AN ASSESSMENT OF THE IMPACT OF POTENTIAL MINING OPERATIONS AT THE ROSEMONT COPPER MINE ON THENIGHT SKY OF SOUTHERN ARIZONA

DRAFT REPORT

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for
SWCA Environmental Consultants

September 2010

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EXECUTIVE SUMMARY

This study presents results from computer calculations of the sky brightness due to proposed operations in the Rosemont Copper Mine (RCM) when viewed from six observation points, three of which are astronomically sensitive sites. The analysis shows that there would be an increase in skyglow at all sites due to RCM operations.At the astronomical Observatory sites, including Fred L Whipple Observatory (FLWO), Jarnac, and Empire Ranch, the increase in brightness of the zenith is 1%, 2% and 4% respectively. In the astronomically "useful" portions of the sky, which we consider here to be out to zenith angle of 70°, the maximum brightening at these sites due to the proposed RCM lighting will be much more significant, reaching 10%, 22% and 32%, respectively.

Though the sky glow impacts of the potential lighting appear modest, particularly at the zenith, a recent study at Kitt Peak National Observatory (Nugent and Massey, 2010), a site also suffering measurable sky glow from the Tucson metropolitan area, has seen no increase in sky brightness over the past 10 years, despite substantial growth is in the region. With this perspective, the proposed lighting at the RCM could cause a greater increase in sky glow at the nearby astronomical sites than has apparently occurred over the past 10 years due to growth in the entire area.

Options that could produce reductions in these impacts are available, though the magnitudes of these potential changes have not been quantified in this study. Though restriction of mining operations to daylight hours may be unlikely, improved shielding and restrictions on vertical aiming angles and azimuths for the portable mine lighting, and reconsideration of the necessity or amounts for some of the proposed lighting may provide some opportunities for mitigation.

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I. INTRODUCTION

Dark night skies have been identified as a resource to be protected as an integral part of the natural environment (ref). This is particularly important in Southern Arizona due to the large investment in astronomical facilities in the region. Pima County and the City of Tucson have long recognized the importance of night sky protection through the adoption and enforcement of Outdoor Lighting Ordinances. Increasingly, proposed developments that could impact dark sky sites are now being required to address the potential impact of new outdoor lighting on dark skies as part of the environmental assessment process.

This study examines the sky glow that would arise from open pit copper mining operations in the Rosemont Copper Mine (RCM) in the Santa Rita Mountains of Southern Arizona. The proposed mine site is shown in Figure 1, along with nearby towns and astronomical facilities. Details of the RCM, showing the potential areas for the mine pit as well as those for the mine headquarters, ore processing area, leach fields and lighted access road, are shown in Figure 2. The sky glow created by the lighting described in this report is calculated using a sophisticated model describing the interaction of light emitted near the ground and interacting with objects and surfaces near the ground, the atmosphere of molecules and aerosols over the mine site and between the mine site and points of observation. These models are described in detail in published papers by Garstang (1986, 1989, 1991) and by Luginbuhl et al. (2009b). These models have been incorporated into a computer program by Dark Sky Partners LLC (DSP).

This assessment provides calculations of how the night sky would be impacted by RCM operations on the best dark sky nights. Our goal is to provide the most realistic assessment of skyglow; we do not evaluate the proposed lighting plan with regard to compliance with the Pima County Outdoor Lighting Code. To this end, we use mean *fixture* lumens for all calculations which give the average light output of a fixture over its operational lifetime. In our judgment this is the best value to use for assessing the impact of RCM outdoor lighting on the night sky. Other model parameters are listed in Table 1.

Figure 1. The location of the Rosemont Copper Mine,, together with regional towns and cities included in sky glow models.

Figure 2. Details of the proposed Rosemont Copper Mine and potential headquarters (facilities) site.

II. STUDY METHODOLOGY

A. The Numerical Model

R. Garstang (Garstang 1986, 1989, 1991) developed and published a model for calculating sky brightness arising from artificial outdoor lighting. This model has been recently improved by Luginbuhl et al. (2009b) to include effects on light propagation caused by blocking of the light emissions by objects near the ground, such as buildings, vegetation and terrain, an improvement essential to accurately connect light emissions measured at the light sources (lamps) with the resultant sky glow. A computer program based on this improved model, developed by Dark Sky Partners LLC, calculates the sky brightness observable from any location and toward any viewing direction due to light emitted from cities and towns or any specific light source or sources (i.e. fixtures). This program allows modeling of specific sources of artificial lighting such as shopping centers, housing developments or industrial projects, with the capability of specifying details such as amounts, spatial distribution, and shielding characteristics of lighting sources (Davis et al. 2006). This computer program was used to assess the impact of lighting at potential RCM mining operations on dark skies of the surrounding region.

B. Data Input for the Model

The inputs for the computer model include parameters describing the atmosphere and ground reflectivity, the location and amounts of light emitted (measured in lumens), the fraction of this light that escapes directly upward into the night sky (the uplight fraction), and the locations from which the sky is observed.

Atmosphere and Ground

Table 1 shows the parameters characterizing the atmosphere and ground; these values were kept constant for all locations. The parameter that describes the amount of aerosol (particulates) or clarity of the atmosphere, K, was set to 0.10. This is lower than the value used by Garstang for typical western cities (K=0.5), but is based on observations made by the National Park Service (NPS) Night Sky Team at Saguaro National Monument and describes the 90th percentile (i.e. the K value was observed to be larger than this 90% of the time), and was recommended by NPS as the most appropriate condition for the analysis (C. Moore, private communication). Such a low value is not entirely unexpected due to the clarity of the air in this region. (It is important to recognize the modeling does not account for increased aerosols that may result from some weather conditions, air pollution, or the mining operations themselves.)

The E_b and β parameters describe blocking of light emitted from light fixtures due to near-ground factors (vegetation, built structures, terrain), and affect both the amount of light escaping into the sky as well as the angular distribution of this upward-directed light. The values indicated for these parameters (i.e. $E_b = 0.4$ and $\beta = 0.1$) produced the best agreement between the model calculations and sky brightness measurements in the work described by Luginbuhl et al. (2009b), except that for this study the β parameter has been increased from their best value of 0.0to 0.1 to better describe the relatively un-vegetated and open nature of the near-ground environment in this region.For the mine site we further modify these figures to $E_b = 0.1$ and $\beta = 0.8$ to better describe the very open / low blocking environment expected at the active mine site. Though the lighting in the pit will eventually become subject to unusual blocking due to the pit walls themselves, DSP feels that the most conservative approach should assume low blocking for this lighting since this will be more accurate at the initial stages of the operation. The ground reflectivity of 0.15 is typical of a wide variety of surfaces (except snow) including terrain, vegetation, dirty concrete and aged asphalt hardtop, and has been found to adequately characterize ground reflectivity for all warm season light pollution modeling efforts to date (Garstang 1986, 1989, 1991, Luginbuhl et al. 2009b and references therein). The larger reflectivity chosen to characterize the mining site (0.25) is based on a conservative interpretation of expected crushed-rock surfaces provided by engineers working for RCM.

These atmospheric parameters describe clear conditions and will lead to modeling results that will show smaller impacts from potential lighting in the RCM as well as from nearby towns than will typically be the case. The purpose in using these clear conditions for the analysis is to show what the impacts would be during the "best" observation nights, when the air is clearest and the stars most visible. It is important to recognize that much of the time the air will be less clear, and the sky glow impacts larger.

Table 1. Atmospheric and Ground Parameters

Parameter	Value	
	Towns	Mine
K	0.10	0.10
E_b	0.40	0.10
β	0.10	0.80
Ground Reflectivity	0.15	0.25

Rosemont Copper MineLighting

The number and types of lights to be modeled in this study were based on the lighting plan developed for this project by M3 Engineering (M3, 2009), and were refined through emails and a meeting with M3 and Rosemont staff and Dark Sky Partners. The parameters listed in Tables 1 through 4 are based on those communications but are different from the values tabulated in M3 (2009). They are consistent with the lighting details given in the lighting map of M3.

Lighting required for nighttime mining operations on the project would consist of four types: 1) fixed lights at the mine headquarters and the pit processing area for parking, walkway, security and general nighttime activity; 2) lighting on shovels and loaders and portable light towers with individually aimable fixtures located at the active mine site that would be moved as the mining operations shift; 3) lighting for leach field activity; 4) roadway lighting on the entry road from Highway 83 to the mine site, and 5) lighting (i.e. headlights) on mining vehicles, also assumed to be located at the active mine site,..

