

# Demonstration Assessment of Light Emitting Diode (LED) Street Lighting, Phase III Continuation

***Host Site: City of Oakland, California***

**Final Report prepared in support of the  
U.S. DOE Solid-State Lighting  
Technology Demonstration Gateway Program  
and PG&E Emerging Technologies Program**

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U.S. Department of Energy  
Pacific Gas & Electric  
City of Oakland, California  
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November 2008

Prepared for the U.S. Department of Energy and  
Pacific Gas & Electric by Energy Solutions



***Pacific Gas and  
Electric Company®***





# Pacific Gas and Electric Company

## Emerging Technologies Program

### Application Assessment Report #0726

#### LED Street Lighting, Phase III Continuation Oakland, CA

Issued: November 2008

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# Preface

Energy Solutions provided monitoring, data collection, and data analysis services for an LED Street Lighting Assessment project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company. In the previous phases of this project, high-pressure sodium luminaires in an Oakland, CA neighborhood were replaced with new “The Edge” LED luminaires from Beta LED/ Ruud Lighting. In this phase (Phase III), four of the existing LED luminaires were replaced with lower-wattage “LEDway” LED luminaires from Beta LED/ Ruud Lighting for analysis. For further details relating to previous phases of this project, please refer to the Phase II final report.

The complete Phase II report is available at the following websites:

<http://www.etcc-ca.com>

<http://www.netl.doe.gov/ssl/techdemos-results.html>

# Acknowledgements

This project was funded by the Emerging Technologies Program of Pacific Gas and Electric Company. Energy Solutions would like to gratefully acknowledge the direction and assistance of Pacific Gas and Electric Company, the City of Oakland, Pacific Northwest National Laboratory (representing the United States Department of Energy), and Ruud Lighting for their participation and support of this project.

## Executive Summary

This report summarizes the third phase of an LED street lighting assessment project conducted to study the applicability of LED luminaires in a street lighting application. In Phase I of the project, pre- and post-installation measurements were taken to assess impacts from the installation of the LED luminaires in a parking lot owned by the City of Oakland. With no significant concerns identified, the project progressed to Phase II, in which fifteen 78-watt LED luminaires replaced a like number of 121-watt high-pressure sodium (HPS) luminaires (nominal 100-watt) on Sextus and Tunis roads between Empire Rd and Coral Rd in a residential area of Oakland.

The complete Phase II report is available at the following web sites:

<http://www.etcc-ca.com>

<http://www.netl.doe.gov/ssl/techdemos-results.html>

In Phase III, the luminaires on one of the Phase II streets were replaced with next generation LED luminaires (58 watts) from the same manufacturer. A total of 4 of the LED luminaires installed in Phase II were replaced. The same suite of lighting performance, electrical power measurements, and economic analyses performed in Phase II were performed for the Phase III LED luminaires. For details relating to project background, scope, and technical methodology, as well as previous results, please refer to the Phase II final report.

Measured electrical results from Phase II and III are tabulated in Table ES-1 below. The metered LED luminaire drew an average of 58.3 watts; significantly less than both the base case HPS luminaire and the previous LED luminaire (Phase II). With an estimated 4,100 annual hours of operation, annual electrical savings are estimated to be approximately 257 kWh per HPS luminaire replaced with Phase III LED luminaire.

**Table ES-I: Potential Demand and Energy Savings**

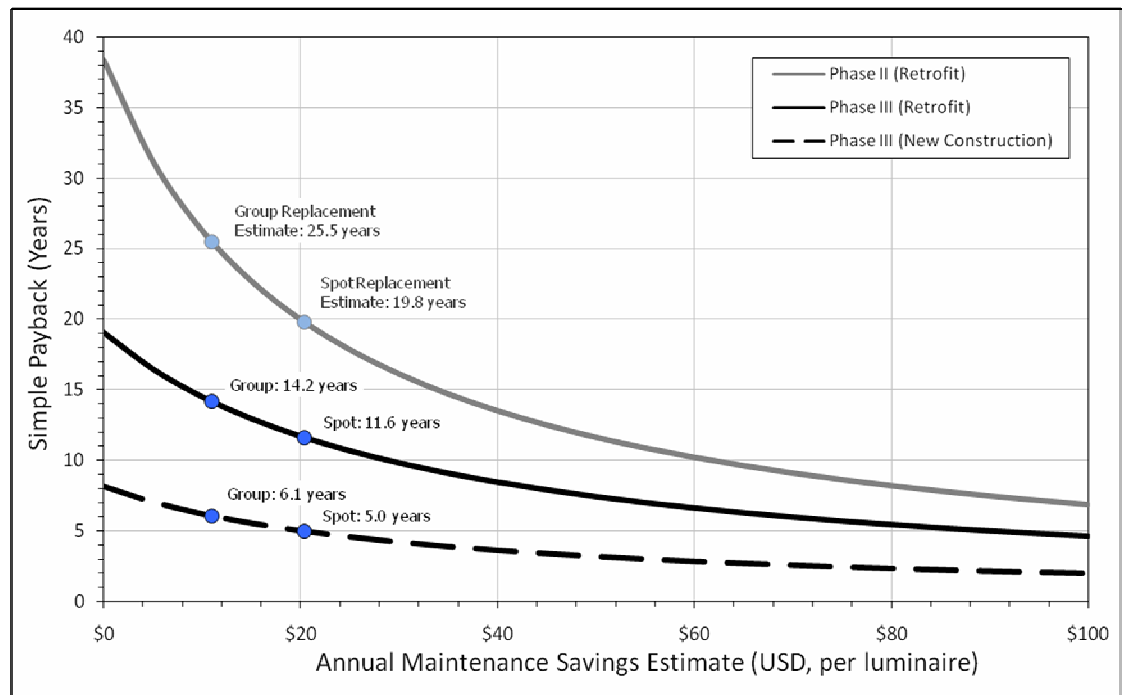
| <b>Luminaire Type</b>                 | <b>Average Power (W)</b> | <b>Power Savings (W)</b> | <b>Annual Energy Savings (kWh)</b> |
|---------------------------------------|--------------------------|--------------------------|------------------------------------|
| <b>High-Pressure Sodium Luminaire</b> | 121.0                    | -                        | -                                  |
| <b>Phase II LED Luminaire</b>         | 77.7                     | 43.3 (36%)               | 178                                |
| <b>Phase III LED Luminaire</b>        | 58.3                     | 62.7 (52%)               | 257                                |

Lighting results show that the lower - wattage Phase III luminaires provided illumination roughly equivalent to the Phase II LED luminaires, and were sufficient to meet the City of Oakland's requirements in all but the largest pole spacing. The Phase III luminaires performed similarly to the Phase II LED luminaires in terms of minimum illuminance and maximum-to-minimum uniformity ratios, with slightly lower average illuminance levels and therefore slightly better average-to-minimum uniformity ratios. Measured illuminance levels under the HPS luminaires and the LED luminaires from Phase II and III are shown in Table ES-II below.

Table ES-II: Photopic Illuminance Levels

|                                | Average<br>Illuminance (fc) | Maximum<br>Illuminance (fc) | Minimum<br>Illuminance (fc) | Avg. to Min.<br>Uniformity<br>Ratio | Max. to Min.<br>Uniformity<br>Ratio |
|--------------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------------|-------------------------------------|
| <b>110' Spacing</b>            |                             |                             |                             |                                     |                                     |
| <i>HPS Luminaire</i>           | 1.00                        | 3.53                        | 0.19                        | 5.4:1                               | 19.0:1                              |
| <i>Phase II LED Luminaire</i>  | 0.58                        | 1.21                        | 0.19                        | 3.1:1                               | 6.5:1                               |
| <i>Phase III LED Luminaire</i> | 0.50                        | 1.21                        | 0.19                        | 2.7:1                               | 6.5:1                               |
| <b>120' Spacing</b>            |                             |                             |                             |                                     |                                     |
| <i>HPS Luminaire</i>           | 0.80                        | 3.72                        | 0.09                        | 8.7:1                               | 40.0:1                              |
| <i>Phase II LED Luminaire</i>  | 0.53                        | 1.49                        | 0.09                        | 5.7:1                               | 16.0:1                              |
| <i>Phase III LED Luminaire</i> | 0.48                        | 1.30                        | 0.09                        | 5.2:1                               | 14.0:1                              |
| <b>165' Spacing</b>            |                             |                             |                             |                                     |                                     |
| <i>HPS Luminaire</i>           | 0.47                        | 2.79                        | 0                           | >10.2:1                             | >60.0:1                             |
| <i>Phase II LED Luminaire</i>  | 0.35                        | 1.21                        | 0                           | >7.5:1                              | >26.0:1                             |
| <i>Phase III LED Luminaire</i> | 0.32                        | 1.11                        | 0                           | >6.8:1                              | >24.0:1                             |

The simple payback periods in this particular case study ranged from 5 years in a new construction scenario with \$20 annual Spot Replacement maintenance savings per luminaire, to 14 years in a retrofit scenario with \$11 annual Group Replacement maintenance savings. This compared with identically calculated simple paybacks of 12 years (new construction with \$20 annual Spot Replacement maintenance savings per luminaire, not shown below) to 25 years (retrofit with \$11 annual Group Replacement maintenance savings) in Phase II. This decrease is the result of reduced energy consumption by the Phase III luminaires leading to greater savings, and reduced luminaire costs resulting in lower initial investments. The full range of simple paybacks for considered economic scenarios, with a maintenance savings range of \$0 to \$100, is shown in Figure ES-1: Simple Payback Period for Various Maintenance Scenarios below. The specific points noted in this figure represent estimated maintenance savings values for the City of Oakland. The detailed economic analysis is provided in the Economic Performance Section.



**Figure ES-1: Simple Payback Period for Various Maintenance Scenarios**

This study, when compared with the Phase II study completed a year ago, provides an impressive example of increasing LED luminaire performance over time. This increasing performance results in greater potential for energy savings, as well as greater potential for economic savings. These economic savings are further increased by decreasing luminaire costs also demonstrated in this study. As the performance continues to increase and the costs continue to decrease, the commercial viability of these luminaires will similarly continue to improve. This will provide early adopters with further impetus to invest in the emerging technology, and has the potential to cause significant reductions in energy use in the future. We believe customers with significant street lighting costs should be encouraged by the results of this demonstration and raise the priority of examining possible changes to their street light operations.

Progress in 12 Months – Phase III Results as compared to Phase II:

- Energy savings increased by 26% (LED luminaire wattage dropped from 78W to 58W)
- Luminaire cost decreased by 34% (From \$610 to \$400)
- Lighting performance maintained

## Demonstration Results

This section summarizes the results of Phase III of this assessment project. For details relating to project background, scope, and technical methodology, as well as previous results, please refer to the Phase II final report available at the following web sites:

<http://www.etcc-ca.com>

<http://www.netl.doe.gov/ssl/techdemos-results.html>

## Electrical Energy Usage and Demand

Power data for a single Phase III LED luminaire were logged using the DENT ElitePro Datalogger from 9/26/2008 to 10/10/2008. As in Phase II, this number of days metered is a product of when the data meter could be installed and removed. No significant variations in power consumption occurred during the measured period.<sup>1</sup>

Over the monitored time period, the LED luminaire in Phase III used an average of 58.3 watts while on. As a result, the estimated nightly usage for the luminaire, assuming 11 hours of operation, is 0.64 kWh.

