and the Hopi House along the Rim Trail was performed, and digital single-lens reflex (DSLR) imaging and scene luminance measurements were taken at several specific locations. Outdoor lighting observations were made during night visits to the Mather Point/Grand Canyon Visitor Center area, Yavapai Geology Museum, South Kaibab Trailhead area, South Rim Recreation Center, and Horace Albright Training Center on the South Rim. These observations show that, with a few notable exceptions, the existing outdoor lighting in developed areas of GRCA is very conservative, and the inherently excellent night sky quality is not significantly degraded by these internal sources. DSLR photography at numerous locations for qualitative and semi-quantitative analysis was also performed. They reveal striking examples of both the excellent night sky quality of the park as well as internal and external threats in the form of both light trespass and sky glow.

Back at the office, a geospatial model of average artificial sky brightness over the region was constructed and is presented. It shows the remarkable geographic context of the park with relation to the large (light-polluted) cities of Los Angeles, California, Phoenix, and Las Vegas. Also, remotely sensed upward radiance data compiled over the past two years was used to estimate current trends in regional sky glow. This analysis predicts that the amount of sky glow has remained stable or declined slightly at most locations in the park.

Natural Lightscape Management Issues at GRCA

Natural lightscape protection objectives are grouped into the following four subject areas: 1) night sky quality condition assessment; 2) developed zone outdoor lighting and scene evaluation; 3) visitor experience opportunity; and 4) park planning. Following is a report of the information collected, an analysis of the information, and management implications for each subject area investigated. An attempt is made here to list most of the issues that would be included in a natural lightscape management plan for GRCA.

Night Sky Quality Condition Assessment—Data Sources and Results

Models

Modeled light pollution data is available for the park and surrounding region (Figure 7). It is based upon the most recent (October 2015) available remote sensing of upward radiance. It is constructed by computing the weighted sum of an area 186 miles (300 km) in radius of the upward radiance contributing to sky glow. The cell size is 1,476 feet (450 m) square. This gives only an approximate idea of the park's resource condition, but total geographic coverage. The map displays the predicted all-sky light pollution ratio (ALR), a ratio of the artificial sky glow to the natural background, for the indicator average all-sky luminance. It is seen that the predicted sky quality in GRCA varies from less than 0.05 to about 0.6, with the darkest parts of the park in the region between North Rim and the northern boundary, while the brightest parts are at the western boundary.

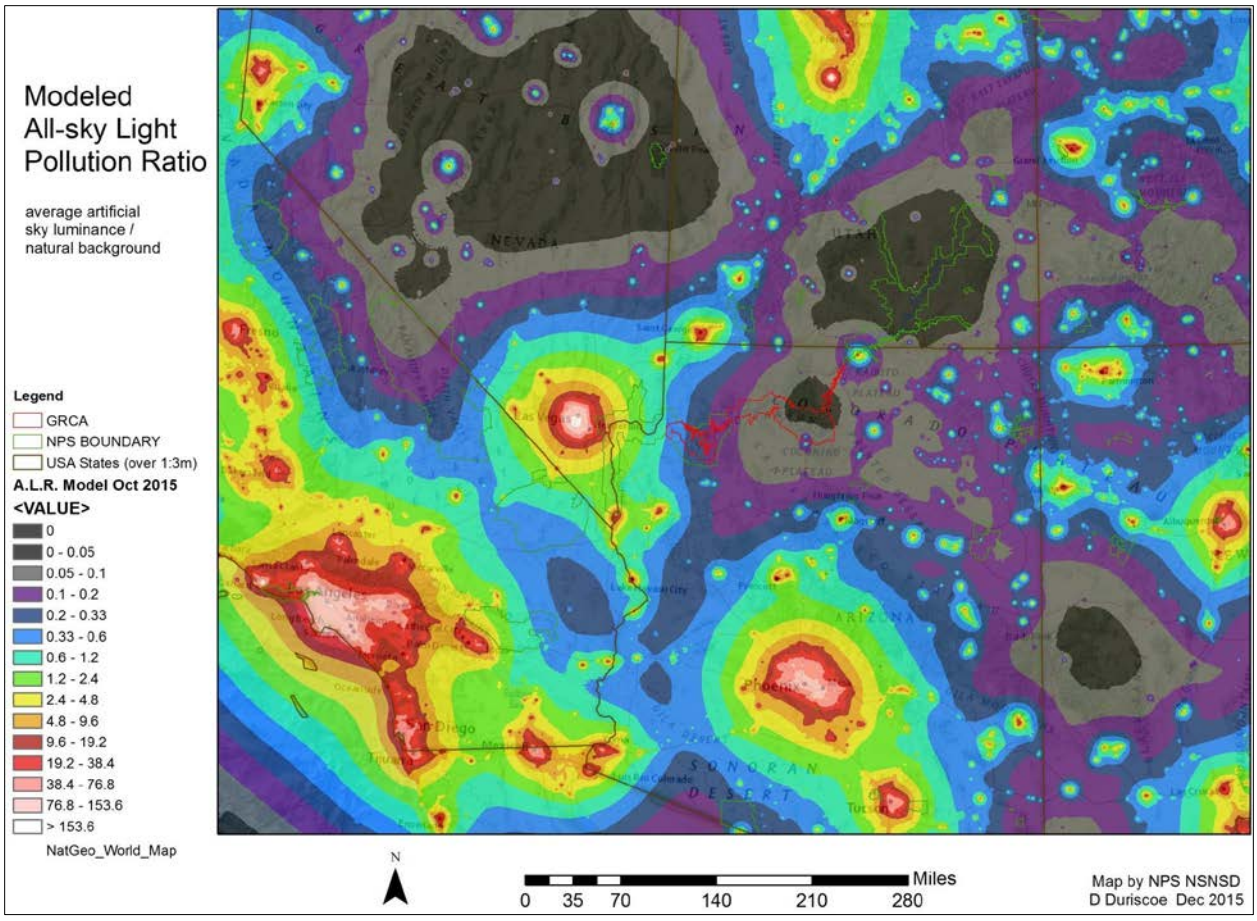

Figure 7. Predicted impact of artificial sky glow over the region surrounding GRCA, based upon October 2015 remotely sensed upward radiance data.

Remote Sensing

Remote sensing of the upward radiance from artificial sources has resulted in world-wide coverage, available from the Suomi National Polar-orbiting Partnership (NPP) satellite, VIIRS day/night band sensor. Data is compiled and reported monthly by the National Oceanic and Atmospheric Administration Earth Observation Group (Figure 8). The units are nano-watts per square centimeter per steradian. These data are available as monthly averages since January 2014; the most recent (October 2015) is displayed in Figure 8. The instrument is sensitive enough to record the lights at North Rim, while South Rim is quite obvious encompassing many pixels (Figure 29).

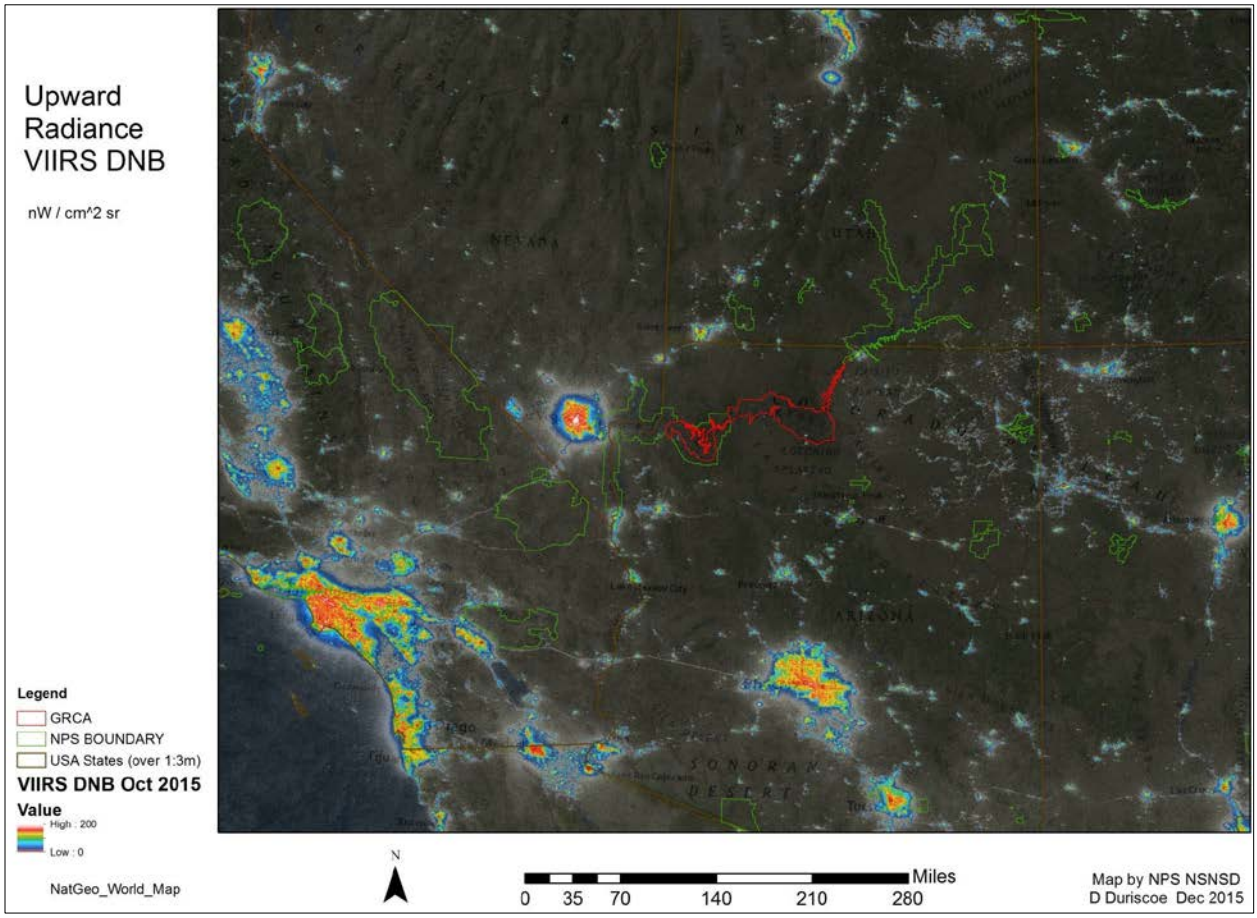

Figure 8. Upward radiance as measured by NPP Suomi satellite, VIIRS day/night band sensor, cloud free composite for October 2015.

Observations

NPS All-sky Photometry: All-sky broadband photometry of sky brightness (or luminance) is an important product of the NPS natural sounds and night skies division. The methods and results of this work are described in detail in peer-reviewed articles (http://www.jstor.org/stable/10.1086/512069). Data processing results in all-sky image mosiacs color coded by calibrated sky brightness in V magnitudes per square arc second (an inverse logarithmic scale--a smaller number indicates brighter luminance). All-sky photometry is especially important in protected areas, such as wilderness or Class I airsheds where protecting visibility is

critical to scenic values, since distant light sources such as cities and towns will produce much more sky glow near the horizon than overhead.

Historic data collection has occurred in GRCA (Figure 9). Previous collection years include 2007 and 2008. Reports from these site visits are available on the world wide web with a Google Earth interface; the kml file can be downloaded at (http://www.jstor.org/stable/10.1086/512069). Once installed, individual reports and sky brightness maps may be accessed for the "reference data set" of each data collection event (night). The reference data set is the set of images that presents the most accurate or most representative of the artificial sky luminance observed.

All-sky photometric data was collected at five locations (Figure 9). These data are presented below, organized by observing site, in a format similar to the Google Earth reports. Observations made in conjunction with all-sky photometry include a visual narrative, an estimation of naked eye limiting magnitude (NELM), and an estimation of Bortle Class. Measurements include recording sky brightness with a hand-held Unihedron Sky Quality Meter (SQM), and all-sky imaging with a calibrated CCD camera. Imaging with a color DSLR camera was also performed at selected sites. For a detailed explanation of the data tables presented see (http://www.jstor.org/stable/10.1086/512069).

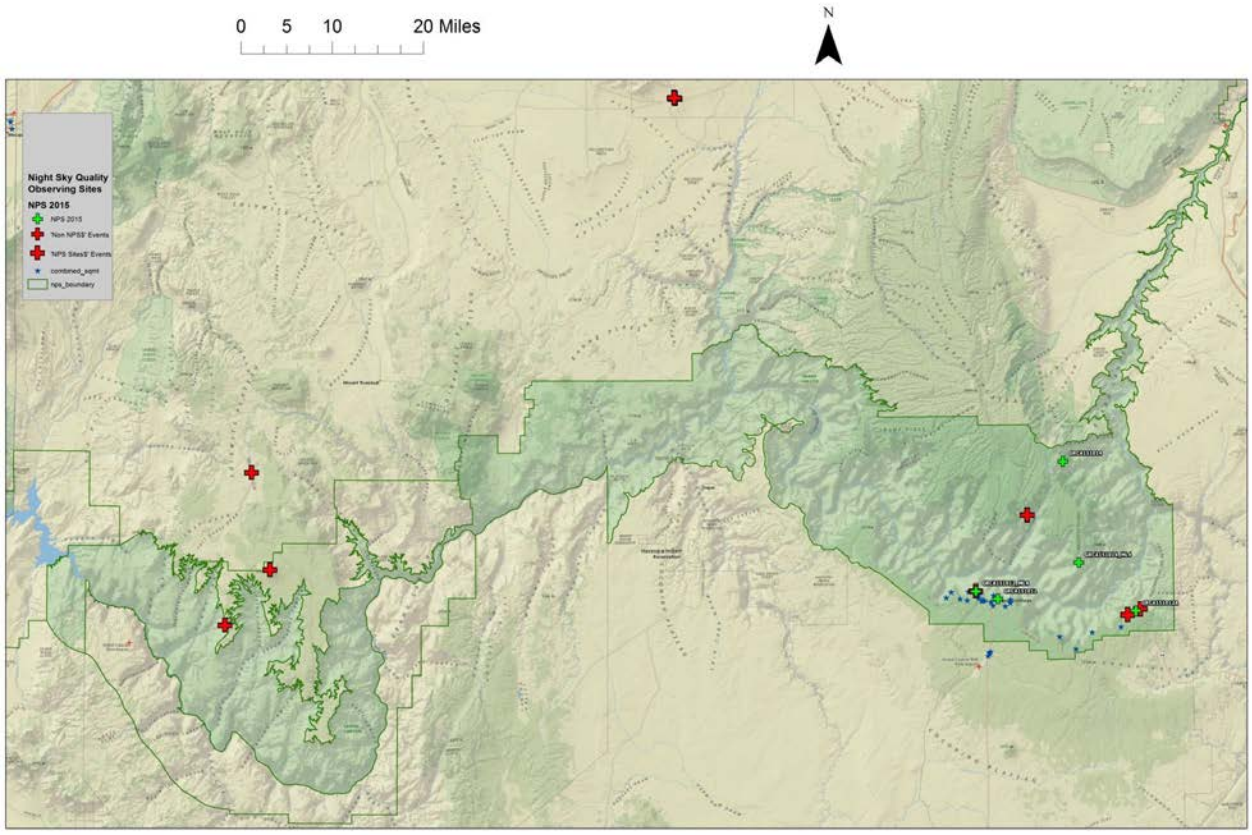

Figure 9. Location of historic and October 2015 all-sky photometry sites (red and green crosses, respectively). Also shown are locations of SQM-L observations in the Globe at Night database (blue stars).

Powell Memorial Site

Longitude	-112.15125		**Wind Speed (mph)**	6
Latitude	36.07321		**Extinction Coeff. (mag/airmass)**	0.13
Elevation (m)	2150		**NELM**	7
Date	11-Oct-2015		**Bortle Class**	2
Time (LMT)	22.12		**Synthetic SQM**	21.38
Observers	D Duriscoe, B Meadows, J White		**SQI All- sky**	95.4
Air temp. (°C)	18.3		**SQI to Z.A. 70°**	97.8
R. H. (%)	35		**Number of stars visible**	3890

Table 2. Event metadata, atmospheric extinction, and visual indicators.

Field Narrative: "Clear night with no visible clouds in the hemisphere seen. Warm and still with 6 mph breeze. Slight haze on west and southwest horizon, but stars visible to 5 degrees above horizon. Milky Way is visible as an almost complete band from southwest to northeast. Almost 25 degrees wide at the south end. Light domes of Phoenix (large and bright through Milky Way), Tusayan, and Las Vegas were brightest. Dust lanes easily visible. Southern Milky Way slightly diminished along horizon due to haze. SQM = 21.63."

Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec^2	**µcd/ m^2**	**mag/ arcsec^2**	**µcd/ m^2**	
Zenith	21.67	233	> 24.5	< 17	< 0.10
Mean All-sky	21.18	364	24.12	24	0.10
Brightest	19.91	1,160	20.13	948	5.54
Darkest	21.65	235	> 24.5	< 17	< 0.10
Median	21.22	347	24.85	12	0.05
Illuminance Measures					
	mags	**milli-lux**	**mags**	**milli-lux**	
Horizontal	-6.51	1.02	-3.00	0.04	0.05
Max Vertical	-6.01	0.64	-3.97	0.10	0.25

Table 3. Numeric photometric indicators of night sky quality.

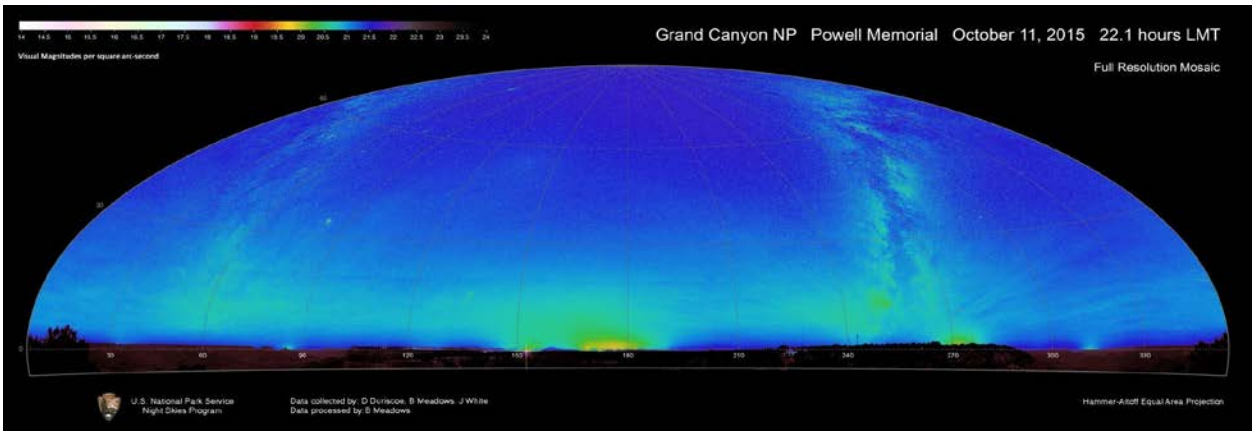

Figure 10. Full resolution mosaic of photometrically calibrated images.

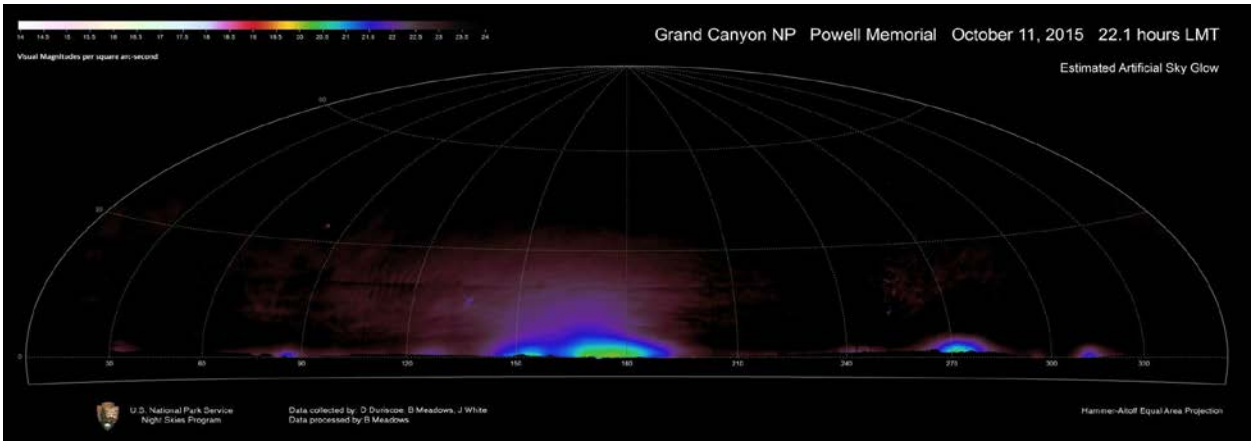

Figure 11. Estimated anthropogenic sky glow after subtraction of the natural sky model.

Mather Point/Grand Canyon Visitor Center Bus Parking Site

Longitude	-112.11		**Wind Speed (mph)**	1
Latitude	36.06		**Extinction Coeff. (mag/airmass)**	0.14
Elevation (m)	2171		**NELM**	7.0
Date	11-Oct-2015		**Bortle Class**	3
Time (LMT)	21.92		**Synthetic SQM**	21.29
Observers	D Duriscoe, J White, B Meadows		**SQI All- sky**	95.7
Air temp. (°C)	16.8		**SQI to Z.A. 70°**	98.0
R. H. (%)	41		**Number of stars visible**	3680

Table 4. Event metadata, atmospheric extinction, and visual indicators.

Field Narrative: "Near the star party location; good site for lots of telescopes and people. Few glare sources, worst is restroom light to the north which was covered. Glow from Phoenix, Prescott, Arizona, and Las Vegas brightest, but there seems to be a significant glow from the Grand Canyon Village area. Distant cities extend to only 5 degrees above horizon, Grand Canyon Village maybe 15 degrees but much fainter. Very bright airglow tonight obscuring the Milky Way low in the southwest. Not the best of nights for that reason, but transparency is excellent and seeing is good. SQM 21.71 but suspect, visually looks much brighter."

Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec^2	**µcd/ m^2**	**mag/ arcsec^2**	**µcd/ m^2**	
Zenith	21.60	249	> 24.5	< 17	< 0.10
Mean All-sky	21.10	393	24.38	19	0.08
Brightest	19.96	1,112	20.24	860	5.03
Darkest	21.58	250	> 24.5	< 17	< 0.10
Median	21.15	370	25.03	10	0.04
Illuminance Measures					
	mags	**milli-lux**	**mags**	**milli-lux**	
Horizontal	-6.59	1.10	-2.91	0.04	0.05
Max Vertical	-6.15	0.73	-3.90	0.09	0.23

Table 5. Numeric photometric indicators of night sky quality.

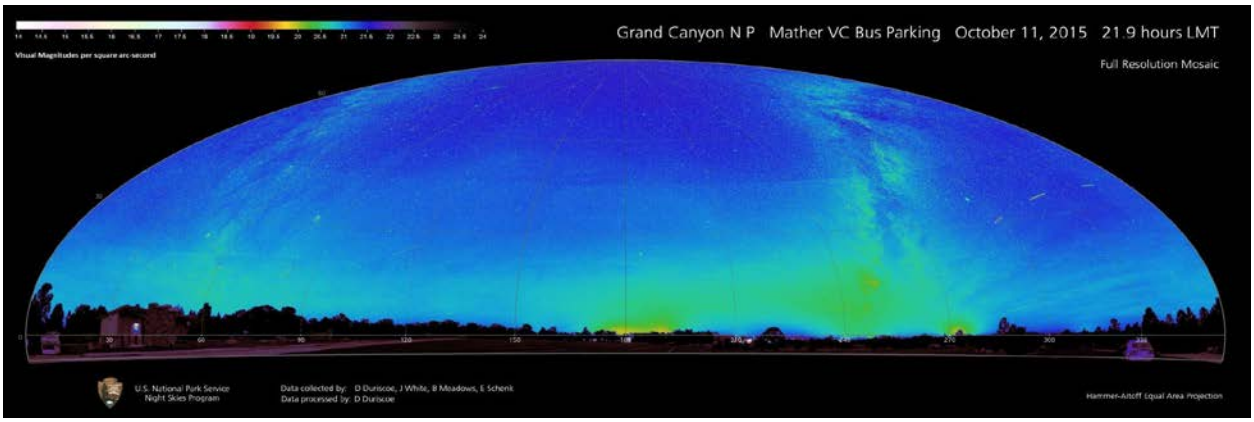

Figure 12. Full resolution mosaic of photometrically calibrated images.

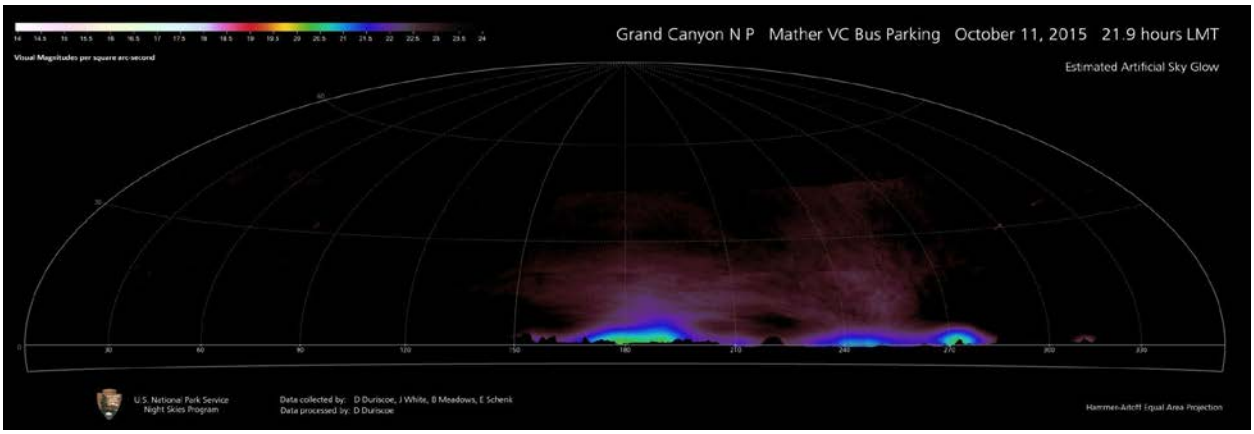

Figure 13. Estimated anthropogenic sky glow after subtraction of the natural sky model.

Navajo Point Site

Longitude	-111.84		**Wind Speed (mph)**	4
Latitude	36.04		**Extinction Coeff. (mag/airmass)**	0.13
Elevation (m)	2266		**NELM**	7.0
Date	11-Oct-2015		**Bortle Class**	3
Time (LMT)	23.93		**Synthetic SQM**	21.39
Observers	D Duriscoe, B Meadows, J White		**SQI All- sky**	98.9
Air temp. (°C)	14.3		**SQI to Z.A. 70°**	99.6
R. H. (%)	44.0		**Number of stars visible**	3980

Table 6. Event metadata, atmospheric extinction, and visual indicators.

Field Narrative: "Site on east end of Navajo Point, view to south and west blocked, east good. Bright airglow, seeing good, transparency very good. A near total absence of artificial sky glow from this location, but Phoenix is blocked by horizon obstruction to the south. Tuba City, Arizona, biggest light dome to the east but very small and extends less than 5 degrees high, Cameron light dome all but invisible faint and low, Flagstaff light dome barely seen above the horizon. SQM 21.48."

Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec^2	**µcd/ m^2**	**mag/ arcsec^2**	**µcd/ m^2**	
Zenith	21.67	234	> 24.5	< 17	< 0.10
Mean All-sky	21.24	345	25.73	5	< 0.04
Brightest	20.43	722	20.99	431	2.52
Darkest	21.65	234	> 24.5	< 17	< 0.10
Median	21.28	328	> 25.1	< 10	< 0.03
Illuminance Measures					
	mags	**milli-lux**	**mags**	**milli-lux**	
Horizontal	-6.48	0.99	-1.76	0.01	0.02
Max Vertical	-5.92	0.59	-2.30	0.02	0.05

Table 7. Numeric photometric indicators of night sky quality.

Figure 14. Full resolution mosaic of photometrically calibrated images.

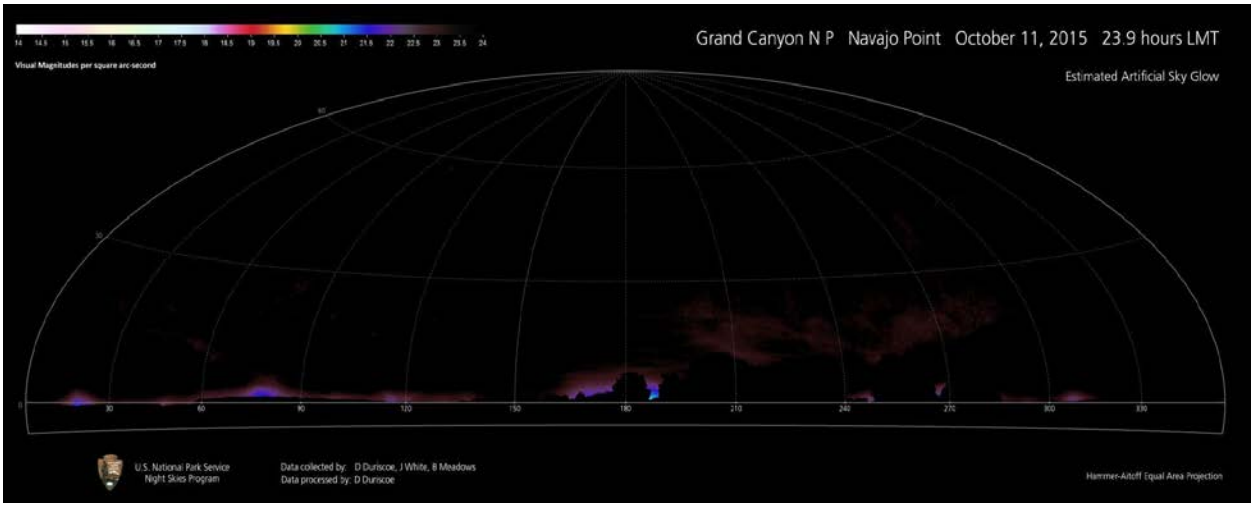

Figure 15. Estimated anthropogenic sky glow after subtraction of the natural sky model.

Point Imperial Site

Longitude	-111.98		**Wind Speed (mph)**	5
Latitude	36.28		**Extinction Coeff. (mag/airmass)**	0.12
Elevation (m)	2680		**NELM**	7.0
Date	13-Oct-2015		**Bortle Class**	3
Time (LMT)	19.07		**Synthetic SQM**	21.27
Observers	D Duriscoe, B Meadows, J White		**SQI All- sky**	97.8
Air temp. (°C)	14.4		**SQI to Z.A. 70°**	99.5
R. H. (%)	25		**Number of stars visible**	3710

Table 8. Event metadata, atmospheric extinction, and visual indicators.

Field Narrative: "Site at viewpoint, north and west blocked by trees but good view to the east. Seeing good, transparency very good, high airglow, changing rapidly. Many individual lights see to the east but very little sky glow, small light domes from Page, Arizona, and Tuba City, brightest is south, Phoenix/Prescott, still no more than 5 degrees tall, relatively faint, certainly fainter than Venus. Breezy, parking lot OK for astronomy but certainly not ideal."

Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec^2	**µcd/ m^2**	**mag/ arcsec^2**	**µcd/ m^2**	
Zenith	21.26	341	> 24.5	< 17	< 0.10
Mean All-sky	21.06	407	25.08	10	0.04
Brightest	19.72	1,387	20.29	821	4.80
Darkest	21.58	249	> 24.5	< 17	< 0.10
Median	21.12	383	> 25.1	< 10	< 0.03
Illuminance Measures					
	mags	**milli-lux**	**mags**	**milli-lux**	
Horizontal	-6.60	1.11	-1.56	0.01	0.01
Max Vertical	-6.20	0.77	-3.30	0.05	0.13

Table 9. Numeric photometric indicators of night sky quality.

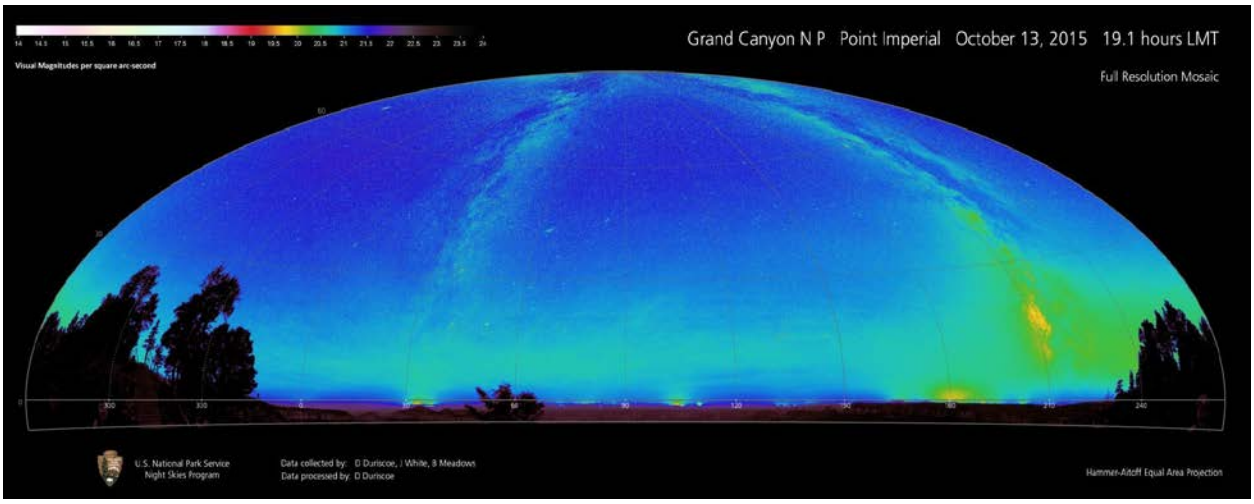

Figure 16. Full resolution mosaic of photometrically calibrated images.

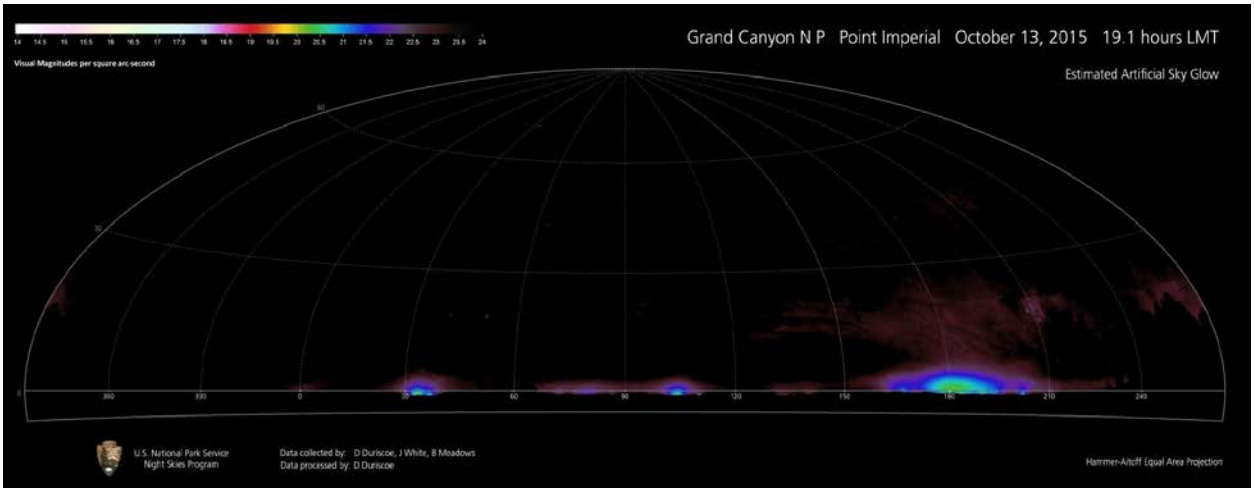

Figure 17. Estimated anthropogenic sky glow after subtraction of the natural sky model.