The fixed lights in the ore processing/facilities area consists of a mixture of high pressure sodium and low pressure sodium lamps (see Table 2) producing a total of 1,118,675 lumenscontained within fully shielded fixtures, i.e. none of the light is emitted directly upward. The pit lighting consists primarily of high pressure sodium lamps mounted on the active shovels and drills and produces a total of 2,151,610. This lighting is directed toward the active mining location and practically cannot be full-cutoff lighting. We estimate that about 30% of this lighting will be direct uplight.

Leach field lighting consists of portable 1000 W high pressure sodium lights producing 561,600 lumens (Table 2). These fixtures are mounted with adjustable gimbals, allowing the fixtures to be aimed in different directions and at different angles relative to the horizon (see Appendix A). Although DSP contacted Baldor Electric Company, a manufacturer of a potential portable lighting system suggested by RCM representatives, the representatives of Baldor were unable to produce the photometric information needed to accurately evaluate the fraction of light directed upward as a function of aiming angle of the fixtures. Therefore, for this study DSP is forced to estimate this fractional uplight value. We assume that they would typically be aimed at 30° below the horizon and direct 30% of the light upward, but they may at times be directed essentially straight sideways toward the horizon, as is often observed when such lights are used on construction sites. We note that Baldor does offer an option for a light shield for their portable lights, though no photometric information was available for this option.

Roadway lighting for the entry road uses only full cutoff, low-pressure sodium fixtures and generates a total of 1,029,600 lumens.

For the vehicular lighting we have no specific information either on the manufacturers and types of the mining vehicles to be used, nor for the lighting that would be installed on this equipment. To estimate the light output from the vehicles, we scale the lumens from values typical of automobile headlights. From Schoettle et al. (2004), car headlights average 3786 effective lumens/vehicle with an uplight fraction of 0.11. We assume the same uplight fraction, but increase the light output from each mine vehicle to 10,000 lumens, about three times that of a typical car. All vehicular lighting is assumed to be located at the active mining site, i.e. no attempt has been made to model lighting produced when the vehicles are transporting materials on roadways.

Table 2 gives the details of the mine lighting sources, while Table 3 gives the locations and lighting associated with all modeled light sources, for the RCM as well as seven cities, towns and jurisdictions expected to be contributors to sky glow in the region (see below).

Table 2. Details of Proposed Rosemont Copper Mine Lighting (HPS= High Pressure Sodium, LPS = Low Pressure Sodium, INC = Incandescent).

LOCATION	TYPE OF LAMP	NUMBER OF LAMPS	TOTAL LUMENS
FACILITIES:			
ADMIN	50W HPS	6	12,636
ADMIN	90W LPS	28	199,099
TOTAL			*211,735*
PROCESSING AREA			
TAILING FILT	50W HPS	9	18,954
CONCEN. FILT	50W HPS	4	8,424
TANK FARM	50W HPS	6	12,636
TAILING THICK	50W HPS	9	18,954
TIRE CHANGE AREA	90W LPS	6	42,664
CU/MOLY CONC THICK	50W HPS	74	155,844
ELECTROPLATING	50W HPS	9	18,954
SOLVENT EXTR.	50W HPS	4	8,424
ACID STORAGE	50W HPS	5	10,530
WATER TANK	90W LPS	3	21,332
CONVEYOR	50W HPS	57	120,042
LV FUEL STATIION	50W HPS	2	4,212
TRUCK WASH	50W HPS	12	25,272
MINE/TRUCK SHOP	50W HPS	11	39,600
MINE/TRUCK SHOP	90W LPS	18	127,992
CRUSHER/MINE SUBS	50W HPS	2	4,212
CRUSHER/MINE SUBS	90W LPS	12	85,328
MAIN SUBSTATION	90W LPS	15	106,660
LAYDOWN	90W LPS	8	56,885
REFUELING/EXP STOR	LPS		20,020
TOTAL			*906,940*
MINE PIT:			
SHOVEL (EACH)	35 W HPS	57	66,690
UP TO 3 OPERATING	400W HPS	12	315,900
	1000W HPS	18	1,263,600
3 DRILLS	VARIOUS HPS		407,400
LOADERS	XENON		78,000
SUPPORT AREAS W/PIT	LPS		20,020
TOTAL			*2,151,610*
ENTRY ROAD	90W LPS	72	511,969
LEACH FIELD	1000 W HPS	8	561,600
VEHICLES	INC, 10000	16	160,000

There were three alternatives for RCM lighting considered for this study (Appendix C), and the lighting detailed in this section is for alternative 1. The other two alternatives differ only in that lighting for the leach field is in different locations, but the total amount of lighting is the same in all alternatives. DSP judged that this small variation would have no discernable impact on skyglow for all observation points except that from Highway 83, where the impact would be minor.

Cities, Towns and other Jurisdictions:

The largest source of nighttime lighting relevant to this study is eastern Pima County. Data used in this assessment was taken from an earlier study (Davis et al, 2006) which evaluated the nighttime light produced in Pima County based on census tract population data and lumen/capita data derived from references cited therein. We adopted data for 2010 given in the above reference. The light outputs for all other towns included in this study were calculated assuming 1710 lm per capita with 10% uplight fraction and projected 2010 populations from the U.S. Census Bureau. These are typical values for communities without any outdoor lighting controls (Luginbuhl et al 2009a and references therein).

Observation Points

The observation sites listed in Table 4 were set in consultation with SWCA and were reviewed by the Forest Service. These sites were chosen to because: a) they represent nearby astronomical sites that are dark-sky critical, b) nearby towns and c) a site on state highway 83 which will experience the maximum visual impact.

All calculations are for a wavelength of 550nm, a wavelength representative of the astronomical Johnson V band and the peak sensitivity of the human eye. This wavelength has become the standard for both astronomical measurements of sky brightness and those produced by the National Park Service (Duriscoe, Luginbuhl & Moore, 2007).

Table 3. Light Source Locations and Outputs.

Location	Latitude (d:m:s)	Longitude (d:m:s)	Elevation (meters)	Population	Lumens	Uplight Fraction
Rosemont Mine Site						
Ore Processing Area	31:50:18	−110:44:58	1570		1,118,675	0.000
Mine Pit	31:49:51	−110:45:44	1630		2,151,610	0.300
Entry Road	31:51:08	−110:43:20	1490		561,600	0.000
Leach Field	31:49:30	−110:44:37	1590		511,969	0.300
Vehicles	31:50:18	−110:44:58	1570		160,000	0.110
Total					*4,503,854*	
Other Communities						
Tucson/Eastern Pima	--	--	810	1,050,000	1,795,500,000	0.082
Nogales, SON	31:20:00	−111:00:00	800	160,000	273,600,000	0.100
Nogales, AZ	31:33:41	−110:59:55	1103	19,573	33,469,830	0.100
Benson	31:58:54	−110:16:52	1067	4,833	8,264,430	0.100
Sonoita	31:40:46	−110:39:21	1490	910	1,556,100	0.100
Tubac	31:36:46	−111:02:30	982	2,000	3,420,000	0.100
Sierra Vista	31:32:44	−110:16:38	1394	43,320	74,077,200	0.100

Table 4. Observation Sites

Observation Sites	Latitude (d:m:s)	Longitude (d:m:s)	Elevation (meters)	Distance From Pit (km)	Azimuth (Deg)
FLWO (Mt. Hopkins)	31:41:19	−110:53:07	2600	19	37
Jarnac Observatory	31:58:37	−110:43:10	1060	17	194
Sonoita	31:40:46	−110:38:50	1490	20	327
Corona de Tucson	31:57:21	−110:45:49	1040	14	179
Highway 83	31:49:28	−110:42:51	1520	4.5	277
Empire Ranch	31:47:32	−110:37:44	1392	13	288

III. IMPACTOF PROPOSED ROSEMONT COPPER MINE LIGHTING ON NIGHT SKY BRIGHTNESS

We calculated predicted sky brightness for the current condition (2010) and with the addition of the RCM lighting (see Tables 2 and 3) as seen from the six observation points listed in Table 4. For each case, we calculated the sky brightness from the horizon directly above the mine site (zenith angle of 89°) to the horizon directly opposite (zenith angle of –89°), passing through the zenith. We show both the total sky brightness in nanoLamberts[1] (nL) and the fractional increase in sky brightness due to RCM lighting as listed in Table 3.

To help understand the visual impact of the numbers and ratios described in the following subsections, readers should be aware that a brightness ratio of 1.1:1 (or 10%) is only just perceptible to most people when the two sources of light can be directly compared, with one appearing directly adjacent to the other. In this sense a 10% brightening may seem to be likewise only just perceptible. A brightness ratio of 50% (1.5:1) would be perceptible to most observers.