Consolidated power data for the baseline HPS luminaire, the Phase II LED luminaire, and the Phase III LED luminaire are shown below:

**Table I: Luminaire Power Data**

| <b>Luminaire Type</b>                     | <b>Voltage<br/>(V)</b> | <b>Current<br/>(A)</b> | <b>Power<br/>(W)</b> | <b>Power<br/>Factor</b> | <b>Estimated Nightly Usage<br/>(11 hr, kWh)</b> |
|-------------------------------------------|------------------------|------------------------|----------------------|-------------------------|-------------------------------------------------|
| <b>High Pressure<br/>Sodium Luminaire</b> | 120.22                 | 1.01                   | 121.01               | 0.99                    | 1.33                                            |
| <b>Phase II LED<br/>Luminaire</b>         | 120.53                 | 0.65                   | 77.69                | 0.99                    | 0.85                                            |
| <b>Phase III LED<br/>Luminaire</b>        | 120.98                 | 0.49                   | 58.25                | 0.98                    | 0.64                                            |

## Lighting Performance

### ILLUMINANCE

#### FIELD TESTING

Photopic and scotopic illuminance measurements were taken on a 395' x 36' grid over an area containing luminaires spaced 110', 120', and 165' apart. The grid spacing was 12' north-south over the entire area, 12' east-west where the luminaire spacing was 120', and 11' east-west where the luminaire spacing was either 165' or 110'. The illuminance levels were taken at a height of 18"

<sup>1</sup> See Appendix A1.

above ground – the lowest level that could be achieved with the combination of leveling tripod and detectors. The levels were measured with a Solar Light PMA 220 meter with Photopic and Scotopic detectors and a Solar Light PMA 2100 meter cross calibrated to the PMA 220. Measurements were taken in lux, and converted to footcandles using a factor of 0.0929. Luminaire mounting heights were approximately 29’.

The average photopic and scotopic illuminance values for the luminaires were calculated for each degree of luminaire spacing and for the entire test area based on measured values. These values, as well as the maximum and minimum measured values, were used to calculate the average and maximum uniformity ratios<sup>2</sup>.

In addition to photopic and scotopic illuminance levels, mesopic illuminance levels were also calculated. These were derived using the Mesopic Optimization of Visual Efficiency (MOVE) model, and assuming a surface reflectance of 0.07 (given by IESNA RP-8-00 as the reflectance for asphalt road surfaces R2 and R3<sup>3</sup>). This assumption was used to convert between illuminance and luminance, as required by the available model. The MOVE model is a performance-based model for mesopic photometry developed at the Helsinki University of Technology. More information can be found online, at <http://www.lightinglab.fi/CIETC1-58/move.html>.

Due to the in situ nature of the monitoring, some measurement locations were obstructed. When possible, data for these locations was estimated to be the same as that from equivalent locations on the grid. These locations are denoted with italics in the data.

Consolidated illuminance values are shown below:<sup>4</sup>

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<sup>2</sup> For both the HPS and LED luminaires, the photopic and scotopic illuminance values were below the sensitivity of the illuminance meter in the middle of the 165’ spacing. Exact uniformity ratios for these spacing and over the entire test area could therefore not be calculated (calculation would require dividing by zero). Instead, the smallest possible uniformity ratios for those areas were calculated, using the minimum illuminance detectable by the meter (0.05 fc) and stating that the actual uniformity ratio must be greater than this value; i.e. if the average illuminance were 0.5 fc and the measured minimum were 0 fc, the average-to-minimum uniformity ratio would be greater than 10:1 ( $0.5 \div 0.05$ )

<sup>3</sup> Table 1 of *American National Standard Practice for Roadway Lighting*. ANSI / IESNA RP-8-00. Approved 6/27/2000

<sup>4</sup> For more details, see Appendix A2

Table II: Illuminance Values over 110' Spacing

| HPS<br>Luminaires           | Average (fc) | Max (fc) | Min (fc) | Avg. to Min.<br>Uniformity Ratio | Max. to Min.<br>Uniformity Ratio |
|-----------------------------|--------------|----------|----------|----------------------------------|----------------------------------|
| Photopic                    | 1.00         | 3.53     | 0.19     | 5.4:1                            | 19.0:1                           |
| Scotopic                    | 0.77         | 2.69     | 0.09     | 8.3:1                            | 29.0:1                           |
| Mesopic                     | 0.94         | 3.38     | 0.13     | 7.3:1                            | 26.4:1                           |
| Phase II LED<br>Luminaires  |              |          |          |                                  |                                  |
| Photopic                    | 0.58         | 1.21     | 0.19     | 3.1:1                            | 6.5:1                            |
| Scotopic                    | 1.16         | 2.32     | 0.28     | 4.2:1                            | 8.3:1                            |
| Mesopic                     | 0.76         | 1.49     | 0.23     | 3.3:1                            | 6.4:1                            |
| Phase III LED<br>Luminaires |              |          |          |                                  |                                  |
| Photopic                    | 0.50         | 1.21     | 0.19     | 2.7:1                            | 6.5:1                            |
| Scotopic                    | 1.00         | 2.51     | 0.26     | 3.8:1                            | 9.7:1                            |
| Mesopic                     | 0.59         | 1.38     | 0.21     | 2.9:1                            | 6.6:1                            |

Table III: Illuminance Values over 120' Spacing

| HPS<br>Luminaires           | Average (fc) | Max (fc) | Min (fc) | Avg. to Min.<br>Uniformity Ratio | Max. to Min.<br>Uniformity Ratio |
|-----------------------------|--------------|----------|----------|----------------------------------|----------------------------------|
| Photopic                    | 0.80         | 3.72     | 0.09     | 8.7:1                            | 40.0:1                           |
| Scotopic                    | 0.60         | 2.88     | 0.09     | 6.4:1                            | 31.0:1                           |
| Mesopic                     | 0.74         | 3.57     | 0.09     | 8.0:1                            | 38.5:1                           |
| Phase II LED<br>Luminaires  |              |          |          |                                  |                                  |
| Photopic                    | 0.53         | 1.49     | 0.09     | 5.7:1                            | 16.0:1                           |
| Scotopic                    | 1.03         | 3.07     | 0.09     | 11.1:1                           | 33.0:1                           |
| Mesopic                     | 0.68         | 1.85     | 0.09     | 7.4:1                            | 19.9:1                           |
| Phase III LED<br>Luminaires |              |          |          |                                  |                                  |
| Photopic                    | 0.48         | 1.30     | 0.09     | 5.2:1                            | 14.0:1                           |
| Scotopic                    | 0.96         | 2.60     | 0.26     | 3.7:1                            | 10.0:1                           |
| Mesopic                     | 0.57         | 1.47     | 0.15     | 3.8:1                            | 9.7:1                            |

Table IV: Illuminance Values over 165' Spacing

| <b>HPS<br/>Luminaires</b>               | <b>Average (fc)</b> | <b>Max (fc)</b> | <b>Min (fc)</b> | <b>Avg. to Min.<br/>Uniformity Ratio</b> | <b>Max. to Min.<br/>Uniformity Ratio</b> |
|-----------------------------------------|---------------------|-----------------|-----------------|------------------------------------------|------------------------------------------|
| Photopic                                | 0.47                | 2.79            | 0               | >10.2:1                                  | >60.0:1                                  |
| Scotopic                                | 0.35                | 2.14            | 0               | >7.5:1                                   | >46.0:1                                  |
| Mesopic                                 | 0.42                | 2.66            | 0               | >9.1:1                                   | >57.3:1                                  |
| <b>Phase II<br/>LED<br/>Luminaires</b>  |                     |                 |                 |                                          |                                          |
| Photopic                                | 0.35                | 1.21            | 0               | >7.5:1                                   | >26.0:1                                  |
| Scotopic                                | 0.67                | 2.32            | 0               | >14.4:1                                  | >50.0:1                                  |
| Mesopic                                 | 0.45                | 1.49            | 0               | >9.7:1                                   | >32.0:1                                  |
| <b>Phase III<br/>LED<br/>Luminaires</b> |                     |                 |                 |                                          |                                          |
| Photopic                                | 0.32                | 1.11            | 0               | >6.8:1                                   | >24.0:1                                  |
| Scotopic                                | 0.62                | 2.34            | 0               | >13.3:1                                  | >50.4:1                                  |
| Mesopic                                 | 0.38                | 1.28            | 0               | >8.2:1                                   | >27.6:1                                  |

Table V: Illuminance Values over Entire Test Area

| <b>HPS<br/>Luminaires</b>               | <b>Average (fc)</b> | <b>Max (fc)</b> | <b>Min (fc)</b> | <b>Avg. to Min.<br/>Uniformity Ratio</b> | <b>Max. to Min.<br/>Uniformity Ratio</b> |
|-----------------------------------------|---------------------|-----------------|-----------------|------------------------------------------|------------------------------------------|
| Photopic                                | 0.67                | 3.72            | 0               | >14.5:1                                  | >80.0:1                                  |
| Scotopic                                | 0.51                | 2.88            | 0               | >10.9:1                                  | >62.0:1                                  |
| Mesopic                                 | 0.62                | 3.57            | 0               | >13.3:1                                  | >77.0:1                                  |
| <b>Phase II<br/>LED<br/>Luminaires</b>  |                     |                 |                 |                                          |                                          |
| Photopic                                | 0.45                | 1.49            | 0               | >9.6:1                                   | >32.0:1                                  |
| Scotopic                                | 0.88                | 3.07            | 0               | >18.9:1                                  | >66.0:1                                  |
| Mesopic                                 | 0.59                | 1.85            | 0               | >12.6:1                                  | >39.8:1                                  |
| <b>Phase III<br/>LED<br/>Luminaires</b> |                     |                 |                 |                                          |                                          |
| Photopic                                | 0.40                | 1.30            | 0               | >8.6:1                                   | >28.0:1                                  |
| Scotopic                                | 0.90                | 3.00            | 0               | >19.4:1                                  | >64.6:1                                  |
| Mesopic                                 | 0.47                | 1.47            | 0               | >10.1:1                                  | >31.6:1                                  |

To enhance qualitative understanding of illuminance level, surface plots were generated using standard settings in Microsoft Excel. These plots are shown below:

