Night Sky Condition Assessment from Minidoka National Historic Site and Craters of the Moon National Monument and Preserve

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Executive Summary

The National Park Service Natural Sounds and Night Skies Division (NSNSD) visited Minidoka National Historic Site (MIIN) and Craters of the Moon National Monument and Preserve (CRMO) between June 2-6, 2021 to conduct night sky condition assessments for both parks as part of a larger interagency effort between the NPS and BLM to assess resource conditions ahead of the proposed Lava Ridge Wind Farm development. NPS night sky data will provide an up-to-date night sky condition assessment prior to project development and will be used as input for modeling future sky glow conditions based on proposed lighting required for the Lava Ridge project.

Results from all-sky measurements at Minidoka National Historic Site indicate night sky quality was moderately to heavily impacted from skyglow city skyglow and direct glare sources. The greatest impact to night sky quality at Minidoka was skyglow from Twin Falls, ID. Additional impacts included unshielded direct glare sources from residential and agricultural facilities near the site. Despite these impacts, portions of the sky at Minidoka retained a sense of naturalness and were overall in much better condition than surrounding communities allowing observations of natural night sky features such as the Milky Way and thousands of stars.

To assess overall sky brightness an all-sky light pollution ratio (ALR) was derived by comparing the average sky luminance from artificial light to a reference condition of a naturally dark site. At Minidoka the ALR was 2.63 indicating average sky brightness was 2.63 times brighter than natural conditions. The primary source of artificial light was Twin Falls, ID. Zenith (overhead) sky brightness is generally the darkest portion of a sky, and often last to be impacted from artificial lights. At Minidoka, zenith sky brightness was 1.1 times brighter than natural conditions indicating skyglow has impacted the darkest region of the sky. Horizontal illuminance, or light incident on the ground, was 1.5 times brighter than natural conditions. This indicates the landscape of Minidoka at night is illuminated by artificial light compared and brighter than a naturally illuminated environment. Maximum vertical illuminance, also known as light trespass, represents the maximum sky brightness an observer would experience. Vertical illuminance was 4.3 times brighter than natural conditions in the direction of Twin Falls, ID. Minimum vertical illuminance was 2 times brighter than natural conditions. The proposed Lava Ridge wind farm is predicted be visible between 340-94 degrees azimuth, or 114 degrees across the horizon. This overlaps with the darkest portion of the horizon (lowest vertical illuminance) as observed from Minidoka, potentially impacting sky quality and visitor experience. Despite measured and observed impacts to night sky quality from artificial light, natural sources of light such as the Milky Way were easily observed, especially overhead. Faint celestial features and the details in the Milky Way indicated portions of the sky at Minidoka were only moderately impacted retain a sense of natural quality.

Results from all-sky measurements at Craters of the Moon National Monument and Preserve indicate sky quality at Craters of the Moon was excellent with only minor impacts from skyglow. The main sources of impact were the light domes of Burley, ID and Twin Falls, ID along the southern horizon. Overall, this site at Craters of the Moon provided opportunities to observe a pristine night sky overhead with the possibility to fully dark adapt and observe even the faintest details.

To assess overall sky brightness an all-sky light pollution ratio (ALR) was derived by comparing the average sky luminance from artificial light to a reference condition of a naturally dark site. At Craters of the Moon the ALR was 0.38 indicating average sky brightness was only 0.38 times brighter than natural conditions. The primary source of artificial light emanated from Burley, ID which created a small light dome. A smaller light dome from Twin Falls, ID was also visible along the southwest horizon. Zenith (overhead) sky brightness is generally the darkest portion of a sky, and often last to be impacted from

artificial lights. At Craters of the Moon there was no measurable artificial light at zenith indicating pristine natural conditions. Horizontal illuminance, or light incident on the surface, was 0.16 times brighter than natural conditions. This indicates the landscape of Craters of the Moon at night was very close to natural brightness. Maximum vertical illuminance, also known as light trespass, was double that of natural conditions measured in the direction of Burley, ID. The proposed Lava Ridge wind farm is predicted be visible between 198-260 degrees azimuth, or 62 degrees across the horizon. This does not overlap with the darkest portion of the horizon as observed from Craters of the Moon, limiting potential impacts to an area already impacted by light domes. With only minor measured and observed impacts to sky quality from artificial light, natural sources of light such as the Milky Way were easily observed in nearly all directions. Faint celestial features and the details in the Milky Way indicated most of the nocturnal environment at Craters of the Moon provides a unique visitor experience.

Overview

Jeremy White of the National Park Service Natural Sounds and Night Skies Division (NSNSD) visited Minidoka National Historic Site (MIIN) and Craters of the Moon National Monument and Preserve (CRMO) between June 2-6, 2021 in response to a technical assistance request from the parks to NSNSD (TAR# 19778). Night sky condition assessments were requested for both parks as part of a larger interagency effort between the NPS and BLM to assess resource conditions ahead of the proposed Lava Ridge Wind Farm development. The proposed development may impact night sky visual quality and sky brightness. The project boundary indicates potential visual impacts from wind turbine lights between 340° and 94° azimuth, a total of 114° across the horizon, as observed from the visitor center at Minidoka. From Craters of the Moon Laidlaw Corral, potential impacts would be visible between 198° and 260° azimuth, or 62° degrees across the horizon. The primary objective of this visit was all-sky data collection at both sites with a calibrated CCD camera providing measures of sky brightness from natural and anthropogenic sources. These data will provide an up-to-date night sky condition assessment prior to project development and will be used as input for modeling future sky glow conditions based on proposed lighting required for the Lava Ridge project. Secondary objectives included spectral measurements of zenith skyglow, color images to provide visual nighttime reference, and visual assessment of the nighttime scene.

Summary

All-sky photometric measurements, spectra of zenith skyglow, and visual observations were successfully collected at MIIN and CRMO between June 2-June 4, 2021. The results indicate sky quality at Minidoka was moderately impacted at zenith and heavily impacted along the horizon. Several light domes were visible along the horizon as were many individual direct light sources, with one direct source originating from a park facility. Average sky luminance was 2.63 times brighter than average natural conditions while zenith sky brightness was 1.14 times brighter than average natural conditions. Vertical illuminance, incident light on a vertical surface, was brightest in the direction of Twin Falls, ID, and measured 4 times brighter than natural conditions. Vertical illuminance was lowest between 0-30° azimuth which overlaps with the direction of the proposed wind farm.

Results from Craters of the Moon indicate minor impacts along the southern horizon and very good conditions overhead. Light domes from Twin Falls and Burley were visible to the south but low on the horizon. No direct sources of light were observed. Average sky luminance was 42% brighter than average natural conditions. Zenith sky brightness was natural, with no measurable anthropogenic light. Vertical illuminance was brightest in the direction of Burley, ID and was twice as bright as natural conditions. From this observation point the proposed wind farm would be in line with existing impacts along the horizon. Vertical illuminance was lowest between 330-30° azimuth which does not overlap with the direction of the proposed wind farm.

Observation Points

Monitoring points were selected through a collaborative effort by NPS and BLM staff for daytime visual resource assessments. Each site, called a Key Observation Point (KOP), will be used to assess visual resources at each park and identify resources at risk from the proposed development. Night sky observation points were informed by the KOP locations. Requirements for the night sky assessment necessitated a slight deviation from the exact KOP but were very close (Table 1). Generally, night sky observation points are selected based on park need, a full 360° field of view with minimal terrain blocking, and no direct glare sources from local lights.

Site	Lat	Long
Minidoka NHS	42.67969	-114.24466
Craters of the Moon NM	43.03635	-113.72842

Table 1 Night sky observation points

Figure 1 Park building used to block a bright light source due south of the observation point.

Minidoka

The MIIN KOP is located immediately north of the Minidoka visitor's center. The night sky observation point was selected 100m north west of the established KOP along the gravel path leading to the old fire station. This site not only allowed a 360° view of the horizon, but also used a park facility to the south to provide a strategic blocking of a bright light source otherwise unavoidable in other areas of the park (Figure 1).

Craters of the Moon

The CRMO KOP is located at the east end of the Laidlaw airstrip at Laidlaw Corral in the south-central portion of the Preserve. The night sky observation point is located immediately east of the KOP on a small rise on the south side of Kimama Cave Rd. The slight elevation gain of this observation point allowed for a full 360° degree field of view.