When considering the results presented in the following subsections, readers should be aware that localized and unpredictable variations in very low altitude atmospheric dust content, caused for example by low-level winds or by the mining operations themselves, and blocking by vegetation or terrain, including (variable) terrain relief produced by the mining operations, can make actual sky brightness near the horizon much brighter or fainter than predicted here. The values indicated the zenith angles of 85° or greater should be taken only as a general indication, but not likely accurate to better than 50% in predicting absolute sky brightnesses for any given night.Because of these uncertainties calculations were not made for angles greater than 89° from the zenith or 1° altitude.

A.Fred Lawrence Whipple Observatory

Figure 3 shows the variation in sky brightness as observed from FLWO along the semi-circle passing through the mine site (right side of the graph), the zenith (middle of the graph) and ending at the horizon opposite the mine site (left side of the graph). The predicted current sky glow arising from natural air glow plus artificial sky glow from the seven cities and towns listed in Table 3, as well as the effect of the proposed lighting at the RCM shown in Tables 2 and 3, are shown as the curves lying above the natural curve and distinguishable particularly toward the RCM (right side of the graph).The lowest curve shows the natural condition, i.e. the sky glow that would be observed without any artificial light in the region.

[1] A nanoLambert (nL) is a unit of luminance or surface brightness. 1 Lambert = 1 lumen/sq cm for a uniformly diffusing surface. A naturally dark sky has a brightness of about 54 nL at the zenith, rising (due to natural causes) to approximately 100 nL 10° above the horizon (see the lowest curve in Figure 3).

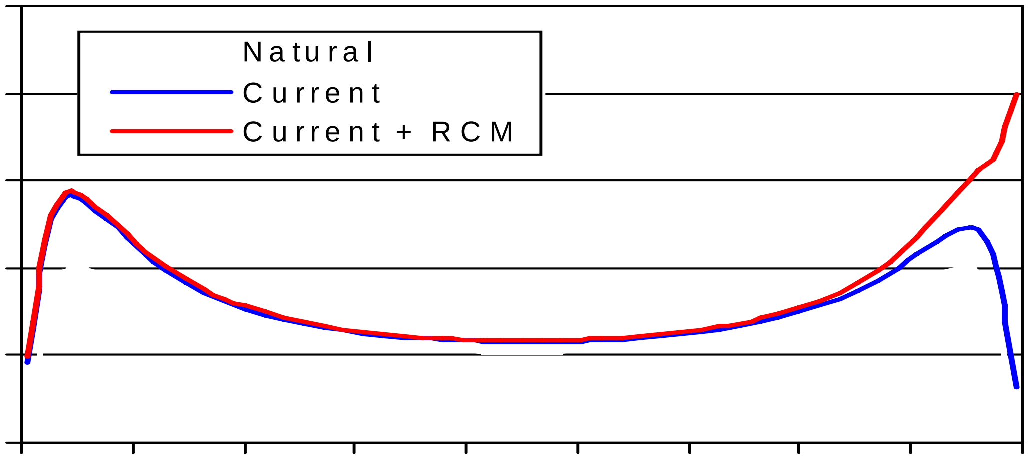


Figure 3.Horizon to horizon sky brightness at FLWO on the semi-circle originating toward the RCM site (azimuth 37°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 217°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.

To more clearly display the effects of the RCM lighting on the night sky, Figure 4 displays fractional sky brightness increases due to proposed RCM lighting, i.e. ratios of the predicted sky brightness to the current condition. A value of 1.10 means that the indicated condition is 10% brighter than the reference condition; 1.05 is 5% brighter.

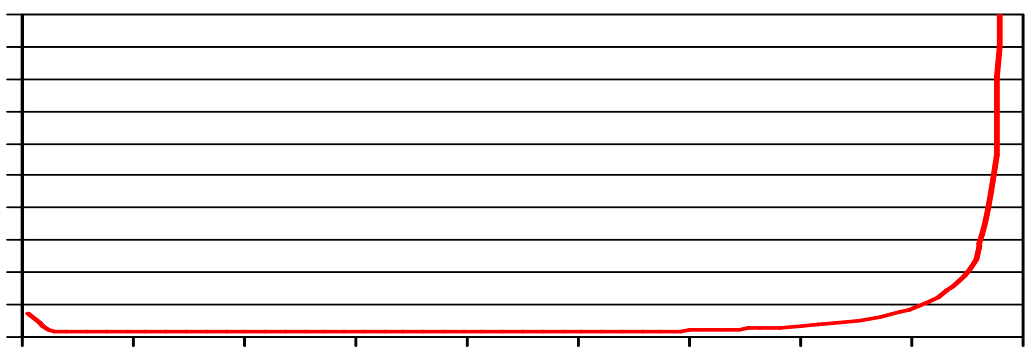


Figure 4. Brightness ratio as viewed from FLWO toward the RCM site.

Table 5. Sky brightness ratiosas viewed from FLWO at selected zenith angles toward the RCM.

Zenith present I love Sunday Angle	Brightness Ratio (predicted/current)
0°	1.01
45°	1.03
60°	1.05
70°	1.10
80°	1.28
85°	1.63
89°	6.24

From Figure 4 and Table 5 it can be seen that the proposed RCM lighting would brighten the sky by about 1% at the zenith , increasing to 5% at a zenith angle of 60° (30° above the horizon), 63% at 85°, and 524 % at 89° (1° above the horizon). We note that, due to the altitude difference, the RCM will appear 3° below the horizon as viewed from FLWO.

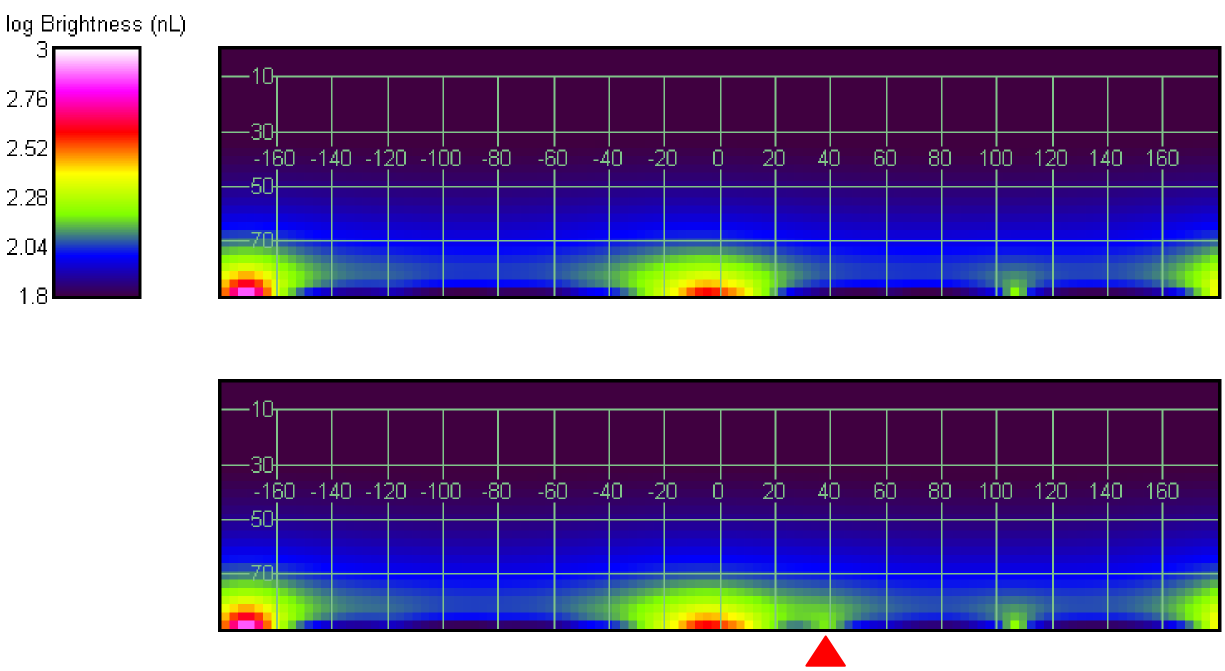


Figure 5. An all-sky false-color panoramic map of the sky glow visible from FLWO.The upper panel shows the current condition; the lower the condition predicted with the addition of the proposed RCM lighting. The grid and numbers on this and the following images indicate Zenith Angle and azimuth; the red triangle indicates the azimuth of the RCM.

Figure 5 shows false-color panoramic maps of the current and predicted sky brightness over the entire sky as viewed from FLWO. The increase in the sky glow above the RCM site (azimuth 37°, indicated by the triangle) is discernible. The other distinct sky glow domes at azimuth 0°, 190°

(–170°) and 108° arise from Tucson, Nogales and Sonoita, respectively.

