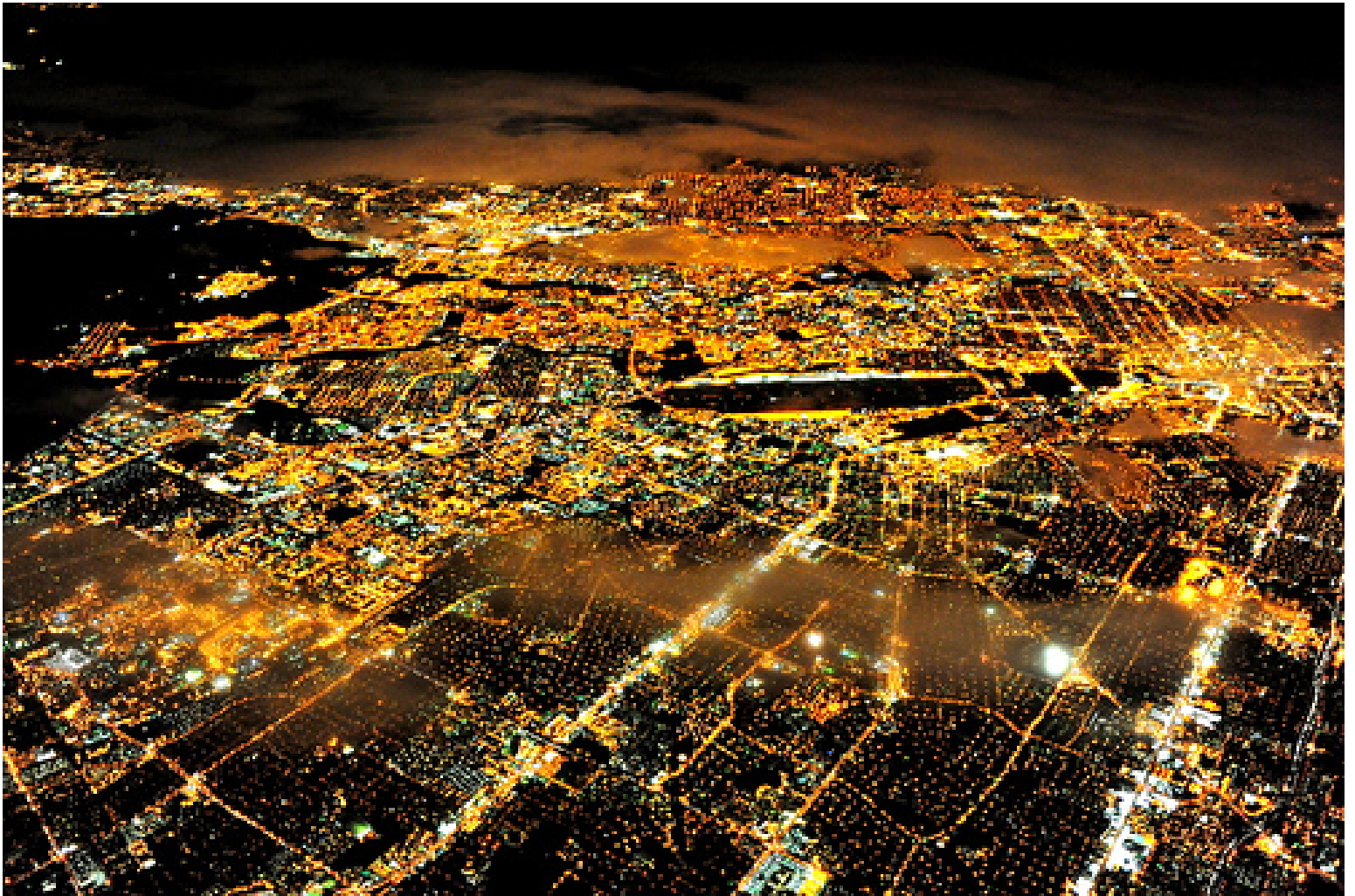


City of San José Public Streetlight Design Guide



February 2011



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I. Background and Purpose

In October 2007 the City of San José (“City”) adopted its Green Vision, an ambitious, comprehensive plan that seeks to reduce the carbon footprint of the City by more than half in 15 years. One of the goals of the 10-point plan is to replace 100 percent of the City’s streetlights with “smart” zero emission lighting by 2022. In this context, “smart” refers to streetlights equipped with a remote monitoring and adaptive control system; “zero emission” is defined as streetlights powered exclusively by renewable energy.

In December 2008, the San José City Council adopted Resolution No. 74739 revising City Policy 4-2: Public Streetlights, to advance its Green Vision streetlight goal. The revised policy allows the City to take advantage of broad spectrum (white) street lighting technologies, such as light emitting diode (LED), plasma and induction (a type of fluorescent) lights. These advanced technologies are more energy-efficient and longer-lasting than the streetlight technology stipulated in the previous policy: specifically low- and high-pressure sodium (also known as high intensity discharge or HID). The policy also permits the City to dim its streetlights in the late evening hours when reduced pedestrian and vehicular traffic justify lower light levels.

Reducing the energy consumption of the City’s streetlights will ultimately facilitate the City’s efforts to power those lights with renewable energy. It will also help reduce the City’s cost to power its 62,000 streetlights, which is currently approximately \$4 million per year.

The Council conditioned implementation of the new public streetlight policy on the adoption of a public streetlight design guide. This *Public Streetlight Design Guide* comprises three separate sections:

1. The “Public Streetlight Replacement Guide” establishes design guidelines for replacing existing public streetlights and outlines the application of luminance effectiveness multipliers which modifies the luminance to account for increased visibility under white light.
2. The “Public Streetlight Installation Guide” establishes design guidelines for installing new public streetlights in the City and outlines the application of luminance effectiveness multipliers which modifies the luminance to account for increased visibility under white light.
3. The “Adaptive Street Lighting Design Guide” establishes design guidelines for dimming public streetlights when reduced pedestrian and vehicular traffic justify lower light levels.

The *Public Streetlight Design Guide* makes use of state-of-the-art lighting science and internationally and nationally recommended street lighting design practices to maintain if not improve the quality of lighting on the City’s streets; reduce energy consumption; and protect astronomical research.

The Public Streetlight Design Guide relies on roadway lighting design guidelines issued by the Illuminating Engineering Society of North America (IESNA) and the International Commission on Illumination (abbreviated as CIE from its French title).

IESNA is considered the nation’s technical authority on illumination. The independent, member-based professional organization synthesizes research, investigations, and discussions to

develop lighting design recommendations intended to promote good lighting practice. IESNA publishes nearly 100 varied technical publications that include recommended practices for a variety of specific lighting applications such as office, sports, and outdoor lighting, and lighting for healthcare facilities. Its members are largely based in the United States, Canada and Mexico.

CIE, or Commission Internationale de l'Éclairage, is an international, independent authority on illumination. Its member countries span the globe. Like IESNA, CIE provides an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting. It also publishes standards, reports and other publications concerned with the science, technology and art of lighting.

All three sections of the *Public Streetlight Design Guide* reference IESNA's *American National Standard Practice for Roadway Lighting*, (Recommended Practice (RP)-8-00) in part or whole. IESNA's RP-8 provides the design basis for lighting roadways, adjacent bikeways, and pedestrian ways. Between 1991 and 2011, San José used the 1964 version of RP-8 to determine the appropriate wattage, spacing and height for public streetlights installed in the City. With the adoption of this *Public Streetlight Design Guide*, the City will shift to the current edition of RP-8, adopted in 2005, for the installation of new streetlights. The street classifications and luminance method criteria outlined in RP-8-05 are also utilized in the "Public Streetlight Replacement Guide" and the "Adaptive Street Lighting Design Guide", respectively. In the future, the City will review any changes to these standards and make appropriate recommendations to the City Council for adoption.

Adopting the current version of RP-8 was necessary for the City to make use of the International Commission on Illumination's *Recommended System for Mesopic Photometry Based on Visual Performance* (CIE 191:2010). For several decades the international lighting community has discussed the need to revise photometric practice to recognize that the color of light has a significant effect on vision, particularly peripheral vision, in outdoor, low-light conditions (called 'mesopic' vision). CIE's *Recommended System of Mesopic Photometry*, which was adopted by the international lighting standards body in 2010, summarizes the scientific basis for the recommended system and provides guidelines for its use and application. The result: a low-pressure (yellow light) or high-pressure (orange-pink light) sodium streetlight can be replaced with a broad spectrum (white) streetlight that emits less light for equal or better visibility. Both the "Public Streetlight Replacement Guide" and "Public Streetlight Installation Guide" employ CIE 191's recommended system of mesopic photometry.

San José's "Adaptive Street Lighting Design Guide" principally relies on RP-8's design criteria to determine when, where, and by what degree the City should dim its lights. To date, IESNA has not issued a formal adaptive lighting design guide. However, the organization has informally acknowledged that it is reasonable to use its existing design criteria for this purpose. In support of this, the City's Adaptive Street Lighting Design Guide references CIE's report on this subject: *Lighting of Roads for Motor and Pedestrian Traffic* (CIE 115:2010). This report, which was issued initially in 1995 and updated in 2010, provides a structured model for dimming lights depending upon variables such as traffic volume or weather conditions.

All three design guides were also informed by a streetlight demonstration and study organized by the City and led by its consultant, Clanton & Associates, which was held in March 2010. The study systematically compared the performance of different streetlight technologies—LPS, HPS, induction and LED—at full brightness and dimmed approximately by half. A survey ascertained

the public's response to those lights. A small target visibility study determined how well people could detect objects under the lights at different lighting levels. The latter research was led by Dr. Ron Gibbons, a lighting and visibility expert affiliated with Virginia Polytechnic Institute, State University and the Virginia Tech Transportation Institute. The study corroborated CIE's findings on mesopic lighting and helped establish the parameters for when, where and how much the City may dim its lights.

Due to their greater efficiency, in terms of lighting design as well as energy consumption, Clanton & Associates recommends that San José use LED streetlights to light the City's roadways. The City's shorter, more decorative pedestrian lights may employ either LED or induction technology.

II. Public Streetlight Replacement Guide

Purpose

The purpose of this section of the *Public Streetlight Guide* is to provide the City with a methodology for replacing existing high intensity discharge (HID) streetlights with broad spectrum (white) light streetlights, such as light emitting diode (LED) technology. This document should only be used for the replacement of public streetlights.