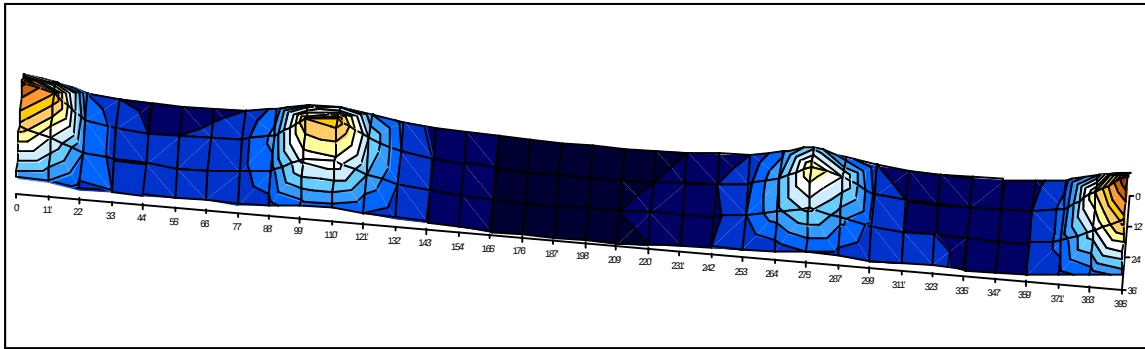


Figure 1: HPS Photopic Surface Plot

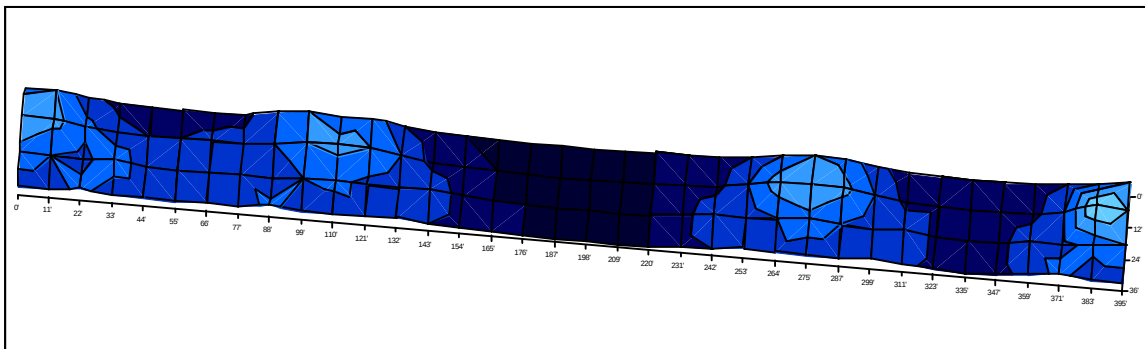


Figure 2: Phase II LED Photopic Surface Plot

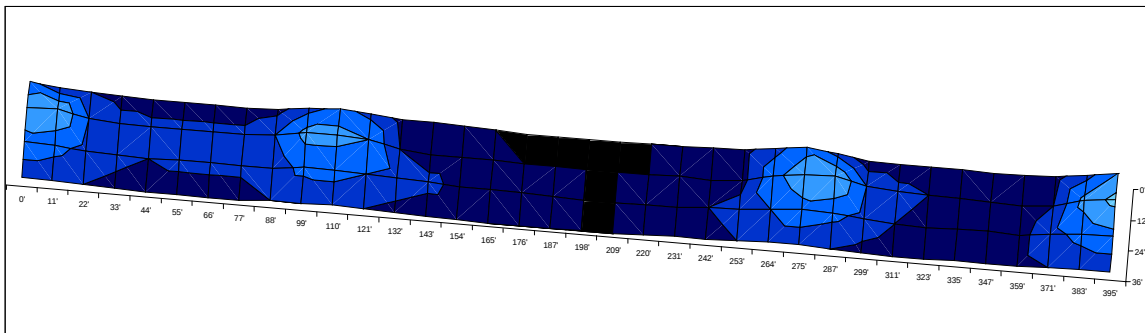


Figure 3: Phase III LED Photopic Surface Plot

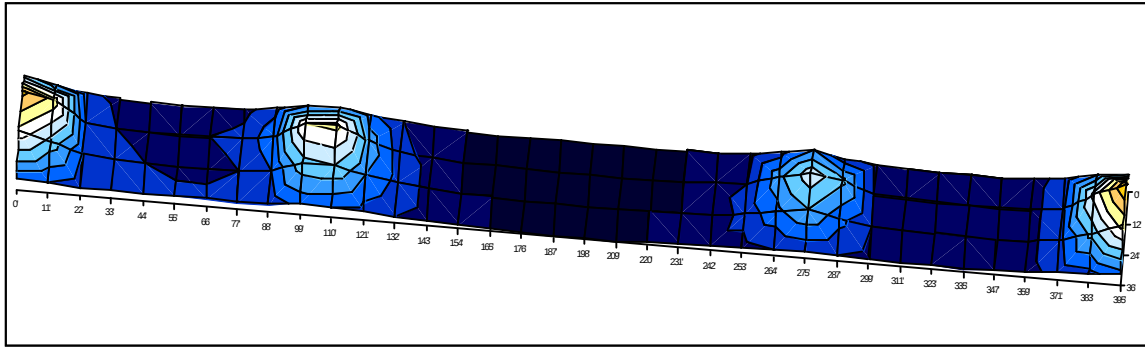


Figure 4: HPS Scotopic Surface Plot

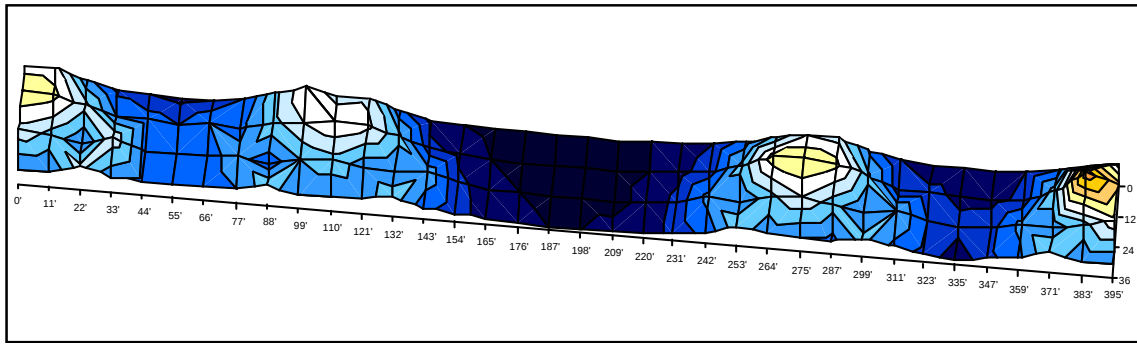


Figure 5: Phase II LED Scotopic Surface Plot

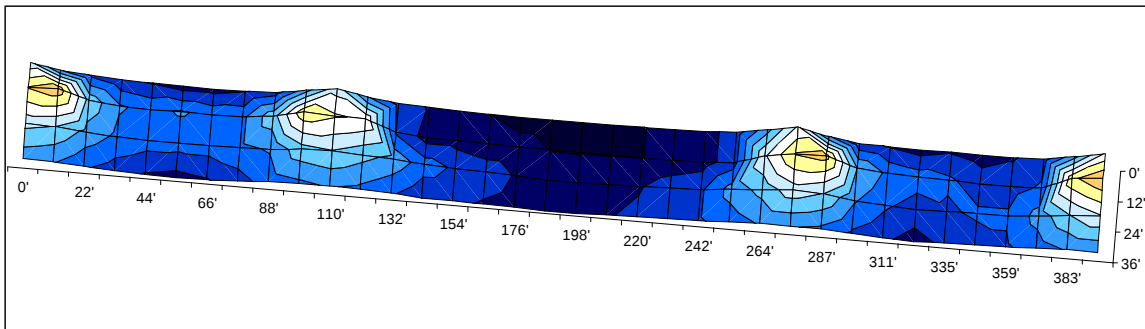


Figure 6: Phase III LED Scotopic Surface Plot

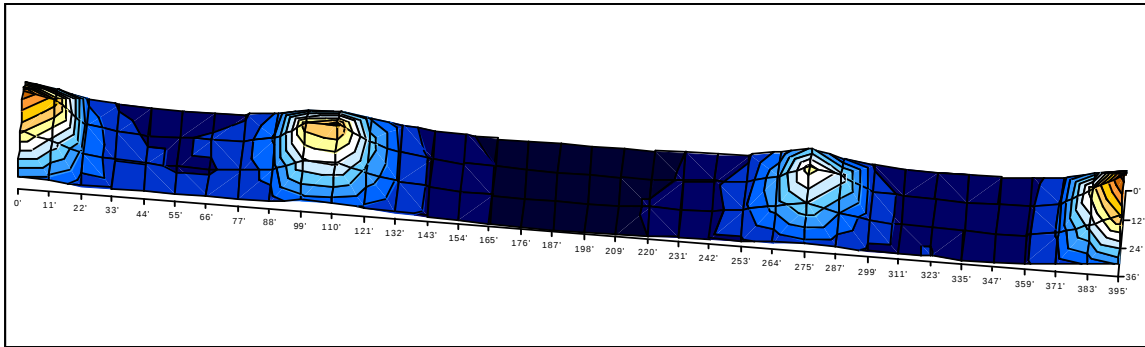


Figure 7: HPS Mesopic Surface Plot (MOVE)

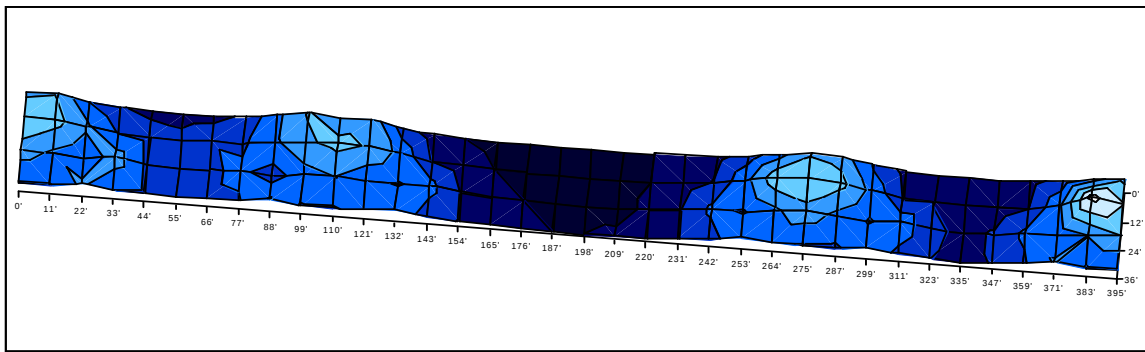


Figure 8: Phase II LED Mesopic Surface Plot (MOVE)

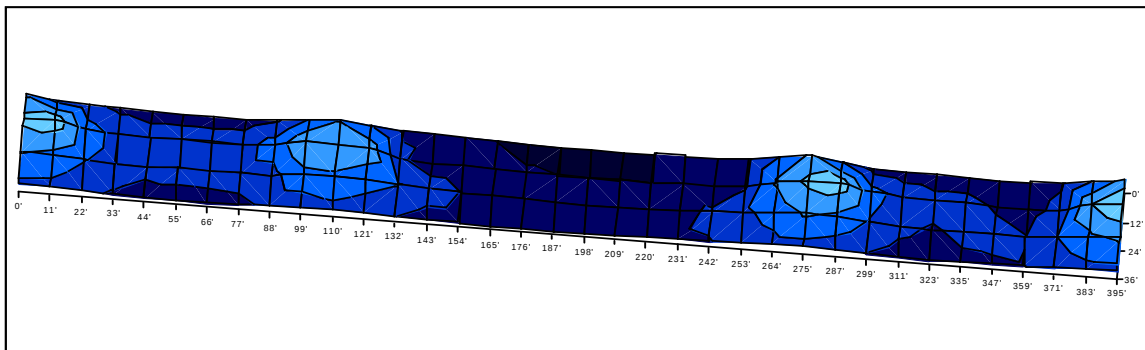


Figure 9: Phase III LED Mesopic Surface Plot (MOVE)

## MODELING

In addition to field measurements, computer simulations were run to model luminaire performance for a hypothetical street. This modeling was done primarily as verification of the field measurements, but also provides useful data for comparison which eliminates factors associated with the specific installation site. Additionally, greater precision for hypothetical data can be achieved using computer simulations than is possible for real-world data gathered in the field.