B.Jarnac Observatory

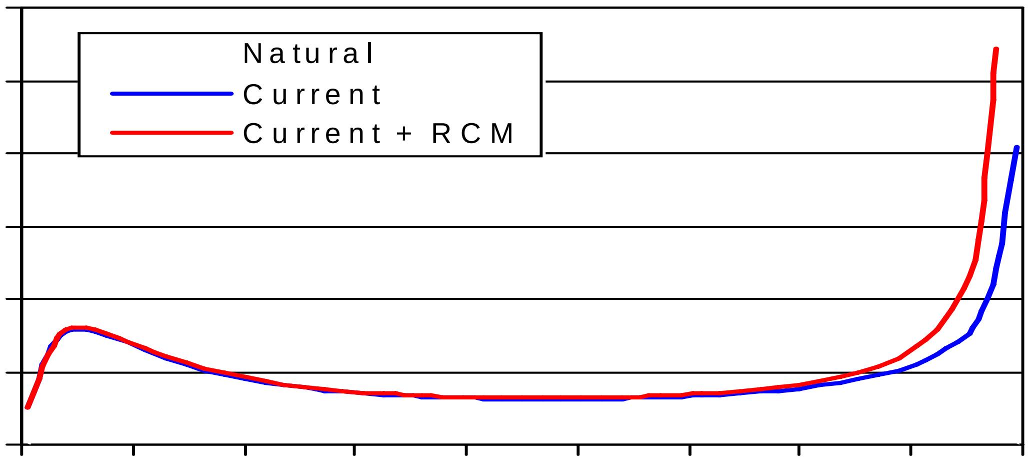


Figure 6.Horizon to horizon sky brightness at Jarnac Observatory on the semi-circle originating toward the RCM site (azimuth 194°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 14°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.

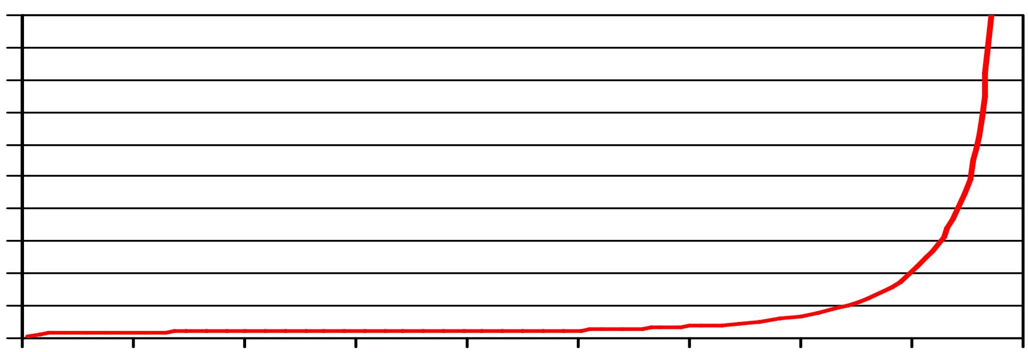


Figure 7. Brightness ratio as viewed from FLWO toward the RCM site.

Table 6. Sky brightness ratios as viewed from Jarnac Observatory at selected zenith angles toward the RCM. There is no entry at Zenith Angle 89° because the RCM appears at ZA 88.2°.

Zenith Angle	Brightness Ratio (predicted/current)

0°	1.02
45°	1.06
60°	1.11
70°	1.22
80°	1.63
85°	2.23
89°	*

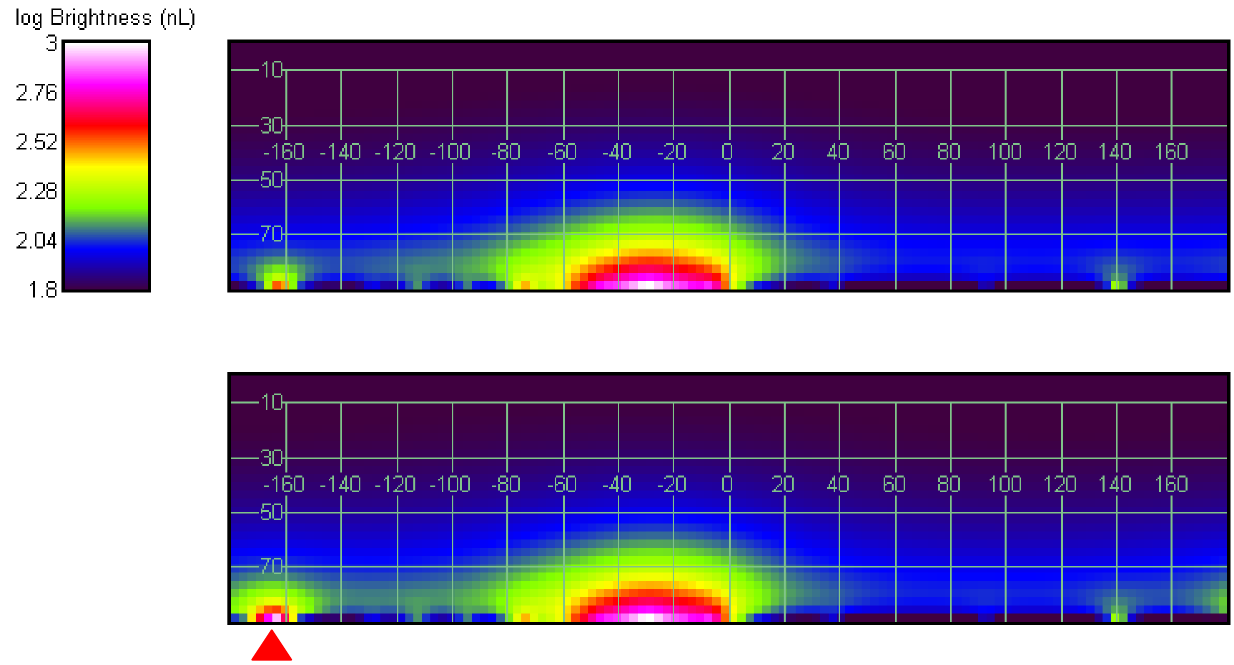


Figure 8. An all-sky false-color panoramic map of the predicted sky glow visible from Jarnac Observatory. The triangle indicates the azimuth of the RCM, which from this observation point is nearly coincident with Nogales.

C. Sonoita

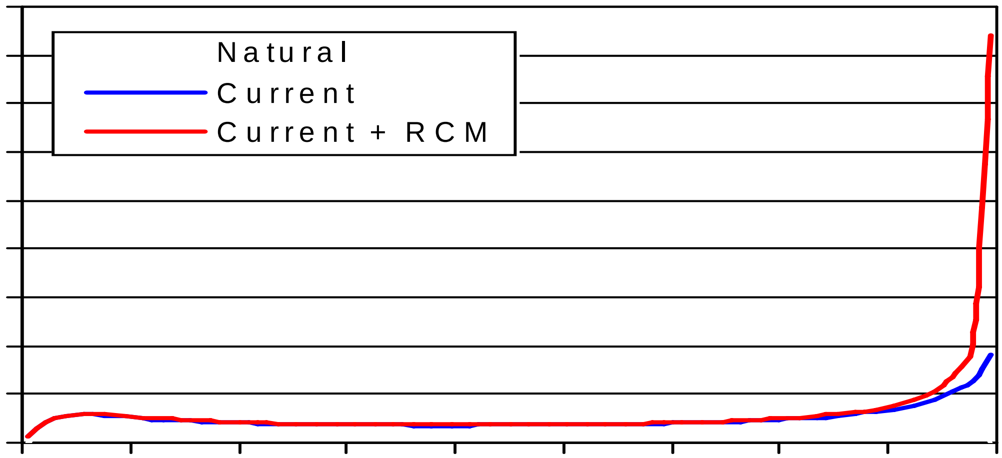
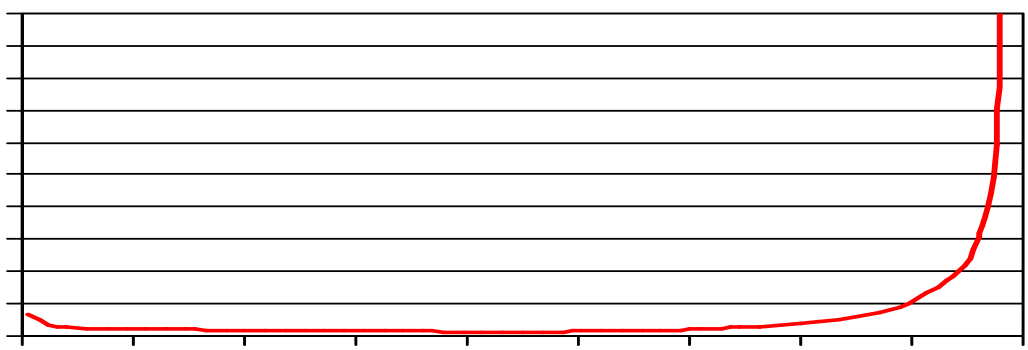


Figure 9. Horizon to horizon sky brightness at Sonoita on the semi-circle originating toward the RCM site (azimuth 327°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 147°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.