In conformity with standard lighting practice, the streetlight replacements merely replace in-kind; they are not designed to increase the lighting level of existing street lighting design standards. They are equivalent to the streetlight they replace in that they provide comparable visibility for the stretch of street illuminated by the existing light.

A broad spectrum replacement light is considered ‘equivalent’ to the existing HID light if it can deliver an average mesopic luminance within 10% of the existing average mesopic luminance, in accordance with the International Commission on Illumination’s *Recommended System for Mesopic Photometry Based on Visual Performance* (CIE 191:2010).

For decades lighting experts discussed the need to reform photometric practice to recognize that the color of light has a significant effect on vision in outdoor, low-light conditions (called ‘mesopic’ conditions). After extensive deliberation, CIE adopted a methodology for valuing the greater efficacy of white light in outdoor, low-light conditions (called “mesopic” vision), such as night-time driving. CIE’ 191 quantifies the improved performance of white light through the use of lumen effectiveness multipliers. The result: a low-pressure sodium (yellow light) or high-pressure sodium (orange-pink light) streetlight can be replaced with a broad spectrum (white) streetlight that emits less light for equal or better visibility.

Due to their greater efficiency, in terms of lighting design as well as energy consumption, Clanton & Associates recommends that San José use LED streetlights to light the City’s roadways. The City’s shorter, more decorative pedestrian lights may employ either LED or induction technology.

Continuous Lighting on Straight Streets and Intersections

Table 1 gives examples of LED lumen equivalents with current technology under specific street conditions with a mounting height of 32’. The replacements provided are recommended for both continuous lighting on straight streets and intersections. Replacing the existing lighting with the designated LED lumen specifications will deliver an equivalent mesopic luminance to continuously lighted streets and an illuminance level that meets current design practices for intersections. Manufacturers can use Table 2 to determine an equivalent LED replacement. Neither table applies to new streetlight installation which is provided in the next section. The light level standards vary between one-for-one replacements and new installation because of the values of IESNA recommended light levels. Many of streetlights that will undergo a one-for one replacement were designed with the recommended values from IESNA RP-8-64. Since the City is moving to adopt the most recent version of IESNA RP-8-05, the light levels have changed and all new streetlight installations will be designed with this recommended criterion.

Municipalities are not required to adopt IESNA light level recommendations. Maintaining the same light level for the one-for-one replacements will suffice. Updating existing streets to meet the newest version of RP-8 is not practical and will cause the City to incur substantial costs.

TABLE 1 REPLACEMENT GUIDE FOR EXISTING LUMINAIRES							
Street Classification	Fixture Spacing	Low Pressure Sodium				High Pressure Sodium	
		55 Watt	90 Watt	135 Watt	180 Watt	250 Watt	360 Watt
Major	200'			4	6	7	8
	160'			4	6	7	
	120'			4	6	7	
Collector	200'		2	3	5	7	
	160'		2	3	5	7	
	120'		2	3	5	7	
Minor	300'	1	2				
	250'	1	2				
	200'	1	2				
	160'	1	2				
	120'	1	2				

Lumen Specifications:

1. 2,600 Initial Lumens in Type II distribution
2. 3,650 Initial Lumens in Type II distribution
3. 7,300 Initial Lumens in Type II distribution
4. 7,500 Initial Lumens in Type II distribution
5. 9,450 Initial Lumens in Type II distribution
6. 11,550 Initial Lumens in Type II distribution
7. 17,600 Initial Lumens in Type II distribution
8. 21,100 Initial Lumens in Type II distribution

There are many LED manufacturers that may deliver the LED lumen packages listed above. Table 2 and the explanation that follows it under the header “Determining Equivalency” provide a methodology to determine equivalency for other LED products. Table 2 outlines the existing photopic and mesopic luminance for a variety of street classifications, spacing, luminaire wattage and sources. The photopic luminance values in this table do not need to be updated.

Street Classifications

The following definitions were adopted by the City of San José and describe each type of street classification. They are comparable to those used by the Illuminating Engineering Society of North America’s (IESNA) RP-8-05.

Major:

A facility which accommodates major movements of traffic not served by expressways or freeways which connect areas of principal traffic generation and important rural roadways leaving the city. Major streets are designed mainly for the movement of through traffic, which may include light rail transit, but also normally performs a secondary function of providing access to abutting properties. Even though abutting property has access to the facility, parking and loading may be restricted or prohibited to improve the capacity for moving traffic. The number of lanes depends on the volume of traffic though majors are generally planned to contain four or more travel lanes. In San José, a major street is defined as being between 80 feet and 130 feet wide. Average daily traffic volumes typically range from 7,500 to 50,000 vehicles.

Collector:

A facility which serves internal traffic movements within an area and connects this area with the major and local streets. Collectors do not handle long through trips but do provide access to abutting properties. Traffic control devices may be installed to protect or facilitate traffic on a collector street. Two or four lane streets can be accommodated on a collector. A collector street is defined as being between 60 feet and 90 feet wide. Average daily traffic volumes typically range from 2,000 to 16,000 vehicles.

Minor:

A facility having the primary function of providing access to immediately adjacent land. Minor streets may be divided into subclasses according to the type of land served, such as residential and industrial. One lane of traffic in each direction is the standard for minor streets. A minor street is defined as being less than 60 feet wide. Average daily traffic volumes typically range from 50 to 2,000 vehicles.

TABLE 2 PERFORMANCE FOR EXISTING LUMINAIRES: PHOTOPIC AND MESOPIC LUMINANCE								
Street Classification	Fixture Spacing	Lamp Type	Photopic Luminance			Mesopic Luminance		
			Average Luminance	Max:Min	Avg:Min	Average Luminance	Mesopic Max:Min	Mesopic Avg:Min
Major	200'	135W LPS	0.52	3.7	1.7	0.42	4.4	1.9
		180W LPS	0.78	3.8	2.0	0.67	4.5	2.1
		250W HPS	1.12	3.8	1.9	1.06	4.1	1.9
		360W HPS	1.50	3.3	1.9	1.45	3.5	1.9
		400W HPS	2.10	3.9	1.9	2.07	4.2	2.0
	160'	135W LPS	0.66	3.3	1.7	0.55	3.8	1.8
		180W LPS	0.95	3.4	1.9	0.84	4.0	2.1
		250W HPS	1.45	3.6	2.1	1.40	3.8	2.2
		360W HPS	1.93	3.3	1.9	1.89	3.5	2.0
		400W HPS	2.68	3.5	2.1	2.68	3.7	2.1
	120'	135W LPS	0.89	3.0	1.8	0.78	3.5	1.9
		180W LPS	1.36	2.6	1.7	1.25	3.0	1.8
		250W HPS	1.92	2.5	1.7	1.88	2.7	1.8
		360W HPS	2.57	2.5	1.7	2.56	2.6	1.8
		400W HPS	3.54	2.6	1.8	3.59	2.7	1.8
Collector	200'	90W LPS	0.31	3.5	1.6	0.23	4.3	1.7
		135W LPS	0.51	3.7	1.7	0.41	4.4	1.8
		180W LPS	0.77	3.8	1.9	0.66	4.5	2.1
		250W HPS	1.15	4.8	2.3	1.10	5.3	2.4
		360W HPS	1.53	4.6	2.2	1.48	5.0	2.3
		400W HPS	2.12	4.4	2.1	2.09	4.8	2.2
	160'	90W LPS	0.40	4.0	2.0	0.31	5.0	2.2
		135W LPS	0.66	3.0	1.7	0.55	3.5	1.8
		180W LPS	0.97	3.2	1.9	0.86	3.8	2.1
		250W HPS	1.46	3.6	2.1	1.41	3.8	2.2
		360W HPS	1.94	3.3	1.9	1.90	3.5	2.0
		400W HPS	2.72	3.5	2.1	2.72	3.8	2.2
	120'	90W LPS	0.54	3.5	1.4	0.44	4.2	1.4
		135W LPS	0.87	2.8	1.7	0.76	3.2	1.9
		180W LPS	1.29	2.5	1.6	1.18	2.8	1.7
250W HPS		1.94	2.3	1.6	1.90	2.4	1.7	
360W HPS		2.65	2.4	1.7	2.65	2.6	1.7	
400W HPS		3.59	2.4	1.6	3.65	2.5	1.7	
Minor	300'	55W LPS	0.24	5.00	2.40	0.17	6.57	2.81
		90W LPS	0.36	7.0	3.6	0.27	9.7	4.5
	250'	55W LPS	0.30	3.00	1.50	0.22	3.57	1.60
		90W LPS	0.49	2.7	1.6	0.39	3.1	1.8
	200'	55W LPS	0.35	3.00	1.75	0.27	3.57	1.92
		90W LPS	0.62	1.6	1.2	0.51	1.7	1.3
	160'	55W LPS	0.53	2.25	1.3	0.43	2.5	1.4
		90W LPS	0.76	1.5	1.3	0.65	1.6	1.3
120'	55W LPS	0.61	1.6	1.2	0.50	1.7	1.3	
	90W LPS	1.06	1.3	1.2	0.95	1.4	1.2	

If the luminance effectiveness multipliers from the CIE 191:2010 document are updated, the three rightmost columns of Table 2 will be affected and require recalculation.

Determining Equivalency

The following steps must be taken to determine if a LED product may be considered an equivalent replacement for the City of San José.

1. Use Table 2 to determine the performance of an existing luminaire.
 - a. Identify the existing light source and wattage.
 - b. Select the row that best represents the street classification, and the pole spacing.
 - c. Determine the existing mesopic luminance (luminance effectiveness multiplier has already been applied).

2. Calculate the mesopic luminance of the LED luminaire replacement luminaire.
 - a. Identify the characteristics of the existing luminaire that the LED luminaire is replacing (light source, wattage, street classification, and pole spacing).
 - b. Determine the Scotopic to Photopic (S/P) ratio of the LED luminaire based upon the correlated color temperature of the LED. The S/P ratio is the ratio of scotopic-to-photopic luminous flux of the light source.
 - c. Set up a luminance grid for one cycle of luminaires using IESNA RP-8-05 standard for the setup of calculations points. Perform a computer calculation to determine the photopic luminance of the LED luminaire under the conditions identified in Step 2a. The dimensions and conditions of the street in the computer model must replicate the dimensions and conditions of the street where the existing luminaire is to be replaced. The calculation must be performed under maintained conditions. Meaning that appropriate light loss factors should be applied for the type of luminaire (lamp lumen depreciation, luminaire dirt depreciation, etc.).
 - d. Using the International Commission on Illumination's (CIE 191:2010) information on luminance effectiveness multipliers, calculate the LED mesopic luminance based upon the S/P ratio and the photopic luminance. Note that the mesopic adjustment factor must be applied to each individual calculation point and cannot be generally applied to the average photopic luminance.
 - e. Compare the existing average mesopic luminance from Table 2 to the calculated average LED mesopic luminance.
 - f. If the calculated average LED mesopic luminance is within 10% of the existing mesopic luminance, then the LED luminaire is considered an equivalent replacement.

