December 2013

Puerto Rico Light Pollution

Alexander Philip Haring
Worcester Polytechnic Institute

John Federico DeVries
Worcester Polytechnic Institute

Matthew David Giambrone
Worcester Polytechnic Institute

Matthew Howard Penrose
Worcester Polytechnic Institute

12/17/13

Light Pollution in Puerto Rico

Measuring ground-level light pollution in

San Juan, Puerto Rico

Authors:

John DeVries, Alex Haring, Matthew Giambrone, and Matthew Penrose

Sponsor:
La Junta de Calidad Ambiental

Advisors:
Stanley Selkow and Hugh Lauer

Abstract:

Ground level light pollution is a growing problem across the globe. In Puerto Rico, light pollution is a serious problem for people living in urban environments as well as organisms in the wild. While the health effects of excess light are well documented, the methods for collecting data on ground level light pollution are not. The goal of this project is to develop a procedure for measuring ground level light pollution, and to carry out initial light measurements to lay the groundwork for future studies. Surveys of Puerto Rican citizens were done to get an idea of public awareness of light pollution. The outcomes of the project are a manual for collecting data, initial measurements using the procedure at key locations, as well as a better understanding of public opinion. Our results will be presented to Para la Naturaleza and la Junta de Calidad Ambiental so they can use it to create a plan for future regulation and control of light pollution in Puerto Rico.

EXECUTIVE SUMMARY

The societal demands for adequate lighting on sidewalks, highways, and other public areas result in the continuous increase of artificial light in both urban and rural areas across the globe. Puerto Rico is no exception to this, and the entire island has seen a rapid increase in artificial nighttime lighting over the past thirty years. Excessive lighting can spill over into natural areas through both sky glow and trespass, which negatively affects local flora and fauna. This unwanted light is known as light pollution. Light pollution can be broken down into four different categories:

1. Skyglow is the illumination of the nighttime sky due to artificial lighting.
2. Light Trespass occurs when light is shone where it is not wanted, especially when it crosses property lines.
3. Light Glare is when light is shone directly, or reflected, onto an organism and causes discomfort.
4. Light Clutter is the grouping of many, often colored, lights.

All four of the types of light pollution are prevalent in San Juan, Puerto Rico. Our study focused on ground level light pollution, quantitatively measuring the ambient light level and making qualitative observations about the light trespass and light glare.

The goal of our project was to develop methods of gathering data on ground level light pollution. To accomplish this goal, we developed a protocol for measuring ambient light levels using handheld meters, we tested this method in the field, and surveyed inhabitants of the areas to correlate people's perceptions of light pollution with the meter readings.

The first step in developing our methodology was to learn to use the light meters provided by la Junta de Calidad Ambiental, which were the Extech HD-450, Extech SDL-400,

and Konica/Minolta T-10A. For the purpose of our experiment we needed a light meter that was highly sensitive in even the darkest nighttime areas. We settled on using the Konica/Minolta for our measurements due to its superior accuracy at low levels of lighting. Our method for measuring the ambient light level was created based on the Outdoor Site-Lighting Performance method. A government cartographer divided Old San Juan into 384 100x100m quadrants, and divided each of those into 10x10m sub quadrants. The computer program ArcGIS created the quadrants, and randomly selected 54 to be measured, the number needed to be scientifically significant within the region. This number was determined by using the methodology provided by the JCA. Each quadrant was given a daytime and nighttime assessment noting weather conditions and numbers of lights present. These assessments included day and nighttime photos, as well as a nighttime video. To measure the ambient light, we took 3 luminance measurements at a height of 1.5 meters facing into the quadrant, every 2.5 meters along the perimeter. The ambient light level is calculated from the average of these measurements. In addition, we organized the individual measurements at each quadrant to be correlated with the written descriptions and pictures of the sites. In addition, we wanted to gain a better understanding of the public opinion of artificial lighting in San Juan. The public opinion gives an indicator of whether or not light pollution is a public annoyance. The initial plan for this was to hand out surveys at each quadrant; however it quickly became apparent that this would not get us enough responses. Instead, we created a survey through Survey Monkey and distributed it to the JCA's contact list.

Findings

1. The ambient light level varies greatly from location to location, even those that are close together.
    a. The lowest ambient light level we measured was in front of El Morro, the average luminance was 0.007 footcandles.

   b. A short distance away from the cruise ship dock, we measured the greatest ambient light level which was 1.700 footcandles.
   c. Ground level light pollution can be blocked by trees, buildings, or fences.
2. Even in areas that have low ambient light levels, there can still be individual sources of glare.
   a. The ambient light level in a dark parking lot was on 0.606 footcandles, but one reading taken in the direction of a nearby floodlight registered 1.453 footcandles.
3. Ambient light level measurements do not provide any information about light trespass.
   a. To measure light trespass there must be property line. Trespass is usually measured in case studies where residents have complained about unwanted light shining into their home or onto their property.
   b. Ambient light levels can provide information about areas that potentially have light trespass. If the ambient light level is high in a residential area, there is a good possibility that the tenants are experiencing light trespass.
4. The online survey provided insight into the public opinion of light pollution; however we cannot draw any statistically significant results.
   a. Through Survey Monkey we are not using a random sample, and we do not have enough responses to consider our survey statistically significant.
   b. 50% of the responders believe that light pollution is a serious problem in San Juan.
   c. 60% of the sample population have noticed an increase in artificial lighting in their neighborhoods.

Recommendations

1. Continue to expand this study of light pollution. We have gathered information on Old San Juan, which is one small area of the city. The most important result of our project was the development and refinement of a methodology.
2. Use shielded and full-cutoff lights. This constricts the light produced by a luminaire to a specific area. Shielded and full-cutoff lights reduce light trespass and glare while still illuminating areas that must be well lit.
3. Begin documenting case studies. Individual studies of locations with light trespass will provide more evidence of the light pollution problem.

Table of Contents:

Chapter 1: Introduction

The world is a thriving environment that runs twenty-four hours per day, and as populations grow the demand for more lighting has increased significantly (Aubrecht, Jaiteh, Sherbinin, 2010). The societal demands for adequate lighting on sidewalks, highways and other public areas result in the continuous increase of artificial light in both urban and rural areas across the globe. For example, bright billboards and signage have illuminated Hong Kong for many years, causing interference in everyday life (Walls et al., 2010). Companies like Pro Billboards have recently installed new LED billboards in San Juan that contribute to the visual glare experienced by drivers on highways and to light trespass (See Glossary For Definitions) when located close to residential areas ("Pro Billboards", 2013). The increased luminescence has affected behavior patterns as both humans and wildlife attempt to adapt to light intrusion (Gaston, Bennie, Davies, & Hopkins, 2013; Longcore & Rich, 2004). These increases in unwanted or unintended levels of light lead to a high presence of light pollution, which is defined as any adverse effect caused by artificial lighting ("Dark Skies Awareness: Seeing In The Dark", 2009).

Limited in geographical size, yet laden with industry and dense with population, Puerto Rico is particularly susceptible to the effects of light pollution. The Commonwealth produces massive amounts of light (Cinzano, Falchi, & Elvidge, 2001), contributing to the amount of skyglow and the other forms of light pollution. Multiple urban areas throughout the island radiate energy from wastefully lighting areas where it is not wanted or needed, affecting indigenous wildlife behavior patterns, plant life, and coral reefs (Aubrecht & Elvidge, 2008). The increase in the amount of skyglow, light trespass, glare, over-illumination and clutter (See Glossary) of light has had adverse effects on the human population as well (Chepesiuk, 2009).

Due to the large social, industrial, and cultural value of San Juan (Kinsburner, 2008) as the capital of Puerto Rico, the city is well lit at all times to accommodate the number of people that frequent it on a daily basis. The dense artificial lighting currently used throughout the city produces a significant amount of skyglow that mars the visibility of the night sky. Despite the fact that it has such presence in the commonwealth, light pollution has not been extensively examined in Puerto Rico. Therefore, it is vital that measurements of the presence of light pollution throughout the island be taken.

The goal of this project, which was sponsored by Para la Naturaleza, a prominent Puerto Rican conservation trust, and la Junta de Calidad Ambiental, a government conservation agency, is to assist with initial research on the problem of light pollution in Puerto Rico. One of the major goals was to develop a methodology for future studies on light pollution. This methodology was tested by taking measurements in the field. Another goal of the project was to gauge the public understanding and awareness of light pollution and provide information of it. Our research team travelled to different locations throughout Old San Juan with light meters to log information about ground level illumination. In addition to collecting quantitative data on light pollution, an additional goal was gathering public opinion of light pollution through surveys.

Chapter 2: Background

While astronomers have worried about and measured skyglow, there is a definite lack of research about measuring light pollution separate from skyglow as it affects normal human activities as well as those of other animals and plants. This project was an exploratory study to determine the best methods to accomplish this research. The first step was to define light pollution and its impact on organisms in various environments. The second step was to gain a clear understanding of the tools and methods used around the world to limit the amount of light pollution. The final step was to organize the collected data in a standardized, quantifiable manner for the ease of researchers who will conduct future studies.

RESEARCH AREA INFORMATION

Hundreds of years old, filled with plazas, fortresses, and numerous statues and monuments, Old San Juan is a popular place of tourism. El Castillo de San Felipe del Morro commonly known just as “El Morro” was Puerto Rico’s impenetrable ocean side fortress used to defend the island. This daunting citadel is one of the most frequented sites in Puerto Rico. There are multiple statues dedicated to Christopher Columbus, as well as statues paying tribute to other important persona to Puerto Rico. In order to show their beauty and meaning, a large number of luminaires exist throughout Old San Juan, making it shine at night. A combination of El Morro, multiple ship ports and thriving nightlife activities, makes Old San Juan a highly luminous area. It was for these reasons that this zone was chosen to be the main focus of our study.

LIGHT POLLUTION AS A GLOBAL PROBLEM

Types of Light Pollution

Light Pollution is defined as any adverse effect due to artificial lighting, and can be found to occur in multiple forms ("Dark Skies Awareness: Seeing In The Dark", 2009). The term light pollution is a broad one and contains such subcategories as skyglow, light trespass, glare, and clutter (See the Glossary for definitions).

One prevalent example of ground-level light pollution in the San Juan area is billboards, which are made with light emitting diodes (LEDs) that contribute heavily to the growing intrusive light trespass problem. Recently, advertising companies have been installing large LED lit billboards along highways and throughout the city of San Juan (PRO Billboards, 2013). Pro Billboards announced on their website that the company constructed two 14' by 48' LED billboards along Highway 22 which connects Bayamón and San Juan, two major cities on the island of Puerto Rico.

Light Pollution is a strong marker for wasted energy, which is caused in large part by over-luminescence and light clutter (Chepesiuk, 2009). A clear benefit of measuring light level values will be determining problem areas in which resources are being needlessly used. Once they are determined, different methods can be implemented to streamline the energy efficiency in them to benefit the environment and economy. Objects such as streetlights, LED signs, car headlights, flashlights, and televisions contribute to glare and trespass levels in urban environments. Glare, over-illumination, and light clutter have a stronger presence in metropolitan cities such as San Juan and Bayamón compared with wildlife reserves or deep in El Yunque National Rainforest. That is not to say that light pollution does not exist in these areas. They

merely have different sources and levels of light pollution within them, and the areas with higher levels are more likely to be problem areas than the others.

Effects of Light Pollution on Humans

It has been shown that the human body and the behavior of many animals have biological cycles that are sensitive to natural and artificial light (Chepesiuk, 2009). The human sleep cycle is dependent on sunlight and has various effects on people psychologically. The presence of artificial lighting during the night interrupts the natural sleep cycles of people in addition to causing stress through repeated exposure to unwanted light intrusion in the home. Studies show that artificial lighting suppresses the production of Melatonin (Chepesiuk, 2009), a bodily hormone affecting the entrainment of, or the ability to acclimate to, the sleep cycle. Melatonin is produced significantly more during nighttime darkness than in a lit nighttime region. Melatonin has also been shown to suppress the growth of cancerous tumors when the blood had been exposed to night-time lighting (Cheney 2011). It has also been determined that there is an increased percentage of breast cancer in women who live luminous night-time areas as opposed to the least lit rural areas (Chepesiuk, 2009). Although people are more adaptable to the environment than many species of animals, the adverse effects on humans are still present. The circadian clock of humans is responsible for brainwave, hormone, and cell regulations among other bodily functions (Chepesiuk, 2009). The intrusive trespass of lighting into homes may upset people's natural bodily clock and cause stress and further develop adverse effects.

Effects of Light Pollution on Natural Life

The documented rise in urbanization and the steady development of technology over the past century have naturally led to a significant increase of the use of artificial lighting and, therefore, light pollution. The intrusion of these artificial light sources has had negative

consequences on local ecological systems. Plant life, specifically, undergoes interruptions in its natural photosynthetic cycles that can affect its growth, internal information flow, and pigmentation (Gaston, Bennie, Davies, Hopkins, 2013). On the other hand, mammals as well as female sea turtles have been recorded to choose new breeding grounds with lower levels of light. Turtle hatchlings become disorientated upon birth due to light pollution, causing a sizable drop in their survivability (Taylor and Cozens, 2010). When a female lays her eggs on a dark beach, the hatchlings will instinctively head towards the ocean for survival. However, if the lights in the immediate area are strong enough to cause the baby turtles to become distracted, then this will result in a higher mortality rate in the turtles (Taylor and Cozens, 2010; Witherington, 1992). Certain nocturnal birds use the stars are guidance for their migrations across the landscape. When flying over cities, such as New York City, which produce extensive amounts of artificial light, birds have been seen to become confused and drawn towards buildings. The result of this attraction can be a fatal collision with buildings in cities (Cheney, 2011).