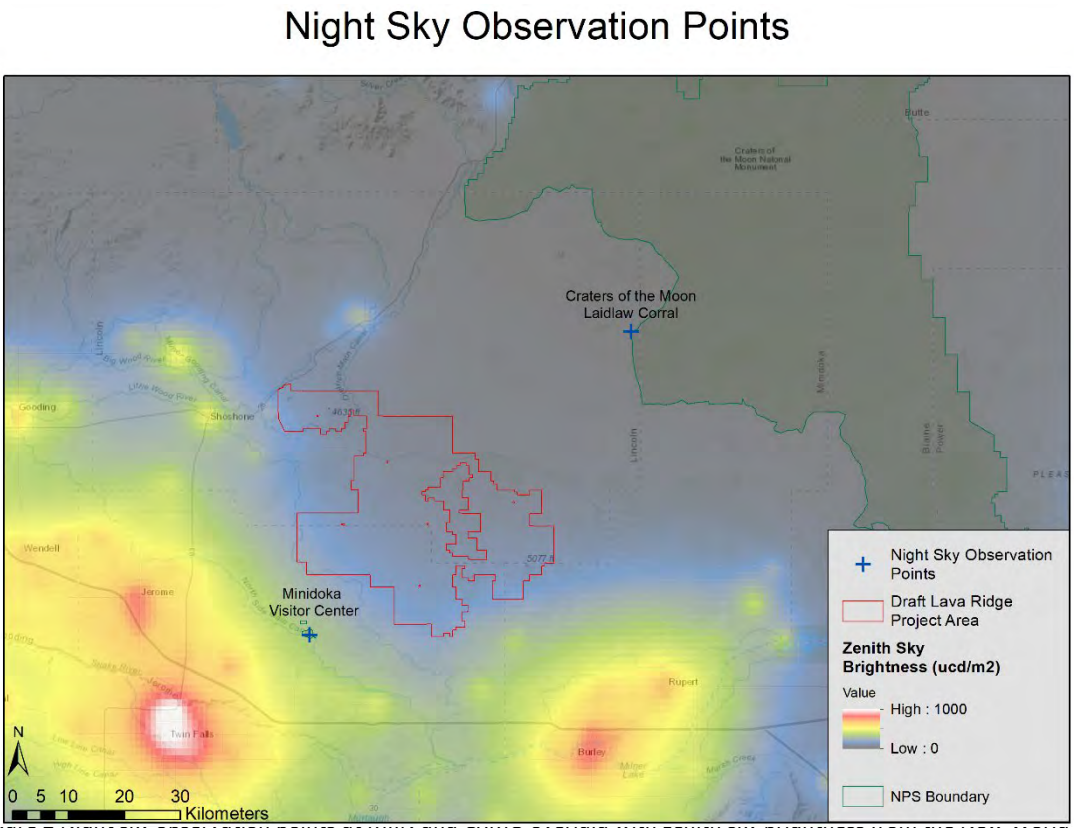


Figure 2 Night sky observation points at MIIN and CRMO overlaid with Zenith Sky Brightness from the New World Atlas of Light Pollution.

NPS All-sky photometry

All-sky broadband photometry of sky brightness (or luminance) is an important product of the NSNSD. Data processing results in all-sky image mosaics color coded by calibrated sky brightness in V magnitudes per square arc second (an inverse logarithmic scale--a smaller number indicates brighter luminance). A false color ramp is used to illustrate changes in sky brightness across the scene with dark blue, purple, and black representing low luminance values, and red and white representing bright luminance. Panoramic luminance maps and accompanying metrics are presented in two forms, “all-sources”, and “artificial skyglow.” All-sources includes both natural and anthropogenic sources of luminance. Artificial skyglow has had natural sources of light subtracted from the image, thus accompanying metrics indicate anthropogenic-only contributions to the nocturnal scene. For more information about all metrics presented here, please see “NPS Night Skies Interpretation Guide” provided with this report. 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.

On this trip, all-sky photometric data was collected at two locations. These data are presented below, organized by observing location. Observations made in conjunction with all-sky photometry may include a visual narrative, an estimation of naked eye limiting magnitude (NELM), and an estimation of Bortle Class. Measurements include all-sky imaging with a calibrated CCD camera and zenith radiance measurements with a calibrated spectrometer. Imaging with a color DSLR camera was also performed at selected sites (see the following section of this report).

NPS NIGHT SKIES PROGRAM DATA NIGHT REPORT

MIIN210602B Minidoka NHS **Visitor Center** **2-Jun-21**

Data Night Attributes

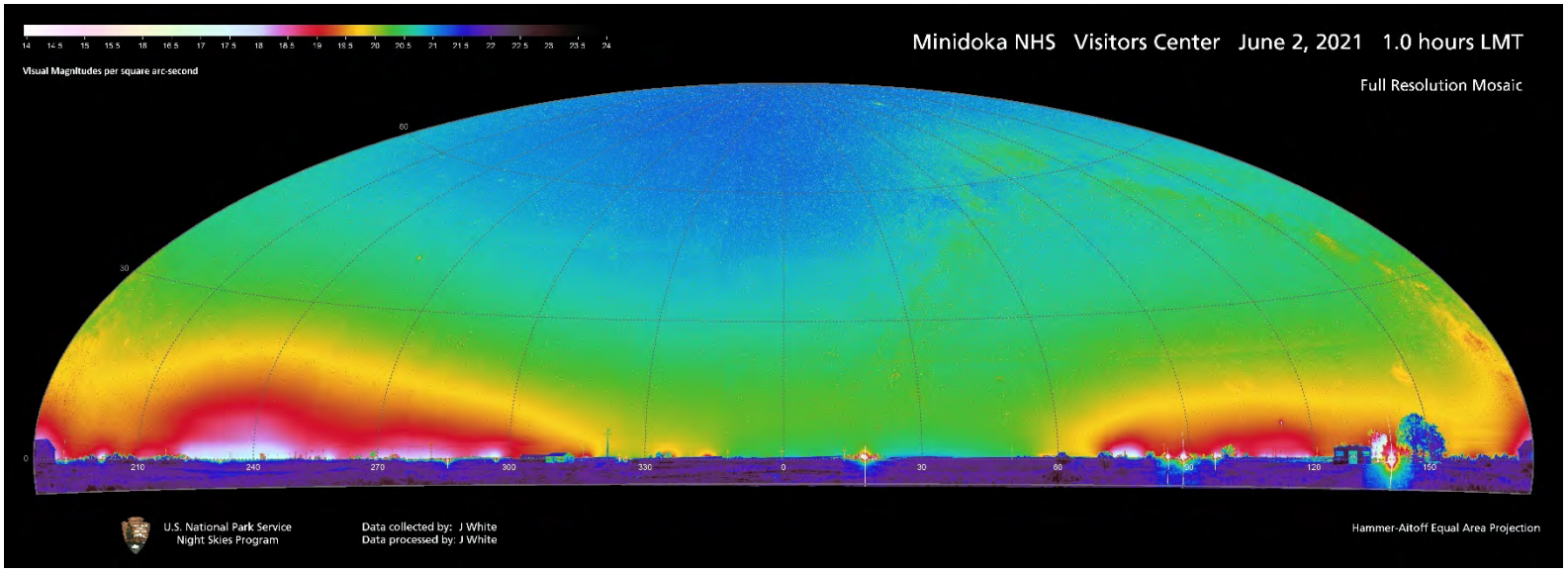
Longitude:	-114.24466	Camera:	SBIG 1	Air temp. (C):	16.7	ZLM:		OBS_1:	J. White
Latitude:	42.67969	# of sets:	1	R. H. (%):	39.0	BORTLE:	5	OBS_2:	
Elevation (m):	1345	Exposure (secs):	12	Wind Speed (mph):	1	SQM:		OBS_3:	

NARRATIVE: Clear and warm. Several light domes visible around the horizon with Twin Falls the largest. Bright dome to the southeast intentionally blocked by park building south west of the visitor center. No clouds with good transparency.