Appendix A: Luminance Effectiveness Multipliers for Retrofit

The purpose of this appendix is to illustrate the application of luminance effectiveness multipliers. These factors are important because it is through these factors that the effectiveness of white light can be quantified. Nighttime vision is more sensitive to white light, meaning less white light is required for comparable visibility when compared to non-white light sources. The effect of broad spectrum or ‘white light’ is calculated using two values: the S/P ratio and the photopic luminance.

S/P Ratio

The S/P ratio is a ratio of scotopic-to-photopic luminous flux of a light source. It is a ratio *specifically applied to luminance*.

S/P ratios less than one have a negative adjustment for white light effectiveness, meaning that the given photopic luminance will be effectively reduced under mesopic conditions. Conversely, S/P ratios greater than one have a positive adjustment for white light effectiveness, meaning the given photopic luminance will be effectively increased. The photopic luminance value is *calculated based upon specific orientation and geometry*.

The International Commission on Illumination (CIE 191:2010) gives examples of sources and corresponding S/P ratios. Also, from a paper published by the IESNA Journal, additional examples of S/P ratios and their sources are given. The below table compiles some of these published S/P ratios.

Reference	Source	Approximate S/P Ratio	Approximate CCT (K)
CIE 191 2010 ¹	Low Pressure Sodium	0.25	1700
	High Pressure Sodium	0.65	2100
	Warm White Metal Halide	1.35	3500
	Daylight Metal Halide	2.45	5500
S.M. Berman 1992 ²	Warm White Fluorescent	1	3000
	Cool White Fluorescent	1.46	3700
	Thin Coat Tri Chrome Fluorescent	1.54	4100
	Daylight Fluorescent	2.22	7500

¹International Commission on Illumination. “Recommended System for Mesopic Photometry Based on Visual Performance.” 2010.

²Berman, S.W. “Energy Efficiency Consequences of Scotopic Sensitivity.” *Journal of the Illuminating Engineering Society*. Winter 1992.

Although the S/P ratio is derived from the spectral power distribution of the light source, it approximately corresponds to the correlated color temperature of that source. This creates an equation to calculate the S/P ratio for any source based upon based upon the correlated color temperature (CCT).

To determine the S/P ratio for any given CCT, the following equation can be used:

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT(K))^2 + 0.001(CCT(K)) - 1.3152$$

Table 4 below lists the calculated S/P ratios for several standard CCTs using the above equation. The equation can also be used to calculate any other CCT not listed below.

CCT (K)	S/P Ratio
1500	0.03
2000	0.40
2500	0.75
3000	1.05
3500	1.33
3700	1.43
4000	1.56
4100	1.61
4300	1.69
4700	1.84
5000	1.93
5500	2.07
6000	2.16
6500	2.23

Recommended range of LED color temperatures (3500K-4300K)

The recommended range of LED color temperatures (3500K to 4300K) is based on visibility and preference. In the *Advanced Street Lighting Technologies Assessment Project for the City of San José (2010)*, it was found that while higher color temperature LEDs are more efficient, subjectively, participants generally preferred lower color temperature LEDs.

The recommended range of color temperatures is not based upon cost and availability. Both of which vary significantly at this time. There are also concerns from the astronomy community about the presence of blue wavelengths in higher color temperature light sources.

Photopic Luminance

The photopic luminance value is determined most easily using lighting calculation software due to the complexity of the geometric calculation. The units are candela per square meter.

Once both the S/P ratio for the source CCT and the photopic luminance is calculated, Table 5 can be used to determine the photopic luminance adjustment factor. In cases where the S/P ratio or the photopic luminance value falls between values listed in the table, a single or double interpolation may be necessary. The luminance effectiveness multiplier is applied to each calculation point of the photopic luminance calculation, performed using lighting calculation software. Once the multiplier has been applied to all calculation points, the average can be calculated which will then be the mesopic average. **The luminance effectiveness multiplier cannot be applied to the average photopic luminance.** The mesopic average must be calculated from the complete set of calculation points that have individually received the appropriate luminance effectiveness multiplier based on the corresponding photopic luminance.

TABLE 5 LUMINANCE EFFECTIVENESS MULTIPLIER (%) (CIE 191:2010 Table 11)										
S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Appendix B: LED Replacement Example

This example illustrates the process for equivalently replacing an existing traditional source luminaire with a broad spectrum LED luminaire.

Existing Conditions

A 135W LPS luminaire located on a collector street, with 200' spacing is going to be replaced with a high performance LED luminaire. Using Table 2, the mesopic performance of the 135W LPS luminaire can be found.

Existing Performance			
Mesopic Values	L_{avg}	L_{avg}/L_{min}	L_{max}/L_{min}
Collector – 200'	0.41	1.8	4.4

Luminance Effectiveness Multipliers

The high performance LED seeking to replace the 135W LPS is 7300 initial lumens with a Type II distribution and has a CCT of 4000K. To calculate the corresponding S/P ratio for this CCT, the following equation is used.

$$CCT = 4000K$$

$$S/p \text{ Ratio} = -7 * 10^{-8}(CCT)^2 + 0.001(CCT) - 1.3152$$

$$S/p \text{ Ratio}_{4000K} = -7 * 10^{-8}(4000)^2 + 0.001(4000) - 1.3152$$

$$S/p \text{ Ratio}_{4000K} = 1.56$$

The photopic luminance was calculated using a simulation model. For each individual calculation point, a luminance effectiveness multiplier was calculated. The table below shows the photopic luminance values of all of the calculation points (cd/m²).

Photopic Luminance (cd/m ²)												
0.23	0.33	0.43	0.45	0.37	0.31	0.28	0.27	0.27	0.27	0.23	0.21	0.22
0.29	0.43	0.58	0.63	0.51	0.40	0.36	0.31	0.28	0.28	0.24	0.23	0.27
0.41	0.63	0.80	0.87	0.65	0.54	0.46	0.36	0.29	0.28	0.25	0.25	0.37
0.59	0.83	1.00	1.00	0.78	0.62	0.52	0.38	0.28	0.28	0.28	0.33	0.54

To calculate the luminance effectiveness multiplier, use CIE 191:2010. Each calculation point is required to go through the process individually. The process to do a single calculation point (1.0 cd/m²) is as follows.

Since the photopic luminance value of 1.0 cd/m² is located within Table 5, but the S/P ratio of 1.56 is not listed, a single interpolation is required to determine the luminance effectiveness multiplier for this particular point.

TABLE 5 PHOTOPIC LUMINANCES ADJUSTMENT FACTOR (%) (CIE 191:2010 Table 11)										
S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Equation for single linear interpolation: $y = y_0 + (x - x_0) * \frac{y_1 - y_0}{x_1 - x_0}$

Linear interpolation: $y = 5\% + (1.56 - 1.45) * \frac{7\% - 5\%}{1.65 - 1.45} = 6.1\%$

Since the S/P ratio is greater than 1, the adjustment is positive. This means that the effective luminance will increase.

The photopic luminance can only be adjusted using this factor. The calculation is:

Mesopic luminance = (1 + white light effectiveness adjustment (%)) * photopic luminance

Mesopic luminance = (1 + 0.061) * 1.0 cd/m²

Mesopic Luminance for this single value = 1.06 cd/m²

Following this same procedure for all of the calculation points yields a calculation grid with the following mesopic luminance (cd/m^2).

Mesopic Luminance (cd/m^2)												
0.26	0.37	0.47	0.49	0.41	0.34	0.31	0.30	0.30	0.30	0.26	0.24	0.25
0.32	0.47	0.63	0.68	0.55	0.44	0.40	0.34	0.31	0.31	0.27	0.26	0.30
0.45	0.68	0.85	0.92	0.70	0.58	0.50	0.40	0.32	0.31	0.28	0.28	0.41
0.64	0.88	1.06	1.06	0.83	0.67	0.56	0.42	0.31	0.31	0.31	0.37	0.58

The following table summarizes the results of these calculations. Since the mesopic luminance is within 10% of the mesopic luminance of the 135W LPS, this LED luminaire with 7300 initial lumens can be considered equivalent.

	L_{avg}	$L_{\text{avg}}/L_{\text{min}}$	$L_{\text{max}}/L_{\text{min}}$
<i>135W LPS Mesopic Luminance</i>	0.41	1.8	4.4
90W LED Mesopic Luminance	0.47	2.0	4.4

III. Public Streetlight Installation Guide

Purpose

The purpose of this section of the *Public Streetlight Guide* is to provide guidance to the City on the lighting design for the installation of new broad spectrum (white) light streetlights, such as light emitting diode (LED) technology. This document is only to be used for public streetlight installations.

Due to their greater efficiency, in terms of lighting design as well as energy consumption, Clanton & Associates recommends that San José use LED streetlights to light the City's roadways. The City's shorter, more decorative pedestrian lights may employ either LED or induction technology.

Lighting Design Criteria

For all new installations, the City shall follow the values set forth in the 2005 version of the Illuminating Engineering Society of North America's (IESNA) *American National Standard Practice for Roadway Lighting* (RP-8-05).

Continuous Lighting on Straight Streets

For continuous lighting on straight streets, the City shall design all new installations to meet the criteria found in Table 3: Luminance Method – Recommended Values. Luminance effectiveness multipliers may be applied to all street classifications except expressways/freeways/highways.

Continuous Lighting on Non-Straight Streets

For continuous lighting on non-straight streets, the City shall design all new installations in accordance with the spacing adjustment guidelines found in Annex D: Situations Requiring Special Consideration.

Intersections

For intersections on continuously lighting urban streets, the City shall design all new installations to meet the criteria found in Table 9: Recommended Illuminance.

Note that because the unit of this criterion is in illuminance, luminance effectiveness multipliers are not applicable for intersections.