Modeling was done using manufacturer .IES files for a hypothetical 450 foot street with luminaire spacings of 100', 150', and 200' (luminaires at 0', 100', 250', and 450'). The width of the modeled street was 40', and mounting heights were kept constant at 28.5'. While it is likely that in a new lighting design the installation parameters would be varied based on the spacing (e.g. different mounting heights, and differently powered luminaires), they were held constant in these simulations for the sake of comparison.

It should be noted that prior to using modeled data for analysis, computer simulations were conducted using parameters as close as possible to those present in the field. These results corresponded very closely to the field measurements. Thereafter the modeling parameters were generalized, which resulted in slightly different values but similar trends.

The baseline HPS luminaire had average photometric illuminance values ranging from 0.951 fc in the 100' spacing to 0.494 fc in the 200' spacing. The minimum illuminance across all spacings was 0.062 fc, with a maximum illuminance of 3.165. The Phase II LED luminaire had average photometric illuminances from 0.568 to 0.294 fc, with a minimum of 0.013 fc and a maximum of 1.160 fc. The averages for the Phase III LED luminaire went from 0.479 to 0.249 fc, ranging from a minimum of 0.011 fc to a maximum of 1.055 fc.

The consolidated results of this modeling for the baseline HPS luminaires, Phase II LED luminaires, and Phase III LED luminaires are shown below:

**Table VI: Photometric Modeling Results**

| <b>Model Segment</b>                | <b>Avg.<br/>(fc)</b> | <b>Max.<br/>(fc)</b> | <b>Min.<br/>(fc)</b> | <b>Avg. to Min.<br/>Uniformity Ratio</b> | <b>Max. to Min.<br/>Uniformity Ratio</b> |
|-------------------------------------|----------------------|----------------------|----------------------|------------------------------------------|------------------------------------------|
| <b>HPS (100' Spacing)</b>           | 0.951                | 3.165                | 0.400                | 2.378:1                                  | 7.911:1                                  |
| <b>Phase II LED (100' Spacing)</b>  | 0.568                | 1.160                | 0.243                | 2.338:1                                  | 4.772:1                                  |
| <b>Phase III LED (100' Spacing)</b> | 0.479                | 1.055                | 0.072                | 6.611:1                                  | 14.551:1                                 |
| <b>HPS (150' Spacing)</b>           | 0.658                | 3.151                | 0.126                | 5.209:1                                  | 24.952:1                                 |
| <b>Phase II LED (150' Spacing)</b>  | 0.391                | 1.151                | 0.056                | 7.021:1                                  | 20.674:1                                 |
| <b>Phase III LED (150' Spacing)</b> | 0.332                | 1.039                | 0.051                | 6.549:1                                  | 20.498:1                                 |
| <b>HPS (200' Spacing)</b>           | 0.494                | 3.114                | 0.062                | 8.019:1                                  | 50.585:1                                 |
| <b>Phase II LED (200' Spacing)</b>  | 0.294                | 1.148                | 0.013                | 22.945:1                                 | 89.579:1                                 |
| <b>Phase III LED (200' Spacing)</b> | 0.249                | 1.012                | 0.011                | 22.636:1                                 | 92.000:1                                 |

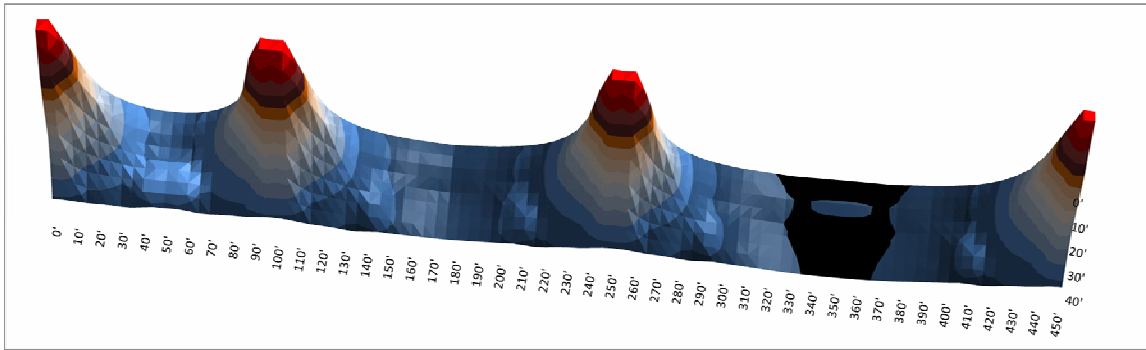


Figure 10: Modeled HPS Photopic Surface Plot

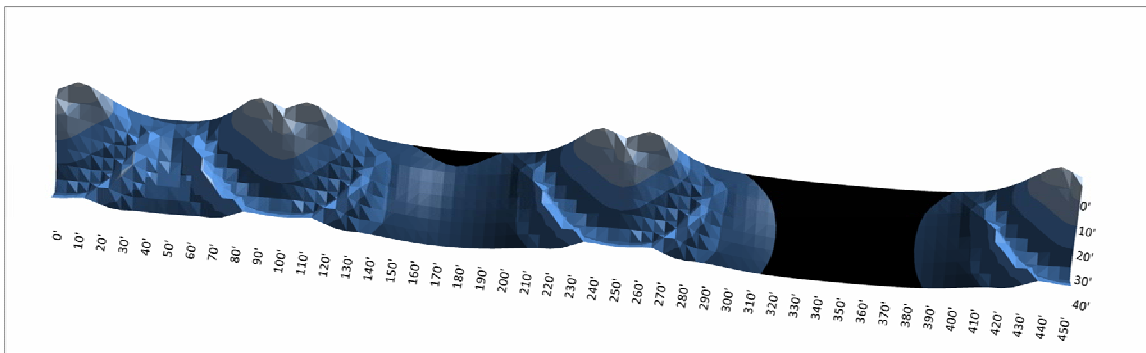


Figure 11: Modeled Phase II LED Photopic Surface Plot

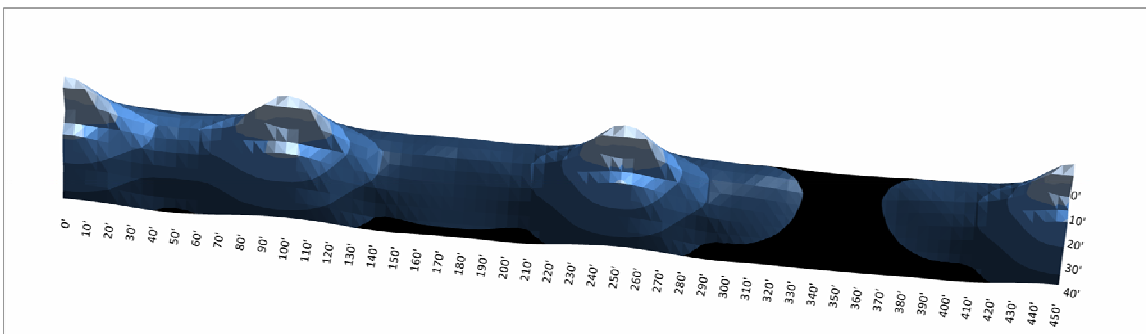


Figure 12: Modeled Phase III LED Photopic Surface Plot

## COLOR

Correlated color temperature (CCT) was measured using a Konica Minolta Chromameter for 3 HPS luminaires and 3 Phase II LED luminaires; and for 4 Phase III LED luminaires. For the LED luminaires, measurements of CCT were taken directly. For the HPS luminaires, the chromameter was unable to calculate the CCT, so chromaticity values ( $x$  and  $y$ ) were measured and then converted to CCT. The average CCT for the HPS luminaires was 1991 K. The average for the Phase II LED luminaires was 6255 K and the average for the Phase III luminaires was 6746 K. It

should be noted that some of the measured difference in illuminance values from Phase II to Phase III may be attributable to the spectrum change described by this change in measured CCT (491 K).

**Table VII: Measured Correlated Color Temperatures**

| <b>HPS<br/>Luminaires</b>           | <b>Correlated Color<br/>Temperature (K)</b> |
|-------------------------------------|---------------------------------------------|
| <b>1</b>                            | 1851                                        |
| <b>2</b>                            | 1965                                        |
| <b>3</b>                            | 2156                                        |
| <b>Avg</b>                          | 1991                                        |
| <b>Phase II LED<br/>Luminaires</b>  |                                             |
| <b>1</b>                            | 6284                                        |
| <b>2</b>                            | 6212                                        |
| <b>3</b>                            | 6269                                        |
| <b>Avg</b>                          | 6255                                        |
| <b>Phase III LED<br/>Luminaires</b> |                                             |
| <b>1</b>                            | 6818                                        |
| <b>2</b>                            | 6592                                        |
| <b>3</b>                            | 6761                                        |
| <b>4</b>                            | 6812                                        |
| <b>Avg</b>                          | 6746                                        |

## PHOTOGRAPHS

To qualitatively analyze color rendition, photos were taken of each luminaire type. They were taken with a Nikon D80 digital camera. The white balance was manually set to 4000K, and later converted to 4300K. This value was chosen as the average of the literature values for color temperature for the baseline HPS lamps (2100K) and the Phase II / III LEDs (6500K). The camera settings were equivalent for each photo:

### **Baseline HPS and Phase II Luminaires**

Flash: No

Focal Length: 18 mm

F-Number: F/6.3

ISO: 400

Exposure Time: 8 sec.

White Balance: 4000K (adjusted to 4300K)

### **Phase III Luminaires**

Flash: No

Focal Length: 18 mm

F-Number: F/6.3

ISO: 200

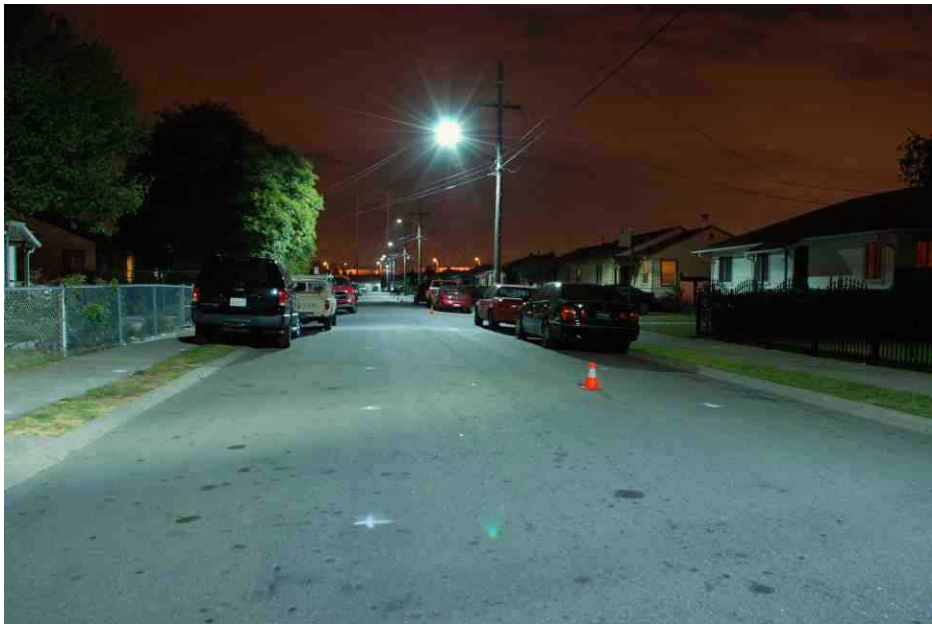
Exposure Time: 15 sec.