Cape Royal Site

Longitude	-111.95		**Wind Speed (mph)**	2
Latitude	36.12		**Extinction Coeff. (mag/airmass)**	0.12
Elevation (m)	2396		**NELM**	7.1
Date	13-Oct-2015		**Bortle Class**	2
Time (LMT)	22.06		**Synthetic SQM**	21.44
Observers	J White, B Meadows, D Duriscoe		**SQI All- sky**	95.8
Air temp. (°C)	18.3		**SQI to Z.A. 70°**	98.5
R. H. (%)	26		**Number of stars visible**	4090

Table 10. Event metadata, atmospheric extinction, and visual indicators.

Field Narrative: "Some haze along horizon, especially to the south and southeast. Airglow is moderately high to the north. Earlier at Point Imperial it was very strong to the north-northeast. Milky Way was almost a complete band, down to 3 degrees at Point Imperial. At 11:50 pm it is about 5 degrees above horizon with easily seen Dust Lanes and a bright Scutum Star Cloud. It is somewhat lost in the Las Vegas light dome. Andromeda and Hercules Cluster easily seen. Stars seen down to 1-2 degrees along southern horizon. SQM = 21.46."

Indicator	Observed		Estimated Artificial		Light Pollution Ratio (Artificial/Natural)
Sky Luminance Measures					
	mag/ arcsec^2	**µcd/ m^2**	**mag/ arcsec^2**	**µcd/ m^2**	
Zenith	21.72	223	> 24.5	< 17	< 0.10
Mean All-sky	21.26	340	24.21	22	0.09
Brightest	19.93	1,143	20.18	905	5.29
Darkest	21.72	220	> 24.5	< 17	< 0.10
Median	21.31	319	24.73	14	0.05
Illuminance Measures					
	mags	**milli-lux**	**mags**	**milli-lux**	
Horizontal	-6.43	0.94	-2.68	0.03	0.04
Max Vertical	-5.95	0.61	-3.43	0.06	0.15

Table 11. Numeric photometric indicators of night sky quality.

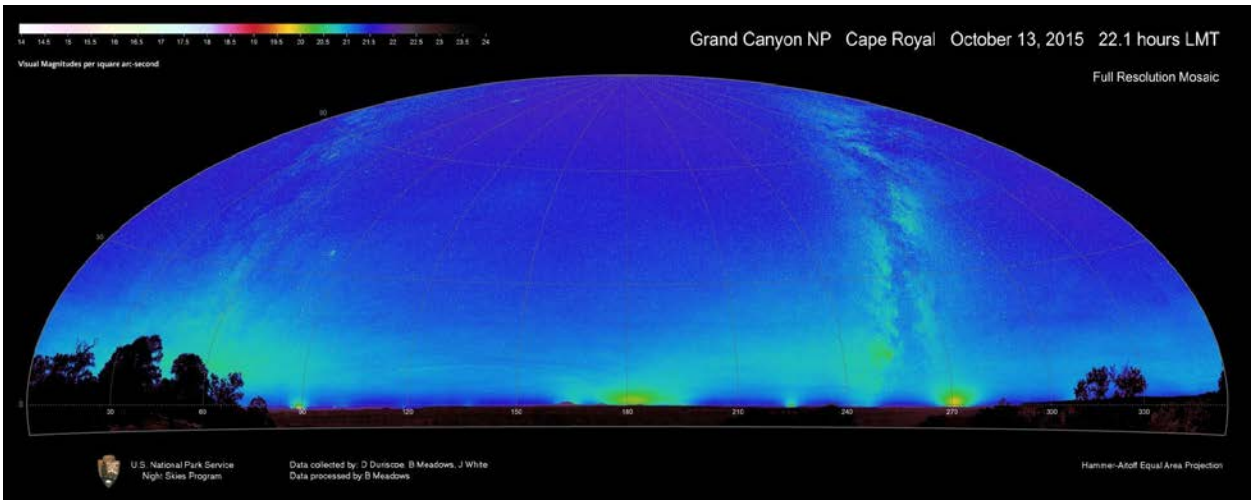

Figure 18. Full resolution mosaic of photometrically calibrated images

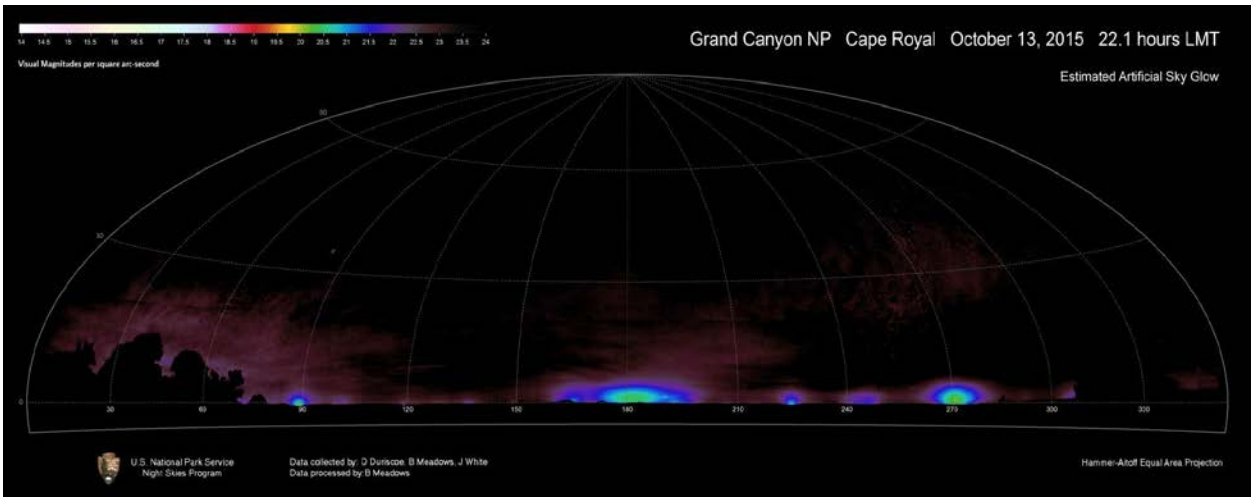

Figure 19. Estimated anthropogenic sky glow after subtraction of the natural sky model.

Single Channel Photometry: The Unihedron SQM and SQM-L are inexpensive photometers that encompass a wide field (120 and 40 degrees, respectively) of the night sky. These instruments are hand-held and may be useful for long term monitoring. They are intended to be aimed at the zenith on clear moonless nights. The single number result is an integration of the area of the sky, with the zenith being weighted much greater than the edges of the field of view.

Databases of SQM and SQM-L measurements are publicly available (see http://www.jstor.org/stable/10.1086/512069, http://www.jstor.org/stable/10.1086/512069). A world-wide combined database of observations since 2007 was obtained courtesy of C.C.M. Kyba. A smattering of observations from South Rim and Tusayan were included, taken in June and July of 2015. These observations are shown plotted on a map in Figure 20. The values are in magnitudes per square arc second. A value of 22.0 is the darkest possible with this instrument, values of 21.5-22.0 are considered to be free of light pollution, since this is the range of the natural background in the absence of the Milky Way. All the values shown along the South Rim in Figure 20 away from development fall within this range. Four observations in the Grand Canyon Village area are slightly brighter, within the range 21.35–21.50. Some brighter values were recorded in Tusayan; the brightest at 19.1, about ten times brighter than the natural background. Additional SQM measurements taken in the canyon and along the North Rim are provided further in the report in tabular format.

Historical Visual Observations: Not addressed, but may warrant research, especially if special astronomical studies have been carried out in the park. There may also be notes available from past amateur star parties. Other nighttime scientific studies, such as work on nocturnal birds or mammals, may have written notes on sky brightness conditions.

DSLR Color Imaging: This method is a tool for both descriptive visual quality assessment and photometry in up to three color channels, if calibrated. It is an excellent method to record the color of artificial sky glow, at least qualitatively. Night photography by professional artists and tourists occurs in the park regularly, and amateur astronomers may take wide field images revealing sky quality conditions at a point in time. Research into the availability of these images might be warranted for a qualitative record of past conditions.

Experiments with a Canon 6D and an 8mm fisheye lens produced some results at Cape Royal. Figures 21 and 22 show this method's capabilities of producing at least semi-quantitative results. Color panoramic images were also taken during this trip with a Sony A7s and Rokinon wide-angle lens at two locations: Cape Royal and Mather Point/Grand Canyon Visitor Center bus parking (Figures 23 and 24). Notice the pronounced green color to the sky produced by the natural airglow, which is a narrowband emission at 557 nm wavelength from oxygen atoms approximately 90 km above the earth's surface. Figures 21–24 all are long time exposures (1–2 minutes) with fast lenses. Also notice the distant light domes from cities have a yellow-orange hue, presumably because of the widespread use of high pressure sodium (HPS) gas discharge lamps in public outdoor lighting. An exception is the town of Tusayan, which shows up in Figures 21 and 23 as white or bluish white. This is probably because the majority of outdoor lighting in this town has been recently installed and its source is white light-emitting diode (LED) rather than HPS.

DSLR photography is a good tool to record light trespass and the impact of bright artificial sources in a naturally dark environment. Since unshielded outdoor lights are exceptionally bright compared to the surroundings, the effect is often exaggerated on such images. Figure 25 demonstrates the

profound impacts even modest outdoor lighting installations can have upon scenic views. It shows most of the developed area of South Rim as seen from Trailview Overlook. This location is only 0.35 miles (0.56 km) from Bright Angel Lodge. More discussion of images of outdoor lighting appears in Section 2.

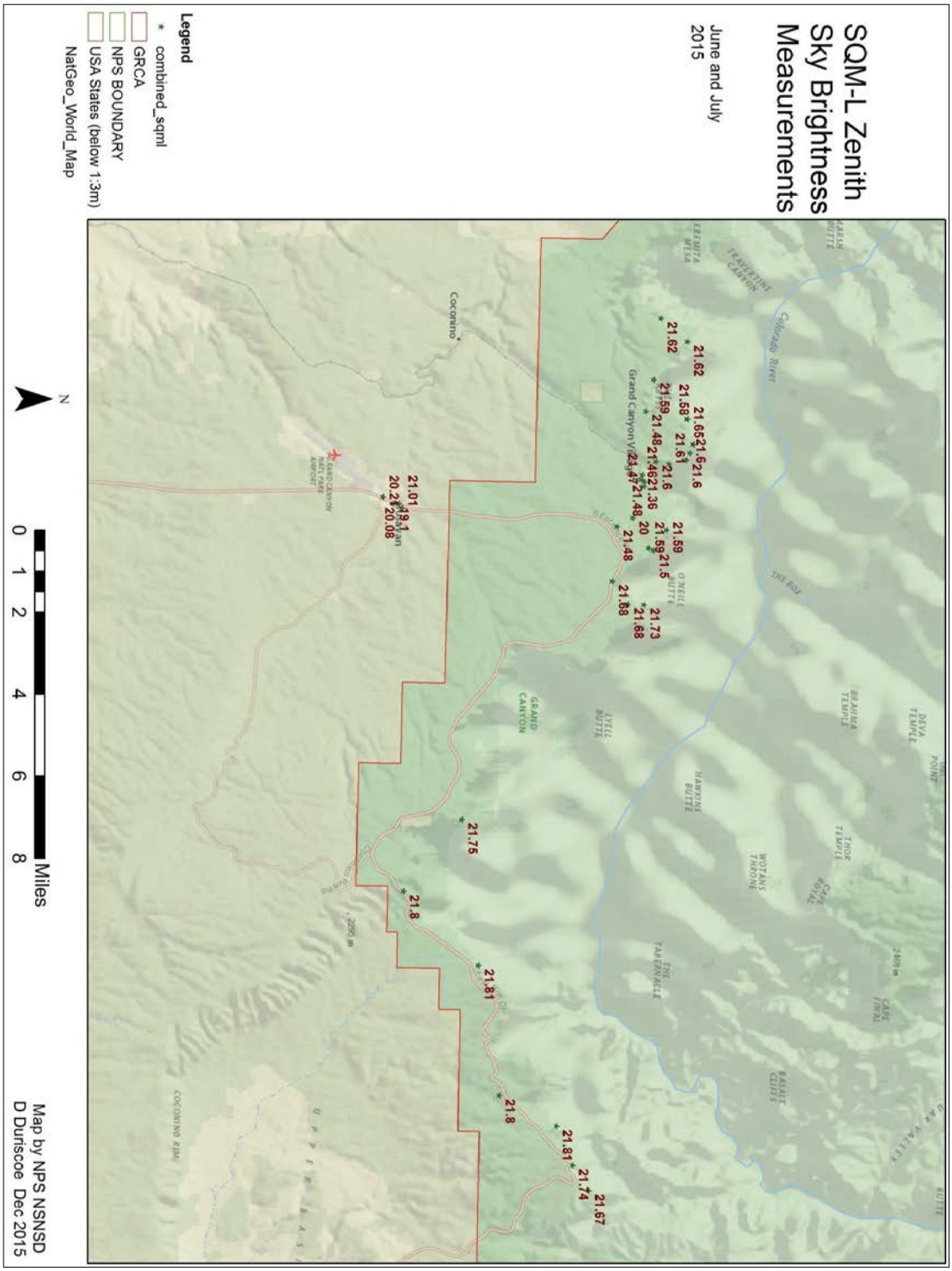

Figure 20. SQM-L single channel photometer measurements at South Rim and Tusayan, summer 2015.

Figure 21. Fisheye view from Cape Royal looking south.

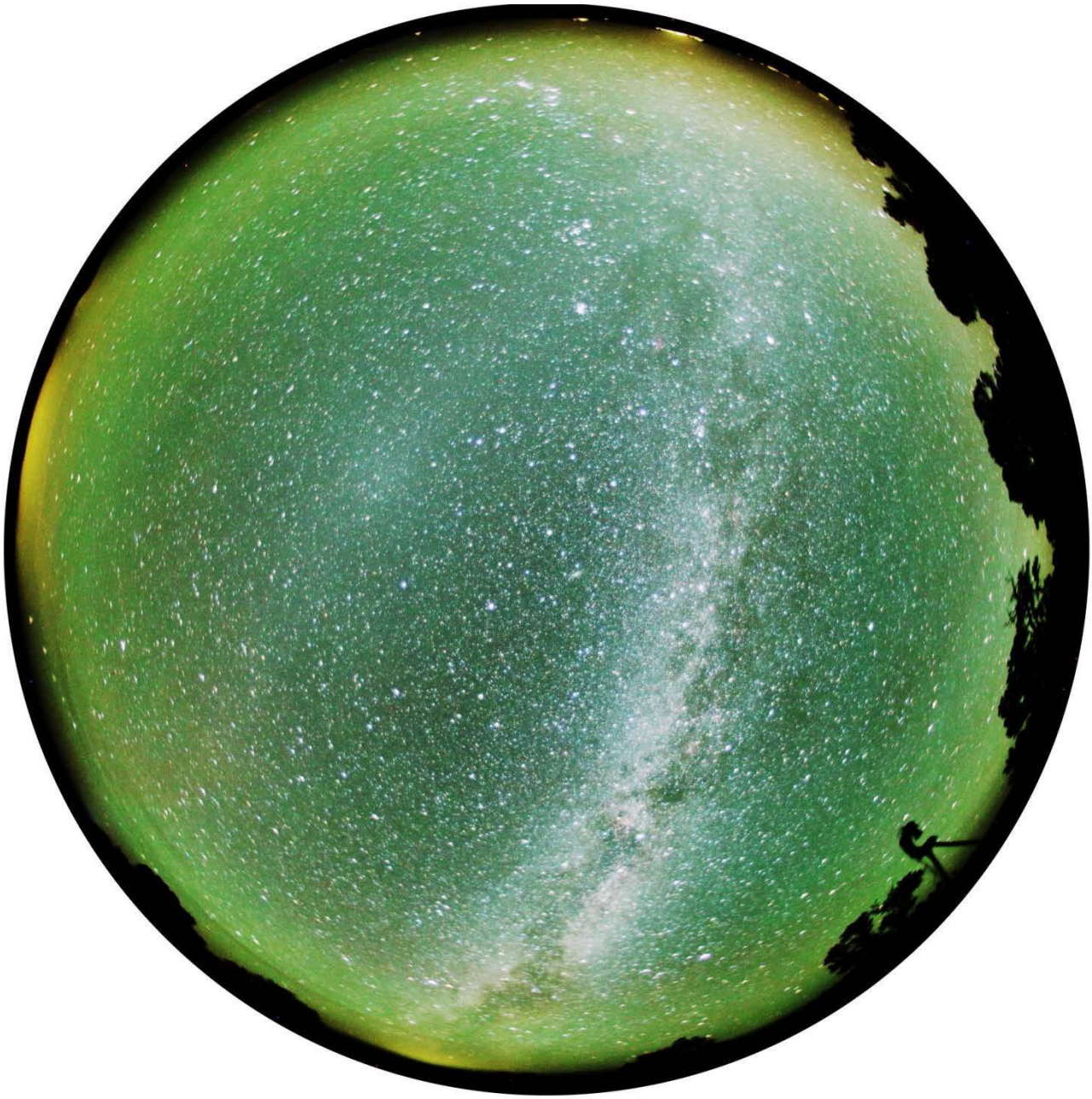

Figure 22. Fisheye view from Cape Royal looking upward.

Figure 23. Panorama from Cape Royal looking south and west.

Figure 24. Panorama from Mather Point/Grand Canyon Visitor Center bus parking, 360 degrees centered looking northwest.

Figure 25. Looking toward South Rim Village from the Rim Trail at Trailview Overlook.

Figure 26. Astronomy enthusiast in the Point Imperial parking lot observing with a refractor telescope.

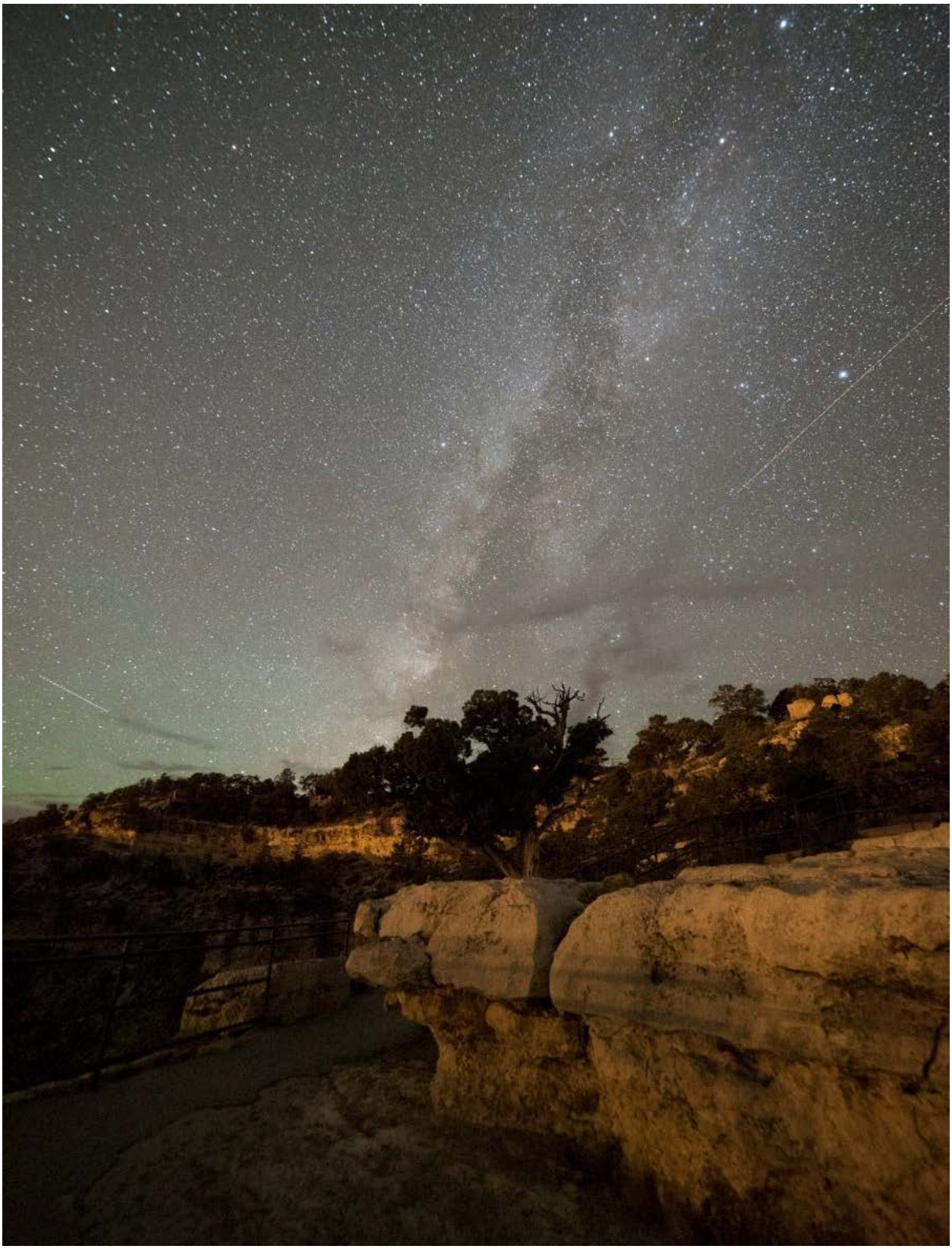

Figure 27. Illumination of the landscape from outdoor lighting 0.3–0.5 miles (0.5–0.8 km) away, Trailview Overlook, Rim Trail, South Rim.

Data Analysis and Interpretation

Geographic Distribution of Artificial Sky Glow

Figure 7 reveals the wide extent of the impact of artificial sky glow, even in the relatively sparsely populated southwest United States. The ALR is a good indicator for protected areas, since the entire hemisphere of sky is weighted equally. Generally, an ALR of 0.6 or less will indicate that the zenith area is unaffected, but there may be very significant visual impacts close to the horizon. This corresponds to the light blue/medium blue boundary in Figure 7. It is immediately apparent, therefore, that people who live in the large metropolitan areas of Los Angeles, Las Vegas, or Phoenix, must travel at least 100 miles (160 km) before reaching a location where the zenith is dark. Of the last remaining truly dark areas (ALR < 0.1) in the region—east-central Nevada, southern Colorado Plateau, and west-central New Mexico—GRCA fortunately lies at the southern edge of the Colorado Plateau, and much of the park appears to be at or below 0.1 (gray/violet boundary in Figure 7). In that regard, the park is currently a rare sanctuary for people seeking the experience of viewing a pristine or near-pristine night sky over the entire hemisphere, in a natural setting with spectacular scenery.

An analysis of the modeled ALR over the total area of GRCA reveals the proportion of area experiencing each sky quality class: 0–0.05 = 22.1%; 0.05–0.1 = 42.8%; 0.1–0.2 = 15.0%; 0.2–0.33 = 12.7%; and 0.33–0.6 = 7.4%. It can be seen that, with almost 65% of the park's area currently at 0.1 or less, GRCA represents one of the best opportunities for night sky protection in the region. Conversely, the 7.4% predicted at greater than 0.33 shows cause for concern.

Indicators of Visual Impact and Functional Consequences

Analysis of the CCD data produced indicator values that denote very slight impact. The light pollution ratios, in the far right column of Tables 3,5, 7, 9, and 11, show that artificial sky glow at the zenith is either absent or less than the detection level of this photometric system. The mean ALRs are less than or equal to 0.1 (10%) at every site visited. According to NPS "State of the Parks" guidance, this places these locations well within the "good" condition category, defined as less than 0.33 (http://www.jstor.org/stable/10.1086/512069).

However, both the ALR model (Figure 7) and historical observations at Twin Point (2002, see http://www.jstor.org/stable/10.1086/512069) and Mt. Dellenbaugh (2007, same reference) demonstrate cause for concern for the westernmost portions of the park, where the ALR is most likely greater than 0.33 currently. It should be noted that an all-sky metric implies that the entire sky is visible. This may not be the case for many situations that visitors will encounter in GRCA, especially below the rim. However, GRCA has many viewpoints deliberately designed to preserve wide-open expansive views, and sky glow near the horizon will be obvious.

The consequences of artificial sky luminance as measured by this indicator to the visual appearance of the night sky are as follows: 0–0.1 = no significant degradation; 0.1–0.33 = one or more areas of the sky near the horizon show artificial sky glow that is easily seen, but does not extend greater than 30 degrees above the horizon; 0.33–0.6 = sky glow covers a very significant part of the sky, nearly to the zenith, and the brightest parts are bright enough to degrade human dark adaptation; 0.6–2.0 = the entire sky has some amount of artificial sky glow, the fainter parts of the Milky Way are invisible, and light from the brighter areas bathes the landscape in an amount of light that allows for easy recognition of objects and prevents dark adaptation; > 2.0 = a level of artificial light that resembles moonlight.

The indicator maximum vertical illuminance ("Max Vertical" in the tables) is more sensitive and relevant to GRCA's night sky than ALR. Vertical illuminance is a measure of the photon flux striking a vertical surface; maximum vertical illuminance is the maximum of all possible orientations of the surface. That is, the surface may be aligned north to south so that light from a large city to the west strikes it, and this is the maximum possible amount of light coming from any direction. Note the illuminance referred to here is from sky glow alone and not from direct light trespass. At Powell Memorial and Mather Point/Grand Canyon Visitor Center this indicator registered 0.25 and 0.23, respectively, when expressed as a ratio of artificial to natural, while all of the other sites it was measured at 0.15 or less. Note that at Mt. Dellenbaugh in 2007, the value 0.62 was recorded, while at Temple Bar in Lake Mead National Recreational Area in 2005—about half way between the western boundary of GRCA and Henderson, Nevada—3.10 was measured (see http://www.jstor.org/stable/10.1086/512069), both as ratios of artificial to natural. This means that at Temple Bar, more than 3 times or 310% of the amount of light that would normally be present was emanating from the sky glow caused by Las Vegas.

When measured in absolute units of milli-lux, this indicator may be compared to the planet Venus, the brightest natural object in the night sky, which produces about 0.10 milli-lux of illumination: Powell Memorial (2015)—0.10; Mather Point/Grand Canyon Visitor Center (2015)—0.09; Twin Point (2002)—0.19; Mt. Dellenbaugh (2007)—0.25; Temple Bar (2005)—1.24. The consequence of relatively bright artificial domes of light near the horizon in this environment is a reduction in visual quality of distant views. Objects as bright or brighter than Venus of artificial origin will definitely be easily noticeable and inconsistent with an otherwise natural scene.

Threats to Natural Lightscapes

The town of Tusayan may be the most significant external threat to visual quality of natural lightscapes in the future. The installation of newer blue-white LED outdoor lights has resulted in a significant light dome of bluer color than cities using HPS as their primary light source (see Figure 21). Possible development of major hotels and other visitor services facilities and a large increase in population of permanent residents may dramatically increase the amount of outdoor lighting used in this community in the future.

Currently the greatest amount of sky glow that may be observed from vantage points on the South Rim comes from the combined light of the Phoenix and Prescott areas. While these sources produce a light dome that does not extend more than 10 or 15 degrees above the horizon (see Figure 21), the brightness of the sky along the horizon is well above natural levels and is difficult to ignore if it is within the view. Las Vegas and Henderson produce a somewhat smaller light dome as seen from the main South Rim vistas, but its core appears to be actually brighter than any other city when viewed from Cape Royal (Figure 23). Data from the western part of the park is required to assess the impact in that area, but it undoubtedly has a significant impact upon wilderness character.

Light trespass is the main threat from within-park sources. This issue is discussed in Section 2.

Trends in Night Sky Quality

Long term monitoring using all-sky photometry may provide valuable insights into current and past trends in the condition of the resource. At the South Rim, previous data from Powell Memorial (http://www.jstor.org/stable/10.1086/512069) and Lipan Point

(http://www.jstor.org/stable/10.1086/512069 , http://www.jstor.org/stable/10.1086/512069) are available. Both locations appear to be essentially unchanged in terms of estimated artificial sky glow between 2007 and 2015. Data from Bright Angel Point (http://www.jstor.org/stable/10.1086/512069) on the North Rim is also available from 2007 and 2008. While we did not re-sample this location on this trip, the data may be compared with Cape Royal. All of the indicators have very similar values between the two measurements.

A new method for tracking trends in potential light pollution at the landscape scale using remote sensing data and a simple model of visual impact is presented here for GRCA sites. Monthly cloud-free composites from the VIIRS day/night band are now available from January 2014 to the present (see http://www.jstor.org/stable/10.1086/512069). The neighborhood around an observing site may be examined over time using an algorithm that weights the effect of emissions artificial lights, as estimated by the upward radiance values in the day/night band cloud-free composites, according to their distance from the observer. A radius of influence of 186 miles (300 km) is utilized (see http://www.jstor.org/stable/10.1086/512069). Figure 28 displays the results of this analysis for nine hypothetical observing sites at locations throughout GRCA. The overall trend at all of the sites appears to be either flat or generally slightly downward over the 22-month period. A few months have upward excursions from the trend; these are most likely due to snow on the ground in winter and fires in summer.

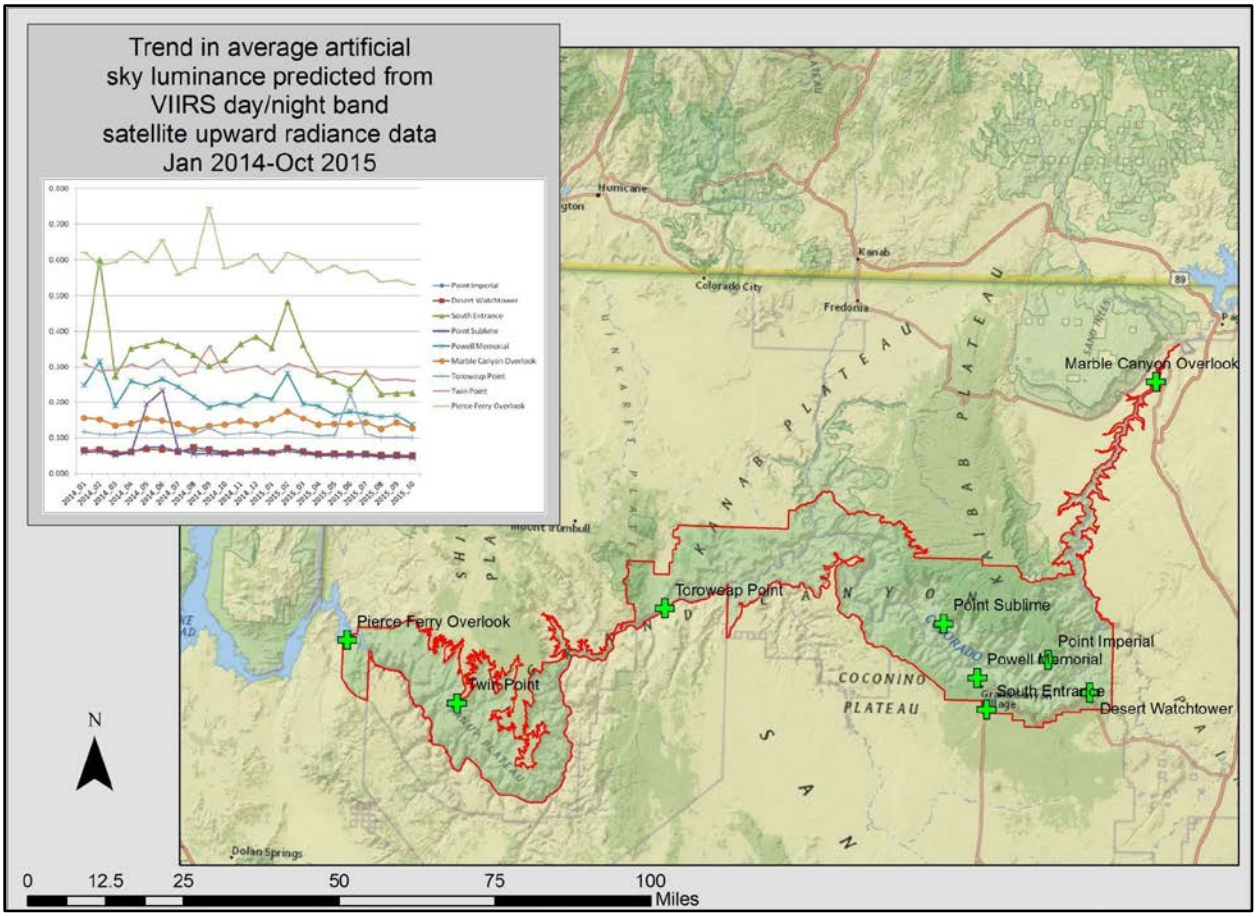

Figure 28. Examination of the trend in predicted ALR at nine hypothetical observing sites representing a wide geographic distribution in GRCA.

Management Implications

External vs. Internal Sources

Internal sources of artificial light do not appear to be a significant source of sky glow at GRCA, as evidenced by the data taken from the Mather Point/Grand Canyon Visitor Center bus parking area. However, light trespass is a significant issue at the South Rim (see Figure 25). This issue is discussed in the section on outdoor lighting (p65).

External sources are currently a minor source of sky glow as observed from sites along paved roads in the main tourist areas of the park, with the brightest areas of the sky resulting from outdoor lighting in the large metropolitan areas of Phoenix and Las Vegas, each more than 100 miles (160 km) distant. However, the Las Vegas area has significant effects on the westernmost portion of the park. Tusayan and its environs may pose a significant future threat, with planned development of major hotels and a potential tenfold population increase. The town's proximity to South Rim tourist areas means that any increase in sky glow will be readily visible, since the brightness of observed sky glow roughly follows the inverse square law with distance from the source. Future developments in the Meadview, Arizona, area are also a concern. Cameron, Arizona, now undergoing major road construction and increases in public outdoor lighting, may be a concern for the Desert View area of the park. Sky brightness data taken at Lipan Point and Navajo Point demonstrate that these sites are now nearly pristine and offer some of the finest night sky viewing opportunities for visitors in any park. GRCA needs to keep abreast of the comment period for planning these developments and provide input to environmental analyses, including measurements of existing conditions as viewed from the park and the potential for degradation from additional lighting, possibly derived from sky glow models.

Making existing sky brightness data publicly available is critical to managing sources of light pollution external to the park, even hundreds of miles/kilometers away. All-sky images with DSLR camera are also compelling if they show a mostly pristine sky with a bright light dome on the horizon. Encouraging the public to get involved in citizen science data collection efforts, such as Globe at Night and Loss of the Night (see http://www.jstor.org/stable/10.1086/512069), not only raises awareness; it gives people an investment in the protection effort.

Importance of Photometric Monitoring

The management of light pollution, like any other pollutant, requires not only identifying and mitigating sources, but also monitoring exposure and knowing the potential effects. After setting a standard for maintaining a certain level of environmental quality, a determination of attainment or non-attainment of the standard may only be made by accurate measurement of the pollutant's intensity, extent, and duration. Single channel devices may be used, but imaging systems will provide the best result in the most efficient manner. Use of the SQM-L should be limited to locations within development at this time (Grand Canyon Village, Tusayan), since the zenith area currently exhibits little or no artificial sky brightness. It is possible that a remote, automatically operated device aimed at one of the external cities (Phoenix or Las Vegas), centered no more than 15 degrees above the horizon, will yield valuable trend data. Correcting for variations in the natural background may be a challenge, however.

All-sky photometry in the western part of the park and at a point near Marble Canyon should be performed to complete geographic coverage of the condition assessment. Toroweap Point, Twin Point, and the Pearce Ferry area are potential locations. Continuous monitoring with an automated

DSLR camera at North or South Rim locations, such as the Grand Canyon Lodge or Yavapai Geology Museum, with the field of view including the major threats from Tusayan, Prescott, and Phoenix, is highly recommended. Monitoring sites should be located where they will provide the most information and/or at particularly sensitive locations. The Mather Point/Grand Canyon Visitor Center area is important because of the use of the area for night sky interpretive programs and the Grand Canyon Star Party.

Continuous imaging with a color DSLR camera broadcast live over the web is a worthwhile endeavor, even if not accurately calibrated to a photometric standard. The educational value and popular appeal of such live images should raise awareness of the issue among a wide audience, as well as providing a service to those who might want to travel to the park immediately for night sky viewing. The image would be most compelling if it were aimed in a direction including a major city light dome: either Phoenix or Las Vegas.