Street Classifications

The following definitions were adopted by the City of San José and describe each type of street classification. They are comparable to those used by the Illuminating Engineering Society of North America's (IESNA) RP-8-05,

Major:

A facility which accommodates major movements of traffic not served by expressways or freeways which connect areas of principal traffic generation and important rural roadways leaving the city. Major streets are designed mainly for the movement of through traffic, which may include light rail transit, but also normally performs a secondary function of providing access to abutting properties. Even though abutting property has access to the facility, parking and loading may be restricted or prohibited to improve the capacity for moving traffic. The number of lanes depends on the volume of traffic though majors are generally planned to contain four or more travel lanes. In San José, a major street is defined as being between 80 feet and 130 feet wide. Average daily traffic volumes typically range from 7,500 to 50,000 vehicles.

Collector:

A facility which serves internal traffic movements within an area and connects this area with the major and local streets. Collectors do not handle long through trips but do provide access to abutting properties. Traffic control devices may be installed to protect or facilitate traffic on a collector street. Two or four lane streets can be accommodated on a collector. A collector street is defined as being between 60 feet and 90 feet wide. Average daily traffic volumes typically range from 2,000 to 16,000 vehicles.

Minor:

A facility having the primary function of providing access to immediately adjacent land. Minor streets may be divided into subclasses according to the type of land served, such as residential and industrial. One lane of traffic in each direction is the standard for minor streets. A minor street is defined as being less than 60 feet wide. Average daily traffic volumes typically range from 50 to 2,000 vehicles.

Luminance Effectiveness Multipliers

Luminance effectiveness multipliers may be applied for all new installation street classifications except expressways/freeways/highways per the International Commission on Illumination's *Recommended System for Mesopic Photometry Based on Visual Performance* (CIE 191:2010). These factors are important because it is through them that the effectiveness of white light can be quantified. Nighttime vision is more sensitive to white light, meaning less white light is required for comparable visibility when compared to non-white light sources.

The effect of broad spectrum or 'white light' is calculated using two values: the S/P ratio and the photopic luminance.

S/P Ratio

The S/P ratio is the ratio of scotopic-to-photopic luminous flux of a light source. It is a ratio specifically applied to luminance.

S/P ratios less than one have a negative adjustment for white light effectiveness, meaning that the given photopic luminance will be effectively reduced under mesopic conditions. Conversely, S/P ratios greater than one have a positive adjustment for white light effectiveness, meaning the given photopic luminance will be effectively increased. The photopic luminance value is a calculated value based upon specific orientation and geometry.

The International Commission on Illumination (CIE 191:2010) gives examples of sources and corresponding S/P ratios. Also, from a paper published by the IESNA Journal, additional examples of S/P ratios and their sources are given. The table below compiles some of these published S/P ratios.

Reference	Source	Approximate S/P Ratio	Approximate CCT (K)
CIE 191 2010 ¹	Low Pressure Sodium	0.25	1700
	High Pressure Sodium	0.65	2100
	Warm White Metal Halide	1.35	3500
	Daylight Metal Halide	2.45	5500
S.M. Berman 1992 ²	Warm White Fluorescent	1	3000
	Cool White Fluorescent	1.46	3700
	Thin Coat Tri Chrome Fluorescent	1.54	4100
	Daylight Fluorescent	2.22	7500

¹International Commission on Illumination. “Recommended System for Mesopic Photometry Based on Visual Performance.” 2010.

²Berman, S.W. “Energy Efficiency Consequences of Scotopic Sensitivity.” *Journal of the Illuminating Engineering Society*. Winter 1992.

Although the S/P ratio is derived from the spectral power distribution of the light source, it approximately corresponds to the correlated color temperature of that source. This creates an equation to calculate the S/P ratio for any source based upon the correlated color temperature (CCT).

To determine the S/P ratio for any given CCT, the following equation may be used:

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT(K))^2 + 0.001(CCT(K)) - 1.3152$$

Table 2 below lists the calculated S/P ratios for several standard CCTs using the above equation. The equation can also be used to calculate any other CCT not listed below.

CCT (K)	S/P Ratio
1500	0.03
2000	0.40
2500	0.75
3000	1.05
3500	1.33
3700	1.43
4000	1.56
4100	1.61
4300	1.69
4700	1.84
5000	1.93
5500	2.07
6000	2.16
6500	2.23

Recommended range of LED color temperatures (3500K-4300K)

The recommended range of LED color temperatures (3500K to 4300K) is based on visibility and preference. In the *Advanced Street Lighting Technologies Assessment Project for the City of San José (2010)*, it was found that while higher color temperature LEDs are more efficient, subjectively, participants generally preferred lower color temperature LEDs.

The recommended range of color temperatures is not based upon cost and availability, both of which vary significantly at this time. There are also concerns from the astronomy community about the presence of shorter wavelengths in higher color temperature light sources.

Photopic Luminance

The photopic luminance value is determined most easily using lighting calculation software due to the complexity of the geometric calculation. The units are candela per square meter.

Once both the S/P ratio for the source CCT and the photopic luminance is calculated, Table 3 can be used to determine the luminance effectiveness multiplier. In cases where the S/P ratio or the photopic luminance value falls between values listed in the table, a single or double

interpolation may be necessary. The luminance effectiveness multiplier is applied to each calculation point of the photopic luminance calculation, performed using lighting calculation software. Once the multiplier has been applied to all calculation points, the average can be calculated which will then be the mesopic average. **The luminance effectiveness multiplier cannot be applied to the average photopic luminance.** The mesopic average must be calculated from the complete set of calculation points that have individually received the appropriate luminance effectiveness multiplier based on the corresponding photopic luminance.

S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Lighting Design Process for New Installations

Performing a lighting design for new installations of streetlights is an iterative process. This occurs because the lighting design is altered (spacing, arrangement, mounting height) until the target criteria for the specific street in question is met. Most efficiently, a simulated model is created to quickly perform the luminance (straight streets) or illuminance (intersection) calculations while allowing easy modification of the streetlight parameters. The following table predicts the approximate luminance effectiveness multiplier for a 4000K source and displays the resulting adjusted luminance criteria based upon the street and pedestrian classification. While only an approximation, this table allows designers a target value to begin design. Once the target luminance is achieved, the luminance effectiveness multipliers can be applied to each individual calculation point.

TABLE 4 PREDICTED ADJUSTED LUMINANCE				
IESNA Criteria		Avg. Luminance (cd/m ²)	Predicted Luminance Effectiveness Multiplier for a 4000K source	Adjusted Average Luminance (cd/m ²)
Major	High	1.2	5.3%	1.14
	Medium	0.9	6.6%	0.84
	Low	0.6	8.1%	0.55
Collector	High	0.8	7.1%	0.74
	Medium	0.6	8.1%	0.55
	Low	0.4	10.8%	0.36
Local	High	0.6	8.1%	0.55
	Medium	0.5	8.7%	0.46
	Low	0.3	11.2%	0.27

Appendix A: Typical New Installation Design Process

The purpose of this example is to illustrate the design process for achieving design criteria for new installations. Calculations are performed for both continuous, straight streets and intersections. The application of luminance effectiveness multipliers is included.

The design process for new installations should follow the outlined process below.

1. Determine the design parameters of the new street, including: median width, luminaire setback, curb to curb width of the street, number of lanes in each direction, street classification, and level of pedestrian conflict. If also determining the lighting for an intersection, determine the street classification of the intersecting street.
2. Determine the criteria that are to be achieved based upon the street classification, level of pedestrian conflict and other intersection street, if applicable, from IESNA RP-8-05.
3. Develop a model of the new street with the design parameters in lighting calculation simulation software such as AGI32.
4. Define luminaires that may be used in the calculation model. Apply light loss factors for maintained conditions (lamp lumen depreciation, luminaire dirt depreciation, etc.) and set the mounting height that will be used for the installation.
5. Set up a luminance calculation grid for one cycle of luminaires using the IESNA RP-8-05 standard for the setup of calculation points. If also performing a calculation for an intersection, terminate the luminance calculation grid prior to the intersection. In the intersection, place an illuminance calculation grid using the IESNA RP-8-05 standard for the setup of calculation points.
6. Continuous Straight Street:
 - a. Begin placing luminaires on the portion of the straight continuous lighted street. Evaluate the outcomes of varying street light arrangements (staggered, opposite, median mounted, single sided, etc) to achieve an appropriate spacing. Although the luminance calculation grid includes only one cycle of luminaires, be sure to continue the cycle in each direction to simulate typical conditions.
 - b. Use Table 4 as an approximate target for the anticipated contribution from the luminance effectiveness multipliers. Once the approximate target is reached, continue to step 6c.
 - c. If the street classification is not expressway/freeway/highway, use the International Commission on Illumination's CIE 191:2010 to calculate the luminance effectiveness multipliers based on the S/P ratio and the photopic luminance. The luminance effectiveness multipliers must be applied to each individual calculation point and cannot be applied to the average photopic luminance.
 - d. Compare the luminance criterion determined in Step 2 to the calculated mesopic luminance in Step 6c. If the mesopic luminance is far above or below the design target, adjust the luminaire spacing and/or wattage and repeat until the value of the mesopic luminance is closer.
 - e. If the calculated mesopic luminance meets or exceeds the luminance criteria, then the luminaire is a viable option.
7. Intersections:

- a. Begin placing luminaires in the standard arrangement at each corner of the intersection.
- b. Because the unit is illuminance, luminance effectiveness multipliers cannot be applied.
- c. Compare the illuminance criteria determined in Step 2 to the calculated illuminance in step 7b. If the calculated illuminance is far above or below the design target, adjust the luminaire wattage and repeat until the value of the calculated illuminance is closer.
- d. If the calculated illuminance meets or exceeds the design target, then the luminaire arrangement is a viable option for that particular intersection.

Appendix B: Minor Street Example

This typical street has one lane with parking on each side of street (36 feet curb to curb), a low pedestrian conflict and intersects with a collector street. The luminaire setback is 1.5'.