White Balance: 4000K (adjusted to 4300K)

One photo for each luminaire type is shown below:



**Figure 13: HPS Photograph**



**Figure 14: Phase II LED Photograph**



Figure 15: Phase III LED Photograph

## Economic Performance

Economic performance was evaluated primarily by simple payback of the Phase III LED luminaires versus the HPS luminaires. Economic performance of Phase III economic results are also compared to those from Phase II. To calculate savings, maintenance and energy costs were taken into account assuming current energy and materials costs. Please see Appendix A4 for more details on estimated energy costs and savings, as well as maintenance savings estimates for both group replacement and spot replacement scenarios.

Table VIII: Annual Luminaire Costs

| Luminaire Type               | Annual Maintenance Cost (per Luminaire) <sup>5</sup> | Annual Energy Cost (per Luminaire) | Total Annual Cost (per Luminaire) |
|------------------------------|------------------------------------------------------|------------------------------------|-----------------------------------|
| HPS (with Spot Replacement)  | \$20                                                 | \$64                               | \$84                              |
| HPS (with Group Replacement) | \$11                                                 | \$64                               | \$75                              |
| Phase II LED                 | \$0                                                  | \$42                               | \$42                              |
| Phase III LED                | \$0                                                  | \$32                               | \$32                              |

<sup>5</sup> Maintenance estimates provided by City of Oakland

Table IX: New Construction Economics

| Luminaire Type                                 | Initial Investment <sup>6</sup> | Incremental Cost | Annual Savings | Simple Payback (Years) |
|------------------------------------------------|---------------------------------|------------------|----------------|------------------------|
| HPS                                            | \$346                           | --               | --             | --                     |
| Phase II LED (vs. HPS with Spot Replacement)   | \$833                           | \$487            | \$42           | 11.6                   |
| Phase II LED (vs. HPS with Group Replacement)  | \$833                           | \$487            | \$33           | 14.9                   |
| Phase III LED (vs. HPS with Spot Replacement)  | \$605                           | \$259            | \$52           | 5.0                    |
| Phase III LED (vs. HPS with Group Replacement) | \$605                           | \$259            | \$43           | 6.1                    |

Table X: Retrofit Economics

| Luminaire Type                                 | Initial Investment <sup>7</sup> | Incremental Cost | Annual Savings | Simple Payback (Years) |
|------------------------------------------------|---------------------------------|------------------|----------------|------------------------|
| HPS                                            | \$0                             | --               | --             | --                     |
| Phase II LED (vs. HPS with Spot Replacement)   | \$833                           | \$833            | \$42           | 19.8                   |
| Phase II LED (vs. HPS with Group Replacement)  | \$833                           | \$833            | \$33           | 25.5                   |
| Phase III LED (vs. HPS with Spot Replacement)  | \$605                           | \$605            | \$52           | 11.6                   |
| Phase III LED (vs. HPS with Group Replacement) | \$605                           | \$605            | \$43           | 14.2                   |

Since simple payback was found to be sensitive to maintenance estimates, a chart was constructed which shows simple payback as a function of annual maintenance savings. Three scenarios were plotted for maintenance estimates ranging from \$0 to \$100: retrofit installation of Phase II LED luminaires, retrofit installation of Phase III luminaires, and new construction installation of Phase III luminaires. As expected, the payback approaches zero as maintenance savings increase. Simple paybacks in the analyzed scenarios ranged from roughly 38 years for the retrofit Phase II scenario with no maintenance savings to roughly 2 years for the new construction Phase III scenario with \$100 annual maintenance savings. Spot and Group replacement estimates specific to this site were also included.

This chart is shown below:<sup>8</sup>

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<sup>6</sup> Phase II initial investments based on manufacturer's pricing as of 1/2008. Phase III initial investments based on manufacturer's pricing as of 11/2008.

<sup>7</sup> Ibid.

<sup>8</sup> Calculations are based on maintenance and energy savings estimates, as described in Appendix A4.

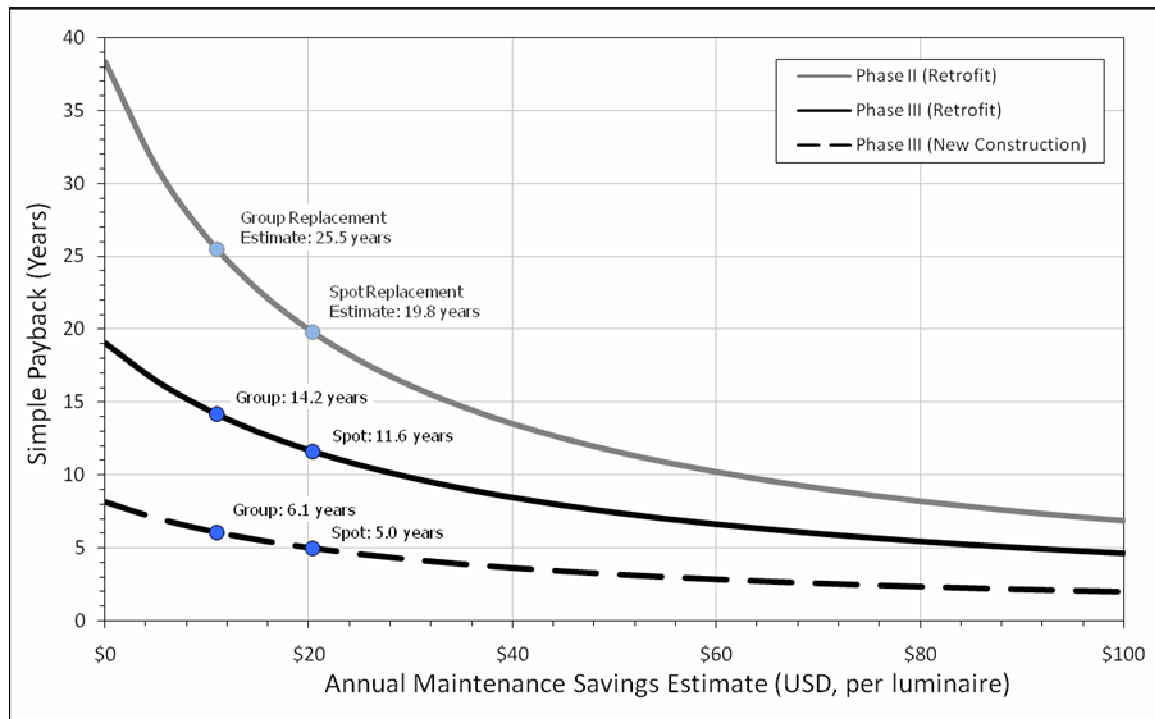


Figure 16: Simple Payback Period for Various Maintenance Scenarios

## Discussion

This report is a follow-up to a previous street lighting assessment (Phase II)<sup>9</sup> that compared LED luminaires to a base case of HPS luminaires. In this report (Phase III), those same LED luminaires were replaced with newer LED luminaires from the same manufacturer, and the performance of all three alternatives was compared. The Phase III LED luminaires drew approximately 58 watts; 20 watts less than the Phase II luminaires and 63 watts less than the HPS luminaires. If the 52% energy savings from replacing HPS luminaires with Phase III luminaires could be achieved with one-half of the estimated electrical usage for roadway lighting in PG&E's service territory, the resulting savings would be over 200 GWh.<sup>10</sup>

The Phase III LED luminaires provided illumination equivalent to the Phase II LED luminaires. This was sufficient illumination to meet the City of Oakland's street lighting requirements in all but the largest spacing, and proved to be a practicable replacement for the 100 - watt HPS luminaires. The City of Oakland standards for new residential installations require an average photopic illuminance of greater than 0.4 footcandles and max - to - min uniformity ratio of less than 6:1. It should be noted that these standards apply to new, residential installations, which may not be the

<sup>9</sup> See Phase II report

<sup>10</sup> Based on an estimated 860 GWh for roadway lighting in PG&E's service territory.

same as those that applied at the time that the poles were installed. The full standards for new street lighting installations are available at <http://www.oaklandpw.com/Asset550.aspx>.

Similarly to the comparison of the Phase II LED luminaires to the HPS luminaires, the Phase III LED luminaires had slightly decreased average photopic illuminance, but improved uniformity. As discussed in the previous assessment, the reduced average illuminance levels do not necessarily denote inferior light performance when minimum illuminance levels are maintained and uniformity is improved. In scotopic and mesopic illuminances as well, the Phase III LED tended to have slightly reduced average and maximum values, but equal or better minimum and uniformity values.

When the luminaires were modeled using computer simulation of a hypothetical street, the Phase II and Phase III LED luminaires displayed similar average and maximum values across all pole spacings. The Phase II luminaire had a higher minimum value than the Phase III luminaire in the 100' spacing, and a lower minimum value in the 200' spacing. In the 150' spacing, these values were similar. Since this was the principle change in performance between the LED luminaires, the uniformity ratios varied in a like manner. This indicates that the different optic used in the Phase III luminaire will tend to be better suited than that used in the Phase II luminaire for large pole spacings, and worse for smaller pole spacings.

The Phase III luminaires were found to pay back in 5-6 years in a new construction scenario, or 12-14 years in a retrofit scenario. This is compared to equivalently calculated paybacks of 12-15 and 20-25 years in Phase II. This shorter payback period is the result of reduced energy consumption by the Phase III luminaires leading to greater savings, and reduced luminaire costs resulting in lower initial investments. All economic variables and calculations were kept constant between the two assessments.<sup>11</sup> The continuing rapid improvements in both LED product efficacy and cost can be expected to lead to equally rapid improvements in their economic payback.

In addition to upfront costs, results of these simple payback calculations are sensitive to the maintenance costs associated with the specific application circumstances. Group replacement procedures for HPS lamps have the potential to reduce maintenance costs by gaining economies of scale with respect to labor, typically the most expensive component. This results in a less favorable comparative economic performance for the LED luminaires. Depending on the estimate used for traditional maintenance, simple paybacks for the Phase III luminaires range from roughly 19 years for a retrofit scenario with no maintenance savings to roughly 2 years for a new construction scenario assuming maintenance savings of \$100 per luminaire.

Utility incentive programs have the further potential to reduce payback to end-users by lowering the initial cost for high performance products such as LEDs. PG&E uses Emerging Technologies assessments to support development of such incentives for emerging energy efficient solutions.

Because the performance and quality of the LED fixtures are critical to the long-term delivery of energy savings, it is vital that incentive programs also include quality control mechanisms. Incentive programs should therefore include performance standards for qualifying products that include minimum criteria for warranty, efficacy, light distribution, and other important criteria.

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<sup>11</sup> See Appendix A4

## Conclusion

LED street lighting continues to show great and improving potential for energy savings. When compared with the previous assessment completed less than a year ago, this demonstration provides an impressive example of improvements in performance of LED luminaires.