X

Figure 10. Brightness ratio as viewed from Sonoita toward the RCM site.

Table 7. Sky brightness ratios as viewed from Sonoita at selected zenith angles toward the RCM.

Zenith Angle	Brightness Ratio (predicted/current)
0°	1.01
45°	1.03
60°	1.06
70°	1.12
80°	1.31
85°	1.59
89°	4.63

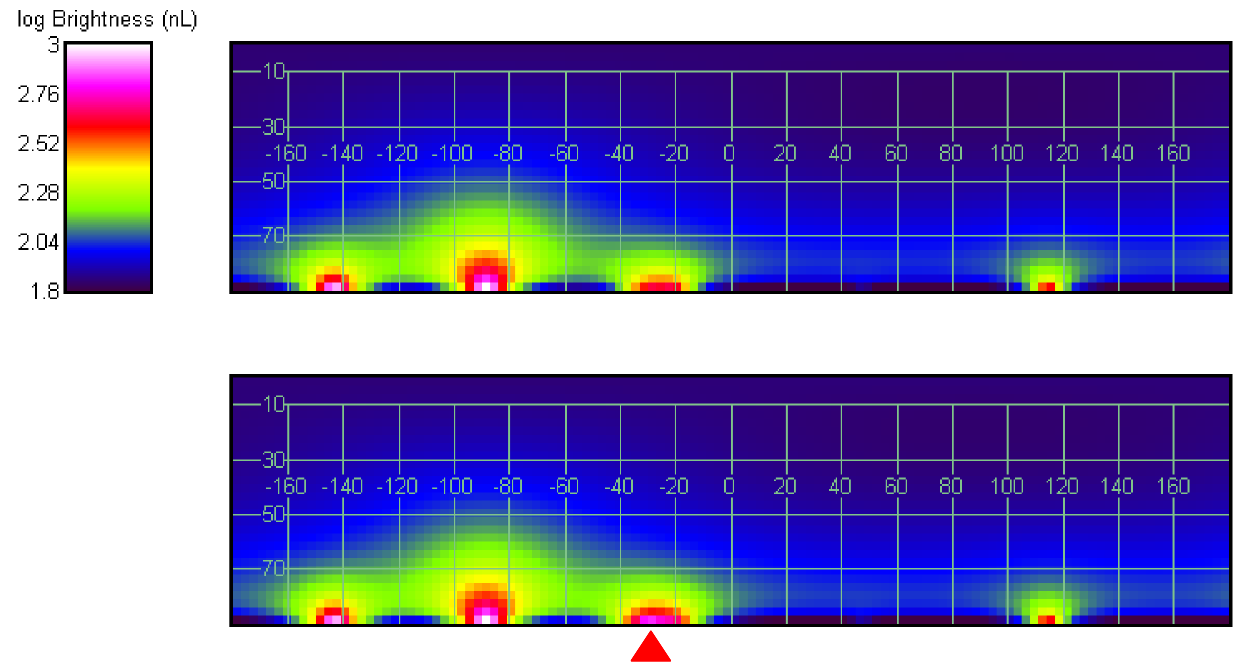


Figure 11. An all-sky false-color panoramic map of the sky glow visible from the Sonoita observation point.The upper panel shows the current condition; the lower the condition predicted with the addition of the proposed RCM lighting. The triangle indicates the azimuth of the RCM. Here the principal light domes at azimuth 215º (–145º), 270º (–90º), 335º (–25º), and 115º, arise from Nogales, Sonoita, Tucson and Sierra Vista, respectively.

D. Corona de Tucson

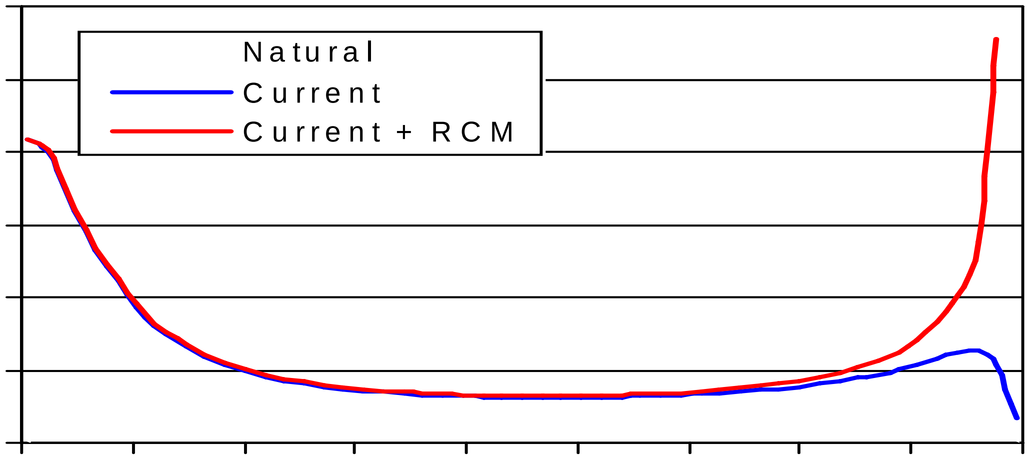


Figure 12. Horizon to horizon sky brightness at Corona de Tucson on the semi-circle originating toward the RCM site (azimuth 179°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 359°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.

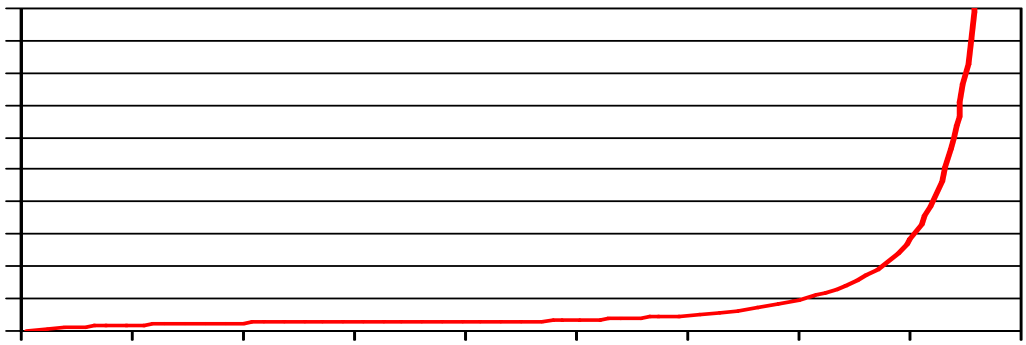


Figure 13. Brightness ratio as viewed from FLWO toward the RCM site.

Table 8. Sky brightness ratios as viewed from Corona de Tucson at selected zenith angles toward the RCM. There is no entry at Zenith Angle 89° because the RCM appears at ZA 87.8°.

Zenith Angle	Brightness Ratio (predicted/current)
0°	1.03
45°	1.08
60°	1.16
70°	1.31
80°	2.19
85°	5.25
89°	*