Animals, insects in particular, are especially susceptible to light pollution because certain species can view different portions of the light spectrum than humans. Moths are more attracted to high-powered, 100 watt, sodium lamps that produce ultraviolet lighting, and are therefore more visible to predators that prey on the captivated insects. Comparatively, moths are much less attracted to low-powered 100-watt sodium lamps, as they do not produce ultraviolet light (Rydell, 1992). The relative levels of absorption from low-pressure sodium lamps compared to pigment absorption are shown in Figure I: Taken from Royal Commission Report (Pollution, 2009). (Pollution, 2009) (See Appendix C: Figures). Although this moth attraction may seem beneficial to all predators, it will favor the faster hunting species of bats over the slower ones, which tend to avoid such lighted areas. This disadvantage threatens the food supply of the slower bat

communities. Artificial lighting at night, as Longcore describes as a “perpetual full moon”, will favor species that have a higher tolerance or adaptability to lighting, disrupting natural prey and predator relationships (Longcore and Rich 2004).

LEGISLATION CONCERNING LIGHT POLLUTION

Notable Regulations Around the World

Many measures have been taken around the world to limit the extent of light pollution in urban environments. Some countries have just taken their first steps into creating useful policies. For example, Liberia has recently acknowledged the dangers of light pollution in its “Save the Sea Turtle and Protect the Mangroves” campaign (“Liberia; Mangroves Protection Awareness in Buchanan,” 2012). This reflects a growing interest in potentially limiting light pollution.

Countries such as South Korea have already begun to control their output of light pollution. The South Korean government passed a law concerning the regulation of artificial lighting, which went into effect February of 2013. This plan takes a rational approach to the issue, not completely eliminating lighting from the environment but reducing its effects (“Where did all the stars go?” 2012). China took a different approach in 2011; while programs were developed that would collect data and public opinion on light pollution, many officials thought that light regulation was unrealistic and sought to enforce voluntary guidelines. However, other officials such as Hahn Chu Hon-keung believed that these guidelines would be ignored. Therefore the thought process behind the addition of billboards is that the level of brightness is already so high that installing a few more billboards will no elevate this level significantly (“Officials Urge Guidelines On Light Pollution...” 2011). Such billboards have been shown to be a problem in many places, such that the US Federal Aviation Administration has even considered pre-emptively banning billboards in orbit of the planet (“Blinded by the Lights” 2008).

These early programs can often take time to develop. For example, in 1996 the Commission of the European Union was asked what plans they had to fix light pollution. A representative of the Commission stated that they were currently assessing the situation and developing more efficient lighting, but required more information before taking serious actions ("Written Question No. 514/96," 1996). The question was asked again 6 years later, to which the commission replied that they did not have enough information to take action. However, different programs such as the Green Light Program were already in place to assess the efficiency of light fixtures ("Written Question E-1207/02," 2002).

The Lombardy Law no. 17 of Lombardy, Italy, was a law passed in 2000 designed to ease the astronomical and economic impacts of wasteful lighting policies throughout the Lombardy district. It sought to do this by creating measures to make other existing lighting policies enforceable (CeloBuio, 2000). A law titled the Protection of the Atmosphere Act in the Czech Republic, based on the Lombardy Law, was passed on February 27th, 2002. This law called for a reduction of light pollution and defined light pollution as "every form of illumination by artificial light which is dispersed outside the areas it is dedicated to, particularly above the level of the horizon" ("Czechs against light pollution," 2002). Similar laws were considered in Laguna Beach, California, but dealt exclusively with lights used during major holidays. According to several petitions, celebrations held on many holidays produced such extreme amounts of light that the trespass became unbearable (Claudia, 2011).

In 2006, British Parliament passed a law with the purpose of severely limiting light pollution. This was made with the goal of limiting the biggest centers of light production in the UK, such as Nelson's Column and the Liver Building in Liverpool (Tom, 2006). The plan of this law was to replace large, bright lights on different landmarks with smaller lights directed at the

ground. This legislation would influence several measures taken in Wales, which sought to maintain the level of darkness in its skies that attracted so many tourists ("Protect night skies plead stargazers; Light pollution is blotting out our views of the stars," 2009). The Brecon Beacons National Park in Wales was able to obtain the much sought-after title of International Dark Sky Reserve from the International Dark-Sky Association, thanks to the efforts of the British Astronomical Society ("Astro-tourism set for star turn with grant of Dark Sky Reserve status to Beacons, 2013).

The next site to obtain this status, being the most recent with a June 28th, 2013 designation, was the Wood Buffalo National Park in Canada. Spanning portions of both the Northwest Territories and the province of Alberta, the park is roughly the size of Switzerland yet contains minimal artificial lighting. In the 4.4 million hectares that it covers, only shielded road lights for the highways that pass through it, and car headlights on the highways are allowed ("No lights in an area big as Switzerland," 2013). This accomplishment displays that providing lighting even in a largely natural area can be accomplished skillfully. Additionally, the success of other programs such as a law passed in Slovenia, which decreased the brightness of the capital city by 20% (Galbraith, 2012), shows that such measures can be effective.

Legislation in Puerto Rico

In 2008, Puerto Rico passed into law Act 218, the Light Pollution Control and Prevention Program, which strived for the "complete eradication" of light pollution, which it defines as skyglow, for the sake of local astronomers, lowering energy costs, reducing conventional pollution, and to protect the indigenous creatures of the island through "necessary and appropriate" measures ("Light Pollution Control and Prevention Program," 2008). However, the governor who supported this program, Anibál Acevedo Vilá, was replaced by Luis Fortuño in the 2009 gubernatorial elections. Fortuño placed much of his focus on other types of pollution, and

Act 218 was reduced much in scope by Act 29 in 2012, which amended Act 218 so more focus could be applied to other kinds of pollution ("Amendment to the Light Pollution Control and Prevention Program," 2012). If it comes to drafting new laws concerning light pollution, it would be a good idea to keep what occurred with these two acts in mind to ensure that the regulations survive.

MEASURING LIGHT POLLUTION

There are several different forms of light pollution: *skyglow*, *light trespass*, *light glare*, and *light clutter*. Skyglow is the measure of light radiated directly upward into the sky, with the use of cameras and special computer software. Light clutter and glare do not have well defined measurements methods currently. Light pollution can be measured quantitatively using different methods and equipment (Kolláth, 2010). Light pollution was first established as a problem and measured in 1970 by Merle Walker (Walker, 1970). Since then, the study of light pollution has grown tremendously, with the creation of many new techniques to collect light pollution data. There are many commercially produced hand-held light meters and computer programs that will collect and analyze light pollution data (Biggs, Fouché, Bilki, & Zadnik, 2012).

Measuring Ground Level Light Pollution

Gathering data about ground level light pollution can only be collected using light meters unlike skyglow which is able to be accurately measured with the use of a camera. The majority of light pollution prevention support is by astronomers who are solely interested in skyglow (Hölker et al., 2010). Therefore, there has been very little research focused on ground level light pollution. Ground level light pollution includes the types glare, trespass light, and clutter, each measured differently. This type of pollution also has much more variation over time, which makes it more difficult to gather meaningful data. The light meters used for skyglow can also be

used for ground level light pollution (Biggs et al., 2012) but due to the narrow scope of the project, we will not be doing these measurements.

The Illuminating Engineering Society of North America recommends that in areas of an extreme lighting source, that the entire area be observed. IESNA does not recommend measuring individual luminaires, because this will not take reflection into account (IESNA, 2000). The Federal Highway Administration Lighting Manual suggests the Outdoor Site-Lighting Performance Method (OSP) to measure the true impact of luminaires. This method creates an imaginary square around the property to be measured. Luminance measurements are then taken every two meters around the square, which will give average luminance inside the square and illumination of each wall. Using these measurements, the location of the maximum trespass lighting can also be located. Measuring the ambient luminance inside the property before measuring the trespass level is beneficial because it gives a reference for the contrast.

Chapter 3: Methodology

Growing awareness of adverse effects of light pollution demands an increased response to the issue, including the gathering of more knowledge of the subject. The goal of this project was to develop methods of gathering data on ground level light pollution for further studies in Puerto Rico. An additional objective was to gain an understanding of residents' knowledge and opinions on light pollution. To accomplish these goals the project was broken down into three main objectives:

1. Developing a method for collection of ground level light pollution data using hand held light meters.
2. Testing this method in the field and collected initial data sets for ground level light pollution.
3. Surveying Puerto Rican citizens to gain a better understanding of the public knowledge and opinion of light pollution.

DEVELOPING A METHOD FOR DATA COLLECTION

One of our main objectives was to develop a method for ground level light pollution data collection. This method needed to be clear and thorough because it lays the groundwork for a long-term light pollution study to be carried out by technicians who must perform these measurement processes on a routine basis. The four aspects of the project were: understanding light meters, deciding which locations were important for data collection, setting the standard set of conditions to gather readings, and designing a plan for organizing the stored data. This method is specific to our research with the JCA. For a more general methodology please refer to our lab manual located in Appendix G.

Understanding the Light Meters

The Junta de Calidad Ambiental (JCA) already owns two light meters for the purpose of studying light pollution, namely the Extech 407026 and the Konica/Minolta T-10A (See Appendix A: Light Meter Data Sheets). The Konica/Minolta device is extremely useful at extremely dark areas because it provides the greatest level of accuracy, which is three decimal places. The Extech photometer is better suited for extreme levels of brightness as it can detect larger quantities of light than the Konica/Minolta is able to. For the reasons of accuracy, we have chosen to conduct all measurements with the Konica/Minolta device.

One of the first steps in developing the research method was to understand the user interface of each meter. They are complicated pieces of equipment with many features and functions, some of which were not needed for our research. We then documented the process and created a manual (See Appendix G: Lab Manual) for setting up each light meter from startup to data collection for future users in the JCA, such that they could easily make many routine measurements. The process of creating the manual was determined after trial runs using the hardware. The purpose of this manual is to minimize the effort required to understand the light meters for the benefit of the operators, who may have not had preexisting experience working with the devices. The manual includes detailed instructions on how to operate the instrument in an easily understandable manner, including graphics and diagrams where appropriate. We used the existing manuals for the devices as references for formatting the guide (See Appendix A: Light Meter Data Sheets).

Choosing Data Collection Locations

While it would have been productive to collect light pollution data all over the island, we were limited in the time given to perform research in Puerto Rico, and therefore were forced to focus on key locations. The San Juan Planning and Territory Office provided a map of Old San

Juan overlaid with 384 quadrants. Each quadrant is 100 meters by 100 meters subdivided into one hundred 10 meter by 10 meter sub-quadrants. Using software (ArcGIS) from the Planning and Territory Office, one 10 by 10 meter sub-quadrant is selected. This method provided statistical information about the light pollution levels of the district.

Ambient Light Level Collection

At each location we made a total of 60 measurements in order to accurately gather the amount of ambient light. The 60 measurements consist of 3 measurements taken every 2.5 meters along the edge of the quadrant (Brons, Bullough, & Rea, 2008). Along each edge of the 10 meter by 10 meter sub-quadrant, measurements were taken facing the interior of the quadrant. Each measurement was parallel to the other 4 measurements on that edge. The ambient light level was then calculated by averaging these 20 values in each sub-quadrant. We chose to construct our quadrants based on the cardinal directions in order to standardize our method of data. We realize that we may be missing a certain aspect of the data collection by orienting our quadrant in this manner, but further studies will have o be conducted in order to conclude that fact.

Standard Conditions for Data Collection

It was crucial to keep detailed notes about the weather conditions when collecting data. This allowed the determination of whether certain conditions produced erratic measurements relative to others, and therefore finding a standard for future studies. However, there were some constraints for data collection that could be implemented while in Puerto Rico. To minimize the sunlight, data was collected after atmospheric twilight, which is when the sun is 18 degrees below the horizon (Kolláth, 2010). In Puerto Rico this condition existed from roughly 6:45 PM to 4:25 AM local time in the seven-week period we performed our study (Gronbeck, 2009).

Storing and Organizing Data

The light meter Konica/Minolta T-10A was used for instantaneous measurements. A reading was taken at each of the 60 points described and recorded by hand on data table. This hand data is then uploaded to a computer. In addition the average of these individual points were calculated and recorded, as well as the maximum reading and the minimum reading.

TESTING THE RESEARCH METHOD IN THE FIELD

During pretesting of the research method, some aspects of the plan were found to be less than effective, and testing these methods located some weaknesses. The three main issues that became apparent while conducting field testing were problems such as mastering the user interface of the various meters, understanding the ideal conditions for data collection, and performing the various methods for storing data.

User Interface of Light Meters

We developed a procedure for using the light meters, but navigating menus and following the procedure in the dark provided its own challenges. The interface is rather simple, but requires a calibration before start up in order to have a zero light reading for comparison. The lack of calibration would cause man difficulties when comparing our data due to the fact that the data between locations may not be comparable. For these reasons, we included a short troubleshooting section in the user manual in order to prevent this simple error.

Achieving Standard Conditions

It is unrealistic to test only on nights with clear weather, because there are so few of them in Puerto Rico. Therefore, a part of the procedure is to maintain an accurate log of the weather conditions at the times of observations. It would be ideal to make measurements in the same time of a lunar cycle, however the times constraints of this project did not allow this and thus affected the standardization of the data and changing the amount of ambient light. There was not enough time to gather concrete data that would be representative of how measurements can vary under

different conditions, but it was enough to provide suggestive analyses for other researchers to reference in the future.

Storing and Organizing Data

We were able to develop a method to store this data for the duration of the project. This was determined by taking measurements, recorded in foot-candles (See Glossary), at several locations. Through first-hand experience we quickly developed an understanding that each of the meters stored its data in its own format, so we had to find a standard in which our data could be presented from each device. To standardize the measurements we converted them all to one unit, footcandles.

DETERMINING PUBLIC OPINION

We asked survey questions in Puerto Rico to assess the general feelings and knowledge of residents of the Commonwealth, especially in the areas that appeared to contain a relatively high level of ground-level light pollution. We used surveys to gather information concerning the opinions of the locals of Puerto Rico. Data was collected through the use of a website, Survey Monkey.

Developing the Questions

Since Spanish and English shared relative dominance in terms of spoken language in Puerto Rico, we chose to conduct these surveys in both languages. We translated our initial questions and revised them with the help of native speakers. Once satisfied with the questions, we submitted them to the JCA for approval by Sr. Alicea. Additionally, we determined that it was best to have a member of our sponsor organization that is fluent in Spanish present for translating follow-up questions on the spot in Puerto Rico.