Outdoor Lighting

Geographic Extent

Regional Setting

GRCA lies in a generally remote area of northern Arizona. The closest large city is Flagstaff. The small cities of Page and Williams, Arizona, are relatively nearby. However, there is enough of a buffer between these cities and the park to warrant very different lighting amounts within park developments than occur in these towns. Indeed, the remarkable absence of artificial light for miles around is one of the park's unique features. An exception is the town of Tusayan, with newer facilities and associated modern outdoor lights. Also, a new wind farm near Williams produces a cluster of flashing red air navigation warning light, visible from high vantage points all over GRCA.

Developed Areas

Within-park permanent development occurs in two areas which are each generally contiguous; the South Rim's Grand Canyon Village area (about 988 acres (400 ha)) and North Rim, a much smaller area with an historic rustic appearance. A few other small developments exist, including the Desert View area, the south Entrance Station, and the Tusayan Museum. Both developments contain facilities of varying ages, degrees of outdoor lighting, and styles. It will be important to identify outdoor lights that are critical to the preservation of the historic character of these areas.

Outdoor Lighting Zones

Addressed by Outdoor Lighting Guidelines, in Section 3.

Existing Conditions

Data Sources

GRCA has the big advantage of a nearly complete outdoor lighting inventory (Williams et al., in DRAFT). This inventory includes supporting documentation, a geospatial database of inventoried light locations, and a relational database of light attributes. We received each of these items but have not reviewed them in any detail up to now.

Remote imagery from VIIRS day/night band is a tool for obtaining approximate quantities of the amount of light applied per unit area. The upward radiance detected by the orbiting satellite depends on several factors besides the amount of light, especially ground albedo and surface roughness. Care should be taken not to use data from winter months when snow will drastically increase the albedo.

The North Rim developments generally have more tree cover than the South Rim, so upward radiance there will be partially masked. However, these data may be useful for tracking changes, especially before and after lighting retrofits. Figure 29 displays a close-up of the upward radiance data for October 2015 on the North and South Rim major developed areas, and also includes the town of Tusayan.

Existing DSLR photography, scene luminance photometry, and SQM and SQM-L measures within development may represent a significant source of historic information. Researching and recording these data sources was not addressed.

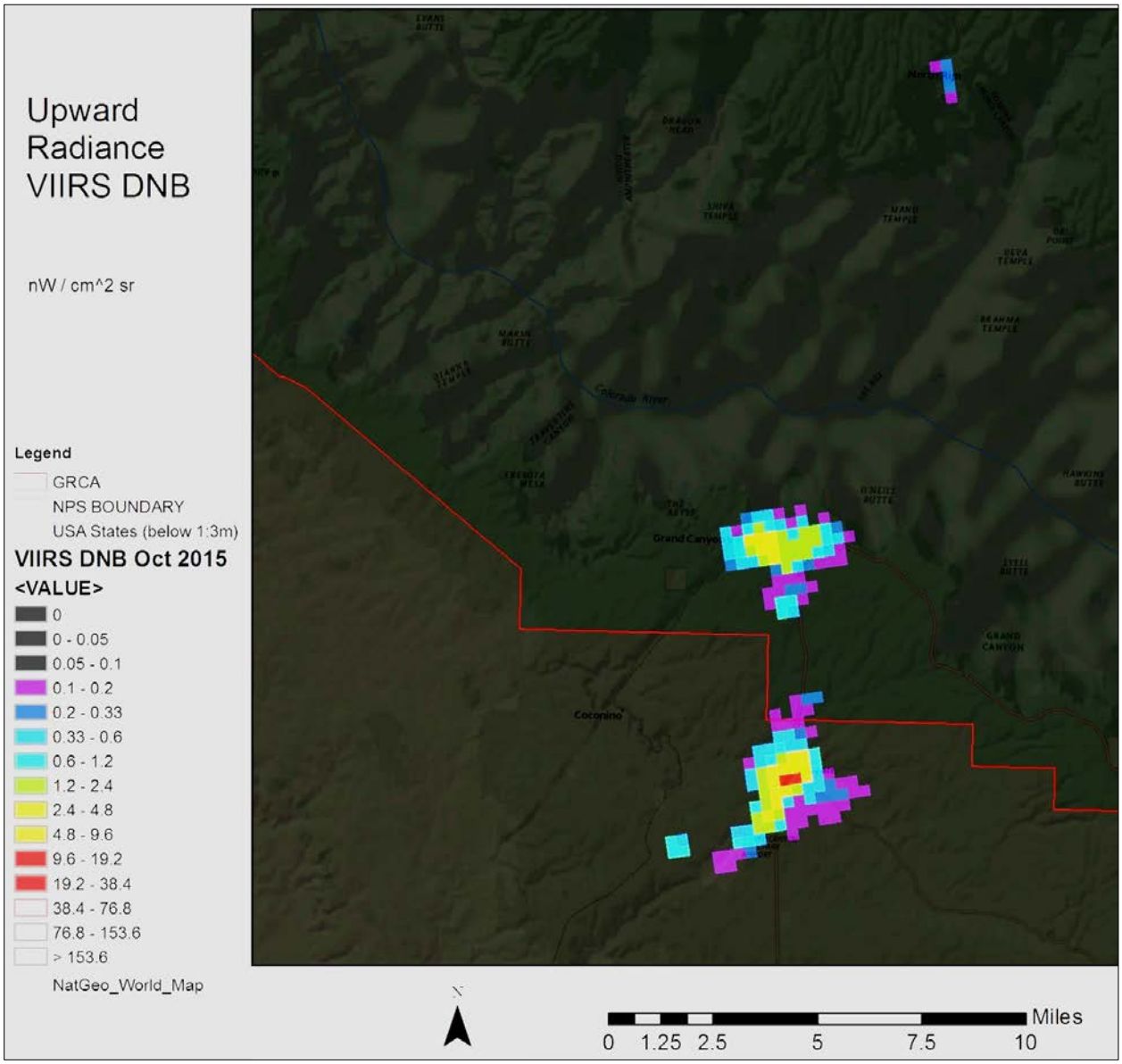

Figure 29. Close-up on VIIRS day/night band data including Tusayan, South Rim, and North Rim developments.

Reconnaissance

We observed that outdoor lighting in all developed areas is generally quite conservative in amount. In addition, a significant number of fixtures were observed to be either disabled or not functioning because of neglected maintenance. Three specific areas were visited on this trip: The Recreation Center for employees on the South Rim near the Albright Training Center; the Rim Trail area on the South Rim between the Hopi House and the Bright Angel Trailhead; and the Yavapai Lodge/Market Plaza area on the South Rim.

Many of the building egress applications in the Grand Canyon village historic district (including Bright Angel Lodge, cabins, and El Tovar Hotel) utilize unshielded "lantern" style wall mounted luminaires. While for the most part the lamps installed in them are low output (800 lumens or less), glare is a significant problem. This is especially true given the sparse use of other types of guidance or area lighting in the vicinity.

There are some particular examples of the use of horizontally aimed flood lights of more modern design (HPS or Halogen) throughout the South Rim area. These create unnecessary amounts of light trespass. A few of these applications are aimed at the canyon itself and are close enough to the rim to be visible in the wilderness areas or from opposite rim viewpoints. Again, while we did not observe more than 10 of these in our recon, they create a lot of light pollution and their retrofit or shielding should be high priority.

New Inventory

Not addressed. Specific lamp types and lumen amounts are not available for many of the sources identified in the existing inventory. In order to make an accurate comparison of before and after statistics, such as lumens per acre and proportion of lumens of varying lamp types, these data should be collected and added to the database before retrofitting takes place.

Scene Luminance and Illuminance Measures

We made measurements at the Recreation Center and the Rim Trail area, as well as at the entrance to the El Tovar Hotel. Both color DSLR imaging and calibrated photometric luminance measures, using a custom high dynamic range algorithm and a scientific CCD camera, were made at a few locations. While the measures are certainly not intended to be a comprehensive inventory, they may be helpful in assigning desired luminance levels for retrofit or new installations in various lighting situations. The luminance of surfaces determines how the eye sees them. At a level of about 3 cd/m^2 and brighter the cones in the foveal area of the retina are fully active, this is so-called "photopic" or color vision. Between 3 and 0.01 cd/m^2 both rods and cones are used to determine an image ("mesopic" vision), while below 0.01 cd/m^2 vision is primarily determined by the rods, or "scotopic." The amount of light and the method of its application will determine the luminance of a scene. Skillful application of outdoor light can yield the desired amount of visibility and color rendition while protecting the environment by not over-lighting. The spectral power distribution of the light source is also important, but luminance maps provide a good tool for assessing whether or not a scene is lit properly.

Figures 30–38 display some of the scenes that were imaged. All the luminance maps illustrate how very much brighter unshielded lamps are compared to the surfaces they are designed to illuminate. The color map scale is logarithmic; red is about 1000 cd/m^2 which appears extremely bright to the mesopic eye. The lamps on the poles in Figure 34 and 35 have a luminance of about 50,000 cd/m^2

and are thus producing a disabling type of glare in this dark environment. The black vertical bars above and below the unshielded lights in the luminance maps are "column bleeds" in the CCD camera's sensor; this is normal for this scientific camera, intended for recording extremely low light scenes.

Figure 30. DSLR image of the Arizona Room area of the Rim Trail.

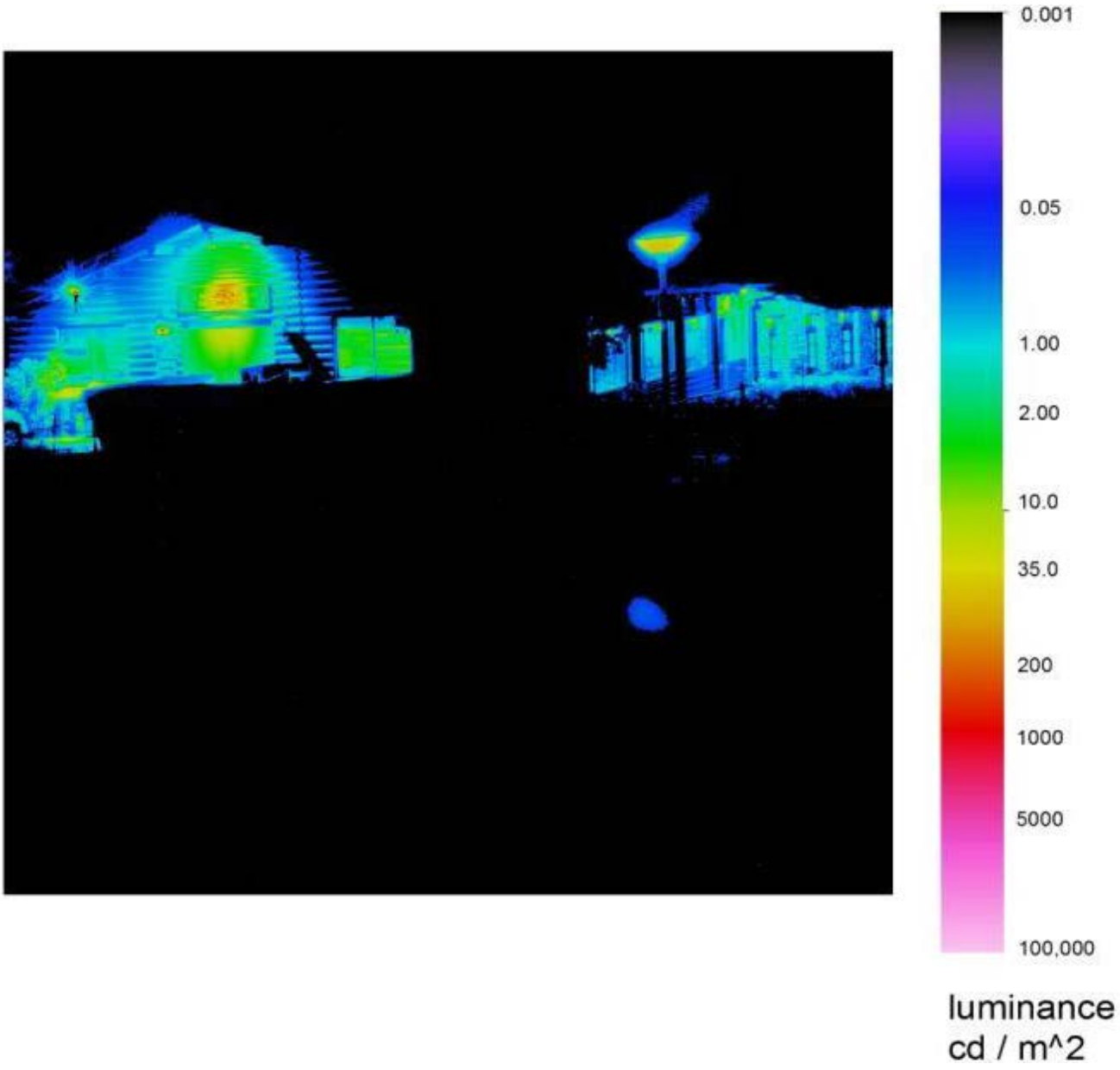

Figure 31. Luminance map of the scene in Figure 30.

Figure 32. DSLR image of the rear entrance to the El Tovar Hotel.

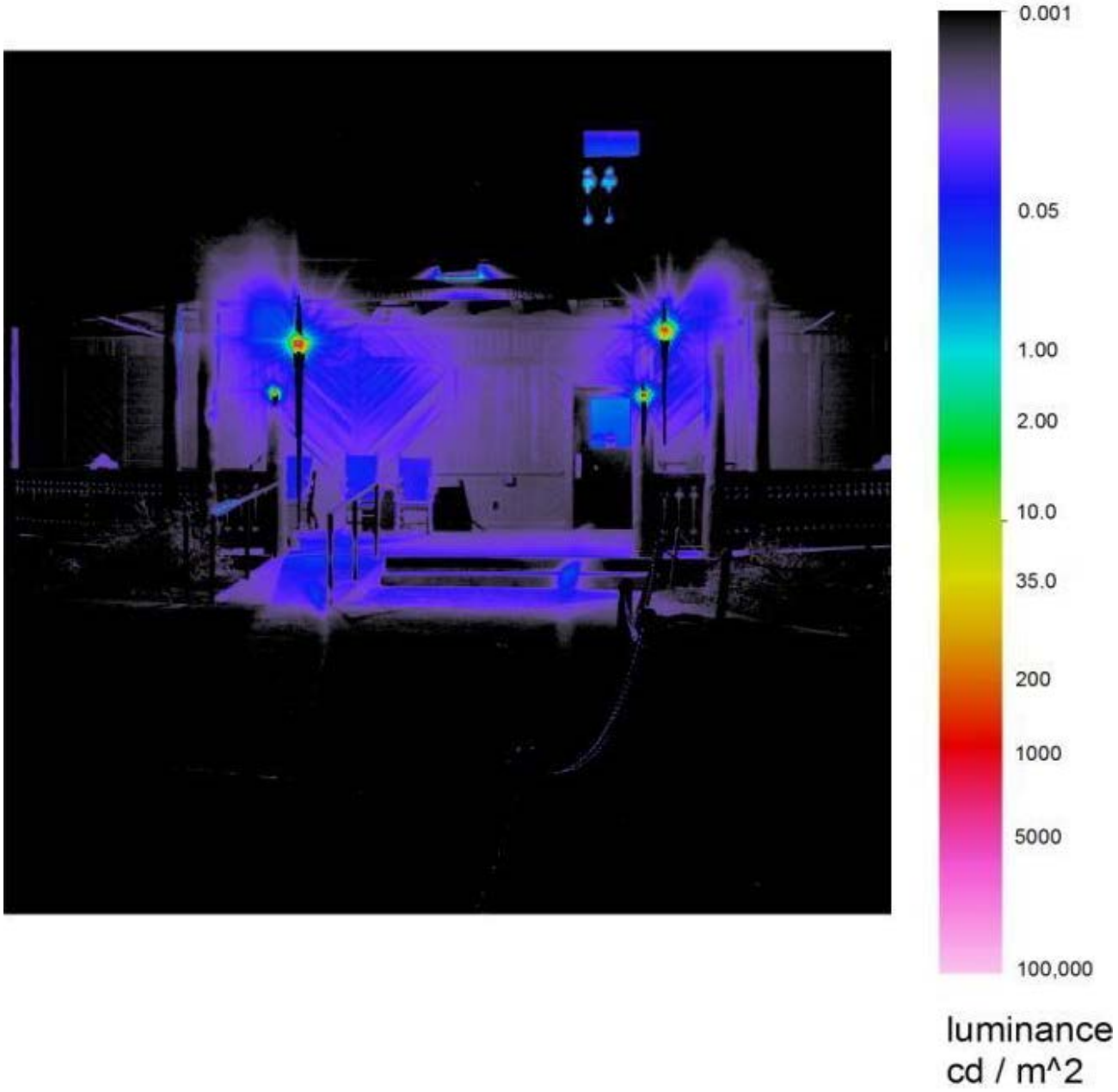

Figure 33. Luminance map of the scene in Figure 32.

Figure 34. DSLR image of the South Rim Recreation Center parking.

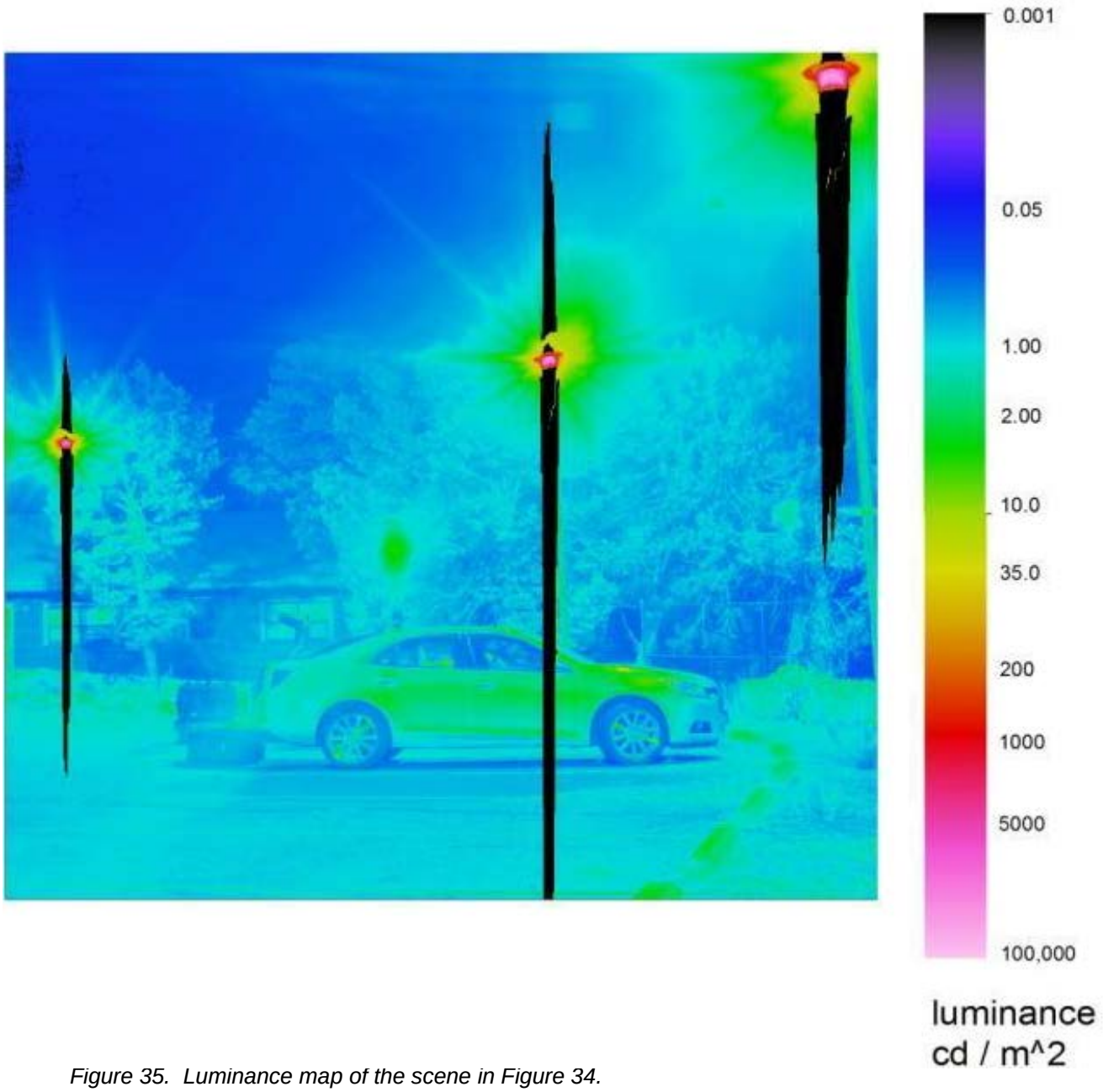

Figure 35. Luminance map of the scene in Figure 34.

Figure 36. DSLR image of egress light at the El Tovar Hotel.

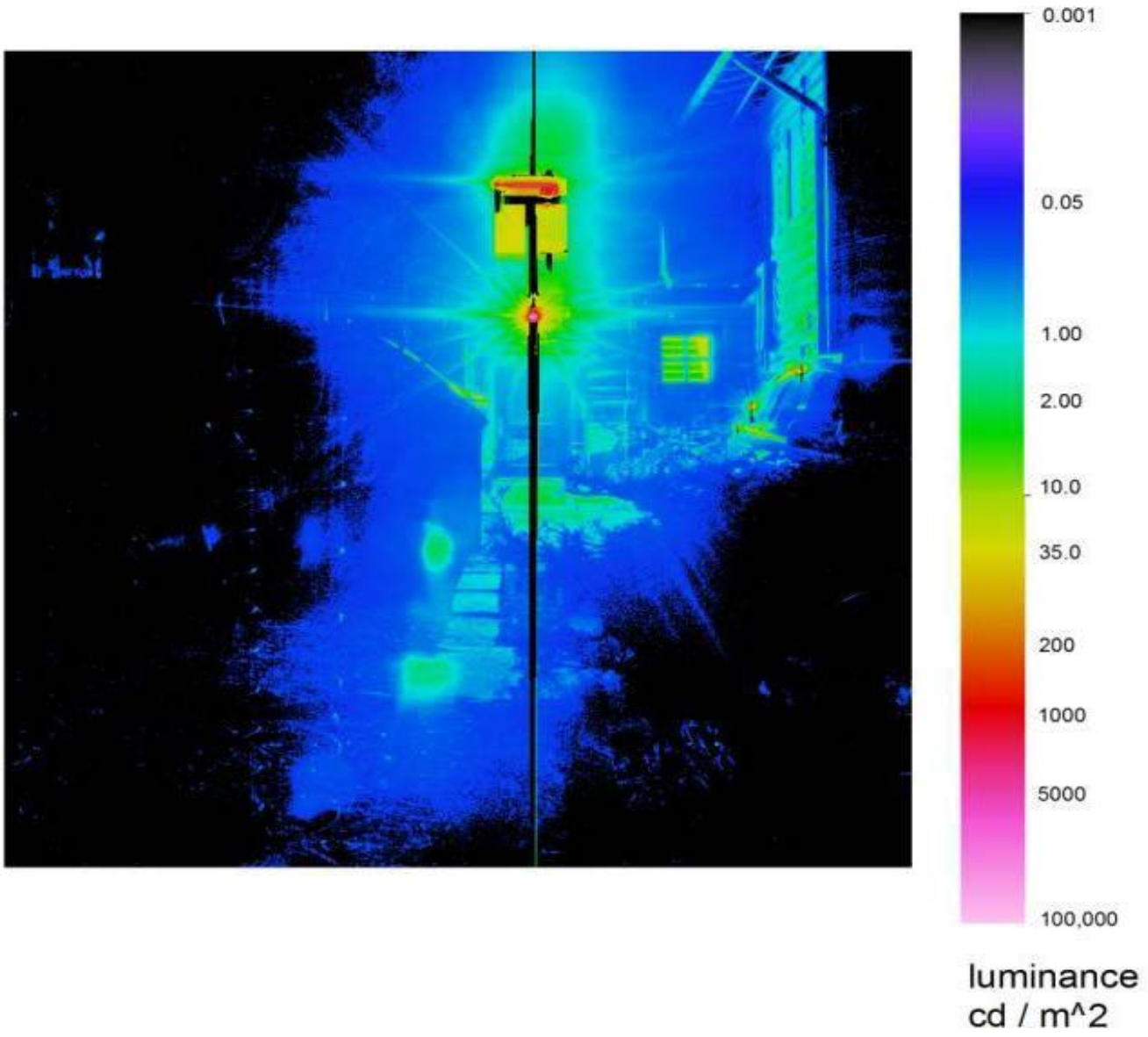

Figure 37. Luminance map of the scene in Figure 36.

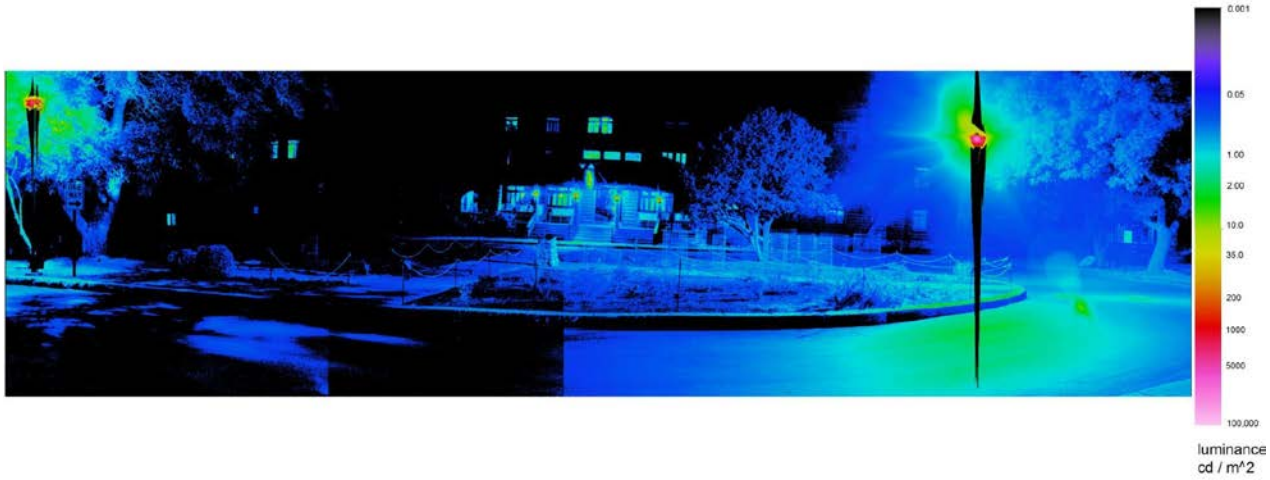

Figure 38. Panoramic luminance map of the front entrance and drive-up area of El Tovar Hotel.

Figures 39–42 are DSLR color images of some observed outdoor lighting issues. In Figure 39 is a wall mounted floodlight that is aimed toward the canyon rim. In Figure 40, the area of illumination is shown; beyond the rock wall is the canyon. This light may be visible from the North Rim. Figure 41 illustrates some bollards that are intended to provide both guidance and walkway illumination, but the glare they produce in this dark environment is probably inhibiting mesopic vision so that anyone walking near the canyon rim will have difficulty with the visibility of the path and the wall. Figure 42 is an image of the Grand Canyon Lodge at night from the walkway below; the canyon is immediately to the left. The large picture windows allow interior light to escape and are visible from some South Rim viewpoints. Figures 43 through 45 show pole mounted lights on the South Rim that likely need to be reviewed for light trespass.

Figure 39. Horizontally aimed floodlight at Hopi House.

Figure 40. Same area as Figure 39, looking in the direction the light is aimed. The canyon is beyond the rock wall.

Figure 41. The Rim Trail area near Kachina Lodge.

Figure 42. Grand Canyon Lodge on the North Rim showing indoor light emanating from large picture windows.

Figure 43. Pole-mounted, partly shielded area lights at Yavapai Point.

Figure 44. Pole-mounted, partly shielded area lights at Market Plaza.

Figure 45. Pole-mounted, partly shielded lights at Shrine of the Ages.

Measures of vertical illuminance (meter held vertically facing the source) at the edges of intended areas of illumination provide a measure of light trespass. If the light primarily comes from one source, and the distance to the source is known, the amount of light trespass at any distance along the same line may be calculated using the inverse square law. Measures were taken along the Rim Trail at the rock wall protecting the canyon rim at locations: near the Hopi House—opposite the north entrance to the El Tovar Hotel and at the patio opposite the Bright Angel Lodge gift shop. Vertical illuminance was measured at these locations at 0.5, 0.27, and 0.4 lux, respectively. Calculation of the vertical illuminance at 1,640 feet (500 m) distance, at hypothetical location within the canyon below the rim, are for the Hopi House light 0.54 mlux and for the Bright Angel Lodge light 2.3 mlux, representing an object 5.4 and 23 times the brightness of Venus when viewed from these locations (see Figure 46).

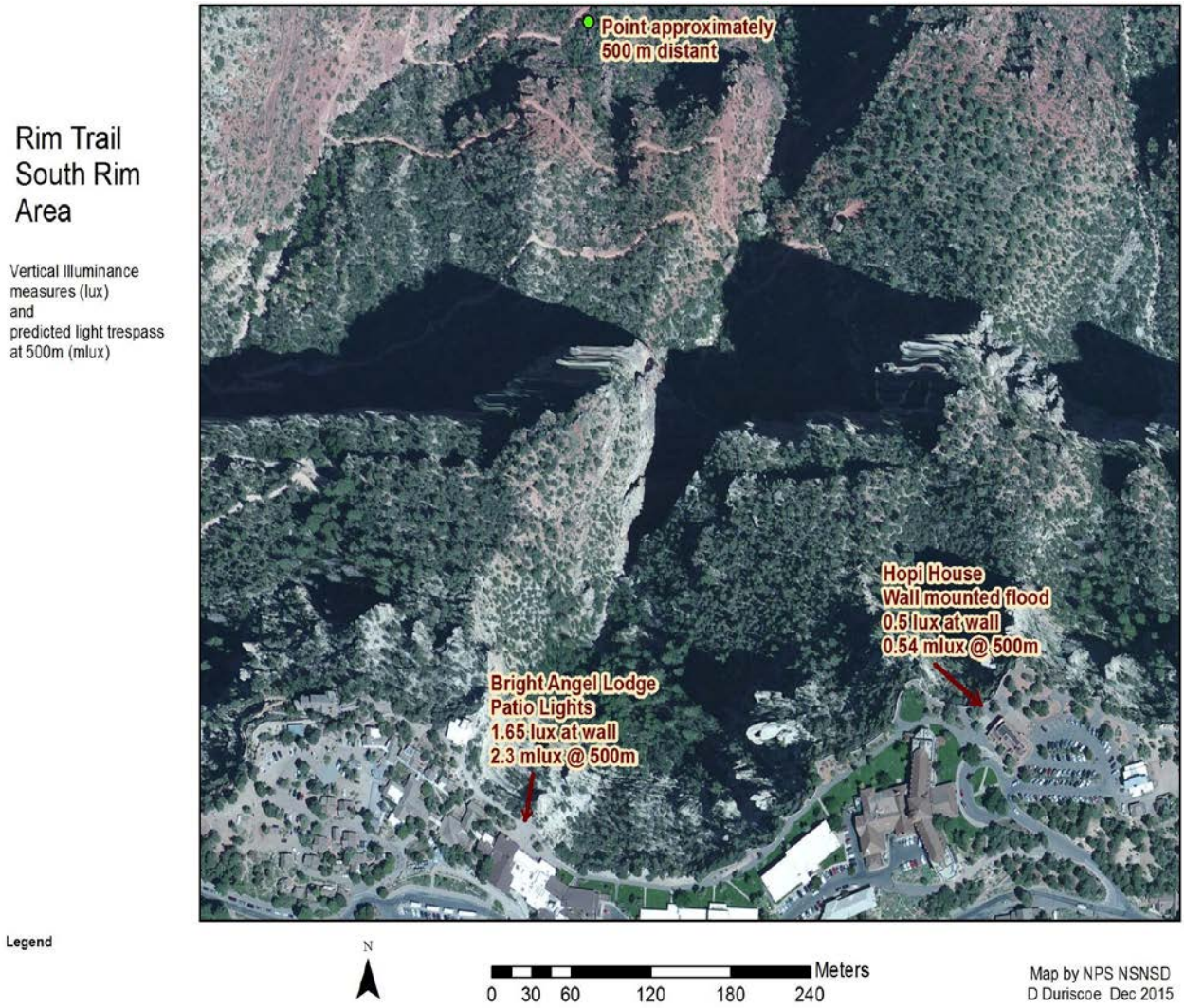

Figure 46. Location of lights observed to be causing excessive light trespass into the canyon.

Horizontal illuminance measures were made at ground level at selected locations along the rim trail and along the roadway at the front entrance to the El Tovar Hotel. The light produced was generally very non-uniform, with typical measured values immediately under luminaires mounted on walls or poles observed at 18–28 lux, while near the rock wall at the canyon rim a value of 0.15 lux was obtained.

Analysis and Comparison to Desired Conditions

Within the areas investigated, the parking area at the South Rim Recreation Center was observed to contain the most egregious outdoor lighting in the park in terms of light trespass; partly shielded HPS luminaires on tall poles (see Figures 34–35). Another bright partly shielded pole light was also observed at the South Kaibab Trailhead near the stables. Retrofitting these five or six individual lights alone would mitigate or eliminate a large percentage of the light trespass currently occurring on the South Rim. Some of these lights are visible for many miles/kilometers from North Rim and

many locations in the wilderness and other areas of the Naturally Dark Zone (NDZ). The individual luminaires use significantly more lumen amounts than the vast majority of other installations observed.

Similar luminaires, but with different lamps, installed on poles were observed in several locations on the South Rim: the Yavapai Geology Museum at Yavapai Point, the parking lot at Market Plaza, and the Shrine of the Ages parking lot. Whether or not this style of lamp is an integral part of the historic character of the area will need to be determined; they appear to be of late 1960s or early 1970s vintage. In any event, they are only partly shielded and result in unnecessary light trespass (see Figures 36–38).

Measured luminance of illuminated surfaces in nearly all the applications visited on this trip was very moderate. Light blue color in Figures 31, 33, 35, 37, and 38 is about 1 cd/m^2 while the transition between dark blue and violet is about 0.01 cd/m^2. Falchi et al. (http://www.jstor.org/stable/10.1086/512069) recommend an average luminance of 0.1 cd/m^2 to limit the effect of over-lighting on natural environments. While this value may be used as a guide for lighting zones 00 and 0, applications in lighting zone 1 may require illumination to brighter luminance values. Figures 33 and 37 demonstrate the conservative use of lighting amount at the El Tovar Hotel. Surfaces, including the walls and floor of the porches, are measured at less than 0.1 cd/m^2 (dark blue and violet colors). This may be due in part to the dark color and low reflectivity of the wood.

An exception is the Recreation Center parking area, where the light-colored automobile was measured at 1–2 cd/m^2. Even the dark pavement is close to 1 cd/m^2. For an intrinsically dark environment, this amount of light appears to be excessive. The glare from the unshielded, pole-mounted light was observed easily from the Rim Trail at Trailview Overlook (see Figure 25, the bright cluster of lights in the center of the image) and even at Powell Memorial (Figure 10, the bright light causing a column bleed at azimuth 155 on the horizon). We spotted them from Grand Canyon Lodge on the North Rim; observation with binoculars confirmed their location.

The desired conditions are elucidated in GRCA's Draft Outdoor Lighting Guidelines, both in terms of illumination levels and standards for environmental protection, and vary depending upon the lighting zone. These issues are discussed further in Section 3.

Management Implications

Use of the Lighting Inventory

The lighting inventory is a powerful tool for assessing the magnitude and scope of a variety of issues related to outdoor lighting, including percentage of lights meeting the lighting guidelines—in total and broken out by area or zone; energy consumption and predicted savings from retrofits; total lumens and lumens per unit area; and aggregate spectral power distribution. It may also be used to predict maintenance needs and capital investment costs. Accurate locations of each light permit modeling of visibility from selected observation points. The development of analysis tools to quickly provide these statistics is encouraged, as they will be of use not only to GRCA but to other parks that might use the same data base method. Accurate updates to the inventory are essential in tracking the progress of retrofits, replacements, and deletions. Management needs to ensure the resources are available and a project leader is assigned to maintain the database.