Progress in 12 Months – Phase III Results as compared to Phase II:

- Energy savings increased by 26% (LED luminaire wattage dropped from 78W to 58W)
- Luminaire cost decreased by 34% (From \$610 to \$400)
- Lighting performance maintained

This progress was achieved using the same generation of LED chip and the same driver as the product used in the Phase II demonstration. All improvements resulted from the manufacturer's development/refinement in the product design.

The economic performance of the luminaires in this demonstration is significantly improved compared to the previous luminaires due to decreased costs and increased savings. As the technical and economic performance of LED luminaires continues to improve and there is growing industry acceptance of their benefits vs. traditional luminaires, early adopters have further impetus to invest in the emerging technology. While not within the scope of this demonstration, many advocate that white-light (broad spectrum) sources (e.g., LEDs) provide greater aesthetic value to an area, as well as providing a perception of greater security because colors and images are more clearly visible. These benefits are over and above the economic and environmental benefit from changing to this new technology and should be valued by each customer. We believe customers with significant street lighting costs should be encouraged by the results of this demonstration and raise the priority of examining possible changes to their street light operations.

# Appendix A: Phase II Monitoring Data

## Appendix A1: Power Data

Table A1.i: Averaged Power Measurements. (Measured with DENT ElitePro Datalogger, 10/08/2007 to 10/11/2007 and 9/26/2008 to 10/10/2008).

|                         | Voltage (v) | Current (a) | Power (W) | Power Factor | Nightly Energy Usage (11 hr, kWh) |
|-------------------------|-------------|-------------|-----------|--------------|-----------------------------------|
| HPS Luminaire           | 120.22      | 1.01        | 121.01    | 0.9947       | 1.33                              |
| Phase II LED Luminaire  | 120.53      | 0.65        | 77.69     | 0.9888       | 0.85                              |
| Phase III LED Luminaire | 120.98      | 0.49        | 58.25     | 0.9833       | 0.64                              |

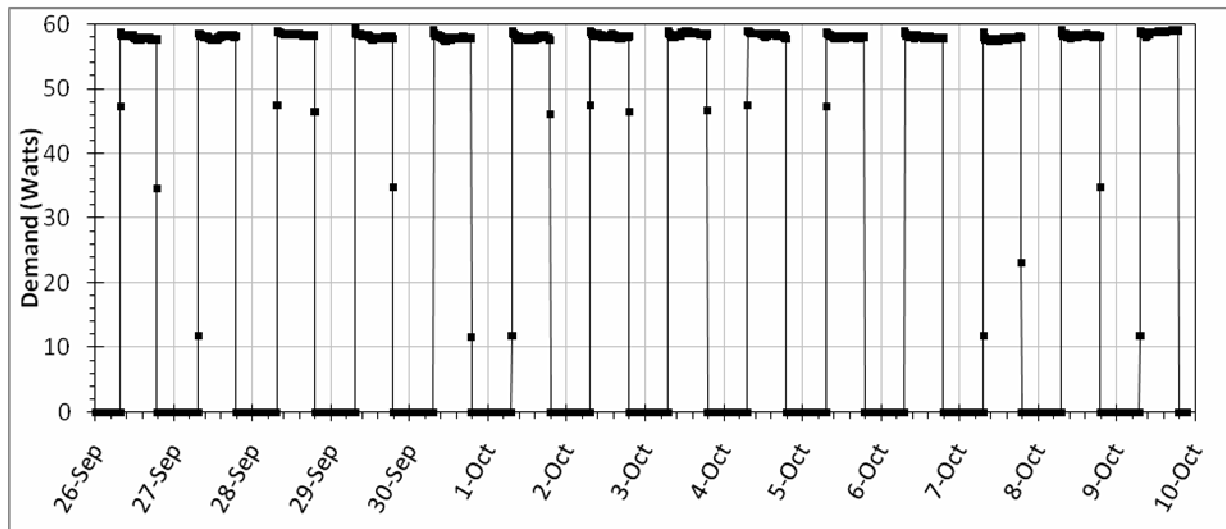


Figure A1.1: Detailed Phase III LED Power Demand (Measured with DENT ElitePro Datalogger, 9/26/2008 to 10/10/2008)

# Appendix A2: Illumination Data

## APPENDIX A2.1: HPS LUMINAIRE DATA

Table A2.1.i: Photopic Illumination over HPS Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference Coordinates (ft) | AA  | AB  | AC  | AD  | AE  | AF  | AG  | AH  | AI  | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ  |     |     |
|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|
| 1                          | 18  | 14  | 7   | 4   | 3   | 2   | 3   | 4   | 8   | 13   | 14   | 10   | 6    | 3    | 2    | 1    | 0    | 0    | 0    | 0    | 0    | 1    | 2    | 4    | 9    | 15   | 8    | 4    | 2    | 1    | 1    | 2    | 3    | 6    | 13   | 17  | 0'  |     |
| 2                          | 38  | 31  | 10  | 6   | 4   | 4   | 5   | 6   | 11  | 28   | 30   | 16   | 7    | 4    | 2    | 1    | 0    | 0    | 0    | 0    | 1    | 2    | 4    | 6    | 13   | 25   | 19   | 6    | 4    | 3    | 3    | 4    | 8    | 25   | 40   | 12' |     |     |
| 3                          | 27  | 19  | 10  | 6   | 5   | 4   | 4   | 6   | 9   | 20   | 21   | 13   | 7    | 4    | 2    | 1    | 1    | 0    | 1    | 1    | 2    | 2    | 3    | 7    | 12   | 17   | 11   | 6    | 4    | 4    | 3    | 3    | 4    | 8    | 18   | 30  | 24' |     |
| 4                          | 11  | 10  | 6   | 7   | 6   | 6   | 6   | 5   | 6   | 9    | 9    | 7    | 5    | 4    | 2    | 1    | 1    | 0    | 0    | 0    | 1    | 3    | 4    | 4    | 5    | 7    | 6    | 4    | 4    | 4    | 5    | 3    | 3    | 4    | 6    | 8   | 11  | 36' |
| 0'                         | 11' | 22' | 33' | 44' | 55' | 66' | 77' | 88' | 99' | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |     |     |     |

Table A2.1.ii: Scotopic Illumination over HPS Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference Coordinates (ft) | AA  | AB  | AC  | AD  | AE  | AF  | AG  | AH  | AI  | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ |     |
|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----|-----|
| 1                          | 15  | 10  | 5   | 3   | 2   | 1   | 2   | 3   | 6   | 10   | 11   | 8    | 4    | 2    | 1    | 0    | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 3    | 6    | 10   | 5    | 3    | 1    | 1    | 1    | 1    | 3    | 5    | 10   | 13 | 0'  |
| 2                          | 29  | 24  | 7   | 4   | 3   | 3   | 4   | 5   | 9   | 22   | 23   | 12   | 5    | 3    | 1    | 1    | 0    | 0    | 0    | 0    | 0    | 1    | 3    | 4    | 12   | 18   | 14   | 4    | 3    | 2    | 2    | 2    | 3    | 6    | 20   | 31 | 12' |
| 3                          | 21  | 15  | 7   | 5   | 4   | 3   | 3   | 4   | 7   | 15   | 16   | 10   | 6    | 3    | 1    | 1    | 0    | 0    | 0    | 0    | 1    | 1    | 2    | 5    | 9    | 13   | 8    | 4    | 3    | 3    | 2    | 2    | 3    | 6    | 14   | 23 | 24' |
| 4                          | 8   | 7   | 5   | 5   | 5   | 5   | 5   | 4   | 5   | 8    | 7    | 6    | 4    | 3    | 2    | 1    | 0    | 0    | 0    | 0    | 1    | 2    | 3    | 3    | 4    | 5    | 4    | 3    | 3    | 3    | 1    | 2    | 3    | 5    | 6    | 9  | 36' |
| 0'                         | 11' | 22' | 33' | 44' | 55' | 66' | 77' | 88' | 99' | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |    |     |

Table A2.1.iii: Mesopic Illumination over HPS Test Area. (In lux; calculated using MOVE model)

| Reference<br>Coordinates (ft) | AA    | AB    | AC   | AD   | AE   | AF   | AG   | AH   | AI    | AJ    | AK    | AL    | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY    | AZ    | BA    | BB   | BC   | BD   | BE   | BF   | BG   | BH    | BI    | BJ    |     |
|-------------------------------|-------|-------|------|------|------|------|------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|------|------|------|------|------|------|-------|-------|-------|-----|
| 1                             | 17.27 | 12.91 | 6.28 | 3.56 | 2.50 | 1.38 | 2.50 | 3.56 | 7.32  | 12.16 | 13.19 | 9.38  | 5.23 | 2.50 | 1.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.38 | 3.56 | 8.02  | 13.67 | 6.97  | 3.56 | 1.38 | 1.00 | 1.00 | 1.38 | 3.00 | 5.63  | 12.16 | 16.00 | 0'  |
| 2                             | 36.44 | 29.66 | 9.06 | 5.23 | 3.56 | 3.56 | 4.60 | 5.63 | 10.41 | 26.80 | 26.64 | 14.97 | 6.28 | 3.56 | 1.38 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.38 | 3.56 | 5.23 | 12.73 | 23.51 | 17.81 | 5.23 | 3.56 | 2.50 | 2.50 | 3.56 | 7.32 | 23.95 | 38.48 | 12'   |     |
| 3                             | 25.78 | 18.05 | 9.06 | 5.63 | 4.60 | 3.56 | 3.56 | 5.23 | 8.36  | 18.83 | 19.86 | 12.16 | 6.65 | 3.56 | 1.38 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.38 | 1.38 | 2.50 | 6.28 | 11.13 | 16.00 | 10.10 | 5.23 | 3.56 | 3.56 | 2.50 | 2.50 | 3.56 | 7.32  | 17.03 | 28.64 | 24' |
| 4                             | 10.10 | 9.06  | 5.63 | 6.28 | 5.63 | 5.63 | 4.60 | 5.63 | 8.68  | 8.68  | 8.36  | 6.65  | 4.60 | 3.56 | 2.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.50 | 3.56 | 3.56 | 4.60  | 6.28  | 5.23  | 3.56 | 3.56 | 4.17 | 1.89 | 2.50 | 3.56 | 5.63  | 7.32  | 10.41 | 36' |
| 0'                            | 0'    | 11'   | 22'  | 33'  | 44'  | 55'  | 66'  | 77'  | 88'   | 99'   | 110'  | 121'  | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264'  | 275'  | 287'  | 299' | 311' | 323' | 335' | 347' | 359' | 371'  | 383'  | 395'  |     |

