Night Sky — A Valuable Resource In the Nation's National Parks

By Donald Henderson, Mark A. Yocke and Henry Hogo

"It was in the cool and pleasant month of September; and long after going to bed we lay awake under the blankets watching the stars that on clear nights always shine with such intense brightness over the lonely Western plains."

". . . along the Little Missouri . . . at night the stars shone with extraordinary brilliancy."

These above quotes, attributed to Theodore Roosevelt approximately 100 years ago, emphasize the significance of the night sky at what is now Theodore Roosevelt NP.

Pete Parry, Canyonlands NP Superintendent, expressed a thought that may represent the thinking of many visitors to the great western national parks: "One of the great Canyonlands experiences is lying spread eagle on a rock in the stillness of a pitch black night observing the myriad of stars overhead."

EPA acknowledges the nighttime skies are an important part of the wilderness experience, especially to campers and backpackers, and feels that this aspect can be considered a value for use in establishing visibility objectives by the Federal land managers.

A magnitude scale for describing the apparent brightness of objects in the sky has been developed by astronomers. The magnitude scale varies from −26.7 for the brightest object in the sky, the sun, to +23 which is the faintest star observed by the 200-inch Mount Palomar telescope. When stars of magnitude six are visible to an unaided eye, the Milky Way galaxy is usually visible. **The magnitude is established such that a change of five units of magnitude indicates a factor of one hundred difference in star brightness.** To illustrate the use of the magnitude scale, the star Sirius in the constellation Carris Majoris is the brightest star in the sky with a magnitude of −1.5. (The planets are excluded.) Polaris (the North Star), has a variable magnitude of about +2.0. Therefore, the magnitude of Polaris is 3.5 units greater than Sirius, and the brightness of Sirius is about 25 times greater than Polaris. The planet Venus is the third brightest object in the sky, exceeded only by the sun and the moon.

The distribution of objects in the sky and their apparent brightness at a given location provide the beauty of the night sky. Man-made lighting and man-made air pollution affects the clarity of the night sky as seen by an observer.

Increased light in the night sky caused by reflection of sunlight from the full moon will decrease the number of visible stars, and reduce the visibility of the Milky Way. These subtle effects of the moon are a natural part of the night sky experience to which most observers do not object. Increased light in the night sky caused by light produced by mans' activities in urban areas (light pollution) diminishes the number of visible stars.

As urban areas have increased in size, light pollution has increased. In recent years this artificial illumination has been a major concern to astronomers. Ground-based astronomical measurements of faint objects made with large telescopes are very sensitive to interference from artificial lighting. The astronomical community has been influential in causing changes in some city ordinances to require control of outdoor lighting to reduce the interference of light pollution on astronomical observations. The cities of Tucson, Ariz., San Jose, Calif., and some small communities near Palomar Observatory have passed ordinances to control outdoor lighting.

No methods for controlling the interference of the moon have been discovered!

The effects of air pollution pose a serious problem to the quality of the night sky. Control of air pollution is being actively pursued under the Clean Air Act Amendments.

Many national park-managed lands have been designated class I under the Clean Air Act Amendments, which specify that air pollution will be controlled to preserve, protect, and enhance the air quality in national parks. Because national parks are to be kept clean from air pollution, efforts are made to prevent industrial development and urban spread near national park class I areas. Therefore, national parks are prime areas for locating astronomical observatories because light and air pollution are controlled. **For this reason, the National Science Foundation is examining the possibility of selecting a national park as a suitable site for future construction and operation of an astronomical observatory.**

Even though provisions exist for controlling intrusion of air pollution in national parks, and light pollution from urban sprawl, or large industries, weaknesses in assessment techniques and the difficulty of enforcing the regulations, may allow threats to diminish the value of the night sky resource in national parks.