Outdoor Lighting Guidelines

GRCA has prepared Draft Outdoor Lighting Guidelines. Chad Moore and Dan Duriscoe of the NPS natural sounds and night skies division reviewed these in December 2014. Some further edits may be made, but overall the document represents a significant step toward protecting natural lightscapes from internal artificial sources. We suggest the following revisions, but the final guidelines are best arrived at by consensus of all interested parties, including concession managers, natural and cultural resource managers, facilities managers, and visitor protection specialists.

Establishing standards for environmental protection, such as for light trespass (measured by maximum vertical illuminance at the zone boundary); amount of light (measured by maximum lumens per unit area of land within a particular application area); illumination of task areas (measured as maximum horizontal illuminance at the ground surface); brightness of illuminated objects (measured as maximum luminance in a scene); and the spectral power distribution of light applied (measured by scotopic/photopic ratio), is the most rigorous method of ensuring natural lightscape protection from outdoor lighting. The guidelines currently mention these standards but numeric thresholds are missing, called out in a table yet to be constructed.

A true "performance" (in terms of escaped or wasted light) approach such as this to outdoor lighting design requires both detailed modeling of design alternatives and field measurements before and after the installation, thus a significant amount of "extra" work. Nevertheless, specifying some thresholds, above which results a situation outside the desired condition, will demonstrate that GRCA is placing at least as much emphasis on the need for protection of natural darkness as on the need for illumination for human nocturnal activities, even if they are never strictly enforced. Table 12 gives a suggested list of environmental standards for each zone and some proposed values. Illuminance values for zones 0 and 1 will depend mostly on the task, but an absolute maximum limit might be specified to prevent unnecessary over-lighting. Chad Moore has commented that "hot spots" are difficult and expensive to control and depend strongly on reflectivity of the surface, especially with wall-mounted lights typical of many of the historic buildings in the park. However, we feel some sort of guidance is warranted, at least for permanent hardscape features. Temporary objects such as parked automobiles would not be considered. The values suggested are somewhat speculative and should be discussed.

Zone	Max Light Trespass (milli-lux)	Max Surface Luminance (cd / m^2)	Avg, Max Horizontal Illuminance at Ground Level (lux)	S/P Ratio	Max Lumens / Hectare
NDZ	0.1 @ 500 m (inward)	0	0, 0	--	--
00	50 at zone boundary (outward)	0.5	0.05, 2	< 0.3	5,000
0	100 at zone boundary (outward)	1	2, 10	< 0.6	25,000
1	200 at zone boundary (outward)	2	4, 20	< 0.6	50,000

Table 12. Proposed measurable standards for outdoor lighting by zone.

Possibly the most important standard in Table 12 is the maximum lumens per hectare. The city of Flagstaff has been quite successful in protecting the US Naval Observatory with a standard of 25,000 lumens per acre (10,000 lumens per hectare) allowed within the zone nearest the observatory, of which only 10% can be non-low pressure sodium (LPS) (which has an S/P ratio of 0.2). Again the values proposed for both lumens/ha and S/P ratio in Table 12 are suggestions that should be reviewed and arrived at by consensus. The point is to establish some kind of standard in the guidelines that will lead to environmental protection while allowing enough flexibility to meet lighting task requirements.

Lighting zones have be carefully identified and mapped in the draft guidelines document. They are conservative, with very little area assigned to zone 1. The vast majority of the developed area is assigned zone 0, including such applications as hotel entrances, plazas, outdoor dining areas, parking lots, and shuttle bus stops. This is a very progressive approach to outdoor lighting in what is often a very busy place at night (South Rim Village). Some of the existing levels of luminance and illuminance may not conform to the recommendations for zone 0. Management should be aware of this and decide exactly where to draw the zone boundaries based upon both human needs and environmental protection.

The boundaries as they exist in the draft lighting guidelines, however, include too much area. In order for the lumens/ha standard to be effective, only areas intended to be lit should be mapped within an outdoor lighting zone other than the NDZ. In many cases, especially in residential areas and utility buildings away from tourist developments, there are areas of land that have been included in zone 0 but contain no development. This is due in part to the low density of development typical of these areas ("South Rim suburban sprawl"). The boundaries should be drawn more precisely to exclude these areas, thus reducing substantially the total land area in zone 0, perhaps using a 164 foot (50 m) buffer around buildings. In other cases, a desire to exclude area lighting, such as the high school soccer field and some of the parking areas at Mather Point/Grand Canyon Visitor Center, may need to be communicated accurately with zoning. These areas should be re-classified as zone 00. Also, roads should be removed from zone 0 and placed either in NDZ or zone 00 if there is no intention of using area lighting.

Landscape architecture plays a major role in applying outdoor lighting at GRCA. Not only should natural scenery as viewed from the NDZ be protected from light trespass and excessively bright areas in the landscape, scenes created within the development at night by outdoor lighting should be as attractive and consistent as possible. Using a mix of lamps of different spectral power distribution often results in color changes in the scene which are distracting and unattractive. The same is true of lighting amount; gradual transitions from light to dark are preferable to abrupt changes.

Guidance for Night Activities

Luminescent pavement markers (or paint) might be useful in areas where people will be hiking at night, especially to Mather Point. At the least, particular areas might be advertised as more appropriate for night activities than others, rather than expecting visitors to come up with their own choices.

Monitoring and Evaluation

The Trailview Overlook location is excellent for monitoring the impacts of most of the South Rim development outdoor lighting. A program of DSLR imaging with a calibrated camera will greatly

assist in evaluating the effectiveness of lighting retrofits and new designs in reducing light trespass and the amount of reflected light escaping into the NDZ.

Consider requiring scene luminance maps at key locations before new lighting and lighting retrofit installations as part of the contract. They would be very useful in documenting the project as a case study and example for future projects in parks.

Continue to monitor visitor satisfaction with the developed area outdoor lighting by keeping track of complaints or reports of people getting lost or injured at night. Park residents should be solicited for an evaluation of the appropriateness, functionality, and success in achieving natural lightscape protection.

Further Dark Sky Measurements

Additional measurements (median, n=5) of GRCA's dark skies were taken at numerous locations throughout the park using a Unihedron SQM. Locations included both developed areas on the North and South Rim and more isolated locations below the rim (Table 13).

	Zenith readings			
Locations	**ag/arcsec²: Median Va**	**Date**	**Time**	**Temp °C**
Shoshone Point	21.52	8/17/2015	22:40	25
Moran Point	21.81	6/16/2015	21:58	26
Lipan Point	21.81	6/16/2015	21:39	26
Buggeln Picnic Area Parking Lot	21.8	6/16/2015	22:10	26
Tusayan Museum Parking Lot	21.8	6/16/2015	21:47	26
Grandview Point	21.75	6/16/2015	22:20	26
Navajo Point	21.74	6/16/2015	21:30	26
Yaki Point	21.73	6/16/2015	22:39	27
Pipe Creek Vista	21.68	6/16/2015	22:53	26
South Kaibab Trailhead	21.68	6/16/2015	22:45	26
Desert View Watchtower	21.67	6/16/2015	21:20	25
Mohave Point	21.65	6/15/2015	21:29	28
Hermits Rest	21.62	6/13/2015	22:53	20
Pima Point	21.62	6/13/2015	23:02	20
Hopi Point	21.62	6/15/2015	21:43	28
Trailview Overlook 2	21.61	6/15/2015	22:17	27
Powell Memorial	21.6	6/15/2015	21:54	27
Maricopa Point	21.6	6/15/2015	22:04	27
Trailview Overlook	21.6	6/15/2015	22:23	26
Monument Creek Vista	21.59	6/13/2015	23:11	20
Yavapai Point	21.59	6/17/2015	22:26	26
GCVC Parking Lot	21.59	6/17/2015	22:17	26
The Abyss	21.56	6/13/2105	23:15	20

Locations	Zenith readings in Mag/arcsec²: Median	Date	Time	Temp °C
Mather Point	21.5	6/17/2015	22:10	26
El Tovar Flagpole	21.48	6/17/2015	22:55	25
Mather Campground	21.48	7/7/2015	23:05	22
Verkamps Visitor Center	21.47	6/17/2015	22:45	25
Kachina/Thunderbird Lodge	21.46	6/17/2015	22:59	26
Bright Angel Lodge Plaza	21.36	6/17/2015	23:02	26
Tusayan: Camper Village	21.01	7/7/2015	22:50	22
Tusayan: Best Western Parking Lot	20.21	7/7/2015	22:38	23
Tusayan: IMAX Parking Lot	20.08	7/7/2015	22:35	23
Park Headquarters Parking Lot	20	6/17/2015	22:38	25
Tusayan: McDonald's Parking Lot	19.1	7/7/2015	22:46	23
Salt Creek Campground	21.74	7/13/2015	21:40	30
Horn Creek Campground	21.48	7/14/2015	21:15	29
Clinic employee parking	18.08	7/15/2015	22:17	23
GC School soccer field	20.56	7/15/2015	22:27	23
Rowe Well Road	21.54	7/15/2015	22:41	25
Dry Park firetower	21.61	7/17/2015	22:14	22
Intersection of Hwy 67 and FS22	21.565	7/17/2015	23:33	23
Cape Royal	21.4	7/17/2015	0:38	22
North Rim entrance station	21.83	7/17/2015	21:43	22
Roosevelt Point	21.55	7/17/2015	0:06	20
Walhalla Overlook	21.38	7/17/2015	0:25	22
Point Imperial	21.555	7/16/2015	23:31	20
Vista Encantada	21.52	7/16/2015	23:55	18
Bright Angel Point	21.73	7/16/2015	22:32	20
Kaibab Trailhead parking lot	21.64	7/16/2015	22:53	19
North Rim campground	21.655	7/16/2015	21:55	24
Grand Canyon Lodge backporch	21.42	7/16/2015	22:11	19
Roaring Springs (Manzanita) bunkhouse	21.74	7/11/2015	21:32	NA
Roaring Springs (Manzanita) bunkhouse	21.625	8/10/2015	22:00	24
Roaring Springs (Manzanita) bunkhouse	21.63	8/11/2015	21:45	23
Roaring Springs (Manzanita) bunkhouse	21.63	8/12/2015	21:45	24
Roaring Springs (Manzanita) bunkhouse	21.695	8/13/2015	21:55	25
Xanterra maintenance yard	21.23	7/13/2015	22:05	24
Dripping Springs and Hermit trail junctio	21.81	7/11/2015	22:00	21
Monument Creek @ Tonto Trail	21.645	7/12/2015	21:40	34
Tuweep Campground	21.42	8/19/2015	22:00	23
South Canyon at top of Redwall	21.64	8/3/2015	21:10	30
Phantom Ranch	21.415	8/9/2015	22:20	26
Phantom Ranch	21.61	8/14/2015	21:00	26

Locations	Elevation (m)	Easting	Northing	Area Observations
Shoshone Point	2215	404617.10	3989537.28	Windy, clear, occasional headlights from East Rim drive
Moran Point	2174	416699.23	3984922.99	North Rim Light
Lipan Point	2238	423102.07	398792.96	Windy
Buggeln Picnic Area Parking Lot	2232	413846.97	3982066.77	Large trees
Tusayan Museum Parking Lot	2197	421909.21	3985750.12	Large Trees, Buildings
Grandview Point	2254	410974.29	3984234.14	Windy, North Rim light, small trees
Navajo Point	2272	424574.88	3988552.35	Tuba City lights
Yaki Point	2208	402398.96	3991026.59	North Rim light, windy
Pipe Creek Vista	2173	401444.99	3989827.73	Windy, North Rim light, small trees
South Kaibab Trailhead	2196	402387.60	3990418.34	Parking lot light, windy, small trees
Desert View Watchtower	2270	425595.18	3989178.80	Buildings, horizon clouds, Tuba City lights, windy, light from ca
Mohave Point	2126	395000.47	3992598.23	Small trees, North Rim Light, Windy
Hermits Rest	2031	391011.14	3991561.51	Large Trees, Horzion Clouds
Pima Point	2060	39.1940.90	3992578.07	North Rim Light, Vegas sky dome
Hopi Point	2145	396005.82	3992823.42	Horzion Clouds, small trees, windy, North Rim Light
Trailview Overlook 2	2135	396804.87	3991915.82	Village lights, windy, small trees
Powell Memorial	2143	396351.44	3992706.17	Tusayan sky dome, horizon clouds, windy, North Rim light
Maricopa Point	2135	396606.87	3992554.61	Horzion clouds, windy, Village lights, North Rim light
Trailview Overlook	2128	396696.60	3991425.64	Village lights, small trees
Monument Creek Vista	2075	393501.88	3991300.57	Large Trees, Horzion Clouds
Yavapai Point	2150	399380.76	3991852.47	North Rim light, Walkway light, building light
GCVC Parking Lot	2167	400084.51	3991168.15	Red lights of Star Party, buildings, horizon clouds
The Abyss	2098	394710.13	3991018.17	Vegas sky dome

Locations	Elevation (m)	Easting	Northing	Area Observations
Mather Point	2162	400241.56	3991362.05	Horizon clouds, North Rim light, windy
El Tovar Flagpole	2100	397544.70	3990998.34	buildings, horizon clouds, glary lights, El Tovar Lights, Hopi Ho
Mather Campground	2135	399270.75	3989975.55	Horizon clouds, large trees
Verkamps Visitor Center	2114	397708.79	3990972.46	Verkamps lights, El Tovar lights, windy
Kachina/Thunderbird Lodge	2099	397396.26	3990875.60	Buildings, horizon clouds, windy, lodge lights
Bright Angel Lodge Plaza	2084	397260.55	3990910.47	Buildings, horizon clouds, glary lights, Bright Angel Lodge light
Tusayan: Camper Village	2014	398697.93	3981847.49	Buildings, glary lights, horizon clouds
Tusayan: Best Western Parking Lot	2008	398220.76	3981117.56	Buildings, glary lights, horizon clouds
Tusayan: IMAX Parking Lot	2011	398444.83	3981731.88	Buildings, glary lights, horizon clouds
Park Headquarters Parking Lot	2120	398905.52	399056.31	Large Trees, buildings, horizon clouds, Parking lot lights
Tusayan: McDonald's Parking Lot	2009	398467.48	3981514.41	Buildings, glary lights, horizon clouds
Salt Creek Campground	1050	395378.00	3993915.00	Mostly clear, warm
Horn Creek Campground	1121	396520.00	3995662.00	
Clinic employee parking	2126	398279.71	398279.71	Mostly clear skies, bright parking lot lights and floodlights
GC School soccer field	2113	397498.36	3990299.51	Nearby lighting from the school and rec center, Milky Way visi
Rowe Well Road	2039	395562.95	3989327.64	No clouds, no obvious light domes
Dry Park fire tower	2739	388986.30	4034920.48	Mostly clear, clouds on southern horizon.
Intersection of Hwy 67 and FS22	2661	398569.47	4029149.10	Clear, storm on the southern and western horizons.
Cape Royal	2410	414510.45	3997968.64	Clear, no moon, milky way near zenith and very bright.
North Rim entrance station	2694	399776.55	4021701.49	Storm coming in from the South but still near horizon, clear sk
Roosevelt Point	2583	414348.02	4008556.52	Partly cloudy (<20%), windy and cold, very bright Milky Way
Walhalla Overlook	2435	415239.50	3998981.47	Clear skies, windy
Point Imperial	2690	412076.22	4015365.58	Windy, partly cloudy, no moon, Milky Way extremely bright.
Vista Encantada	2605	412478.11	4009772.25	Windy, Milky Way very bright, no moon
Bright Angel Point	2481	405678.99	4005985.05	Partly cloudy at horizon, windmill lights near Williams, AZ
Kaibab Trailhead parking lot	2492	404935.75	4008651.17	Partly cloudy, Milky Way very bright, no obvious light domes
North Rim campground	2531	404594.45	4007844.03	Clear skies, some lights from cabins and the general store
Grand Canyon Lodge backporch	2504	405348.24	4006330.33	Partly cloudy at horizon, interior lodge lighting evident
Roaring Springs (Manzanita) bunkhouse	1385	407220.92	4005088.30	Partly cloudy, windy, no obvious lights
Roaring Springs (Manzanita) bunkhouse	1385	407220.92	4005088.30	
Roaring Springs (Manzanita) bunkhouse	1385	407220.92	4005088.30	
Roaring Springs (Manzanita) bunkhouse	1385	407220.92	4005088.30	
Roaring Springs (Manzanita) bunkhouse	1385	407220.92	4005088.30	
Xanterra maintenance yard	2121	397926.93	3990030.88	Taken in the maintenance yard next to the NPS fuel pumps.
Dripping Springs and Hermit trail junctio	1340	389425.00	3991158.00	Clear and cool
Monument Creek @ Tonto Trail	910	393661.00	3992843.00	Clear and warm
Tuweep Campground	1400	314851.69	4010711.12	Hot, calm, hazy from fire, light dome to West
South Canyon at top of Redwall	1002	422155.00	4039820.00	Clear and Hot
Phantom Ranch	768	401387.87	3996023.77	
Phantom Ranch	768	401387.87	3996023.77	

Table 13. SQM readings at select sites in Grand Canyon National Park. Coordinates are in UTM 12S. Additional location and atmospheric conditions provided in the last two tables.

Long-Term Monitoring

Management and staff at Grand Canyon National Park are committed to collecting long-term sky quality measurements and photo documentation. The park has three basic Unihedron SQMs, two with the science and resource management staff and one with the park's interpretative division. Staff will collect data at each of the rim locations at least once annually with additional inner canyon measurements as logistics and weather allows. The park will also collect photo data once per year from several locations (as weather, travel logistics, and funding allows) each year. Locations will focus on potential threats (e.g. Tusayan development, continued Las Vegas growth) and open sky.

Restoration of Night Skies

In 2014, significant changes were made to the Lookout Studio, which is perched on the rim. Changes included both removing unnecessary lighting and improving the few lights that remained (relocating under eaves, adjusting direction of lights, and adjusting bulbs). Photos and a report on the design changes are available upon request from the park.

The park is committed to outreach about both night skies and night sky restoration. In 2014, an exhibit on Grand Canyon night skies was built at Trail Overlook, which includes a view of Grand Canyon Village. Sky quality measurements are also shared with the interpretative staff that uses them in their outreach programs. Figure 47 is an example retrofit of administrative cabin #27 on the North Rim taken on August 12, 2015. The top photo is the exterior fixture with a compact fluorescent lamp (CFL) bulb, the bottom photo is the same fixture with an amber LED bulb.

Figure 47. Retrofit of an exterior fixture on the North Rim.

Action Plan for Achieving Full International Dark-Sky Park Status

The park is currently working with contract lighting engineers to determine a plan for achieving full lighting compliance within five years and substantial (>60%) compliance in three years. The park expects a full plan and recommendations by early summer 2016, with immediate action on "low hanging" fruit retrofits. Additional retrofits will be completed in fall 2016 while concurrent action will be taken to determine appropriate retrofits of historic structures. A second phase of lighting retrofits, including some retrofits of historic structures will occur in 2017 following the recommendations and timeline of the lighting engineering report expected in early summer 2016. A revaluation of the state of the lighting inventory will also be conducted in 2017 to determine if the current action plan is appropriate. Funding for each stage listed (and future work not listed) is primarily through the Grand Canyon Association (GCA), the official nonprofit partner of Grand Canyon National Park. In 2013, GCA demonstrated their commitment to night sky conservation through seed monies to complete the lighting inventory and initiate outdoor lighting planning. They provided additional funds in 2015 to support lighting design and initiate retrofits. By the close of 2015, the GCA board fully embraced night skies and adopted night sky stewardship as one of their primary capital campaigns to fundraise for support of full lighting compliance. Without GCA, this complex and ambitious endeavor would not be possible. The superintendent has approved park funding in the form of in-kind staff salary and equipment.

Visitor Experience

Nighttime Visual Quality

Scenic Views and Night Hiking

Grand Canyon is well known for its grand scenery, which is not limited to daytime hours. Many visitors were observed in the Mather Point area well after sundown at night, enjoying the nocturnal environment and the views of the night sky. Protecting human dark adaptation in these areas is critical. It is quite advantageous to have a network of paved trails that allow people to walk at night without encountering tripping hazards. In this regard the new walkways to Mather Point and along the rim in that area are ideal.

Astronomy and Night Photography

Visitors come from far and wide to enjoy these activities. Visual observing of the night sky with telescopes or binoculars may be practiced by a very small percentage of all park visitors, but there is an expectation that the activity is available in Grand Canyon. We ran across a visitor at Point Imperial observing with a telescope on this trip; it was a big part of his reason for visiting.

Night photography has become extremely popular among visitors with the advent of digital cameras that produce excellent results with minimal effort. The developed viewpoints at GRCA are ideal locations for this activity. It can be extremely valuable to encourage this activity; the information contained in each visitor's images will inform them and anyone else who sees those images about the beauty of the nocturnal scene and its value to the park as a whole.

Wilderness Character

The impact of light trespass and sky glow upon wilderness character is of concern for GRCA, with the majority of the park managed as wilderness, including "below the rim" in the vicinity of the park's developments. In addition, Phantom Ranch is a development with outdoor lights surrounded by wilderness. Light trespass and excessive scene luminance at this location may be visible from viewpoints on the rim, detracting from scenic quality during twilight and at night. This issue has

been described by Nebel and Williams with a visibility model of outdoor lights (http://proceedings.esri.com/library/userconf/proc15/papers/839_474.pdf). While the impact of light domes from distant cities may be considered minor at this time, it cannot be ignored. The indicator maximum vertical illuminance is recommended for monitoring this impact when all-sky photometry is available. In addition, color digital imaging is valuable in illustrating the impacts.

Locations for Night Sky Viewing

The Mather Point/Grand Canyon Visitor Center bus parking area is convenient and has the big advantage of unobstructed horizons. Its use for the park ranger-led programs is an ideal choice. However, glare from the comfort station outdoor light must be mitigated or eliminated, as well as other stray light from the area. Potential: Cape Royal is excellent. Concession-managed as well as NPS areas should be considered. Examples: Near Hopi House, rear of Canyon Village Market "General Store".

Events

Events focus attention on a particular issue, thus are good opportunities for education outreach. Many visitors plan their visits around events of a particular theme, as they offer a variety of experiences and may include guest appearances by outside experts. Events which emphasize the natural nocturnal lightscape include astronomical observing or "star parties," workshops or field institute classes, and citizen science data collection. The annual Grand Canyon Star Party (Figure 48), which includes both North and South Rim locations, is now in its 25th year. On the South Rim, events include a slide show nightly at 8:10 pm, in the theater of the Grand Canyon Visitor Center, followed by free telescope viewing behind the building. On the North Rim, astronomers set up telescopes on the porch of the Grand Canyon Lodge every evening.

Management Implications

Designated Observing Sites

Consider setting aside a new campground or "overnight parking area" for astronomy only. A portion of the Mather Point/Grand Canyon Visitor Center parking could be so designated. At Cape Royal, people should be allowed to spend the night in the parking lot if observing, perhaps by special permit. The location is about as ideal as any on the planet for visual astronomy. At Desert View, a portion of the large parking lot could be designated for overnight parking, as long as light trespass issues are rectified with the gas station and the gift shop/store.

Theoretically, any viewpoint parking lot may be used if parking does not occur "overnight." Most amateur astronomers will know this already, but it could be publicized and encouraged. There are so many of them and just about all are wonderful places for observing.

On the North Rim, encourage people to observe on the patio of the Grand Canyon Lodge after the evening program, not just during the star party. Also, areas along the Point Sublime Road might be found for "non-overnight" observing. For overnight users, those with 4WD vehicles might be encouraged to get a camping permit for Point Sublime, otherwise a special area would have to be set aside. Given the paucity of open areas close to paved roads, encouraging overnight observing on US Forest Service lands might be the best choice.

Public Information

Information on opportunities for nighttime "tourism" should be available and such activities encouraged. This may mean that park rangers or volunteers will need to be available at night to assist visitors with increasing frequency. Concession employees who may be on duty in the evenings at a variety of stations (e.g. food and beverage service, retail sales) might be enlisted to provide information if asked. Park management should be sure they have correct information. Information in media (paper and digital) should be kept up to date and be available, such as articles in the park newspaper, brochures, rack cards, and flyers available at the visitor centers and entrance stations, and on the website. A night web cam would be a wonderful addition to the air quality division's current product (see http://www.nature.nps.gov/air/webcams/parks/grcacam/grcacam.cfm). Media focus on Grand Canyon's dark sky has already occurred, as exemplified by the GCA-funded "Grand Canyon In-Depth" episode on night skies: https://www.youtube.com/watch?v=NOZlhTCW3gM .

Night Sky Interpretation at Grand Canyon National Park

About half of the "Ranger Rendezvous" weekly interpretative programs were astronomy-related (Figures 49–51). Ranger Rendezvous were offered four nights per week March 1 to May 20 (spring season), three nights per week May 21 to September 7 (summer), not counting the Friday night events, and again four times per week September 8 to November 30 (fall). This means on the South Rim, **about two astronomy programs are offered weekly from March 1 to Nov 30** (minus the week of the Star Party when other evening events were cancelled).

Some of resource education's 7:30 pm **Twilight Zone** programs offered three times per week June 14 to August 8 are astronomy-related too, but are not counted in the average of two astronomy programs a week during the spring through fall time period.

Key South Rim Star Party Stats for June 8–15, 2015 (new records in blue!):

- **Night and day astronomer-visitor contacts: 75,886** (vs. 70,852 in 2014); **69,155** by night and 6,731 during the day.
- **Total nighttime attendance: 9,333** (vs. 8,757 in 2014 and 9,542 in 2012). That's an average of 1,166 visitors per night looking through about 7–8 telescopes apiece.
- **Total slide show attendance: 1,863** (full or over-full every night).
- **Constellation Tour attendance (at 9:00, 9:30, and 10:00 pm nightly): 1,329**.
- **99 registered volunteer astronomers donated 2,598 volunteer hours with 40–55 telescopes set up each night.**
- **Highest single night count: 1,460** on the final Saturday (1,050 on Wednesday).

Figure 48. Annual Star Party flyer (2015 provided as an example).

Saturday, May 2
Ranger Rendezvous:
Full Moon Walk
Grand Canyon Visitor Center
7:30 pm
DRESS FOR OUTDOOR PROGRAM

Sunday, May 3
Ranger Rendezvous:
Teddy Roosevelt's Visit
Shrine of the Ages
6:30 pm

Monday, May 4
Evening Program:
Day Into Night
*Phenomena Of The Canyon Sky
Shrine of the Ages
7:30 pm

Tuesday, May 5
Ranger Rendezvous:
From Powell to Power
*Author Tom Martin will discuss his book on Otis "Dock" Marston
Shrine of the Ages
7:30 pm

Wednesday, May 6
Evening Program:
The View from Point Sublime
*Grand Canyon Explorers & Artists
Shrine of the Ages
7:30 pm

Thursday, May 7
Ranger Rendezvous:
Star Talk
*Astronomy
Grand Canyon Visitor Center
8:30 pm

Friday, May 8
Evening Program:
A Thousand Inivisible Cords
*Plant & Animal Relationships
Shrine of the Ages
7:30 pm

Saturday, May 9
Ranger Rendezvous:
Grand Astronomy
Grand Canyon Visitor Center
8:30 pm

Sunday, May 10
Ranger Rendezvous:
Star Walk
*Astronomy
Grand Canyon Visitor Center
8:30 pm
DRESS FOR OUTDOOR PROGRAM

Monday, May 11
Evening Program:
Stories in Stone
Shrine of the Ages
7:30 pm

Tuesday, May 12
Ranger Rendezvous:
Wilderness and the Human Spirit
*Campfire Chat
Sage Loop Campfire Circle, Mather Campground
6 pm

Wednesday, May 13
Evening Program:
God of Hunters
*Mountain Lions
Shrine of the Ages
7:30 pm

Thursday, May 14
Ranger Rendezvous:
Grand Astronomy
Grand Canyon Visitor Center
8:30 pm

Friday, May 15
Special Program:
Humpback Chub
*Presented by Emily Omana
Shrine of the Ages
7:30 pm

Saturday, May 16
Ranger Rendezvous:
Star Walk
Grand Canyon Visitor Center
9 pm
DRESS FOR OUTDOOR PROGRAM

Figure 49. Example of a bimonthly park ranger program flyer, including astronomy and night sky programs.

Saturday, August 22
Special Evening Program:
Echoes From the Canyon
Human History/Living History
McKee Amphitheater
8:00 pm

Sunday, August 23
Ranger Rendezvous:
Teddy Roosevelt's Visit
McKee Amphitheater
6:00 pm

Monday, August 24
Evening Program:
Shifting Perspectives: One Canyon, Many Meanings
McKee Amphitheater
8:00 pm

Tuesday, August 25
Ranger Rendezvous:
Thinking Today About Tomorrow: Managing A Park With 5 Senses
McKee Amphitheater
8:00 pm

Wednesday, August 26
Evening Program:
So What Next: Surviving the Apocalypse at the Grand Canyon
McKee Amphitheater
8:00 pm

Thursday, August 27
Ranger Rendezvous:
Sunset Walk
Yavapai Geology Museum
6:00 pm

Friday, August 28
Science in the Park:
Night Skies
McKee Amphitheater
8:00 pm

Saturday, August 29
Evening Program:
Mountain Lions
Shrine of the Ages Auditorium
6:00 pm

Sunday, August 30
Ranger Rendezvous:
Horses Of The Southwest: Life And Legend
Bright Angel Trailhead
6:00 pm

Monday, August 31
Evening Program:
Our Technicolor Canyon: Color and Our Perception of the Canyon
McKee Amphitheater
8:00 pm.

Tuesday, Sept. 1
Ranger Rendezvous:
Sunset Walk
Yavapai Geology Museum
6:00 pm

Wednesday, Sept. 2
Evening Program:
So What Next: Surviving the Apocalypse at the Grand Canyon
McKee Amphitheater
8:00 pm

Thursday, Sept. 3
Ranger Rendezvous:
Build A Park: Family Program
Sage Loop Campfire Circle
7:00 pm

Friday, Sept. 4
Science in the Park:
Night Skies
McKee Amphitheater
8:00 pm

Saturday, Sept. 5
Evening Program:
Night Skies
Shrine of the Ages Auditorium
6:00 pm

Figure 50. Example of a bimonthly park ranger program flyer, including astronomy and night sky programs.

Saturday, Oct 31
Evening Program:
Teddy Roosevelt's Visit
Mckee Amphitheater
5:30 pm

Sunday, Nov 1
Ranger Rendezvous:
People of the Grand Canyon
Sage Loop Campfire Circle
Mather Campground
6:00 pm

Monday, Nov 2
Evening Program:
Trees, Trees, Trees
Shrine of the Ages Auditorium
7:30 pm

Tuesday, Nov 3
Ranger Rendezvous:
Star Talk
Grand Canyon Visitor Center
7:00 pm

Wednesday, Nov 4
Evening Program:
Grand Canyon Exploration Illustrated
Shrine of the Ages Auditorium
7:30 pm

Thursday, Nov 5
Ranger Rendezvous:
Grand Astronomy
Grand Canyon Vistor Center
7:30 pm

Friday, Nov 6
Evening Program:
A Thousand Invisible Cords
Shrine of the Ages Auditorium
7:30 pm

Saturday, Nov 7
Ranger Redezvous:
Astronomy
Grand Canyon Visitor Center
7:30 pm

Sunday, Nov 8
Ranger Rendezvous:
Astronomy Walk
Grand Canyon Visitor Center
7:30 pm

Monday, Nov 9
Evening Program:
Trees, Trees, Trees
Shrine of the Ages Auditorium
7:30 pm

Tuesday, Nov 10
Ranger Rendezvous:
Sunset Walk
Yavapai Geology Museum
4:30 pm

Wednesday, Nov 11
Evening Program:
Creating Grand Canyon Village
Shrine of the Ages Auditorium
7:30 pm

Thursday, Nov 12
Ranger Rendezvous:
Night Life of the Grand Canyon
Grand Canyon Visitor Center
4:30 pm

Friday, Nov 13
Evening Program:
I Can't Get No Respect: Ravens
Shrine of the Ages Auditorium
7:30 pm

Saturday, Nov 14
Evening Program:
Astronomy
Grand Canyon Visitor Center
7:30 pm

Figure 51. Example of a bimonthly park ranger program flyer, including astronomy and night sky programs.

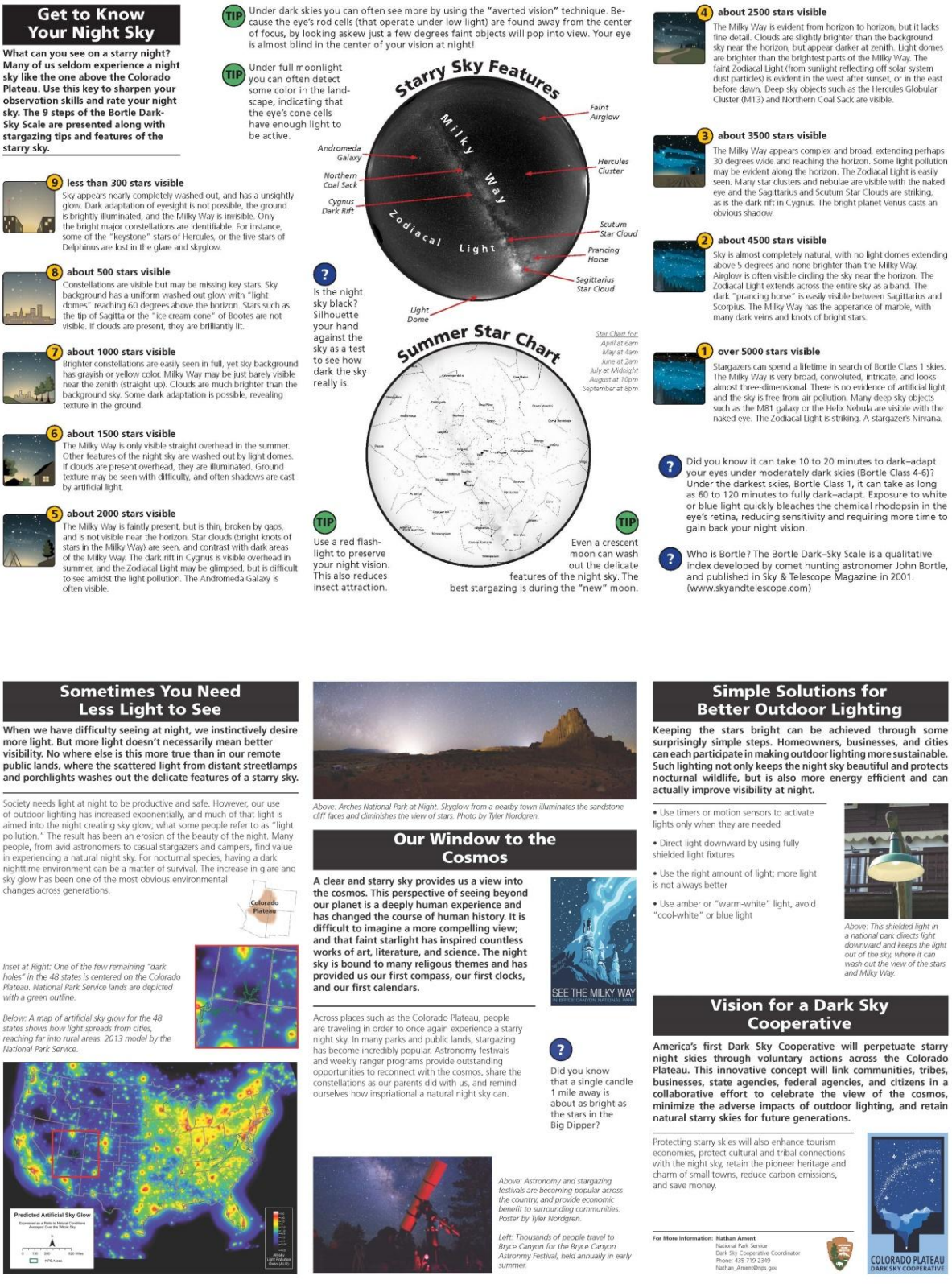

Figure 52. Annual river guide training handout about astronomy and night skies.