Data Set Attributes

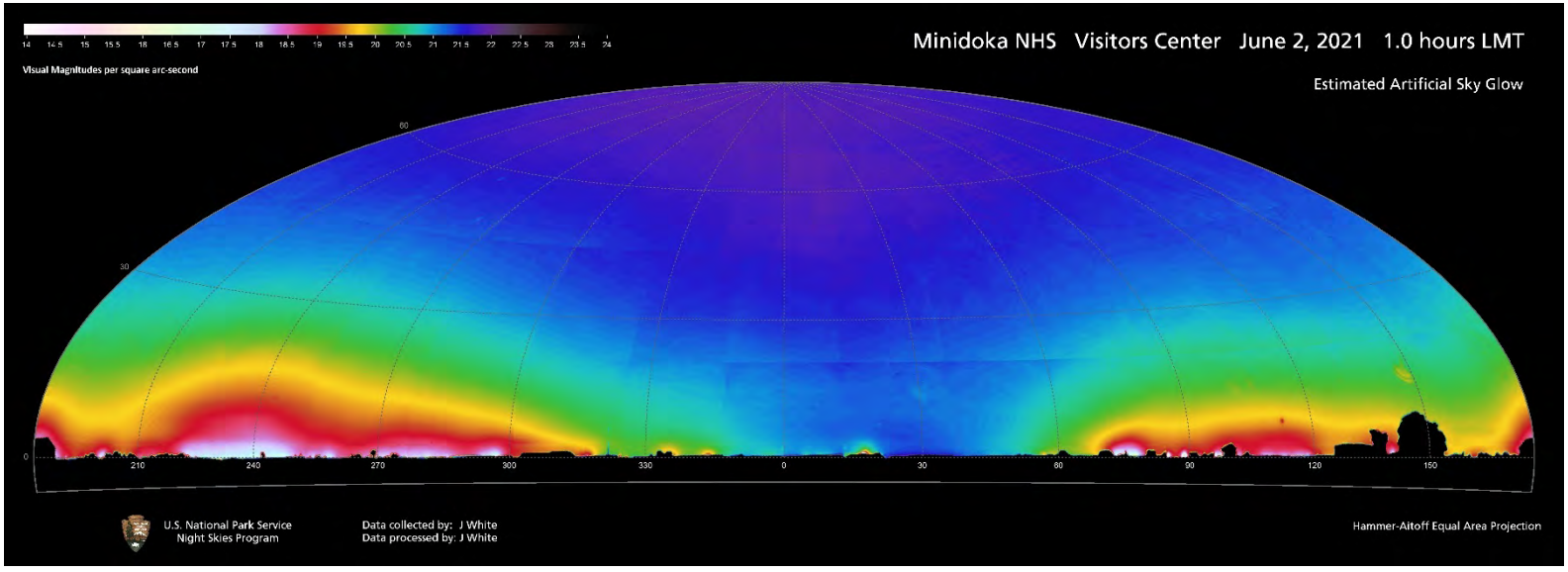
	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
Data Set	Use-able	Col-lection	Pro-cessing	Atmo-sphere:	Zenith airglow (µcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff. (mag/ airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Yes	4	4	4	89	4	better flat fit led to better natural subtraction	0.157	0.03	117	2	0	0.45	0.83	1.1

MIIN210602B_newflat Date (LMT) 2-Jun-21 Time (LMT): 1.04



PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (µcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (µcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest Luminance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
20.14	950	21.15	376	15.39	75,667	20.81	-8.45	2.057	2.221



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (µcd/m^2)	Average Sky Luminance to zenith angle 80° (µcd/m^2)	Average Sky Luminance to zenith angle 70° (µcd/m^2)	Zenith Luminance (µcd/m^2)	Brightest luminance	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
43.6	652	436.2	343.8	196	75,453	2.63	-8.00	1.211	1.723

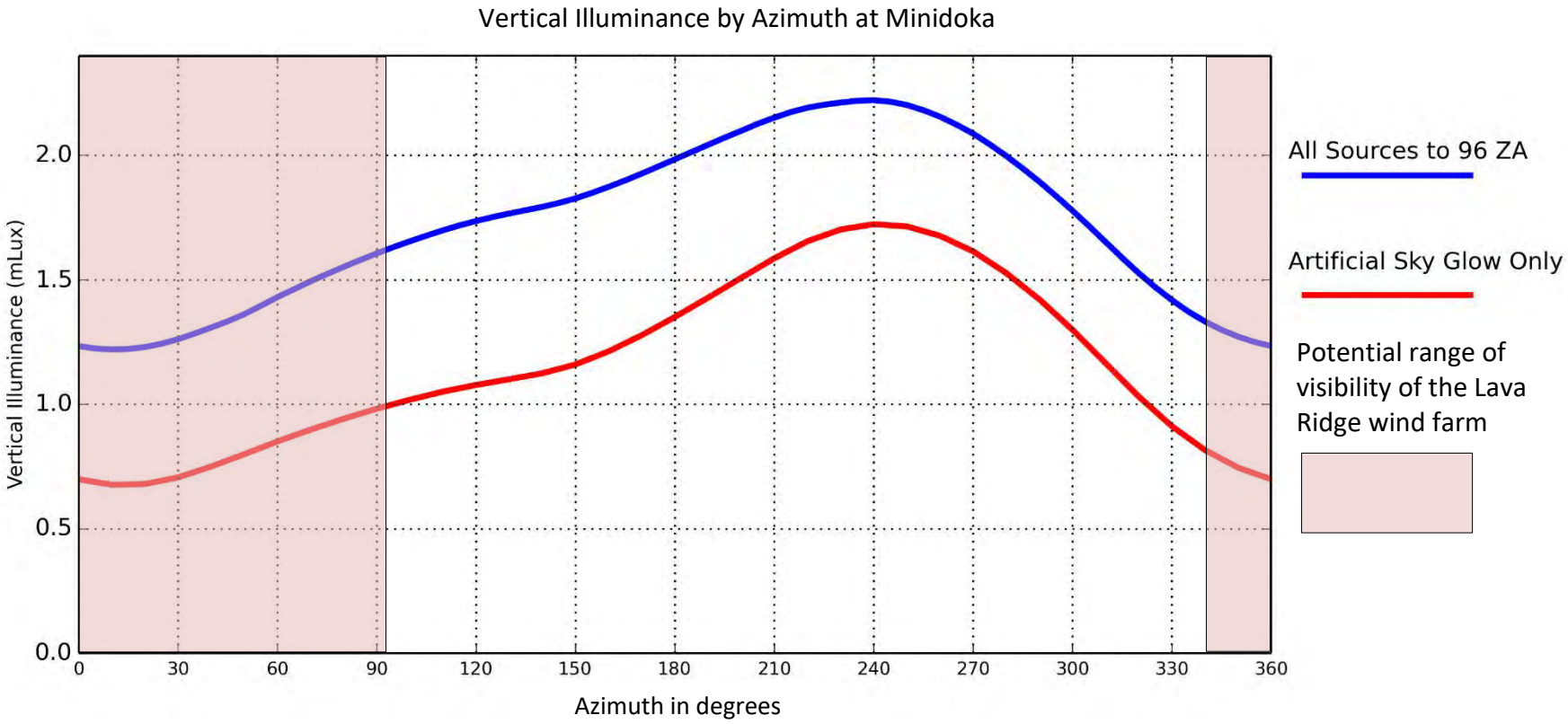


Figure 3 Vertical illuminance (mlux) of all sources (blue) and artificial sources (red) from Minidoka plotted across azimuth with potential visual impact of the proposed Lava Ridge wind farm.

NPS NIGHT SKIES PROGRAM DATA NIGHT REPORT

CRMO210604 Craters of the Moon NM **Laidlaw Corral** **4-Jun-21**

Data Night Attributes

Longitude:	-113.72842	Camera:	SBIG 1	Air temp. (C):	21.1	ZLM:	7.10	OBS_1:	J. White
Latitude:	43.03635	# of sets:	2	R. H. (%):	31.0	BORTLE:	3	OBS_2:	
Elevation (m):	1358	Exposure (secs):	12	Wind Speed (mph):	2	SQM:		OBS_3:	

NARRATIVE: Mostly clear with low clouds to the west and south. Good transparency. Two large visible light domes to the south with a few very small domes to the southeast. Dark overhead and to the west and north. A few faintly visible light domes to the northeast. Milk Way easily visible rising in the east.

