

Final Report

**EVALUATION OF NIGHT SKY MODEL AND
HUMAN PERCEPTION OF NIGHT SKY GLOW**

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Abstract

The National Park Service, Air Quality Division, contracted with Systems Applications, Inc. to develop and evaluate a mathematical model for assessing night sky glow caused by man's activities near national parks. The model has been applied to both Canyonlands and Bryce Canyon national parks to assess the effects of nighttime lighting of the night sky.

An extensive evaluation of the model's ability to predict the observed brightness was performed using data collected during a field experiment conducted at Bryce Canyon in June 1988. After some minor model modifications, results show good agreement between observations and predictions from the night glow model. A second experiment was conducted in October 1988 to quantify human perceptibility of night sky glow caused by nighttime lighting.

The experiment answered and quantified two important parameters: (1) the brightness value at which the glow dome is barely perceptible (i.e., at what level might the edge of a glow dome be first detected by an observer), 4.0×10^{-4} lm/m²/sr, and (2) the perceived edge of the glow dome (i.e., at what value will most people agree that a perceptible edge of a glow dome can be seen), 6.0×10^{-4} lm/m²/sr.

EXECUTIVE SUMMARY

The objective of this study was to quantify and assess the human perceptibility of night sky glow caused by nighttime lighting of the night sky and the predictive ability of a night sky glow model. Because many of the national parks have been designated Class I under the Clean Air Act Amendments, the U.S. Environmental Protection Agency recognizes that the beauty of the night skies is an intrinsically important value to the wilderness experience that needs to be preserved and protected. This study was designed to enable the National Park Service to use the Night Sky Glow Model to both quantitatively and qualitatively assess the predicted impact from proposed lighting projects.

Past studies have addressed development of a model capable of assessing the night sky glow caused by proposed lighting projects. Modifications and improvements in the computer code have led to significant physical improvements in the model's ability to predict night sky glow levels. However, only a limited model evaluation could be performed because of the sparse amount of data suitable for model evaluation. Thus more complete data were needed to quantitatively assess the accuracy of the night sky glow model. Furthermore, new data about human perceptibility of the night sky glow needed to be addressed so that night sky glow predictions could be expressed in terms of perceptibility.

The first set of field experiments was designed to collect night sky glow observation data suitable for evaluating the night sky glow model's predictive ability. The model validation experiment was divided into two phases: (1) measure the sky glow from existing light sources, and (2) measure the sky glow from a special light source whose lighting characteristics were well known. The experiments were performed at Bryce Canyon National Park from 12 to 16 June 1988. A total of 10 experiments were conducted at various distances from both the existing and special light sources. The model's predicted values were quantitatively and qualitatively compared to the observed data through graphical and statistical methods.

The results of these experiments showed that for a dark sky environment, such as that at Bryce Canyon National Park, if the vertical aerosol concentration is assumed to be lower at night than the measured 24-hour average aerosol concentration, then the overall bias of the model is less than 3 percent. Comparison of the model's predictions and observed night sky glow values (using special lights as well as existing lights) showed no significant difference in the model's degree of accuracy, indicating that typical light inventory methods are probably adequate for modeling purposes.

The second set of field experiments was designed to measure human perception of the night sky and was divided into two primary experiments designed to measure (1) the brightness value at which the glow dome was barely perceptible, and (2) the perceived edge of the glow dome. The experiments were performed at Bryce Canyon National Park from 7 to 12 October 1988. A total of 97 individuals were interviewed and their responses measured. A carefully designed questionnaire was used so that the data collected from the experiment could be post-stratified to estimate the general public's perception of the night sky.

The results of these experiments indicated that the brightness value at which the glow dome is barely perceptible is $4.0 \times 10^{-4} \text{ lm/m}^2/\text{sr}$, and that a conservative value at which most observers could perceive the edge of the glow dome was $6.0 \times 10^{-4} \text{ lm/m}^2/\text{sr}$. Extension of these results to the general population, using age as the only discriminating factor between the group sampled and the general population, showed no significant difference in these threshold values.

Contents

Acknowledgments	i
Abstract	ii
Executive Summary	iii
List of Figures	vi
List of Tables	ix
1 INTRODUCTION	1
2 METHODOLOGY FOR MEASUREMENT OF NIGHT SKY BRIGHTNESS .	3
General Requirements	3
Calibration Procedures	3
Measuring Night Sky Glow Observations	5
Calculation of Night Sky Brightness	5
Sample Calculation of Night Sky Brightness	8
3 FIELD EXPERIMENTS	10
Model Validation Experiment	10
Validation of the Night Sky Glow Model	10
Comparison of Night Sky Model Predictions and Night Sky Glow Observations	15
Sky Glow Variation with Light Source Intensity	29
Areal Extent of Night Sky Glow	29
Human Perception Night Sky Glow Experiment	29
Light Sensitivity Experiment	32
Perceived Edge Experiment	33
Human Perception Data Reduction	34
Results of Human Perception Experiments	35
Extension of Perceptibility Results to General Population	39
4 CONCLUSIONS	44
References	45
Appendix A: Calculation of the Night Sky Brightness	

Figures

1	SSP-3 shown with Celestron CB telescope	4
2	Sample of form used for star measurement in estimating extinction coefficient	6
3	Readings on SSP-3 photometer for two different recordings	7
4	Viewing points within Bryce Canyon National Park	12
5a-i	Predicted spatial distribution of sky brightness (10^{-3} lm/m ² /sr): Bryce Canyon: 13, 14-15, and 15-16 June 1988 field experiments	16
6	All pairs of predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park	25
7	All pairs of special light sources--predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park	27
8	All pairs of existing light sources--predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park	28
9	Example of questionnaire to be completed by group participants	31
10	Wall experiment	36
11	Grid experiment	37
12	Sample median luminosities for each perception experiment with 95% confidence bounds	38
13	Sample population versus general population age distribution	40

14	Wall experiment	41
15	Grid experiment	42

Tables

1	Characteristics of the night sky observations for 12-17 June 1988	11
2	Lighting emissions for existing sources	13
3	Particle mass concentration measured at Bryce Canyon National Park	14
4	Comparison of areal sky coverage of glow dome observed in June 1988 experiment and coverage predicted using 4×10^{-4} lm/m ² /sr as threshold for perceptibility	30

1 INTRODUCTION

Many national parks 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. Because national parks are generally located in pristine areas, there is little industrial development and urbanization; therefore, national parks are frequently prime areas for viewing the beauty of the night sky. The Environmental Protection Agency acknowledges that the night skies are an important part of the wilderness experience. The National Science Foundation recognized this and investigated the possibility of locating an astronomical observatory near or in national parks so that lighting from urban areas or from industry would not destroy the capability of viewing the night sky. The National Park Service did not favor this; therefore, siting an observatory near a park was not considered.

The National Park Service, Air Quality Division, contracted with Systems Applications, Inc. (SAI) to develop a mathematical model for assessing night sky glow caused by man's activity near national parks. The model was first applied to Canyonlands National Park (Yocke et al., 1985) to predict the luminosity of scattered light in the night sky caused by operation of a proposed nuclear waste repository. In this study night sky glow and terrain illumination resulting from nighttime operation of the proposed nuclear waste repository were calculated, and the potential for human perception of these effects was estimated. The study involved the following steps: (1) development of a mathematical model of atmospheric optics to predict the night sky glow effects, (2) evaluation 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. The results of the study indicated potential for light pollution from the proposed facility in both a clean atmosphere with visibility greater than 200 miles, and a polluted atmosphere with visibility near 20 miles.

In a second study the computer model was applied to the Bryce Canyon National Park (Carr et al., 1989) area to assess the effects the proposed Alton Coal Project may have on the beauty of the night sky and what effect the impairment of the night sky may have on visitor enjoyment. This study involved the following steps: (1) enhancement of the mathematical model of atmospheric optics to predict the nighttime sky-glow effects of the proposed mining operation; (2) evaluation of the model's prediction performance to the extent possible with existing data; (3) application of

the model to the area surrounding the proposed Alton Coal Project, calculating results from three viewpoints within the park for two lighting scenarios and three meteorological conditions at the Alton Coal Project; (4) estimation of the potential for human perception of the calculated night sky glow and the potential of the night sky glow to obscure starlight; (5) application of the graphics program to several vistas within the park; and (6) providing park personnel with the enhanced computer model and supporting documentation.

In both of the above-referenced studies, only limited model evaluation could be performed because of the meager amount of data available. A more comprehensive evaluation of the model's performance was needed before greater confidence could be placed in its predictions. Thus the first issue to be addressed in Section 3 of this report is quantifying the accuracy of the night glow model after collection of a suitable measurement data base. Furthermore, the issue of human perceptibility of night glow—the ultimate issue that affects visitor enjoyment of the night sky—had not been addressed in either of the above-referenced studies. Although we could develop a highly accurate model of the night glow, we would still be uncertain about what its predictions mean to the human observer. Thus the second issue to be addressed in Section 3 of this report is to quantify the threshold of perceptible night glow based upon scientific field measurements.

The remainder of this report is organized as follows: Section 2 discusses the methodology used for measuring sky brightness; Section 3 discusses the field experiments performed; and Section 4 presents the study conclusions. Appendix A provides details of the calculation of the night sky brightness.

2 METHODOLOGY FOR MEASUREMENT OF NIGHT SKY BRIGHTNESS

GENERAL REQUIREMENTS

Performance of night sky photometry required the use of observational hardware and carefully followed observational techniques. The hardware consisted of three main components: a telescope, a photometer, and a system to provide physical support and tracking (slow motion controls and/or clock drive). The observational techniques involved calibrating the photometer (i.e., to what brightness does a certain number of photometer counts correspond) and measuring sky brightness at various viewing angles.

The telescope used in all of the experiments was an 8-inch Celestron SP-C8 with an effective focal length of $f/5$ when used with the telecompressor. The telecompressor was used during all sky brightness measurements because it increased the field of view and the amount of light gathered so that fainter sky brightness could be measured. Figure 1 shows how the photometer, the OPTEC Solid State Photometer (SSP-3), was mounted with the SP-C8 telescope. A 1.0-mm diameter diaphragm and a two-position filter slider are mounted just before the entrance to the detector of the photometer. The V (or visual) filter was used for all experiments since it most closely corresponds to the human visual system and also makes available a large number of standard stars for instrument calibration. The observations all took place on clear nights when the moon was not visible.

CALIBRATION PROCEDURES

The procedure for instrument calibration required measuring a standard reference star and then measuring a nearby star-free field. Standard stars are those for which the luminosity has been previously measured. Johnson and Morgan (1953) have published a list of 108 standard reference stars used to calibrate the instrument. To perform the calibration, a standard star is centered in the photometer diaphragm and readings are taken from the signal (number of counts) over some time period (typically 10 seconds). The signal is composed of both the starlight and the sky glow. After the star's signal is recorded, the diaphragm is moved with the slow motion controls so that the star is out of view and only the sky glow reading is taken. The sky glow measurement is then subtracted from the reference star's measurement, yielding the amount of light due to the star only. The star counts are then corrected for the earth's atmospheric extinction, yielding the number of counts for that star's particular luminosity.

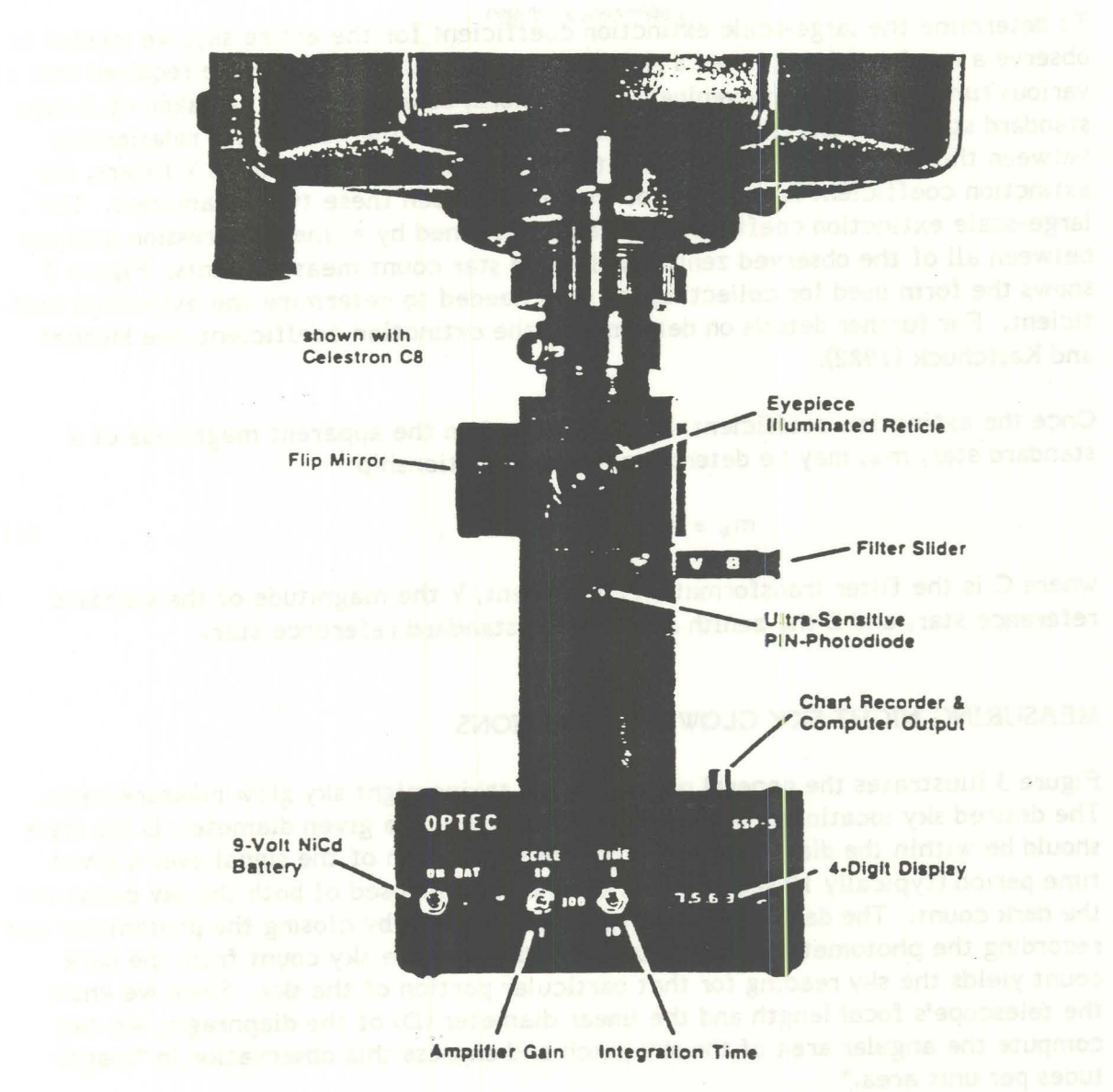


FIGURE 1. SSP-3 shown with Celestron CB telescope.

To determine the large-scale extinction coefficient for the entire sky, we needed to observe a number of stars over a range of air masses. The procedure required that at various times during each evening's observations, counts were to be taken of A-type standard stars at different zenith angles. Because of the near linear relationship between this type of star and the zenith angles when viewed through V filters, the extinction coefficient is the slope of the line between these two parameters. The large-scale extinction coefficient is then determined by a linear regression analysis between all of the observed zenith angles and star count measurements. Figure 2 shows the form used for collecting the data needed to determine the extinction coefficient. For further details on determining the extinction coefficient, see Henden and Kaitchuck (1982).

Once the extinction coefficient, k_v , is known, then the apparent magnitude of a standard star, m_* , may be determined by the relationship

$$m_* = V/C + k_v \cdot \sec Z \quad , \quad (1)$$

where C is the filter transformation coefficient, V the magnitude of the standard reference star, and Z the zenith angle of the standard reference star.

MEASURING NIGHT SKY GLOW OBSERVATIONS

Figure 3 illustrates the general procedure for taking night sky glow measurements. The desired sky location is centered in a diaphragm of a given diameter, D (no stars should be within the diaphragm), and readings are taken of the signal over a given time period (typically 10 seconds). The signal is composed of both the sky count and the dark count. The dark count readings are measured by closing the photometer and recording the photometer "zero" count. Subtracting the sky count from the dark count yields the sky reading for that particular portion of the sky. Since we know the telescope's focal length and the linear diameter (D) of the diaphragm, we can compute the angular area of the sky patch and express this observation in "magnitudes per unit area."

CALCULATION OF NIGHT SKY BRIGHTNESS

The relationship between the sky count readings and the reference star's signal must be used to express the night sky brightness in terms of its absolute magnitude or luminosity. This relationship in magnitudes is:

$$m_s = m_* + 2.5 \log(F_*/F_s) \quad , \quad (2)$$

where F_s is the sky count reading; F_* is the reference star's signal count; m_* is the apparent magnitude of the star at the bottom of the atmosphere; and m_s is the

Date: _____ 1988

Latitude of Observation: _____

Star	V (Mag)	Scale	Average Period (Seconds)	Count			Star	V-v	Altitude (Degrees)	Time (24-Hour Clock)
				Star + Sky + Dark	Sky + Dark	Dark				
γ UMA	2.44									
δ UMA	3.31									
β SER	3.67									
γ OPH	3.75									
α LYR(VEGA)	0.04									
ζ AQL	2.99									
γ UMA	2.44									
δ UMA	3.31									
β SER	3.67									
γ OPH	3.75									
α LYR(VEGA)	0.04	10	10	76000	650	638.6	75350	7.23	25	2330
ζ AQL	2.99									

Additional Information:

Size of telescope: Celestron 8 inch with telecompressor f/5

Photometer: OPTEC SSP-3

Diameter of diaphragm: 1.0 mm

Note: $v = -2.5 \log(c_v)$, where c_v is the count rate for the star only in counts per second.

REMARKS:

FIGURE 2. Sample of form used for star measurement in estimating extinction coefficient.

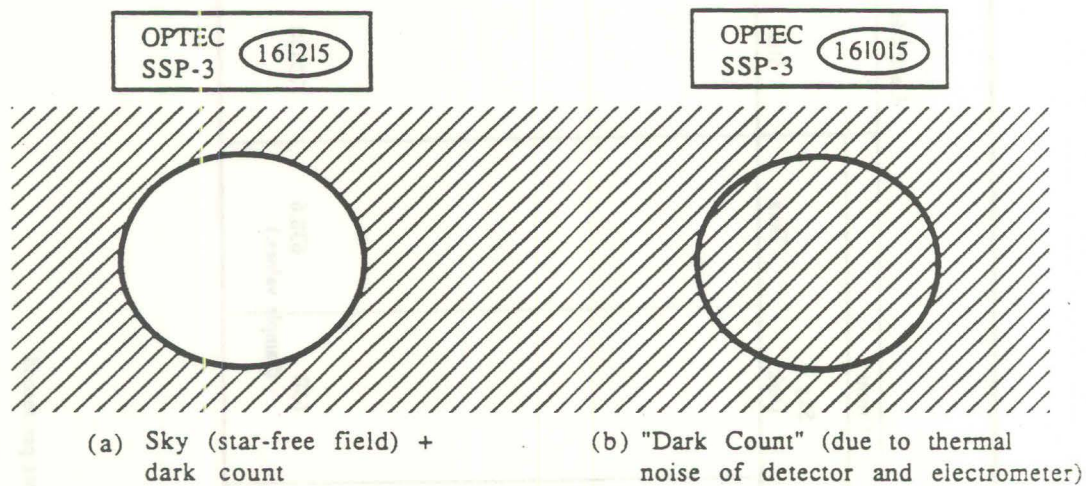


FIGURE 3. Readings on SSP-3 photometer for two different recordings.

brightness of the patch of sky in the diaphragm expressed as a magnitude. Since both F_* and F_s are observed and m_* is determined during the calibration procedure, then m_s will be the sky patch magnitude as observed in the diaphragm of the telescope.