Conducting the Surveys

Conducting the surveys in various localities allowed us to question a large number of Puerto Rican residents living in the Old San Juan area. With this information we tried to gain an

idea as to how much the average Puerto Rican resident understands light pollution, and also to form hypotheses as to how people's perceptions of light pollution vary by environment.

This method proved to be ineffective as most of people willing to answer were tourists who are only exposed to Old San Juan for a matter of days. This also imposed a strong bias in our sample population. In order to continue surveys, we decided to use an additional source, the website Survey Monkey. The electronic survey is easily distributed to a list that the JCA had.

Organization of Responses

The responses were pooled and analyzed based on what category the surveyed individual belonged to. Once the responses were transcribed we determined the correlation between location and level of light with the answers we received. We recorded who said what, as different ages and genders are affected differently in terms of health effects caused by high light exposure levels (See Chapter 2: Background).

Chapter 4: Results and Discussions

This chapter outlines the results of our measurements. Firstly, we gathered qualitative results concerning the light sources at each sampled quadrant in order to make generalizations as to which kinds of sources most needed to be shielded better. Secondly, we gathered quantitative readings that gave us the ambient level of light in the area as well as the levels of light in specific directions. We were also able to learn specifically how a portion of the population of San Juan as a whole feels towards the concept of light pollution.

DAYTIME AND NIGHTTIME SITE ASSESSMENTS (OBSERVATIONS)

To understand the significant of certain readings, we performed qualitative assessments of the areas surrounding each $100m^2$ quadrant that we sought to analyze. These data gatherings included taking notes on the light sources in every cardinal direction from the center of each quadrant, both during the day when we explored the points to determine their safety and accessibility, and also during the night while we performed our measurements. We additionally took a video at night starting at the north position and slowly spinning counter-clockwise in the center of the square, in case different sources were missed in the daytime photographs.

There was a noticeable difference between the observations we made during the day and those we made during the night. This was because some lights were not noticeable during the day, as well as the fact that the actual brightness of the lights could not be determined while they were off during the daytime. The consistency of the collected information varied as our methodology evolved.

This is an example of observations made in Quadrant 182, located in the Muñoz Rivera Park. These observations were performed during the night. (See Appendix E: Collected Observational Data for complete set)

	OBSERVATIONS AT 182 (DAY)
NORTH	9 post lights
EAST	1 post light, a small road contiguous to the park
SOUTH	Traffic lights, lampposts, and a large building
WEST	4 luminaries on the ground, apartment buildings with street lights. The skies here are relatively dark.

The following eight pictures were taken at the site. In the night photo, members of our team can sometimes be seen:

Quadrant 182, North, During The Day And Night

Quadrant 182, East, During The Day And Night

Quadrant 182, South, During The Day And Night

Quadrant 182, West, During The Day And Night

AMBIENT LIGHT CONCENTRATIONS

To assess the general light level in Old San Juan, we based our methodology off of an altered form of the Outdoor Site-Lighting Performance Method to establish the ambient light level of 54 quadrants. However due to time constraints, we were only able to accomplish 27 of these quadrants. Each quadrant we measured is a 10x10m square randomly selected by ArcGIS, a cartography software application. At each site, we used caution tape to set up a quadrant. At each quadrant we took a total of 60 luminance readings using the Konica Minolta T-10A. If a quadrant passed through a building or some other structure, we had a 5 meter tolerance to shift our quadrant due to the tolerance on the GPS that we were using. If the problem still could not be resolved, we would re-select another point randomly to replace the problematic quadrant. We took three measurements every two meters along the perimeter of the quadrant in triplicate for accuracy improvements. In addition, we recorded the time, date, weather, and coordinates at the moment of measurement. We filled out tables located in the appendix to organize our data (See Appendix F: Numerical Data Sheets). Analyzing these measurements in combination with the pictures, videos, and written sight assessments brought us to the following findings:

1. **The ambient light level varies greatly in different areas, even within just Old San Juan.**

The darkest area we measured was the field surrounding El Morro. The average ambient light levels in the points around El Morro were as low as 0.007 footcandles. This is so dark that the less accurate Extech meter registered zero. Other areas such as the boardwalk in front the cruise ships had an average luminance of 1.700 footcandles. To give this some perspective, this is bright enough to read a book without any problem. Unlike sky glow, which is relatively constant over a short distance, ground level light pollution can be blocked by buildings, trees,

and geographic features. Therefore noting which geographically features are present at each of the locations is important.

The map above shows the ambient light level readings throughout all of old San Juan. These were the 27 quadrants that we successfully measured, and although not scientifically significant, one can draw conclusions about different regions and their relative brightness to others. For example, the highly commercialized area at the far West of the map is rather bright compared with that of some of the residential and public areas in the center. The West has lots of night life activities, well illuminated streets and contains the brightly light docks. However, the center of the map has more parks and homes and is relatively darker. Some of the brightest areas were also located on the right side of the map in ports and privately owned properties.

2. **Even in areas of dark ambient light level, there can still be individual sources of glare.**

It is important to record the maximum luminance reading in addition to the ambient light level in each quadrant so that individual luminaires can be identified. One of our quadrants was located on a shipping dock. Overall, the location was very dark with an ambient light level of

0.612 footcandles. There was an unshielded luminaire to the east of our quadrant that provided a discomfort glare to the observer, and a luminance reading of 1.453 footcandles.

3. **Taking ambient light levels does not provide definitive evidence on the existence of trespass.**

Trespass lighting is defined as light crossing over a property line into an area where it is not wanted. Our sample grids were randomly selected 10x10m squares without regard to property lines. The ambient light level can give specific information about the amount of light in the city, and direct us towards areas of the city that may have problems with trespass, but it cannot give any data about trespass in the city as a whole. To gather trespass, separate case studies must be conducted that measure the light crossing into someone's private property. Case studies must also be conducted in public areas such as those with trespass due to hotel lighting. Several people have already contacted the JCA to request case studies of their property, but we will not be conducting these due to time constraints. These will be carried out in the future by the agency.

Even though our data collection method did not relate to light trespass, we can compare the site assessments we performed to the light levels we collected in order to speculate what may or may not be major sources of trespass and glare in Old San Juan. For example, in one quadrant we saw a maximum luminance reading of 0.289 footcandles from the northeastern corner, facing south. Meanwhile, we saw a minimum reading at the southwestern corner facing north. From the pictures we took on-site, we can say that the brightness of the round, unshielded luminaires on the nearby sidewalk had a greater effect than the bright, half-shielded lights over the northern parking lot. This is most likely due to the nature of the lights, as well as the difference in proximity to the point of measurement. With this information future research can search for a

pattern and propose ways to further improve lighting in specific areas and in new luminaries, as a database of collected data grows.

COMPARING SITE ASSESSMENT DATA TO LUMINANCE

We were able to draw additional conclusions by looking at the averages and extrema for each point as a whole. The following table illustrates this method:

Quadrant	Min	Max	Avg
20	.002	.021	.009
52	.001	.013	.007
12	.000	.013	.005
22	.000	.030	.011
54	.058	.576	.196
234	.206	1.073	.423
80	.056	2.176	.805
117	.283	4.640	1.739
203	.071	3.680	.432
284	.010	.094	.031
98	.132	.644	.370
136	.046	.483	.172
99	.055	.583	.233
228	.076	.752	.379
225	.046	.592	.244
297	.042	.316	.147
346	.217	1.453	.612
344	.792	3.177	1.887
322	.152	3.523	1.323
182	.039	.289	.122
323	.030	.527	.214
222	.011	.180	.067
185	.013	.721	.175
186	.173	1.452	.759
187	.099	1.411	.695
155	.215	3.183	.724
195	.009	.245	.062

The extrema and average of each measured point, in the order they were recorded.

The data highlighted in yellow on this table represents the 5 maximum points measured under the minimum, maximum and average values measured, while the blue data represents the 5 minimum points. Some of the quadrants share two or three yellow or blue data points; these can

be determined to be the all-around brightest and darkest measured quadrants, respectively. As such, we can see that points 12, 20, 22, 52 and 284 were the darkest areas while points 117, 155, 322 and 344 were the brightest.

The quadrants 12, 20, 22 and 52 were all located on the property of El Morro, an important landmark in Old San Juan. The area is a large, unlit park with a dimly lit fortress on the northern end, water to the east and west and a tourist area including galleries, bars and a school of arts to the south. It is, therefore, easy to believe that out lowest luminance readings were taken at this site, as well as the fact that the largest readings were taken facing south (except at point 52, where the tourist area was further east than south). Since we had not begun to take pictures at this point in our methodology, the videos taken at the sites were relied upon to perform the analysis. In most of these the picture is almost completely black except when facing the fortress or the buildings to the south. The lack of lighting here adds great contrast to the other measured points and draws attention to the tourist area of Old San Juan as an area to focus upon.

Point 284 was located in a private dock on the southeastern coastline of Old San Juan. We required special permission from the dock master to access this area, which was located in the middle of a dark parking lot. The area has a few lights surrounding it of modest brightness, then two spotlights at a distance away that light up another section of the yard to the east; these can be clearly seen in the site video:

The Two Bright Light Sources At Quadrant 284.

The largest measurements we encountered at this site were facing the east; more specifically the spotlight on the right side of that screenshot. This location illustrates the potential dark levels of a private property, as well of the effects of lights not angled properly. The spotlights that reach the quadrant we are measuring are not intended to bring light to the area we measured, as evidenced by the low value light readings. Therefore, they should be set up to only light up the area they should; that on the other side of the parking lot. Because the light is unshielded and aimed poorly, a massive amount of glare is created that may bother the night workers at the dock or workers on boats in the bay.

Quadrant 117 is the second brightest quadrant observed over the course of this project, with the second highest minimum and average readings as well as the highest maximum reading of 4.640 footcandles. This point was located on a stretch of grass between El Paseo del Morro and La Caleta de las Monjas. The reason the area is so bright is clear from the video: to the east and west there are extremely bright luminaries that illuminate a large wall to the north and the road, while simultaneously producing a large amount of glare since they are only partially shielded. Meanwhile, lights from across the bay provide a decent amount of light to the area. The lights to the west produced the largest amount of light recorded during the course of the project,

while the combination of all the elements involved led to the second highest total luminance average.

The Direction Of The Largest Recorded Luminance Value

This shows the dangers of using unshielded lights; reflections off of nearby objects as well as their own light may cause large amounts of light glare, skyglow, and, potentially, light trespass.

Quadrant 155, located in El Paseo la Princesa, was another of the most illuminant locations in Old San Juan. This was next to a small park along the walkway, and some of the measurements were taken standing inside of a shallow pond. There was a giant ficus tree with an assortment of lights to the east, a single bright luminaire to the north, a brightly lit pathway with 10 luminaries to the south, and a dark overview of the bay to the west. Interestingly enough, the brightest reading was taken facing west and the darkest measured to the south. A potential explanation for this would be that the first measurement West would be measuring along our quadrant line to the North, as shown in this photograph:

Quadrant 155 South, Showing The East To West Quadrant Line

From this image, it can be seen that the first measurement taken facing west (from the southeastern corner) was directly impacted by two lampposts, one of which was directly above the point of measurement. In contrast, the measurement facing south from the northeastern corner, while it could have been very bright, was facing a wall with very little impact from the luminaries in the park, making it one of the darkest points measured at the site. This illustrates the differences that can exist between site assessment results and actual luminance measurements; the brightest measurement recorded was in a direction where there should have been very little luminaires, while the lowest measurement was in a direction with almost 10 different sources of light.

Another bright area was located in a small parking lot in Muelle Frontier, in Quadrant 322. It was necessary to acquire special access to this dock from the dock master. The parking lot which we measured appeared to have very few light sources during the day, but at night it became clear that there were many extremely bright sources that were not visible during the day, and the lamppost closest to our quadrant was much brighter than anticipated:

Quadrant 322, In The Eastern Direction

There is very little wonder that this direction contained the highest measurements taken at this quadrant. The reflection of this light off of the ground even went on to affect our other measurements, as there were no direct luminaries to the north but the light measured there was significant.

Quadrant 344 was the overall brightest quadrant we encountered. Recorded at this site were the highest minimum reading encountered, the fifth highest maximum reading, and the highest average reading. This was located in the private property of El Club Naútico de San Juan, and required special permission from the director of the club to access at night. This location was surrounded by many bright luminaries, as it was located in one of the main parking lots in the club. Additionally, the sand that made up the ground for the parking lot was extremely reflective, complementing the brightness of the lights in such a way that the entire area was illuminated. It is no wonder that the smallest reading seen here was 0.792 footcandles, and that only one other measurement fell below one footcandle.

PUBLIC OPINION

1. The initial surveying method of asking people to fill out a questionnaire was not successful.

The original survey consisted of 7 short questions on a double-sided piece of paper. However, despite the concise formatting, of all the people approached, only tourists were willing to take the time to answer it. This is understandable, as many of the people we came across in Old San Juan were out for the day with their families. Tourists from the mainland United States were the only ones who were willing to complete our survey; however, they had limited knowledge of the lighting of San Juan and struggled to complete the questionnaire. After hours of attempting to collect responses, and only collecting four completed surveys we decided to reassess the methodology as we had previously designed it. It would not be possible for us to complete a physical survey that would give us statistically significant results, as it was not feasible to collect the statistically necessary surveys required in Old San Juan.

2. The online survey provided insight into the public opinion on light pollution.

Sr. Alicea distributed our survey to his colleagues and friends through Survey Monkey. The survey consisted of seven questions about light pollution and can be found in Appendix D: Surveys. We were able to analyze the results of 100 responders, of these the majority were women and there was a wide distribution of ages. Of the responders, 50% believe that light pollution is a very important problem in Puerto Rico. 60% have noticed an increase in artificial lighting in their neighborhood. On a scale from 0 to 10, people ranked the amount of light entering their homes from the streets at a 5 on average. The most common response to classifying the amount of discomfort from artificial light entering their home was moderate discomfort.