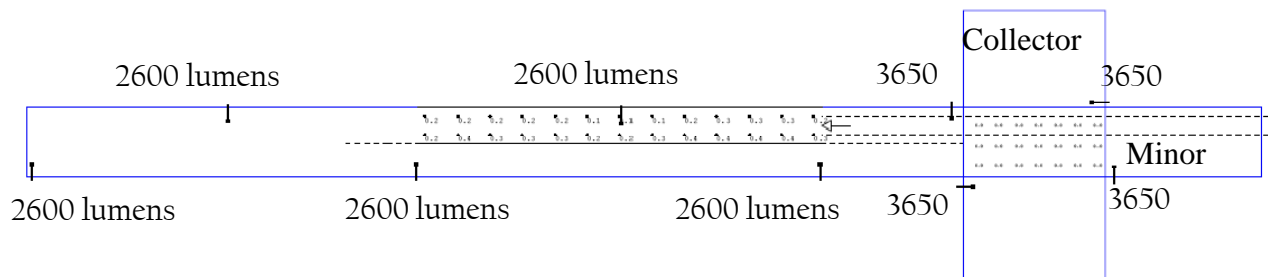
Criteria Per RP-8-05

Continuous Lighting on Straight Street				
	L_{avg}	L_{avg}/L_{min}	L_{max}/L_{min}	L_{vmax}/L_{avg}
Minor – Low Ped.	0.3	6.0	10.0	0.4

Intersection		
	E_{avg}	E_{avg}/E_{min}
Minor/Collector – Low Ped	1.0	4.0

The lighting model is shown below. From Table 4, the target luminance criteria is 0.27 cd/m^2 . The selected lumen package for the continuous lighted, straight street is a 2600 initial lumens. In order to achieve the luminance values required for a minor street with low pedestrian conflict, a staggered arrangement with a spacing of 200' was used.

Because the minor street intersects with a collector street and the pedestrian conflict remained low, LED luminaires with a 3,650 initial lumen package were used at each of the corners of the intersection.



Luminance Effectiveness Multipliers

The LED luminaire with 2600 initial lumens selected for the continuous, straight portion of this street has a correlated color temperature (CCT) of 4000K. To calculate the corresponding S/P ratio for this CCT, the following equation is used.

$$CCT = 4000K$$

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT)^2 + 0.001(CCT) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = -7 * 10^{-8}(4000)^2 + 0.001(4000) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = 1.56$$

The photopic luminance was calculated in the lighting simulation model. For each individual calculation point, a luminance effectiveness multiplier was calculated. The table below shows the photopic luminance values of all of the calculation points (cd/m²).

Photopic Luminance (cd/m ²)												
0.20	0.22	0.20	0.20	0.17	0.13	0.11	0.13	0.20	0.33	0.35	0.31	0.23
0.23	0.35	0.27	0.31	0.28	0.25	0.16	0.28	0.38	0.42	0.42	0.42	0.28

To calculate the luminance effectiveness multiplier, use CIE 191:2010. Each calculation point is required to go through the process individually. The process to do a single calculation point (0.23 cd/m²) is as follows:

Since the photopic luminance value of 0.23 cd/m² is not located within Table 3, nor is the S/P ratio of 1.56, a double interpolation is required to determine the luminance effectiveness multiplier for this particular point.

S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

$$\text{Equation for single linear interpolation: } y = y_0 + (x - x_0) * \frac{y_1 - y_0}{x_1 - x_0}$$

Single interpolation with an S/P ratio of 1.56 and a photopic luminance value of 0.1:

$$y = 15\% + (1.56 - 1.45) * \frac{21\% - 15\%}{1.65 - 1.45} = 18.3\%$$

Single interpolation with an S/P ratio of 1.56 and a photopic luminance value of 0.3:

$$y = 9\% + (1.56 - 1.45) * \frac{13\% - 9\%}{1.65 - 1.45} = 11.2\%$$

<i>S/P Ratio</i>	<i>0.1 cd/m²</i>	<i>0.3 cd/m²</i>
1.56	18.3%	11.2%

Interpolation between luminance values of 0.1 and 0.3 and an S/P ratio of 1.56:

$$y = 18.3\% + (0.23 - 0.1) * \frac{11.2\% - 18.3\%}{0.3 - 0.1} = 13.7\%$$

Since the S/P ratio is greater than 1, the adjustment is positive. This means that the effective luminance will increase.

The photopic luminance can only be adjusted using this multiplier. The calculation is:

$$\text{Mesopic luminance} = (1 + \text{white light effectiveness adjustment (\%)}) * \text{photopic luminance}$$

$$\text{Mesopic luminance} = (1 + 0.137) * 0.23 \text{ cd/m}^2$$

Mesopic Luminance for this single value= 0.26 cd/m²

Following this same procedure for all of the calculation points yields a calculation grid with the following mesopic luminance values (cd/m²).

Mesopic Luminance (cd/m ²)												
0.23	0.25	0.23	0.23	0.19	0.15	0.13	0.15	0.23	0.37	0.39	0.34	0.26
0.26	0.39	0.30	0.34	0.31	0.28	0.18	0.31	0.42	0.46	0.46	0.46	0.31

The following table summarizes the results of these calculations. Since the mesopic luminance meets the IESNA RP-8-05 criteria, the lighting design for this street is a viable solution. Use the photopic values for L_{vmax}/L_{avg} to determine if the design meets criteria.

	L _{avg}	L _{avg} /L _{min}	L _{max} /L _{min}	L _{vmax} /L _{avg}
<i>Criteria</i>	0.3	6.0	10.0	0.4
Photopic	0.26	2.36	3.82	0.38
Mesopic	0.30	2.29	3.59	-

The intersection lighting design criteria is based on illuminance. Because of this, luminance effectiveness multipliers cannot be applied. The calculated illuminance value is 1.26 fc. Since this exceeds the illuminance criteria of 1.0 fc for this particular intersection, the luminaire wattage and arrangement is a viable solution.

Appendix C: Minor Street Example

This typical street has one lane with parking on each side of street (36 feet curb to curb), a high pedestrian conflict and intersects with a collector street. The luminaire setback is 1.5’.

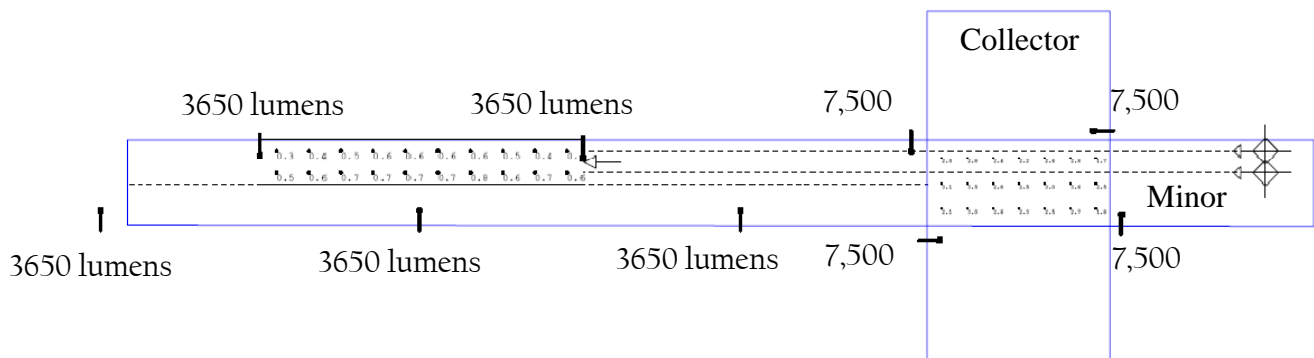
Criteria Per RP-8-05

Continuous Lighting on Straight Street				
	L_{avg}	L_{avg}/L_{min}	L_{max}/L_{min}	L_{vmax}/L_{avg}
Minor – High Ped.	0.6	6.0	10.0	0.4

Intersection		
	E_{avg}	E_{avg}/E_{min}
Minor/Collector – High Ped	2.1	4.0

The lighting model is shown below. From Table 4, the target luminance criteria is 0.55 cd/m². The selected lumen package for the continuous lighted, straight street is a 3650. In order to achieve the luminance values required for a minor street with high pedestrian conflict, a staggered arrangement with a spacing of 125’ was used.

Because the minor street intersects with a collector street and the pedestrian conflict remained high, LED luminaires with a 7,500 initial lumen package were used at each of the corners of the intersection.



Luminance Effectiveness Multipliers

The LED luminaire with 3650 initial lumens selected for the continuous, straight portion of this street has a correlated color temperature (CCT) of 4000K. To calculate the corresponding S/P ratio for this CCT, the following equation is used.

$$CCT = 4000K$$

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT)^2 + 0.001(CCT) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = -7 * 10^{-8}(4000)^2 + 0.001(4000) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = 1.56$$

The photopic luminance was calculated in the lighting simulation model. For each individual calculation point, a luminance effectiveness multiplier was calculated. The table below shows the photopic luminance values of all of the calculation points (cd/m²).

Photopic Luminance (cd/m ²)									
0.34	0.39	0.48	0.58	0.61	0.58	0.58	0.48	0.43	0.40
0.50	0.64	0.66	0.75	0.71	0.70	0.78	0.62	0.66	0.59

To calculate the luminance effectiveness multiplier, use CIE 191:2010. Each calculation point is required to go through the process individually. The process to do a single calculation point (0.5 cd/m²) is as follows:

Since the photopic luminance value of 0.5 cd/m² is located within Table 3, but the S/P ratio of 1.56 is not listed, a single interpolation is required to determine the luminance effectiveness multiplier for this particular point.

S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Equation for single linear interpolation: $y = y_0 + (x - x_0) * \frac{y_1 - y_0}{x_1 - x_0}$

Linear interpolation: $y = 7\% + (1.56 - 1.45) * \frac{10\% - 7\%}{1.65 - 1.45} = 8.7\%$

Since the S/P ratio is greater than 1, the adjustment is positive. This means that the effective luminance will increase.

The photopic luminance can only be adjusted using this factor. The calculation is:
 Mesopic luminance = (1 + white light effectiveness adjustment (%)) * photopic luminance

$$\text{Mesopic luminance} = (1 + 0.087) * 0.5 \text{ cd/m}^2$$

$$\text{Mesopic Luminance for this single value} = 0.54 \text{ cd/m}^2$$

Following this same procedure for all of the calculation points yields a calculation grid with the following mesopic luminance values (cd/m²).

Mesopic Luminance (cd/m ²)									
0.38	0.43	0.52	0.63	0.66	0.63	0.63	0.52	0.47	0.44
0.54	0.69	0.71	0.80	0.76	0.75	0.83	0.67	0.71	0.64

The following table summarizes the results of these calculations. Since the mesopic luminance meets the IESNA RP-8-05 criteria, the lighting design for this street is a viable solution. Use the photopic values for L_{vmax}/L_{avg} to determine if the design meets criteria.