Grand Canyon

National Park Service
U.S. Department of the Interior
Grand Canyon National Park

Visitor Comment Form

Thank you for taking time to comment on your experience at Grand Canyon National Park.
Complete each section below; please print.

Name David [redacted]
Address [redacted]
Sherwood, AR 72120

Date 08/19/2014
Phone [redacted]
Email [redacted]

Nature of Comment

- [x] *Compliments:* Thank you for taking time to compliment the park or staff.
- [x] *Suggestions/General Remarks:* Your input is important to park managers.
- [ ] *Concerns:* Describe the nature of your concern, and provide as much detail as possible. If your comment stems from a particular incident, please try to give the time, date, and names of any involved personnel.

Comments

Reber

Dear Superintendent and Grand Canyon Staff,

I am writing to express a favorable review and support for the night sky talk given at the McKee Amphitheater on 8/18/14 at 8pm. I am not sure of the last time any of you attended the talk, but I found it eye-opening and informative. In addition to informing me about various astronomical phenomena, the ranger giving the talk told me about the park's attempts to limit light pollution. I am from the southeastern US, an area with a fair amount of light pollution. My honest thought prior to the talk was, "Oh yeah, we should probably do something about that." During the talk, the ranger showed us pictures of what the night sky looks like over the Grand Canyon. He told us how he himself has had the experience of having his shadow cast by the

Use the reverse side to continue your comments if needed. When completed, please hand to any National Park Service employee or fold on dotted lines, tape, and drop into any US Post Office mail box. Do not staple.

printed on 100% recycled paper 0512

comments continued

light of the Milky Way. Simply incredible! Thanks to his talk and your park's efforts, I was exposed to a reality I did not know existed (not an everyday occurrence). I realize most people come to the park for its daytime views, but thanks to that talk I now realize that I have been missing out on something I could see from my hometown (eventually, I hope). Please accept this review as my strongest support and encouragement for the park to continue investing in light pollution reduction and the talks which inform us what the sky can look like (especially in the Eastern US)

National Park Service
Grand Canyon National Park
P.O. Box 129
Grand Canyon, AZ 86023

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Comment regarding _____

Person distributing or receiving comment form

Name _____

Date _____

Location _____

Remarks

Route to

_____ _____

_____ _____

_____ _____

Routing Comments

tape closed

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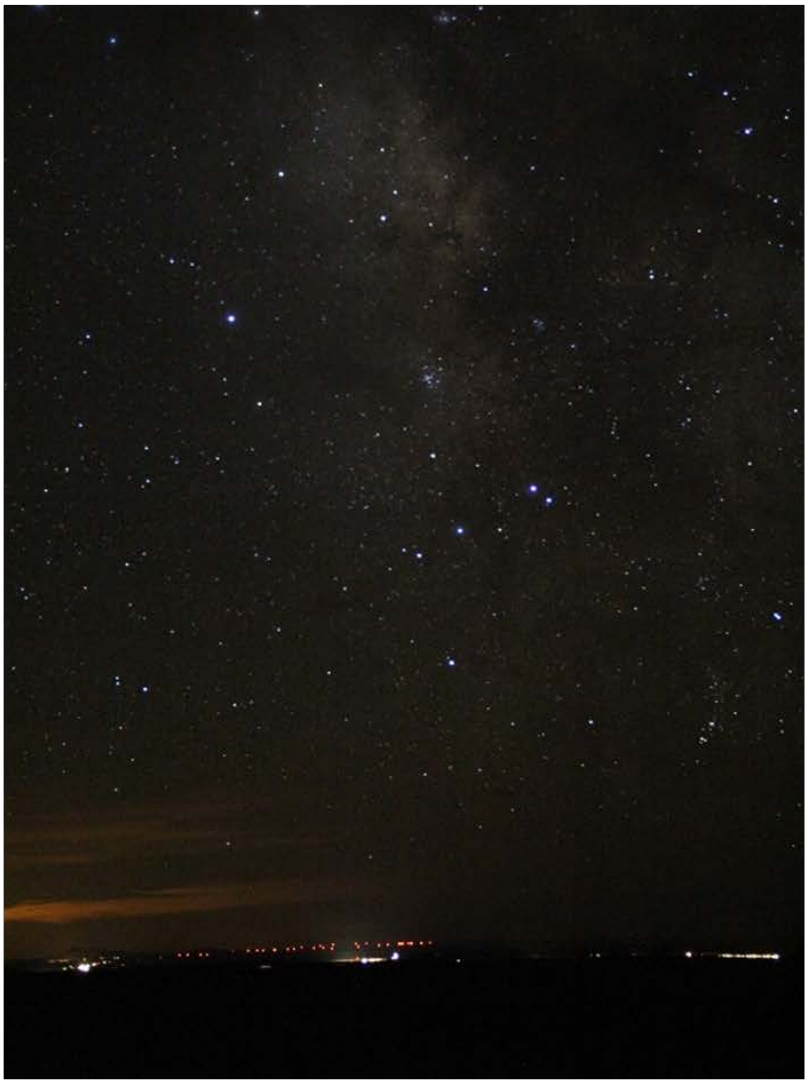
Figure 53. An example of visitor feedback (August 19, 2014).

North Rim Community Meeting

Night Sky Stewardship and You

Come learn about upcoming improvements to outdoor lighting,
the effects of light pollution,
and Grand Canyon's pursuit of Dark Sky Park designation

Where: North Rim Community Building
When: 6pm October 14th
Questions? Contact GRCA Physical Scientist Ed Schenk at 638-7817 or email edward_schenk@ nps.gov



Night sky view from the North Rim looking at the South Rim

Figure 54. Example of a flier for a community event in fall 2015. Community outreach occurred multiple times at both the Grand Canyon Village and North Rim developed area.

Section 2

GRCA Lighting Inventory

This effort produced a complete inventory of all lighting fixtures at GRCA in support of night sky stewardship. Initial data collection represents baseline lighting conditions as of December 2014. Subsequent lighting improvements (retrofits) require updates to the database. Data were used to demonstrate compliance with lighting guidelines and support the nomination as an international dark sky park per the IDA guidelines.

Content was a collaborative effort with NPS employees from GRCA and the NPS natural sounds and night skies division. Baseline data collected by GCA night sky project staff Laura Williams and volunteers is show below in Tables 14–24 with representative light fixtures shown in Tables 25–28.

Summary Statistics

	Number of Bulbs	Number of Fixtures
Bulbs Per Fixture Known	4,078	3,770
Bulbs Per Fixture Unknown[1]	970 (estimate)	970
Totals	**5,048**	**4,740**

Table 14. Total numbers. [1]One bulb per fixture was assumed when data missing.

Number of Fixtures	1,750
Percentage of Fixtures	37%

Table 15. Compliant fixtures. Compliant criteria include at least one of the following: fully shielded, motion sensor control, timer control, lumens < 500lm.

Fully Shielded Fixtures

	Number of Bulbs	Number of Fixtures
Bulbs Per Fixture Known	1,083	1,035
Bulbs Per Fixture Unknown[1]	161 (estimate)	161
Totals	**1,244**	**1,196**

Table 16. Fully shielded totals. [1]One bulb per fixture was assumed when data missing.

Bulb Base Type	Number of Bulbs	Number of Fixtures
Standard Edison	467	459
Pin	268	229
Integrated LED	21	21
Mogul	17	17
Other	1	1
Unknown	470	469

Table 17. Bulb base type totals.

Bulb Base Type	NDZ	LZ-00	LZ-0	LZ-1	Totals
Standard Edison	2	17	368	80	**467**
Pin	0	24	170	74	**268**
Integrated LED	0	2	19	0	**21**
Mogul	0	0	17	0	**17**
Other	0	0	1	0	**1**
Unknown	0	25	431	14	**470**
Totals	**2**	**68**	**1,006**	**168**	**1,244**

Table 18. Bulb base type by lighting zone. Numbers reflect estimated number of bulbs

Bulb Base Type	South Rim Village	North Rim Developed Area	Desert View	Phantom Ranch	All Others	Totals
Standard Edison	371	32	36	13	15	**467**
Pin	238	22	5	2	1	**268**
Integrated LED	17	3	0	0	1	**21**
Mogul	8	0	2	0	7	**17**
Other	0	1	0	0	0	**1**
Unknown	423	13	30	1	3	**470**
Totals	**1,057**	**71**	**73**	**16**	**27**	**1,244**

Table 19. Bulb base type by park area. Numbers reflect estimated number of bulbs.

Not Fully Shielded Fixtures

	Number of Bulbs	Number of Fixtures
Bulbs Per Fixture Known	2,995	2,735
Bulbs Per Fixture Unknown[1]	809 (estimate)	809
Totals	**3,804**	**3,544**

Table 20. Not fully shielded totals.[1]One bulb per fixture was assumed when data missing.

Bulb Base Type	Number of Bulbs	Number of Fixtures
Standard Edison	1,803	1,720
Pin	222	131
Integrated LED	56	51
Mogul	43	40
Other	61	42
Unknown	1,619	1,560

Table 21. Bulb base type totals.

Bulb Base Type	NDZ	LZ-00	LZ-0	LZ-1	Totals
Standard Edison	16	84	1,633	70	**1,803**
Pin	0	29	183	10	**222**
Integrated LED	0	14	42	0	**56**
Mogul	0	8	24	11	**43**
Other	0	0	55	6	**61**
Unknown	26	31	1,494	65	**1,616**
Totals	**42**	**166**	**3,431**	**162**	**3,801**

Table 22. Bulb base type by lighting zone. Numbers reflect estimated number of bulbs.

Bulb Base Type	South Rim Village	North Rim Developed Area	Desert View	Phantom Ranch	All Others	Totals
Standard Edison	1,112	548	72	31	40	**1,803**
Pin	87	106	1	25	3	**222**
Integrated LED	20	8	14	11	3	**56**
Mogul	4	29	0	6	4	**43**
Other	15	16	30	0	0	**61**
Unknown	1,475	53	54	3	34	**1,619**
Totals	**2,713**	**760**	**73**	**76**	**84**	**3,804**

Table 23. Bulb base type by park area. Numbers reflect estimated number of bulbs.

Lumens

	Bulbs < 500lm	Bulbs > 500lm	Totals
Fully Shielded	6	311	**317**
Not Fully Shielded	161	1,259	**1,420**
Totals	**167**	**1,570**	**1,737**

Table 24. Lumen totals.

GRCA Lighting Inventory Representative Fixture Photographs
Fully Shielded Fixtures

Location	Lighting Information	
Bright Angel Lodge	Standard Edison base HPS bulb	
North Kaibab Trailhead water station	Integrated LED LPS bulb	
Science and Resource Management building	Integrated LED base LED bulb	
Desert View Watchtower Road	Pin base Fluorescent bulb	

El Tovar Hotel	Standard Edison base Halogen bulb	

Table 25. Representative photos of fully shielded fixtures at park locations.

Not Fully Shielded Fixtures

Location	Lighting Information	
Phantom Ranch NPS barn	Mogul base Incandescent bulb	
Bright Angel Lodge	Standard Edison base CFL bulb	
Phantom Ranch Trail	Standard Edison base CFL bulb	

Community Building	Pin base Halogen bulb	

Table 26. Representative photos of not fully shielded fixtures at park locations.

Residential Fixtures

Location	Lighting Information	
South Rim residential	Not fully shielded Standard Edison base	
South Rim residential	Not fully shielded Standard Edison base CFL bulb	
Desert View residential	Fully shielded Standard Edison base CFL bulb	

South Rim residential	Fully shielded Standard Edison base	

Table 27. Representative photos of residential fixtures.

Fixtures on Historic Buildings

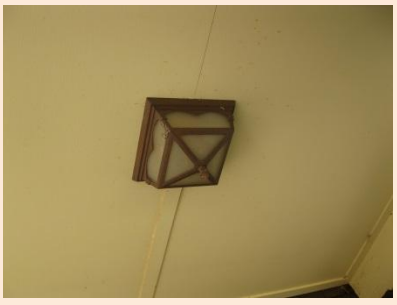
Location	Lighting Information	
El Tovar Hotel	Not fully shielded Standard Edison base CFL bulb	
El Tovar Hotel	Incomplete information	
Kolb Studio	Not fully shielded CFL bulb	

Table 28. Representative photos of fixtures on historic buildings.

Section 3

Management Documents

NPS Management Policies

An assortment of laws and directives at the federal and park level serve as guidelines for GRCA in its mission to protect natural night skies. From the 1916 Organic Act to the NPS *Management Policies 2006*, section on lightscape management, the federal government has laid out a basis for the idea of protecting night skies. In addition to these, the Director's *A Call to Action Report* (2012), Action 27 reaffirms the National Park Service's support towards the protection of dark sky resources. The GRCA *Foundation Statement* provides further guidance and approval for extending park protection of night skies. Some examples of relevant NPS Management Policies are summarized below.

National Park Service Organic Act

The Organic Act was passed in 1916 to protect and manage the national park lands of the United States. The act protected the ecological and scenic values within federal lands, under which fall dark sky resources.

> "The service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Section 4.10, Lightscape Management (2006)

This service-wide document of management policies (Figure 55) provides the National Park Service with required and recommended actions to manage programs and parks. Included within is a Lightscape Management Plan, which lays out specific guidelines and recommendations for light management and use.

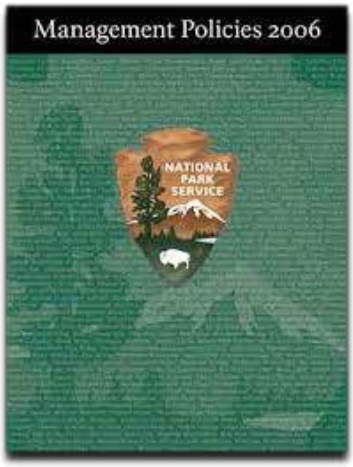


Figure 55. NPS Management Policies 2006.

> "The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human caused light....The stars, planets, and earth's moon that are visible during clear nights influence humans and many other species of animals, such as birds that navigate by the stars or prey animals that reduce their activities during moonlight nights.
>
> "Improper outdoor lighting can impede the view and visitor enjoyment of a natural dark night sky. Recognizing the roles that light and dark periods and darkness play in natural resource processes and the evolution of species, the Service will protect natural darkness and other components of the natural

lightscape in parks. To prevent the loss of dark conditions and of natural night skies, the Service will minimize light that emanates from park facilities, and also seek the cooperation of park visitors, neighbors, and local government agencies to prevent or minimize the intrusion of artificial light into the night scene of the ecosystems of parks. The Service will not use artificial lighting in areas such as sea turtle nesting locations where the presence of the artificial lighting will disrupt a park's dark-dependent natural resource components.

"The Service will:

- restrict the use of artificial lighting in parks to those areas where security, basic human safety, and specific cultural resource requirements must be met
- use minimal-impact lighting techniques;
- shield the use of artificial lighting where necessary to prevent the disruption of the night sky, natural cave processes."

***Green Parks Plan* (4/2012)**

The Green Parks Plan (Figure 56) is a long-term strategic plan for management of NPS operations in a sustainable manner.

Figure 56. NPS Green Parks Plan.

"The NPS will minimize the impact of facility operations on the external environment. Outdoor experiences can be adversely affected by facility operations. Exterior lighting can reduce dark night sky quality and vehicle traffic can diminish the natural silence and sounds of an ecosystem. Reducing the impact of NPS operations on the environment will improve the visitor experience and protect natural and cultural resources through the preservation of night skies, natural sounds, water quality, ecosystems, and viewsheds.

Objectives

1. The NPS will reduce light pollution from park facilities with the goal of dark night sky preservation.
2. The NPS will minimize sound pollution in the outdoor environment.
3. The NPS will ensure that all facilities and operations are sustainably integrated into the park landscape to minimize impact on the natural and cultural environment."

Night Sky Management

"America's national parks contain many cherished treasures; among them are captivating natural sounds and awe-inspiring night skies. The joy of listening to the quiet symphony of nature or the beauty of seeing the Milky Way stretching overhead have become rare

experiences in our lifetimes, but they can still be found in many of our national parks. Natural sounds and natural darkness, though often overlooked, are essential in keeping our national treasures whole. They are magnificent in their own right, but also inspirational to the visitors who come to national parks, vital to the protection of wilderness character, fundamental to the historical and cultural context, and critical for park wildlife.

"The Natural Sounds and Night Skies Division uses science, engineering, and technology to understand and better manage these spectacular resources. We pioneer innovative techniques to measure the impact of noise and light pollution, develop new approaches to safeguard natural sounds and natural darkness, and identify management solutions to restore these public resources.

"The Natural Sounds and Night Skies Division works to protect, maintain, or restore acoustical and dark night sky environments throughout the National Park System. We work in partnership with parks and others to increase scientific understanding and inspire public appreciation of the value and character of soundscapes and star-filled skies. We welcome your interest in learning about these sublime resources of our national parks and the efforts you can take to help us preserve them for future generations. Whether it's simply talking a little softer or turning off an outdoor light, you too can make a difference in the protection of these vital resources. Most of all, we encourage you to experience for yourself the natural soundscapes and lightscapes of your national parks."

The Director's *A Call to Action* (2012)

The Director's *A Call to Action* (Figure 57) is a guideline for employees and partners that contains specific goals and measurable actions, and charts a path towards unified goals.

"Starry, Starry Night: Action 27
Lead the way in protecting natural darkness as a precious resource and create a model for dark sky protection by establishing America's first Dark Sky Cooperative on the Colorado Plateau in collaboration with other federal agencies, partners, and local communities."

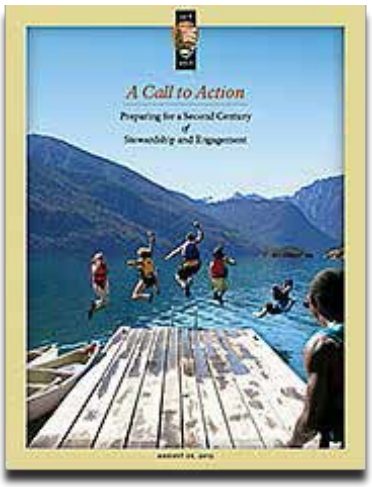


Figure 57. A Call to Action.

As an essential piece of the newly formed Colorado Plateau Dark Sky Cooperative, GRCA is taking lighting, conservation, and educational steps to fulfill the mission of the *A Call To Action* #27, Starry, Starry Night. This voluntary initiative forms America's first Dark Sky Cooperative, and links communities, tribes, businesses, state/federal agencies, and citizens in a

collaborative effort to celebrate the view of the cosmos, minimize the impact of outdoor lighting, and ultimately restore natural darkness to the area. A Grand Canyon International Dark Sky Park designation would bring further awareness and legitimacy to the Cooperative and would add this signature park to other parks on the Colorado Plateau who have recently achieved provisional dark sky status.

Transportation Plans

The Environmental Assessment for the recent South Rim transportation plan addresses outdoor lighting. See http://www.nps.gov/grca/learn/management/upload/7_Chapter_2_Alt_D_Mitigation_Comparison.pdf, page 121.

A Design Guide for Outdoor Lighting in Parks

GRCA's experience may lead to major advances in outdoor lighting for NPS natural area parks. The park should consider compiling this information into a reference for application in similar areas.

Regional Planning

GRCA's place in the context of other federal land management agencies, tribal lands, private lands, and state and county authorities on this issue is important. The designation as an International Dark Sky Park may influence planning with regard to outdoor lighting that might affect the park's night skies. For example, the potential creation of Grand Canyon Heritage National Monument, US Forest Service NEPA actions on access easements to potential future development, and other current and future issues in the region that may affect natural lightscapes within the park should be monitored and input provided accordingly.

GRCA is *the flagship park* in the Colorado Plateau Dark Sky Cooperative. Active involvement in this regional effort and *A Call to Action* item by park management and staff will demonstrate the leadership role by the stewards of one of America's best-known places (see https://www.facebook.com/Colorado-Plateau-Dark-Sky-Cooperative-303828049796706/).

Local Community Support

Lighting Ordinances

Coconino County has a strict lighting ordinance for unincorporated areas. In order to be a good neighbor, GRCA will demonstrate that outdoor lighting in the park will have a similar standard (see http://www.coconino.az.gov/documentcenter/view/4617). The city of Flagstaff has even stricter ordinances with regulations on spectral power distribution, amount of light, and the establishment of outdoor lighting zones (see http://www.flagstaff.az.gov/DocumentCenter/Home/View/14707). The use of low S/P ratio public lighting in both the city and county suggests an encouragement of the same in GRCA. The town of Tusayan, a gateway community to the South Rim, is in the process of applying for an IDA dark sky place designation as well.

Grand Canyon Lighting Policies

GRCA is currently revising their lighting guidelines and management plan. A draft of the revised policy is included below on the following pages, as is the current *Lighting Policy* (2004). The revised policy is currently under review in the National Park Service both in the park and with the natural sounds and night skies national and regional teams; it may change before going into effect. The draft is provided "as-is" to display the commitment of the park to natural dark skies, all information in the

draft should be considered preliminary and not binding. The draft policy will meet or exceed lighting ordinances of both Coconino and Mohave counties.

Grand Canyon National Park Night Sky Protection and Exterior Lighting Policy (January 2004)

I. Purpose

A. The dark night skies over Grand Canyon provide a source of enjoyment and wonder for both visitors and residents. They have historically been an essential part of the visitor experience. The purpose of this policy is to ensure that the skies over Grand Canyon National Park remain dark for future generations to enjoy.

B. It is the intent of this policy to require lighting practices and systems that will minimize light pollution and conserve energy while maintaining safety.

II. Applicability

A. This policy is applicable for the installation of any and all new exterior lighting in GRCA, except as listed below.

1. The following light sources are exempt from the provisions of this policy.

A) Isolated light sources under 50 watts.

B) Emergency lighting by police, fire and other authorities.

C) Lighting required in Federal Aviation Administration regulations for the safe operation of helicopters and other airships. Consult with GRCA for means of mitigating light pollution and glare.

D) Holiday lighting.

E) Temporary construction lighting. Consult with GRCA for means of mitigating light pollution and glare.

B. The replacement or retrofitting of existing lighting in order to meet the provisions of this policy is strongly encouraged, but is not immediately required unless specifically called for by the superintendent.

The park, concessioners, and other entities within the park should inventory and examine existing exterior lighting sources to determine which of them do not meet the provisions of this policy and should implement a program to retrofit or replace lighting as necessary.

Contact GRCA for information related to determining whether existing lighting meets this policy and for information related to retrofitting or replacing existing lighting.

C. Communities outside the park are beyond the jurisdiction of this policy, but they are encouraged to adopt this or similar policies to control light pollution, and to seek information from the park and others concerning exterior lighting. Refer also to the informational sources discussed elsewhere in this document.

D. This policy provides guidelines for the installation of lighting, but is not intended to specify where illumination is required. For example, a limit on illumination levels for roadways does not imply which roadways should be illuminated.

In general lighting should be installed only where necessary for public safety, or to illuminate necessary informational signs and displays, as recommended by the designer and approved by the park.

In deciding where lighting should be installed, it is important to consider that the lighting will be in a national park, where public expectations for illumination, as well as traditional practices for lighting, may be different from those of an urban environment.

E. This policy is intended to apply to exterior lighting only.

III. Shielding

A. All light fixtures shall at a minimum be fully shielded to provide full cutoff. A fully shielded fixture is defined as one that allows no light from either the lamp or fixture to be projected above the horizontal.

The light pattern from fixtures shall be further restricted (to the extent practical) so that light is directed onto only those areas that require illumination.

B. Lights near the canyon rim shall have additional shielding to prevent light from being directed into the canyon.

C. Signs and displays shall be lit from above with fully shielded lighting.

D. Light sources which do not meet the above requirements and are prohibited include:
   1. Floodlights.
   2. Ornamental luminaires (with visible light sources).

IV. Illumination

A. As noted above, this policy provides limits on illumination levels but is not intended to specify where illumination is required.

B. Illumination levels for roads, parking, pathways, bikeways, and other improvements.
   1. Follow the minimum recommended illumination levels of the Illuminating Engineering Society of North America (IES). Refer to Table 29 below for "Guidelines for Levels of Illumination Based on IES Recommendations, Grand Canyon National Park." Designers should consult the *IES Lighting Handbook* for additional information. If the table does not apply to a particular condition, provide an alternate recommendation for review and approval by GRCA. Illumination levels may be set higher than the standards given only if warranted by safety considerations, as recommended by the designers and approved by the park.

Locations	Minimum (footcandles)	Average (footcandles)	Uniformity Ratio (Average: Minimum)
Roads[1]	0.07	0.4	6:1
Parking[2]	0.13	0.5	4:1
Walkways / bikeways near roads / buildings	0.03	0.2[3]	6:1
Walkways / bikeways distant from roads / buildings	0.17	0.5[4]	6:1
Steps	0.25	1[5]	4:1
Signs	Signs should not be lit except where necessary to provide essential information, and only where the information is needed at night. Where signs are to be lit, provide fully shielded lighting (at the top of the sign), having the minimum illumination necessary to allow the sign to be read. (Use small lighting fixtures only.)		

Table 29. Guidelines for Levels of Illumination Based on IES Recommendations, Grand Canyon National Park, 10/02. General: Provide the lowest levels of illumination needed for safety, as recommended by the IES. Use the table above where applicable. If the table above does apply to a particular condition, provide a recommendation for review and approval by Grand Canyon National Park.

[1]IES recommendation for local, residential roads.
[2]IES recommendation for vehicle use areas having low activity.
[3]IES recommendation for residential areas.
[4]IES recommendation for the locations described.
[5]IES recommendation for commercial area sidewalks.

2. The overall illumination for any area shall not exceed 25,000 lumens per acre averaged over the entire area.
3. Area lighting designs shall include computer printouts of projected illumination levels, demonstrating compliance with this policy.

   If designers believe that a particular design condition does not allow the illumination level guidelines of this policy to be met, provide alternative recommendations (for review and approval by GRCA) that will minimize illumination levels.

C. Illumination for athletic events and recreation shall follow IES recommendations. All athletic and recreational events shall be scheduled for completion by 8:45 pm, and lighting shall be turned off by 9 pm unless the event carries beyond its originally scheduled time of completion.

D. Note that 1 footcandle = 1 lumen/sq. ft. 1 acre = 43,560 sq. ft., so that 1,000 lumens/acre = 0.0230 footcandles.

V. Lamps

A. Lamps shall be chosen for energy efficiency.

B. In areas where color rendition is not an issue, the preferred lamp type is LPS, which has the advantages of highest efficiency and immediate restrike. It also provides light that can be easily filtered out by astronomical observatories.

C. In areas where a moderate level of color rendition is needed, GRCA maintenance has standardized the use of HPS. Most parking areas that require lighting would be included in this category.

D. In areas where a high-level color rendition is important (as for signs and displays), other lamp types may be used, provided the fixture is properly shielded and meets other requirements of this document.

E. Mercury vapor lamps are prohibited.

VI. Appearance of Fixtures

A. Appearance of fixtures for site lighting shall meet the requirements of page 54 of the *Grand Canyon National Park Architectural Character Guidelines* (Figure 58) unless otherwise approved by Grand Canyon National Park.

VII. Vehicle Headlights

A. Designers of transportation systems should take steps to ensure that unnecessary glare from vehicle headlights does not reach other public areas.

VIII. Review and Approval of Lighting Installations

A. Proposals for the installation of new lighting are subject to review and approval by the National Park Service. Contact Mark Johnston (Grand Canyon National Park) at 928-638-7906 for review and approval procedures.

IX. Additional Information

A. A valuable source of public information concerning preservation of night skies can be found through IDA (www.darksky.org).

SITE LIGHTING

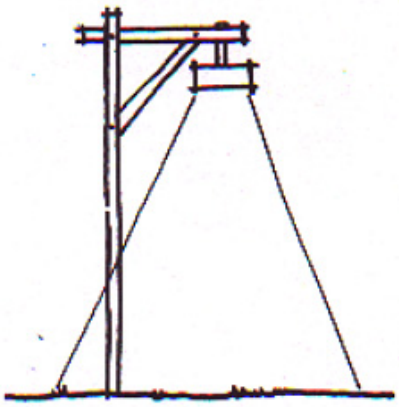
Light pollution caused by excess reflected light into the sky at or near the Grand Canyon is a serious concern. The introduction of exterior lighting in the Park should be limited to only those areas and cases where human safety requires some level of exterior illumination. Lighting for ornamental purposes is not appropriate.

Lighting should be accomplished with fixtures designed to reflect the principles of rustic architecture wherever possible. Pole-mounted fixtures should be mounted at heights suitable for the intended lighting purpose, and mounting heights should be no higher than that required to accomplish the desired objective. Roadway or parking lot light standards should only be as high as required to accomplish the necessary illumination while being in scale with the surrounding landscape and structures. For example, pole heights could be 25-30 feet in areas where existing tree stands effectively camouflage the poles. Lights located in conjunction with a barren overlook along the rim would only be appropriate if mounted on low standards or poles to minimize intrusion of the structures in the surrounding landscape.

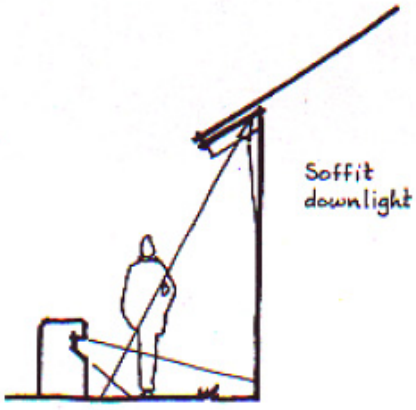
Poles and luminaire housings should be finished to blend with other materials consistent with the principles of rustic architecture. Light fixtures illuminating pedestrian walks or plazas should be from 12-15 feet in height in order to be appropriately scaled to the pedestrian and still out of reach of vandals.

Luminaire types should be selected for correctness of color rendition, longevity of lamp life, and low energy requirements. Light should be directed downward onto the ground surface to be lighted to the maximum extent possible, and the cutoff angle and distribution pattern should be carefully considered to achieve effective light levels without visible glare from an exposed light source. Low-level bollard type light fixtures should be considered where they can be effective without becoming too dominant in the landscape. Ornamental luminaries with visible light sources are not acceptable.

54



High cut-off downlight



Soffit downlight

Bollard light

Figure 58. Page 54 of the "Grand Canyon National Park Architectural Character Guidelines"

DRAFT Standard Operating Procedure: Park Outdoor Lighting Guidelines

This standard operating procedure provides park managers with artificial lighting guidelines and best management practices to minimize light pollution and maximize the stewardship of the natural lightscape at GRCA. When implemented, these practices will:

- protect the night sky experience for park visitors;
- ensure the most natural lightscape possible continues to be available for visitor enjoyment, while providing necessary lighting for safety;
- protect nocturnal wildlife, especially in the backcountry areas, from negative impacts of artificial light;
- help meet the park's sustainability goals by reducing energy use;
- reduce financial cost of exterior lighting in the park by an estimated 60 to 80 percent; and
- provide environmental leadership in fully sustainable outdoor lighting.

These guidelines accomplish this purpose by providing park managers with policy-based recommendations and best management practices as follows:

- delineating lighting zones in the park and identifying standards for environmental protection in each zone that is consistent with NPS policy;
- identifying protocols for monitoring park lighting to ensure consistency with lighting zone guidelines;
- identifying management options to ensure that light pollution from within the boundaries of GRCA is not degrading the natural lightscape quality;
- defining assessment tools for prioritizing available management options;
- identifying indicators of overall night sky quality;
- identifying methods for monitoring lightscape conditions to identify threats to the lightscape from inside and outside the boundaries of GRCA; and
- identifying opportunities for cooperation and partnering with surrounding communities to reduce light pollution visible within, but originating outside, park boundaries.

Draft Lighting Guidelines (possibly enacted 2016)

Background

One of Grand Canyon's most profound experiences is at night, whether the starry night sky is seen above the rim, spread out over the canyon's depths, or as slivers and craggy shapes from within the inner canyon walls. NPS management policies and GRCA management documents have recently begun to address the protection of this nighttime environment. A nighttime environment completely unaltered by artificial light is termed a *natural lightscape*. Maintaining the most natural lightscape possible in park environments, including developed areas, is recognized by the NPS as an important component of visitor experience and an integral part of the park ecosystem.

The natural lightscape at GRCA is already impacted throughout the park, relative to its original state unaffected by artificial lighting, by light pollution originating both inside and outside the park. This is documented by night sky quality assessments performed by the NPS NST in 2007 and 2008 on both the South and North rims at Grand Canyon. To prevent the further loss of this resource at all national parks, and to promote its restoration, NPS *Management Policies 2006*, in section 4.10, Lightscape Management, directs parks to minimize the light that emanates from park facilities, to seek the cooperation of park visitors, and to partner with surrounding communities and neighbors to reduce the impact of light pollution upon the park (NPS 2006). The management policies

specifically direct parks to 1) restrict the use of artificial lighting in parks to those areas where security, basic human safety, and specific cultural resource requirements must be met; 2) use minimal impact lighting techniques; and 3) shield artificial lighting to prevent the disturbance of ecological processes and degradation of the scenic night sky.

GRCA park management documents also support natural lightscape protection, including the *General Management Plan* (NPS 1995), *Foundation Statement* (NPS 2010), and GRCA *2012–2016 Goals and Objectives* (NPS 2012), which specify, "Manage artificial lighting, maintain or enhance natural visibility conditions (Class I Airshed), and protect scenic views so Grand Canyon may be officially designated an International Dark Sky Park."

Grand Canyon also participates in the Colorado Plateau Dark Sky Cooperative, created in collaboration with other federal agencies, partners, and local communities in support of the 2016 Starry Starry Night in *A Call to Action*. Parks and communities throughout the Colorado Plateau committed to protect their own and each other's night skies, recognizing that the Colorado Plateau is one of the last areas in the continental US with a large amount of minimally impaired night skies.

In keeping with these policies, planning documents, and collaborative efforts, a careful evaluation of lighting needs, guided by these lighting guidelines, should be part of every facility review, study, or project. Lighting should not be used when it is not required for specific safety or cultural requirements, and current uses should be mitigated or discontinued if they do not meet the lighting guidelines outlined in this document.

Recommendations of the IES commonly used by lighting designers are intended for urban environments and may lack the environmental sensitivity required for natural lightscape protection in national parks. The darker the environment, the less illumination is necessary due to the dark adaptation of the human eye. Park visitors and staff are frequently transitioning between lit and unlit areas, unlike in cities where lighting is more uniform. Adding too much light, especially glare, can actually reduce both visibility and safety. (Yosemite 2011, NST *Outdoor Lighting,* undated)

The NPS *Management Policies 2006*, in Section 8.2.5.1, Visitor Safety, recognizes the simultaneous directives of protecting visitor safety and protecting park resources as follows:

> ". . . the Park Service strives to protect human life and provide for injury-free visits. The Service will do this within the constraints of the 1916 Organic Act. The primary—and very substantial—constraint imposed by the Organic Act is that discretionary management activities may be undertaken only to the extent that they will not impair park resources and values.
>
> "The means by which public safety concerns are to be addressed is left to the discretion of superintendents and other decision-makers at the park level . . . . Examples include decisions about whether to install warning signs or artificial lighting . . . . Some forms of visitor safeguards typically found in other public venues—such as fences, railings, and paved walking surfaces—may not be appropriate or practicable in a national park setting."

In reference to high-risk recreational visitor activity, which at GRCA may be interpreted as much of the recreational activity outside of developed areas, the management polices state,

> "Park visitors must assume a substantial degree of risk and responsibility for their own safety when visiting areas that are managed and maintained as natural, cultural, or recreational environments."

It is worth noting that even within developed areas at Grand Canyon, there are multiple locations without the types of safeguards that might exist in urban areas. For instance, there are not railings along the much of the canyon rim in the developed areas, but there are protective railings at highly frequented canyon rim overlooks.