In magnitude units, a diaphragm of area A in arc-second squared ($"^2$) is related to the actual magnitude by the following expression:

$$\text{mag}/(^{\circ})^2 = m_s + 2.5 \cdot \log A \quad (3)$$

We can then determine the area of the diaphragm by knowing the size and focal length of the telescope, and the diameter of the diaphragm. The actual magnitude per arc-second squared for the sky patch can then be determined from the above expression. By using the formula shown below, the results for the brightness, b , can then be expressed in units of lumens/ m^2/sr :

$$b = 34.08/(\pi \cdot 10^5) \cdot \exp(20.7233 - 0.92104 \cdot \text{mag}/(^{\circ})^2) \quad (4)$$

Sample Calculation of Night Sky Brightness

To clarify the night sky brightness calculation, let us take, as an example, observations of the standard reference star Alpha Lyra (Vega), whose standard visual magnitude is +0.04. The star was viewed at a zenith angle of 25° ; the sky brightness of interest is a sky patch 10° above the horizon (zenith angle of 80°). The transformation slope for the V filter was 1.000. The extinction coefficient on the observation night was 0.18 magnitudes.

The following counts were made for the sky patch and star:

Star signal (star + sky + dark)	= 76000
Mean sky signal (the signal next to the star) (sky + dark)	= 650
Net star count	= 75350
Observed sky patch (sky + dark)	= 646.4
Dark count (dark)	= 638.6
Sky patch	= 7.8

The air mass is equal to the $\sec(25^\circ) = 1.1034$.

Using Equation 1, we have for the apparent magnitude of the standard star, m_* ,

$$m_* = 0.04/1.00 + 0.18 \cdot (1.1034) = 0.239$$

Using this result and substituting into Equation 2 yields

$$m_s = 0.239 + 2.5 \cdot \log(75350/7.8) = 10.20,$$

which is the magnitude of the sky patch as seen through the diaphragm with the V filter.

To apply Equation 3, we need first determine the area of the diaphragm in arc-seconds. The focal length of the f/5 telescope in millimeters is

$$F = 8.0 \text{ in} \cdot (25.4 \text{ mm/in}) \cdot 5 = 1016 \text{ mm}$$

The scale, s , for a telescope of focal length F in millimeters is $s = 206265''/1016 \text{ mm} = 203.0''/\text{mm}$. The angular diameter will then correspond to $203.0''/\text{mm} \cdot 1.0 \text{ mm} = 203.0''$ on the sky. The area is then given by $\pi \cdot (d/2)^2$ and in this case is

$$A('')^2 = \pi \cdot (203.0/2)^2 = 32371 ('')^2$$

Finally, using Equation 3, we obtain

$$\text{mag}/('')^2 = 10.20 + 2.5 \cdot \log(32371) = 21.48$$

and using Equation 4, the brightness of the night sky in $\text{lm}/\text{m}^2/\text{sr}$ is

$$b = 34.08/(\pi \cdot 10^5) \cdot \exp(20.7233 - 0.92104 \cdot 21.48) = 2.79 \cdot 10^{-4}$$

Appendix A contains calculations of the night sky brightness for both the night sky model evaluation and human visual perception experiments.

3 FIELD EXPERIMENTS

Two field experiments were conducted at Bryce Canyon National Park. The first experiment conducted from 12-16 June 1988 was designed to validate the night sky glow computer model; the second experiment conducted from 7-12 October 1988 was designed to measure the human perceptibility of night sky glow.

MODEL VALIDATION EXPERIMENT

The experiment was divided into two phases. Phase 1 measured the sky glow from existing light sources, and Phase 2 measured the sky glow from a special light source. The measurement sites and distances for all phases are presented in Table 1. Figure 4 presents all of the observation and light source locations.

A detailed emission inventory was collected for the two existing light sources (Tropic and Rodeo Grounds) studied in this phase of the experiment. As Table 2 shows, this inventory included the number of light sources, types of lights, and power ratings for the lights. This information was then used in the computer modeling to compare the observations with predicted results from the night sky glow computer model.

A special light source array consisting of 21 500-watt lightbulbs was used for all of the special light source experiments.

An experiment to measure how the glow dome was affected by a reduction in light source emissions was conducted during the evenings of 15-16 June. An experiment was planned to measure how sky glow varies as a function of aerosol background values, but we were unable to perform it because the aerosol background did not significantly change (Table 3) during the entire experiment period. An experiment was also planned to estimate how the night sky glow varies as a function of distance from the light source; however, not enough data were collected at the same elevation angle at various distant viewpoints to yield meaningful results.

Validation of the Night Sky Glow Model

The data collected during the field experiment were reduced and analyzed following the procedures discussed in Section 2. This section compares the model's performance to observed values both qualitatively and quantitatively through graphical and statistical methods.

TABLE 1. Characteristics of the night sky observations for 12-17 June 1988.

Observing Location	Source Location	Distance (km)	Date of Observation
Inspiration Point	Maintenance yard	2.08	12-13 June
Inspiration Point	Tropic, Utah	7.30	12-13 June
East Creek	Maintenance yard	3.20	13-14 June
Bryce Point	Maintenance yard	3.25	14-15 June
Meadow near maintenance yard	Maintenance yard	0.80	14-15 June
Inspiration Point	Maintenance yard	2.08	14-15 June
End of runway, Bryce Airport	Rodeo grounds	5.10	15-16 June
Rte. 22 to Antimony 3.65 miles from triangle	Rodeo grounds	6.80	15-16 June
Meadow near maintenance yard	Maintenance yard	0.80	16-17 June
East Creek	Maintenance yard	3.20	16-17 June

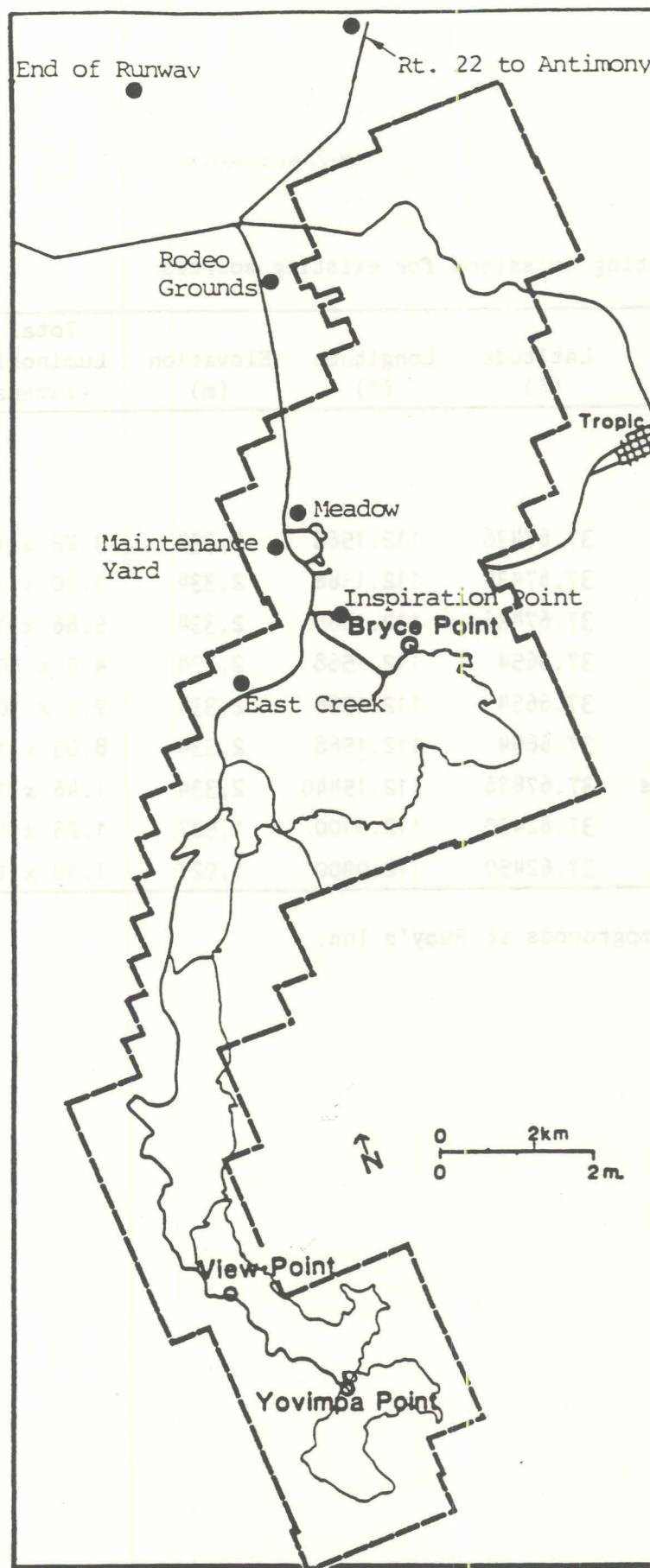


FIGURE 4. Viewing points within Bryce Canyon National Park.

TABLE 2. Lighting emissions for existing sources.

Area	Latitude (°)	Longitude (°)	Elevation (m)	Total Luminosity (lumens)	Light Type
<u>Existing</u>					
Ruby's Inn	37.67436	112.1568	2,334	4.22×10^5	Sodium vapor
Ruby's Inn	37.67436	112.1568	2,334	1.40×10^4	Halogen
Ruby's Inn	37.67436	112.1568	2,334	5.86×10^5	Mercury vapor
Campground*	37.6654	112.1568	2,334	4.0×10^3	Sodium vapor
Campground*	37.6654	112.1568	2,334	2.5×10^4	Halogen
Campground*	37.6654	112.1568	2,334	8.05×10^4	Mercury vapor
Rodeo grounds	37.67886	112.15440	2,334	1.46×10^6	Halogen
Tropic, Utah	37.62450	112.0900	1,927	1.25×10^6	Mercury vapor
Tropic, Utah	37.62450	112.0900	1,927	1.12×10^5	Sodium vapor

* These are campgrounds at Ruby's Inn.

TABLE 3. Particle mass concentration measured at Bryce Canyon National Park ($\mu\text{g}/\text{m}^3$). (Source: Tom Cahill, Air Quality Group, University of California at Davis)

	Fine ($D < 2.5 \mu\text{m}$)	Coarse* ($2.5 \mu\text{m} < D < 10 \mu\text{m}$)	Total (PM10)
Saturday 06/11/88	3.9	5.1	9.0
Wednesday 06/15/88	4.5	4.5	9.0
Mean Annual (1982-1984)	2.6 $\mu\text{g}/\text{m}^3$		
Mean Summer (1982-1984)	3.7 $\mu\text{g}/\text{m}^3$		

* Derived from fine and PM10 channels.

Comparison of Night Sky Glow Model Predictions and Night Sky Glow Observations

Appendix A.1 shows the measured night sky values obtained during the June experiment. For each of the night sky observation scenarios, the night sky glow model was run to the nearest one degree for the area of interest with a background visual range of 180 km. These high-resolution values were then paired with the observational values. Figures 5a-5i depict the modeled night sky values. Some of the night sky contour values are not labeled due to their close spacing; the order of all contours is 0.2, 0.3, 0.5, 0.7, 1.0, 2.0, 3.0, 4.0, 8.0, and 10.0 ($\times 10^{-3}$ lm/m²/sr). In general these values show slight overprediction of the extent of the night sky dome. It should be noted that the asymmetrical pattern of the glow dome seen in Figures 5a, 5c, 5d, and 5h was the result of interpolation and the cubic spline curve fitting of the predicted model values. If the model were run at a high resolution over the entire night sky, then the pattern was nearly symmetrical about the light source. In normal applications of the night sky glow model, the interpolation problem would not be noticeable since light sources are at various locations and distances from the observer.

Figure 6 is a plot of all valid paired observed and predicted values noted during the June experiment, assuming the data were normally distributed. The linear correlation coefficient was found to be 0.85; thus 0.73 of the variance of the predicted values was accounted for by the variation in the observed values. The scatter about the line of regression, which is a measure of the goodness of fit, was 0.798 ln(lm/m²/sr), indicating that 68 percent of the pairs fall within a factor of 2.22 of the line of regression. The line of regression was found to have a slope of 1.02. An analysis of variance showed a value of 72.3, which means that the probability that the observations and predictions happen to be correlated due to chance alone is much less than 1 percent; thus the correlation is highly significant. The mean difference between the predicted and observed values was $+2.83 \times 10^{-3}$ lm/m²/sr, with a mean absolute error of 2.99×10^{-3} lm/m²/sr. Two possible explanations for the overprediction of the observed values are (1) if the nighttime aerosol concentration is lower than the average daily values used (shown in Table 3), the model will predict luminosities higher than those actually observed, and (2) the vertical aerosol concentration profile was not well known; thus if the actual profile had relatively lower aerosol concentrations than those measured at the surface as shown in Table 3, then the model would have overpredicted the observed luminosities.

Using a vertical aerosol profile with lower concentration corresponding to a background visual range of 391 km, which is probably more representative of the nighttime visibility conditions than is the 180-km visual range deduced from the 24-hour average aerosol concentrations shown in Table 3, resulted in values decreasing by a factor of 2.5 and a mean difference between the predicted and observed values of only 4×10^{-5} lm/m²/sr. The mean absolute error was 1.37×10^{-3} lm/m²/sr. Part of the absolute error may be

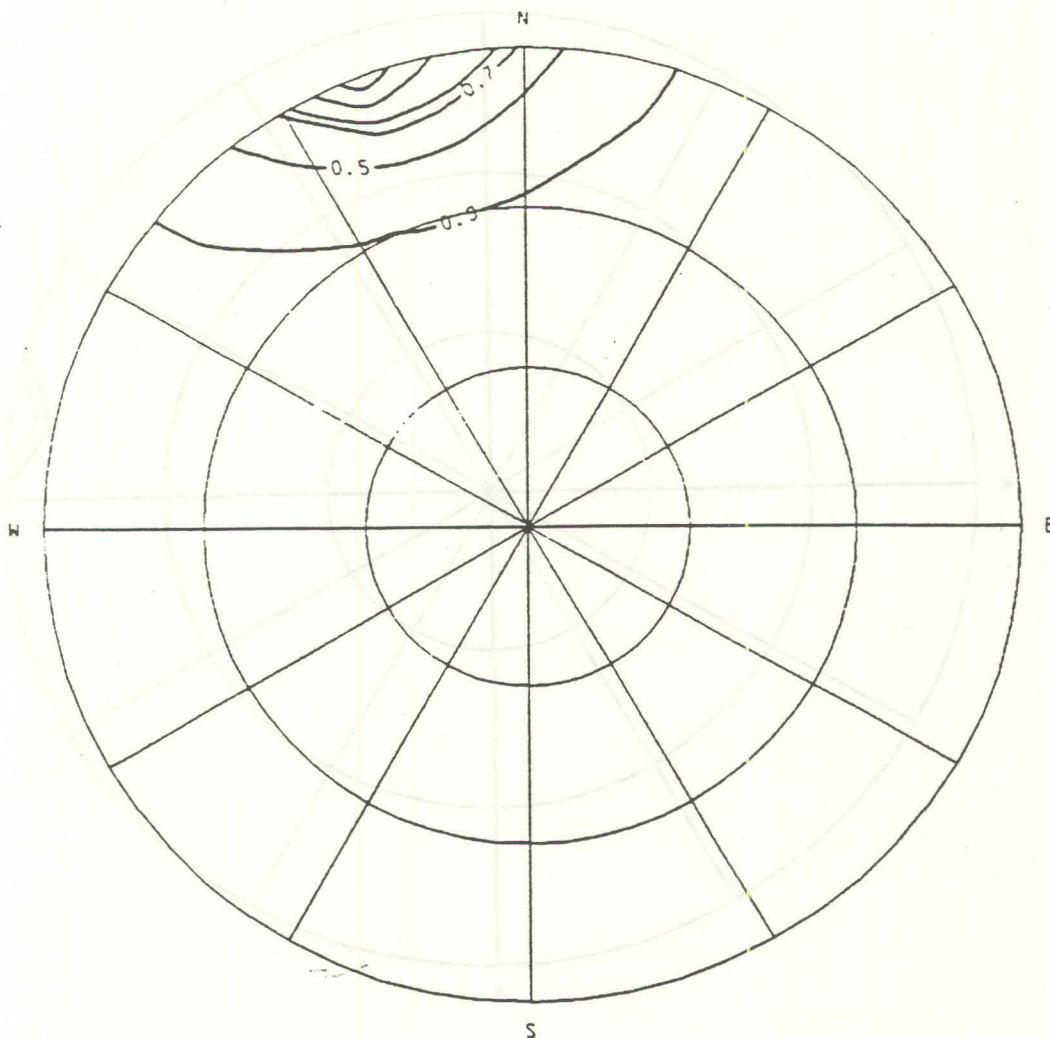


FIGURE 5-a. Predicted spatial distribution of sky brightness ($10^{-3} \text{ lm/m}^2/\text{sr}$): Bryce Canyon; 13 June 1988 field experiment; 21 500-watt bulbs at a distance of 2.08 km from source; Inspiration Point to maintenance yard.