	L _{avg}	L _{avg} /L _{min}	L _{max} /L _{min}	L _{vmax} /L _{avg}
Criteria	0.6	6.0	10.0	0.4
Photopic	0.57	1.68	2.29	0.4
Mesopic	0.62	1.64	2.2	-

The intersection lighting design criteria is based on illuminance. Because of this, luminance effectiveness multipliers cannot be applied. The calculated illuminance value is 2.6 fc. Since this exceeds the illuminance criteria of 2.1 fc for this particular intersection, the luminaire wattage and arrangement is a viable solution.

Appendix D: Collector Street Example

This typical street has two lanes with parking on each side of the street (60 feet curb to curb), a low pedestrian conflict, a five foot median and intersects with another collector street.

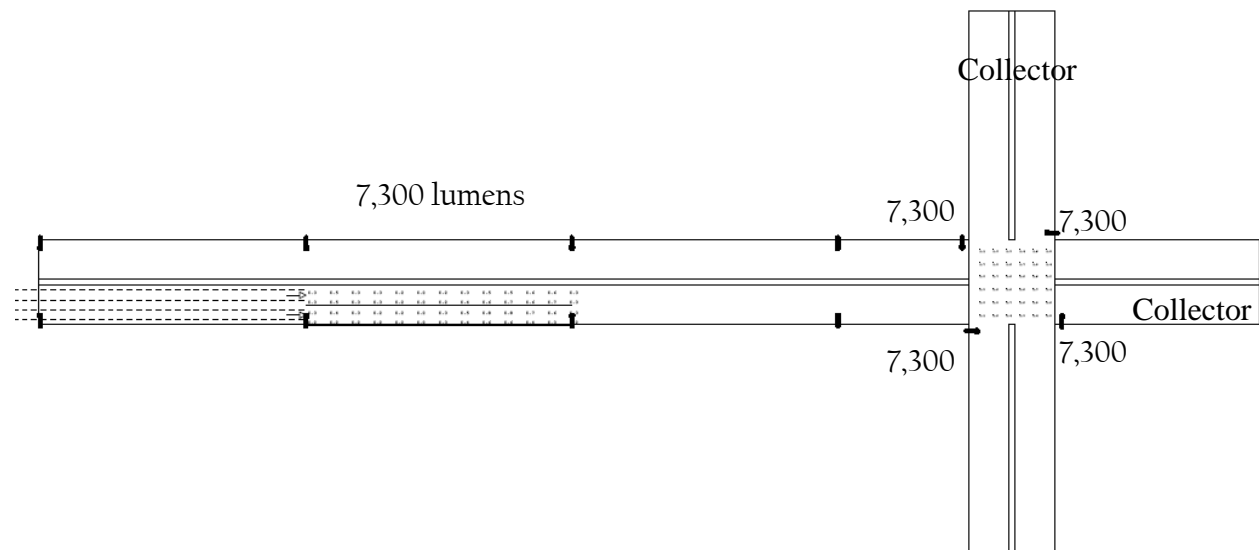
Criteria Per RP-8-05

Continuous Lighting on Straight Street				
	L_{avg}	L_{avg}/L_{min}	L_{max}/L_{min}	L_{vmax}/L_{avg}
Collector – Low Ped.	0.4	4.0	8.0	0.4

Intersection		
	E_{avg}	E_{avg}/E_{min}
Collector/Collector – Low Ped	1.2	4.0

The lighting model is shown below. From Table 4, the target luminance criteria is 0.36 cd/m^2 . The selected lumen package for the continuous lighted, straight street is a 7,300 initial lumen package. In order to achieve the luminance values required for a collector street with low pedestrian conflict, an opposite arrangement was used with a spacing of 200'.

Because the collector street intersects with another collector street and the pedestrian conflict is low, LED luminaires with a 7,300 initial lumen package were used at each of the corners of the intersection.



Luminance Effectiveness Multipliers

The LED luminaire with 7,300 initial lumens selected for the continuous, straight portion of this street has a correlated color temperature (CCT) of 4000K. To calculate the corresponding S/P ratio for this CCT, the following equation is used.

$$CCT = 4000K$$

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT)^2 + 0.001(CCT) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = -7 * 10^{-8}(4000)^2 + 0.001(4000) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = 1.56$$

The photopic luminance was calculated in the lighting simulation model. For each individual calculation point, a luminance effectiveness multiplier needs to be calculated. The table below shows the photopic luminance values of all of the calculation points (cd/m²).

Photopic Luminance (cd/m ²)												
0.28	0.48	0.35	0.27	0.23	0.18	0.19	0.31	0.50	0.54	0.55	0.60	0.29
0.28	0.47	0.31	0.26	0.22	0.20	0.24	0.38	0.57	0.68	0.61	0.7	0.29
0.26	0.36	0.27	0.24	0.22	0.23	0.32	0.51	0.76	0.84	0.72	0.59	0.27
0.19	0.18	0.16	0.19	0.17	0.19	0.26	0.41	0.59	0.64	0.39	0.27	0.19

To calculate the luminance effectiveness multiplier, use CIE 191:2010. Each calculation point is required to go through the process individually. The process to do a single calculation point (0.19 cd/m²) is as follows.

Since the photopic luminance value of 0.19 cd/m² is not located within Table 3, nor is the S/P ratio of 1.56, a double interpolation is required to determine the luminance effectiveness multiplier for this particular point.

TABLE 3 LUMINANCE EFFECTIVENESS MULTIPLIER (%) (CIE 191:2010 Table II)										
S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Equation for single linear interpolation: $y = y_0 + (x - x_0) * \frac{y_1 - y_0}{x_1 - x_0}$

Single interpolation with an S/P ratio of 1.56 and a photopic luminance value of 0.1:

$$y = 15\% + (1.56 - 1.45) * \frac{21\% - 15\%}{1.65 - 1.45} = 18.3\%$$

Single interpolation with an S/P ratio of 1.56 and a photopic luminance value of 0.3:

$$y = 9\% + (1.56 - 1.45) * \frac{13\% - 9\%}{1.65 - 1.45} = 11.2\%$$

S/P Ratio	0.1 cd/m ²	0.3 cd/m ²
1.56	18.3%	11.2%

Interpolation between luminance values of 0.1 and 0.3 and an S/P ratio of 1.56:

$$y = 18.3\% + (0.19 - 0.1) * \frac{11.2\% - 18.3\%}{0.3 - 0.1} = 15.1\%$$

Since the S/P ratio is greater than 1, the adjustment is positive. This means that the effective luminance will increase.

The photopic luminance can only be adjusted using this multiplier. The calculation is:

$$\text{Mesopic luminance} = (1 + \text{white light effectiveness adjustment (\%)}) * \text{photopic luminance}$$

$$\text{Mesopic luminance} = (1 + 0.151) * 0.19 \text{ cd/m}^2$$

Mesopic Luminance for this single value= 0.22 cd/m²

Following this same procedure for all of the calculation points yields a calculation grid with the following mesopic luminance values (cd/m²).

Mesopic Luminance (cd/m ²)												
0.31	0.52	0.39	0.30	0.26	0.21	0.22	0.34	0.54	0.58	0.59	0.65	0.32
0.31	0.51	0.34	0.29	0.25	0.23	0.27	0.42	0.62	0.73	0.66	0.75	0.32
0.29	0.40	0.30	0.27	0.25	0.26	0.35	0.55	0.81	0.89	0.77	0.64	0.30
0.22	0.21	0.18	0.22	0.19	0.22	0.29	0.45	0.64	0.69	0.43	0.30	0.22

The following table summarizes the results of these calculations. Since the mesopic luminance meets the IESNA RP-8-05 criteria, the lighting design for this street is a viable solution. Use the photopic values for L_{vmax}/L_{avg} to determine if the design meets criteria.

	L _{avg}	L _{avg} /L _{min}	L _{max} /L _{min}	L _{vmax} /L _{avg}
Criteria	0.4	4.0	8.0	0.4
Photopic	0.37	2.3	5.3	0.3
Mesopic	0.41	2.2	4.9	-

The intersection lighting design criteria is based on illuminance. Because of this, luminance effectiveness multipliers cannot be applied. The calculated illuminance value is 1.5 fc. Since this

exceeds the illuminance criteria of 1.2 fc for this particular intersection, the luminaire wattage and arrangement is a viable solution.

Appendix E: Major Street Example

This typical street has three lanes with parking on each side of the street (95 feet curb to curb), a medium pedestrian conflict, a 14 foot median and intersects with a collector street.

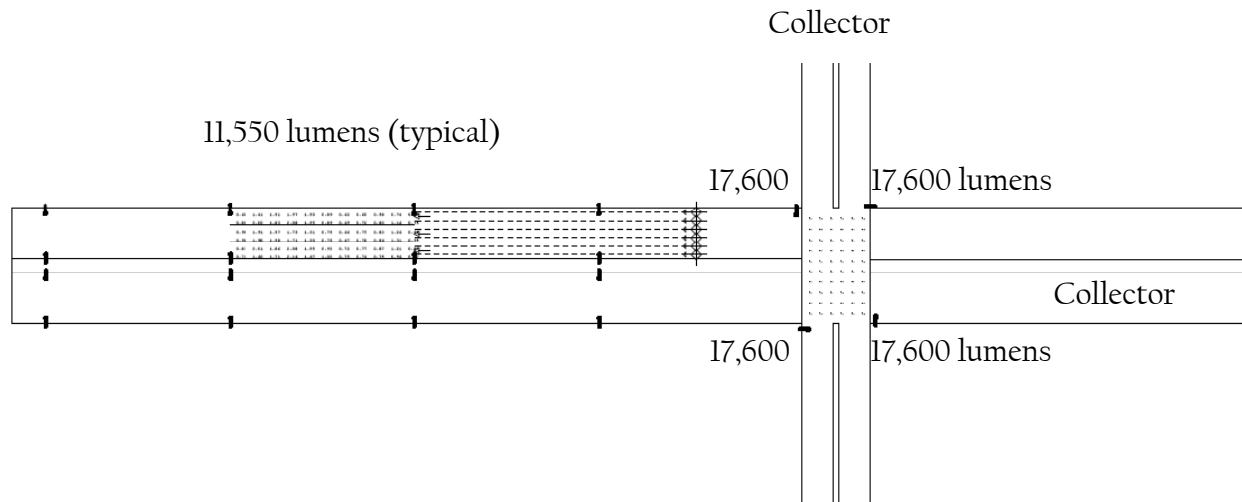
Criteria Per RP-8-05

Continuous Lighting on Straight Street				
	L_{avg}	L_{avg}/L_{min}	L_{max}/L_{min}	L_{vmax}/L_{avg}
Major – Medium Ped.	0.9	3.0	5.0	0.3

Intersection		
	E_{avg}	E_{avg}/E_{min}
Major/Collector – Medium Ped.	2.2	3.0

The lighting model is shown below. From Table 4, the target luminance criteria is 0.84 cd/m². The selected lumen package for the continuous lighted, straight street is a 11,550 initial lumen package. In order to achieve the luminance values required for a major street with medium pedestrian conflict, an opposite arrangement (both curb and median mounted) was used with a spacing of 175’.