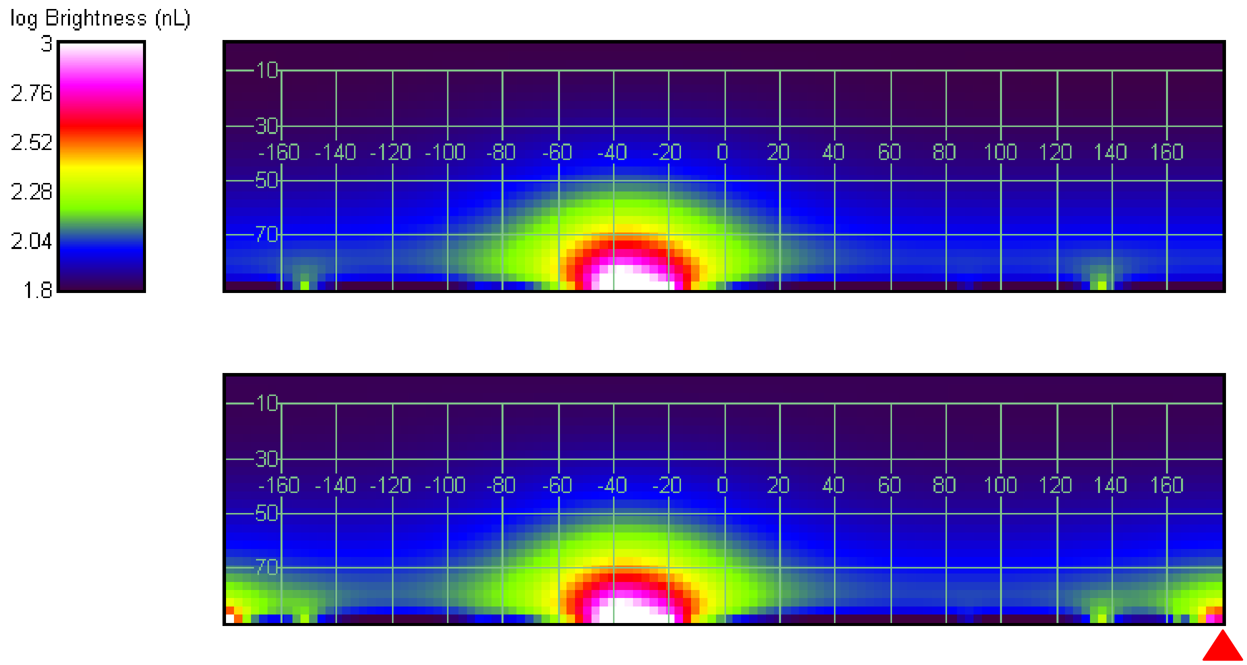


Figure 14. An all-sky false-color panoramic map of the sky glow visible from Corona de Tucson.The upper panel shows the current condition; the lower the condition predicted with the addition of the proposed RCM lighting.The triangle indicates the azimuth of the RCM. Here the principal light dome at azimuth 340º (–20º) arises from Tucson.

E. Highway 83

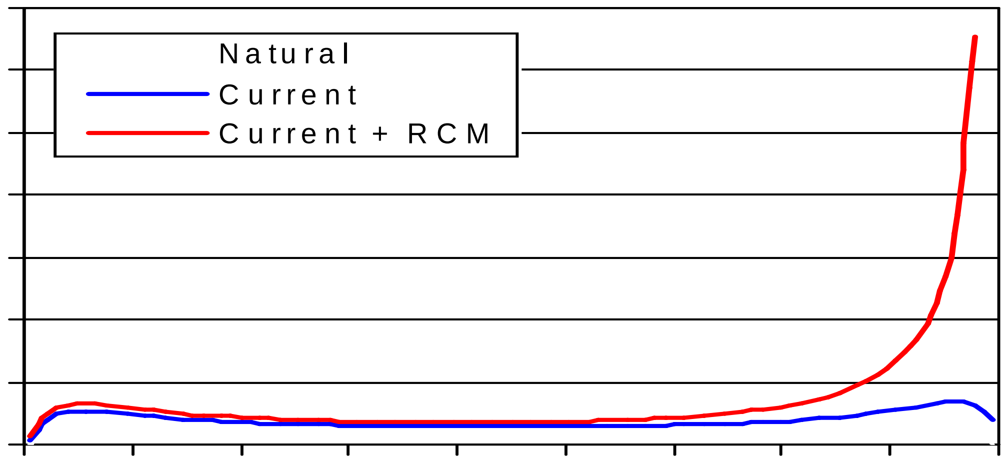


Figure 15. Horizon to horizon sky brightness at Highway 83 on the semi-circle originating toward the RCM site (azimuth 277°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 97°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.

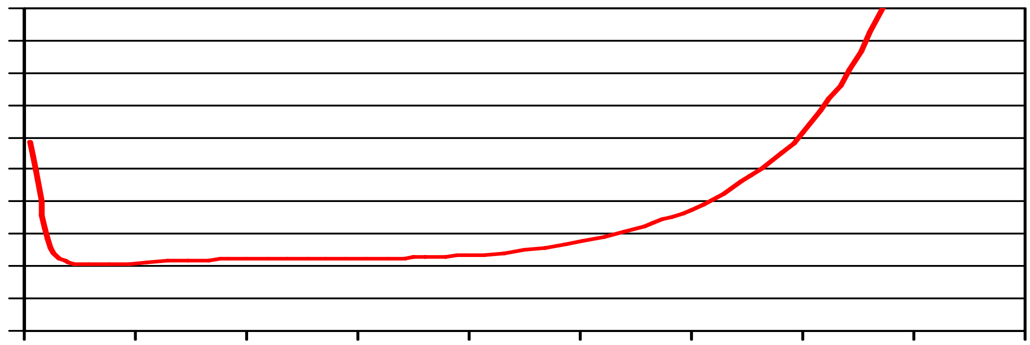


Figure 16. Brightness ratio as viewed from Highway 83 toward the RCM site.

Table 9. Sky brightness ratios as viewed from Highway 83 at selected zenith angles toward the RCM. There is no entry at Zenith Angle 89° because the RCM appears at ZA 89°.

Zenith Angle	Brightness Ratio (predicted/current)
0°	1.25
45°	1.55
60°	1.86
70°	2.41
80°	5.00
85°	10.4
89°	*

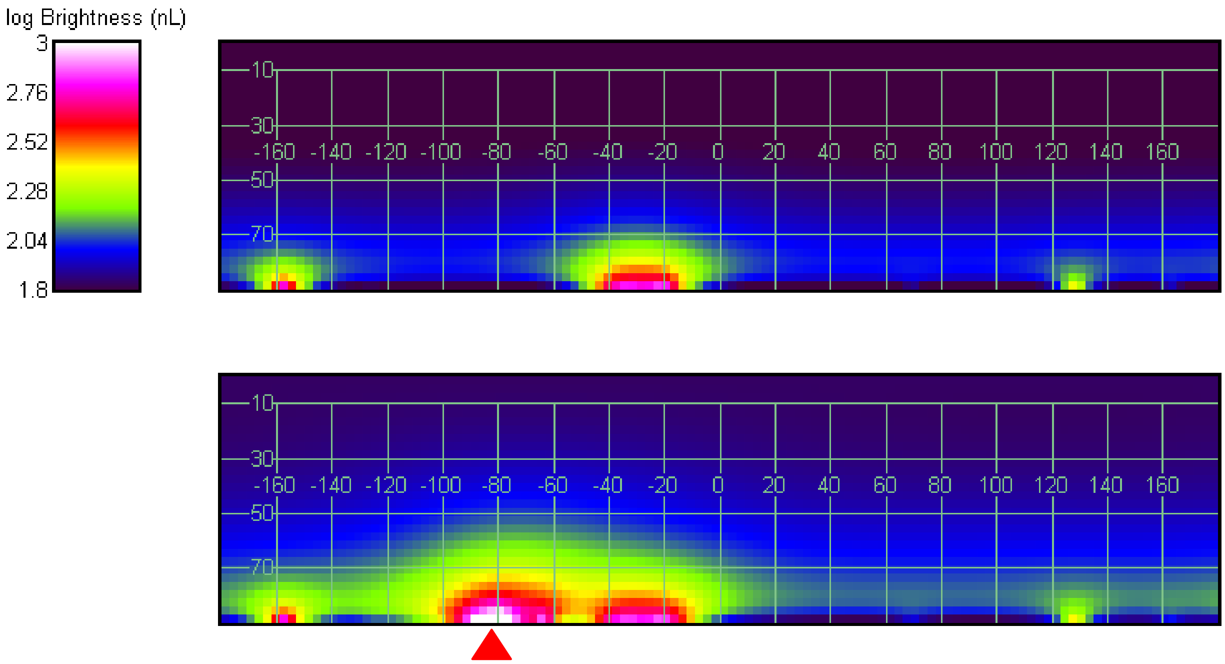


Figure 17. An all-sky false-color panoramic map of the sky glow visible from Highway 83.The upper panel shows the current condition; the lower the condition predicted with the addition of the proposed RCM lighting.The triangle indicates the azimuth of the RCM. Here the principal light domes at azimuth 205º (–155º), 330º (–30º), and 125º, arise from Nogales, Tucson and Sierra Vista, respectively.