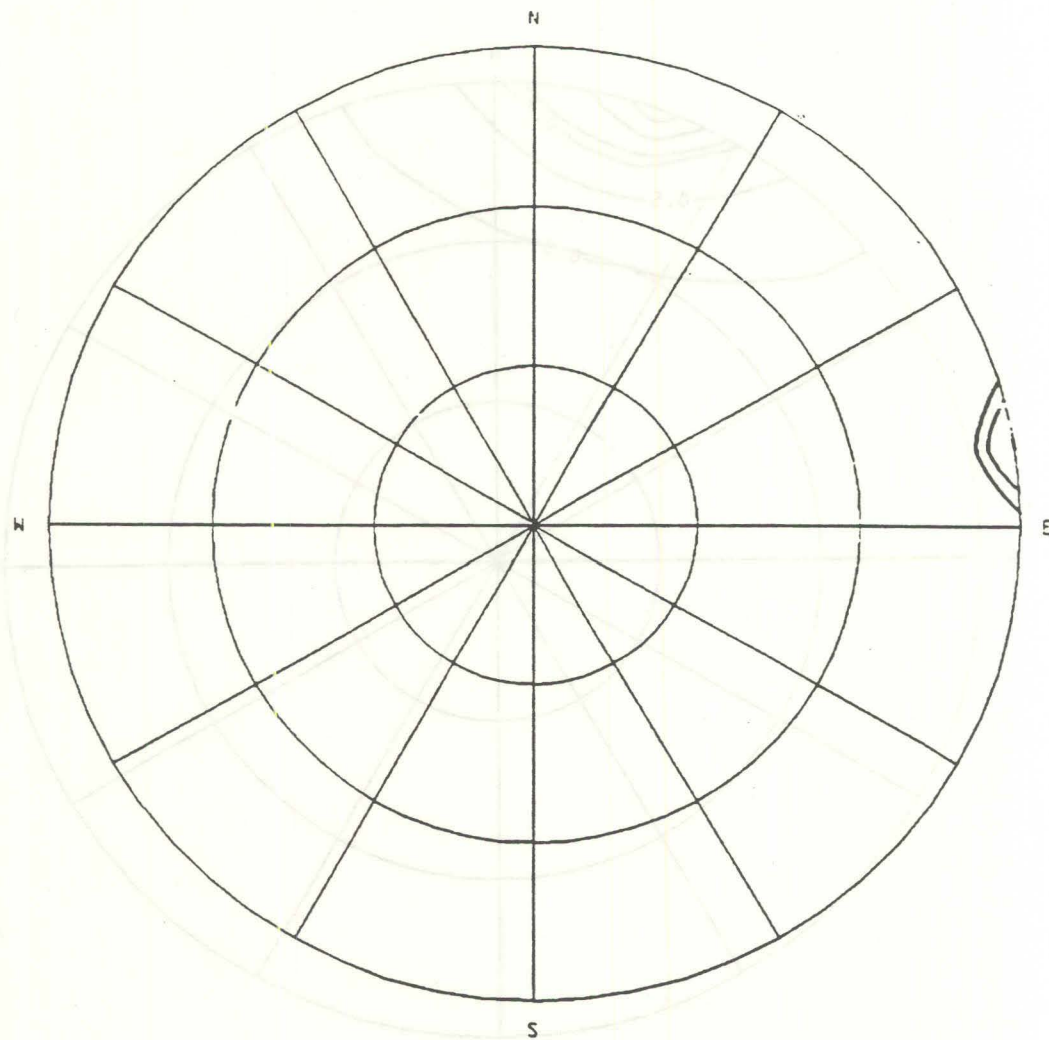


FIGURE 5-b. Predicted spatial distribution of sky brightness ($10^{-3} \text{ lm/m}^2/\text{sr}$): Bryce Canyon; 13 June 1988 field experiment; 62 mercury vapor and 6 sodium vapor lights at a distance of 7.3 km from source; Inspiration Point to Tropic, Utah.

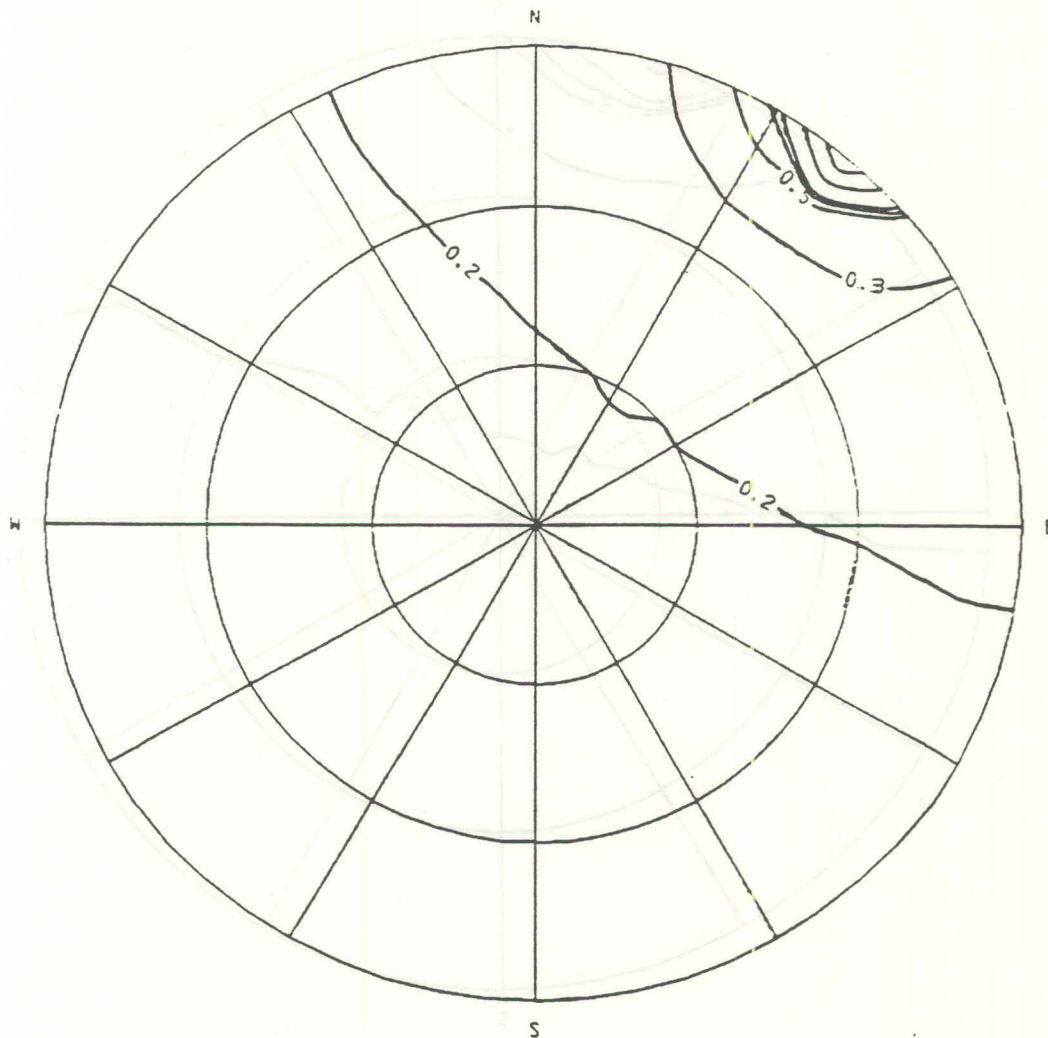


FIGURE 5-c. Predicted spatial distribution of sky brightness (10^{-3} lm/m²/sr): Bryce Canyon; 14-15 June 1988 field experiment; 21 500-watt bulbs at a distance of 3.2 km from source; north of East Creek to maintenance yard.

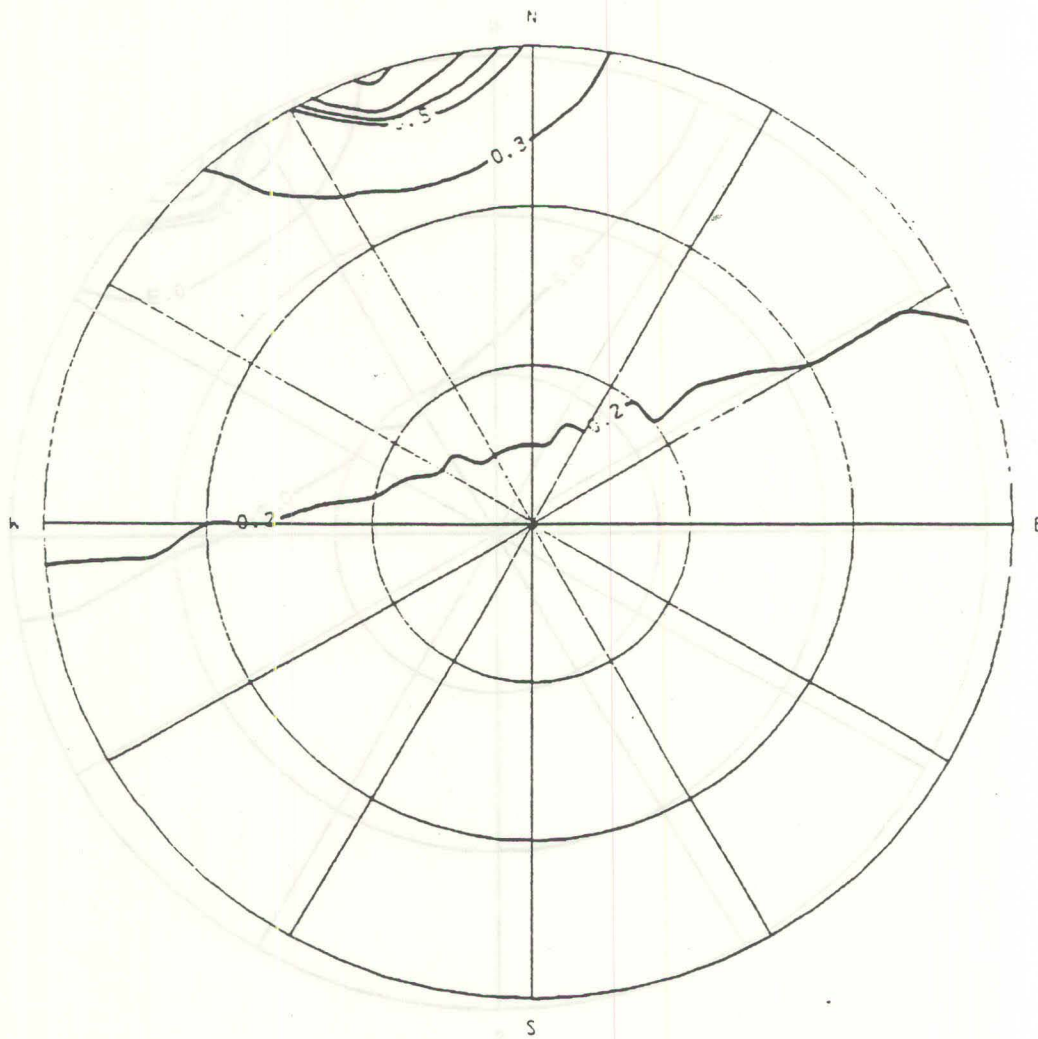


FIGURE 5-d. Predicted spatial distribution of sky brightness ($10^{-3} \text{ lm/m}^2/\text{sr}$): Bryce Canyon; 14-15 June 1988 field experiment; 21 500-watt bulbs at a distance of 2.08 km from source; Inspiration Point to maintenance yard.

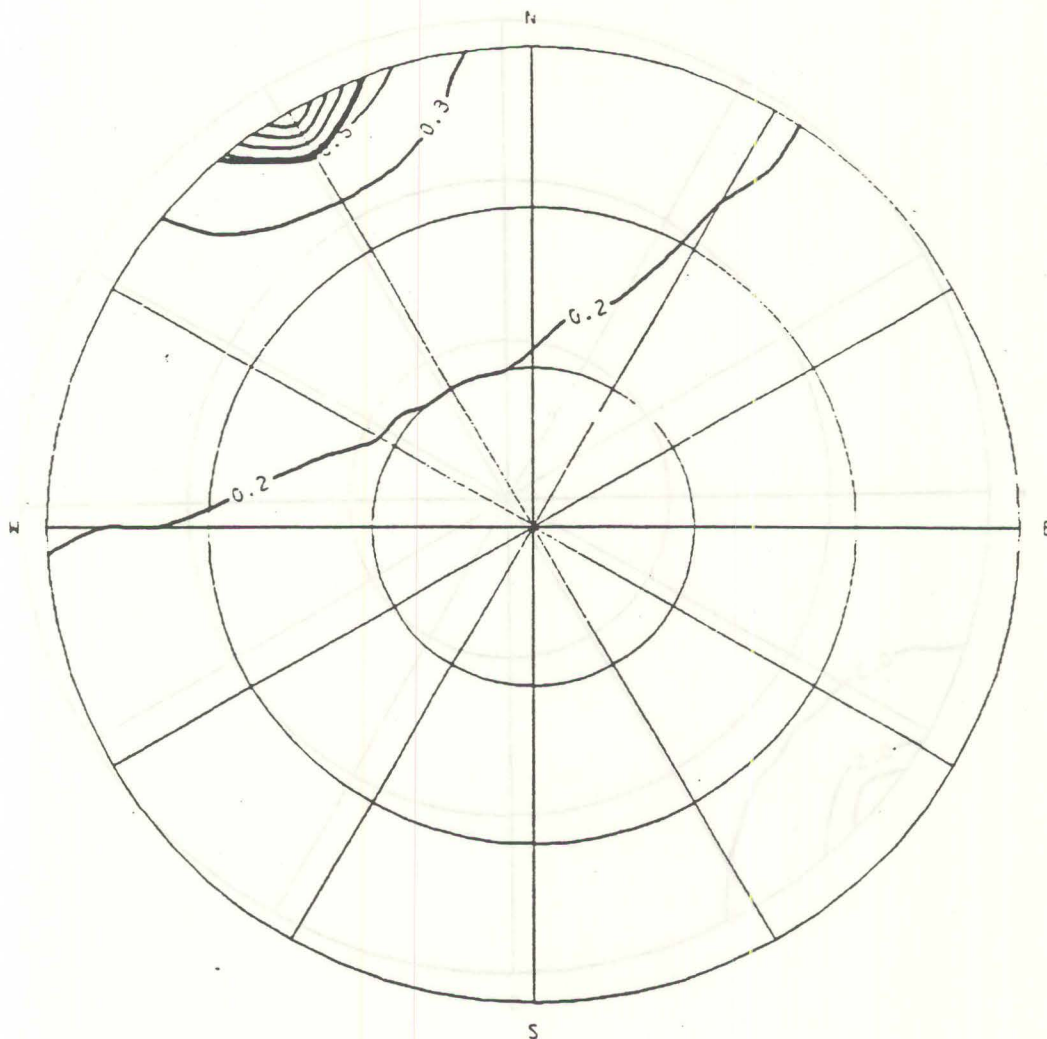


FIGURE 5-e. Predicted spatial distribution of sky brightness (10^{-3} lm/m²/sr): Bryce Canyon; 14-15 June 1988 field experiment; 21 500-watt bulbs at a distance of 3.25 km from source; Bryce Point to maintenance yard.

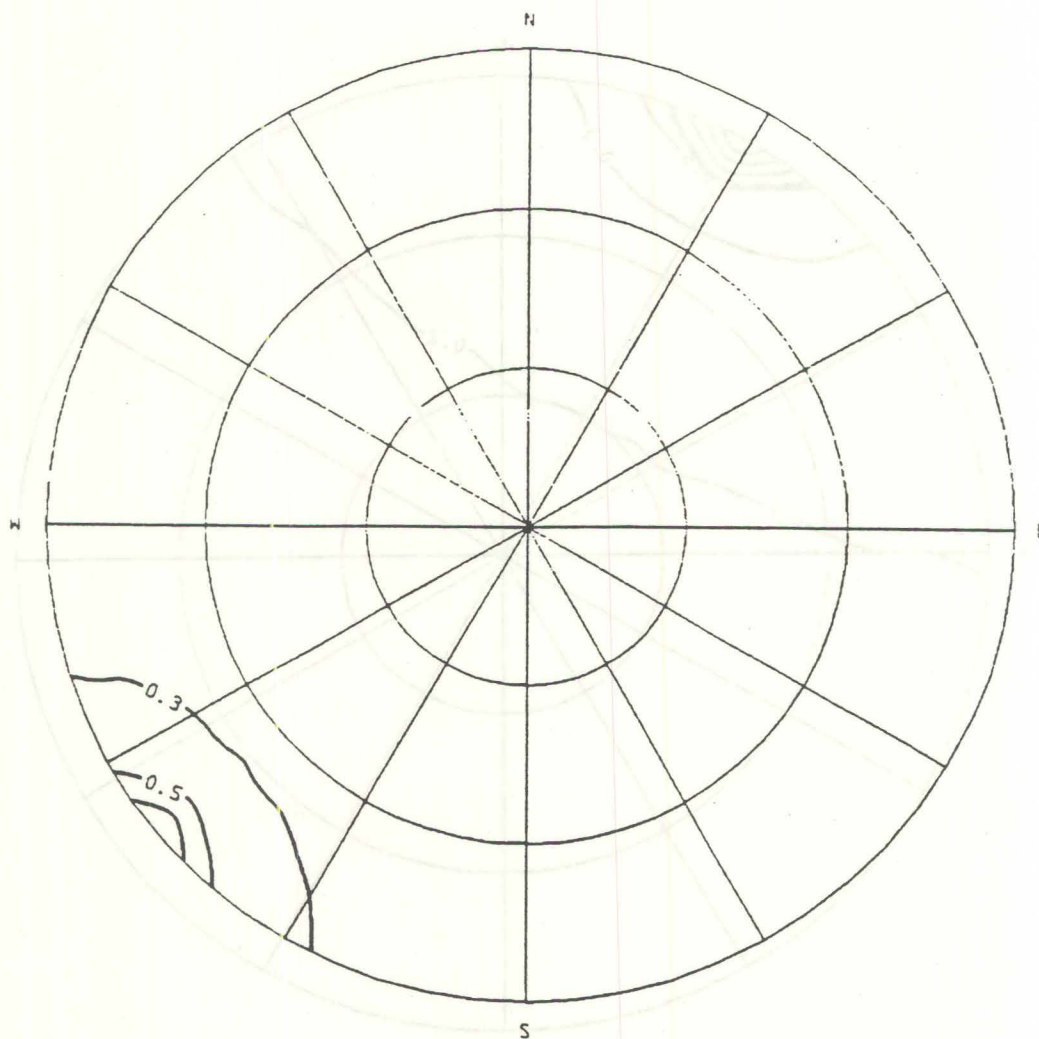


FIGURE 5-f. Predicted spatial distribution of sky brightness (10^{-3} lm/m²/sr): Bryce Canyon; 14-15 June 1988 field experiment; 21 500-watt bulbs at a distance of 0.80 km from source; meadow near North Campground to maintenance yard.