Through the application of carefully considered lighting mitigations and thoroughly evaluated lighting technology, the safety and wayfinding of park visitors and staff can be addressed without significant negative impact to Grand Canyon's night sky. A large percentage of the park will be delineated as a NDZ, where no permanent artificial light will be installed and where no permanent artificial light should be visible from other park areas. In developed areas, the need for outdoor lighting should emphasize applications where accessibility, security and/or safety are principal concerns, in particular areas with tripping hazards and high night visitation. Except for conflict areas (roadway intersections with high nighttime pedestrian activity) and basic wayfinding, lighting should not be provided for streets, roads, or many of the park's walkways and bikeways. In some cases, improved signage or reflective coatings may adequately address safety or wayfinding issues and reduce or eliminate a need for artificial lighting. Dusk to dawn lighting for "security" purposes is rarely warranted in parks. General lighting, or lighting on trails, should not be expected, and lighting should be present only for specific targeted needs. Well-designed and well-controlled low-level lighting in the right locations will provide safer and more comfortable light than too much lighting at ineffective locations.

These guidelines are designed to evolve over time as research on ecological impact of artificial lighting continues and as lighting technology changes. It is recommended that these guidelines be reviewed every other year to incorporate evolving technology, new research, and NPS policies.

Lighting Zones

The use of lighting zones (LZ) was originally developed by the International Commission on Illumination (CIE) and appeared first in the US in IES *Recommended Practice for Environmental Lighting*, RP–33-99. The original system employed four lighting environmental zones, currently named LZ-1 through LZ-4. Recently, the CIE, IES, and IDA have all addressed a fifth zone of extreme environmental sensitivity (LZ-0) that is incorporated into the Joint IDA-IES *Model Lighting Ordinance* (IDA-IES MLO 2011).

The NPS NST proposes two additional restrictive zones throughout NPS units: LZ-00, to articulate where lighting is generally not desired but may be allowed for specific targeted needs, and a NDZ, a zone where no permanent lighting is allowed (NPS NST, *Interim Guidance for Outdoor Lighting Zones*, 2013). Additionally, LZ-3 and LZ-4 are by definition inappropriate for all NPS units, and LZ-2 has been determined to be inappropriate for GRCA given the pattern of nighttime use, expectations of the public, and the sensitivity of the resource.

The primary purpose of delineating lighting zones in a national park is to protect the natural lightscape to the greatest extent practical through the definition of desired conditions (or expectations) within each zone. Higher light intensity zones should be kept as small as possible or omitted in favor of zones that are more restrictive of outdoor lighting. Delineated zones should reflect the desired conditions of the area, not necessarily the existing ambient conditions (NPS NST 2013). Lighting zones are best implemented when correlated with existing management zones and/or park areas (IDA-IES MLO 2011).

Delineation of lighting zones also helps park users 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 and activities in mind. Higher intensity zones should be restricted to just those areas where needed, but should not be so fragmented into islands that a visitor or employee is constantly transitioning between different lighting zones and consequently markedly different lighting levels (NPS NST 2013).

The zoning process should also be cognizant of proximity to wilderness areas (NPS NST 2013). For example, inner canyon wilderness may not be protected from light pollution if it is adjacent to a high intensity (i.e. brighter) lighting zone, such as the Desert View developed area, or the Yavapai Geology Museum.

Standards for Environmental Protection: Light trespass at each zone boundary should be controlled. Measurement of light trespass, in units of illuminance (lux), is relatively quick and easy, and standards for maximum light trespass at each zone boundary must be met to ensure environmental protection.

The total lumens installed and operated outdoors per unit area of development will be limited to a maximum amount for each zone. Even with full shielding, a significant amount of outdoor light escapes to the environment by reflection off surfaces. Limiting installed lumens per acre or lumens per square foot will limit environmental impact from escaped artificial light. These amounts are qualitatively described in Table 30 for each zone.

Light-ing Zone	Recommended Uses or Areas	Continuity of Illumination	Zoning Considerations
NDZ	A NDZ where **no permanent lighting is allowed**, providing the best possible protection of natural lightscapes. Humans are provided the best opportunity for dark adaptation and enjoyment of natural lightscapes. Nocturnal wildlife habitat is afforded maximum protection.	**No illumination**	**This is the default lighting zone for undeveloped areas in parks** and should cover the majority of land area in the park, specifically wilderness areas at GRCA. Temporary small portable lighting, i.e., flashlights and headlamps, allowed only where needed for human travel or work.
LZ-00	A dark ambient environment with an **absolute minimal level of lighting.** Permanent artificial light fixtures exist only where critical for human safety or where mandated by codes and are for discrete tasks only. Nighttime activities in this zone are oriented to darkness at night. There is minimal impact to human dark adaptation and enjoyment of a natural lightscape. There is minimal disruption of nocturnal wildlife habitat.	**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 good glare control and minimal brightness. Light timing controls will minimize light duration. This zone is recommended for developed campgrounds, inner canyon developed areas, and other areas located adjacent to sensitive habitats, such as parking areas with limited nighttime use, low use entrance stations, outdoor amphitheaters, remote employee residences, and administrative or maintenance facilities with infrequent nighttime activity.
LZ-0	A dark ambient environment with a **reasonably low level of lighting for basic human safety and basic park operations.** Permanent artificial light fixtures exist only where necessary for safety, where mandated by codes, or where a discrete need is identified. Activities in this zone may require artificial light. There is an expectation among visitors and staff for minimal artificial illumination.	**Lighting is largely discontinuous** and within the zone there are substantial unlit areas. Some high use corridors may have continuous lighting.	**This is the default lighting zone for developed areas in parks.** Lighting is used for a variety of safety and operational needs. Lighting is apt to be limited to certain times with restrictions on intensity and lamp color. This zone is recommended for entrance stations open at night, outdoor interpretive displays frequented at night, administrative facilities with moderate nighttime activity, most visitor centers, most residential areas, and high visitor use areas adjacent to sensitive habitats.
LZ-1	To provide a **modest level of lighting to meet visitor expectations, safety concerns, and park operational needs** in busy park environments. Permanent artificial lighting is used for general human safety consideration and in keeping with the historic/cultural landscape; lighting is not used	**Lighting is largely continuous** along corridors and somewhat uniform, but lighting is seldom operating throughout the night.	Most lighting applications permitted, but at illumination levels below typical suburban or residential practices. Examples include transportation stations and busy staging areas, areas of high vehicle-pedestrian conflict, dense visitor lodging areas, and highly congested areas within large national parks, with the exception that this zone should not be applied adjacent to, or where light trespass could stray

	for convenience. There is increased emphasis on color rendition thus white light is more apt to be used in this zone. There is a moderate impact to human dark adaptation and the experiencing of natural lightscapes within this zone. Likewise there may be an impact to nocturnal wildlife habitat, so thus this zone should generally not be applied adjacent to a sensitive environment.		into a sensitive habitat or wilderness area.

Table 30. Proposed lighting zones at Grand Canyon National Park (Table adapted from NPS NST Interim Guidance for Outdoor Lighting Zones*, 2013)*

NDZ is strongly recommended by the NST specifically for use in national parks. LZ-00 is recommended to use where environmental sensitive is very high yet there is still a clear need for artificial illumination. LZ-0 and LZ-1 zones are recommended in the Joint IDA-IES *Model Lighting Ordinance* for use in developed areas in parks. LZ-1 in particular allows flexibility for lighting busy park environments, including parking lots, task areas, and retail business while minimizing light pollution.

Zones with higher lighting intensity (LZ-2, LZ-3, and LZ-4) are outlined in the Joint IDA-IES *Model Lighting Ordinance* for use in suburban or urban areas and are not appropriate for zoning inside a national park.

LZ-1 should be applied sparingly, given the park's high elevation, varied topography, high ground albedo (high light reflectivity of desert, dry sand, dry soil, and snow as opposed to lower light reflectivity of vegetation and wet soil at other parks), proximity to wilderness and sensitive wildlife habitat, and potential for light trespass to remote areas within and without park boundaries. Even low ambient lighting within LZ-1 can have greater negative impact than similar lighting in other environments without these multiple considerations specific to Grand Canyon (Benya Burnett Consultancy, *Grand Canyon National Park South Rim Visitor Center Lighting Concept Design – Summary Report*, 2013).

There may be areas in the park in which existing lighting is at a higher intensity than LZ-1. These areas will be identified in the lighting inventory database and prioritized for light retrofit implementation.

Residential Areas: All residences within park boundaries will be included in light fixture retrofit plans as appropriate in regards to the lighting zone. Enforcement of residential lighting compliance (i.e., light fixtures installed by residents, lights left on all night) will be primarily complaint driven. As with noise complaints that are based on a local noise ordinances, light complaints can be addressed based on a resident's lack of compliance with park lighting guidelines.

Interior Lighting: These guidelines are intended to address primarily exterior lighting. However, interior lighting that is unshielded by blinds or other methods can create significant light pollution. One example on the South Rim is the El Tovar Hotel room lights—curtains or blinds are provided

but are not always used by guests. Another example is restrooms in campground areas, where bright interior light spills out of doors when opened. Large windows intended for viewing during the day (i.e., at the Grand Canyon Lodge) can become huge lit reflectors at night creating light trespass into sensitive resource areas. This is often made worse by the fact that they are also locations for large chandeliers and other decorative lights. Lights in stairwells and on landings intended for egress safety may be over lit and remain on all night. Choosing interior lighting fixtures will not be addressed in these guidelines. However, other mitigation options for minimizing light pollution from interior lighting are included in these guidelines, where appropriate.

Lighting zone boundaries are shown in Figures 59–61. Description of each zone:

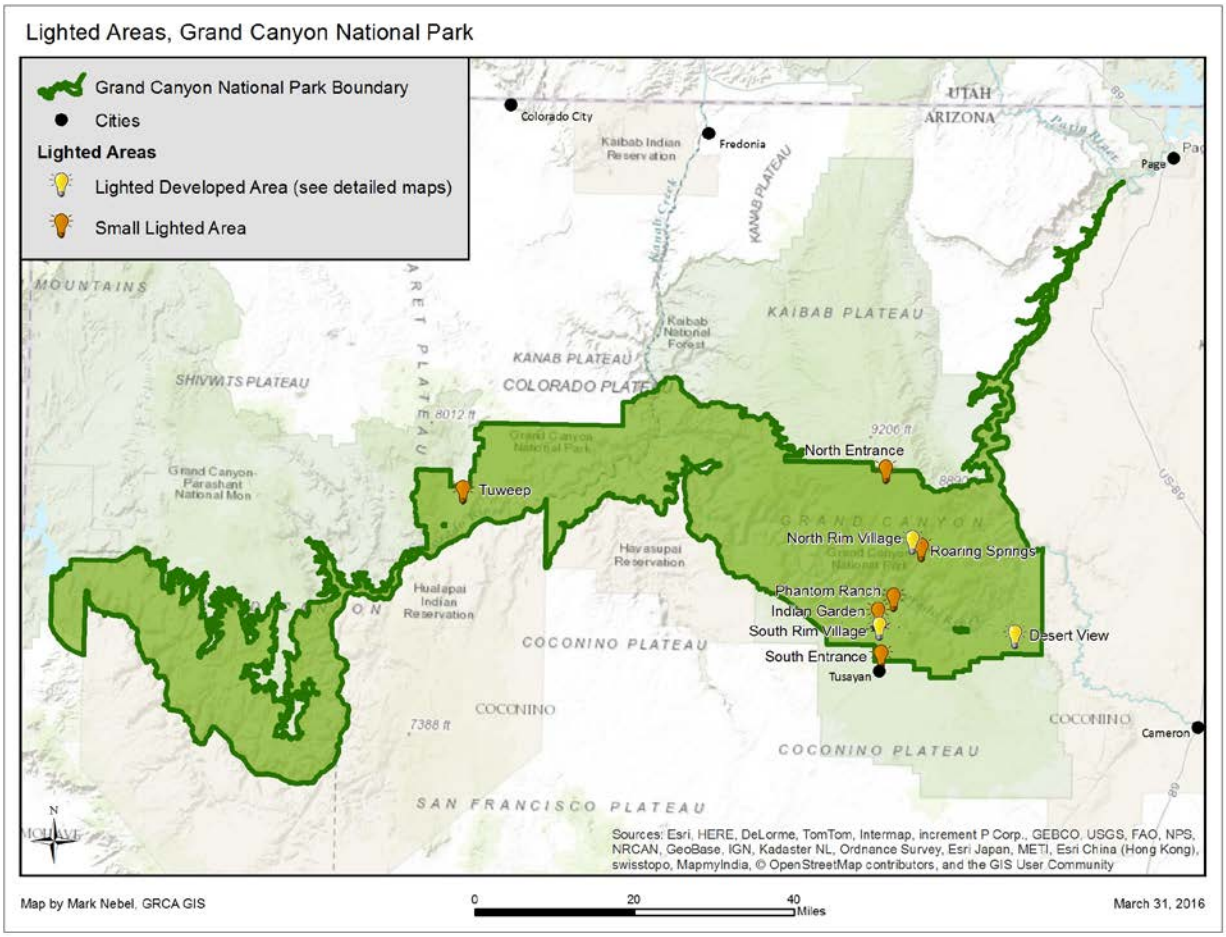
Naturally Dark Zone (NDZ): All wilderness areas and minimally developed remote areas adjacent to wilderness areas, particularly along the canyon rim. Specifically (in addition to wilderness areas): corridor trails (i.e., North Kaibab, South Kaibab, Bright Angel, and Hermit trails), Desert View Drive (not including South Kaibab Trailhead and Desert View developed area), Shoshone Point, canyon rim trails on both South and North rims, Hermit Road (not including Hermits Rest area), and the scenics road to Cape Royal and Point Imperial and overlooks.

Lighting Zone 00 (LZ-00): All campgrounds, including corridor management zone campgrounds and developed area campgrounds, developed inner canyon areas adjacent to wilderness, and canyon rim areas with minimal nighttime use and/or use intended to allow for night sky appreciation (i.e., outdoor amphitheaters and some trailheads). Specifically: Roaring Springs, Tuweep, Hermits Rest, Indian Garden, Phantom Ranch, Bright Angel Campground, Cottonwood Campground, Mather Campground, North Rim Campground, Desert View Campground, North Rim outdoor amphitheater (near the Campground), McKee Amphitheater, Mather Amphitheater, Mather Point, North Kaibab Trailhead, and South Kaibab Trailhead.

Lighting Zone 0 (LZ-0): This is the default zone for the developed areas in the park, including the Desert View, North and South entrance stations and most of the North Rim, Desert View, and South Rim developed areas, including Grand Canyon Visitor Center, and Yavapai Geology Museum.

Lighting Zone 1 (LZ-1): High visitor use areas not adjacent to the NDZ, and maintenance operations requiring task lighting. Specifically: South Rim Village maintenance area, helibase, shuttle bus maintenance area, North Rim and South Rim wastewater treatment plants, trail ops, jail, Xanterra fire and security, clinic/EMS buildings and parking lots, Market Plaza general store/bank/post office area, Yavapai Lodge main building, and concessions/GCA warehouse and receiving areas.

Figure 59: Full map of Grand Canyon National Park: general location and lighting zones



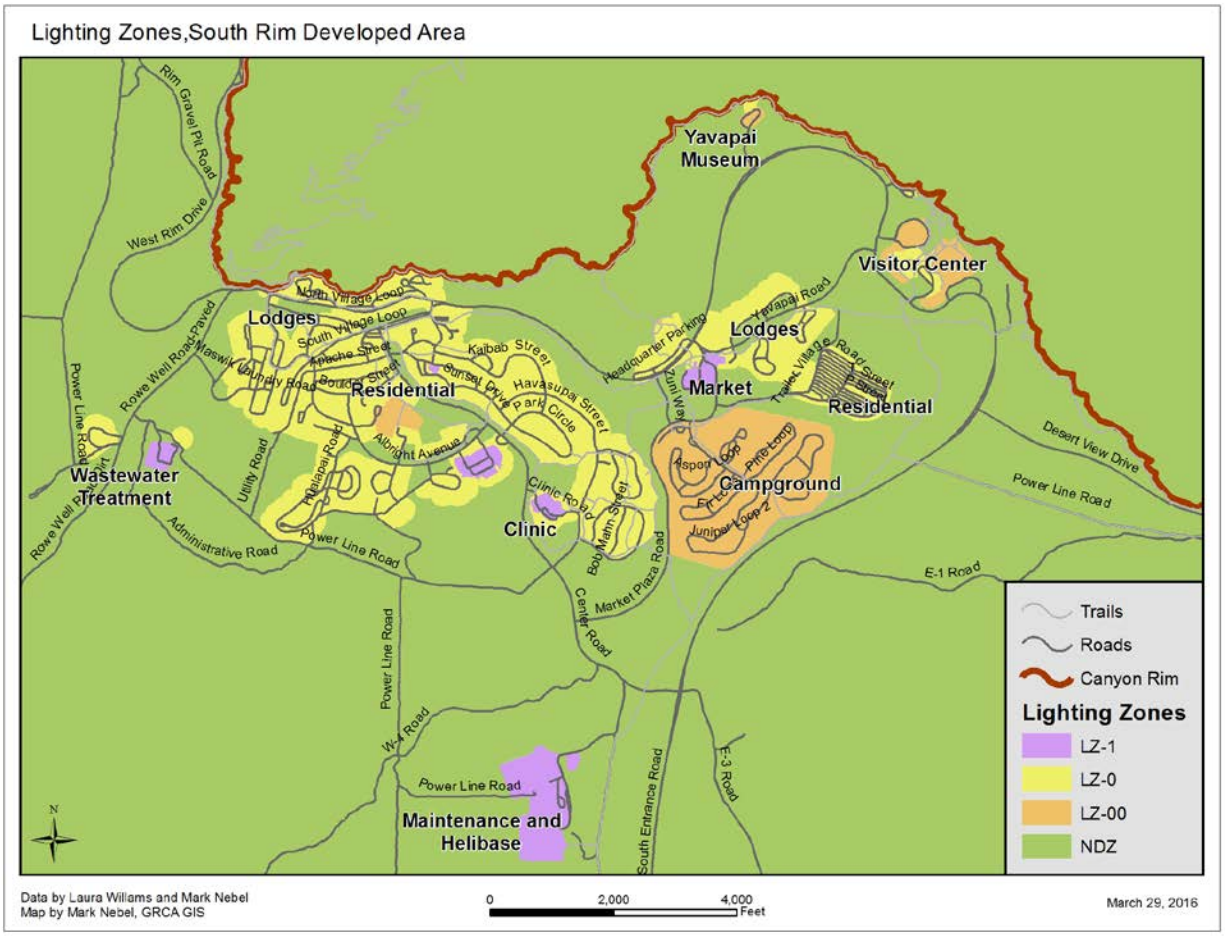


Figure 60. Lighting zones in South Rim Village developed area.

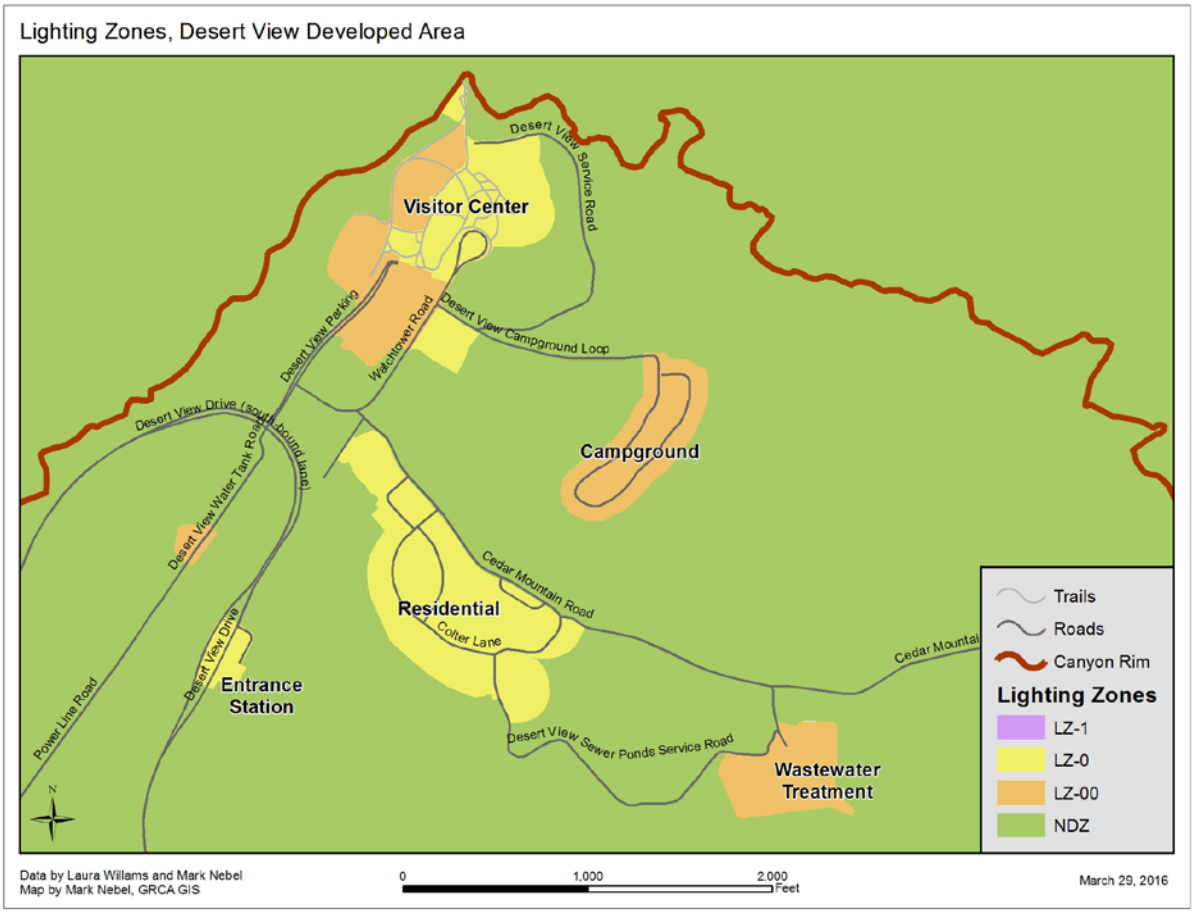


Figure 61. Lighting zones in Desert View developed area.

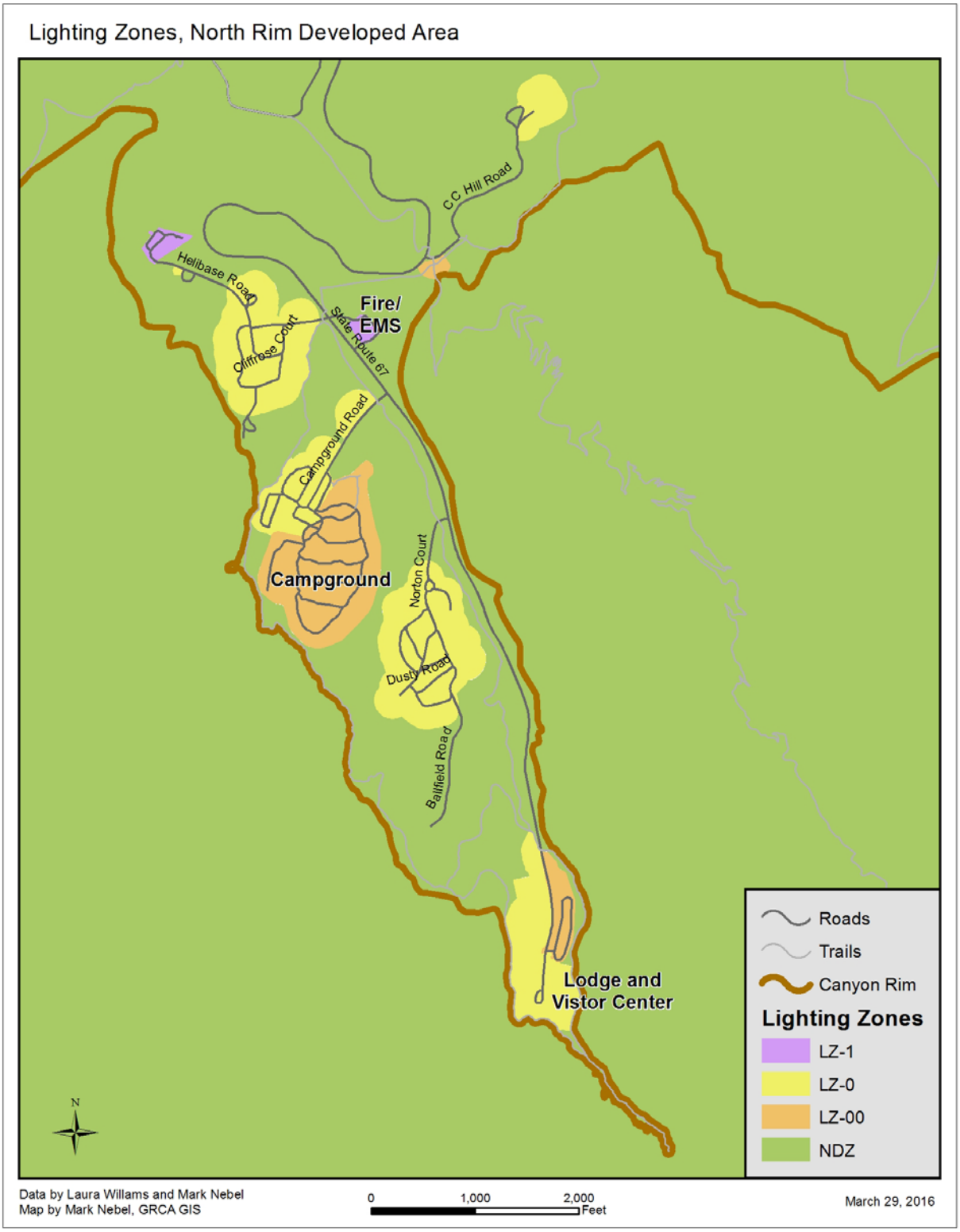


Figure 62. Lighting zones in North Rim developed area.

Lighting Guidelines

How to Use These Guidelines

This chapter presents a step-by-step process for park electricians, planners, managers, and architects to review existing and/or proposed lighting in the park. The guidelines emphasize multi-mitigation strategies to best achieve fully sustainable solutions. Adopting only one approach, such as shielding, is seldom adequate. The following mitigations must be reviewed sequentially and used in concert with one another. Specific targets (i.e., a specific light level or light color) will vary per zone, but all mitigation strategies should be evaluated in all zones where artificial lighting is permitted, according to the specific targets of each zone. They are, in order:

I. Light only WHERE needed
II. Light only WHEN needed
III. SHIELD lights and direct them downward
IV. Use the MINIMUM AMOUNT of light necessary
V. Select lamps with WARMER COLORS
VI. Select the most ENERGY EFFICIENT lamps and fixtures

(NPS NST *Interim Guidance for Outdoor Lighting in National Parks*, Version 0.6. DRAFT. Undated.)

Applicability and Monitoring

- These mitigations are to be applied to all new and retrofitted lights.
- These guidelines have been written, and are expected, to conform to existing applicable codes. However, codes change and interpretations of codes occasionally vary among lighting experts. All applicable lighting and exit discharge lighting codes should be followed, including the International Building Code (IBC), the International Existing Building Code (IEBC), and the National Fire Protection Agency (NFPA) Life Safety Code and any other applicable codes or regulations specified by the NPS Denver Service Center Design Standards, available here: http://www.nps.gov/dscw/dstandards.htm
- An exterior lighting inventory was completed in 2015. This inventory records spatial and tabular data for all lights in the park and monitors compliance with these guidelines. A standard operating procedure was finalized to document protocols for outdoor lighting inventory data collection and data management.
- Existing exterior lights will be evaluated for compliance with these mitigations based on inventory data that has been collected and evaluated. Ninety percent of existing lights will be removed, retrofitted, or otherwise altered to be compliant with these guidelines within 5 years of approval of these guidelines. Plans will be made to subsequently bring 100% of the park's lights into compliance with this plan. These percentages and time frames are a standard requirement of achieving IDA Dark Sky Park status.
- This document is not intended to replace compliance procedures required or recommended by the office of planning and compliance. All light retrofit or other changes will continue to require necessary compliance procedures, with the additional requirement that new or retrofitted exterior lighting should be compliant with these guidelines.
- Periodic monitoring of exterior lighting, using protocols established by the exterior lighting inventory, will be conducted during and after light retrofits to confirm compliance with these guidelines.
- Periodic informal monitoring of visibility of interior lights will be conducted to evaluate and prioritize management options for light pollution emitted by interior lighting.

I. Light Only WHERE Needed

First Establish Whether Lighting is Needed: Permanent outdoor lighting is a pollutant to be used judiciously for specific needs, following restrictions and guidance outlined in zoning. Other pollutants or potentially hazardous substances are similarly used minimally for human safety, such as chlorine in water treatment. Outdoor lighting generally will be restricted to "areas where security, basic human safety, and specific cultural requirements must be met" (NPS *Management Policies 2006*, Section 4.10). Convenience, providing the feeling of increased security, and decorative lighting are insufficient reasons to warrant lighting at night in a national park.

Pursue Alternatives First: Consider methods for providing safety other than permanent illumination. If the problem is lack of pathway visibility at night, determine if non-illumination solutions are adequate, such as painting curbs or steps, retroreflective markers, luminescent markers, using light-colored pavement and surfaces, providing flashlights, trimming vegetation to minimize deep shadows, or smoothing out walkway tripping hazards. Signs and markers may be made visible with retro-reflective or photo-luminescent coating. When in doubt, choose the minimum impact solution to best achieve the NPS mission (NPS NST undated).

Naturally Dark Zone (NDZ): No permanent exterior or interior light fixtures will be installed in the NDZ. Note that some permanent structures with windows may be installed in this zone (i.e., composting toilets), and these structures should not contain interior lighting.

Lighting Zones 00, 0 and 1 (LZ-00, LZ-0, and LZ-1): For most human activities in the park outside the NDZ, the recommended lighting application is listed at the end of this section in Table 31. Other applications not addressed in this table should be weighed carefully. **Do not assume that lighting is always needed.**

Exceptions:

In addition to the guidance in Table 31 the following guidelines and exceptions will apply in all zones outside the NDZ:

RVs and Trailers: RVs and trailers in employee residential areas will be subject to the same guidelines as permanent structures in the zone where they are located. This refers specifically to trailers and RVs at residential developed areas (i.e., Trailer Village, Pinyon Park, Norton Court trailers, and all other employee residential trailer sites in the North Rim, South Rim, or Desert View developed areas).

Park staff should explore options for educating visitors in RVs and trailers at campgrounds in developed areas (specifically North Rim, Mather and Desert View campgrounds) regarding park lighting guidelines, including take-home information to assist visitors in improving lighting in their hometowns. Tying "dark hours" to existing "quiet hours" can be effective in retaining the desired lightscape characteristics. Other long-term solutions should be pursued. Many campground visitors often expect the park to provide darker conditions at campgrounds than at other park areas to allow for night sky appreciation, and even a small amount of light pollution from a small number of visitors can damage this opportunity for other camping visitors.

Much of the mitigation of RV and trailer light pollution, whether in employee residential or visitor campground areas, will be complaint driven, based on park guidelines or ordinances, as are noise complaints.

Decorative or Architectural Lighting: No lighting that exists solely for decorative or architectural purpose will be permitted in any zone, with few exceptions, detailed below.

Seasonal Lighting: Seasonal decorations using typical low-wattage unshielded bulbs are permitted on buildings in LZ-0 and LZ-1 from November 15 through January 15 (Flagstaff Zoning Code). Seasonal decorative lights will not be permitted in developed campgrounds, which are intended to allow for a more natural experience of the night sky.

Solar Garden Lights: Temporary small solar-powered lights (sometimes colloquially called solar garden lights or landscape lights) of approximately 50 lumens or less per fixture may be used to illuminate walkways or driveways in LZ-0, and LZ-1 (Flagstaff Zoning Code). These lights will not be permitted in the NDZ or in LZ-00 and are not to be used for decorative purposes but rather along driveways, walkways, or uneven pathways for wayfinding and illuminating tripping hazards. Multiple fixtures of this type should not exceed 500 lumens per site (i.e., the area associated with a single structure or infrastructure element), which will be approximately 10–20 lights depending on each light's lumen output.

Example of solar garden lights in Figure 63. Note that light spacing in these images is NOT the spacing that would be recommended by these lighting guidelines; rather these images are to identify the type of fixture meant by the term solar garden lights.

Figure 63. Examples of solar garden lights.

Flagpoles: It is standard practice for flags at some inner canyon ranger stations, specifically Phantom Ranch, Indian Garden, and Tuweep, and also at some entrance stations, to remain lit overnight for visitor wayfinding and for hikers with emergencies to easily locate the ranger station. Flags raised at other flagpoles should, when possible, be taken down overnight instead of lit. In any case where flags will be lit overnight, all guidelines for lighting in that zone will be applied to the flagpole light (NPS NST undated).

Historic Light Fixtures: If illumination from a historic light is determined to be necessary, but the fixture is not compliant with these guidelines, potential solutions include changing the bulb type or reducing the light level. Turning off the light permanently by eliminating the electrical connection, provided alternate lighting can be installed, is another option for areas that require illumination currently provided by a historical light. (NPS NST undated).

Emergency Lighting: Temporary emergency lighting is exempt from lighting guidelines, with the restriction that whoever is the onsite leader of that emergency is responsible for turning lights off and/or returning them to their usual method of control when there is no longer an emergency.

II. Light Only WHEN Needed

Proposed Light Curfew: After it is determined that illumination is needed for a specific reason at a location, that illumination should only be used WHEN it is needed. Many lights inside park boundaries can be subject to a proposed 10 pm–6 am curfew when lights should be extinguished or, if light is truly needed overnight and dimming controls have been installed, dimmed by at least 30%. Alternately lights should be extinguished or dimmed when not in use, if hours of non-use are different than the curfew hours. (IDA-IES MLO, 2011) (Dick, Robert. *Guidelines for Outdoor Lighting in RASC Dark-sky Preserves and IDA Dark Sky Places*, 2012) (Chaco Culture National Historic Park *Outdoor Lighting Guidelines*, 2013) (Death Valley National Park *Guidance for Outdoor Lighting*, 2012)

Exceptions to the Proposed Light Curfew:

- Residential buildings will be encouraged to turn off exterior lights during curfew hours. Residents may want to leave exterior lights on during curfew hours for multiple reasons, such as leaving for or returning from work or recreational activities, expecting guests, using outdoor space, etc., and residents are left to their discretion when choosing to leave exterior lights on for specific purposes. However, residential lights should not be left on overnight all night every night without a specific purpose.
- Businesses open 24 hours or during curfew hours (i.e., hotels and lodges), though these businesses will be encouraged to dim their lights if feasible during curfew hours.
- Code requirements for 24-hour lighting.
- Illumination for athletic events, i.e., at a school athletic field: events shall be scheduled for completion by 8:45 pm, and lighting shall be turned off by 9 pm unless the event carries beyond its originally scheduled time of completion.

Interior Lights: Interior lighting should be turned off when inside areas are not being used. If possible, interior areas with large windows facing wilderness or the NDZ should not be used after dark. If this is not possible, blinds or another blocking alternative should be installed and used or different illumination levels for day and night should be considered.

Light Controls: Light controls should be provided for each light. Light controls will ensure that each light is 1) turned off when sufficient daylight is available; 2) turned on only when there is inadequate daylight; 3) turned on only when it is needed; and 4) turned off or dimmed after high use activities have subsided. Dusk-to-dawn lighting using a photocell alone is rarely necessary and should be evaluated on a case by case basis. Any lights determined to be necessary dusk-to-dawn must be dimmed or subject to motion sensors during the proposed curfew period (NST NPS

undated). All light fixtures should have full manual override (i.e., manual switches or an override option in a timer). Manual timers are discouraged given that they may need regular reprogramming due to seasonal changes and frequent power interruptions at the park.