Data Set Attributes

Data Set	Quality Flags				Natural Sky Model			Extinction				Collection Properties			
	Use-able	Col-lection	Pro-cessing	Atmo-sphere:	Zenith airglow (µcd/m²)	Fit quality	Natural sky model fit notes	Ext. coeff.(mag/ airmass)	Std err Y	# stars used	# stars reject	% Clouds	Ave. Point Error	Max Point Error	total bias drift
1	Y	5	4	4	83		set to 0 nL at zenith	0.175	0.04	143	2	5	0.35	0.81	1.7
2	Y	5	4	4	76		set to 0 nL at zenith	0.183	0.06	131	10	5	0.34	0.82	1.4

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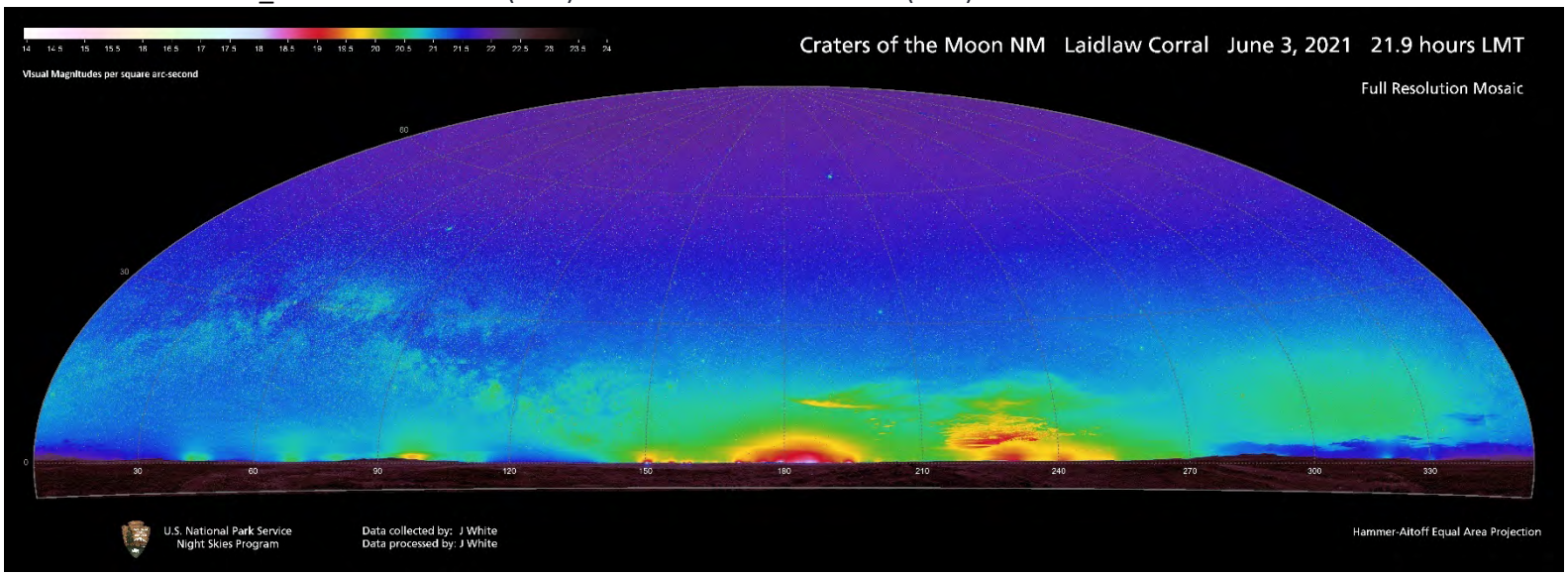
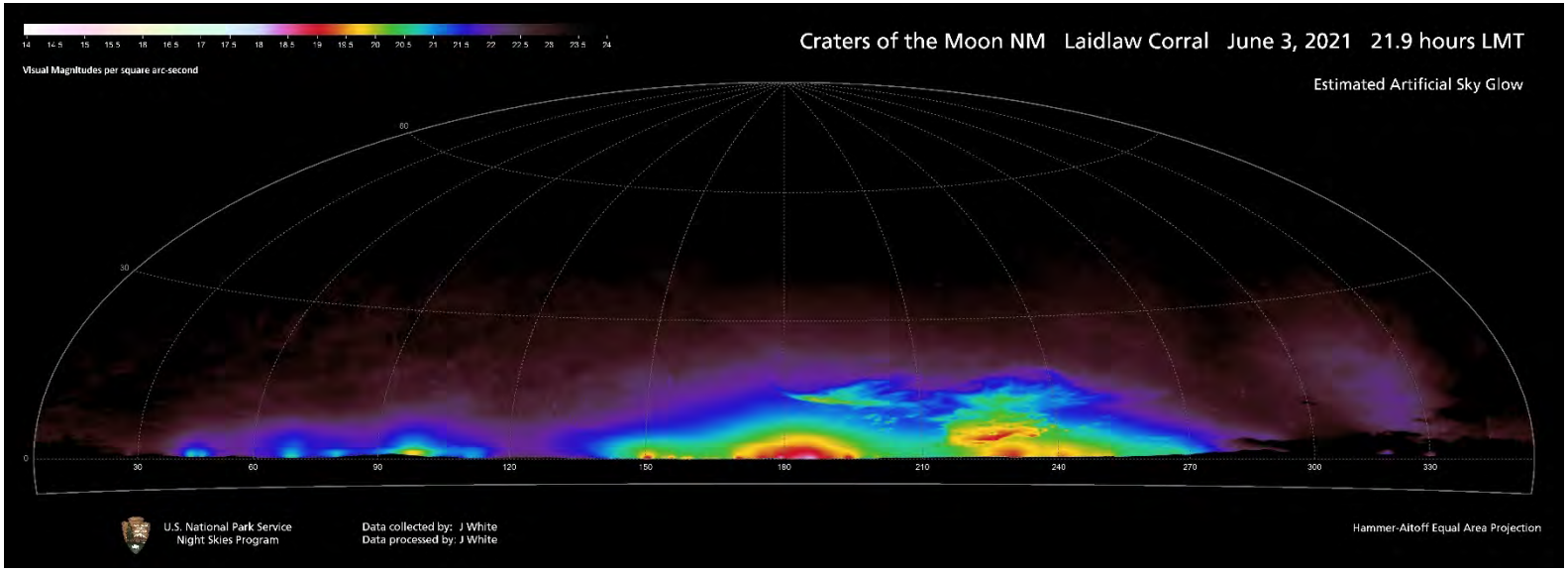


PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (µcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (µcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest luminance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.15	377	22.07	161	18.19	5,754	21.69	-7.43	0.885	0.814



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (µcd/m^2)	Average Sky Luminance to zenith angle 80° (µcd/m^2)	Average Sky Luminance to zenith angle 70° (µcd/m^2)	Zenith Luminance (µcd/m^2)	Brightest Luminance	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
86.4	96	44.4	24.7	4	5,584	0.38	-5.92	0.111	0.362