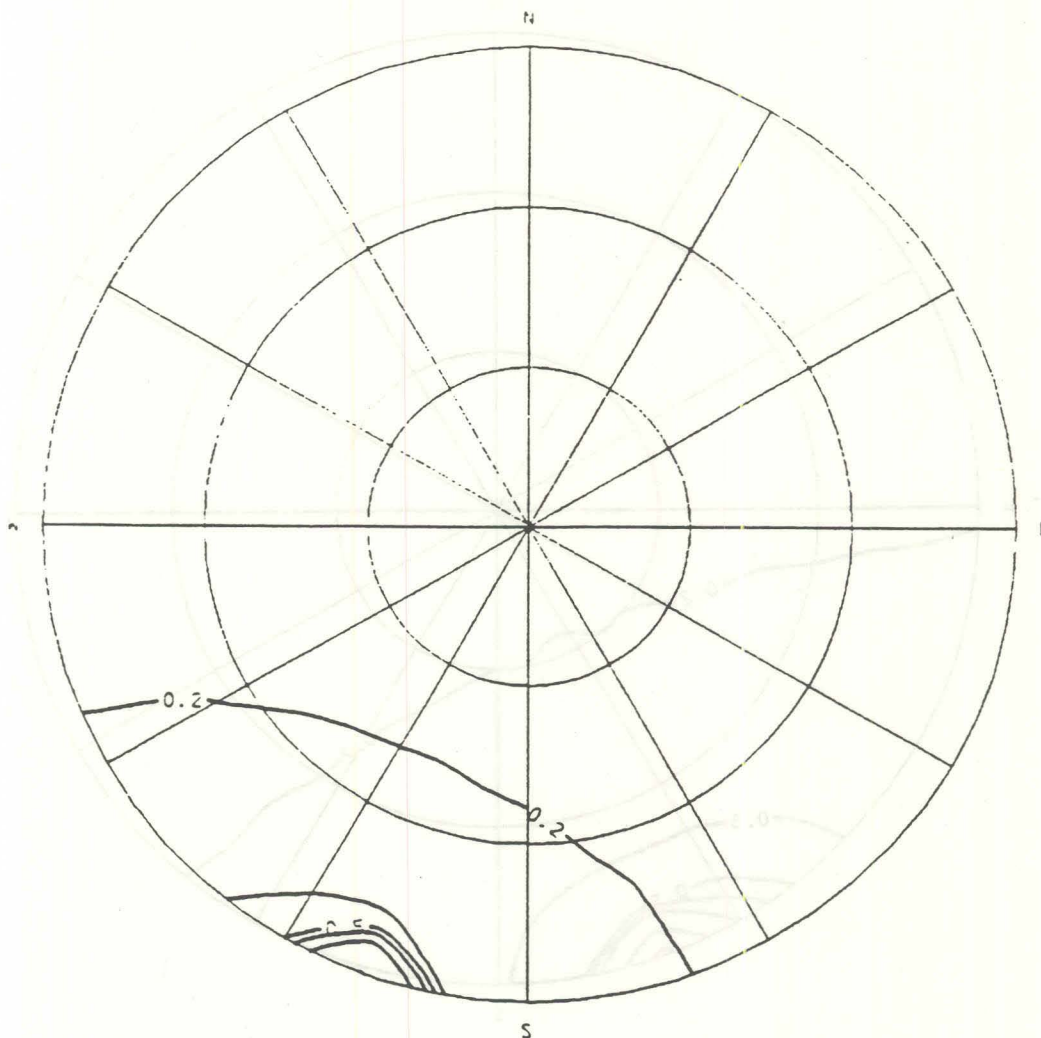


FIGURE 5-g. Predicted spatial distribution of sky brightness (10^{-3} lm/m²/sr): Bryce Canyon; 15-16 June 1988 field experiment; (no Rodeo lights); outdoor lights at a distance of 5.10 km from end of airport runway to motel complex.

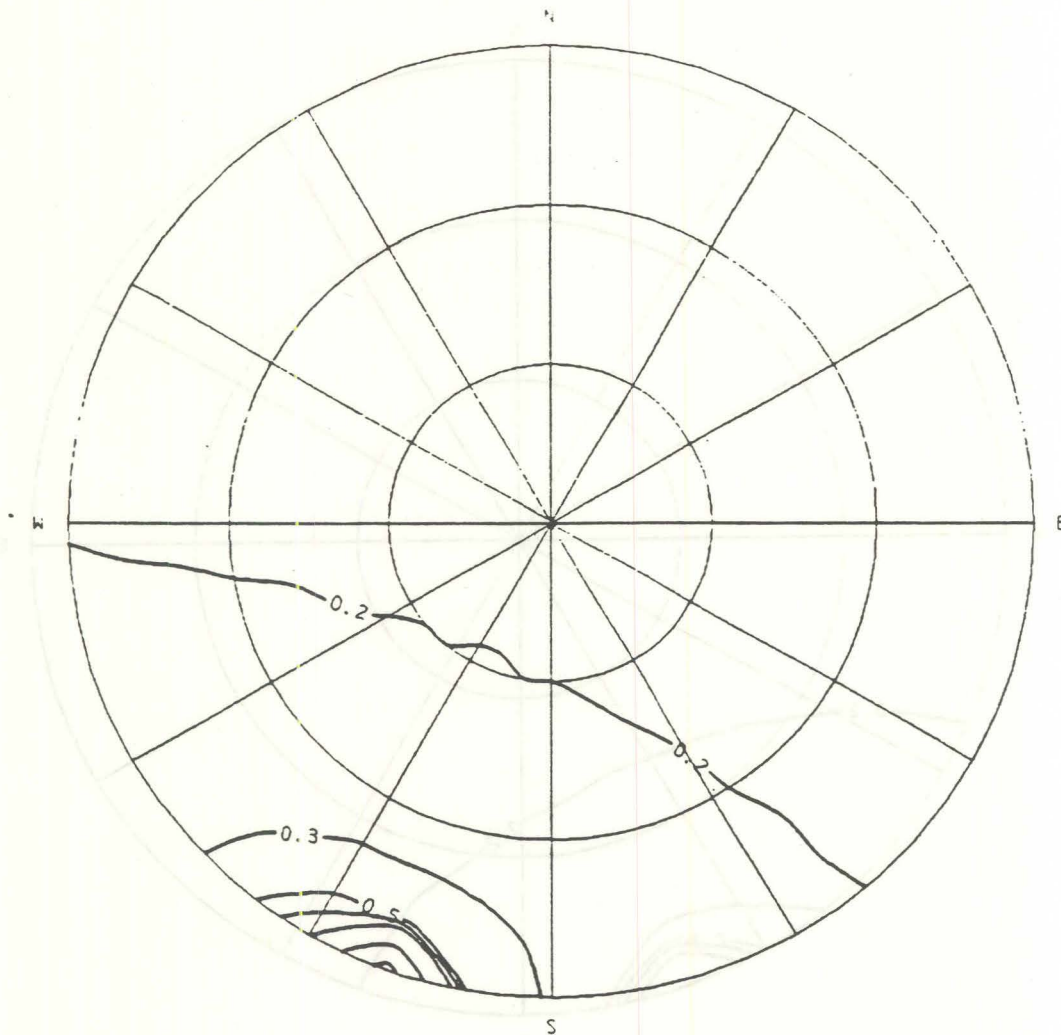


FIGURE 5-h. Predicted spatial distribution of sky brightness (10^{-3} $\text{lm/m}^2/\text{sr}$): Bryce Canyon; 15-16 June 1988 field experiment; 146 various outdoor lights at a distance of 5.10 km from source; end of Rodeo to airport runway.

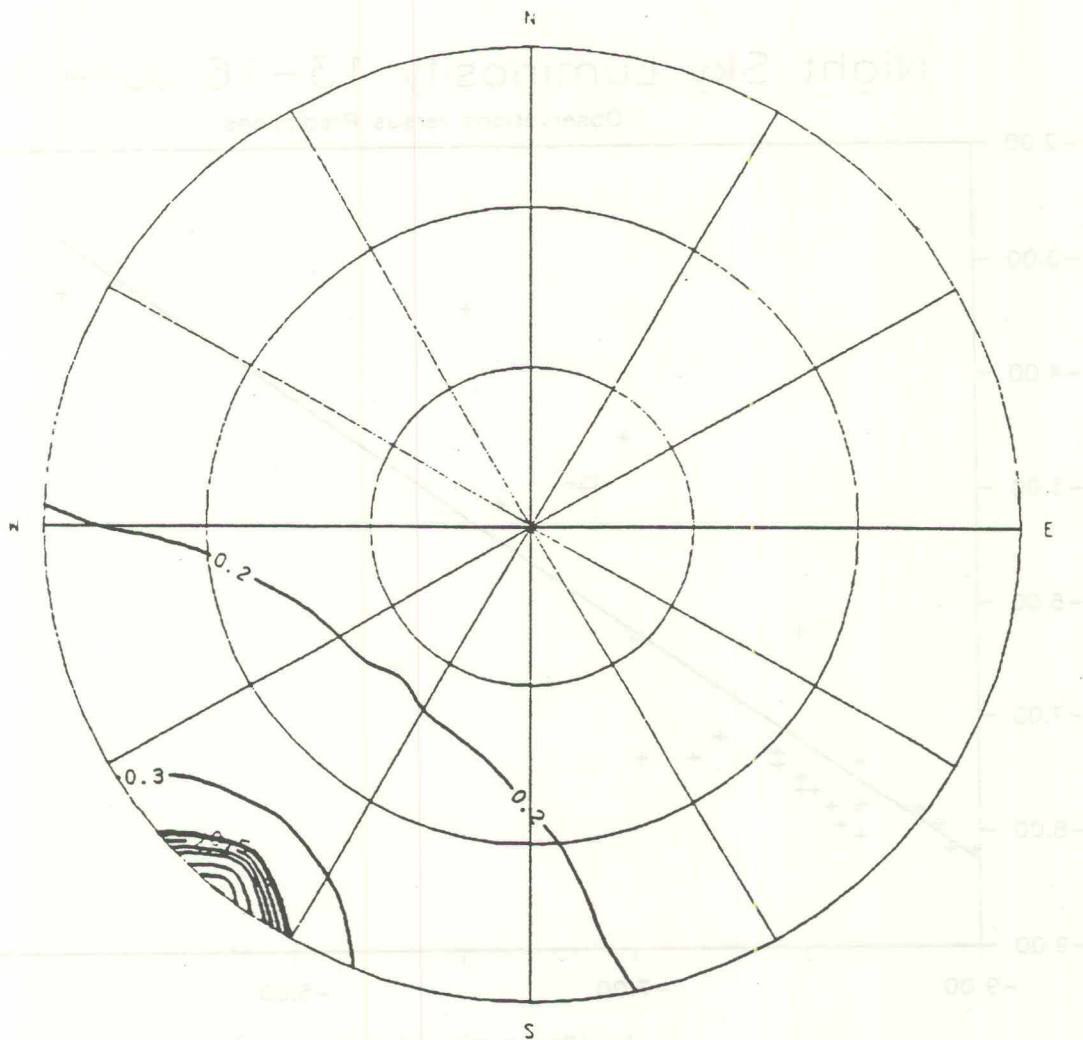


FIGURE 5-i. Predicted spatial distribution of sky brightness ($10^{-3} \text{ lm/m}^2/\text{sr}$): Bryce Canyon; 15-16 June 1988 field experiment; 146 various outdoor lights at a distance of 6.80 km from source; 3.65 mi on Rte. 22 to Antimony to Rodeo.

Night Sky Luminosity 13-16 June 1988

Observations versus Predictions

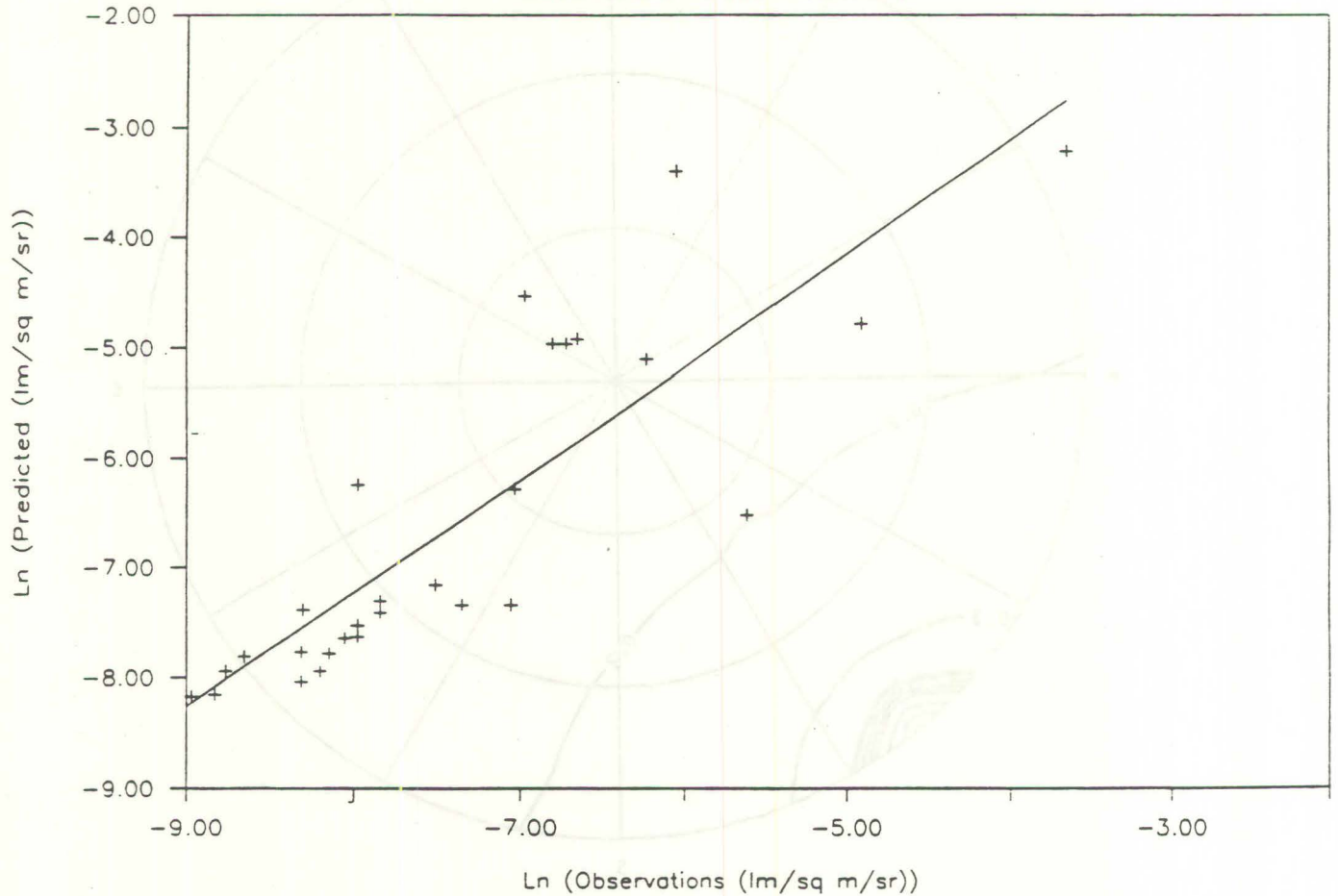


FIGURE 6. All pairs of predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park.

attributable to measurement error, which is typically 5 to 10 percent of the observed value. When the background visual range of 391 km was used, the resulting overall bias of the model was found to be less than 3 percent.

To assess the effects of the inaccuracy of light emission estimates on the accuracy of the model's predictions, the light sources were divided into two groups. The first group contained the existing light sources (Tropic and rodeo grounds) for which a detailed emission inventory and subsequent light emission estimates were made. The light emission estimates were based on typical industry standards for spectral distribution, power rating, and luminous efficacy. Thus these estimates would be typical of the estimates made available from a proposed development project. The second group contained the special light sources (21 500-watt lightbulbs) whose spectral distribution, power rating, and luminous efficacy were known with a high degree of accuracy; these emissions would thus be representative of the best possible estimate of light emissions. By comparing these two groups, we can estimate the degree of accuracy with which we can rely on the model's results to be applicable to proposed development projects.

Figures 7 and 8 are plots of the paired values from the nightglow experiments. The linear correlation coefficients were found to be 0.79 for the special light sources and 0.90 for the existing light sources. The scatters about the line of regression, which is a measure of goodness of fit, were found to be 0.54 and 0.82 $\ln(\text{lm}/\text{m}^2/\text{sr})$, respectively, which means 68 percent of the pairs fall within 1.71 and 2.27 of the line of regression. The lines of regression were found to have a slope of 1.09 and 0.98. An analysis of variance showed that both correlations were significant at the 1 percent confidence level. The mean differences between the predicted and observed values were $+1.85 \times 10^{-3}$ for the special light source and $+4.22 \times 10^{-3} \text{ lm}/\text{m}^2/\text{sr}$ for the existing light source with mean absolute errors of 2.13×10^{-3} and $4.22 \times 10^{-3} \text{ lm}/\text{m}^2/\text{sr}$, respectively. Thus the model tended to overpredict the mean by factors of 3.26 and 2.30, respectively. Since the model's prediction errors cannot be attributable to imprecise measurement of the emission inventory, the data were assumed to be equally valid whether the special or existing light sources were used. Applying a reduction in the vertical aerosol profile similar to that used for all paired values resulted in a mean difference of 2.5×10^{-4} for the special light source and $2.56 \times 10^{-4} \text{ lm}/\text{m}^2/\text{sr}$ for the existing light source with a mean absolute error of 8.03×10^{-4} and $2.18 \times 10^{-3} \text{ lm}/\text{m}^2/\text{sr}$, respectively. Thus the model both overpredicts and underpredicts by factors of 1.30 and 0.92 when the more probable vertical aerosol concentration profile is used. This bias is extremely small when the logarithmic characteristic of human perception is considered. When a human perceives a light to be twice as bright as another light, the light is actually 10 times as bright. Thus a 30 percent increase in actual brightness would yield only an 11 percent increase in perceived brightness. Similarly, an 8 percent decrease in actual brightness would yield a 3 percent decrease in perceived brightness.

Night Sky Luminosity 13-16 June 1988

Special Lights (Obs vs Predictions)

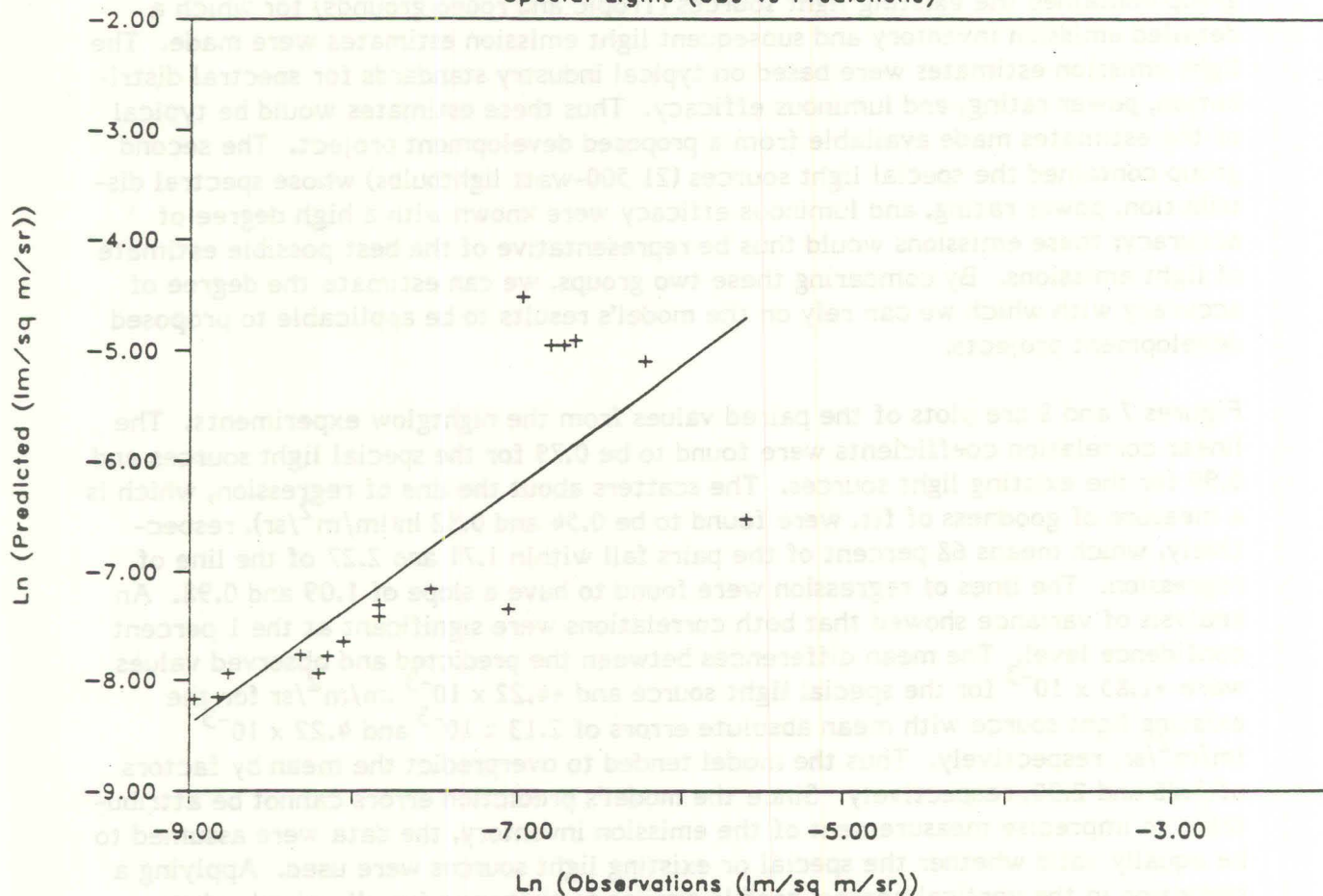


FIGURE 7. All pairs of special light sources—predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park.