F. Empire Ranch

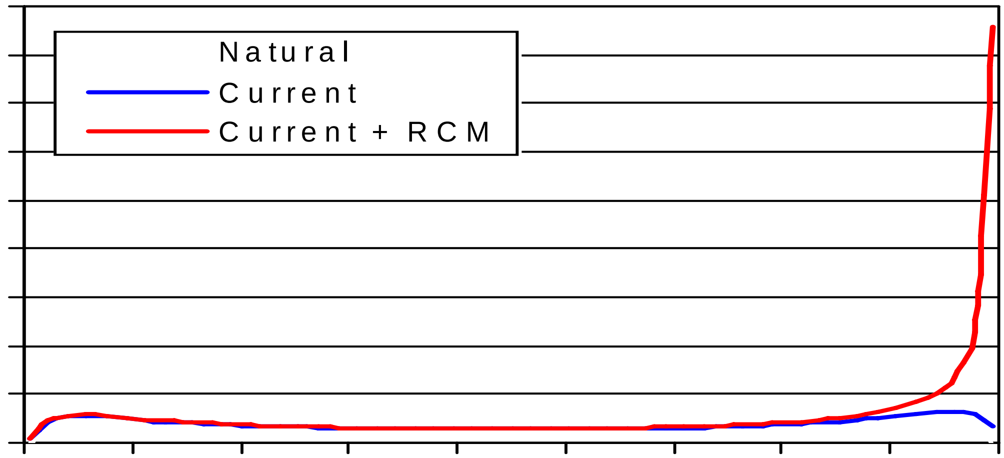


Figure 18. Horizon to horizon sky brightness at Empire Ranch on the semi-circle originating toward the RCM site (azimuth 288°, zenith angle +90°) and ending at the point on the horizonopposite (azimuth 108°, zenith angle –90°). The blue line shows the predicted current sky brightness profile arising from the 7 existing cities and towns listed in Table 3; the red line shows the predicted additional contribution of the RCM lighting described in Table 2.

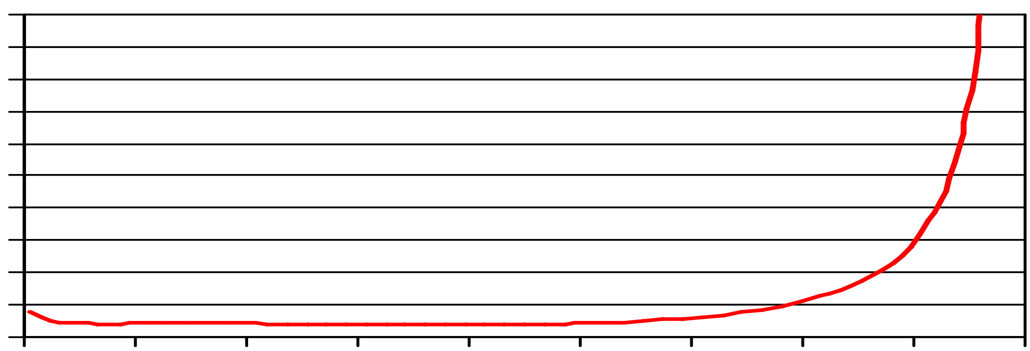


Figure 19. Brightness ratio as viewed from Empire Ranch toward the RCM site.

Table 10. Sky brightness ratios as viewed from Empire Ranch at selected zenith angles toward the RCM.

Zenith Angle	Brightness Ratio (predicted/current)
0°	1.04
45°	1.10
60°	1.17
70°	1.32
80°	2.05
85°	3.88
89°	26.3

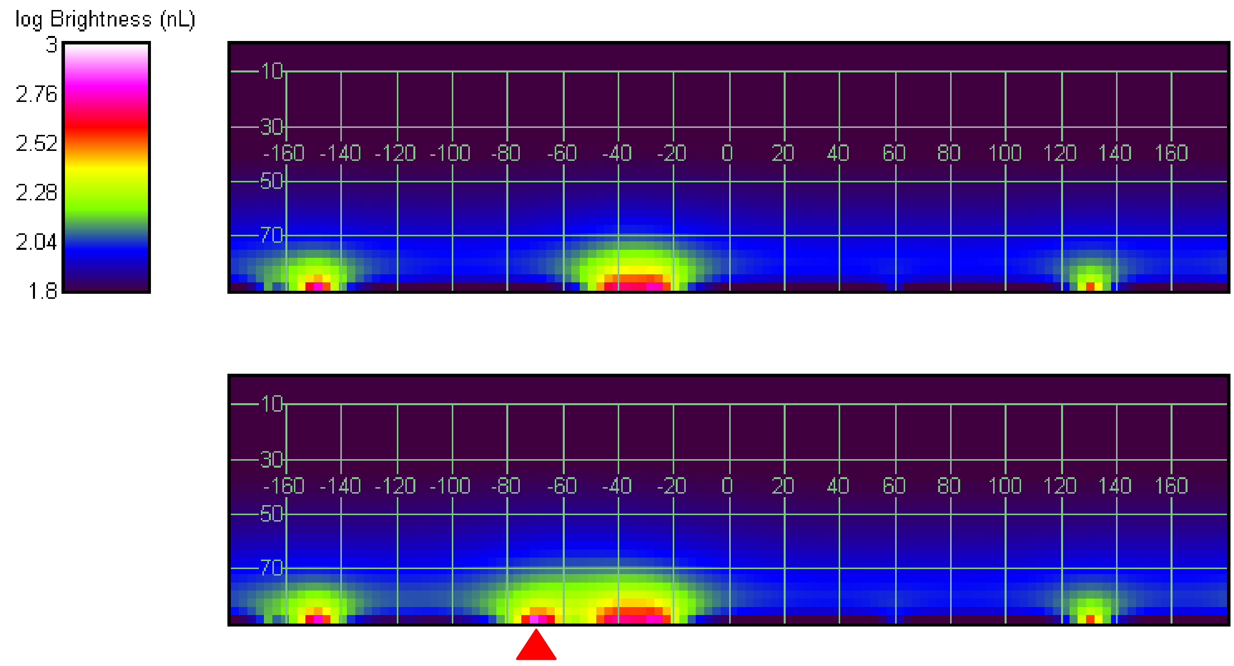


Figure 20. An all-sky false-color panoramic map of the sky glow visible from Empire Ranch.The upper panel shows the current condition; the lower the condition predicted with the addition of the proposed RCM lighting. The triangle indicates the azimuth of the RCM.Here the principal light domes at azimuth 210º (–150º), 330º (–30º), and 130º, arise from Nogales, Tucson and Sierra Vista, respectively.

IV. Potential Mitigation Strategies

In rough order of importance or mitigation effectiveness, the following strategies could be employed to decrease the impacts of the lighting used at Rosemont Copper Mine.

A. Access Road Lighting

Continuous roadway lighting is generally considered a safety benefit only where significant amounts of oncoming traffic, with the resultant glare produced by oncoming headlights, necessitates a general level of illumination to provide visibility. Given the low volumes of traffic expected on this roadway, the presence of adequate lighting provided integral to each vehicle should be adequate for safety seat operation of traffic along the access road, obviating the need for continuous roadway lighting. It is noted that all of this traffic must in any case travel the entirely unlighted stretch of

Highway 83 after leaving the access roadway.

B. Hours of Operation

Performing mining operations during daylight hours only would allow the elimination of 86%-92% of the total lighting, and completely eliminate all unshielded lighting. The sky glow reduction arising from the RCM would be reduced by somewhat more than this figure due to the elimination of unshielded floodlighting at the RCM site.

C. Portable Fixture Shielding

The uplight fraction from these very poorly shielded fixtures could be improved with the addition of shields on the upward portion of the luminaires, conceptually following the huge improvements in sports lighting technology seen in the last five to 10 years. If the shields are not available from the manufacturer, it may not be an unreasonable number to have manufactured. It may be possible to entirely replace the stock flood light fixtures with higher quality partially shielded or completely shielded floodlights generally used for sports lighting (see Appendix C for an example). Though the precise reduction in sky glow and the brightness of directly visible light fixtures is difficult to precisely quantify, a reduction of sky glow of three quarters (75%), could be easily expected.

D. Portable Fixture Aiming

Keepingthe portable light fixtures located at the active mine site aimed as far as possible below the horizon and away from the directions toward these parks could substantially reduce sky glow and direct visibility impacts. Without specific photometric information for the fixtures or information on aiming constraints the improvements expected cannot be quantified, and practically assuring that such aiming is maintained could be problematic.

E. Dust Reduction

Methods to mitigate dust reduction such as paving heavily used roads, wetting the ground or limiting operation during windy conditions can considerably decrease aerosol/dust concentrations in the lower atmosphere and therefore light scattered toward the observation points from the mine site. The sky glow reductions from this mitigation are unknown.

V. Discussion and Conclusions

The calculations performed for this study indicate that the proposed outdoor lighting for mining operations within the RCM would produce an increase in sky glow from 1% to 4% at the zenith for five of the six observation points analyzed; the brightening reaches a maximum of 25% at the zenith when observed from the nearby portion of Highway 83.