Astronomical Timers: Astronomical timers are specifically recommended when feasible to combine controls for seasonal changes in sunset/sunrise with a clock timer. These devices can be programmed for different operation during busy seasons or weekend operations (NPS NST undated). The flexibility and features of astronomical timers in particular allow for lights to be on only when needed, thus saving lamp life, and eliminating the need to be reset for seasonal changes or frequent power outages, thus reducing park staff time managing light control. Astronomical timers can also guarantee lights are regularly on at appropriate times without requiring reprogramming, better protecting visitor and employee safety for illuminating tripping or other hazards. Initial cost of quality astronomical timers is offset by having energy efficient, well-run facilities, reduced staff time devoted to light control, and reduced light replacement due to increased lamp life. Other automatic timers and smart lighting controls can be investigated and used when appropriate. Photocells in combination with timers to achieve a similar result to astronomical timers may also be appropriate. As with all equipment purchases, evaluating features, equipment durability and performance, user reviews, and methods for making instructions available to appropriate staff, should precede purchasing and implementing smart lighting controls.

Motion Sensors: Motion sensors may not always be the best solution for reducing light pollution. Motion sensors must be sensitive to the difference between humans and abundant wildlife at the park. The intermittent on and off lighting may be more disruptive to humans and wildlife than a constant low level of lighting. Dimming lights to a very low light level for a predetermined amount of time during lower use levels, i.e., 8–10 pm or during proposed curfew hours, may be a better solution than using a motion sensor during that time, and should be evaluated on a case by case basis.

III. SHIELD Lights and Direct Them Downward

Shielding is a very effective mitigation; a fully shielded light typically produces 1/10th as much sky glow as an unshielded globe and substantially less glare. Limiting glare allows for the use of less illumination for the same amount of visual performance. Reduced glare also allows people to dark-adapt more quickly and gives people a sense of "good lighting" even though actual illumination levels are far less than what they may be accustomed to (NPS NST undated).

Exterior lighting fixtures should at minimum be shielded so that no light is cast upward. The engineering term for this is "full cut-off," also known as "fully shielded." Fixtures described as "cut-off" or "semi cut-off" or "partially shielded" should not be used (NPS NST undated). Luminaires equipped with adjustable mounting devices, permitting alteration of luminaire aiming in the field, are not permitted (IDA-IES MLO 2011).

Naturally Dark Zone (NDZ): Permanent artificial lighting from any other park zones should not be visible from within the NDZ. Given the widely varying topography at GRCA, full cut-off fixtures may not be sufficient to prevent light trespass from other lighting zones into the NDZ.

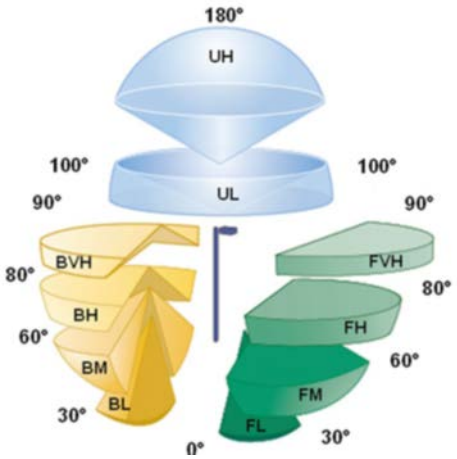
Viewshed Analysis: Create viewshed analysis maps to evaluate if a proposed light is in a location and/or at a height where it is likely to be visible in the NDZ. If possible, position a test light and an

observer to confirm whether or not the proposed light would be visible in the NDZ. If a light is confirmed to be visible, or likely to be visible in the NDZ, additional shielding and/or a custom shielding solution must be applied to the fixture so it is not visible in the NDZ. If additional or custom shielding is not possible, the light should not be installed.

Viewshed analysis, in combination with the park's lighting inventory, can also be used to identify existing lights that are likely to be visible in the NDZ, and specifically where those lights are likely to be visible. Anecdotal reports have identified some of these lights. It may be possible to work with backcountry hikers or river runners to confirm whether or not additional lights identified by viewshed analysis are visible in the NDZ. This combination of viewshed analysis and observations will inform light retrofit plans for altering, removing, or restricting usage fixtures visible in wilderness areas.

Interior Lights: Blinds, shades, curtains, window tinting, or other forms of minimizing light spread from interior spaces should be used where possible to reduce light trespass into the outdoor environment. Blinds should be provided in all park housing, and residents will be encouraged as part of the housing policy to close their blinds at night when interior lights are on. Park staff will work with concessioners to encourage visitors to close blinds, curtains, or other window coverings after sunset (where available) and to establish feasibility of installing window coverings or tinting if necessary.

"BUG" Ratings for Exterior Lighting: The IES Technical Manual 15, *Luminaire Classification System for Outdoor Luminaires*, recommends evaluating fixtures based on three factors: backlight, uplight, and glare—also called BUG ratings (Figure 64). BUG ratings are available from some light manufacturers based on photometric testing of the light fixture. These ratings include a letter and number. The letter will indicate the type of feature being rated: B for backlight, U for uplight, and G for glare. The number will correspond to a specific photometric reading from the light fixture that has been defined by the IES and is thus consistent among manufacturers. The use of these ratings is relatively recent as of the writing of these guidelines. If it is available, it will be included on the packaging of a light fixture or in specifications from a manufacturer. It is expected that these ratings will be available for an increasing number of light fixtures in the future, but they will not likely be available for all fixtures as of the writing of these guidelines. If BUG ratings are not available, the following guidance will assist in choosing lights using similar criteria. (IES Technical Memorandum 15-11, *Luminaire Classification System for Outdoor Luminaires*, 2011) (IDA- IES MLO 2011)



UH: Uplight High
UL: Uplight
BVH: Backlight Very High (included in Glare)
BH: Backlight High (included in Glare)
BM: Backlight Medium
BL: Backlight Low
FVH: Frontlight Very High (included in Glare)
FH: Frontlight High (included in Glare)
FM: Frontlight Medium
FL: Fronlight Low

Figure 64. BUG classification system.

Backlight (yellow area in Figure 64, labeled BVH, BH, BM and BL): Backlight ratings will not always be useful for evaluating light trespass potential at GRCA. Backlight ratings are intended to measure light thrown behind the light and potentially outside the area intended to be lit and potentially trespassing onto neighboring properties. Throughout much of the park, lighting for safety includes illuminating for proximity of large animals, elk in particular. Rather than minimizing a light's directional backlight according to property, roadway, or pathway boundaries as is recommended for many urban or suburban areas, it may be preferable to maximize the light spread to illuminate areas to the side of a pathway or roadway where large animals may be present.

Light trespass into wilderness areas or sensitive wildlife habitats, specifically the NDZ, can vary dramatically depending on light location and nearby topography. Backlight ratings might be useful depending on the light locations, but they will not always be sufficient for evaluating exactly where light trespass will occur given the widely varying topography at GRCA. Spatial viewshed analysis should be consulted to evaluate the extent of light trespass.

That said, there will be occasions where backlight ratings will be a useful measure, for instance, in wall-mounted lighting, where light spread back onto the wall is both wasteful and has the potential to create a hot spot with glare on the wall. Wall mounted lighting, or lighting at other locations where a backlight rating should be used, should have a backlight rating of B0 (Backlight—Zero).

Uplight (blue area in Figure 64, labeled UH and UL): Uplight ratings evaluate light shining above a 90 degree angle. If a BUG rating is available from a manufacturer, an uplight rating of U0 (Uplight—Zero) is equivalent to using a full cut-off (also called a fully shielded) light fixture. All new or retrofitted lights for which an uplight rating is available should have an uplight rating of U0 (U—Zero), with exceptions as noted below. (NPS NST undated) Lights that emit no light above the horizontal, functionally the same as a U0, can be used when uplight rating is not available.

Historic fixtures are often unshielded. Any potential changes to historic fixtures should be done in consultation with appropriate park staff, specifically a historic architect or cultural resource specialist. In some cases it may be determined that it is possible to retrofit the fixture with a fully shielded fixture that is congruent in design to the historic fixture. If it is determined that retrofitting historical fixtures is not possible due to cultural considerations, bulb brightness in these fixtures must be drastically reduced to minimize glare. Specifically these bulbs should 1) produce no more than 300 lumens (approximately the light emitted by a 40-watt incandescent bulb), unless code restrictions (i.e., National Fire Code egress requirements) require more light; and 2) should be off whenever possible, in particular between the hours of 10 pm and 6 am. In addition, any historic unshielded fixtures should be diffused if possible (i.e., using translucent glass instead of transparent glass), if diffusion is consistent with historical or cultural considerations, to be determined by consultation with appropriate park historic or cultural resource specialists.

Very low-level marker lighting (i.e, LEDs embedded in pathways or roadways) may, in some locations, be preferable to other lighting options. These, by definition, cannot be shielded, but may create a far lower overall impact in light pollution than other lighting options, such

as pole lighting or bollards. These lights should not emit more than 50 lumens per fixture (approximately the light emitted by an 0.3-watt LED or 3-watt incandescent lamp)

Glare (upper portions of yellow and green areas in Figure 64, labeled BVH, BH, FVH, FH): Glare ratings will be the most useful part of BUG ratings when evaluating lights for the park. Glare ratings measure the light emitted from a fixture between the 60 and 90 degree angle below the horizontal. The light bulb must be adequately recessed inside the fixture edges and the fixture designed to reduce or eliminate light emitted from the fixture between 60 and 90 degrees below the 90 degree horizontal mark. This specification restricts sideways light more than a fixture with an uplight rating of zero (also known as a full cut-off or fully shielded fixture.) When BUG ratings are available from the light fixture manufacturer, all new or retrofitted lights should have a G0 (Glare—Zero) rating. This rating divides the area with glare potential into two sections, so the fixture emits 10 lumens of light between the 80 to 90 degree section and no more than approximately 600 lumens is emitted between the 60 and 80 degree section.

Glare from LED lights can be particularly noticeable because LED emitters are very directional. Ideally LED emitters should not be visible from normal standing height near any LED lights.

Summary: Use IES BUG ratings when available from the manufacturer; always use light fixtures that are at a minimum fully shielded. Light trespass beyond the intended area of use must be eliminated by custom modification if necessary, regardless of the zone in which the light is located.

IV. Use the MINIMUM AMOUNT of Light Necessary

Light emitted from any fixture only spreads a certain distance; beyond that it is dark. The brighter the light emitted from a fixture, the darker the darkness around it will seem. In a park environment with a substantial amount of unlit areas, it is safer to maintain a generally low level of lighting to allow quicker and safer dark adaptation than to allow overly bright light levels that limit dark adaptation. Successfully implementing low illumination levels also requires good control of glare, which is primarily achieved through shielding. Transitions of lower to higher intensity lighting, and vice versa, will also assist in creating the safest situation for users as it allows the eye to adapt gradually. (NPS NST undated)

In addition, parks are sensitive environments, and because there is no amount of lighting completely free of environmental impacts, resource protection additionally dictates that the minimum amount of light be applied to meet the task. It is common in parks to apply substantially lower illumination than is typically recommended in urban environments; 250–500 lumens is an ideal brightness for a wide variety of park lighting applications (roughly equivalent to a 7-watt CFL or 5-watt LED). (NPS NST undated)

The lumen output of individual light fixtures should also be kept in perspective with the mounting height. Higher mounting heights often require less fixtures, but higher lumen output; while with lower mounting heights, especially bollard (i.e. post) lighting, the opposite is true. Using too bright of a fixture in a low mounting height will create a very bright "hot spot" on the ground surface. This will skew the range of brightness values perceived by the eye, resulting in glare and a poor adaptation level. Thus there is a desire, both from the human need perspective and the environmental

perspective, to have relatively uniform lighting when lighting is required and to avoid hot spot and large jumps in illumination level.

Uniformity can be calculated as the ratio between the maximum light level in an area and the average light level throughout the same area. In areas where relatively consistent light is important (i.e., at Americans with Disabilities Act (ADA)-accessible parking locations), the uniformity ratio should be kept small in order to ensure a consistent overall spread of light. There are some tasks and applications where uniformity is important, while other situations, such as pathway illumination, where uniformity is far less important or often not desirable.

Lighting levels for specific applications in each park lighting zone are available in Table 31 at the end of this section.

Light designs should include calculations to confirm performance to recommended light levels using modern computer lighting programs (Yosemite 2011) (IDA-IES MLO 2011). When this is not possible, test existing or proposed lights with a light meter.

V. Select Lamps with WARMER COLORS

The color tint of white light is often measured in Kelvins (K), a scale in which warm-toned white light has smaller values (1800–3000°K) and cold-toned light has larger values (5000°K and higher) (Yosemite 2011). Cooler white light can provide better visual acuity, color rendition, and performance in many situations, but often has a disproportionally high impact upon human dark adaptation, nocturnal wildlife, and ecosystem function. Because of this greater impact, white light should be used only in certain specific locations where color rendering is essential to cultural values or human safety, otherwise lamps with a warmer tone (i.e., those that are yellowish, amber, or red) should be used to minimize off-site aesthetic and environmental impacts and preserve human eye dark adaptation. Lighting should be ≤ (less than or equal to) 3500°K when color rendition is critical to the task and ≤2500°K otherwise (NPS NST undated). Lighting with color temperature ≤2500°K will reduce glare, reduce insect attractions, minimize impact to human dark adaptation, and minimize ecological effects. Narrowband amber LED is the preferred outdoor lighting color in natural areas.

Ultraviolet (UV) light is also disruptive to biological systems and should be minimized when possible, particularly in LZ-00 and LZ-0. Insects are attracted to both blue light and UV light (NPS NST undated, RASC)

Narrow spectrum amber LED, LPS, blue-filtered LED, or yellow CFLs with color temperatures ≤2500°K are the preferred type of bulb in locations where general illumination for safety or security is the primary concern and color rendition for tasks is not necessary, specifically:

- Pedestrian walkways and driveways
- Parking lots
- Outdoor security
- Residential or low to medium use egress

(Flagstaff Zoning Code)

Warm white LED or warm white CFLs (≤3500°K) are the preferred type of bulb in locations where color rendition is required to preserve the effectiveness of an activity, specifically:

- High-use public building egress where historic cultural values are important

- Outdoor maintenance or repair areas where maintenance or repair work may be necessary on a regularly scheduled, task-specific (i.e., boat de-rigging), or emergency basis.
- Sign or exhibit lighting
- Outdoor recreational and athletic field areas
- Outdoor seating areas
- Service station canopies

(Flagstaff Zoning Code)

No white lights above 2500°K should be illuminated continuously from dusk to dawn; instead they should have timers, switches, motion sensors, or other means of limiting the amount of time they are illuminated.

VI. Use the Most ENERGY EFFICIENT Lamps and Fixtures

Select lamps that provide the greatest luminous efficacy in lumens per watt, after giving consideration to other design constraints and objectives. Luminous efficacy should not trump environmental protection standards in Zones 00 and 0, however, or in protecting the NDZ. Also consider the fixture efficiency and application of light. The most energy savings can be gained by electing not to install the light in the first place, by operating it for a limited amount of time, by reducing the amount of light to the minimum necessary, and by preventing stray light and directing the light only at the intended task. Luminaire efficiency ratings combine the efficiency of the fixture, the lamp, and the lamp ballast or LED driver. Some fixtures, especially historic fixtures, decorative fixtures, and older designs have efficiencies as low as 25%, so that 75% of the light never makes it to the intended target. (NPS NST undated)

Energy efficiency is mandated by Executive Order 13423 and 13514, and is critical in reducing the NPS carbon footprint. It is probable that the park can reduce outdoor lighting energy use by over 80% using these multiple mitigations. Some parks have even reached 98% energy savings (using only 2% as much electricity) by mitigating the impacts of outdoor lighting through multiple strategies. (NPS NSNS undated)

Other Considerations

Shuttle Bus and Car Headlights: The location of overlooks on Hermit Road and Desert View Drive are such that shuttle bus and car headlights may occasionally be seen from large areas inside the inner canyon NDZ. Light impact from vehicles has not frequently been addressed in other park's lighting guidelines. Bus and car headlights are necessary for moving vehicles and cannot be managed in the same manner as permanent exterior lighting. That said, light pollution from moving vehicles may, in some locations, be higher than the light allowed for permanent lighting for the zone of a particular area (such as Hermit Road). The impact of shuttle bus and car headlights shining into the NDZ can be significant. Potential mitigations for this issue should be explored. Examples include educating and encouraging visitors to turn off vehicle lights when parked at overlooks and to use regular headlights (not high beams) when entering or exiting park overlooks, or to explore adding native vegetation where possible to shield or minimize vehicle light trespass into the NDZ.

Portable Lights, Including Headlamps: Temporary small portable lighting, i.e., flashlights, lanterns and headlamps, may be necessary for human travel, tasks, or work in areas in lighting zones that would otherwise have minimal or no artificial lighting. Portable lights with high lumen ratings that may be appropriate for some applications (i.e., caving or bicycling) are not necessary or

appropriate for most uses in a park environment. Brighter headlamps will interfere with human dark adaptation and will make it more difficult to see outside the headlamp's light spread than when using either red light or a low (50–100 lumen) headlamp setting.

Best management practices for park staff working with and in the backcountry include:

- Educating visitors regarding portable light use in public park documents where possible, e.g., *Trip Planner*, backcountry permits, inner canyon and trailhead kiosks, etc.; use information from this standard operating procedure for guidance in consultation with the park's backcountry working group.
- Practicing and encouraging responsible portable light use, specifically that when stationary or in a campground portable light use should be: 1) used in red lamp mode; 2) if red lamp mode is not available, on the lowest illumination setting available; and 3) held whenever possible by hand or around the neck and not around the head. Portable light use in all campgrounds should be limited between the hours of 10 pm and 6 am to task-required lighting only.
- Allowing exceptions to the above guidance for portable light use for hiking or other mobile activity at night in rough and/or unfamiliar terrain (including corridor trails) OR unless hands-free use and more light is needed temporarily for safety, i.e., setting up camp stove, cooking, cleaning up food, or setting up or taking down a tent. Excessively bright headlamp and flashlight use is in particular damaging to other visitors and staff toward which the light is directed.
- Exploring longer term options for requiring visitors to comply with these best practices for portable lighting, including the possibility of instituting portable light lumen limits or recommendations in the NDZ and LZ-00.
- Campfires, including social and cooking fires, are not considered artificial or portable lighting for the purposes of these guidelines.

Historic Landscapes and Structures: Cultural landscapes, historic buildings, structures, small-scale landscape features, and districts can be significant to the history of a national park. These property types are often listed or eligible for listing on the National Register of Historic Places. NPS management practices require us to manage such resources in a way that retains their historic character through preservation. Such places reflect the history of park development, architectural trends of the past, NPS initiatives, community planning, and other important aspects of our history. Providing lightning necessary for safety within historic districts and cultural landscape areas and on individual buildings and structures will require careful planning and considerations to preserve the characters that make historic properties eligible for the national register. Working with these kinds of properties may result in additional expenses related to lighting needs that must be considered early on in the planning process.

Light Maintenance and Park Environment:

- 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. For instance, staff time required to change light bulbs that require frequent replacement should be weighed against the cost of a fixture or bulb that requires less frequent replacement.
- For lamps with replaceable bulbs, bulbs and bulb ballasts will be standardized to ensure appropriate light level, color, quality, and ease of replacement.

- Unnecessary light fixtures will be removed, relocated, or, in the case of historical fixtures, disconnected from an electrical source and left in place.
- Park locations experience extremes of temperature, elevation, and exposure. As a result, light sources must be suitable for all expected operating conditions. Lights, bulbs, and related equipment, must be rated for extreme weather conditions, i.e., heat and cold, dryness, thunderstorms, blizzards, etc.

Snow Accumulation and Clearing: Design lighting with consideration for snow removal. Assume that mechanized equipment will be used. Locating lighting away from pavement is essential. Use taller lighting equipment to permit lighting to remain effective in heavy snowfall (Yosemite 2011).

Pedestrians and Bicycles: Design lighting in consideration of the park's use by pedestrians and bicycles. Snowmobiles may also be used on the North Rim. Particularly avoid light fixtures and poles that will be prone to damage or causing injury, such as bollard lights near pathways (Yosemite 2011). Pedestrians should be encouraged to wear light colored or reflective clothing when walking along or crossing roadways.

Lighting Applications and Light Levels by Zone

Table 31 is not a prescription to light all areas to the maximum light level, but a guideline for average and maximum light values only after alternatives to lighting have been considered and it is determined that illumination is necessary.

Light levels are expressed in footcandles. Multiply by 10 for lux. Area lighting designs should include computer printouts of projected illumination levels, demonstrating compliance with these guidelines. Footcandles are standard measurements used by lighting designers, and can be measured with an illuminance meter. If footcandle (or lux) measurements are not possible, see Appendix A: Lighting Equipment for fixture and bulb recommendations for specific applications. See the Appendix B: Definitions and Acronyms section for details about terms used in this table.

[Note: there is a lot that can be done with motion sensor or pedestrian-switched lighting, flashing or other warning lights when pedestrians are present, etc. other than lighting. I think it is important to mention those here.

Application	LZ-00	LZ-0	
	Light Level and Uniformity same as LZ unless noted otherwise	Where and When	Light Level and Uniformity
Roads posted 25mph or less	*Where:* High pedestrian conflict areas. *When:* On during high use or 24 hours; extinguished or dimmed during curfew hours.	*Where:* High pedestrian conflict areas. *When:* On 24 hours; dimmed during curfew hours.	*Light Level:* Avg 0.05 fc, Max 0.3 fc Uniformity 6:1
Roads posted >25mph	*Where:* High pedestrian conflict areas. *When:* On during high use or 24 hours; dimmed during curfew hours.	*Where:* High pedestrian conflict areas. *When:* On 24 hours; dimmed during curfew hours.	*Light Level:* Avg 0.05 fc, Max 0.3 fc Uniformity 6:1
Parking lot—ADA accessible	*Where:* Limited to portions of lots marked for ADA-accessible use (if any) and requiring night access, including ramps to adjacent buildings and/or walkways. *When:* Extinguish or dim lights after use hours.	*Where:* Limited to portions of lots marked for ADA accessible use, if any, and requiring night access, including ramps to adjacent buildings and/or walkways. *When:* Dim lights after use hours.	*Light Level:* Avg 0.5 fc, Max 2.5 fc Uniformity 4:1
Parking lot—high night activity	N/A	*Where:* Minimal lighting, illumination for some of the lot, drives, and surrounding walkways, but not necessarily uniform. *When:* Shut off after use hours.	*Light Level:* Avg 0.05 fc, Max 1.0 fc Uniformity 10:1

Parking lot—moderate night activity	N/A	*Where:* Minimal lighting, illumination for some of the lot, drives, and surrounding walkways, but not necessarily uniform. *When:* Shut off after use hours.	*Light Level:* Avg 0.05 fc, Max 1.0 fc Uniformity 10:1
parking lot—low night activity	Little or no lighting. *When:* Shut off after use hours.	*Where:* Little or no lighting. *When:* Shut off after use hours.	*Light Level:* Avg 0.01 fc, Max 0.05 fc (Benya, 2013) Non-uniform lighting acceptable
Walkways and bikeways—high night activity including ADA accessible walkways with night use	N/A	*Where:* Relatively uniform lighting for walkways and bikeways near ADA areas or where curbs or other hazards exist near or along walkway. Otherwise only guidance lighting and not uniform path illumination. *When:* Dim lighting during curfew hours.	*Light Level:* Avg 0.05 fc, Max 0.5 fc Uniformity 8:1
Walkways and bikeways—medium night activity	N/A	*Where:* Minimal for main and secondary walkways, not necessarily uniform, or intersections only. *When:* Shut off or dim lighting during curfew hours.	*Light Level:* Avg 0.05 fc, Max 0.5 fc Uniformity 12:1
Walkways and bikeways—low night activity	*Where:* Lighting not recommended OR minimal wayfinding for main walkways. *When:* Shut off during curfew hours.	*Where:* Minimal wayfinding for main walkways. *When:* Shut off during curfew hours.	*Light Level:* Avg 0.01 fc, Max 0.05 fc Non-uniform lighting is acceptable
Steps along walkways and bikeways	N/A	*Where:* Provide illumination for every step in public areas and at public buildings; guidance and presence detector recommended for sensitive areas. *When:* Same as other walkway lighting in the same area.	*Light Level:* Avg 0.1 fc, Minimum at center of each step Max 0.5 fc
Gas station—driveway	N/A	*Where:* Minimal or no driveway lighting; guidance lighting or reflective paint may be used instead. When: Shut off or dim when unattended. Consider motion control for after hours.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity is not critical

Gas station—pump area (pump island and 10 feet (3 m) on either side)	N/A	*Where:* Task lighting only. *When:* Dim when unattended. Consider motion control for after hours.	*Light Level:* Avg 1.0 fc, Max 5.0 fc Uniformity 4:1
Work areas—SAR, fire, outdoor maintenance area, pumps, electrical boxes, fueling stations)	*N/A*	*Where:* Task lighting as determined by usage. *When:* Shut off or dim when unattended or not in use. Consider motion control for after hours.	*Light Level:* Avg 1.0 fc, Max 5.0 fc Uniformity 4:1
Storage yards	N/A	*Where:* No lighting unless storage yards will be accessed at night. If lighting is necessary, consider motion control.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity 4:1
Egress at active public or park administration buildings, including ADA-accessible entrances (drip line of canopy and twice the width of doors, or 10 feet (3 m) out from entrances without canopies)	*Where:* Ranger stations and utility buildings may have egress, step, and flagpole lighting. *When:* All lights will be off when buildings are unused by the public and during curfew except flagpoles, which must use downward facing low level lights. Exceptions are emergencies or when repairs to any infrastructure must be made at night. *Light Level:* Avg. 0.05 fc, Max 0.3 fc	*Where:* Egress and pathways to and from buildings, especially to and from parking lots. No perimeter lighting. *When:* Turned off within 30 minutes of building closure OR dimmed when not in use.	*Light Level:* Avg 1.0 fc, Max 3.0 fc
Residential and visitor lodging egress (active): (twice the door width by 6 feet (1.8 m) from the door).	N/A .	*Where:* Egress, under canopies and pathways to and from building, especially at steps and to and from parking lots. No perimeter lighting. *When:* Dim or shut off during curfew or when not in use.	*Light Level:* Avg 0.5 fc, Max 1.0 fc Uniformity is not critical
Residential and visitor lodging egress (inactive)	N/A	*Where:* Egress only. *When:* Shut off during curfew or when not in use.	*Light Level:* Avg 0.05 fc, Max 0.5 fc Uniformity is not critical
Shuttle bus stops	N/A	*Where:* Lighting under canopy; spill light limited to immediately surrounding area. *When:* Shut off after shuttle hours.	*Light Level:* Avg 0.2 fc, Max 1.5 fc Uniformity 6:1

Remote rest and visitor support facilities, including remote restrooms	*Where:* Restrooms will have egress lighting. *When:* Extinguished during curfew hours. *Light Level:* Avg. 0.1 fc, Max 0.5 fc	*Where:* Low-level lighting confined to interior spaces and egress exterior. *When:* Adaptive and motion controlled; restroom lights: dimmed during curfew hours.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity is not critical
Bulletin board/kiosk	No lighting at kiosks or bulletin boards in this zone.	*Where:* Only for signage critical to night uses and wayfinding, businesses open 24 hours (i.e., hotels). Tightly controlled for no light trespass. Small LED lamps in display case recommended, this also applies to interior displays that have potential for light trespass into wilderness areas (i.e., Yavapai Geology Museum). *When:* Shut off or dimmed during curfew hours; consider using motion control.	*Light Level:* Avg 1.0 fc, Max 2.0 fc
Vending machines	N/A	Vending machines lights must be deactivated if not inside a building or enclosure, or if the vending machine light is visible outside the building or enclosure. Deactivating light in a vending machine by removing the light bulb, or disconnecting electrical current to the bulb, while leaving the remainder of the machine fully functional.	N/A
Roadway signs	Roadway signs should not be illuminated; use retro reflective coating or other methods for visibility.	Same as LZ-00	N/A
Restroom interiors	*Where:* Only in campgrounds, not in remote overlook areas. *When:* Dimming controls should be available during curfew hours.	*When:* Dimmed at night, interior <10x the exterior egress light. Consider bi-level occupancy sensors to minimize light spill out windows.	*Light Level:* Avg 1.0 fc, Max 2.5 fc

Application	**LZ-1**	
	Where and When	**Light Level and Uniformity**
Roads posted 25mph or less	*Where:* High pedestrian conflict areas. *When:* On 24 hours, consider motion control.	*Light Level:* Avg 0.2 fc, Max 1.5 fc Uniformity 6:1
Roads posted >25mph	*Where:* Some intersections and high pedestrian conflict areas. *When:* 24 hours.	*Light Level:* Avg 0.2 fc, Max 1.5 fc Uniformity 6:1

Parking lot—ADA accessible	Same as LZ-0.	Same as LZ-0.
Parking lot—high night activity	*Where:* Uniform illumination for the entire lot, driveways and walkways. *When:* Shut off or dim after use hours and during curfew hours.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity 4:1
Parking lot—moderate night activity	*Where:* Minimal lighting, illumination for some of the lot, drives, and surrounding walkways, but not necessarily uniform. *When:* Shut off after use hours.	*Light Level:* Avg 0.05 fc, Max 1.0 fc Uniformity 10:1
parking lot—low night activity	*Where:* Little or no lighting. *When:* Shut off after use hours.	*Light Level:* Avg 0.01 fc, Max 0.05 fc (Benya, 2013) Non-uniform lighting acceptable
Walkways and bikeways—high night activity including ADA accessible walkways with night use	*Where:* Relatively uniform lighting for walkways and bikeways near ADA areas or where curbs or other hazards exist near or along walkway. Otherwise only guidance lighting and not uniform path illumination. *When:* Dim lighting during curfew hours.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity 8:1
Walkways and bikeways—medium night activity	*Where:* Minimal for main and secondary walkways, not necessarily uniform. Or intersections only. *When:* Shut off or dim lighting during curfew hours.	*Light Level:* Avg 0.05 fc, Max 0.5 fc Uniformity 12:1
Walkways and bikeways—low night activity	*Where:* Minimal wayfinding for main walkways. *When:* Shut off during curfew hours.	*Light Level:* Avg 0.01fc, Max 1.0 fc Uniformity not critical
Steps along walkways and bikeways	*Where:* Provide illumination for every step in public areas and at public buildings. *When:* Same as other walkway lighting in the same area.	*Light Level:* 0.1 fc minimum at center of each step, Max 0.5 fc
Gas station—driveway	*Where:* Minimal driveway lighting; guidance lighting or reflective paint may be used instead. *When:* Shut off or dim when unattended. Consider motion control for after hours.	*Light Level:* Avg 0.1 fc, Max 1.0 fc Uniformity is not critical
Gas station— pump island and 10 feet (3 m) on either side	*Where:* Task lighting. *When:* Dim when unattended. Consider motion control for after hours.	*Light Level:* Avg 5.0 fc, Max 20 fc Uniformity 4:1
Work areas— SAR, fire, outdoor maintenance area, pumps, electrical boxes, fueling stations	*Where:* Task lighting as determined by usage. *When:* Shut off or dim when unattended or not in use. Consider motion control for after hours.	*Light Level:* Avg 5.0 fc, Max 20 fc Uniformity 4:1
Storage yards	Same as LZ-0.	Same as LZ-0.

Egress at active public or park administration buildings, including ADA-accessible entrances (drip line of canopy and twice the width of doors, or 10 feet (3 m) out from entrances without canopies)	*Where:* Egress and pathways to/from building, especially to/from parking lots. No perimeter lighting. *When:* Turned off within 30 minutes of building closure OR dimmed when not in use.	*Light Level:* Avg 2.0 fc, Max 5.0 fc
Residential and visitor lodging egress (active): (twice the door width by 6 feet (1.8 m) from the door).	N/A	N/A
Residential and visitor lodging egress (inactive)	N/A	N/A
Shuttle bus stops	Same as LZ-0.	Same as LZ-0.
Remote rest and visitor support facilities, including remote restrooms	N/A	N/A
Bulletin board/kiosk	Same as LZ-0.	Same as LZ-0.
Vending machines	Same as LZ-0.	Same as LZ-0.
Roadway signs	Same as LZ-00.	N/A
Restroom interiors	Same as LZ-0.	Same as LZ-0.

Table 31. Light applications and light levels in this table were first taken from Yosemite National Park Lighting Guidelines*, Table A—Lighting Application Guidelines and Table B—Design Lighting Levels. However, given conditions at GRCA, noted above in the lighting zones section (Benya 2013), lower light levels are called for in most applications. Light levels in this table that are lower than Yosemite's are based on the following documents:*

Benya Burnett Consultancy. Grand Canyon National Park South Rim Visitor Center Lighting Concept Design—Summary Report*, August 8, 2013.*

Death Valley National Park Guidance for Outdoor Lighting in Death Valley National Park International Dark-Sky Park Designation Nomination Package*, November 2012*.

Denali National Park and Preserve Interim Specifications and General Guidelines for Outdoor Lighting*, March 2013.*

Lightscape Quality Monitoring And Mitigations

Technology for monitoring night sky quality is varied and evolving. This document, as a standard operating procedure for Outdoor Lighting Guidelines, is not the appropriate place to outline night sky quality monitoring methods and schedules, nor mitigation options for light pollution originating outside the park. However, night sky monitoring is the best method by which to determine the impact of light pollution on the state of the park's natural lightscape and to identify targets for mitigation options. The park should pursue drafting a separate document, as appropriate, to document monitoring standards and mitigation options, guided by the following information:

- The NPS NST visited GRCA in 2007 and 2008 and collected sky quality data from both the North Rim and South Rim with a qcamera. This type of monitoring is not expected to be available with great frequency, but is the highest quality sky quality assessment currently available.
- Sky quality Monitoring using a Unihedron SQM has become a standard measuring tool, but data collection points are limited to the sky zenith only. This monitoring tool has the advantage of being lightweight, portable, and relatively inexpensive. The park should consider establishing permanent SQM installations (work of this type is already being done at University of Arizona at Tucson), and regular monitoring by staff in remote backcountry locations where permanent monitoring installation or transporting heavy camera equipment are not practical or possible.
- All-sky monitoring in black and white using a standard DSLR camera and fish-eye lens is a process that is currently being established by IDA. This method is not as detailed as the NST's CCD camera data, but is more detailed than using a Unihedron SQM. The park should determine appropriate locations for this type of monitoring and establish a regular monitoring schedule. This type of monitoring in particular will quickly be able to identify changes in external impacts to Grand Canyon's night sky.
- The NPS does not have authority over light pollution that originates outside its boundaries but nonetheless impacts the quality of its lightscape. That said, nearby towns and communities, notably Flagstaff as a Dark Sky Community, have already begun or established night sky protection policies. The Colorado Plateau Dark Sky Cooperative was established specifically to build connections between communities on the Colorado Plateau and raise awareness and improve night skies throughout the Colorado Plateau. GRCA should in the long term seek to work with as assist nearby communities, towns, or cities, whose light pollution already degrades, or could further degrade, Grand Canyon's night skies.

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Flagstaff Zoning Code. Chapter 10-20: Administration, Procedures and Enforcement. Divisions 10 20.40.100 Outdoor Lighting Permits, 10-50.70 Outdoor Lighting Standards, 10-80.20 Definition of Specialized Terms, Phrases, and Building Functions.

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Grand Canyon National Park *2012–2016 Goals and Objectives*, 2012.

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Yellowstone National Park Outdoor Lighting Standards. Second Edition, August 2011.

Yosemite National Park Lighting Guidelines. Developed by Benya Lighting Design for the US National Park Service. May 6, 2011.

Appendix A: Lighting Equipment

An appendix will be created later (likely as a part of a future park outdoor lighting guideline) with recommendations for specific fixtures and bulbs, both for ease of choosing fixtures and to encourage standardization. This plan is being written at a time when lighting technology is rapidly changing. It is likely that within 5–10 years, most of the specific lamps, ballasts, and other lighting equipment recommended in such an appendix will become obsolete, and it will be incumbent on the designers of specific projects to interpret the intent of this document before making product selections. Moreover, ongoing research may change recommended lighting spectra, light levels, and other recommendations or requirements of this document, and other adjustments may also be necessary. However, it is unlikely that the basic guiding principles will change. When in doubt, use these principles while adopting new lighting technology in the park, and good results are likely.

Pending specific recommendations for GRCA, consult lighting guidelines from Yosemite National Park and Death Valley National Park, and IDA.