Night Sky Luminosity 13-16 June 1988

Existing Lights (Obs vs Predictions)

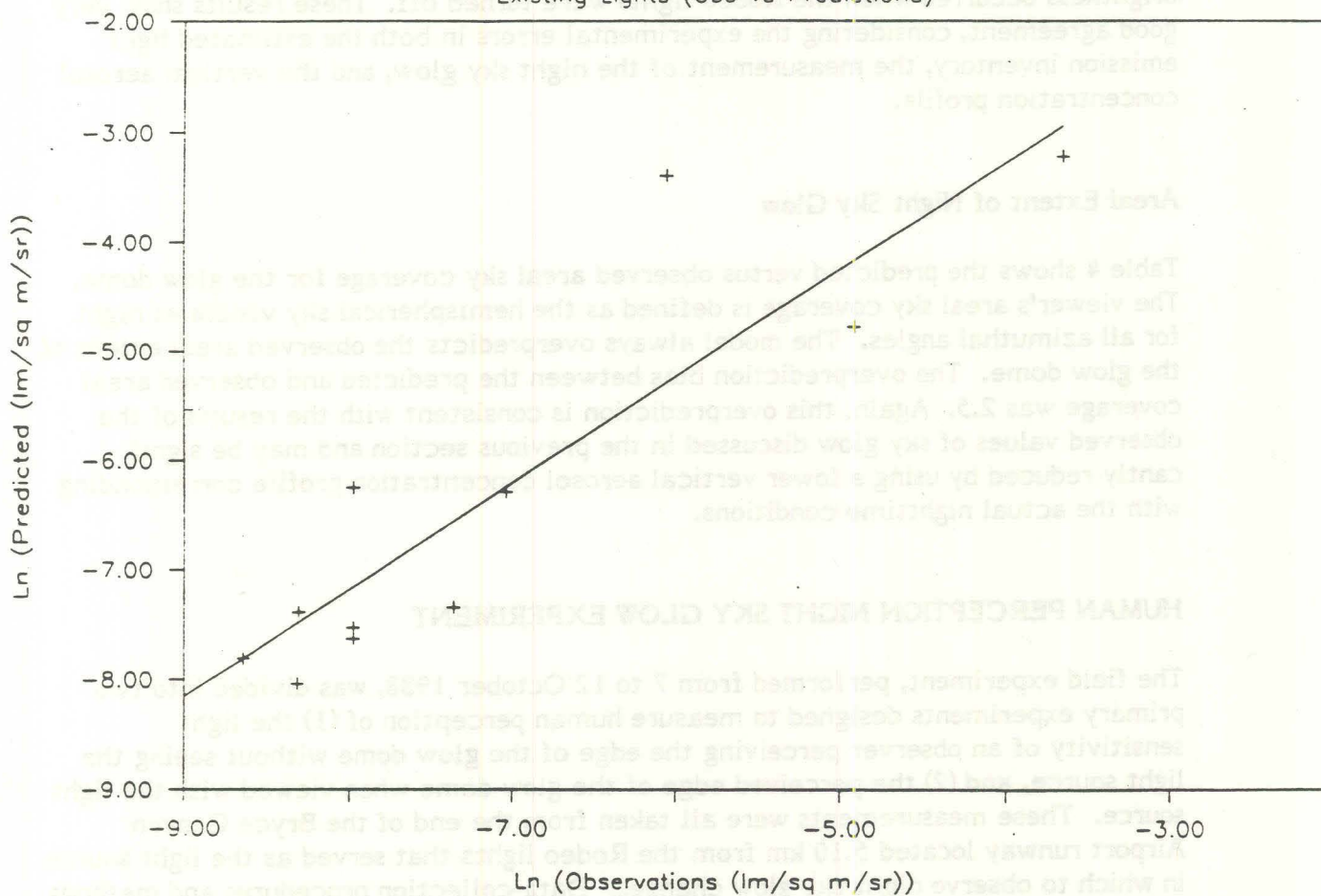


FIGURE 8. All pairs of existing light sources--predicted vs. observed night sky brightness values; 13-16 June 1988; Bryce Canyon National Park.

Sky Glow Variation with Light Source Intensity

The model predicts a linear decrease in light intensity with light emission decrease. The light emissions and lighting type from Table 2 show that for the Rodeo grounds and Ruby's Inn, the predicted decrease in brightness if the Rodeo lights were turned off would be 61.2 percent. The mean peak brightness measurements taken during the 15-16 June experiment (Appendix A.1) indicate that a 71.5 percent decrease in brightness occurred when the Rodeo lights were turned off. These results show very good agreement, considering the experimental errors in both the estimated light emission inventory, the measurement of the night sky glow, and the vertical aerosol concentration profile.

Areal Extent of Night Sky Glow

Table 4 shows the predicted versus observed areal sky coverage for the glow dome. The viewer's areal sky coverage is defined as the hemispherical sky visible at night for all azimuthal angles. The model always overpredicts the observed areal extent of the glow dome. The overprediction bias between the predicted and observed areal coverage was 2.5. Again, this overprediction is consistent with the results of the observed values of sky glow discussed in the previous section and may be significantly reduced by using a lower vertical aerosol concentration profile corresponding with the actual nighttime conditions.

HUMAN PERCEPTION NIGHT SKY GLOW EXPERIMENT

The field experiment, performed from 7 to 12 October 1988, was divided into two primary experiments designed to measure human perception of (1) the light sensitivity of an observer perceiving the edge of the glow dome without seeing the light source, and (2) the perceived edge of the glow dome when viewed with the light source. These measurements were all taken from the end of the Bryce Canyon Airport runway located 5.10 km from the Rodeo lights that served as the light source in which to observe night sky glow changes. Data-collection procedures and methods of light-source measurement for both experiments are described in the following paragraphs.

A carefully designed questionnaire allowed the data collected from group participants to be post-stratified to estimate the general public's perception of the night sky (Figure 9). These questionnaires were completed by park personnel during a brief interview session with the volunteers prior to their participation in the experiment. At no time prior to or during the experiment were discussions held regarding the implications the experiment might have for environmental issues.

TABLE 4. Comparison of areal sky coverage of glow dome observed in June 1988 experiment and coverage predicted using $4 \times 10^{-4} \text{ lm/m}^2/\text{sr}$ as threshold for perceptibility.

Location	Area Observed (%)	Area Predicted (%)	Date
Inspiration-Tropic	0	<1	12-13 June 1988
Inspiration-Maintenance Yard	2	6	12-13 June 1988
East Creek-Maintenance Yard	<1	2	13-14 June 1988
Inspiration-Maintenance Yard	1.5	2.5	14-15 June 1988
Bryce Point-Maintenance Yard	<0.5	1.5	14-15 June 1988
Meadow-Maintenance Yard	0.5	1.5	14-15 June 1988
Airport-Rodeo Grounds	1.0	1.5	15-16 June 1988
Route 22-Rodeo Grounds	<0.5	1.5	15-16 June 1988

1. Where do you live? Country _____
 State _____
 City _____

2. What is your present occupation? _____
 If retired, former occupation: _____

3. Race? (circle one) Black White American Indian
 Asian Hispanic Other _____

4. What is your birthdate? _____ / _____ / _____

5. Do you wear contact lens or glasses? (circle one) Contact lens Glasses None

6. Are you wearing contact lens or glasses now? (circle one) Yes No

7. When was your last eye exam? (circle one)
 A. Within the last year C. Over two years ago
 B. Within the last two years D. Last prescription, if known right _____
 left _____

8. Sex? (circle one) Male Female

9. Height from ground to eye level: _____ ft. _____ in.

Date: _____ / _____ / _____ Departure Time: _____

EXPERIMENT A

Part 1

Distance

Part 2

Distance

EXPERIMENT B

Part 1

Point	Coordinates	
	x	y
1		
2		
3		

Midpoint: _____

Part 2

Point	Coordinates	
	x	y
1		
2		
3		

Midpoint: _____

REMARKS:

FIGURE 9- Example of questionnaire to be completed by group participants.

Starting at 8:00 p.m. MST, at approximately half-hour intervals, four volunteers were shuttled to the experiment site. To "dark-adapt" their eyes, the participants were asked to avoid looking at lights during the drive to the site, and no participant responses were taken within 10 minutes of their arrival at the experiment site. During the 10 minutes, participants were briefed regarding what they would be doing, and measurements were taken of their ground-to-eye height. Then each participant was conducted through the two experiments and their responses recorded by members of the experimental team. To avoid bias in responses from waiting participants, they were conducted away from the experiment area and shown views of the stars and planets through two telescopes made available for their viewing enjoyment. At the end of each half hour, a new group of participants arrived and the process was repeated.

For each night's experiment, night sky brightness measurements were recorded from the base of the light source located at 1.25° above horizontal to 30° at 2° intervals. For each observation angle, three separate measurements were recorded to give an estimate of the measurement error. The telescope and photometer were used to make calibration and light measurements of the glow dome, following the procedures discussed in Section 1 (Appendix A.2 contains the results of these observations). These measured values of brightness were then paired with each participant's observations to quantify his/her perception of the glow dome.

Light Sensitivity Experiment

This experiment was designed to measure how sensitive an observer is to changes in lighting conditions within his field of view in estimating the size of the glow dome from a constant light source against a dark sky. An observer was asked to move from a location in which no glow dome could be discerned (viewing angle was too high) until he was first able to detect a change in sky brightness (relative to the sky above). The experiment was then repeated but with the lights turned on and off to test if observers could detect changes between the night sky (background) and the glow dome emitted by the light source. This provided a measure of the ability of the human eye to detect changes in lighting conditions relative to a dark sky.

To limit the observer's viewing angle, a wall 8 ft x 12 ft was placed between the observer and the distant light source. The observer then stood behind the wall and was asked if the glow dome from the light source could be detected. A text was developed that described a "barely perceptible" glow to insure that each group of subjects was interpreting the experiment in the same way. The subject was first directed to a spot on the near side of the wall so that the glow dome was partly visible and was then told: "The purpose of this part of the experiment is to measure how high into the sky you can see the dome extend. We do this with the barrier (wall) and a scale we have marked on the ground. Right now we are letting your eyes adjust to looking at the dome. We will be asking you to pick out what we call the top edge of the dome, that is, the first point at which you can perceive light as opposed

to darkness. To orient yourself, try looking directly up to the dark sky above and bringing your vision down toward the dome until you see light. Also try this from the side. When you feel you have an idea of where in the sky you can see the edge, let me know and we will step over here (to position behind wall) so we can measure the distance." The subject was then directed to a mark 35 feet from the wall and told: "See if you can perceive the top of the glow dome over the top of the wall. If you can see it, move up (towards the wall) until the top of the dome matches up with the top of the wall, and if you can't see it, move back (away from the wall) as much as you need to to get the appropriate position, with the top of the dome at the top of the wall." Once the subject was in position, the measurement was taken.

The second phase of the experiment was designed to measure when the human eye can detect changes in night sky lighting. The subject was told, "Now we will turn the dome off. This will give you a chance to compare the natural night sky with the illuminated. The reason we do this is that some people observe a change when the dome comes back on (dome was turned off at this point). Now let your eyes adjust for a few seconds, and when I turn the dome on, if you observe a change, readjust your position until the top of the dome is once again at the top of the wall." The dome was then turned on again and when the subject indicated that he was ready, his position was measured and recorded. Any other pertinent conditions--such as cloud cover, time of observation, or peculiarities of subject--were noted.

Perceived Edge Experiment

In this experiment, the perceived size and edge of the glow dome were measured when the observer was allowed to view the entire glow dome. The experiment was then repeated but with the lights turned on and off to identify the location of the edge of the glow dome as perceived by the observer when viewed against a dark background sky. This yielded an absolute lower limit to the luminosity level for an estimate of the size and extent of the glow dome.

This experiment employed a window frame (4 ft x 8 ft) with a wire mesh grid (1-inch grid spacing) that was stretched across the upper half of the frame across the viewer's field of vision when viewed in the direction of the light source. This allowed the observer to view all portions of the glow dome, as well as the light source, at the same time. The wire mesh grid was labeled with numbers along the window frame edge in both the horizontal and vertical directions. The viewer stood 3.5 feet behind the window and was asked to determine the shape of the glow dome by defining the coordinate positions for the horizontal and vertical extent of the dome. Four points were determined to be sufficient to describe the shape of the glow dome (center, one vertical, and two horizontal). A text was developed that described "edge of the glow dome" to insure that each group of subjects was interpreting the experiment in the same way.

With the subject standing in position behind the window, he was told, "The purpose of this experiment is to identify the edge of the light dome when viewed with the light source. I will ask you to identify three points for me: the upper, right, and left-side limits of the dome. The edge of the dome is not a sharp line. The edge of the dome is where the light ends. It is where you can still just barely see light, and after which the night sky remains unaffected. The light dome is not simply the brightest core of light, but includes the outer, barely perceivable, reaches of light. One way to decide where the edge of the dome is located is to compare the light dome to the night sky. Look above you, and then move your eyes down towards the dome. The upper limit, or edge, of the dome is where you can first see light. You can do the same for the right and left sides of the dome. After you have decided where the edge of the dome is, I will move this pointer along the grid. I want you to tell me to stop when the leading edge hits the edge of the dome. I'll do this for the upper, right and left limits." When this procedure was completed, the three points were recorded. The subject was then told, "Now I want you to tell me where you think the center of the dome is, where the dome is brightest. Again I'll move the pointer along the grid and you let me know when the leading edge is in the center of the dome."

After the center point was recorded, the second part of the experiment was begun by telling the subject, "In the second part of this experiment we will turn the light dome off and then on, and ask you to again find the edge of the dome. After the dome has been turned off and on, you may or may not find that the edges of the dome have changed. After the dome is turned back on, I'd like you to decide where the edge of the dome is, as you did previously, and we will repeat the process." The measurements for this second part of the experiment were recorded, and other pertinent conditions were noted such as cloud cover, time of observation, or peculiarities of the subject.

HUMAN PERCEPTION DATA REDUCTION

The human perception experiments were performed from 7 to 12 October 1988; however, data collected during the evening of the 7th were not used in the analysis because the group of people used were park personnel or employees at the park. The purpose of the experiment on that night was to resolve technical and logistical problems in collecting the data. During the five nights of the experiments, a total of 97 individuals were interviewed and their responses measured.

For both the light sensitivity and the perceived edge experiment and for each phase, the distance from the wall or grid and height of the observer was transformed to an elevation angle, θ_e :

$$\theta_e = \tan^{-1}(\text{height of observation-eye height of observer}) / (\text{distance from wall or grid})$$

These calculated elevation angles were linearly interpolated to the luminosity of the observed elevation angles taken simultaneously during each evening's experiment. These data were then plotted (luminosity versus elevation angle) along with the standard deviation of the observing error to give an estimate of the variation in the luminosity measurement for the observations taken each evening. The data were examined to see if there were inconsistencies between different data sets. No large variation was noted in the data sets except for a spike that occurred towards the tail of distribution curve on certain days. Upon closer examination, these days and time periods corresponded with experiments during which low-level cloudiness was noted.

To determine the extent to which these observations might have been distorted by cloudiness, the observations were binned into two categories--non-cloudy and cloudy periods. Binning the data showed that the cloudy periods caused the observers to increase their estimates of the height of the glow dome. This discrepancy can be attributed to reflections from the clouds. Unfortunately, not enough data was collected during these periods to estimate the percentage brightness increase due to low-level cloudiness. A total of 10 observations were determined to be contaminated and were not used in any subsequent analyses.

During the preliminary analysis of observed data from the grid experiment, it was noted that the areal extent of the glow dome was contaminated by a light source to the right of the dome. This light source distorted the edge of the glow dome so much that the areal extent of the dome could not be determined.

RESULTS OF HUMAN PERCEPTION EXPERIMENTS

To estimate the "barely perceptible" edge and the size and extent of the glow dome, cumulative distribution frequency curves of +1 (high) and -1 (low) standard deviations of the observed luminosity were made for each experiment (Figures 10 and 11). These high and low standard deviations provide an estimate of the range of the experimental error in measuring the luminosity. For each experiment the median luminosity value is the statistic that is most representative of the characteristics of the entire group.

Light was represented in log scale for greater accuracy. The shape of the cumulative distribution frequency reveals the relative sensitivity of the experiments. The sharp slopes of the wall experiment indicate a uniformity of measurement across subjects, whereas the more gradual slopes of the grid experiments indicate a finer degree of measurement.