Because the major street intersects with a collector street and the pedestrian conflict is medium, LED luminaires with a 17,600 initial lumen package were used at each of the corners of the intersection.



Luminance Effectiveness Multipliers

The LED luminaire with 11,550 initial lumens selected for the continuous, straight portion of this street has a correlated color temperature (CCT) of 4000K. To calculate the corresponding S/P ratio for this CCT, the following equation is used.

$$CCT = 4000K$$

$$S/P \text{ Ratio} = -7 * 10^{-8}(CCT)^2 + 0.001(CCT) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = -7 * 10^{-8}(4000)^2 + 0.001(4000) - 1.3152$$

$$S/P \text{ Ratio}_{4000K} = 1.56$$

The photopic luminance was calculated in the lighting simulation model. For each individual calculation point, a luminance effectiveness multiplier needs to be calculated. The table below shows the photopic luminance values of all of the calculation points (cd/m²).

Photopic Luminance (cd/m ²)										
0.60	1.41	1.51	1.98	1.50	0.89	0.62	0.60	0.58	0.74	0.55
0.80	2.00	1.83	2.08	1.55	0.89	0.69	0.72	0.80	1.16	0.75
0.98	1.91	1.57	1.73	1.31	0.75	0.66	0.75	0.83	1.26	0.94
0.98	1.90	1.58	1.71	1.30	0.75	0.67	0.78	0.86	1.31	0.95
0.83	2.01	1.86	2.08	1.55	0.92	0.72	0.77	0.87	1.21	0.8
0.72	1.60	1.71	2.16	1.67	1.02	0.75	0.74	0.75	0.96	0.67

To calculate the luminance effectiveness multiplier, use CIE 191:2010. Each calculation point is required to go through the process individually. The process to do a single calculation point (2.00 cd/m²) is as follows.

Since the photopic luminance value of 2.00 cd/m² is located within Table 3, but the S/P ratio of 1.56 is not, a single interpolation is required to determine the luminance effectiveness multiplier for this particular point.

S/P	Photopic Luminance (cd/m ²)									
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5
0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

Equation for single linear interpolation: $y = y_0 + (x - x_0) * \frac{y_1 - y_0}{x_1 - x_0}$

$$y = 3\% + (1.56 - 1.45) * \frac{4\% - 3\%}{1.65 - 1.45} = 3.6\%$$

Since the S/P ratio is greater than 1, the adjustment is positive. This means that the effective luminance will increase.

The photopic luminance can only be adjusted using this multiplier. The calculation is:

$$\text{Mesopic luminance} = (1 + \text{white light effectiveness adjustment (\%)}) * \text{photopic luminance}$$

$$\text{Mesopic luminance} = (1 + 0.036) * 2.0 \text{ cd/m}^2$$

$$\text{Mesopic Luminance for this single value} = 2.07 \text{ cd/m}^2$$

Following this same procedure for all of the calculation points yields a calculation grid with the following mesopic luminance values (cd/m²).

Mesopic Luminance (cd/m ²)										
0.66	1.48	1.58	2.05	1.57	0.96	0.68	0.66	0.64	0.80	0.61
0.86	2.07	1.90	2.14	1.62	0.96	0.75	0.78	0.86	1.23	0.81
1.05	1.98	1.64	1.80	1.38	0.81	0.72	0.81	0.90	1.33	1.01
1.05	1.97	1.65	1.78	1.37	0.81	0.73	0.84	0.93	1.38	1.02
0.90	2.08	1.93	2.14	1.62	0.99	0.78	0.83	0.94	1.28	0.86
0.78	1.67	1.78	2.22	1.74	1.09	0.81	0.80	0.81	1.03	0.73

The following table summarizes the results of these calculations. Since the mesopic luminance meets the IESNA RP-8-05 criteria, the lighting design for this street is a viable solution. Use the photopic values for L_{vmax}/L_{avg} to determine if the design meets criteria.

	L _{avg}	L _{avg} /L _{min}	L _{max} /L _{min}	L _{vmax} /L _{avg}
Criteria	0.9	3.0	5.0	0.3
Photopic	1.15	2.1	3.9	0.26
Mesopic	1.2	2.0	3.7	-

The intersection lighting design criteria is based on illuminance. Because of this, luminance effectiveness multipliers cannot be applied. The calculated illuminance value is 2.35 fc. Since this exceeds the illuminance criteria of 2.2 fc for this particular intersection, the luminaire wattage and arrangement is a viable solution.

IV. Adaptive Street Lighting Design Guide

Purpose

Roadway lighting is typically designed for peak traffic conditions that may exist on a given stretch of street. These conditions include traffic volume, the presence of pedestrians, ambient luminance, and similar conditions. Advances in lighting control technology now allow public agencies to modify luminaire light output to match the environmental conditions likely present at a particular time. This is called adaptive lighting. Adaptive lighting not only reduces energy consumption of the street lighting system, but also prevents over-lighting, reduces glare, and minimizes light pollution.

The purpose of this section of the *Public Streetlight Guide* is to provide guidance on how the City may lower light levels of City-owned public streetlights and to what extent based upon static and conditional parameters. The City's adaptive lighting criteria are drawn from the current version of the Illuminating Engineering Society of North America's (IESNA) *American National Standard Practice for Roadway Lighting* (RP-8-05).

Adaptive Lighting Design Luminance Criteria

Adaptive lighting can be applied to both new and existing streetlights. For each, the provisions that allow for a reduction in lighting are dependent on street and pedestrian classifications.

Street Classifications

The following definitions were adopted by the City of San José and describe each type of street classification. They are comparable to those used by the Illuminating Engineering Society of North America's (IESNA) RP-8-05 ,

Major:

A facility which accommodates major movements of traffic not served by expressways or freeways which connect areas of principal traffic generation and important rural roadways leaving the city. Major streets are designed mainly for the movement of through traffic, which may include light rail transit, but also normally performs a secondary function of providing access to abutting properties. Even though abutting property has access to the facility, parking and loading may be restricted or prohibited to improve the capacity for moving traffic. The number of lanes depends on the volume of traffic though majors are generally planned to contain four or more travel lanes. In San José, a major street is defined as being between 80 feet and 130 feet wide. Average daily traffic volumes typically range from 7,500 to 50,000 vehicles.

Collector:

A facility which serves internal traffic movements within an area and connects this area with the major and local streets. Collectors do not handle long through trips but do provide access to abutting properties. Traffic control devices may be installed to protect or facilitate traffic on a collector street. Two or four lane streets can be accommodated

on a collector. A collector street is defined as being between 60 feet and 90 feet wide. Average daily traffic volumes typically range from 2,000 to 16,000 vehicles.

Minor:

A facility having the primary function of providing access to immediately adjacent land. Minor streets may be divided into subclasses according to the type of land served, such as residential and industrial. One lane of traffic in each direction is the standard for minor streets. A minor street is defined as being less than 60 feet wide. Average daily traffic volumes typically range from 50 to 2,000 vehicles.

The following definitions describe each type of pedestrian classification from the IESNA RP-8-05.

High:

Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are downtown retail areas, near theaters, concert halls, stadiums, and transit terminals.

Medium:

Areas where lesser numbers of pedestrians utilize the streets at night. Typical are downtown office areas, blocks with libraries, apartments, neighborhood shopping, industrial, older city areas, and streets with transit lines.

Low:

Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications but may be typified by suburban single family streets, very low density residential developments, and rural or semi-rural areas.

The above classifications do not need to depend on the adjacent land use – a designation that would not change over time. Since the pedestrian and vehicular traffic use in any given area will change over time, the definitions may be applied temporally to the current (or anticipated) conditions of the streetscape, with the expectation that the conditions will change during the night. For example, a stadium may be classified as a high conflict area during a sporting event, but after the event spectators are cleared, the same area could be classified as a low conflict area. Comparably, a retail area may be classified as high conflict in the peak hours of the evening, but the late night and early morning volume will not require the same level of conflict classification. Pedestrian counts are not necessary to determine the pedestrian classification.

One or more of the following should be considered when determining a change in conflict level:

- Changes in vehicular traffic volume (A change from high to low conflict is represented by a 90% reduction from peak traffic.)
- Typical closing hours of surrounding businesses
- Daily changes in public transportation schedules
- Changes in parking regulations

- Sampled pedestrian activity. IESNA guidelines recommend: Low – 10 or fewer per hour, Medium – 11-100 per hour, High – over 100 per hour

New Installations

The required criteria for new installation applications are based upon the selected street and pedestrian classification from IESNA RP-8-05. While there are several design criteria that IESNA RP-8-05 requires, such as average luminance, uniformity ratio (average to minimum and maximum to minimum), and veiling luminance ratio, the implementation of adaptive lighting can only modify the average luminance value.

Once the IESNA RP-8-05 design criteria are met based upon the applicable street and pedestrian classifications, (determined based upon average hourly vehicular traffic volumes and pedestrian conflicts) the average luminance value can be reduced to an adapted state. An adapted state is achieved when vehicular traffic volumes fall below 10% of peak hourly totals. The adapted low state yields an adapted luminance of 50% of the design average luminance. While most situations will change from high to low, the medium level may also be used as an intermediate state.

It should also be noted that lights should not dim quickly. Although a 50% difference in light level is not easily visible, a *sudden change* in light level is visible. Most manufacturers build in a fade rate to accommodate this issue.