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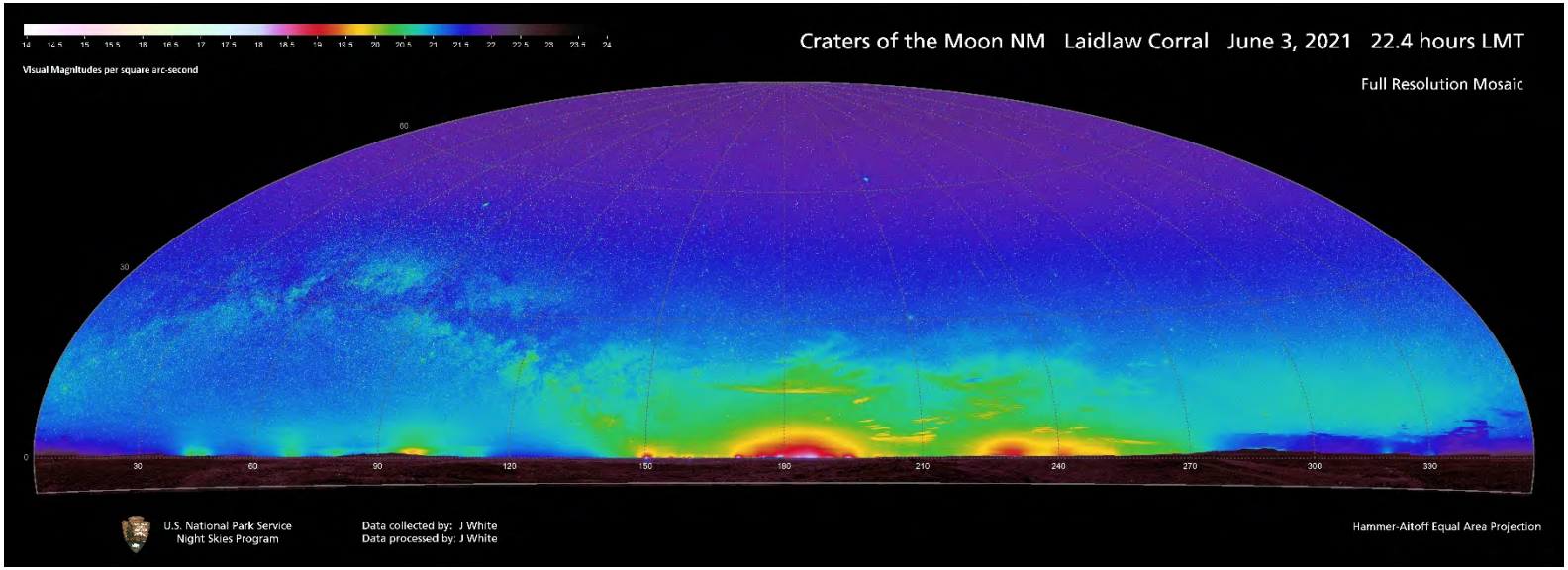
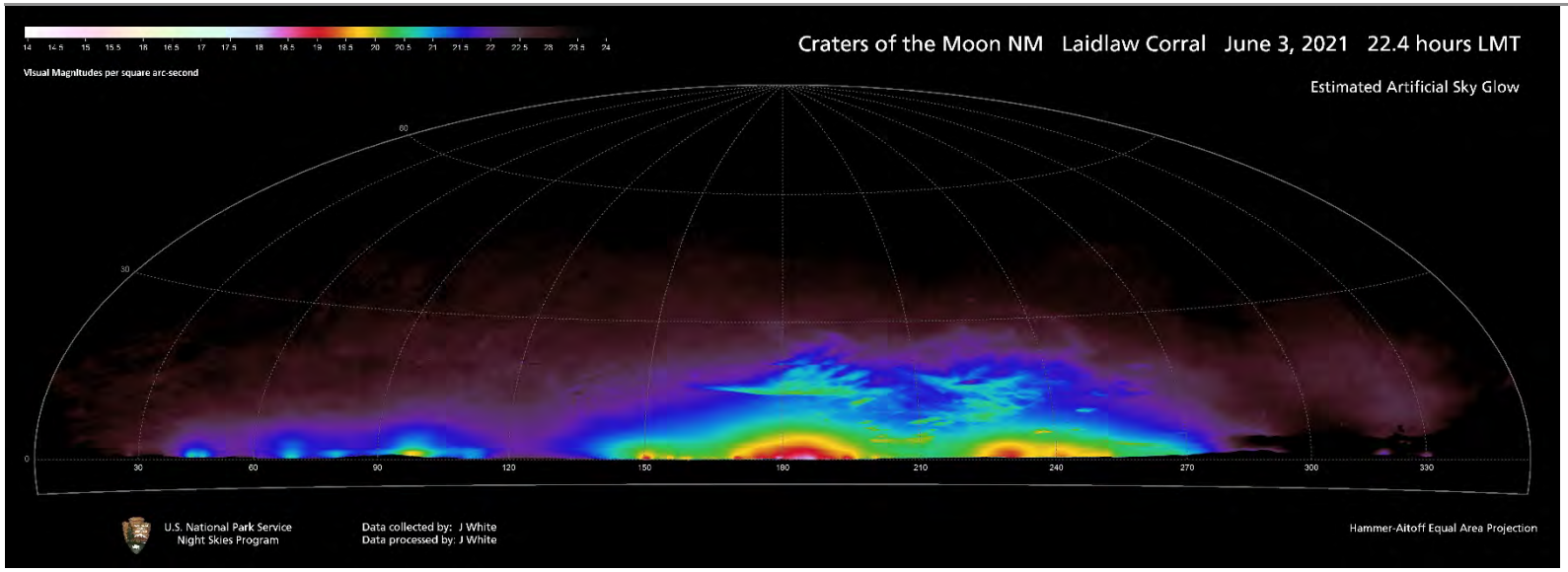


PHOTOMETRY OF ALL SOURCES

Average Sky Luminance (mag arcsec^{-2})	Average Sky Luminance (µcd/m^2)	Zenith Luminance (mag arcsec^{-2})	Zenith Luminance (µcd/m^2)	Brightest luminance (mag arcsec^{-2})	Brightest luminance	Synthetic SQM (mag arcsec^{-2})	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
21.16	371	22.11	155	18.09	6,271	21.70	-7.41	0.873	0.830



PHOTOMETRY OF ARTIFICIAL SKYGLOW

Sky Quality Index (SQI)	Average Sky Luminance (µcd/m^2)	Average Sky Luminance to zenith angle 80° (µcd/m^2)	Average Sky Luminance to zenith angle 70° (µcd/m^2)	Zenith Luminance (µcd/m^2)	Brightest luminance	All-sky light pollution ratio (ALR)	Total luminous emittance (mags)	Illuminance (mlux) Horizontal	Max Vert
84.8	105	55.5	31.3	0	6,105	0.42	-6.02	0.134	0.398

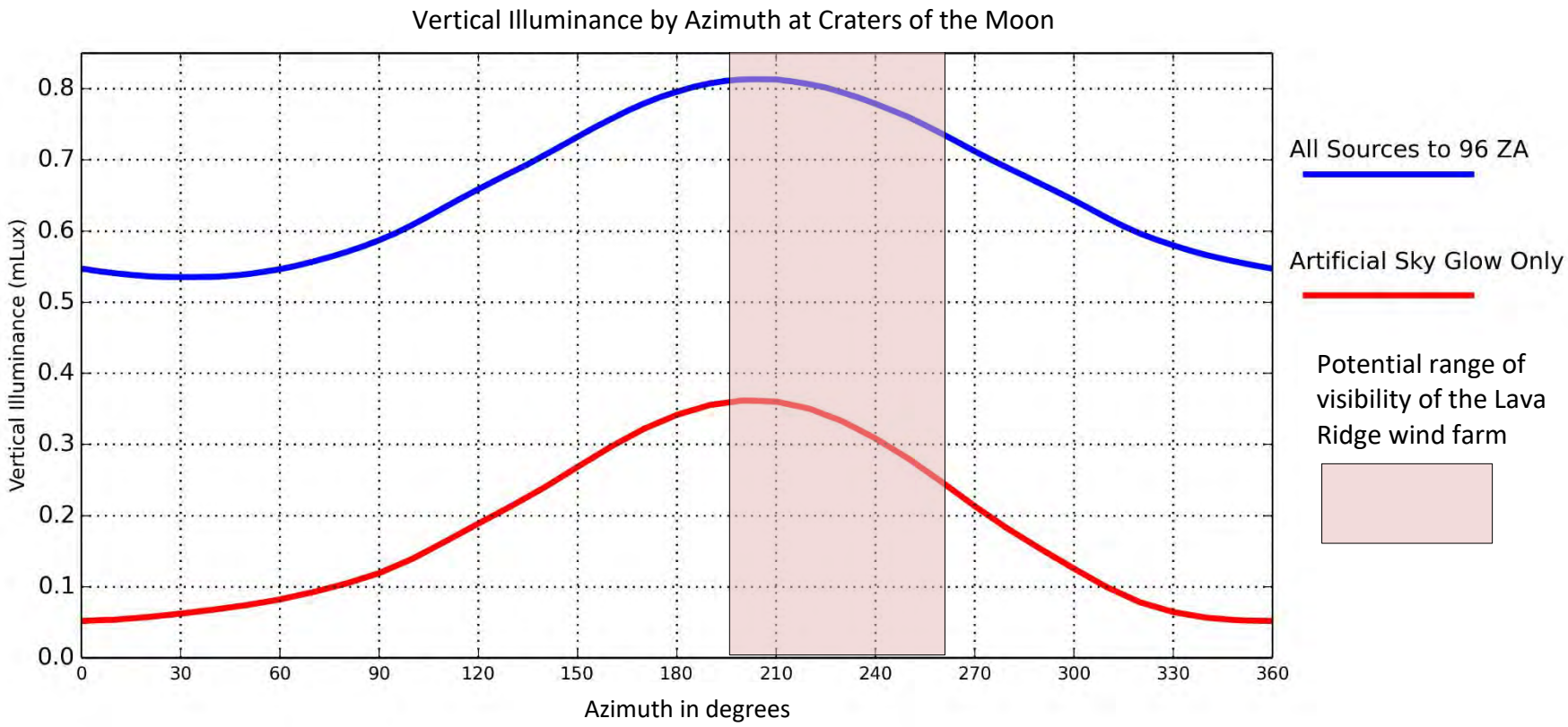


Figure 4 Vertical illuminance (mlux) of all sources (blue) and artificial sources (red) plotted across azimuth with potential visual impact of the proposed Lava Ridge wind farm.