Two of the questions in the online survey were meant to identify the most prevalent sources of outdoor artificial lighting as well as the amount of discomfort that each source provides for those living in their direct vicinity. The five most referenced categories in the one hundred responses that we analyzed were: lamp posts, roadways and vehicles; buildings, houses, and hotels; billboards; and parks, gardens, and parking lots. Lamp posts held the second highest number of references, and were found to be moderately discomforting by 34% of those who listed it in the survey. Only a quarter of those surveyed referenced roadways and vehicles, but it shared a tie between moderately and very discomforting at a solid 28%. The most frequently referenced category was buildings, houses, and hotels. It too had a tie between moderately and very discomforting at a slightly higher 30%. Billboards placed third in terms of frequency, but they shared a tie between moderately and extremely discomforting at 34%. Much to our surprise parks, gardens, and parking lots was the only group that had its highest categories in both very and extremely discomforting. The very and extremely discomforting ratings for this category each received 33.33% of the vote.

Although the results from this survey are not statistically significant, as the amount of surveys required to accomplish this status would be large, we can see that light pollution is seen as a problem by those surveyed. At the same time it must be noted that the sample population may be biased based on their preexisting connection to the Junta de Calidad Ambiental. If nothing else, this is evidence that the research on light pollution, and the public perception of it, should continue. The tabular data from the survey can be seen Appendix D: Surveys.

Chapter 5: Conclusions and Recommendations

CONCLUSIONS ABOUT OUR METHODOLOGY

This methodology was developed based on the similar Outdoor Site-Lighting Performance method, which is used for case studies. At this point, it is time to assess the effectiveness and value of conducting this study. The goal of the study is to find ambient light levels throughout a section of the city. When viewed on an individual site basis, will this provide information beyond that which a researcher could conclude through observations? Since this method will not be directly used for enforcement, does it need to be quantified in this manner? One way to test this would be to give one researcher just the observations and pictures, and give a second researcher the observations, pictures, and the luminance readings. It would be interesting to compare the conclusions drawn from the provided information. Another potential use for this study is the ability to come to conclusions and make general statements about the light levels for a larger surveyed area. Unfortunately, we did not take enough measurements to be statistically significant; however we are able to see the type of information that will be provided.

If this survey is continued until 54 randomly selected locations in Old San Juan are measured, statements such as the average ambient light level in Old San Juan could be made. We must ask what conclusions could be drawn from this. Old San Juan has several different land uses including residential, commercial, and tourism. The lighting requirements in these different locations are different, so higher light levels could be justifiable. If this is the case than making general statements about ambient light levels in Old San Juan may not be helpful in addressing the real problem of light pollution. Another research question is whether our method generates a

definitive ambient light level measurement. If our grid was laid out on an angle instead of lined up with the cardinal directions, would we calculate a different average ambient light level? Slight variation may be acceptable; however the directional nature of light could potentially cause significantly different results. Luminaires we measured in the cardinal directions might be ignored, while other sources that were not directly measured might be, which would likely cause a high degree of variance in the results. Despite this, we would not be able to measure both cardinal and inter-cardinal directions; if we were to rotate the quadrant 45 degrees to get those measurements, we would be creating a second quadrant that covers a different area of land. While the two quadrants might be centered on the same point, the two would have to be analyzed separately.

Additionally, we would not be able to place a circle centered at each quadrant because the distance between the opposite side of the quadrant and the point on the edge of the circle would vary based on location based on the edge of the circle. Since light values can vary so much when just a little distance is gained or reduced, this is not optimal for measuring the light values. It is also important to note that an area on a map cannot be divided into circles or octagons, which would allow analysis of all 8 directions, without ignoring a significant amount of the surface area of the zone to be observed. Therefore, while a square quadrant system based on cardinal directions may not seem the best way to perform measurements at each point (since it potentially ignores some light values), it is the most practical way to analyze ambient lighting. In order to take this missed data into account, however, it is recommended that photographic and analytical site assessments also incorporate these directions.

RECOMENDATIONS

Old San Juan has shown to have varying levels of light readings. They differ from area to area influenced by a number of factors such as geographical obstacles. However, it can be gathered from our research that a number of areas have light sources that spill light into areas outside of their own. This spillage is a possible cause of light trespass in residential areas. One trend that we noticed was lower income housing, especially in public apartments, had much lower light levels than wealthy residential areas. Overall, the brightest areas we visited were tourism districts. This is expected because it provides an increased level of safety. Situations like this can justify bright lighting, but abutting properties can be negatively affected if the lighting is not controlled. Our methodology is not designed to determine this, because it can be used to identify potentially problematic areas; however case studies are necessary for measuring trespass and enforcing regulations.

We recommend that the implementation of semi-cutoff, full-cutoff, and shielded lighting be promoted. The difference we were able to see when these types of lights were used was very evident both quantitatively in our measurements as well as qualitatively when the lights were viewed. These types of luminaires can decrease three types of light pollution, trespass, glare, and sky glow. Angled lights should be discouraged, when lights are angled they create unnecessary glare, can cause trespass, and waste light. This is shown in detail with examples in Appendix H.

It is highly recommended that case studies be done on specific property lines in order to precisely determine amounts of trespass into residents' properties. A separate methodology will be needed for this. Enforcing regulations is one of the more challenging aspects of light pollution, however many other states and countries have developed protocols for this. Arizona is

considered to be one of the most progressive states, as far as light pollution is concerned, so they will have several protocols which the JCA could adopt for enforcement.

Glossary

Illuminance: The measure of light being shone on a surface, weighted to represent wavelengths visible to the human eye (Approximately between 390 nm and 770 nm). It is measured in Lux (lx), (lumens per square meter) and foot-candles (lumens per square foot).

Light Clutter: A product of light pollution that occurs when a large number of lights exist in a small area. It is usually caused by colored lights or business signs

Light Glare: A product of light pollution that occurs when a bright light source comes in direct contact with an organism, causing discomfort.

Light Trespass: A product of light pollution that occurs when light is shone where it is not wanted, such as into private property or a natural habitat.

Luminosity: The brightness of a light source of a certain wavelength as it appears to the eye, measured as the ratio of luminous flux to radiant flux at that wavelength

Luminous Flux: The power of light, weighted to measure the wavelengths perceived by the human eye. Luminous flux is most commonly measured in terms of its Systeme International (SI) unit, the lumen (lm).

Natural Light: The light radiated from celestial objects as opposed to light created by man-made objects.

Over-illumination: A product of light pollution that occurs when more lighting is produced than is actually needed. It is a key cause of the other forms of light pollution.

Skyglow: A product of light pollution; the illumination of the nighttime sky due to artificial lighting. Blocks the visibility of stars and distorts astronomical data.

Appendices:

APPENDIX A: LIGHT METER DATA SHEETS

Extech 407026

EXTECH INSTRUMENTS
A FLIR COMPANY

Experience the Extech Advantage

PRODUCT DATASHEET

Heavy Duty Light Meters

Datalogging Model Available
Automatically stores up to 16,000 readings or manually store/recall up to 99 readings.

Features:

- HD450 Datalogger model automatically stores up to 16,000 readings or manually store/recall up to 99 readings
- Wide range to 40,000Fc or 400,000 Lux
- Cosine and color corrected measurements
- Utilizes precision silicon photo diode and spectral response filter
- Peak mode (10mS) captures highest reading
- Relative mode indicates change in light levels
- Min/Max and Data Hold
- Large backlit LCD display with 40-segment bar graph
- Heavy Duty rugged double molded housing
- Built-in USB port
- Includes light sensor with 3ft (1m) cable and protective cover, Windows® compatible software with USB cable, hard carrying case, and 9V battery

Specifications	
Fc Range	40, 400, 4000, 40.00kFc
Lux Range	400, 4000, 40k, 400kLux
Accuracy	±5% rdg
Max Resolution	0.01Fc/0.1Lux
Datalogging (HD450)	16,000 continuous readings; 99 selected readings
PC interface	USB
Dimensions	6.7 x 3.1 x 1.6" (170 x 80 x 40mm)
Weight	13.7oz (390g)

Ordering Information:

HD400 .....Heavy Duty Light Meter
HD400-NIST ..Heavy Duty Light Meter with Calibration Traceable to NIST
HD450 .....Heavy Duty Datalogging Light Meter
HD450-NIST ..Heavy Duty Datlogging Light Meter with Calibration Traceable to NIST
TR100 .....Tripod for meters with tripod mount feature

3 YEAR WARRANTY

www.extech.com

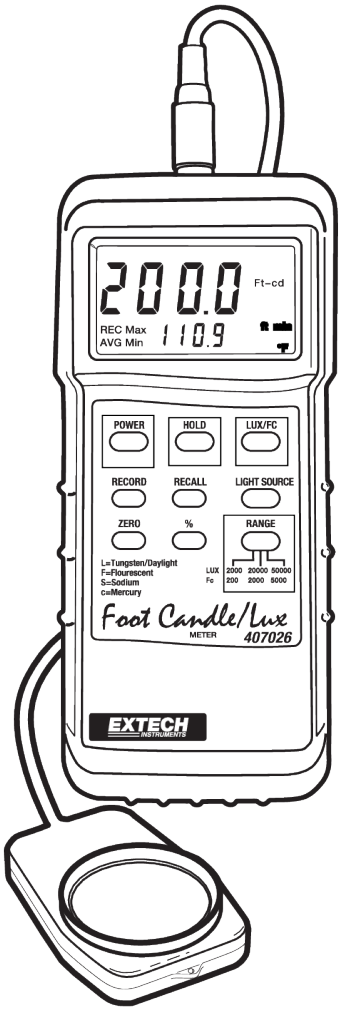
4/22/12 - Rt

EXTECH INSTRUMENTS

USER GUIDE

Heavy Duty Meter

Model 407026



CE

Introduction

Congratulations on your purchase of the Extech Heavy Duty Light Meter. This light meter offers selectable lighting types, data record/recall, relative display mode, and PC interface. This professional meter, with proper care, will provide years of safe reliable service.

Specifications

General Specifications

Circuit	Custom one-chip LSI microprocessor circuit
Display	3-1/2 digit (2000 count) LCD display with contrast adjustment
Measurement ranges	LUX: 0 to 50,000 LUX (3 range); Fc: 0 to 5000 Fc (3 range); Relative mode: 0 to 1999%
Data Hold	Freezes displayed reading
Lighting Types	Sodium, Daylight/Tungsten, Fluorescent and Mercury
Sensor Structure	Cosine/color corrected photo-diode meets C.I.E.
Memory Store/Recall	Records/Recalls Max/Min/Avg readings
Sample rate	0.4 seconds (approx.) per reading
Zero Adjust	Push-button procedure
Auto Power Off	After approx. 10 minutes
Data Output	RS-232 PC serial interface (optional software/cable PN 407001)
Operating conditions	0 °C to 50 °C (32 °F to 122 °F); <80% RH
Power Supply	9V battery
Power consumption	Approx. 5 mA DC. (approx. 200 hr battery life)
Weight	320 g (0.71 lbs.)
Dimensions	Instrument: 180 x 72 x 32 mm (7.1 x 2.8 x1.3") Sensor: 85 x 55 x 17.5 mm (3.3 x 2.2 x 0.7")

Range Specifications

Measurement	Range	Display	Resolution	Accuracy
LUX	2,000 LUX	0-1,999 LUX	1 LUX	± (4% + 2 digits)
	20,000 LUX	1,800-19,990 LUX	10 LUX	of full scale
	50,000 LUX	18,000-50,000 LUX	100 LUX	
Foot Candles	200 Fc	0-186.0 Fc	0.1 Fc	
	2,000 Fc	167-1,860 Fc	1 Fc	
	5,000 Fc	1,670-5,000 Fc	10 Fc	
Relative mode	0-1999%		1%	

Note: The accuracy specification above applies to calibration performed using a precision standard incandescent tungsten light source of 2856^{O}K with meter on the tungsten setting.

Meter Description

1 LCD Display

2 Keypad

3 Light sensor

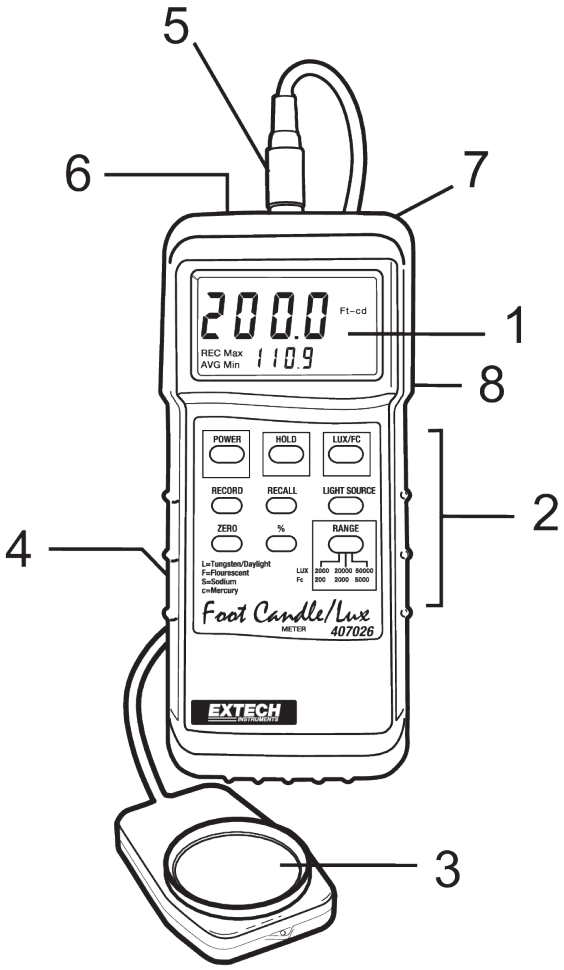
4 Battery compartment (rear)

5 Sensor input

6 RS-232 PC Interface jack

7 Protective Holster

8 LCD Contrast Adjust



Operation

Meter Power and Automatic Power Off

1. Press the POWER button to turn the meter on. If the display does not switch on, check the 9V battery.
2. Press the POWER button again to turn the meter off.
3. The meter has an automatic power off feature that conserves battery energy. After 10 minutes the meter automatically shuts off. To defeat this feature, press the RECORD button to put the meter in the recording mode.