The most conservative estimate for the threshold of detectability of the glow dome can be derived by examining the lower standard deviation of the observed luminosity for each experiment. Figure 12 shows the values of the lower and higher standard deviations, along with the 95 percent confidence bounds based on the assumption that the experimental errors are randomly distributed. The wall experiment, designed to

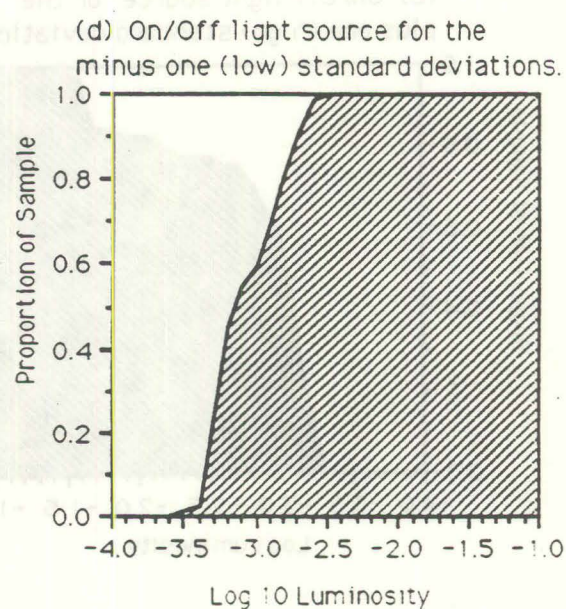
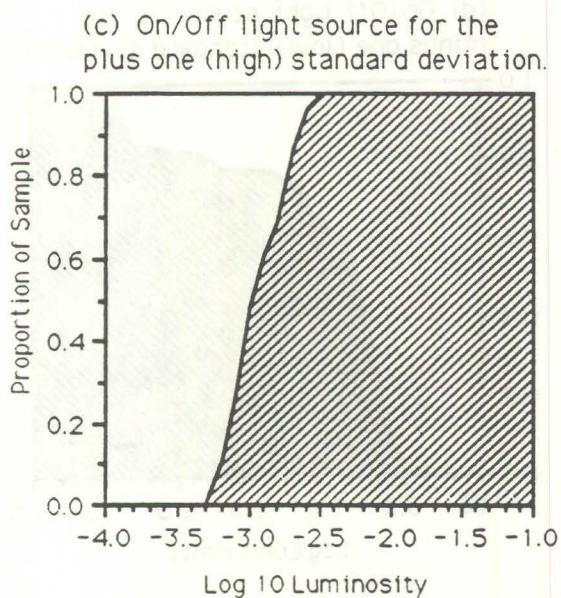
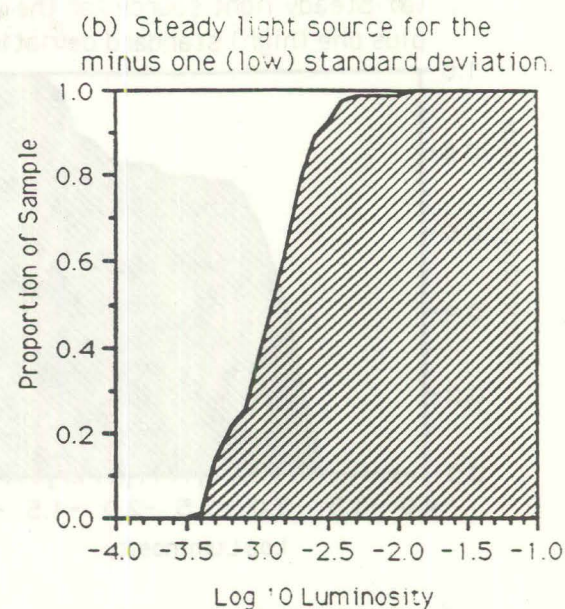
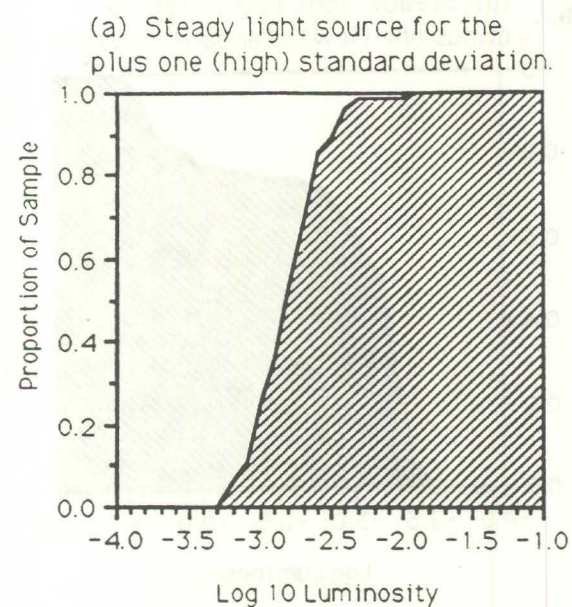


FIGURE 10. Wall Experiment. Sample population versus observed threshold luminosity.

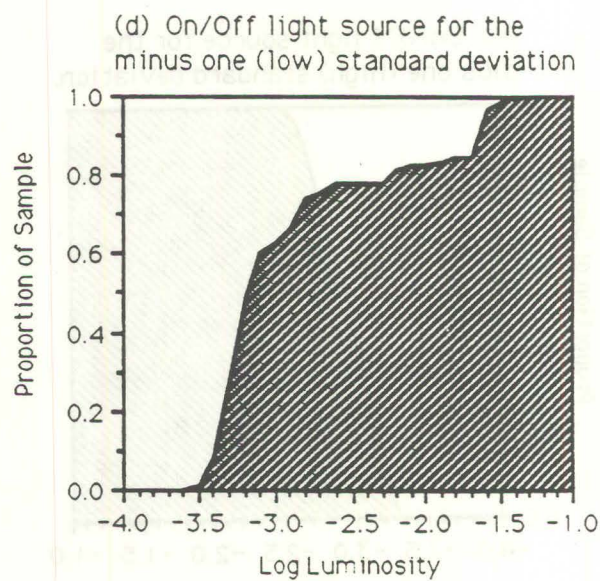
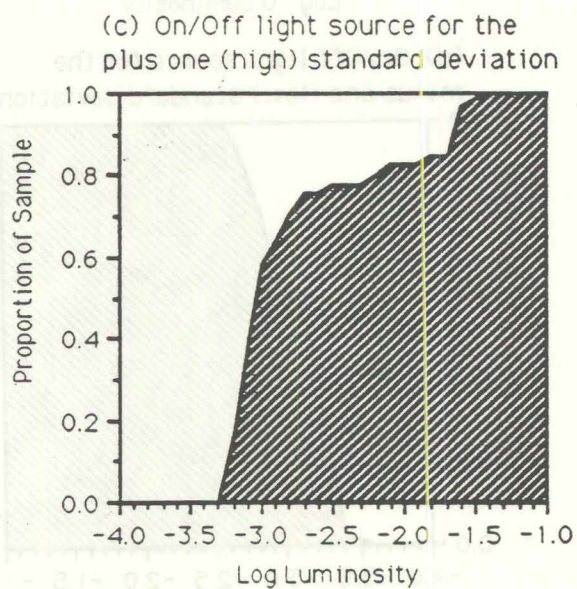
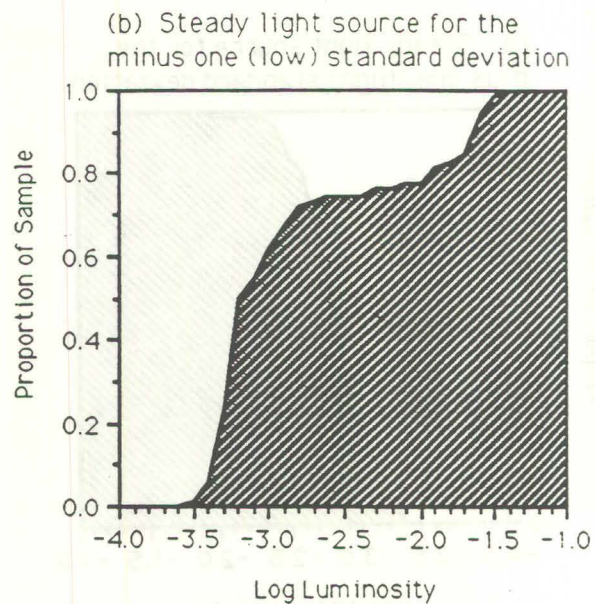
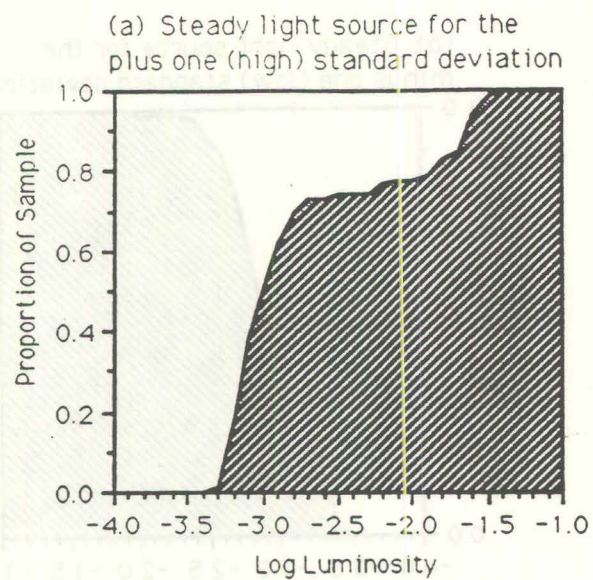


FIGURE 11. Grid experiment. Sample population versus observed threshold luminosity.

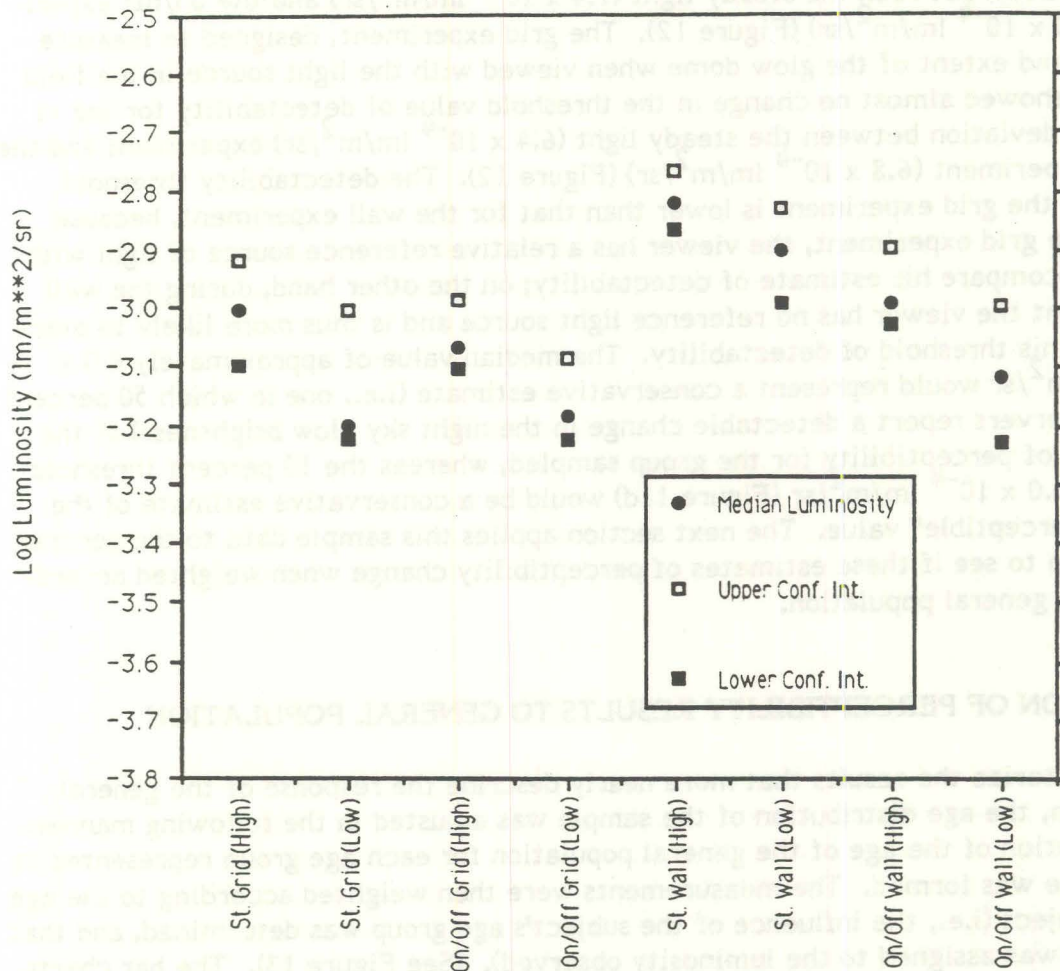


FIGURE 12. Sample median luminosities for each perception experiment with 95% confidence bounds.

estimate the light sensitivity of the observer in locating the edge of the glow dome, shows a significant decrease in the threshold value of detectability for the -1 standard deviation between the steady light (1.4×10^{-3} lm/m²/sr) and the on/off experiment (9.0×10^{-4} lm/m²/sr) (Figure 12). The grid experiment, designed to measure the size and extent of the glow dome when viewed with the light source in the field of view, showed almost no change in the threshold value of detectability for the -1 standard deviation between the steady light (6.4×10^{-4} lm/m²/sr) experiment and the on/off experiment (6.8×10^{-4} lm/m²/sr) (Figure 12). The detectability threshold value for the grid experiment is lower than that for the wall experiment, because during the grid experiment, the viewer has a relative reference source of light with which to compare his estimate of detectability; on the other hand, during the wall experiment the viewer has no reference light source and is thus more likely to overestimate his threshold of detectability. The median value of approximately 6.0×10^{-4} lm/m²/sr would represent a conservative estimate (i.e., one in which 50 percent of all observers report a detectable change in the night sky glow brightness) of the threshold of perceptibility for the group sampled, whereas the 10 percent threshold value of 4.0×10^{-4} lm/m²/sr (Figure 11d) would be a conservative estimate of the "barely perceptible" value. The next section applies this sample data to the general population to see if these estimates of perceptibility change when weighted according to the general population.

EXTENSION OF PERCEPTIBILITY RESULTS TO GENERAL POPULATION

To characterize the results that more nearly describe the response of the general population, the age distribution of the sample was adjusted in the following manner. A distribution of the age of the general population for each age group represented in our sample was formed. The measurements were then weighted according to the age of the subject (i.e., the influence of the subject's age group was determined, and that influence was assigned to the luminosity observed). (See Figure 13). The bar charts show the age distributions of the sample and the general population. Unfortunately, we were unable to further subdivide these categories by race or sex because the data sample set would be too small in many of the categories. However, age is the most important variable in differences noted between individuals. Weale (1975) showed that visual acuity deteriorates after the age of about 45 years; during the subsequent four decades the loss amounts to some 80 percent.

The cumulative distributions (higher and lower) of luminosities observed are shown for each experiment in Figures 14 and 15 for the modified data. These graphs can be seen as representative of the general population, whereas Figures 10 and 11 are representative of just the sample. Applying the weighting adjustment factors determined from Figure 13 shows that the differences between the general population and the sample population are almost imperceptible (Figures 10 and 11 vs. Figures 14 and 15). Our sample was remarkably close to the true age distribution with the exception of the 10 to 19-year-old group. Even after weighting the subjects in this age group, their influence remains minimal. Thus the conclusions drawn for

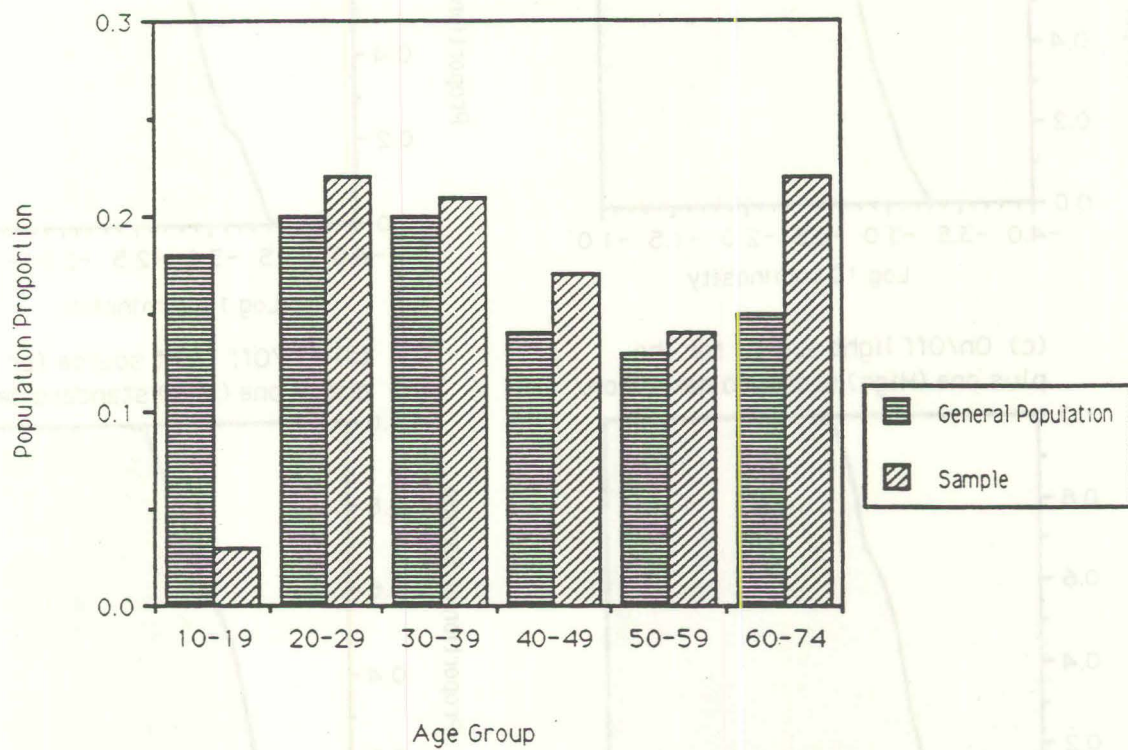


FIGURE 13. Sample population versus general population age distribution.