APPENDIX A2.2: PHASE II LED LUMINAIRE DATA

Table A2.2.i: Photopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference<br>Coordinates (ft) | AA  | AB  | AC  | AD  | AE  | AF  | AG  | AH  | AI  | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ  |     |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|
| 1                             | 9   | 10  | 5   | 3   | 2   | 2   | 2   | 3   | 7   | 10   | 8    | 9    | 4    | 2    | 1    | 0    | 0    | 0    | 0    | 0    | 1    | 1    | 2    | 4    | 7    | 10   | 9    | 5    | 2    | 1    | 1    | 1    | 2    | 4    | 7    | 10  | 0'  |
| 2                             | 13  | 11  | 8   | 5   | 4   | 4   | 5   | 5   | 7   | 10   | 11   | 10   | 7    | 3    | 2    | 1    | 0    | 0    | 0    | 0    | 1    | 2    | 3    | 7    | 12   | 13   | 11   | 7    | 3    | 3    | 2    | 2    | 3    | 7    | 16   | 13  | 12' |
| 3                             | 9   | 7   | 6   | 9   | 5   | 4   | 5   | 6   | 4   | 7    | 8    | 6    | 5    | 6    | 3    | 1    | 1    | 0    | 0    | 0    | 1    | 3    | 6    | 5    | 7    | 9    | 7    | 5    | 7    | 3    | 2    | 3    | 6    | 8    | 10   | 24' |     |
| 4                             | 5   | 5   | 8   | 5   | 5   | 4   | 5   | 5   | 8   | 5    | 5    | 6    | 7    | 4    | 3    | 2    | 1    | 1    | 1    | 1    | 1    | 3    | 4    | 7    | 6    | 5    | 5    | 7    | 5    | 3    | 1    | 3    | 5    | 8    | 5    | 36' |     |
| 0'                            | 11' | 22' | 33' | 44' | 55' | 66' | 77' | 88' | 99' | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |     |     |

Table A2.2.ii: Scotopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference<br>Coordinates (ft) | AA  | AB  | AC  | AD  | AE  | AF  | AG  | AH  | AI  | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ |
|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----|
|                               | 1   | 20  | 20  | 11  | 6   | 4   | 3   | 4   | 7   | 15   | 22   | 17   | 18   | 8    | 3    | 1    | 0    | 0    | 0    | 0    | 1    | 2    | 4    | 8    | 14   | 19   | 18   | 9    | 4    | 2    | 2    | 1    | 4    | 7    | 13   | 17 |
|                               | 2   | 25  | 23  | 17  | 10  | 9   | 7   | 10  | 9   | 15   | 19   | 22   | 20   | 14   | 5    | 3    | 1    | 0    | 0    | 0    | 1    | 3    | 6    | 14   | 24   | 25   | 23   | 14   | 5    | 5    | 3    | 3    | 5    | 15   | 33   | 26 |
|                               | 3   | 18  | 15  | 10  | 18  | 9   | 8   | 9   | 11  | 8    | 13   | 15   | 11   | 10   | 12   | 5    | 2    | 1    | 0    | 0    | 2    | 5    | 11   | 10   | 15   | 19   | 14   | 10   | 13   | 7    | 5    | 6    | 11   | 11   | 15   | 21 |
|                               | 4   | 10  | 10  | 17  | 11  | 9   | 9   | 9   | 10  | 15   | 10   | 10   | 11   | 15   | 8    | 5    | 3    | 2    | 1    | 1    | 2    | 2    | 5    | 8    | 15   | 10   | 9    | 14   | 9    | 6    | 2    | 6    | 9    | 16   | 10   | 10 |
| 0'                            | 11' | 22' | 33' | 44' | 55' | 66' | 77' | 88' | 99' | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |    |

Table A2.2.iii: Mesopic Illumination over LED Test Area. (In lux; calculated using MOVE model)

| Reference Coordinates (ft) | AA    | AB    | AC    | AD    | AE   | AF   | AG   | AH   | AI    | AJ    | AK    | AL    | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY    | AZ    | BA    | BB   | BC   | BD   | BE   | BF   | BG    | BH    | BI    | BJ   |
|----------------------------|-------|-------|-------|-------|------|------|------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|------|------|------|------|------|-------|-------|-------|------|
| 1                          | 12.07 | 12.74 | 7.06  | 4.24  | 2.94 | 2.50 | 2.94 | 4.61 | 9.46  | 13.23 | 10.64 | 11.56 | 5.50 | 2.50 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.59 | 2.94 | 5.50 | 9.18  | 12.48 | 11.56 | 6.42 | 2.94 | 1.59 | 1.00 | 2.94 | 5.16  | 8.89  | 11.96 | 0'   |
| 2                          | 16.00 | 14.15 | 10.64 | 6.74  | 5.84 | 5.16 | 6.74 | 6.42 | 9.46  | 12.48 | 13.91 | 12.74 | 9.18 | 3.86 | 2.50 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 2.50 | 4.24 | 9.18 | 15.07 | 16.00 | 14.15 | 9.18 | 3.86 | 3.86 | 2.50 | 3.86 | 9.46  | 19.88 | 16.23 | 12   |
| 3                          | 11.56 | 9.46  | 7.35  | 11.56 | 6.42 | 5.50 | 6.42 | 7.66 | 5.50  | 8.89  | 10.10 | 7.66  | 6.74 | 7.97 | 3.86 | 1.59 | 1.00 | 0.00 | 0.00 | 0.00 | 1.59 | 3.86 | 7.66 | 6.74 | 9.46  | 11.82 | 9.18  | 6.74 | 8.89 | 4.61 | 3.35 | 4.24 | 7.66  | 10.10 | 12.99 | 24'  |
| 4                          | 6.74  | 6.74  | 10.64 | 7.06  | 6.42 | 5.84 | 6.42 | 6.74 | 10.10 | 6.74  | 6.74  | 7.66  | 9.46 | 5.50 | 3.86 | 2.50 | 1.59 | 1.00 | 1.00 | 1.59 | 3.86 | 5.50 | 9.46 | 7.66 | 6.74  | 6.42  | 6.42  | 9.18 | 6.42 | 4.24 | 1.59 | 4.24 | 10.37 | 6.74  | 6.74  | 36'  |
|                            | 0'    | 11'   | 22'   | 33'   | 44'  | 55'  | 66'  | 77'  | 88'   | 99'   | 110'  | 121'  | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264'  | 275'  | 287'  | 299' | 311' | 323' | 335' | 347' | 359'  | 371'  | 383'  | 395' |

APPENDIX A2.3: PHASE III LED LUMINAIRE DATA

Table A2.3.i: Photopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference Coordinates (ft) | AA   | AB   | AC  | AD  | AE  | AF  | AG  | AH  | AI  | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ   |
|----------------------------|------|------|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 1                          | 8.0  | 5.0  | 4.0 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 3.0 | 6.0  | 8.0  | 6.0  | 3.0  | 3.0  | 2.0  | 1.0  | 0.0  | 0.0  | 0.0  | 0.0  | 1.0  | 1.0  | 2.0  | 3.0  | 6.0  | 9.0  | 6.0  | 2.0  | 2.0  | 2.0  | 1.0  | 2.0  | 3.0  | 6.0  | 10.0 | 0'   |
| 2                          | 12.0 | 13.0 | 7.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 7.0 | 11.0 | 11.0 | 10.0 | 4.0  | 2.0  | 2.0  | 2.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 2.0  | 1.0  | 3.0  | 9.0  | 12.0 | 13.0 | 7.0  | 5.0  | 4.0  | 3.0  | 2.0  | 4.0  | 11.0 | 14.0 | 12   |
| 3                          | 9.0  | 8.0  | 6.0 | 5.0 | 4.0 | 5.0 | 5.0 | 5.0 | 5.0 | 8.0  | 8.0  | 7.0  | 6.0  | 5.0  | 3.0  | 3.0  | 3.0  | 2.0  | 1.0  | 1.0  | 2.0  | 2.0  | 4.0  | 5.0  | 7.0  | 9.0  | 8.0  | 6.0  | 4.0  | 3.0  | 4.0  | 3.0  | 6.0  | 8.0  | 9.0  | 24'  |
| 4                          | 5.0  | 5.0  | 4.0 | 3.0 | 2.0 | 2.0 | 2.0 | 2.0 | 4.0 | 4.0  | 5.0  | 4.0  | 3.0  | 2.0  | 2.0  | 1.0  | 1.0  | 1.0  | 1.0  | 1.0  | 2.0  | 3.0  | 3.0  | 4.0  | 5.0  | 5.0  | 4.0  | 3.0  | 2.0  | 2.0  | 3.0  | 3.0  | 4.0  | 5.0  | 5.0  | 36'  |
|                            | 0'   | 11'  | 22' | 33' | 44' | 55' | 66' | 77' | 88' | 99'  | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |

Table A2.3.ii: Scotopic Illumination over LED Test Area. (In lux; measured with Solar Light PMA220 with PMA2130 and PMA2131)

| Reference Coordinates (ft) | AA   | AB   | AC   | AD   | AE  | AF   | AG  | AH   | AI   | AJ   | AK   | AL   | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX   | AY   | AZ   | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH   | BI   | BJ   |
|----------------------------|------|------|------|------|-----|------|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 4                          | 11.2 | 10.3 | 7.5  | 5.6  | 3.7 | 2.8  | 3.7 | 5.6  | 8.4  | 9.3  | 10.3 | 9.3  | 7.5  | 4.7  | 4.7  | 3.7  | 2.8  | 1.9  | 1.9  | 3.7  | 4.7  | 5.6  | 6.5  | 8.4  | 10.3 | 10.3 | 9.3  | 6.5  | 4.7  | 2.8  | 4.7  | 5.6  | 6.5  | 8.4  | 10.3 | 36'  |
| 3                          | 16.8 | 15.9 | 12.1 | 9.3  | 8.4 | 8.4  | 9.3 | 10.3 | 14.9 | 14.9 | 15.9 | 14.0 | 12.1 | 8.4  | 6.5  | 5.6  | 3.7  | 1.9  | 1.9  | 2.8  | 3.7  | 5.6  | 6.5  | 11.2 | 14.0 | 17.7 | 15.9 | 10.3 | 7.5  | 5.6  | 6.5  | 7.5  | 11.2 | 15.9 | 18.7 | 24'  |
| 2                          | 25.2 | 27.1 | 14.9 | 10.3 | 9.3 | 10.3 | 9.3 | 9.3  | 14.9 | 24.3 | 22.4 | 21.5 | 6.5  | 2.8  | 2.8  | 1.9  | 1.9  | 0.9  | 0.9  | 0.9  | 0.9  | 1.9  | 2.8  | 5.6  | 18.7 | 25.2 | 26.1 | 13.1 | 9.3  | 8.4  | 7.5  | 5.6  | 7.5  | 24.3 | 28.0 | 12'  |
| 1                          | 16.8 | 10.3 | 6.5  | 4.7  | 3.7 | 2.8  | 2.8 | 3.7  | 5.6  | 12.1 | 17.7 | 10.3 | 5.6  | 3.7  | 1.9  | 0.9  | 0.0  | 0.0  | 0.0  | 0.0  | 0.9  | 1.9  | 2.8  | 5.6  | 12.1 | 19.6 | 10.3 | 4.7  | 3.7  | 2.8  | 3.7  | 2.8  | 5.6  | 12.1 | 19.6 | 0'   |
|                            | 0'   | 11'  | 22'  | 33'  | 44' | 55'  | 66' | 77'  | 88'  | 99'  | 110' | 121' | 132' | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264' | 275' | 287' | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383' | 395' |