Display ZERO Calibration

Please perform a zero calibration before each use. This will ensure the highest accuracy.

1. Place the sensor cover over the light sensor, effectively blocking all light to the sensor.
2. Select the 2,000 LUX range using the RANGE switch.
3. Press the ZERO button. The reading should be zero.
4. Remove the sensor cover from the light sensor and proceed.

Selecting the unit of measure

Press the LUX/Fc button to select the desired unit of measure. The display icons will reflect the current setting.

Selecting a light source

Select the type of lighting to be measured by pressing the LIGHT SOURCE button. The display will indicate the lighting type icon (see icon list below).

L = Tungsten/Daylight (use this setting when calibrating with a Tungsten lamp)

F = Fluorescent

S = Sodium

C = Mercury

Note: For Halogen and Metal Halide light use the Tungsten setting

Taking Measurements

Hold the light sensor in the area where light is to be collected. The light being measured must encompass the entire surface of the light sensor dome (pin point lighting such as with LED light cannot be measured).

The display will indicate the light intensity value in LUX or Foot candles (Fc). Note that since the main display area is limited to a reading of '1999', the right-most digit in the 20,000 LUX and 5,000 Fc ranges appears on the lower LCD line. In the 50,000 LUX range, the last two digits appear on the lower LCD line

It may be necessary to adjust the display contrast due to a change in viewing angle or voltage drift. Use the LCD Contrast adjustment located on the right side of the meter to set the preferred contrast.

Display Range Selection

Take a measurement starting at the highest range and then work down using the RANGE switch. If the display shows dashes along the top of the reading area (¯ ¯ ¯), the input exceeds the maximum value for the selected range; select a higher range. If the display shows dashes along the bottom of the reading area (_ _ _), the input is too low; select a lower range.

Data Hold

While measuring, press the HOLD button to freeze the reading. The LCD will display D.H. indicating that the Data Hold function is engaged. Press HOLD again to return to normal operation.

Relative % Mode

In the RELATIVE mode of operation, the meter displays light level as a comparison to a reference value. The reference value is stored by pressing the '%' button while the desired light level reference is on the display. When the button is pressed, '100%' will be displayed and the '%' icon will appear.

After the '%' button is pressed, light measurements will be displayed as a percentage of the reference value. For example, if the light level reference is 1000 LUX, a display of 500 LUX will be represented as 50%. Further, a light level of 250 LUX will display as 25%. Use the equation below:

$$\text{Display \%} = \frac{\text{Light measurement}}{\text{Stored reference light measurement}} \times 100$$

Press the '%' button again to return to normal operation.

Maximum (MAX), Minimum (MIN), and Average (AVG) readings

The meter can keep track of the highest, lowest, and average readings for later recall.

1. Press the RECORD button to start tracking the MAX, MIN, and AVG readings. The REC display will switch on.
2. When desired, press the RECALL button.
3. The MAX display icon appears next to the REC display icon. The reading shown is the highest reading encountered since the RECORD button was pressed.
4. Press RECALL twice more to view the MIN and AVG readings.
5. Press the RECORD button to return to normal operation.

RS-232 PC Interface

This meter is equipped with a RS-232 serial data port. This interface is for use with the Extech Data Acquisition Software (Part number 407001) and enables the user to capture, store and display readings on a PC. Contact Extech or refer to the 407001 user manual for details on the PC interface.

Battery Replacement

When the low battery indicator appears (LBT), replace the battery as soon as possible. Reliable readings can be obtained for several hours after the first appearance of the low battery indication. To replace the battery:

1. Remover the meter's rubber protective holster.
2. The battery compartment is located on the lower back of the meter. Pry the battery compartment cover off using a small coin or screwdriver and remove the battery.
3. Replace the 9V battery and reinstall the cover.
4. Ensure that the battery cover is secured after replacing the battery.

You, as the end user, are legally bound (**Battery ordinance**) to return all used batteries and accumulators; **disposal in the household garbage is prohibited!**

You can hand over your used batteries / accumulators at collection points in your community or wherever batteries / accumulators are sold!

Disposal: Follow the valid legal stipulations in respect of the disposal of the device at the end of its lifecycle

Typical Light Levels

Lux	Foot Candles		Lux	Foot Candles	
		Factories			**Home**
20-75	2-7	Emergency Stairs, Warehouse	100-150	10-15	Washing
75-150	7-15	Exit/Entrance Passages	150-200	15-20	Recreational Activities
150-300	15-30	Packing Work	200-300	20-30	Drawing Room, Table
300-750	30-75	Visual Work: Production Line	300-500	30-50	Makeup
750-1,500	75-150	Typesetting: Inspection Work	500-1,500	50-150	Reading, Study
1,500-3,000	150-300	Electronic Assembly, Drafting	1,000-2,000	100-200	Sewing
		Office			**Restaurant**
75-100	7-10	Indoor Emergency Stairs	75-150	7-15	Corridor Stairs
100-200	10-20	Corridor Stairs	150-300	15-30	Entrance, Wash Room
200-750	20-75	Conference, Reception Room	300-750	30-75	Cooking\Dinning Room
750-1,500	75-150	Clerical Work	750-1,500	75-150	Show Window
1,500-2,000	150-2000	Typing, Drafting			
		Store			**Hospital**
75-150	7-15	Indoors	30-75	3-7	Emergency Stairs
150-200	15-20	Corridor/Stairs	75-100	7-10	Stairs
200-300	20-30	Reception	100-150	10-15	Sick Room, Warehouse
300-500	30-50	Display Stand	150-200	15-20	Waiting Room
500-750	50-75	Elevator	200-750	20-75	Medical Exam Room
750-1,500	75-150	Show Window, Packing Table	750-1,500	75-150	Operating Room
1,500-3,000	150-300	Storefront, Show Window	5,000-10,000	500-1000	Eye Inspection

Common Conversion Factors

Illuminance (Visible Flux Density)	1 lm/m^2 =	1 lux (lx)
		10^{-4} lm/cm^2
		10^{-4} phot (ph)
		9.290 x 10^{-2} lm/ft^2
		9.290 x 10^{-2} foot-candles
Luminance (Visible Flux Density per Solid Angle)	1 $lm/m^2/sr$ =	1 $candela/m^2$
Luminous Intensity (Visible Flux per Solid Angle)	1 lm/sr =	1 candella
Luminous Flux (Visible Flux)	1 lumen (lm) =	1.464 x 10^{-3} watts @ 555 nm

Konica/Minolta T-10A

Main Specifications of T-10A

Model		Illuminance Meter T-10A (Standard receptor head)	Illuminance Meter T-10MA (Mini receptor head)	Illuminance Meter T-10W$_S$A (Waterproof mini receptor head)	Illuminance Meter T-10W$_L$A (Waterproof mini receptor head)
Type		Multi-function digital illuminance meter with detachable receptor head (Multi-point measurements of 2 to 30 points is possible)			
Illuminance meter class		Conforms to requirements for Class AA of JIS C 1609-1: 2006 "Illuminance meters Part 1: General measuring instruments" Conforms to DIN 5032 Part 7 Class B		Conforms to requirements for special Illuminance meters of JIS C 1609-1: 2006 *1	
Receptor		Silicon photocell			
Relative spectral response		Within 6% (f_1') of the CIE spectral luminous efficiency V (λ)			
Cosine response (f_2)		Within 3%		Within 10%	
Measuring range		Auto range (5 manual ranges at the time of analog output)			
Measuring function		Illuminance (lx). illuminance difference (lx). illuminance ratio (%). integrated illuminance (lx·h). integration time (h). average illuminance (lx).			
Measuring range	Illuminance	0.01 to 299,900 lx; 0.001 to 29,990 fcd		1.00 to 299,900 lx; 0.1 to 29.990 fcd *2	
	Integrated illuminance	0.01 to 999,900 x 10^3 lx·h 0.001 to 99,990 x 10^3 fcd·h / 0.001 to 9999 h			
User calibration function		CCF (Color Correction Factor) setting function: Measurement value x 0.500 to 2.000			
Linearity		±2% ±1 digit of displayed value			
Temperature/ humidity drift		Within ±3%			
Computer interface		USB			
Printer output		RS-232C			
Analog output		1 mV/digit, 3 V at maximum reading; Output impedance: 10 KΩ; 90% response time: 28 ms			
Display		3 or 4 Significant-digit LCD with backlight illumination (Automatic illumination)			
Power source		2 AA-size batteries / AC adapter AC-A308 (optional; for 1 to 10 receptors) or AC adapter AC-A311 (optional; for 1 to 30 receptors)			
Battery life		72 hours or longer (when alkaline batteries are used) in continuous measurement			
Operating temperature /humidity range		-10 to 40°C, relative humidity 85% or less (at 35°C) with no condensation		5 to 40°C, relative humidity of 85% or less (at 35°C) with no condensation	
Storage temperature / humidity range		-20 to 55°C, relative humidity 85% or less (at 35°C) with no condensation		0 to 55°C, relative humidity of 85% or less (at 35°C) with no condensation	
Dimensions		69 x 174 x 35 mm	Main body: 69 x 161.5 x 30 mm Receptor: Ø16.5 x 13.8 mm		
Cord length		–	1 m	5 m	10 m
Weight (without battery)		200 g (7.0 oz.)	205 g	260 g (Receptor head only: 120 g)	340 g (Receptor head only: 200 g)

*1 Conforms to requirements for Class AA of JIS C 1609-1: 2006 for all items except cosine response (f_2).
*2 Although measurements below 1.00 lx are possible, they may not be stable due to the effects of electrical noise.
<Notes regarding mini receptors and waterproof mini receptors>
*Do not touch the cable during measurements. Doing so may result in unstable measurement values.
*Secure the cable during measurements. Failure to do so may result in unstable measurement values.

APPENDIX B: MEASURING SKYGLOW

(This information has been requested by Sr. Alicea, should the JCA decide to include skyglow measurements in later data collection.)

DSLR Cameras and handheld light meters can be used to measure the type of light pollution known as skyglow (Biggs, Fouché, Bilki, & Zadnik, 2012; Kolláth, 2010). DSLR cameras have the ability to take an image in the .RAW format of the night sky. A .RAW image only applies preprocessing, which includes defective pixel correction and focus control. There is no compression, and the image saved contains much more data than a .JPG or .PNG (Ramanath, Snyder, Yoo, & Drew, 2005). The additional requirement for measuring skyglow with a camera is a fish eye lens. Fish eye lenses expand the view of the camera equally in all directions. This allows for a full picture of the night sky to be taken. The clearest image of the night sky is taken with an aperture of f/2.0. Using a filter that blocks infrared radiation without distorting the picture improves the data. The program *MaxIm DL* is the standard computer software used to calibrate and gather data from the captured images (Duriscoe, Luginbuhl, & Moore, 2007).

The technique of using a camera has created opportunities for large scale studies to be carried out by asking people to submit their pictures for analysis (Rabaza, Galadí-Enríquez, Estrella, & Dols, 2010). Most of the recent light pollution studies of skyglow have used the camera technique in addition to traditional handheld devices. Hand held devices are still used to collect data, because less calibration is required and the luminance data can be collected directly. The skyglow data is usually overlaid onto maps, using a color scale to show the intensity of the incident light (Biggs et al., 2012). Skyglow studies must be conducted under a certain set of conditions. There cannot be any direct light; this will skew the luminance reading. Cloudy skies will also give incorrect luminance readings. Readings must be taken after atmospheric twilight, which is when the sun is 18 degrees below the horizon (Kolláth, 2010).

APPENDIX C: FIGURES AND DATA TABLES

FIGURE 4-I

The relative absorption of plant pigments relative to emissions from low-pressure sodium lamps

The figure shows three main classes of plant pigments, found in varying combinations in all flowering plants, and their ability to absorb light of different wavelengths.