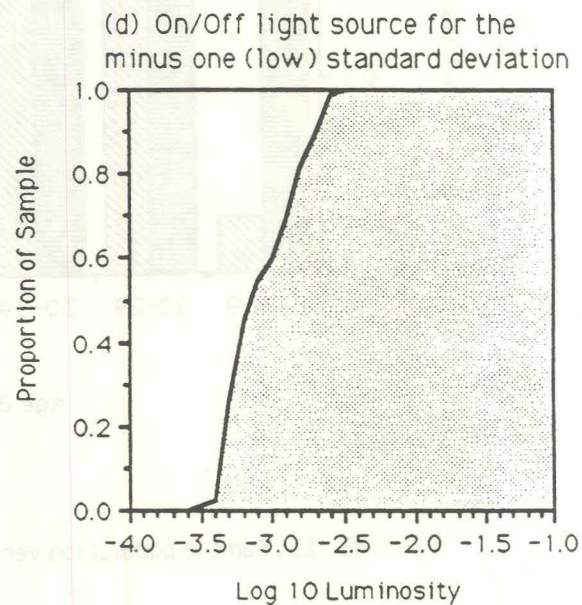
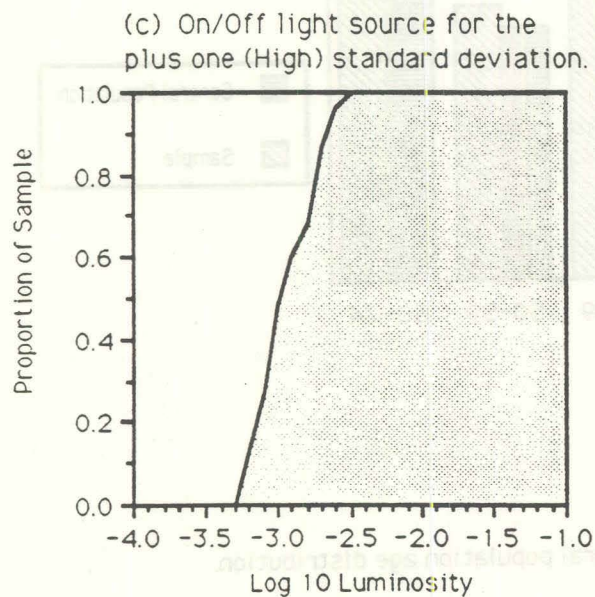
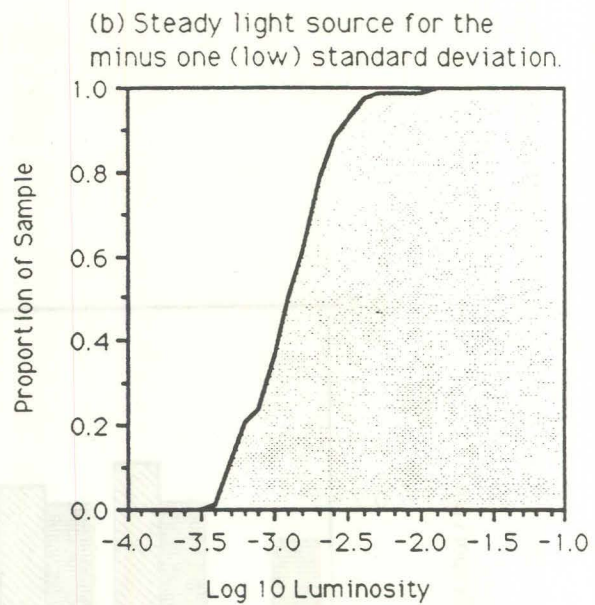
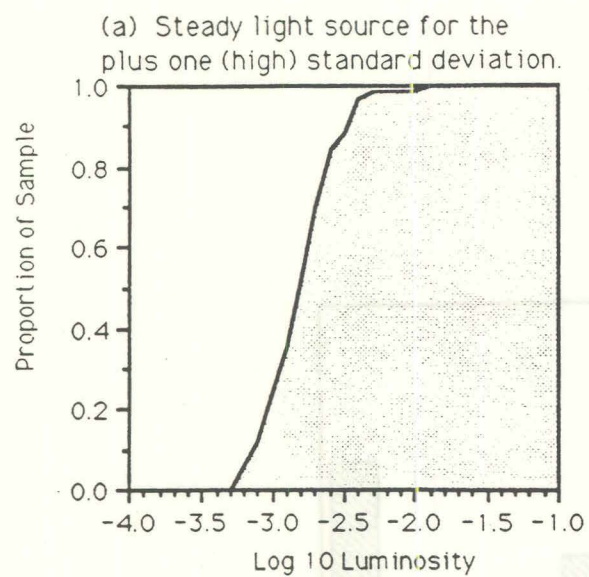


FIGURE 14. Wall Experiment. General population versus observed threshold luminosity.

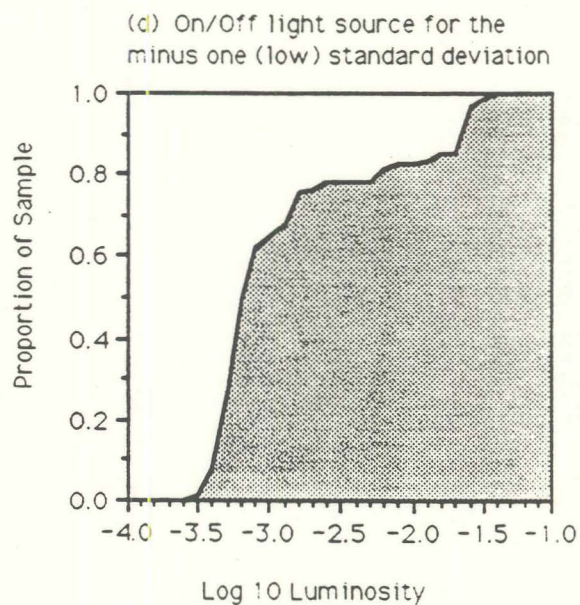
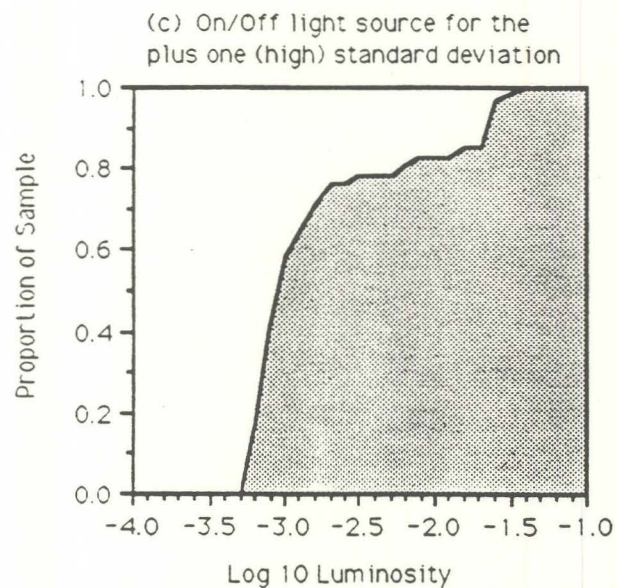
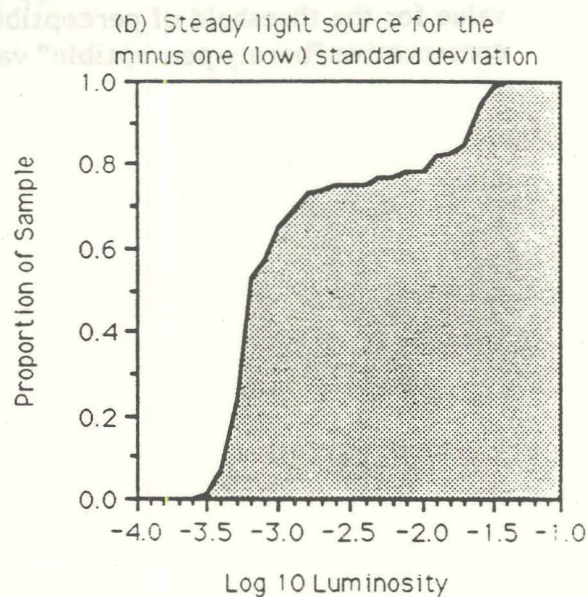
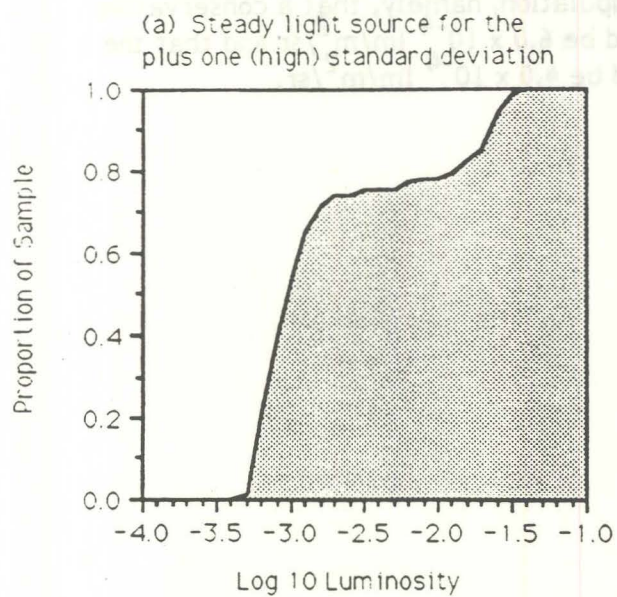


FIGURE 15. Grid Experiment. General population versus observed threshold luminosity.

4 CONCLUSIONS

The predictive ability of the Night Sky Glow Model to assess the night sky glow caused by human activities has been evaluated. The model tended to overpredict the extent of the night sky dome brightness by an average difference of 2.83×10^{-3} $\text{lm/m}^2/\text{sr}$, with a significant correlation coefficient of 0.85. These overpredictions are believed to result from the fact that nighttime vertical aerosol profile concentrations are lower than the measured average daily aerosol concentrations used in the model. When the vertical aerosol profile was adjusted to reflect the more likely nighttime conditions, the model was found to overpredict by an average difference of only 4×10^{-5} $\text{lm/m}^2/\text{sr}$, which is much less than the measurement error. In order to improve model performance, more accurate vertical aerosol profiles are needed.

An experiment has been performed to quantify the human perceptibility of the night sky glow caused by nighttime lighting. The results of the experiment indicate that for the dark sky environment at Bryce Canyon National Park, 6.0×10^{-4} $\text{lm/m}^2/\text{sr}$ would be a conservative value for the threshold of perceptibility, whereas 4.0×10^{-4} $\text{lm/m}^2/\text{sr}$ would be a conservative estimate of the "barely perceptible" threshold. This value compares favorably with the value reported by Blackwell (1946) of 6×10^{-4} $\text{lm/m}^2/\text{sr}$ for a 50 percent probability of detection threshold. Extension of these results to the general population using age as the only discriminating factor between the group sampled and the general population showed no significant difference in these threshold values.

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BRIGHTNESS OF NIGHT SKY FOR MODEL EVALUATION STUDY

89011 1

Brightness of Night Sky Calculation

Observation Location: Inspiration Point
 Light Source Location: Tropic, Utah
 Distance: 7.30 km

Latitude: 37.6135507 Longitude: 112.1683078
 Latitude: 37.6240580 Longitude: 112.0865244

Date: June 12-13 1988

Time 24 hour clock (MDT)	Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Counts			Lumens per meter ² /sr	Remarks
					Sky + Dark	Dark	Sky		
55	-4	0.00	100	10	6165	6100	65	2.48E-04	Base of glow dome
100	0	0.00	100	10	6150	6120	30	1.14E-04	Top of glow dome
105	-2	0.00	100	10	6170	6124	46	1.75E-04	Mid point of glow dome

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Gamma UMA	Transformation slope for filter:	1.000
Visual Magnitude:	2.44	Extinction coefficient that night:	0.074
Altitude Angle Viewed:	42	Temperature:	5 C
Star's Signal:	839	Relative Humidity:	20 %
Scale used star signal:	10	Weather Conditions:	Few high clouds near horizon not near glow dome

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 82 degrees

Brightness of Night Sky Calculation

Observation Location: Inspiration Point Latitude: 37.6135507 Longitude: 112.1683078 Date: June 12-13 1988
 Light Source Location: Maint Yard Bryce Park Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 2.08 km

Time 24 hour clock (MDT)	Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Counts			Lumens per meter ² /sr	Remarks
					Sky + Dark	Dark	Sky		
105	-3	0.00	100	10	6356	6110	246	9.38E-04	Base of Trees on horizon of glow dome
110	7	0.00	100	10	6253	6110	143	5.45E-04	Midpoint of glow dome
115	12	0.00	100	10	6295	6192	103	3.93E-04	Varying altitude of glow dome
120	18	0.00	100	10	6266	6190	76	2.90E-04	Varying altitude of glow dome
123	23	0.00	100	10	6271	6199	72	2.75E-04	Top of Glow Dome
130	-3	-4.25	100	10	6254	6190	64	2.44E-04	Left Side of glow dome
133	-3	4.25	100	10	6240	6190	50	1.91E-04	Right side of glow dome
137	-3	0.00	100	10	6240	6215	25	9.53E-05	Natural Background Near Horizon

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Gamma UMA Transformation slope for filter: 1.000
 Visual Magnitude: 2.44 Extinction coefficient that night: 0.074
 Altitude Angle Viewed: 42 Temperature: 5 C
 Star's Signal: 839 Relative Humidity: 20 %
 Scale used star signal: 10 Weather Conditions: Few high clouds near horizon not near glow dome

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 343 degrees

Brightness of Night Sky Calculation

Observation Location: East Creek Latitude: 37.6072464 Longitude: 112.1983042 Date: June 13-14 1988
 Light Source Location: Maint Yard Bryce Park Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 3.2 km

Time	Counts							Remarks
24 hour clock	Altitude	Azimuth	Scale	Avg Time	Sky + Dark	Dark	Sky	
(MDT)	Degrees	Degrees		seconds				
108	1	0.00	100	10	6100	5975	125	6.13E-04 Varying Glow Dome
110	1	0.00	100	10	6237	5975	262	1.28E-03 Max Glow Dome
141	5	0.00	100	10	6300	6225	75	3.68E-04 Top of Glow Dome
151	1	15.00	100	10	6306	6280	26	1.27E-04 Right Edge of Glow Dome - Short 5 lights
155	1	-15.00	100	10	6320	6288	32	1.57E-04 Left Edge of Glow Dome
159	1	15.00	100	10	6375	6330	45	2.21E-04 Right Edge of Glow Dome - Full Set
155	1	0.00	100	10	6200	6175	25	1.23E-04 Natural Background Sky Brightness

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Delta UMA	Transformation slope for filter:	1.000
Visual Magnitude:	3.31	Extinction coefficient that night:	0.003
Altitude Angle Viewed:	51	Temperature:	10 C
Star's Signal:	323	Relative Humidity:	20 %
Scale used star signal:	10	Weather Conditions:	Thin Cirrus Clouds located behind glow dome

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 38 degrees

Note: Both light source and viewing location are at 2420m above sea level however, the intervening terrain ridge of 2469m prevents viewing of the true base of the glow dome
 Distance to intervening terrain from viewing location is 1.8km. Thus 1.56 degrees of the dome is below the observers line of sight.

Brightness of Night Sky Calculation

Observation Location: Bryce Point Latitude: 37.6054348 Longitude: 112.1567287 Date: June 14-15 1988
 Light Source Location: Maint Yard Bryce Park Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 3.25 km

Time	Altitude	Azimuth	Scale	Avg Time	Sky + Dark	Dark	Sky	Lumens per	Remarks
24 hour clock	Degrees	Degrees		seconds				meter2/sr	
(MDT)									
48	-1	0.00	100	10	6170	5770	400	1.96E-03	Max Glow Dome (Base)
50	11	0.00	100	10	5810	5760	50	2.45E-04	Top of Glow Dome

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Delta UMA	Transformation slope for filter:	1.000
Visual Magnitude:	3.31	Extinction coefficient that night:	0.003
Altitude Angle Viewed:	51	Temperature:	12 C
Star's Signal:	323	Relative Humidity:	30 %
Scale used star signal:	10	Weather Conditions:	Calm no winds, No clouds

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 330 degrees

Brightness of Night Sky Calculation

Observation Location: Meadow near Maint Yard Latitude: 37.6362319 Longitude: 112.1680343 Date: June 14-15 1988
 Light Source Location: Maintenance Yard Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 0.80 km

Time					Counts			Lumens per meter ² /sr	Remarks
24 hour clock (MDT)	Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky		
2345	25	0.00	100	10	5920	5890	30	1.47E-04	Top of glow dome
2350	16	0.00	100	10	5936	5904	32	1.57E-04	Mid-point of glow dome
2355	5	0.00	100	10	6086	5910	176	8.63E-04	Base of glow dome
2358	25	0.00	100	10	5996	5970	26	1.27E-04	Top of glow dome
2359	25	0.00	100	10	6000	5960	40	1.96E-04	Nat Back (base of glow dome)
1	5	0.00	100	10	6000	5995	5	2.45E-05	Nat Back (top of glow dome)

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Delta UMA	Transformation slope for filter:	1.000
Visual Magnitude:	3.31	Extinction coefficient that night:	0.003
Altitude Angle Viewed:	51	Temperature:	12 C
Star's Signal:	323	Relative Humidity:	30 %
Scale used star signal:	10	Weather Conditions:	Thin cirrus clouds behind glow dome

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 227 degrees

Note: Trees obscured lowest portion of glow dome.

Brightness of Night Sky Calculation

Observation Location: Inspiration Point Latitude: 37.6135507 Longitude: 112.1683078 Date: June 14-15 1988
 Light Source Location: Maint Yard Bryce Park Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 2.08 km

Time						Counts		Lumens per meter ² /sr	Remarks
24 hour clock (MDT)	Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky		
105	-1	0.00	100	10	5965	5720	245	1.20E-03	Base of glow dome
110	11	0.00	100	10	5800	5735	65	3.19E-04	Top of glow dome
115	6	0.00	100	10	5815	5735	80	3.92E-04	Midpoint of glow dome
120	-1	0.00	100	10	5950	5724	226	1.11E-03	Base of glow dome
123	-1	0.00	100	10	5780	5760	20	9.81E-05	Nat Background at Base of glow dome
130	11	0.00	100	10	5810	5760	50	2.45E-04	Nat Background at top of glow dome

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Delta UMA Transformation slope for filter: 1.000
 Visual Magnitude: 3.31 Extinction coefficient that night: 0.003
 Altitude Angle Viewed: 51 Temperature: 10 C
 Star's Signal: 323 Relative Humidity: 30 %
 Scale used star signal: 10 Weather Conditions: Clear, very light winds, few high cirrus not near glow dome

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 343 degrees

Brightness of Night Sky Calculation

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: June 15-16 1988

Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919

Distance: 3.15 km

Time	Altitude	Azimuth	Scale	Avg Time	Sky + Dark	Dark	Sky	Lumens per	Remarks
(MDT)	Degrees	Degrees		seconds				meter ² /sr	
15	1	0.00	100	1	1117	594	523	2.56E-02	Base of glow dome
15	1	0.00	100	1	1130	598	532	2.61E-02	Base of glow dome
20	1	0.00	100	1	750	594	156	7.65E-03	Base of glow dome without rodeo lights
21	1	0.00	100	1	742	597	145	7.11E-03	Base of glow dome without rodeo lights
22	12	0.00	100	1	605	600	5	2.45E-04	Top of glow dome without rodeo lights
23	12	0.00	100	1	606	601	5	2.45E-04	Top of glow dome without rodeo lights
24	12	0.00	100	1	608	600	8	3.92E-04	Nat Background near top of glow dome
25	1	0.00	100	1	608	600	8	3.92E-04	Nat Background near horizon
30	30	0.00	100	10	6155	6090	65	3.19E-04	Milky Way Brightness
35	30	0.00	100	10	6140	6090	50	2.45E-04	Near Milky Way
40	17	0.00	100	1	615	608	57	3.43E-04	Top of glow dome (full set of lights)
41	1	0.00	100	1	1130	605	525	2.57E-02	Base of glow dome
45	9	0.00	100	1	623	610	13	6.37E-04	Various altitudes
48	5	0.00	100	1	630	612	18	8.83E-04	Various Altitudes

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor

Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Delta UMA Transformation slope for filter: 1.000
 Visual Magnitude: 3.31 Extinction coefficient that night: 0.003
 Altitude Angle Viewed: 51 Temperature: 15 C
 Star's Signal: 323 Relative Humidity: 20 %
 Scale used star signal: 10 Weather Conditions: Clear and calm; Visual Range at 2pm 150km

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation

Observation Location: Rt 22 Antimony 3.65 mi Latitude: 37.721709 Longitude: 112.107659 Date: June 15-16 1988

Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919

Distance: 6.8 km

Time					Counts		Lumens per meter ² /sr	Remarks
24 hour clock (MDT)	Altitude Degrees	Azimuth Degrees	Scale Avg Time seconds	Sky + Dark	Dark	Sky		
115	1	0.00	100	1 650	602	48	2.35E-03	Base of glow dome
116	1	0.00	100	1 650	602	48	2.35E-03	Base of glow dome
120	7.5	0.00	100	1 622	615	7	3.43E-04	Top of glow dome
122	4	0.00	100	1 612	605	7	3.43E-04	Midpoint of glow dome
128	1	0.00	100	1 609	605	4	1.96E-04	Nat Background at base of glow dome

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor

Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Delta UMA

Transformation slope for filter:

Visual Magnitude: 3.31

Extinction coefficient that night:

Altitude Angle Viewed: 51

Temperature:

10 C

Star's Signal: 323

Relative Humidity:

25 %

Scale used star signal: 10

Weather Conditions: Clear and calm

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 220 degrees

Some of the light sources may have been turned off after 0100 MDT

Brightness of Night Sky Calculation

Observation Location: East Creek Latitude: 37.6072464 Longitude: 112.1983042 Date: June 16-17 1988
 Light Source Location: Maint Yard Bryce Park Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 3.2 km

Time	Altitude	Azimuth	Scale	Avg Time	Sky + Dark	Dark	Sky	Lumens per	Remarks
(MDT)	Degrees	Degrees		seconds				meter ² /sr	
1158	22	20.00	100	10	5452	5400	52	2.55E-04	Peak value approximately 20 degrees to the right of the glow dome
1159	1	0.00	100	10	5470	5440	30	1.47E-04	Glow dome near horizon
1201	22	20.00	100	10	5485	5460	25	1.23E-04	Nat sky count at 20 degrees to the right of the center
1205	1	0.00	100	10	5457	5440	17	8.34E-05	Nat sky count at horizon

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Delta UMA Transformation slope for filter: 1.000
 Visual Magnitude: 3.31 Extinction coefficient that night: 0.003
 Altitude Angle Viewed: 51 Temperature: 13 C
 Star's Signal: 323 Relative Humidity: 45 %
 Scale used star signal: 10 Weather Conditions: Completely overcast estimated base of clouds is 8000 feet above ground level

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 38 degrees

Note: Both light source and viewing location are at 2420m above sea level however,
 the intervening terrain ridge of 2469m prevents viewing of the true base of the glow dome
 Distance to intervening terrain from viewing location is 1.8km. Thus 1.56 degrees
 of the dome is below the observers line of sight.