Appendix B: Definitions and Acronyms

≥: Greater than or equal to

≤: Less than or equal to

Absolute Photometry: Photometric measurements (usually of a solid-state luminaire) that directly measure the footprint of the luminaire. Reference Standard: IES LM-79 (IDA-IES MLO 2011)

Albedo: A measurement of the diffuse reflectivity or reflecting power of a surface. Fresh white snow has a high albedo and will reflect 80–90% of sunlight or artificial light back up from the ground. Wet soil, forest, and dense ground vegetation have a low albedo and will reflect less than 20% of sunlight or artificial light. The prevailing conditions at GRCA of desert, dry soil, dry sand, and light colored rocks have a higher albedo than vegetation and will reflect 20–40% of sunlight or artificial light.

Architectural Lighting: Lighting designed to reveal architectural beauty, shape, and/or form and for which lighting for any other purpose is incidental. (IDA-IES MLO 2011)

Astronomic Time Switch: An automatic lighting control device that switches outdoor lighting relative to time of solar day with time of year correction. (IDA-IES MLO 2011)

Backlight: For an exterior luminaire, lumens emitted in the quarter sphere below horizontal and in the opposite direction of the intended orientation of the luminaire. For luminaires with symmetric distribution, backlight will be the same as front light. (IDA-IES MLO 2011)

BUG: A luminaire classification system that classifies backlight (B), uplight (U) and glare (G) (Figure 64). The three components of BUG ratings are based on IES TM-15-07 (revised):

- *Backlight*, which creates light trespass onto adjacent sites. The B rating takes into account the amount of light in the BL, BM, BH, and BVH zones, which are in the direction of the luminaire OPPOSITE from the area intended to be lighted.
- *Uplight*, which causes artificial sky glow. Lower uplight (zone UL) causes the most sky glow and negatively affects professional and academic astronomy. Upper uplight (UH) not reflected off a surface is mostly energy waste. The U rating defines the amount of light into the upper hemisphere with greater concern for the light at or near the horizontal angles (UL).
- *Glare*, which can be annoying or visually disabling. The G rating takes into account the amount of frontlight in the FH and FVH zones as well as BH and BVH zones. (IDA-IES MLO 2011)

Canopy: A covered, unconditioned structure with at least one side open for pedestrian and/or vehicular access. (An unconditioned structure is one that may be open to the elements and has no heat or air conditioning.) (IDA-IES MLO 2011)

CFL: Compact fluorescent lamps

Common Outdoor Areas: One or more of the following: a parking lot; a parking structure or covered vehicular entrance; or a common entrance or public space shared by all occupants of the domiciles. (IDA-IES MLO 2011)

Conflict Area: Conflict areas are typically junctions, intersections, roundabouts, and pedestrian crossings, where significant streams of motorized traffic intersect with each other, or with other road users such as pedestrians and cyclists. From British Standard for Highway Lighting BS5489: 2003, cited online here: https://www.theilp.org.uk/resources/ilp-technical-reports/plg02-the-application-of-conflict-areas-on-the-highway/

Curfew: A time defined by lighting guidelines when outdoor lighting is reduced or extinguished. (IDA-IES MLO 2011)

DSP: IDA International Dark Sky Place, which includes Dark Sky Reserves, Dark Sky Parks, and Dark Sky Communities

Emergency Conditions: Generally, lighting that is only energized during an emergency; lighting fed from a backup power source; lighting for illuminating the path of egress solely during a fire or other emergency situation; or lighting for security purposes used solely during an alarm. National park specific emergencies include search and rescue (SAR) or other temporary emergencies in unpredictable locations. (IDA-IES MLO 2011)

Exit Discharge: Designated stairs, aisles, corridors, ramps, escalators, walkways, and exit passageways leading [from an exit] to a public way. (National Fire Protection Agency, *Life Safety Code,* 2012)

FCO: Full cut-off luminaires (0% up-light or fully shielded) (Dick 2012)

Footcandle: The standard imperial unit used to measure illuminance, or the amount of light falling onto a surface, such as a roadway or athletic field. One footcandle equals one lumen per square foot. One footcandle equals approximately 10 lux. (Luginbuhl, Christian, B, *Pattern Outdoor Lighting Code*, 2010)

Forward Light: For an exterior luminaire, lumens emitted in the quarter sphere below horizontal and in the direction of the intended orientation of the luminaire. (IDA-IES MLO 2011)

Fully Shielded Luminaire: A light fixture constructed in such a manner that all light emitted by the fixture, either directly from the lamp or a diffusing element, or indirectly by reflection or refraction from any part of the fixture, is projected below the horizontal. Any structural part of the light fixture providing this shielding must be permanently affixed, and part of the fixture, not part of any surrounding building or architectural elements. (IDA-IES MLO 2011)

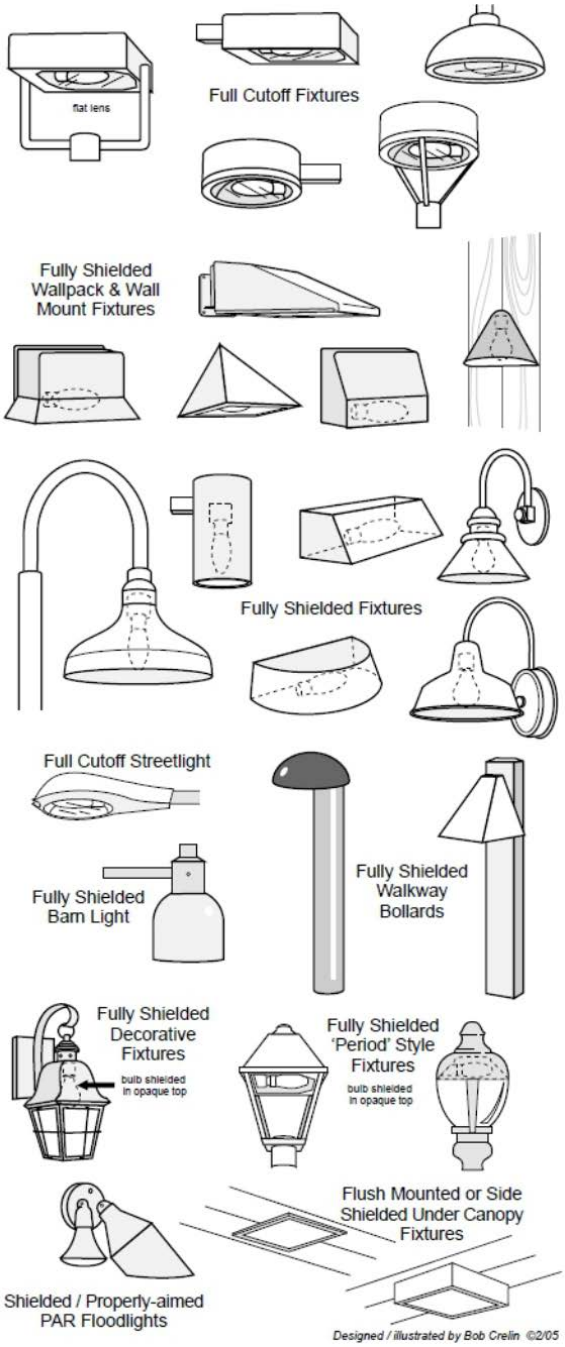


Figure 65. Examples of fully shielded luminaires. (IDA-MLO 2011)

Glare: Lighting entering the eye directly from luminaires or indirectly from reflective surfaces that causes visual discomfort or reduced visibility. (IDA-IES MLO 2011)

GRCA: Grand Canyon National Park

HID: High intensity discharge lamps (LPS, HPS, MH lamps) (Dick 2012)

HPS: High pressure sodium lamps ("yellow" colored lamps) (Dick 2012)

IDA: International Dark-Sky Association (IDA-IES MLO 2011)

IES: Illuminating Engineering Society of North America (IDA-IES MLO, 2011)

Illuminance: The amount of light falling onto a unit area of surface (luminous flux per unit area); measured in footcandles or lux. (Luginbuhl 2010)

Industry Standard Lighting Software: Lighting software that calculates point-by-point illuminance that includes reflected light using either ray-tracing or radiosity methods. (IDA-IES MLO 2011)

Lamp: A generic term for a source of optical radiation (i.e. "light"), often called a "bulb" or "tube." Examples include incandescent, fluorescent, HID lamps, and LPS lamps, as well as LED modules and arrays. (IDA-IES MLO 2011)

Landscape Lighting: Lighting of trees, shrubs, or other plant material as well as ponds and other landscape features. (IDA-IES MLO 2011)

LED: Light emitting diode

LED, Narrow-Spectrum Amber: An LED with a peak wavelength between 585 and 595 nanometers and a full width at 50 percent power no greater than 15 nanometers. (Flagstaff Zoning Code)

Light Fixture, Outdoor: A complete lighting assembly (including the lamp, housing, reflectors, lenses, and shields), less the support assembly (pole or mounting bracket). Includes luminous tubes, lamps or similar devices, permanently installed or portable, used for illumination, decoration, or advertisement. Such devices shall include, but are not limited to lights used for:

A. Parking lot or parking garage lighting;
B. Roadway and driveway lighting;
C. Pedestrian or walkway lighting;
D. Entryway lighting;
E. Recreational areas;
F. Landscape lighting;
G. Billboards and other signs (advertising or other);
H. Display area lighting;
I. Building or structure decoration; and
J. Building overhangs and open canopies.

(Luginbuh, 2010)

Light Pollution: Any adverse effect of artificial light including, but not limited to, glare, light trespass, skyglow, energy waste, compromised safety and security, and impacts on the nocturnal environment. (IDA-IES MLO 2011)

Light Trespass: Light that falls beyond the property it is intended to illuminate. (IDA-IES MLO 2011)

Lighting: "Electric," "man-made," or "artificial" lighting. See "lighting equipment." (IDA-IES MLO 2011)

Lighting Equipment: Equipment specifically intended to provide gas or electric illumination, including but not limited to, lamp(s), luminaire(s), ballast(s), poles, posts, lens(s), and related structures, electrical wiring, and other necessary or auxiliary components. (IDA-IES MLO 2011)

Lighting Zone: An overlay zoning system establishing legal limits for lighting for particular parcels, areas, or districts in a community. (IDA-IES MLO 2011)

LPS: Low pressure sodium lamps (monochromatic, single color lamps) (Dick 2012)

Lumen: The unit of measure used to quantify the amount of light produced by a lamp or emitted from a luminaire (as distinct from "watt," a measure of power consumption). (IDA-IES MLO 2011)

Luminaire: The complete lighting unit (fixture), consisting of a lamp, or lamps and ballast(s) (when applicable), together with the parts designed to distribute the light (reflector, lens, diffuser), to position and protect the lamps, and to connect the lamps to the power supply. (IDA-IES MLO 2011)

Luminaire Lumens: For luminaires with relative photometry per IES, it is calculated as the sum of the initial lamp lumens for all lamps within an individual luminaire, multiplied by the luminaire efficiency. If the efficiency is not known for a residential luminaire, assume 70%. For luminaires with absolute photometry per IES LM-79, it is the total luminaire lumens. The lumen rating of a luminaire assumes the lamp or luminaire is new and has not depreciated in light output. (IDA-IES MLO 2011)

Lux: The standard metric unit used to measure illuminance, or the amount of light falling onto a surface, such as a roadway of athletic field. One lux equals one lumen per square meter. One lux equals approximately 0.1 footcandles. (Luginbuhl 2010)

MH: Metal halide lamps ("white" colored lamps) (Dick 2012)

Mounting Height: The height of the photometric center of a luminaire above grade level. (IDA-IES MLO 2011)

New Lighting: Lighting for areas not previously illuminated; newly installed lighting of any type except for replacement lighting or lighting repairs. (IDA-IES MLO 2011)

Partly Shielded Luminaire: A luminaire with opaque top and translucent or perforated sides, designed to emit most (but not all) light downward. (IDA-IES MLO 2011)

Photoelectric Switch: A control device employing a photocell or photodiode to detect daylight and automatically switch lights off when sufficient daylight is available. (IDA-IES MLO 2011)

Relative Photometry: Photometric measurements made of the lamp plus luminaire, and adjusted to allow for light loss due to reflection or absorption within the luminaire. Reference standard: IES LM-63. (IDA-IES MLO 2011)

Seasonal Lighting: Temporary lighting installed and operated in connection with holidays or traditions. (IDA-IES MLO 2011)

Shielded Directional Luminaire: A luminaire that includes an adjustable mounting device allowing aiming in any direction and contains a shield, louver, or baffle to reduce direct view of the lamp. (IDA-IES MLO 2011)

Sign: Advertising, directional, or other outdoor promotional display of art, words and/or pictures. (IDA-IES MLO 2011)

Sky Glow: The brightening of the nighttime sky that results from scattering and reflection of artificial light by moisture and dust particles in the atmosphere. Skyglow is caused by light directed or reflected upwards or sideways and reduces one's ability to view the night sky. (IDA-IES MLO 2011)

Translucent: Allowing light to pass through, diffusing it so that objects beyond cannot be seen clearly (not transparent or clear). (IDA-IES MLO 2011)

Uniformity: Uniformity is the ratio between the maximum light level in an area and the average light level throughout the same area. It is measured in foot-candles (or lux) on the ground (*Yellowstone National Park Outdoor Lighting Standards*, 2011). Lower uniformity ratios (e.g., 4:1) are intended for areas in which the level of light should be kept relatively consistent between lights, i.e., along a curb near an ADA parking lot area. Higher uniformity ratios (e.g., 20:1) are intended for areas in which consistent lighting is not necessary to illuminate hazards, but where more widely spaced lighting between which light levels drop significantly may be appropriate for wayfinding or similar applications.

Unshielded Luminaire: A luminaire capable of emitting light in any direction including downwards. (IDA-IES MLO 2011)

Uplight: For an exterior luminaire, flux radiated in the hemisphere at or above the horizontal plane. (IDA-IES MLO 2011)

Wilderness: Approximately 94% or 1,143,918 acres of GRCA qualifies for wilderness as described in the 1964 Wilderness Act and NPS Management Policies 2006. GRCA wilderness must go through the US Congress to acquire formal wilderness designation. However, NPS management policies require that all proposed wilderness area be managed in the same manner as designated wilderness. Accordingly, GRCA will take no action to diminish Wilderness eligibility; and will continue to preserve wilderness character and values. (Jalbert, E-mail correspondence 2014)

Appendix C: Light Bulb Outputs and Comparison

See Appendix B: Definitions and Acronyms for detailed description of lumens, lux, and footcandles. Footcandle measurements decrease the further the measurement is recorded from a light. For example, a 13-watt CFL will produce fewer footcandles of light 6 feet (1.8 m) from a light than 3 feet (0.9 m) from the same light.

Ultraviolet Light:

- LED, halogen, and incandescent bulbs emit little or no UV light.
- CFLs, mercury vapor, metal halide, HPS, and LPS bulbs emit UV light, though LPS emits less UV than HPS.

Light Spectrum:

- Note that there are two different types of amber LED lights: narrow-band amber and phosphor coated filtered amber, and that they have slightly different spectrums.
- LPS has an emission spectrum similar to narrow-band amber LED lights.
- HPS has an emission spectrum similar to an phosphor coated filtered amber LED light.
- HPS and phosphor coated filtered amber LEDs allow for more color rendition (ability to distinguish colors in low light levels) than LPS and narrow-band amber LEDs. However, HPS and phosphor coated filtered amber LEDS create more sky glow.
- In both cases, the spectrum of the LED lights is generally more aesthetically pleasing to the human eye than either LPS or HPS.

RASC and IDA DSP PROGRAMS

APPENDIX C - Light Output from Typical Lamps for Comparison Purposes (Metric and English Units)

Lamp Types	Lumens# (Intensity)	Lux## at 6 m### (fc at 20 ft)	Lux## at 2 m### (fc at 6.5 ft)	Lux## at 1 m### (fc at 3.3 ft)
Incandescent*				
7 watt	60	0.13 (0.01)	1.2 (0.11)	4.8 (0.45)
15 watt	128	0.28 (0.03)	2.6 (0.24)	10.2 (0.95)
40 watt	342	0.8 (0.07)	6.8 (0.63)	27.2 (2.5)
60 watt	513	1.1 (0.10)	10.2 (0.95)	40.8 (3.8)
100 watt	855	1.9 (0.18)	17.0 (1.6)	68.0 (6.3)
Metal Halide (MH)				
70 watt	3,000	6.6 (0.61)	59.7 (5.5)	238.7 (22)
100 watt	5,800	12.8 (1.2)	115.4 (11)	461.6 (43)
High-pressure Sodium (HPS, LED**)				
35 watts	2025	4.5 (0.42)	40.3 (3.7)	161.1 (15)
50 watts	3600	8.0 (0.74)	71.6 (6.6)	286.5 (27)
70 watts	5450	12.1 (1.2)	108.4 (10)	433.7 (40)
100 watts	8550	18.9 (1.8)	170.1 (16)	680.4 (63)
Low Pressure Sodium (LPS)				
18 watts	1570	3.5 (0.32)	31.2 (2.9)	124.9 (12)
35 watts	4000	8.8 (0.82)	79.6 (7.4)	318.3 (30)
55 watts	6655	14.7 (1.4)	132.4 (12)	529.6 (49)
Compact Florescent Lamps (CFL)				
9 watt (40 w equivalent)	550	1.2 (0.11)	10.9 (1.0)	43.8 (4.1)
13 watt (60 w equivalent)	850	1.9 (0.18)	17.9 (1.7)	71.6 (6.6)
LED				
1 watt (White) ***	100	2.8 (0.3)	25 (2.3)	100 (9.3)
1 watt (amber) ***	75	2.1 (0.2)	19 (1.8)	75 (7.0)
3 watt amber A19+	90	0.5 (0.005)	4.0 (0.37)	12 (1.1)
3 watt amber PAR16+	90	1.8 (0.17)	16 (1.5)	50 (4.6)
7 watt amber PAR30+	200	5.5 (0.51)	50 (4.6)	200 (19)
13 watt amber PAR38+	400	11 (1.0)	100 (9.3)	400 (37)

* Incandescent lamp luminous efficiency is approximately 1/10 HPS (photopic vision)
** Efficacy of commercially available white LEDs are approximately same as HPS (ca. 2012)
*** Assumes a 1 steradian illumination angle and no external optics, typical for 2011
Note: Fixture, lamp degradation before cleaning or replacement may decrease these to <50%.

Lumens is the total amount of light emitted in all directions (over 4π steradians)

Assumes no fixture losses.

Lux (fc) is the amount of light illuminating a surface of one metre (foot) square

1 Lux = 1 Lumen / (4π dist^2) (where distance is in metres) = 0.093 foot candles
1 fc = 1 Lumen / (4π dist^2) (where distance is in feet) = 10.78 Lux

+ Measurements by IDA

Note: Lamp and light luminaire technologies are under constant development resulting in more lumen per watt (efficacy). This table can be used for comparative purposes. The author advises care in using this table to prevent over-lighting a given area. We advise users to obtain current information on the lamp being considered for use.

RASC and IDA GOL, November 2012 32

Table 32. The above table is taken from the Guidelines for Outdoor Lighting in RASC Dark-Sky Preserves and IDA Dark Sky Places*, adopted by the Royal Astronomical Society of Canada, March 2008 and adopted by the IDA, November 2012, written by Robert Dick, Royal Astronomical Society of Canada and Canadian Scotobiology Group.*

Appendix D: Reference Illumination Levels

Lux Readings for Full Moon:
Quarter moon = 0.01 lux
Full moon = about 0.25 lux

Lux Readings for Twilight:
Nautical twilight = 1 lux
Astronomical twilight = less than 1 lux
Civil twilight (the time between when the sun sets and when civil twilight ends): up to 3 or 4 lux

How many lux cause the pupil to stay fully dilated: 1–3 lux

Full sunlight: 100,000 lux

Appendix E: GRCA Electrical Standards

Park Standards 11/07 Electrical

1. Use GE panel boards, load centers, or GE capable: meaning that GE breakers will fit and work properly in the panel board or load center.

2. Ufer ground will be installed. Will be in the immediate area of the expected placement of the electrical service. Will either be stubbed up in an accessible and suitable location or have wire long enough to reach the expected final landing at the service entrance without splicing. Shall be marked and protected until such time that the work on the Ufer ground is completed.

3. On all the lighting circuits use #10 AWG wire or larger for long term energy savings and help with the problems of harmonic distortion. #10 wire is to be use with 20 amp circuit breakers.

4. T8–32 watt fluorescent light bulbs are the standard light bulbs for halls and offices (straight lamps only).

5. For outside building lights and streetlights: for entrances compact fluorescent (13 watt), LED, or incandescent are ok. HPS bulbs with medium or mogul bases are to be used on perimeters building lighting and streetlights. For HPS fixtures, no electronic ballast (this is due to lighting in this area).

6. For indoor areas or bay lighting use MH with mogul bases (250 watt and 400 watt preferred) or T8–32 watt (straight lamps only). This is for bulb standardization.

7. Isolated-grounded receptacles: colored orange should be installed at all known or planed computer workstations. Each circuit shall have its own neutral. Harmonic rated circuit breakers will be used on these circuits.

8. In the areas that metal studs are used, metal electrical boxes will be used. A.) In places were metal doorframes are within 6 feet (1.8 m) of a switch, receptacle, electric motor, or electric box, the doorframe will be bonded. Exception to A: when doorframe is mounted in metal studs that have metal electrical boxes mounted on the metal studs on the same wall, bonding wire will not be required.

9. Electrical metal tubing will not be used as a means of grounding or bonding.

10. When a metallic cover plate is used the grounded terminal shall be to the top. On ceiling and floor it is whichever is logical.

11. On 120/208 systems there will be no down sizing of the neutral (meaning that the neutral will be the same size as the other conductors in that circuit or service).

12. For every 120-volt circuit there will be one neutral wire for that circuit.

13. Electric hand dryers. The park standard is American dryer model DR10TN. Other models may be used as long as the motion sensor, heating element and fan motors are interchangeable with the American dryer model DR10TN.

14. Display lighting will be done with in the following guidelines:
    a. Track Lighting: all light fixtures that are that are used will also work on HALO Power-Trac track. Light bulbs will be of medium base halogen bulbs. LED's are ok wherever they can be used.
    b. Display Cases: T-8 light 32watt bulbs (straight lamps only); 13 watt CFL; for fiber optics, the base bulb will be a medium base bulb prefer halogen type; LEDs are ok where ever they can be used.
    c. Other Yypes of Displays: medium base bulbs for flood and spot lights; T-8 32 watt or 13-watt CFL for fluorescent lighting; LED's are ok were ever they can be used

Appendix F: Light Spectrum Research

Information and research regarding various impacts of light spectrum is available on the Flagstaff Dark Skies Coalition website:
http://www.flagstaffdarkskies.org/for-wonks/lamp-spectrum-light-pollution/

A research paper documenting varying impacts of light spectrum on sky glow is available here:
http://www.sciencedirect.com/science/article/pii/S0022407313004792

The following book describes many research studies about the impact of artificial light on different species of nocturnal wildlife, in some cases documenting the impact of light spectrum:
Rich, Catherine and Travis Longcore, editors. *Ecological Consequences of Artificial Night Lighting*. Island Press, Washington. 2006.

Section 4

Letters of Support

The following is a small sample of the local community support for GRCA's dark night skies. Due to submission deadlines this is merely a small example of the extraordinary support that the park receives to maintain, preserve, and enhance our night skies, astronomy programs, and general outreach for visibility, astronomy, and wilderness character.

1400 WEST MARS HILL ROAD FLAGSTAFF, AZ 86001
928-774-3358 FAX (928) 774-6296

January 16, 2016

Board of Directors
International Dark-Sky Association
3223 North First Avenue
Tucson, Arizona 85719-2103

Dear International Dark-Sky Association Board of Directors:

I am pleased to support the International Dark Sky Park designation being sought by Grand Canyon National Park.

I have been working with representatives of the Park Service on dark-sky related matters for several years now, beginning with their first contacting me about the Colorado Plateau Dark-Sky Cooperative, and continuing with looking for IDA recognition of the local monuments, as well as with extensive participation in the 2014 conference held here in Flagstaff.

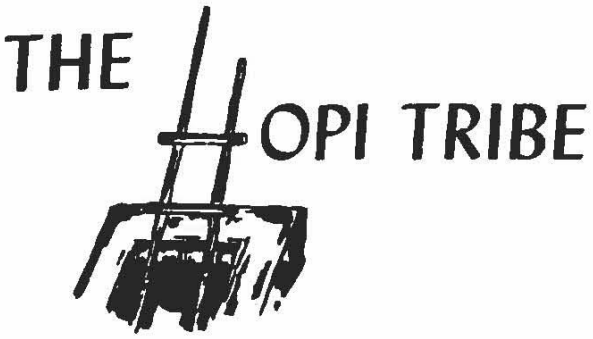
As you know, Flagstaff and the Colorado Plateau remain one of the leading dark-sky sensitive areas in the world. Several communities in the area, as well as a number of parks and monuments, are seeking or already have received dark-sky designations. GCNP, as one of the largest and most significant natural attractions in the United States, would be an important addition to the regional dark-sky assets, and I know the NPS staff there has been working toward this designation for some time. What better place nationally than to showcase good dark-sky practices to millions of visitors could there be?

I am happy to endorse GCNP's nomination for IDA Dark Sky Park status and urge your positive evaluation of their efforts.

Yours sincerely,

Jeffrey Hall

Jeffrey Hall
Director



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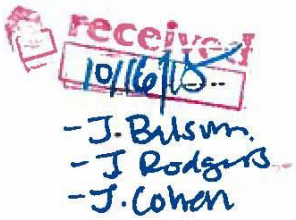

September 24, 2015

David V. Uberuaga, Superintendent
Attention: Jane Rodgers, Deputy Chief, Science and Resource Management
Grand Canyon National Park
P.O. Box 129
Grand Canyon, Arizona 86023

Dear Superintendent Uberuaga,

This letter is in response to your correspondence dated September 16, 2015, regarding the Grand Canyon National Park pursuing designation as an official Dark Sky Park.

The Hopi Tribe claims cultural affiliation to prehistoric cultural groups in Grand Canyon National Park and the Grand Canyon is a Traditional Cultural Property of the Hopi Tribe. The Hopi Cultural Preservation Office supports identification and avoidance of prehistoric archaeological sites and Traditional Cultural Properties, and we consider the archaeological sites that are habitations of our ancestors to be "footprints" and Hopi Traditional Cultural Properties. Therefore, we appreciate your continuing solicitation of our input and your efforts to address our concerns.

And therefore, the Hopi Cultural Preservation Office supports the designation of the Grand Canyon National Park as a Dark Sky Park, awarded by the International Dark Sky Association, as "a location of exceptional nighttime beauty, dark skies education, and preservation of the nighttime environment." And therefore, we appreciate the Park completing the lighting inventory and retrofitting light fixtures to comply with lighting guidelines in preparation for submitting a Dark Sky Park application in 2016.

If you have any questions or need additional information, please contact me at 928-734-3611 or lkuwanwisiwma @hopi.nsn.us. Thank you again for your consideration.

Respectfully,

Leigh J. Kuwanwisiwma, Director
Hopi Cultural Preservation Office

xc: Arizona State Historic Preservation Office

P.O. Box 123 KYKOTSMOVI, AZ 86039 (928) 734-3000

Dave Uberuaga
Superintendent
Grand Canyon National Park
20 S. Entrance Road
Grand Canyon, AZ 86023

Dear Dave Uberuaga:

The TAAA is fully supports the pursuit of International Dark Sky Park status for Grand Canyon National Park. There are many reasons for supporting such an endeavor. The economic benefits to using the right light equipment and footprint are a strong motivation in their own right. Environmental impacts are equally important, considering GCNP's role as a keystone of the Climate Friendly Parks Program, a teaming of over 1000 National Park staff members and stakeholders to seriously attack the generation of greenhouse gasses and other environmental impacts due to the existence of the Parks.

These purposes are strong motivators to be supporters of the pursuit of International Dark Sky Park status in their own right. In addition, the Tucson Amateur Astronomy Association has, as one of our core missions, public outreach and education in astronomy. Our organization performs many public outreach support events each month for schools, YMCA/YWCA, Boys and Girls clubs, and over a dozen annual state and county park events and other community festivals. One of our key outreach activities is to coordinate the activities for the annual Grand Canyon Star Party.

The Tucson Amateur Astronomy Association is a co-sponsor, with the National Park Service, of the Grand Canyon Star Party, an eight day-and-night event at the Grand Canyon National Park. We gather over 100 volunteer astronomers from around the world for a public outreach, with daytime solar, lunar, and planetary viewing and night time telescope observing. For June 2015, we had over 75,000 visitor contacts for the 8 day and night event. This outreach activity is raising environmental awareness of a large number of people.

Achieving International Dark Sky Park status would attract many more visitors to educate in night sky awareness, as well as in the proper application of lighting methods as they see the very real effects of wise light use. For the Grand Canyon National Park to become an International Dark Sky Park will make the venue a go-to destination for truly dark skies, and allow The Tucson Amateur Astronomy Association to pursue its public astronomical education and environmental awareness mission with increased effectiveness.

Accordingly, The Tucson Amateur Astronomy Association is a strong supporter of Grand Canyon National Park's pursuit of International Dark Sky Park status. We encourage the International Dark-Sky Association to take timely action to process the GCNP request to become a Provisional International Dark Sky Park. Please contact us immediately if there is any additional support we can provide.

Sincerely,

Signature: Bonnie a Bell Date: January 18, 2016

Address: PO Box 41254

City: Tucson State: AZ Zip: 85717

United States Department of the Interior

NATIONAL PARK SERVICE
INTERMOUNTAIN REGION
12795 West Alameda Parkway
P.O. Box 25287
Denver, Colorado 80225-0287

IN REPLY REFER TO:
IMRO-RSS-NR (1242)

JAN 14 2016

Board of Directors
International Dark-Sky Association
3223 North First Avenue
Tucson, Arizona 85719-2103

Dear IDA Board of Directors:

The National Park Service Intermountain Region's Natural Resources Division is pleased to support the nomination of Grand Canyon as an International Dark Sky Park (IDSP). Grand Canyon National Park is arguably unparalleled as a destination for awe inspiring views, including the naturally dark night sky. It was first established as a Forest Reserve in 1893, a Game Preserve in 1906, and finally, a National Monument in 1908 when President Theodore Roosevelt used his authority under the Antiquities Act of 1906. Although multiple bills to establish it as a national park were submitted between 1882 and 1911, it received its current status when the Grand Canyon National Park Act was signed by President Woodrow Wilson in 1919. It was designated a UNESCO World Heritage Site in 1979.

Grand Canyon has been a recognized destination for astronomy events for many decades. In 2015, the park held its 25th annual Grand Canyon Star Party event, at locations on both sides of the canyon. During the primary visitation season, specific astronomy interpretation events are offered at least two times per week at South Rim locations. In addition to special events, park staff members routinely make telescopes available for visitors behind the Grand Canyon Visitor Center (South Rim) and the Grand Canyon Lodge (North Rim) each evening.

Due to the unique panoramic view at many locations within and along the canyon rim, the park offers a vast number of night sky viewing locations for astronomy and night photography enthusiasts. The night sky is not only important to astronomy enthusiasts but is also interwoven into the traditional stories of all the tribes with traditional associations to the Grand Canyon. Grand Canyon's efforts to enhance dark night skies preservation is important for protection of this valuable natural, cultural, and scientific resource and for many more reasons that can be outlined here.

The Intermountain Region's Natural Resources Division has supported membership in the International Dark Sky Association (IDA) since July 2011. We appreciate the efforts of IDA and the opportunity to join the worldwide network of committed individuals who care deeply about

preserving the beauty and heritage of our night skies. We fully support the efforts of Grand Canyon National Park as they seek designation as an IDSP. We believe its nomination and ongoing efforts to conserve dark skies will benefit park visitors, nearby communities, and future generations. Should you have any questions, please contact Randy Stanley at 303-987-6890.

Sincerely,

Patrick Malone
Assistant Regional Director, Natural Resources Division

cc: David Uberuaga, Superintendent, Grand Canyon National Park
Kurt Fristrup, Science & Technology Branch Chief, NSNSD, WASO
David Vana-Miller, Resource Stewardship Program Manager, IMR-NR
Randy Stanley, Natural Sounds & Night Skies Coordinator, IMR-NR
Nathan Ament, Colorado Platèau Dark Skies Coordinator, IMR-NR

January 19, 2016

VIA ELECTRONIC COPY ONLY- NO HARD COPY TO FOLLOW

Board of Directors
International Dark-Sky Association
3223 North First Avenue
Tucson, Arizona 85719-2103

Dear IDA Board of Directors:

The Colorado Plateau Dark Sky Cooperative is pleased to support the Grand Canyon National Park International Dark Sky Park nomination. The park is located in one of the most remote regions in the continental U.S., and offers an exceptional, unfettered view of the dark night skies over the Colorado Plateau. The dark skies of Grand Canyon have immense value to astronomical viewing, cultural resources, and wildlife conservation in the region. For the last 25 years, Grand Canyon has partnered with the Tucson Amateur Astronomy Association and the Saguaro Astronomy Club of Phoenix to host the free Grand Canyon Star Party on the North and South Rim. In addition, Grand Canyon International Dark Sky Park designation would assist in the conservation of dark night skies in the neighboring Flagstaff Area National Monuments, Grand Canyon-Parashant National Monument, Kaibab National Forest, Coconino National Forest, the Navajo Nation, Flagstaff, Sedona, and Tusayan.

As an integral piece of the newly formed Colorado Plateau Dark Sky Cooperative, Grand Canyon is taking lighting, conservation, and educational steps to fulfill the mission of the NPS Call To Action #27, Starry Starry Night. This voluntary initiative forms America's first Dark Sky Cooperative, and links communities, tribes, businesses, state/federal agencies, and citizens in a collaborative effort to celebrate the view of the cosmos, minimize the impact of outdoor lighting, and ultimately restore natural darkness to the area. Grand Canyon International Dark Sky Park designation would bring further awareness and legitimacy to the Cooperative.

We fully support the efforts of Grand Canyon National Park as they seek designation of the Grand Canyon International Dark Sky Park. Such efforts to conserve dark skies will benefit park visitors, nearby communities, and future generations. Should you have any questions, please contact Nate Ament at 435-719-2349.

Sincerely,

Nate Ament

Colorado Plateau Dark Sky Cooperative Coordinator

COCONINO COUNTY ARIZONA

Art Babbott
District 1

Lena Fowler
District 5

January 20, 2015

David Uberuaga, Superintendent
Grand Canyon National Park
20 S. Entrance Road
Grand Canyon, AZ 86023

Dear Superintendent Uberuaga:

As Coconino County Supervisors whose boundaries include the Grand Canyon and neighboring communities, we strongly endorse the efforts of Grand Canyon National Park (GCNP) in pursuing a Dark-Sky Park designation from the International Dark-Sky Association (IDA).

GCNP annually draws millions of visitors from around the world to enjoy the one of the seven wonders of the world. The Grand Canyon's spectacular night sky views on the remote and rugged Colorado Plateau are one element of a rare and beautiful resource that must be protected.

Designation as an International Dark-Sky Park can help protect night sky views at the Park for future generations; can promote environmentally responsible outdoor lighting; and, potentially, can serve to educate millions from around the world about night sky conservation.

Grand Canyon National Park protects over 1 million acres of superlative views, wilderness, and unique recreational opportunities. The night sky also represents a key component of that GCNP environment. It is a remarkable location for dark night sky viewing and we support the GCNP's effort to be awarded the Dark-Sky Park designation.

Sincerely,

Art Babbott, District 1
Coconino County Board of Supervisors
219 East Cherry Avenue
Flagstaff, Arizona 86001
ababbott@coconino.az.gov
928-679-7151

Lena Fowler, District 5
Coconino County Board of Supervisors
219 East Cherry Avenue
Flagstaff, Arizona 86001
lfowler@coconino.az.gov
928-283-4518

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Dan Duriscoe
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Chad Moore
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Jeremy White

Major funding provided by the estate of Joe Orr through the Grand Canyon Association: the non-profit partner of Grand Canyon National Park.

Many others have provided time and support to make this application possible. For those of you who have helped but are not listed, a very sincere thank you.