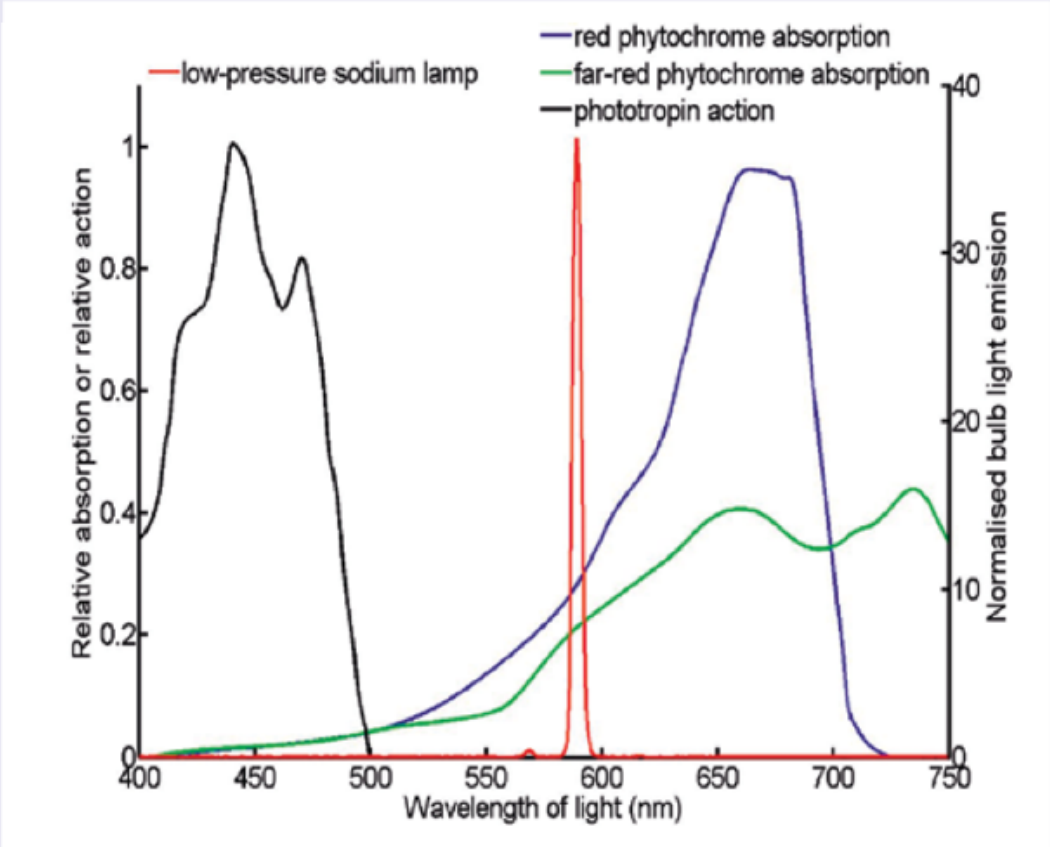
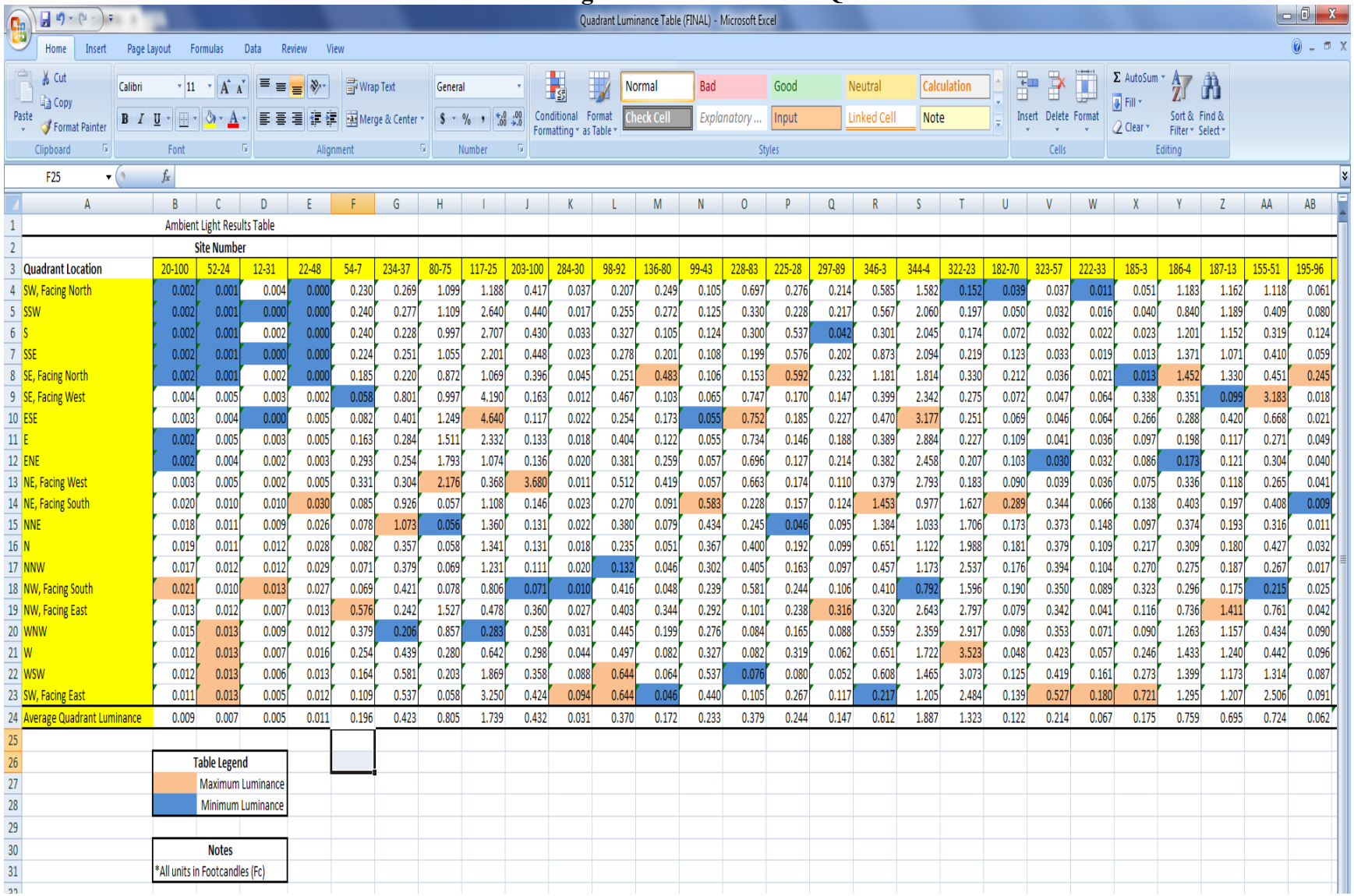


Figure I: Taken from Royal Commission Report (Pollution, 2009).

Table I: Average Luminesce At Each Quadrant



Quadrant Luminance Table (FINAL) - Microsoft Excel

Ambient Light Results Table

	Site Number																										
Quadrant Location	20-100	52-24	12-31	22-48	54-7	234-37	80-75	117-25	203-100	284-30	98-92	136-80	99-43	228-83	225-28	297-89	346-3	344-4	322-23	182-70	323-57	222-33	185-3	186-4	187-13	155-51	195-96
SW, Facing North	0.002	0.001	0.004	0.000	0.230	0.269	1.099	1.188	0.417	0.037	0.207	0.249	0.105	0.697	0.276	0.214	0.585	1.582	0.152	0.039	0.037	0.011	0.051	1.183	1.162	1.118	0.061
SSW	0.002	0.001	0.000	0.000	0.240	0.277	1.109	2.640	0.440	0.017	0.255	0.272	0.125	0.330	0.228	0.217	0.567	2.060	0.197	0.050	0.032	0.016	0.040	0.840	1.189	0.409	0.080
S	0.002	0.001	0.002	0.000	0.240	0.228	0.997	2.707	0.430	0.033	0.327	0.105	0.124	0.300	0.537	0.042	0.301	2.045	0.174	0.072	0.032	0.022	0.023	1.201	1.152	0.319	0.124
SSE	0.002	0.001	0.000	0.000	0.224	0.251	1.055	2.201	0.448	0.023	0.278	0.201	0.108	0.199	0.576	0.202	0.873	2.094	0.219	0.123	0.033	0.019	0.013	1.371	1.071	0.410	0.059
SE, Facing North	0.002	0.001	0.002	0.000	0.185	0.220	0.872	1.069	0.396	0.045	0.251	0.483	0.106	0.153	0.592	0.232	1.181	1.814	0.330	0.212	0.036	0.021	0.013	1.452	1.330	0.451	0.245
SE, Facing West	0.004	0.005	0.003	0.002	0.058	0.801	0.997	4.190	0.163	0.012	0.467	0.103	0.065	0.747	0.170	0.147	0.399	2.342	0.275	0.072	0.047	0.064	0.338	0.351	0.099	3.183	0.018
ESE	0.003	0.004	0.000	0.005	0.082	0.401	1.249	4.640	0.117	0.022	0.254	0.173	0.055	0.752	0.185	0.227	0.470	3.177	0.251	0.069	0.046	0.064	0.266	0.288	0.420	0.668	0.021
E	0.002	0.005	0.003	0.005	0.163	0.284	1.511	2.332	0.133	0.018	0.404	0.122	0.055	0.734	0.146	0.188	0.389	2.884	0.227	0.109	0.041	0.036	0.097	0.198	0.117	0.271	0.049
ENE	0.002	0.004	0.002	0.003	0.293	0.254	1.793	1.074	0.136	0.020	0.381	0.259	0.057	0.696	0.127	0.214	0.382	2.458	0.207	0.103	0.030	0.032	0.086	0.173	0.121	0.304	0.040
NE, Facing West	0.003	0.005	0.002	0.005	0.331	0.304	2.176	0.368	3.680	0.011	0.512	0.419	0.057	0.663	0.174	0.110	0.379	2.793	0.183	0.090	0.039	0.036	0.075	0.336	0.118	0.265	0.041
NE, Facing South	0.020	0.010	0.010	0.030	0.085	0.926	0.057	1.108	0.146	0.023	0.270	0.091	0.583	0.228	0.157	0.124	1.453	0.977	1.627	0.289	0.344	0.066	0.138	0.403	0.197	0.408	0.009
NNE	0.018	0.011	0.009	0.026	0.078	1.073	0.056	1.360	0.131	0.022	0.380	0.079	0.434	0.245	0.046	0.095	1.384	1.033	1.706	0.173	0.373	0.148	0.097	0.374	0.193	0.316	0.011
N	0.019	0.011	0.012	0.028	0.082	0.357	0.058	1.341	0.131	0.018	0.235	0.051	0.367	0.400	0.192	0.099	0.651	1.122	1.988	0.181	0.379	0.109	0.217	0.305	0.180	0.427	0.032
NNW	0.017	0.012	0.012	0.029	0.071	0.379	0.069	1.231	0.111	0.020	0.132	0.046	0.302	0.405	0.163	0.097	0.457	1.173	2.537	0.176	0.394	0.104	0.270	0.275	0.187	0.267	0.017
NW, Facing South	0.021	0.010	0.013	0.027	0.069	0.421	0.078	0.806	0.071	0.010	0.416	0.048	0.239	0.581	0.244	0.106	0.410	0.792	1.596	0.190	0.350	0.089	0.323	0.296	0.175	0.215	0.025
NW, Facing East	0.013	0.012	0.007	0.013	0.576	0.242	1.527	0.478	0.360	0.027	0.403	0.344	0.292	0.101	0.238	0.316	0.320	2.643	2.797	0.079	0.342	0.041	0.116	0.736	1.411	0.761	0.042
WNW	0.015	0.013	0.009	0.012	0.379	0.206	0.857	0.283	0.258	0.031	0.445	0.199	0.276	0.084	0.165	0.088	0.559	2.359	2.917	0.098	0.353	0.071	0.090	1.263	1.157	0.434	0.090
W	0.012	0.013	0.007	0.016	0.254	0.439	0.280	0.642	0.298	0.044	0.497	0.082	0.327	0.082	0.319	0.062	0.651	1.722	3.523	0.048	0.423	0.057	0.246	1.433	1.240	0.442	0.096
WSW	0.012	0.013	0.006	0.013	0.164	0.581	0.203	1.869	0.358	0.088	0.644	0.064	0.537	0.076	0.080	0.052	0.608	1.465	3.073	0.125	0.419	0.161	0.273	1.399	1.173	1.314	0.087
SW, Facing East	0.011	0.013	0.005	0.012	0.109	0.537	0.058	3.250	0.424	0.094	0.644	0.046	0.440	0.105	0.267	0.117	0.217	1.205	2.484	0.139	0.527	0.180	0.721	1.295	1.207	2.506	0.091
Average Quadrant Luminance	0.009	0.007	0.005	0.011	0.196	0.423	0.805	1.739	0.432	0.031	0.370	0.172	0.233	0.379	0.244	0.147	0.612	1.887	1.323	0.122	0.214	0.067	0.175	0.759	0.695	0.724	0.062

Table Legend
Maximum Luminance
Minimum Luminance

Notes
*All units in Footcandles (Fc)

APPENDIX D: SURVEYS

English Version:

Quadrant_____

Hello, we are students from Worcester Polytechnic Institute working with the Environmental Quality Board of Puerto Rico to study light pollution in San Juan. With your cooperation we will be able to gather information regarding people's opinions about environmental light pollution. This information will be used to help identify problems with artificial lighting in th area. Your participation in this survey is voluntary, and your answers are confidential and anonymous. We thank you for taking a few minutes of your time to answer our questions.

1. In Puerto Rico there are numerous environmental issues, including light pollution. Which level of importance would you rate the issue of light pollution? (Circle one number)

    1 Not at all important
    2 Slightly important
    3 Moderately important
    4 Very important
    5 Extremely important

2. What artificial light sources have you noticed in the area? Also, please classify each lig source as not at all annoying, slightly, moderately, very, or extremely annoying. (Fill i the blank and select the level of annoyance)

Source	Not at All	Slightly	Moderately	Very Much	Extrem
_____	1	2	3	4	5
_____	1	2	3	4	5
_____	1	2	3	4	5
_____	1	2	3	4	5

3. Have you noticed an increase in the nighttime lighting in your area? (Circle one answer)

Yes No

4. Do you live in the direct vicinity? (Circle one answer) (If no, skip 5 & 6)

Yes No

5. If Yes, please rate the amount of light that enters your home from the street. (Circle one number)

(No light) 0 1 2 3 4 5 6 7 8 9 10 (A lot of light)

6. Select the level of annoyance you have from light entering your home. (Select one answer)

Not at All Slightly Moderately Very Much Extremely

7. Is there anything else you would like to tell us relating to light pollution? Are there any other areas of the city that you feel are more problematic?

PLEASE COMPLETE THE FOLLOWING BACKGROUND INFORMATION:

Sex: _____Male _____Female

What year were you born? 19____

THANK YOU FOR YOUR TIME AND PARTICIPATION.

Spanish Version:

Quadrante_____

Hola, somos estudiantes de Worcester Polytechnic Institute y trabajamos con la Junta de Calidad Ambiental de Puerto Rico para estudiar la contaminación lumínica en San Juan. Con su cooperación estaremos disponibles conseguir información en relación con lo que opina la gente de la contaminación lumínica. Ésta información se usará para identificar los problemas que existen de la luz artificial en el área. Su participación es voluntaria y sus respuestas son completamente confidenciales y anónimas. Muchas gracias por su tiempo y pase buen día.