Recently, the Department of Energy proposed to locate and operate a nuclear waste repository within one mile of Canyonlands NP. The repository would operate 24-hours each day with necessary outdoor lighting to perform the work and provide lighting for security at night. If this facility were allowed to be constructed and operate at the proposed location (Davis or Lavender Canyon) just east of the park boundary, the type of experiences related by President Theodore Roosevelt and Superintendent Parry would be diminished.

Superintendent Parry, and Tom Wylie, Resource Management Specialist, Canyonlands NP (currently Superintendent, Florissant Fossil Beds National Monument) and Cecil Lewis, Air Quality Coordinator, Rocky Mountain Regional Office, recommended an evaluation of the effects of outdoor lighting from the proposed nuclear waste repository were it to be located near Canyonlands NP. The Air Quality Division contracted to Systems Applications, Inc. to perform the study. The purpose was to determine if human perception of night sky brightness viewed from Canyonlands NP would be significantly affected by 24-hour operation of the proposed nuclear waste repository.

Those conducting the study recognize that the park has "outstanding opportunities for solitude." Park visitors have identified solitude, including viewing the pristine nighttime sky, as a value contributing to their enjoyment of the park.

Systems Applications, Inc. developed a mathematical technique to study the potential impact of light pollution from the proposed repository sites in Davis and Lavender Canyons. In this study night sky glow and terrain illumination resulting from nighttime operation of the proposed nuclear waste repository were calculated, and estimates of the potential for human perception of these effects were made. The study involved the following steps: (1) Development of a mathematical model of atmospheric optics to predict the night sky glow effects; (2) Verification of the model's prediction performance; (3) Application of the model to the area surrounding the proposed facility; (4) Estimation of the potential of the night sky glow to obscure starlight; and (5) Development of a computer program to depict graphically the views of terrain features under different conditions of illumination.

Two computer programs were written for this study. The first is a numerical model of atmospheric optics for prediction of night sky glow.

The Night Sky Glow Model was designed to predict the luminosity of scattered light in the night sky due to operation of the proposed nuclear waste repository. Such a model must be capable of predicting the glow in any portion of the sky under various atmospheric conditions and must be flexible enough to address any combination of facility sites and viewing points within the park. Because of the complexity of the equations and the large number of calculations required, a numerical (computer) modeling approach was used.

The second program produces three-dimensional views of terrain features visible from within the park and shows the relative luminosity of these terrain features during nighttime operations of the proposed repository. The program models terrain illumination from both natural and artificial light sources, and then plots simulated nighttime photographs.

Figures 1 and 2 are examples of graphic output from the night sky glow predictions. The four shading patterns indicate the degree of perceptibility of the predicted night glow. It should be noted that the perceived brightnesses of the shading patterns do not illustrate the actual brightness of the sky predicted by the model. The patterns only aid in interpreting the results.

The nighttime response of the human visual system has been estimated in psychophysiological studies. From the data in these studies it is clear that the threshold of visual detection (i.e., the minimum amount of light that can be visually detected) varies considerably among individuals and depends to a significant extent upon acclimation time and background lighting. On the basis of these studies we adopted a threshold of detectability (or the luminosity increment that is just barely perceptible) for the average human population to be about 5×10^{-4} lm m^{-2} sr (lumens per square meter per steradian) above a background nighttime sky luminosity. Using these same data, we selected about 2×10^{-4} lm m^{-2} sr and about 5×10^{-3} lm m^{-2} sr to represent, respectively, "perceptible" and "very perceptible" luminosity.

Figures 1 and 2 reveal that the predicted night glow associated with the Davis Canyon site would be perceptible for either of the two extreme visual range values of 30 or 391 kilometers. The impacts are predicted to be greatest at the closest viewing sites and to decrease with increasing distance from the sites.