Table A2.3.iii: Mesopic Illumination over LED Test Area. (In lux; calculated using MOVE model)

| Reference Coordinates (°) | AA    | AB    | AC   | AD   | AE   | AF   | AG   | AH   | AI   | AJ    | AK    | AL    | AM   | AN   | AO   | AP   | AQ   | AR   | AS   | AT   | AU   | AV   | AW   | AX    | AY    | AZ    | BA   | BB   | BC   | BD   | BE   | BF   | BG   | BH    | BI    | BJ    |     |
|---------------------------|-------|-------|------|------|------|------|------|------|------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|------|------|------|------|------|------|------|-------|-------|-------|-----|
| 1                         | 9.47  | 6.08  | 4.58 | 3.43 | 2.51 | 2.25 | 2.25 | 2.51 | 3.66 | 7.17  | 9.61  | 6.83  | 3.66 | 3.20 | 1.96 | 0.97 | 0.00 | 0.00 | 0.00 | 0.00 | 0.97 | 1.32 | 2.25 | 3.66  | 7.17  | 10.67 | 6.83 | 2.76 | 2.51 | 2.25 | 2.51 | 1.63 | 2.51 | 3.66  | 7.17  | 11.45 | 0'  |
| 2                         | 13.81 | 14.85 | 8.40 | 6.08 | 5.90 | 6.08 | 5.90 | 5.90 | 8.40 | 12.89 | 12.64 | 11.72 | 4.58 | 2.25 | 2.25 | 1.96 | 1.32 | 0.97 | 0.97 | 0.97 | 1.96 | 1.63 | 3.66 | 10.53 | 13.81 | 14.74 | 8.09 | 5.90 | 4.98 | 4.79 | 3.66 | 2.99 | 4.79 | 12.89 | 15.78 | 12    |     |
| 3                         | 10.25 | 9.32  | 7.17 | 5.90 | 4.98 | 5.71 | 5.71 | 5.90 | 6.08 | 9.17  | 9.32  | 8.25  | 7.17 | 5.71 | 3.88 | 3.66 | 3.20 | 1.96 | 1.32 | 1.63 | 2.51 | 2.99 | 4.58 | 6.25  | 10.39 | 9.32  | 6.83 | 4.79 | 3.66 | 4.58 | 4.79 | 4.08 | 7.00 | 9.32  | 10.53 | 24'   |     |
| 4                         | 6.25  | 6.08  | 4.79 | 3.66 | 2.51 | 2.25 | 2.51 | 2.99 | 4.98 | 5.17  | 6.08  | 5.17  | 4.08 | 2.76 | 2.76 | 1.90 | 1.63 | 1.32 | 1.32 | 1.90 | 2.76 | 3.66 | 3.88 | 4.98  | 6.08  | 6.08  | 5.17 | 3.88 | 2.76 | 2.25 | 3.43 | 3.66 | 3.88 | 4.98  | 6.08  | 6.08  | 36' |
| 0'                        | 11'   | 22'   | 33'  | 44'  | 55'  | 66'  | 77'  | 88'  | 99'  | 110'  | 121'  | 132'  | 143' | 154' | 165' | 176' | 187' | 198' | 209' | 220' | 231' | 242' | 253' | 264'  | 275'  | 287'  | 299' | 311' | 323' | 335' | 347' | 359' | 371' | 383'  | 395'  |       |     |

# Appendix A3: Project Layout

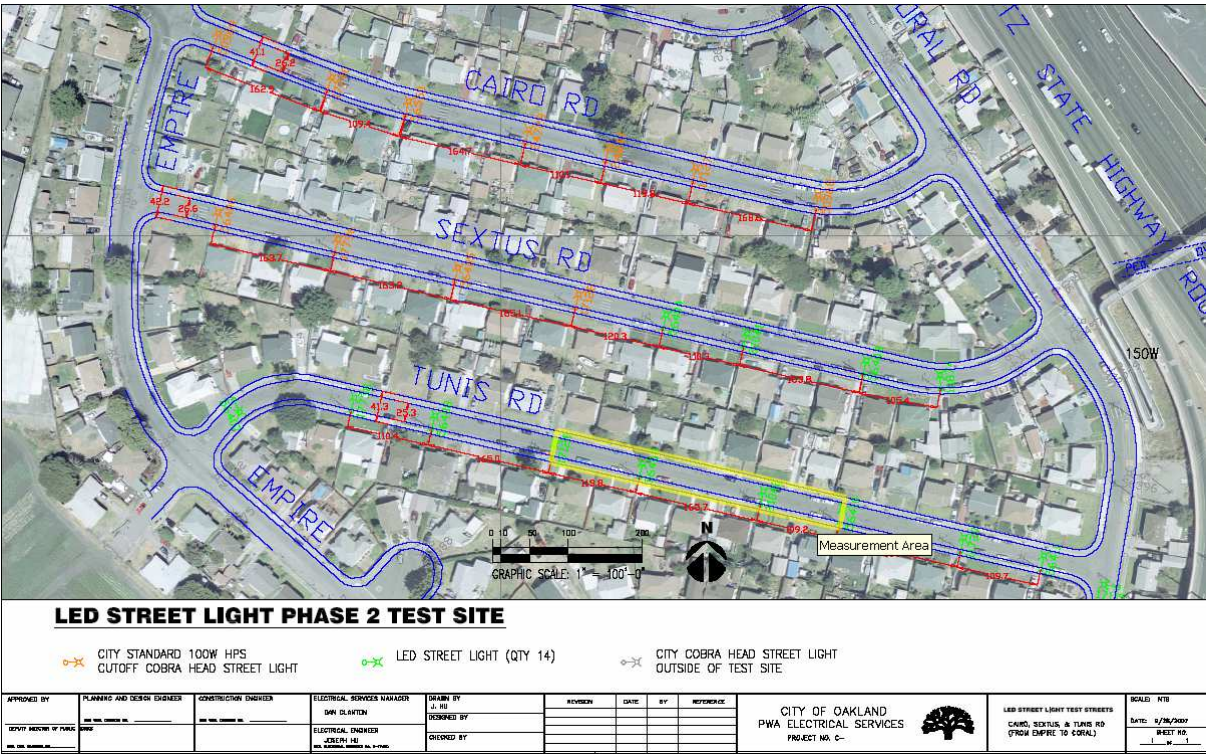


Figure A3.1: Image of Test Site and Measurement Area

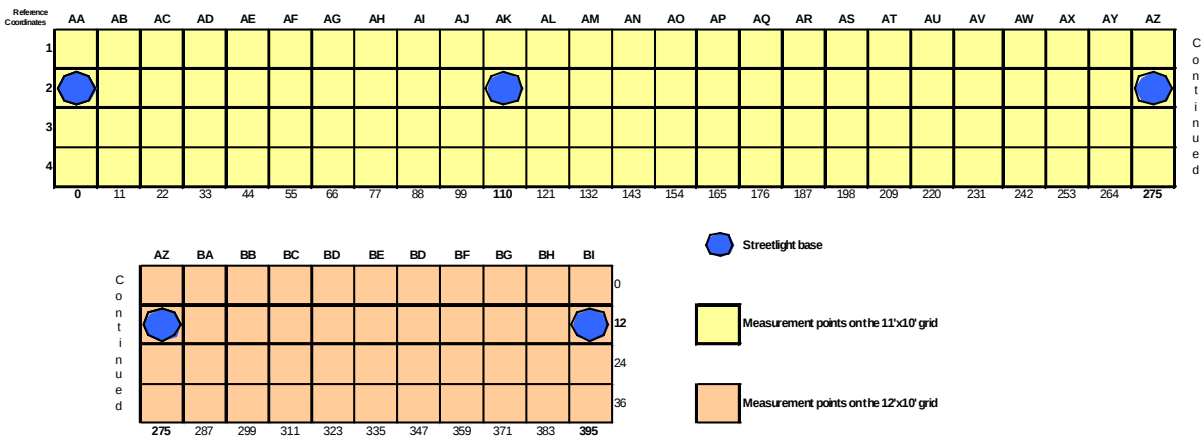


Figure A3.2: Schematic of Measurement Area and Grid

## Appendix A4: Economic Analysis

| Phase III Estimated Annual Energy Costs                                                                                                                                                                                                                                                                                                               |        |                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|-----------------------------|
| <b>Estimated Annual Savings for LED:<sup>1</sup></b>                                                                                                                                                                                                                                                                                                  |        | <b>31.73 \$ per Fixture</b> |
| <b>100 Watt HPS</b>                                                                                                                                                                                                                                                                                                                                   |        |                             |
| Monthly Fixed Charge <sup>2</sup>                                                                                                                                                                                                                                                                                                                     | 5.3290 | \$/fixture                  |
| Annual Cost <sup>3</sup>                                                                                                                                                                                                                                                                                                                              | 63.95  | \$/yr                       |
| <b>LED</b>                                                                                                                                                                                                                                                                                                                                            |        |                             |
| Demand                                                                                                                                                                                                                                                                                                                                                | 58.25  | W                           |
| Usage <sup>4</sup>                                                                                                                                                                                                                                                                                                                                    | 238.83 | kWh                         |
| Rate <sup>5</sup>                                                                                                                                                                                                                                                                                                                                     | 0.1253 | \$/kWh                      |
| Monthly Fixed Charge <sup>5</sup>                                                                                                                                                                                                                                                                                                                     | 0.1904 | \$/fixture                  |
| Annual Cost <sup>6</sup>                                                                                                                                                                                                                                                                                                                              | 32.22  | \$/yr                       |
| <sup>1</sup> 100W HPS Annual Cost - LED Annual Cost<br><sup>2</sup> Based on PG&E LS-2 Rate Structure<br><sup>3</sup> Monthly Fixed Charge x 12<br><sup>4</sup> Assuming 4,100 hr/yr. From PG&E LS-2 Rate Structure<br><sup>5</sup> Based on Linear Regression from PG&E LS-2 Rate Structure<br><sup>6</sup> Usage x Rate + Monthly Fixed Charge x 12 |        |                             |

| Estimated Simple Payback for Phase III LED Fixtures                                                                                         |                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| <b><u>New Construction</u></b>                                                                                                              |                                   |
| Simple Payback (Spot Replacement):                                                                                                          | <b>4.96 Years</b>                 |
| Simple Payback (Group Replacement):                                                                                                         | <b>6.06 Years</b>                 |
| <b><u>Retrofit</u></b>                                                                                                                      |                                   |
| Simple Payback (Spot Replacement):                                                                                                          | <b>11.60 Years</b>                |
| Simple Payback (Group Replacement):                                                                                                         | <b>14.16 Years</b>                |
| <b><u>Details</u></b>                                                                                                                       |                                   |
| <b><u>Annual Savings</u></b>                                                                                                                |                                   |
| Annual Energy Savings:                                                                                                                      | 31.73 \$ per Year                 |
| Annual Maintenance Savings (Spot Replacement) <sup>1</sup> :                                                                                | 20.40 \$ per Year                 |
| Annual Maintenance Savings (Group Replacement) <sup>1</sup> :                                                                               | 10.97 \$ per Year                 |
| <i>Total Annual Savings (Spot Replacement):</i>                                                                                             | <i>52.13 \$ per LED Luminaire</i> |
| <i>Total Annual Savings (Group Replacement):</i>                                                                                            | <i>42.70 \$ per LED Luminaire</i> |
| <b><u>Incremental Costs</u></b>                                                                                                             |                                   |
| New Construction:                                                                                                                           | 258.55 \$ per LED Luminaire       |
| Retrofit:                                                                                                                                   | 604.65 \$ per LED Luminaire       |
| <sup>1</sup> Sum of Average Annual Item Repair Costs. Does not include administrative overhead, major repair, or other miscellaneous costs. |                                   |