Table 1 illustrates the minimum average luminance value from IESNA RP-8-05 for each street and pedestrian classification and the adapted luminance of each.

TABLE 1 NEW INSTALLATION: LUMINANCE METHOD CRITERIA (TABLE 3)*			
Selected Street Classification	Selected Pedestrian Classification	Average Luminance (cd/m ²)*	Adapted Luminance (cd/m ²) 50% Reduction
Major	High	1.2	0.6
	Medium	0.9	0.45
	Low	0.6	0.3
Collector	High	0.8	0.4
	Medium	0.6	0.3
	Low	0.4	0.2
Minor	High	0.6	0.3
	Medium	0.5	0.25
	Low	0.3	0.15

* From IESNA RP-8-05.

Existing Conditions

For existing streets, adaptive standards may also apply. Since the existing streets were designed to meet a set of design criteria that is now out of date, the average luminance that is currently present on the streets is considered to be the ‘design’ luminance. The ‘design’ luminance can

then be reduced to an adapted state during periods of reduced activity. An adapted state is achieved when vehicular traffic volumes fall below 10% of the peak hourly totals. The adapted state yields an adapted luminance of 50% of the 'design' luminance.

Appendix A: Concept of Adaptive Lighting

Both the IESNA and the International Commission on Illumination's (CIE) *Lighting of Roads for Motor and Pedestrian Traffic* (115:2010) provide for adaptive lighting. While the methodology of the two organizations varies, the resultant light levels are similar. The IESNA provides a more conservative approach than the CIE on the degree to which it recommends lights be dimmed and therefore is recommended for the City of San José. The maximum dimming level using RP-8-05 is 50 percent compared to 62 percent using the CIE's 115. The values in Table 1 represent IESNA's methodology. Given that IESNA has not adopted an explicit adaptive lighting design guide, CIE's adaptive lighting methodology is provided as supporting documentation.

IESNA RP-8-05

IESNA allows for adaptive lighting and varying luminance criteria for streets based on the level of pedestrian conflict. The IESNA states that the level of pedestrian conflict is closely related to the abutting land use and defines three levels of conflict: high, medium, and low. When lighting criteria is selected, the worst case of pedestrian conflict is chosen to adequately light the roadway. However, this level is also time dependant and may be high at one point in the night and low at another. RP-8-05 describes all of the pedestrian conflict levels and implies the use of adaptive standards.

CIE 115:2010

CIE takes a more detailed approach by defining all of the parameters that contribute to the need for lighting on a street. These include: speed, traffic volume, traffic composition, presence of medians, intersection density, presence of parked vehicles, ambient luminance, and visual guidance. This approach allows for a more detailed tailoring of the lighting criteria to individual stretches of street. It also recognizes that some of these parameters are static (speed, median, intersection density) and some are conditional (traffic volume, traffic composition). How these conditional parameters vary between peak use of the road and a reduced level of activity define the required luminance criteria for each time period.

Appendix B: Determining the Adaptive Lighting Criteria

To arrive at the adaptive standards, the data from the City of San José Advanced Streetlighting Technologies Assessment Project was evaluated as well as the IESNA and CIE methods. The following three sections describe how each supports this adaptive lighting standard.

Advanced Streetlighting Technologies Assessment Project

The City of San José conducted an assessment of several different energy-efficient, broad spectrum ('white light') streetlight technologies including light emitting diodes (LED) and induction, to determine which types and attributes of those technologies might provide the greatest energy savings while preserving, if not increasing visibility and minimizing light pollution.

The studies indicate that detection distances under broad spectrum technologies are on par or exceed detection distances under existing LPS or HPS technologies. In general, most of the broad spectrum lighting technologies did not have a substantial decrease in detection distance when either the power or the output of the luminaire was reduced by approximately 50%.

The subjective survey results show that participants favor broad spectrum sources over the currently installed HPS and LPS sources. The survey also found that even with a reduction in light level, participants felt that the broad spectrum technologies still provided enough illumination on the street.

IESNA

Table 2 defines the IESNA luminance criteria for streets based on the road classification and the level of pedestrian conflict. For each of the street types, criteria are given for high, medium, and low levels of pedestrian activity. The IESNA descriptions of pedestrian conflict are:

High:

Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are down- town retail areas, near theaters, concert halls, stadiums, and transit terminals.

Medium:

Areas where lesser numbers of pedestrians utilize the streets at night. Typical are downtown office areas, blocks with libraries, apartments, neighborhood shopping, industrial, parks, and streets with transit lines.

Local:

Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications but may be typified by suburban single family streets, very low density residential developments, and rural or semi-rural areas.

TABLE 2 LUMINANCE CRITERIA (TABLE 3)*

STREET ND AREA CLASSIFICATION		AVG. LUMIN. $L_{avg}(cd/m^2)$	MAX UNIFORM. RATIO L_{avg}/L_{min}	MAX UNIFORM. RATIO L_{max}/L_{min}	MAX VEILING LUMIN. RATIO L_{vmax}/L_{avg}
STREET	PEDESTRIAN ACTIVITY CLASSIFICATION				
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

*From IESNA RP-8-05

Roadway lighting is typically designed for the highest level of pedestrian activity that will ever occur on the road. However, if this level changes and the lighting system is capable of changing as well, the system can be set to provide the most appropriate lighting for a particular time of night. Note that for each roadway type, the luminance value drops by 50% from a high to low level of pedestrian activity.

The uniformity requirements do not change in proportion to the changes in luminance. In some cases, the uniformity criteria stay the same with a change in pedestrian conflict level. However, for adaptive lighting, only the luminance levels can change on a roadway. Because the pole spacing and mounting height are fixed, uniformity remains unchanged.

CIE

The CIE tables on the following pages are for illustration only and should not be used to dim street lighting levels. For purposes of this example, the CIE method has been adapted and modified to typical traffic conditions found in the City of San José (traffic volumes, intersection densities, and similar conditions). To show the range of luminance criteria allowed within the CIE system, two scenarios were outlined – a peak and a reduced light condition. For a roadway, these scenarios are characterized by the following eight parameters: speed, traffic volume, traffic composition, separation of roadway, intersection density, allowance of curb parking, ambient luminance, and visual guidance/traffic control. The roadway ‘M-Value’ is determined from these parameters.

After calculating the M-Value, criteria can be determined for the Luminance Method. The luminance method is used internationally as the primary method for lighting major traffic routes and primary streets. This design method determines how 'bright' the roadway is by determining the amount of light reflected from the pavement in the direction of the driver.

To determine the lighting criteria for a particular application, Table 3 is used with an appropriate weighting factor applied to each parameter. To illustrate a typical range of factors, the following example calculates the M-Value using Table 3. Within this table, appropriate weighting factors under each static and conditional parameter were selected to represent a change in nighttime conditions from peak activity to a reduced level. This Sum of Weighting Factors (V_{ws}) represents the highest and lowest activity levels that the roadway will experience. The exact M-Value is then calculated as:

$$M_{Value} = 6 - V_{ws}$$

Example:

To illustrate a representative change in luminance level for the City of San José streets, we changed only two of the conditional parameters: traffic volume and traffic composition. The values selected for each weighting factor are shown in red in Table 3. Where the weighting factor resulted in a decimal, the value was rounded from 1.5 to 2 for a more conservative estimate. These selections result in the following M-values for each condition:

$$M_{Value_{PEAK}} = 6 - 5 = 1$$

$$M_{Value_{REDUCED}} = 6 - 2 = 4$$

Table 4 shows the maintained average luminance criteria, allowing for lamp lumen depreciation and dirt depreciation, for a given M-value. With the M-values determined for this example, the luminance criteria ranges from an average of: 2.0 cd/m² to 0.75 cd/m². In this example, the luminance level can be reduced by more than 50% when the traffic volume and composition change.

Note that extreme cases, where all negative or all positive weighting factors are selected, may sum to a value greater than 6 or less than 1. The equation and tables are calibrated to accommodate most changes in driving conditions. For any case where the M value exceeds those given in Table 4, use the appropriate lowest (or highest) luminance criteria given.

TABLE 3 PARAMETERS FOR THE SELECTION OF LIGHTING FOR MOTORIZED TRAFFIC[†]				
<i>Parameter</i>	<i>Options</i>	<i>Weighting Factor WF</i>	<i>WF Selected for Peak Use</i>	<i>WF Selected for Reduced Activity Use</i>
STATIC PARAMETERS				
Speed	Very High	1	0.5	0.5
	High > 35 mph design speed	0.5		
	Moderate <= 35 mph design speed	0		
Full-Width Median or Center Turn Lane	No	1	1	1
	Yes	0		
Intersection Density	High >= 2 per mile	1	1	1
	Moderate < 2 per mile	0		
Visual Guidance / Traffic Control*	Poor (Guidance Features: 0; Hazards: 7+)	0.5	0	0
	Good (Guidance features: 1; Hazards: 4 – 6)	0		
CONDITIONAL PARAMETERS				
Traffic Volume**	Very high (> 100001 vehicles/day)	1	0.5	-1
	High (60001 – 100000 vehicles/day)	0.5		
	Moderate (30001 – 60000 vehicles/day)	0		
	Low (10001 – 30000 vehicles/day)	-0.5		
	Very low (< 10000 vehicles/day)	-1		
Traffic Composition	Mixed with high percentage of non-motorized (non-motorized traffic > 10%)	2	2	0
	Mixed (non-motorized < 10%)	1		
	Motorized only	0		
Curb Parking Allowed	Present	0.5	0	0
	Not present	0		
Ambient Luminance	High (Urban)***	1	0	0
	Moderate (Urban Residential)***	0		
	Low (Suburban and Rural)***	-1		
Sum of Weighting Factors			5	1.5****

[†] From Table 1 in CIE 115:2010

* Guidance Features: curbs/stripping, retro reflectors/guardrails

Hazards: merging lanes, driveways, curves, high intersection density, weaving, no center left, parking, poor signage, advertising, school zones, no signalization

** Values based on review of City of San José average daily traffic volumes.

*** Descriptions based on City of San José City, City Council Policy – Outdoor Lighting on Private Developments, revised 2000.

**** V_{ws} that result in a decimal should be rounded up to the nearest whole number, representing a conservative change in driving conditions.

TABLE 4 LUMINANCE CRITERIA BY M CLASS						
M Value	M1	M2	M3	M4	M5	M6
Average Luminance (cd/m ²)	2.0	1.5	1.0	0.75	0.5	0.3