Indicators of visual impact and functional consequences

Minidoka NHS

Analysis of the CCD data produced indicator values that denote moderate resource impacts from internal and external sources. Photometry of artificial skyglow at zenith (overhead) measured 196 ucd/m^2 which is 114% brighter than average natural conditions. This indicates sky quality degradation in the darkest region of the sky reducing visibility of stars. Despite anthropogenic impact, the subtle details of the Milky Way were visible including dust lanes and other structural features.

The All-sky light pollution ratio (ALR) was 2.63, or 263% brighter than average natural conditions. An ALR above 2.0 indicates the entire sky has some amount of artificial sky glow and the fainter parts of the Milky Way are invisible. Light from the brighter areas illuminates the landscape allowing for easy recognition of objects. For visitors, full dark adaptation is not possible and significant glare may be present.

Several factors contributed to the high ALR at MIIN. Most notable was the light dome of Twin Falls, ID. The light dome extended more than 50° across the horizon and more than 20° in altitude. Smaller domes from the communities of Jerome and Burley were also easily visible. Direct glare also contributed to degraded sky quality. Two lights on a maintenance facility near the visitor's center within the park contributed to glare and light spill, while additional bright light sources were detected outside of the park boundaries between 60° and 90° azimuth from the observation point. One prominent glare source was observed due south from the observation point and was intentionally blocked by a park service building as it would have saturated the CCD camera.

Vertical illuminance is a measure of the photon flux striking a vertical surface and can be useful in quantifying light trespass. The indicator maximum vertical illuminance (Max Vert) is the maximum measure of all possible orientations around the azimuth. Note the illuminance referred to here is from sky glow alone and not from direct light trespass as described in the previous paragraph. From Minidoka maximum vertical illuminance measured 1.7 mlux at 240° azimuth. This aligned with Twin Falls, ID and indicates an addition of more than 4 times or 430% more illumination to the park's nocturnal environment over average natural conditions. Minimum vertical illuminance was measured at 0.67 mlux at 10° azimuth. Figure 3 displays vertical illuminance by azimuth from all sources of light and just artificial sources. The predicted visual extent of the Lava Ridge windfarm is also plotted to illustrate how the addition of light may affect ambient conditions. As observed from MIIN, the predicted visual range of the wind farm would be 340° to 96° which overlaps with the lowest vertical illuminance measures.

Craters of the Moon NM

Analysis of the CCD data produced indicator values that denote minimal to slight resource impacts from external sources. Photometry of artificial skyglow at zenith (overhead) measured <0.10 ucd/m^2, indicating any anthropogenic sources were less than our camera sensitivity. The dominant source of light at zenith was natural airglow. Diffuse deep sky objects were easily visible and a naked-eye limiting magnitude of 7.1 indicates excellent conditions overhead.

For Craters of the Moon, analysis of the second data set was used, due to the passing clouds over Twin Falls. Continued passing clouds likely contributed to a slight increase in overall sky brightness and vertical illuminance. The All-sky light pollution ratio (ALR) was 0.41, or 41% brighter than average natural conditions indicating good overall conditions. An ALR of 0.4 indicates generally good conditions with 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. The Milky Way is visible across the sky but may be lost near the horizon with anthropogenic light masking some celestial features. For visitors, full dark adaptation is possible in most directions.

The most prominent contributions to ALR at CRMO was skyglow from Burley, Twin Falls and Jerome. These three domes were visible to the naked eye and stood out from the otherwise dark horizon. These domes also masked the Milky Way just at the horizon but did not mask other celestial features. Dark adaptation was possible looking in most directions. The ALR was likely inflated slightly be stray clouds reflecting light from the Burley and Twin Falls light dome. Visual observations, especially at zenith indicated conditions more closely associated with values lower than 0.4.

Vertical illuminance is a measure of the photon flux striking a vertical surface and can be useful in quantifying light trespass. The indicator maximum vertical illuminance (Max Vert) is the maximum measure of all possible orientations around the azimuth. Note the illuminance referred to here is from sky glow alone and not from direct light trespass as described in the previous paragraph. At Craters of the Moon maximum vertical illuminance measured 0.39 mlux at 200° azimuth and was consistent between 180-200°. This aligns with Burley, ID and the surrounding communities and indicates a doubling of illuminance or 100% more vertical illumination into park's nocturnal environment over average natural conditions. Minimum vertical illuminance was measured 0.05 mlux, just 12% brighter than natural conditions, at an azimuth of 0°. Figure 4 displays vertical illuminance by azimuth from all sources of light and just artificial. The predicted visual extent of the Lava Ridge windfarm is also plotted to illustrate how the addition of light may affect ambient conditions. As observed from CRMO, the predicted visual range of the wind farm would be 198° to 260° which aligns with moderate vertical illuminance impacts from existing sources.

Spectral Measurements

A spectrometer was used to record the spectral composition of zenith at both MIIN and CRMO. With a spectral resolution of 2nm, the spectrometer records the distribution of radiant power across the visible spectrum, from 380nm (violet) to 780nm (red). Synthetic photometry can be performed on the raw data to produce the same luminance metrics as the CCD system and other instruments. Methodology for spectral analysis have not been fully developed so here we provide a spectral snapshot of the zenith sky at each park. Unlike the CCD camera there is no natural sky subtraction process, therefore values represent all sources of light.

Minidoka

Synthetic photometry of spectral data from MIIN indicated a zenith sky brightness of 21.2 mags/arc second, close to the CCD measurement of 21.1 (spectral data were collected one night after CCD data). The spectral profile (Figure 5) shows a prominent spike at 556nm from natural airglow, as well as a significant amount of blue light between 430nm and 460nm. This is likely contribution from LED sources as there are no natural sources in this portion of the spectrum emitting at this power.