1. En Puerto Rico hay múltiples conflictos ambientales, incluyendo la contaminación lumínica. ¿Cuál nivel de importancia escogieras para el conflicto de la contaminación lumínica? (Marque con un círculo UN número)

    1 No es importante
    2 Poco importante
    3 Moderadamente importante
    4 Muy Importante
    5 Extremamente importante

2. ¿Cuáles fuentes de la luz artificial ha notado Ud. en el área? También clasifique cada fuente como: no es molesto, poco molesto, moderadamente molesto, muy molesto, o extremamente molesto. (Escribe el fuente en la línea escoge el nivel de la molestia)

Fuente	No es	Poco	Moderadamente	Muy	Extremamente
_____	1	2	3	4	5
_____	1	2	3	4	5

_____	1	2	3	4	5
_____	1	2	3	4	5

3. ¿Ha notado Ud. un aumento de la luz artificial en dónde vive? (Marque con un círculo UNA respuesta)

Yes No

4. ¿Vive Ud. en éste área? (Marque con un círculo UNA respuesta) (Si no, sáltese 5 & 6) →

Yes No

5. Clasifique la cantidad de luz de la calle que entra en su casa. (Marque con un círculo UN número)

(No hay luz) 0 1 2 3 4 5 6 7 8 9 10 (Hay mucha luz)

6. Clasifique el nivel de molestia que se siente Ud. de la luz en la calle que entra en su casa. (Marque con un círculo UNA respuesta)

Nada Poca Moderada Mucha Extrema

7. ¿Hay algo más que le gustaría decirnos en relación con San Juan y la contaminación lumínica? ¿Conoce a otros lugares que tengan problemas con la contaminación lumínica?

POR FAVOR COMPLETE LA SIGUIENTE INFORMACIÓN GENERAL:

Sexo: Hombre _____ Mujer _____

¿En cual año se nació? 19_____

MUCHAS GRACIAS POR SU TIEMPO Y SU PARTICIPACIÓN

Survey Monkey Version:

La contaminación lumínica en Puerto Rico

Hola, somos estudiantes de Worcester Polytechnic Institute y trabajamos con la Junta de Calidad Ambiental de Puerto Rico para estudiar la contaminación lumínica en San Juan. Con su cooperación deseamos conseguir información en relación con lo que opina la gente sobre la contaminación lumínica. Ésta información se usará para identificar los problemas que existen de contaminación ambiental por luz artificial en areas. Su partticipación es voluntaria y sus respuestas son completamente confidenciales y anónimas. Muchas gracias por su tiempo y pase buen día.

1. En Puerto Rico hay múltiples problemas ambientales, incluyendo la contaminación lumínica. ¿Cuál nivel de importancia escogieras para la problemática de la contaminación lumínica en la isla?

- No es importante
- Poco Importane
- Moderadamente importante
- Muy importante
- Extremamene importante

2. ¿Ha notado Ud. un aumento en la iluminación artificial en el área donde vive?

- Sí
- No

3. Escriba los fuentes de la luz artificial que ha notado en el área donde vive.

Tipo de luz 1	
Tipo de luz 2	
Tipo de luz 3	
Tipo de luz 4	
Tipo de luz 5	

4. Clasifique los fuentes siguientes de la luz artificial en el área donde vive como: no es molesto, poco molesto, moderadamente molesto, muy molesto, o extremamente molesto.

	No es	Poco	Moderadamente	Muy	Extremamente
Tipo de luz 1					
Tipo de luz 2					
Tipo de luz 3					
Tipo de luz 4					
Tipo de luz 5					

5. Clasifique la cantidad de luz de la calle que entra en su casa. ("0" es no hay luz y "10" es hay mucha luz)

1 2 3 4 5 6 7 8 9 10

6. Clasifique el nivel de molestia que se siente Ud. de la luz en la calle que entra en su casa.

Nada Poca Moderada Mucha Extrema

7. ¿Hay algo más que le gustaría dercirnos en relación con Puerto Rico y la contaminación lumínica? ¿Conoce a otros lugares que tengan problemas con la contaminación lumínica?

8. ¿Es Ud. hombre o mujer?

Hombre

Mujer

9. ¿En cuál año se nació?

Done

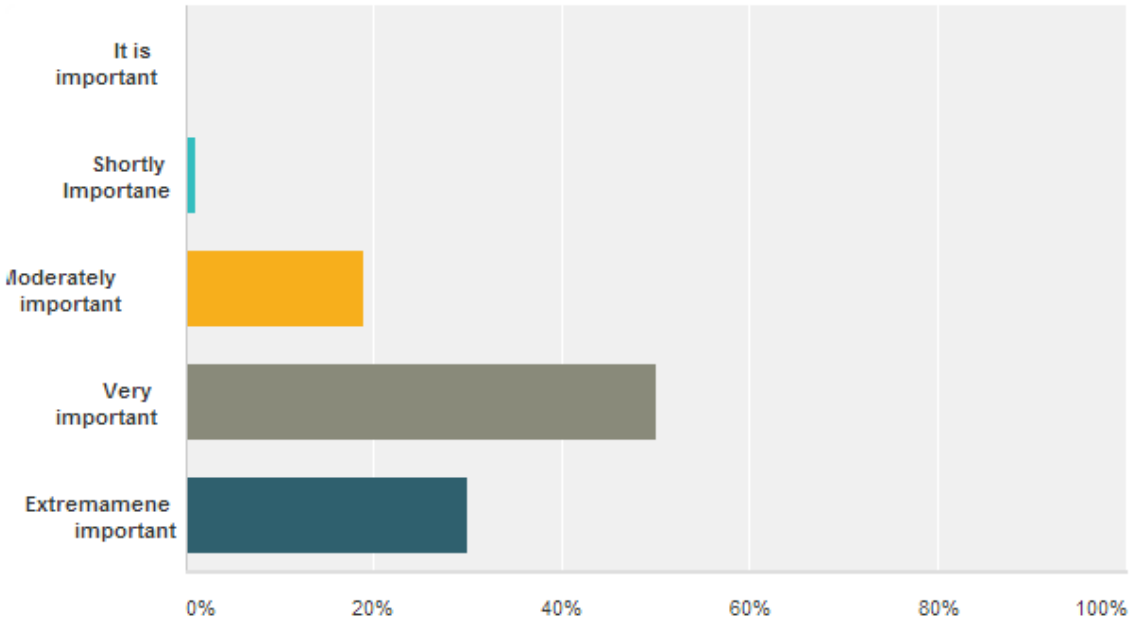
Question 1 Results **

Q1

Personalize | Chart downloads

In Puerto Rico there are many environmental problems, including light pollution. What level of importance escogieras to the problem of light pollution on the island?

Answered: 100 Skipped: 0



Response options	Answers	
It is important	0%	0
Shortly Importane	1%	1
Moderately important	19%	19
Very important	50%	50
Extremamene important	30%	30
Total		100

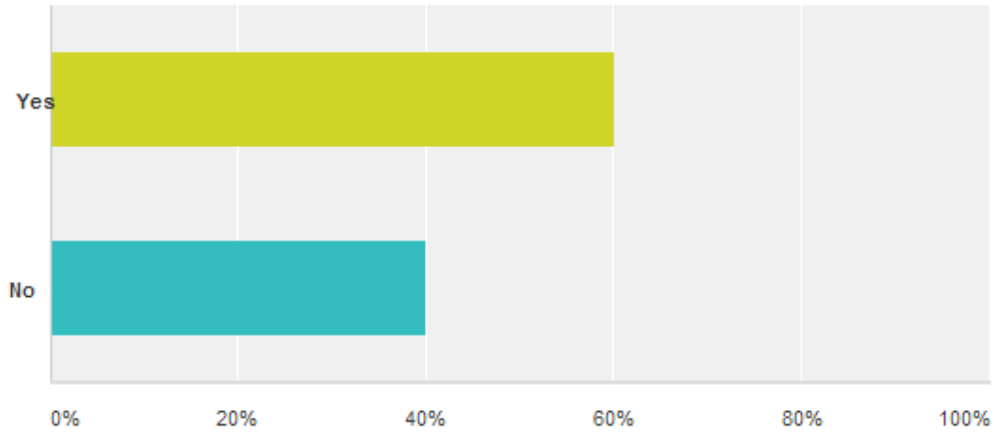
Question 2 Results

Q2

Personalize | Chart downloads

Have you noticed an increase in outdoor artificial lighting in the area where you live?

Answered: 100 Skipped: 0



Response options	Answers	
Yes	**60%**	60
Not	**40%**	40
Total		100

Question 3 Results

Q3

List the types of outdoor artificial light that has been noticed in the area where you live.

Answered: 87 Skipped: 13

Response options		Answers	
Type of Light 1	Replies	98.85%	86
Light type 2	Replies	78.16%	68
Type of Light 3	Replies	49.43%	43
Type of Light 4	Replies	18.39%	16
Type of Light 5	Replies	4.60%	4

Question 4 Results and Questions 5 Results

The most commonly listed responses and their rating of discomfort were tabulated for in the following chart.

	No Es	Poco	Moderadamente	Muy	Extremamente	Total Votes
Postes	8	13	15	6	2	44
Carreteras/Vehiculos	4	5	7	7	2	25
Edificios/Casas/Hoteles	8	4	17	17	11	57
Billboards	0	0	13	12	13	38
Parques/Jardines/Estacionamientos	1	0	5	6	6	18

	No Es	Poco	Moderadamente	Muy	Extremamente	Total Votes
Postes	18.18%	29.55%	34.09%	13.64%	4.55%	100.00%
Carreteras/Vehiculos	16.00%	20.00%	28.00%	28.00%	8.00%	100.00%
Edificios/Casas/Hoteles	14.04%	7.02%	29.82%	29.82%	19.30%	100.00%
Billboards	0.00%	0.00%	34.21%	31.58%	34.21%	100.00%
Parque/Jardín/Estacionamiento	5.56%	0.00%	27.78%	33.33%	33.33%	100.00%

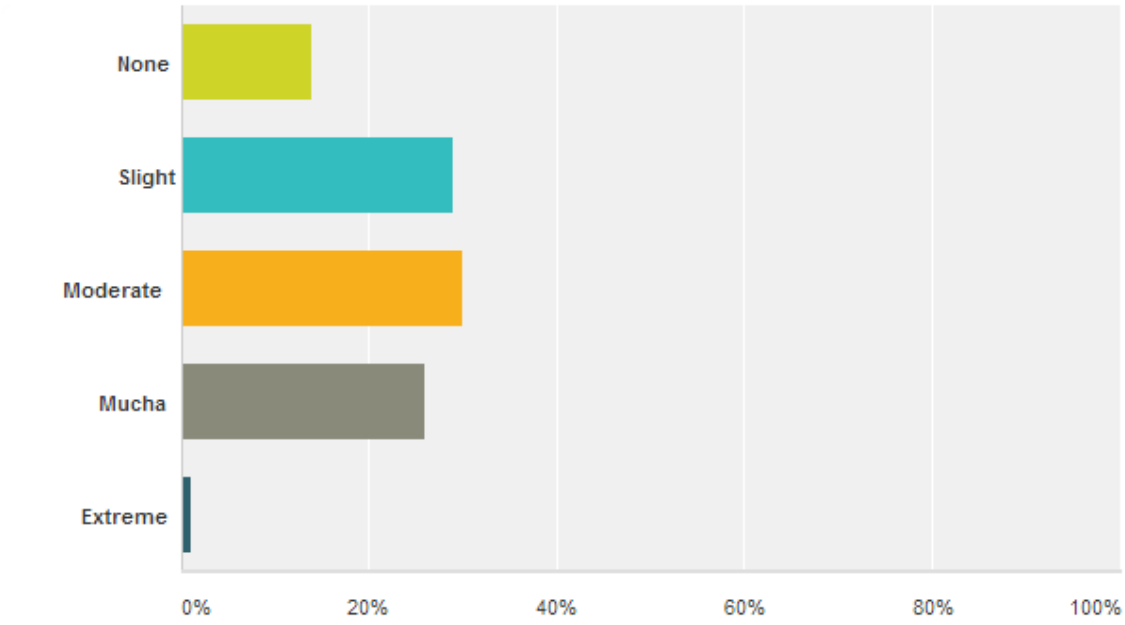
Question 6 Results **

Q6

Personalize | Chart downloads

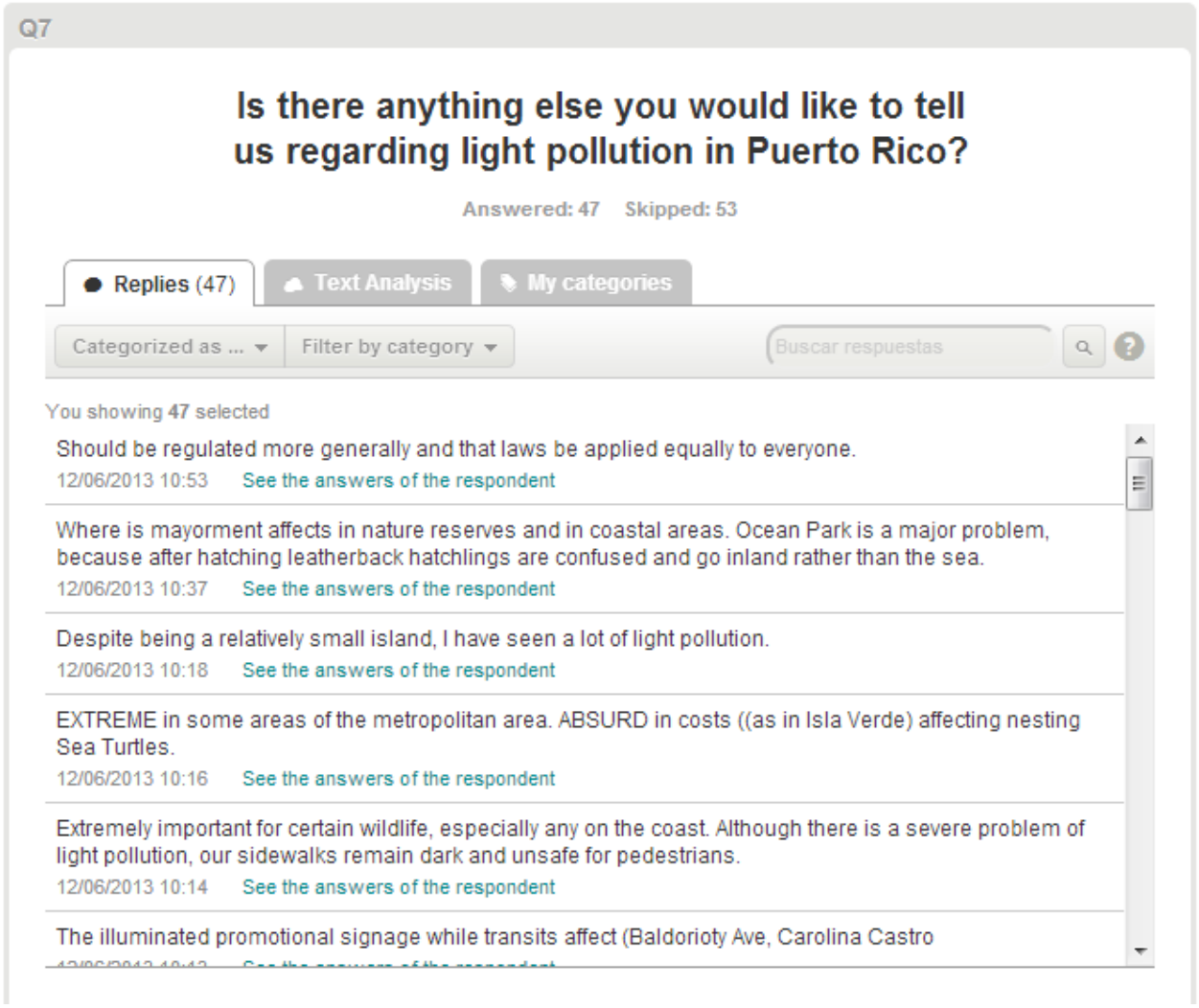
Classify the level of discomfort you feel artificial light in the street that enters your home.