At the astronomical Observatory sites, including FLWO, Jarnac, and Empire Ranch, the increase in brightness of the zenith is 1%, 2% and 4% respectively. In the astronomically "useful" portions of the sky, which we consider here to be out to zenith angle of 70°, the brightening at these sites due to the proposed RCM lighting will be much more significant, reaching 10%, 22% and 32%, respectively in the direction of the mine operations.

Though the sky glow impacts of the potential lighting appear modest, a recent study at Kitt Peak National Observatory (Nugent and Massey, 2010), also suffering measurable sky glow from the Tucson metropolitan area, has seen no increase in sky brightness over the past 10 years, despite substantial growth is in the region. The authors attribute this to more than 30 years of successful efforts at reducing the impacts outdoor lighting throughout Tucson and Pima County. With this perspective, the proposed lighting at the RCM will cause a greater increase in sky glow at these sites that might have occurred over the past 10 years due to growth in the entire area. For the FLWO particularly, a large world-class Observatory facility with many millions of dollars investment, this increase may be viewed with some concern.

Options that could produce reductions in these impacts are available, though the magnitudes of these potential changes have not been quantified in this study. Though restriction of mining operations to daylight hours may be unlikely, improved shielding and restrictions on vertical aiming angles and azimuths for the portable mine lighting, and reconsideration of the necessity or amounts for some of the proposed lighting may provide some opportunities for mitigation.

VI. References

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VII. APPENDICES

Appendix A. Portable light tower for potential use at the Rosemont Copper Mine

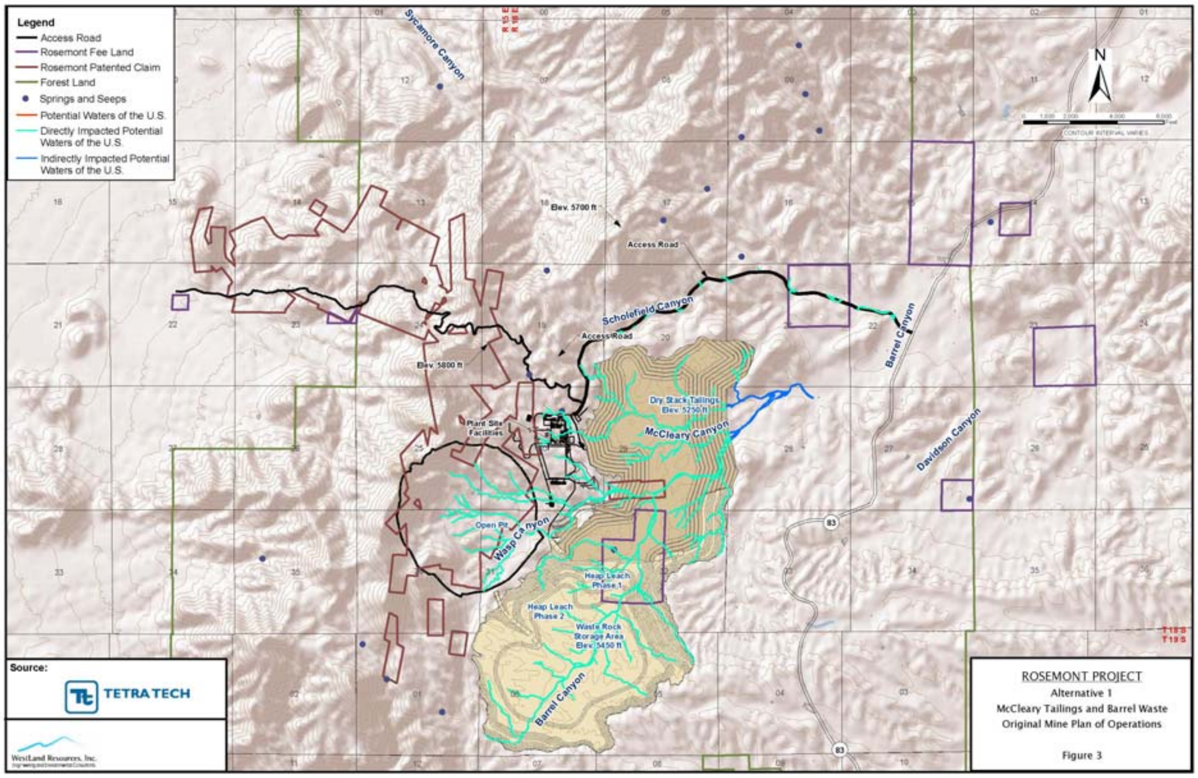
Appendix B. Shielded floodlight fixtures

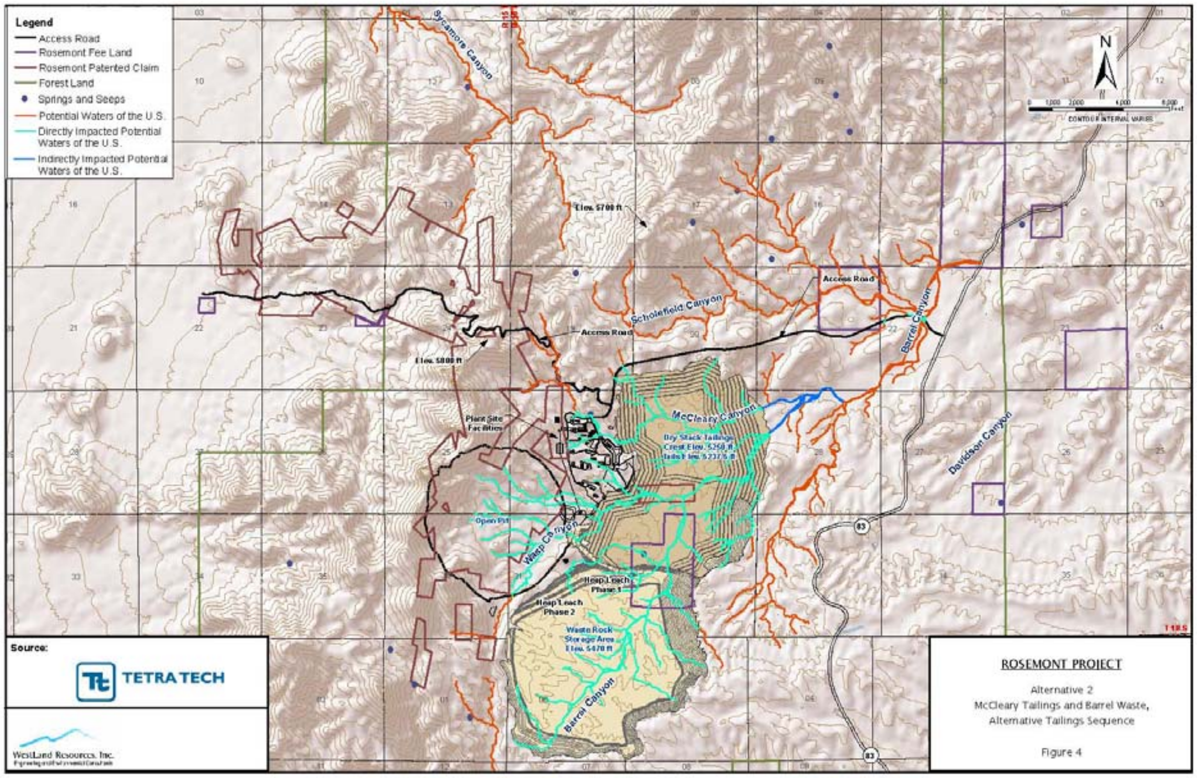
MUSCO Lighting
100 1st Avenue West
P.O. Box 808
Oskaloosa, Iowa 52577

800/825-6030
641/673-0411
Fax: 641/673-4852

LSG product

Appendix C. Alternative Lighting Scenarios for the Rosemont Copper Mine Project




Legend
Access Road
Rosemont Fee Land
Rosemont Patented Claim
Forest Land
Springs and Seeps
Potential Waters of the U.S.
Directly Impacted Potential Waters of the U.S.
Indirectly Impacted Potential Waters of the U.S.
Source:
TETRA TECH
WestLand Resources, Inc.
Sycamore Canyon
Scholefield Canyon
McCleary Canyon
Barrel Canyon
Davidson Canyon
Wasp Canyon
Access Road
Plant Site Facilities
Open Pit
Heap Leach Phase 1
Heap Leach Phase 2
Waste Rock Storage Area
CONTOUR INTERVAL VARIES
ROSEMONT PROJECT
Alternative 2
McCleary Tailings and Barrel Waste,
Alternative Tailings Sequence
Figure 4