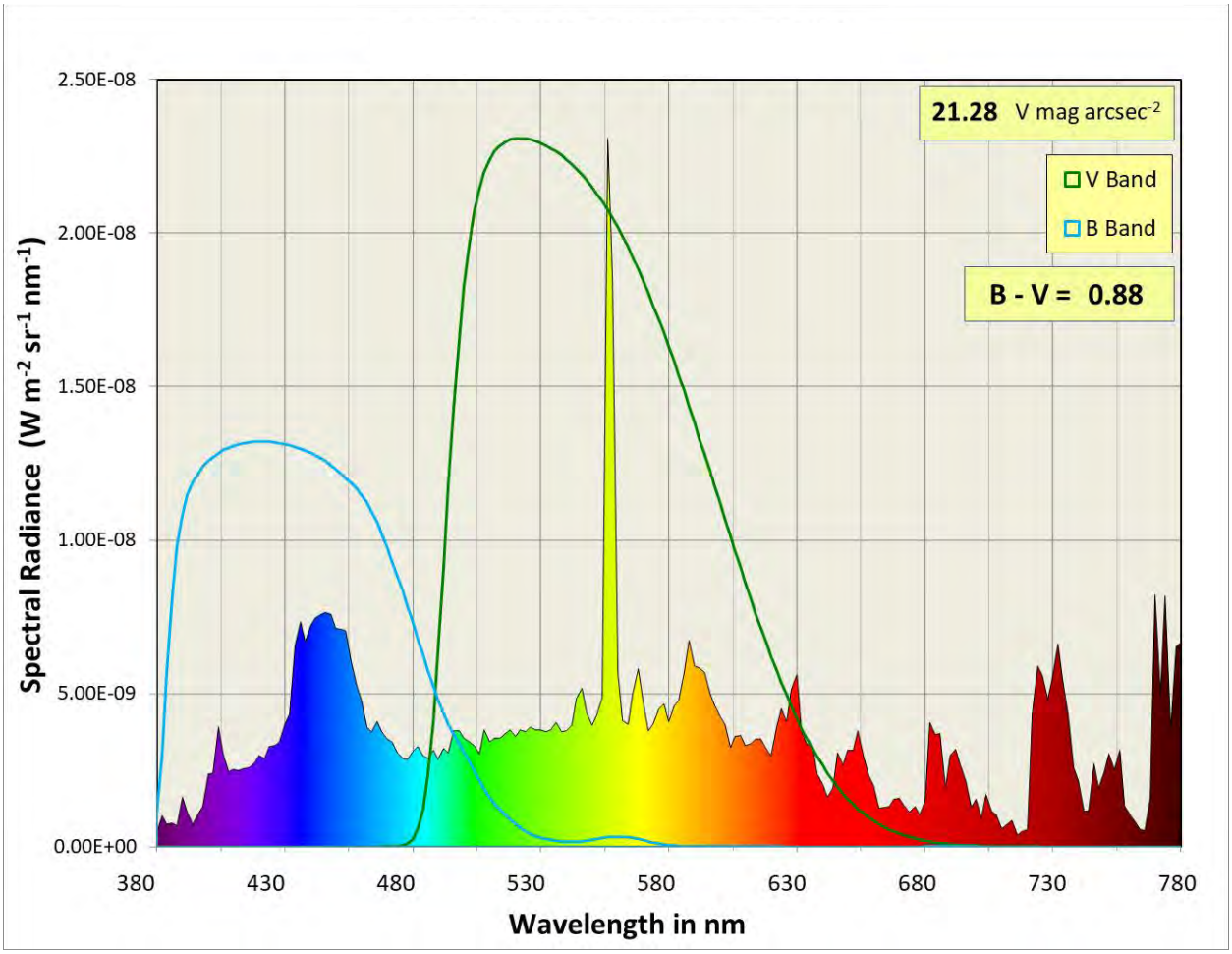


Figure 5 Spectral profile of zenith luminance at Minidoka NHS. Natural airglow is prominent at 558nm. Significant radiance between 430-460nm indicates scattered light from blue rich sources are impacting zenith.

Craters of the Moon

Synthetic photometry of spectral data from MIIN indicated a zenith sky brightness of 22.1 mags/arc second, in line with the CCD measurement of 22.1. The spectral profile (Figure 6) shows a prominent spike at 558nm and a smaller spike at 630nm, both from natural oxygen emissions. This profile as well as the synthetic magnitude measure indicate a zenith condition unfettered by artificial sources.

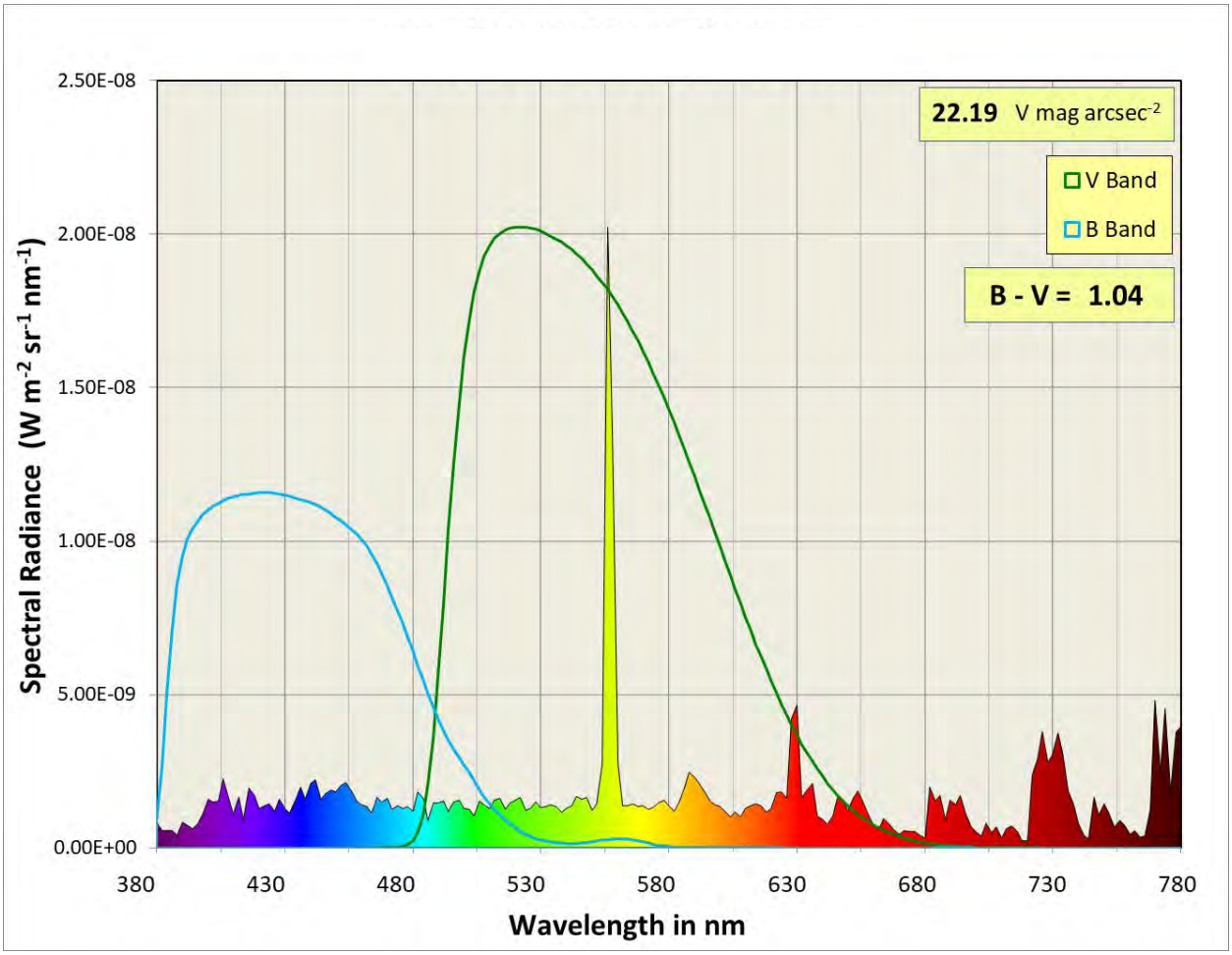


Figure 6 Spectral profile of zenith from Craters of the Moon NM. Natural airglow is prominent at 558nm and 630nm, which aligns with green and red oxygen emission lines. Synthetic photometry and lack of other spectral signatures indicate a pristine zenith condition.

Photographic Observations

Minidoka

Color photography provides a tool for descriptive visual quality assessments of the nocturnal scene which can be more representative of a visitor's experience. At MIIN, a Nikon D850 with a Sigma 8mm fisheye lens was used to capture an all-sky imaged from just west of the visitor center (Figure 7). In addition to capturing the Milky Way detail and green airglow to the north, the image also shows the numerous artificial sources around the horizon. A Sony a7sII with a 24mm lens was used to capture a >180-degree panorama from the Minidoka Key Observation Point (KOP) located at the visitor center (Figure 8). This panorama documents existing light domes and point sources and full extent of horizon that may be impacted by the Lava Ridge windfarm. Finally, light trespass from park facility lights was documented to demonstrate the impact of unshielded or partially shielded lights in an otherwise dark setting. Although the light was housed in a cannister fixture, the LED element hung below the edge of the shield allowing for considerable spill light (Figure 9a). The light color temperature was "warm white" and estimated at 3000K yet still attracted many hundreds of insects (Figure 9b). Based on this observation we recommend the light be turned off if it is not required. If light is required at this facility, we recommend a fully recessed cannister light with a 2200K color temperature with a maximum of 800 lumens. If the lighting task is just for orientation to the facility door, 400 lumens will suffice.

Figure 7 Fisheye image from Minidoka NHS, oriented north up, east right. While the impact of skyglow is evident around the horizon, natural features such as the Milk way are still very prominent. Note the moonrise to the east just above the horizon.

Figure 8 Panorama from the Minidoka visitor's center key observation point.

Figure 9 Light trespass across MIIN illuminating the visitor center and park grounds emanating from two facility lights which were not fully shielded (a). In addition to light trespass the lights attracted hundreds of insects (b).

Craters of the Moon

As with Minidoka, a Nikon D850 with a Sigma 8mm fisheye lens was used to capture an all-sky image from Laidlaw Corral (Figure 10). This fisheye illustrates the impact of Burley and Twin Falls on the southern horizon and the lack of anthropogenic light around west, north, and east. The Milky Way is easily visible with fine structural details apparent. A panorama of the southern horizon (Figure 11) documents in greater detail the Burley and Twin Falls light domes, but also shows the incredible detail visible in the Milky Way. And finally, a panorama looking north shows the lack of anthropogenic light over Craters of the Moon National Monument.