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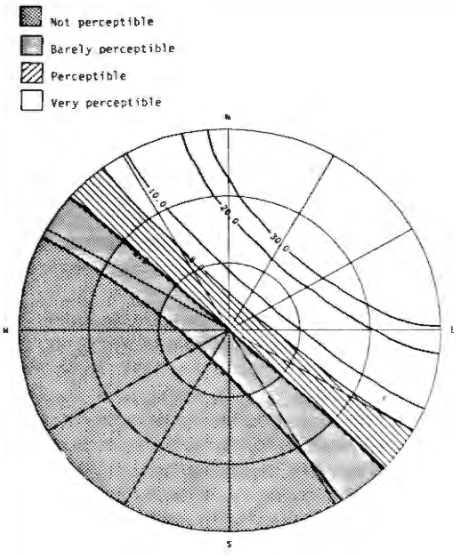


Figure 1. *Spatial distribution of sky brightness (10^{-3} $lm/m^2/sr$) due to the facility located at Davis Canyon as seen from Davis Canyon. (Assumed visual range of 30 km.)*

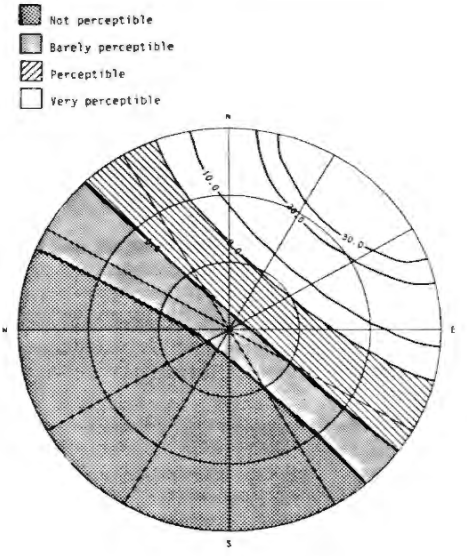


Figure 2. *Spatial distribution of sky brightness (10^{-3} $lm/m^2/sr$) due to the facility located at Davis Canyon as seen from Davis Canyon. (Assumed visual range of 391 km.*

Comparison of observed and predicted brightness provides some encouragement that the model predicts luminosities that are approximately correct. The tendency of the model to underpredict sky brightness close to the source is probably attributable to uncertainty about the actual light source distribution. One would expect that the effect of uncertainty about the source distribution is greatest close to the source and diminishes with increasing distance from the source. This tendency is exhibited in the model results.

Given the uncertainty in the light source data as well as other input to the model, we conclude that the model performance is acceptable and that the model is appropriate for application to the Canyonlands area. This evaluation of the Night Sky Glow Model is by no means comprehensive. A more thorough evaluation of the model is required if great confidence must be placed in its predictions.

When applied to the light emission of the proposed nuclear waste repository the Night Sky Glow Model predicts sky luminosities that should be perceptible (from either the Davis Canyon or Lavender Canyon site). As one would expect, the night glow is predicted to be greatest at the closest viewing sites and to decrease with increasing distance from the sites. The size and character of the night glow "dome" varies depending on the viewing site and the atmospheric aerosol.

Typically, the extent of the brightness portions of the night glow "dome" is larger for a polluted atmosphere than for a clear atmosphere. This is because under polluted conditions the amount of light scattered is greatest near the source due to higher aerosol concentrations (recall that night glow is caused only by light that is scattered back to the observer). However, as the light propagates from the source under polluted conditions, it is rapidly attenuated (because of the large amount of light that is scattered out of the light path). Therefore, the overall extent of the night glow "dome" is smaller in a polluted atmosphere than in a clean atmosphere.

The following conclusions can be drawn from this study:

The proposed nuclear waste repository, located at either the Davis Canyon or Lavender Canyon site, will probably cause a perceptible night glow and obscure the view of dim stars and the Milky Way in some portions of the sky from many locations within Canyonlands NP.

Some terrain features visible from Canyonlands NP will be illuminated directly by repository lighting at either of the two proposed repository sites and would be visible from adjacent parts of the park.

We have performed only limited verification and evaluation of predictions of the models developed and used in this study. More comprehensive evaluation of the models is required before great confidence can be placed in their predictions.

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