Brightness of Night Sky Calculation

Observation Location: Meadow near Maint Yard Latitude: 37.6362319 Longitude: 112.1680343 Date: June 16-17 1988
 Light Source Location: Maintenance Yard Latitude: 37.63152117 Longitude: 112.1748724
 Distance: 0.80 km

Time					Counts				
24 hour clock	Altitude	Azimuth	Scale	Avg Time	Sky + Dark	Dark	Sky	Lumens per	Remarks
(MDT)	Degrees	Degrees		seconds				meter ² /sr	
30	3	0.00	100	10	5740	5460	280	1.37E-03	Base of glow dome (trees below this elevation angle)
35	60	0.00	100	10	5570	5425	145	7.11E-04	Glow dome at 90 degrees overhead
40	60	0.00	100	10	5495	5460	35	1.72E-04	Natural background at 60 degrees
45	3	0.00	100	10	5440	5425	15	7.35E-05	Natural count at horizon

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Delta UMA	Transformation slope for filter:	1.000
Visual Magnitude:	3.31	Extinction coefficient that night:	0.003 C
Altitude Angle Viewed:	51	Temperature:	12 %
Star's Signal:	323	Relative Humidity:	60
Scale used star signal:	10	Weather Conditions:	Cloud deck estimated at 8,000 ft AGL reflects much of the light

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 227 degrees

Note: Trees obscured lowest portion of glow dome.

Appendix A.2

BRIGHTNESS OF NIGHT SKY FOR HUMAN PERCEPTION STUDY

Brightness of Night Sky Calculation Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838
 Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919
 Distance: 3.15 km

Date: October 8 1988

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Counts		Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
				Sky + Dark	Dark				
1.25	0.00	100	1	918.0	636.0	282.0	6.30	17.58	11966 1.01E-02
3	0.00	100	1	680.3	633.0	47.3	8.24	19.52	2008 1.69E-03
4	0.00	100	1	662.7	635.3	27.3	8.84	20.11	1160 9.77E-04
6	0.00	100	1	646.3	636.7	9.7	9.97	21.24	410 3.45E-04
8	0.00	100	1	646.0	635.0	11.0	9.83	21.10	467 3.93E-04
10	0.00	100	10	646.4	638.6	7.9	10.19	21.47	334 2.81E-04
12	0.00	100	10	649.2	639.3	9.9	9.94	21.21	421 3.55E-04
14	0.00	100	10	647.6	638.4	9.2	10.02	21.29	392 3.30E-04
16	0.00	100	10	645.8	636.1	9.7	9.96	21.24	412 3.47E-04
18	0.00	100	10	642.6	635.8	6.8	10.35	21.63	287 2.42E-04
20	0.00	100	10	641.8	633.3	8.5	10.10	21.38	362 3.05E-04
22	0.00	100	10	642.5	635.9	6.6	10.39	21.66	279 2.35E-04
24	0.00	100	10	642.5	635.9	6.6	10.38	21.65	281 2.37E-04
28	0.00	100	10	641.6	634.6	6.9	10.33	21.60	294 2.48E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient that night:	0.18
Altitude Angle Viewed:	65	Temperature:	0 C
Calculated Star Signal	753	Relative Humidity:	85 %
Scale used star signal:	1	Weather Conditions:	Generally clear and calm condensation started to form around 2200

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: October 9 1988
 Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919 Time: 2000-2100
 Distance: 3.15 km

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Counts per Second		Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
				Sky + Dark	Dark				
1.25	0.00	100	1	890.3	598.0	292.3	6.19	17.46	13346 1.12E-02
4	0.00	100	1	623.3	597.3	26.0	8.81	20.09	1187 9.99E-04
6	0.00	100	10	613.6	603.0	10.6	9.79	21.06	484 4.07E-04
8	0.00	100	10	608.7	600.2	8.5	10.03	21.30	388 3.27E-04
10	0.00	100	10	608.9	601.6	7.3	10.20	21.47	332 2.79E-04
12	0.00	100	10	609.9	603.6	6.3	10.35	21.63	288 2.42E-04
14	0.00	100	10	612.6	605.2	7.4	10.17	21.45	339 2.86E-04
16	0.00	100	10	613.8	606.3	7.5	10.16	21.43	344 2.90E-04
18	0.00	100	10	614.4	608.1	6.4	10.34	21.62	291 2.45E-04
20	0.00	100	10	618.8	608.6	10.2	9.83	21.11	464 3.91E-04
22	0.00	100	10	616.0	607.4	8.5	10.02	21.30	390 3.28E-04
24	0.00	100	10	618.8	610.5	8.3	10.06	21.33	377 3.18E-04
26	0.00	100	10	617.9	609.1	8.8	9.99	21.27	402 3.38E-04
28	0.00	100	10	617.1	609.5	7.6	10.15	21.42	347 2.92E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
 Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient (mag/air mass):	0.108
Altitude Angle Viewed:	65	Temperature:	7 C
Calculated Star Signal	753	Relative Humidity:	55 %
Scale used star signal:	1	Weather Conditions:	Mostly cloudy with mid to high level clouds. Star measurement calculation impossible.

Extinction coefficient based on visibility during the day.

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: October 9 1988
Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919 Time: 2100-2200
Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
1.25	0.00	100	1	970.3	615.7	354.7	5.98	17.25	16191	1.36E-02
4	0.00	100	1	640.0	610.7	29.3	8.68	19.96	1339	1.13E-03
6	0.00	100	10	628.6	612.9	15.7	9.36	20.63	718	6.05E-04
8	0.00	100	10	621.0	609.7	11.4	9.71	20.99	519	4.37E-04
10	0.00	100	10	620.0	610.8	9.2	9.95	21.22	418	3.52E-04
12	0.00	100	10	617.4	611.5	5.9	10.43	21.71	268	2.26E-04
14	0.00	100	10	619.2	612.2	7.0	10.24	21.51	320	2.69E-04
16	0.00	100	10	619.2	612.4	6.9	10.26	21.53	313	2.64E-04
18	0.00	100	10	619.7	611.8	8.0	10.10	21.37	364	3.06E-04
20	0.00	100	10	618.0	612.0	6.0	10.40	21.67	275	2.32E-04
22	0.00	100	10	618.9	613.8	5.1	10.58	21.85	234	1.97E-04
24	0.00	100	10	619.0	613.5	5.5	10.50	21.78	251	2.11E-04
26	0.00	100	10	619.7	613.0	6.7	10.29	21.56	306	2.58E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Alpha LYR Transformation slope for filter: 1.000
Visual Magnitude: 0.04 Extinction coefficient (mag/air mass): 0.108
Altitude Angle Viewed: 65 Temperature: 7 C
Calculated Star Signal 753 Relative Humidity: 55 %
Scale used star signal: 1 Weather Conditions: Mostly cloudy with mid to high level clouds. Star measurement calculation impossible.

Extinction coefficient based on visibility during the day.

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation

Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838

Date: 10 Oct 1988

Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919

Time: 2045-2100-2115

Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
1.25	0.00	100	1	864.0	622.0	242.0	6.30	17.58	11996	1.01E-02
4	0.00	100	1	644.3	618.0	26.3	8.71	19.99	1305	1.10E-03
6	0.00	100	10	633.8	618.8	15.0	9.32	20.60	744	6.26E-04
8	0.00	100	10	630.3	621.9	8.4	9.96	21.23	415	3.49E-04
10	0.00	100	10	630.6	623.6	7.1	10.14	21.41	350	2.95E-04
12	0.00	100	10	631.7	625.3	6.4	10.25	21.52	317	2.67E-04
14	0.00	100	10	632.7	627.7	4.9	10.53	21.80	245	2.06E-04
16	0.00	100	10	634.5	627.7	6.8	10.18	21.45	339	2.85E-04
18	0.00	100	10	636.6	629.1	7.5	10.07	21.34	373	3.14E-04
20	0.00	100	10	637.2	629.6	7.6	10.06	21.33	377	3.17E-04
22	0.00	100	10	636.9	627.9	9.0	9.88	21.16	444	3.74E-04
24	0.00	100	10	637.0	627.5	9.5	9.82	21.10	469	3.95E-04
28	0.00	100	10	638.5	627.5	11.0	9.66	20.93	545	4.59E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor

Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient that night:	0.027
Altitude Angle Viewed:	65	Temperature:	0 C
Calculated Star Signal	753	Relative Humidity:	85 %
Scale used star signal:	1	Weather Conditions:	Uniform cloud cover behind entire viewing dome.

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation
Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: 11 oct 1988
Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919 Time: 2030-2100
Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
1.25	0.00	100	1	757.7	607.3	150.3	6.82	18.10	7447	6.27E-03
4	0.00	100	1	625.7	604.0	21.7	8.92	20.20	1073	9.04E-04
6	0.00	100	10	618.2	607.6	10.6	9.70	20.98	523	4.41E-04
8	0.00	100	10	616.4	609.0	7.4	10.09	21.37	365	3.07E-04
10	0.00	100	10	614.1	608.0	6.1	10.30	21.57	302	2.54E-04
12	0.00	100	10	616.0	608.3	7.7	10.05	21.32	381	3.21E-04
14	0.00	100	10	614.8	609.2	5.6	10.39	21.66	279	2.35E-04
16	0.00	100	10	614.8	609.5	5.3	10.46	21.73	261	2.20E-04
18	0.00	100	10	616.7	610.3	6.4	10.25	21.52	317	2.67E-04
20	0.00	100	10	616.5	611.2	5.3	10.45	21.73	263	2.21E-04
22	0.00	100	10	617.5	611.8	5.7	10.38	21.65	281	2.36E-04
24	0.00	100	10	617.3	613.0	4.3	10.68	21.95	213	1.79E-04
26	0.00	100	10	621.0	614.9	6.1	10.29	21.57	304	2.56E-04
28	0.00	100	10	619.4	613.6	5.7	10.37	21.64	284	2.39E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient that night:	0.0277
Altitude Angle Viewed:	65	Temperature:	0 C
Calculated Star Signal	753	Relative Humidity:	85 %
Scale used star signal:	1	Weather Conditions:	Weather in back of glow dome. High uniform cloud layer.

Should not interfere with results.

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: 11 Oct 1988
Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919 Time: 2135-2230
Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(") ²	S10 units No.	Lumens per meter ² /sr
1.25	0.00	100	1	810.7	624.7	186.0	6.59	17.86	9213	7.76E-03
4	0.00	100	1	651.0	629.7	21.3	8.94	20.22	1057	8.90E-04
6	0.00	100	10	637.0	625.2	11.8	9.58	20.85	586	4.94E-04
8	0.00	100	10	633.9	624.4	9.5	9.82	21.09	471	3.96E-04
10	0.00	100	10	632.3	624.7	7.6	10.07	21.34	375	3.16E-04
12	0.00	100	10	631.4	625.3	6.1	10.31	21.58	301	2.53E-04
14	0.00	100	10	630.1	625.8	4.3	10.69	21.96	211	1.78E-04
16	0.00	100	10	631.1	626.2	4.9	10.53	21.80	244	2.06E-04
18	0.00	100	10	631.9	625.9	6.0	10.31	21.59	299	2.52E-04
20	0.00	100	10	631.9	626.7	5.2	10.48	21.75	256	2.15E-04
22	0.00	100	10	630.3	625.1	5.2	10.47	21.75	258	2.17E-04
24	0.00	100	10	630.7	625.4	5.3	10.45	21.73	263	2.21E-04
26	0.00	100	10	633.4	624.9	8.5	9.94	21.21	421	3.55E-04
28	0.00	100	10	633.4	625.4	8.0	10.00	21.28	396	3.34E-04
30	0.00	100	10	633.5	622.9	10.6	9.70	20.97	525	4.42E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient that night:	0.0277
Altitude Angle Viewed:	65	Temperature:	0 C
Calculated Star Signal	753	Relative Humidity:	85 %
Scale used star signal:	1	Weather Conditions:	Clouds over entire background. Glow dome appears to extend higher into sky

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation
Human Perception Study

Observation Location: End of Runway at Bryce Latitude: 37.7124711 Longitude: 112.135838 Date: 12 Oct 1988
Light Source Location: Rodeo Grounds and Inn Latitude: 37.6743649 Longitude: 112.1567919 Time: 2000-2030
Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
1.25	0.00	100	1	940.3	615.7	324.7	6.14	17.42	13886	1.17E-02
4	0.00	100	1	658.0	615.0	43.0	8.34	19.61	1839	1.55E-03
6	0.00	100	10	643.3	617.2	26.1	8.88	20.16	1116	9.40E-04
8	0.00	100	10	640.0	618.9	21.2	9.11	20.38	905	7.62E-04
10	0.00	100	10	636.8	621.4	15.4	9.45	20.73	660	5.56E-04
12	0.00	100	10	631.4	617.5	13.9	9.56	20.84	594	5.01E-04
14	0.00	100	10	630.4	616.3	14.1	9.55	20.83	602	5.07E-04
16	0.00	100	10	628.5	617.4	11.0	9.82	21.09	472	3.97E-04
18	0.00	100	10	628.8	617.7	11.1	9.81	21.08	476	4.01E-04
20	0.00	100	10	629.2	619.3	9.9	9.93	21.20	425	3.58E-04
22	0.00	100	10	628.8	618.9	9.9	9.93	21.21	423	3.57E-04
24	0.00	100	10	631.7	619.7	12.0	9.72	21.00	515	4.33E-04
26	0.00	100	10	631.0	621.5	9.5	9.97	21.25	408	3.43E-04
28	0.00	100	10	631.7	622.5	9.2	10.01	21.28	395	3.33E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor
Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used:	Alpha LYR	Transformation slope for filter:	1.000
Visual Magnitude:	0.04	Extinction coefficient that night:	0.1722
Altitude Angle Viewed:	65	Temperature:	5 C
Calculated Star Signal	753	Relative Humidity:	85 %
Scale used star signal:	1	Weather Conditions:	Clear and cool. Only a few clouds near the horizon

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees

Brightness of Night Sky Calculation

Human Perception Study

Observation Location: End of Runway at Bryce

Latitude: 37.7124711

Longitude: 112.135838

Date: 12 Oct 1988

Light Source Location: Rodeo Grounds and Inn

Latitude: 37.6743649

Longitude: 112.1567919

Time: 2100-2130

Distance: 3.15 km

---Average Counts Per Second---

Altitude Degrees	Azimuth Degrees	Scale	Avg Time seconds	Sky + Dark	Dark	Sky	Mag Sky Patch magnitude	Mag per sq sec mag/(")2	S10 units No.	Lumens per meter2/sr
1.25	0.00	100	1	1086.7	631.3	455.3	5.78	17.05	19474	1.64E-02
4	0.00	100	1	679.3	631.3	48.0	8.22	19.49	2053	1.73E-03
6	0.00	100	10	654.3	632.6	21.7	9.08	20.36	928	7.81E-04
8	0.00	100	10	653.2	639.7	13.5	9.60	20.87	577	4.86E-04
10	0.00	100	10	651.4	638.7	12.7	9.66	20.93	545	4.59E-04
12	0.00	100	10	649.4	634.8	14.5	9.52	20.79	622	5.23E-04
14	0.00	100	10	648.2	636.3	11.9	9.74	21.01	508	4.27E-04
16	0.00	100	10	647.3	636.0	11.3	9.79	21.07	482	4.06E-04
18	0.00	100	10	639.9	628.9	11.0	9.82	21.10	469	3.95E-04
20	0.00	100	10	638.3	628.0	10.3	9.89	21.17	441	3.71E-04
22	0.00	100	10	638.3	629.2	9.0	10.03	21.31	386	3.25E-04
24	0.00	100	10	640.6	630.8	9.8	9.94	21.22	421	3.54E-04
26	0.00	100	10	639.7	630.3	9.4	9.99	21.26	403	3.40E-04
28	0.00	100	10	639.2	630.7	8.5	10.10	21.37	364	3.06E-04

Telescope Information:

Celestron SP-C8, 8-inch, effective focal ratio of f/5 with telecompressor

Photometer SSP-3 with 1.0mm diameter diaphragm

Additional Information:

Standard Star used: Alpha LYR

Transformation slope for filter:

1.000

Visual Magnitude: 0.04

Extinction coefficient that night:

0.1722

Altitude Angle Viewed: 65

Temperature:

4 C

Calculated Star Signal: 753

Relative Humidity:

85 %

Scale used star signal: 1

Weather Conditions: Clear and cool. Only a few clouds near the horizon

Note: Zero degree azimuth is directed towards the center of the light source True Azimuth Direction: 206 degrees