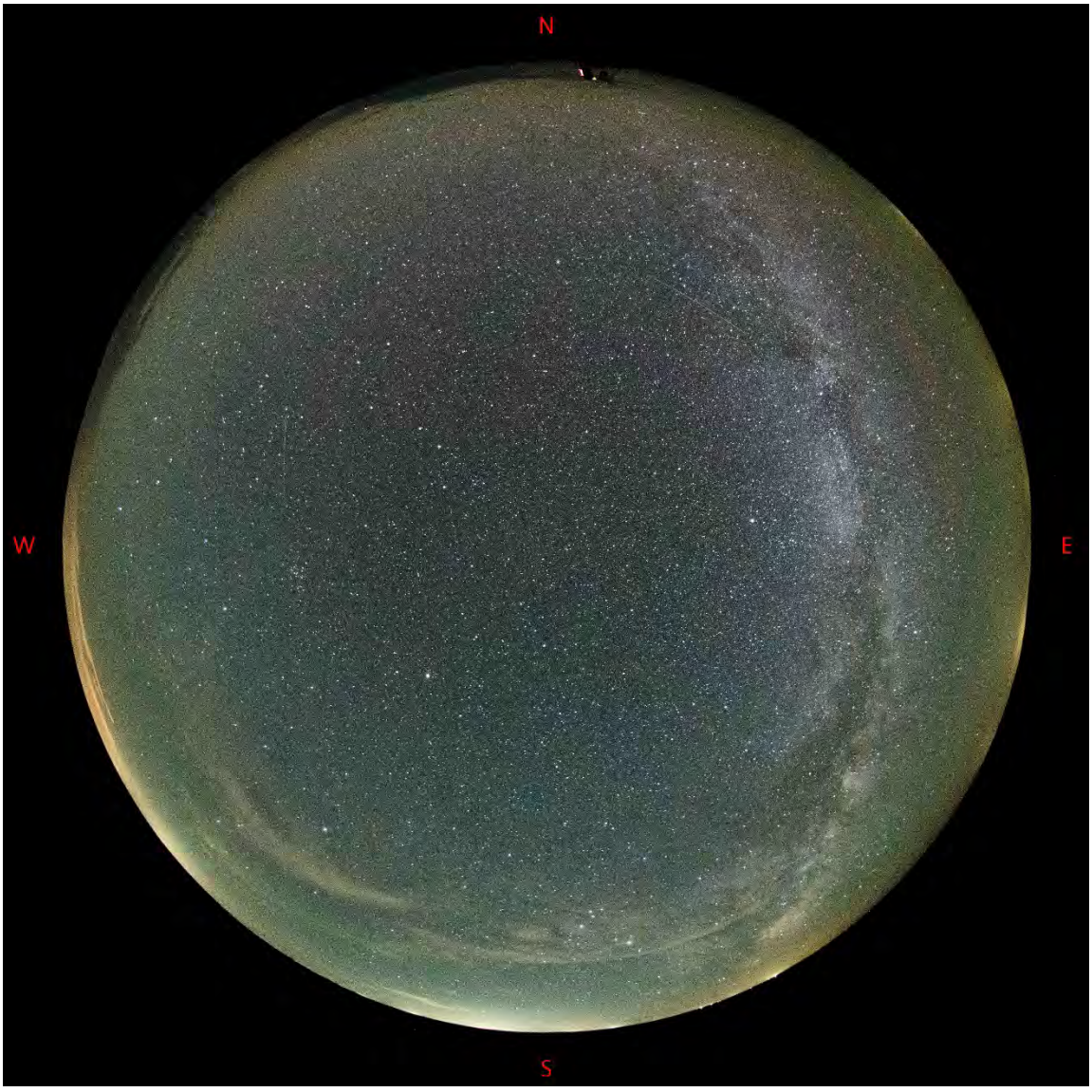


Figure 10 Fisheye image from Laidlaw Corral observation point. Burley is easily visible due south as is Twin Falls to the southwest. Despite these light domes, night sky condition is still very good. The Milky Way shows incredible detail, and natural airglow is readily apparent.

Figure 11 Panorama looking south and west from Craters of the Moon Laidlaw Corral night sky observation point.


Figure 12 Panorama looking north and east into Craters of the Moon National Monument from the night sky observation point.

Appendix A - NPS Night Skies Data Interpretation

All-Sky Images and Metrics Interpretation

Each page in this section shows two panoramic images associated with each data set. The date and time are in local mean time (LMT). The top image shows the observed night sky, which contains light from both natural and artificial sources. We use magnitude per square arcsecond for measuring the sky surface brightness. A sky surface brightness of 22 mag/arcsec^2 would be considered pristine, and a sky surface brightness < 20 mag/arcsec^2 would be considered greatly deviated from the natural condition. The warmer colors in these images represent brighter skies. In the top image, purple and dark blue colors indicate unpolluted sky, and the Milky Way under the natural condition appears green in this color scheme. The bottom image shows only the skyglow from artificial sources. Light domes along the horizon from the nearby area are more apparent in this bottom image.

Photometry of All Sources

Average Sky Luminance: average sky brightness containing all light sources measured in mag/arcsec^2 and μcd/m^2. The natural reference is 21.6 mag/arcsec^2 or 250 μcd/m^2.

Zenith Luminance: zenith sky brightness containing all light sources. This measure is calculated from the median pixel value of an approximately one-degree diameter circle centered on the zenith. 22.0 mag/arcsec^2 or 172 μcd/m^2 is generally considered to represent the darkest part of pristine skies. Any value lower (brighter) than 21.3 mag/arcsec^2 usually indicates significantly degraded sky quality unless the Milky Way is overhead or the natural airglow or the zodiacal light is bright.

Brightest Luminance: brightest sky brightness containing all light sources. The brightest part of the Milky Way is 19.6 mag/arcsec^2 or 1500 μcd/m^2. Brighter values will begin to impair dark adaptation, and values brighter than 17.0 mag/arcsec^2 can cast shadows.

Synthetic SQM: the hypothetical SQM value approximated from the image containing all light sources.

Total luminous emittance: the total luminous flux from the sky if all the light were collected into a point, like a star. This value excludes the light from individual stars and planets and glare from unshielded lights but includes the Milky Way, airglow, zodiacal light, and skyglow. It can be compared with the moon at various phases: magnitude -8 at crescent, -11 at half phase, and -12.5 at full phase. A value larger (darker) than -7.0 is exceptionally dark; between -7.5 and -7.0 is typical for near pristine locations. A value smaller (brighter) than -8.0 usually indicates significantly degraded sky quality.

Illuminance: the amount of visible light incident on a unit surface area in millilux (mlux). The impact from a light source is weighted by the cosine of its angle of incidence. The horizontal illuminance describes the amount of light landing on a horizontal surface. It provides the illuminance measurement of the

entire sky at a glance but is not sensitive to skyglow near the horizon. The vertical illuminance describes the light striking a vertical surface. The vertical illuminance better reflects the brightness of sources near the horizon. Since a vertical surface can be held facing many different directions, we report the vertical illuminance measured at the direction that gives the largest value. The natural reference condition for moonless nights is 0.8 mlux for horizontal and 0.4 mlux for vertical illuminance.

Photometry of Artificial Skyglow

Sky Quality Index (SQI): this index is no longer being used.

Average Sky Luminance: average skyglow brightness in $\mu cd/m^2$.

Average Sky Luminance to zenith angle (ZA) 80°: average skyglow brightness in $\mu cd/m^2$ from zenith to 80° down towards the horizon.

Average Sky Luminance to ZA 70°: average skyglow brightness in $\mu cd/m^2$ from zenith to 70° down towards the horizon.

Zenith Luminance: skyglow brightness at zenith in $\mu cd/m^2$.

Brightest Luminance: brightest skyglow brightness in $\mu cd/m^2$.

All-sky light pollution ratio (ALR): the total skyglow brightness divided by the natural dark sky set at 250 $\mu cd/m^2$. If the sky is completely free of skyglow, this ratio is zero. Generally, ALR values less than 0.3 indicate excellent conditions, 0.3 to 2.0 indicate impaired sky quality (though areas of the sky may reveal important natural features), and greater than 2.0 indicate the natural night sky is not readily visible.

Total luminous emittance: the total luminous flux from skyglow if all the light were collected into a point, like a star. For comparison, Sirius or Jupiter has magnitude of -2, Venus -4, crescent moon -8, half-moon -11, and full moon -12.5.

Illuminance: the illuminance values from skyglow. See the *Illuminance* entry in the previous subsection for result interpretation.