Answered: 100 Skipped: 0



Response options	Answers	
Nothing	14.00%	14
Slight	29.00%	29
Moderate	30%	30
Mucha	26%	26
Extreme	1%	1
Total		100

Question 7 Results



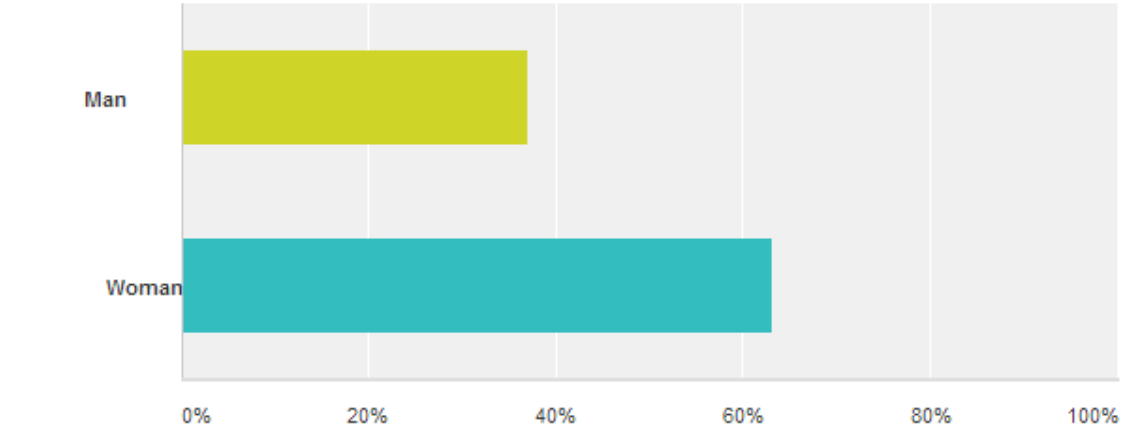
Question 8 Results **

Q8

Personalize | Chart downloads

Is you man or woman?

Answered: 100 Skipped: 0



Response options	Answers	
Man	37%	37
Woman	63%	63
Total		100

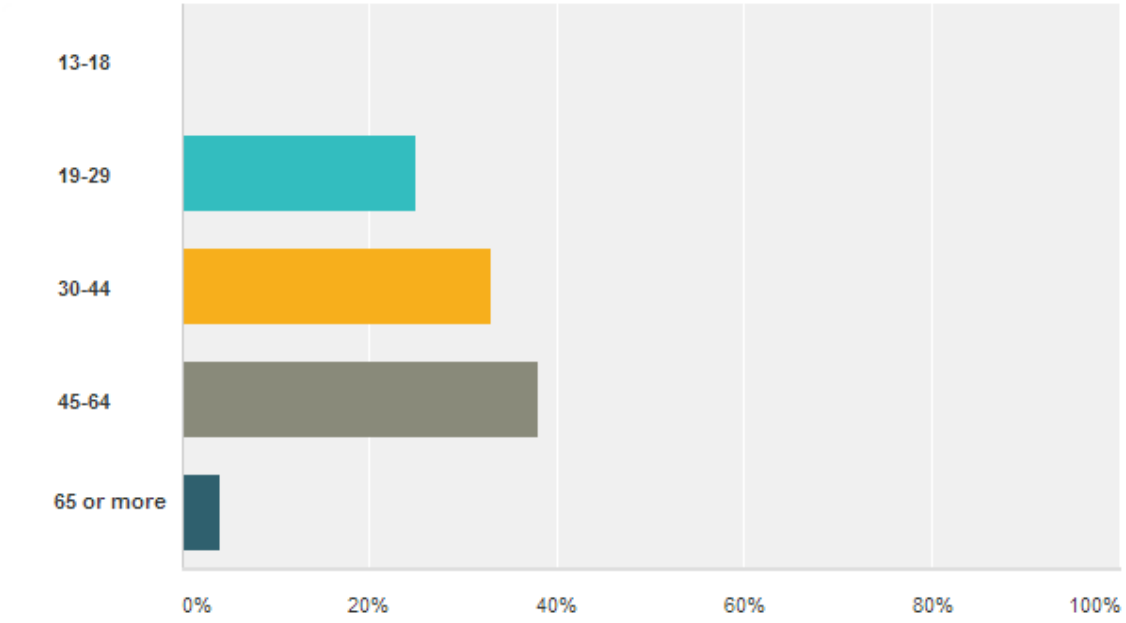
Question 9 Results **

Q9

Personalize | Chart downloads

In which age group you fall?

Answered: 100 Skipped: 0



Response options	Answers	
13-18 years	0%	0
19-29 years old	25%	25
30-44	33%	33
45-64 years	38%	38
65 or more	4%	4
Total		100

**

Any grammatical errors in the questions were due to an error in Survey Monkey's translation of the questions. However, the survey was conducted in Spanish**

APPENDIX E: COLLECTED OBSERVATIONAL DATA

In this appendix is the collection of the observational data of all quadrants sampled. Included are recording of light fixtures in each of the cardinal directions as well as photographs of each direction. Due to our methodology evolving, sites 12, 20, 22, 52, 54, 80, 98, 99, 117, 136, 203, 234, and 284 were not given site assessments or taken in photographic form.

The following observations were made during the day at quadrant 155.

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
155	12/3/2013	2:40PM	233142.0314	269928.9278	The beginning of El Paseo la Princesa

	OBSERVATIONS AT 155 (DAY)
NORTH	Two bright lamps and Paseo la Princesa
EAST	5 luminaries and a public park area, as well as the governor's house atop the wall along El Paseo. There is a massive ficus with hanging vines.
SOUTH	One large wall along El Paseo
WEST	The sea, with miscellaneous ships. Across the water is Casa Bacardi
SOUTHWEST	7 lampposts and 6 floodlights directed at the wall and into the sea.

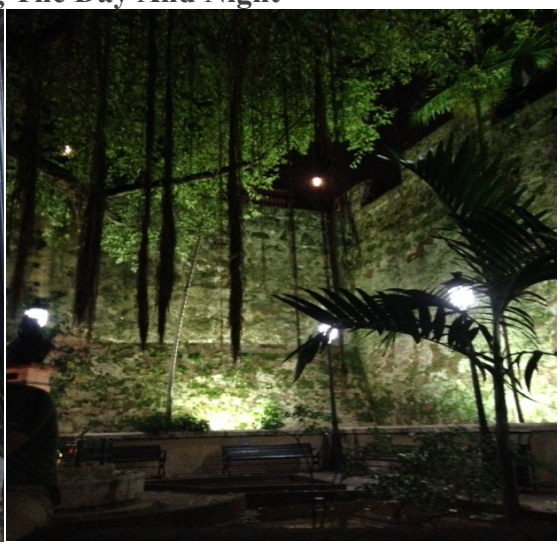
	OBSERVATIONS AT 155 (NIGHT)
NORTH	A bright luminaire lighting up the walkway, and cover that blocks the sky.
EAST	The wall of the fort and 5 luminaires
SOUTH	3 lampposts in the area, then 7 along the pathway
WEST	The San Juan Bay
MISC	Every light impacts the readings

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
155	12/4/2013	7:59pm	233142.0314	269928.9278	The beginning of El Paseo la Princesa

Quadrant 155 Pictures

Quadrant 155 North, During The Day And Night

Quadrant 155 East, During The Day And Night

Quadrant 155 South, During The Day And Night


Quadrant 155 West, During The Day And Night


These were the observations made in Quadrant 182, which was located in the Muñoz Rivera Park. These observations were performed during the night only as daytime observations were not conducted.

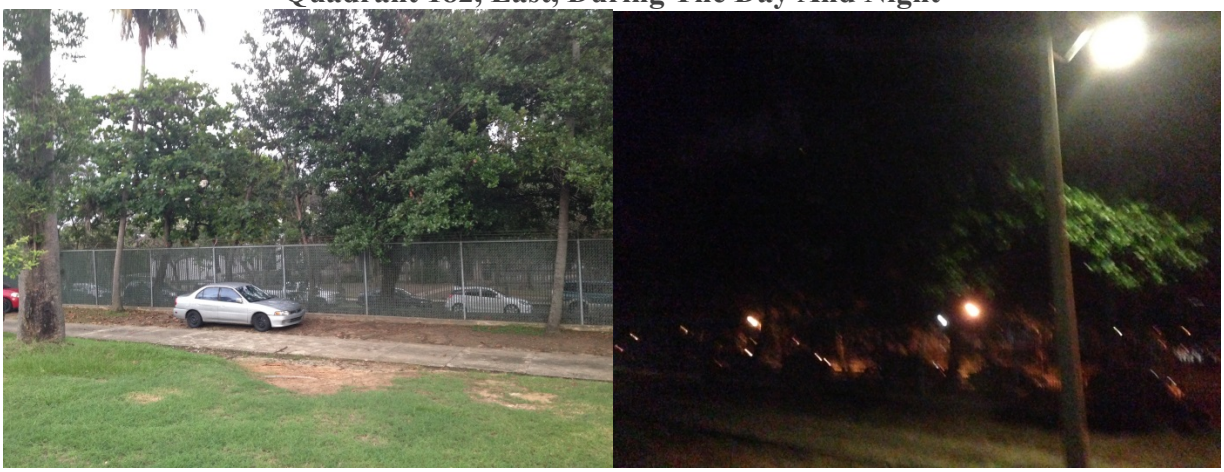
	OBSERVATIONS AT 182 (NIGHT)
NORTH	9 post lights
EAST	1 post light, a small road contiguous to the park
SOUTH	Traffic lights, lampposts, and a large building
WEST	4 luminaries on the ground, apartment buildings with street lights. The skies here are relatively dark.

The following eight pictures were taken at the site. In the night photos, pictures of the team cleaning up the collection area of the materials used for measurements can sometimes be seen:

Quadrant 182 Pictures

Quadrant 182, North, During The Day And Night

Quadrant 182, East, During The Day And Night



Quadrant 182, South, During The Day And Night

Quadrant 182, West, During The Day And Night

The next table includes the observations we made in Quadrant 185, which was located in a small park. These observations were performed during the day.

	OBSERVATIONS AT 185 (DAY)
NORTH	2 streetlights along a road. Across the road there are trees, a park and a beach
EAST	2 road lights and many trees
SOUTH	3 lampposts
WEST	4 lampposts in the park

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
185	11/20/2013	3:00pm	236112.0314	269998.9273	Luis Muñoz Rivera Park

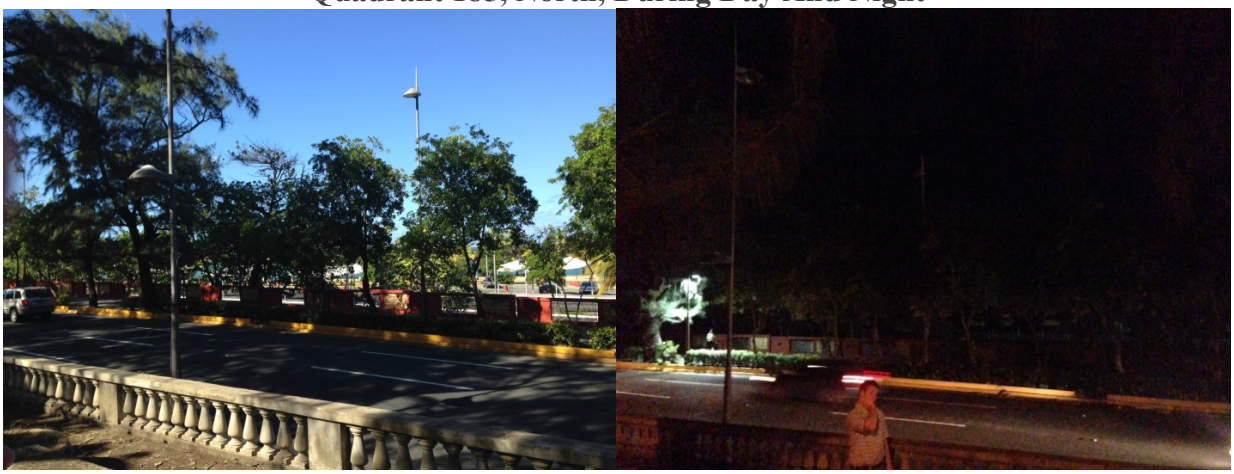
The following observations were conducted at night at quadrant 185.

	OBSERVATIONS AT 185 (NIGHT)
NORTH	4 public lights, many trees and headlights from cars on Ponce de León Ave (which may impact readings)
EAST	Many trees, with no lights
SOUTH	Many trees, a round lamppost and a well-lit playground
WEST	4 lampposts in the park and many trees. The sky is clear.

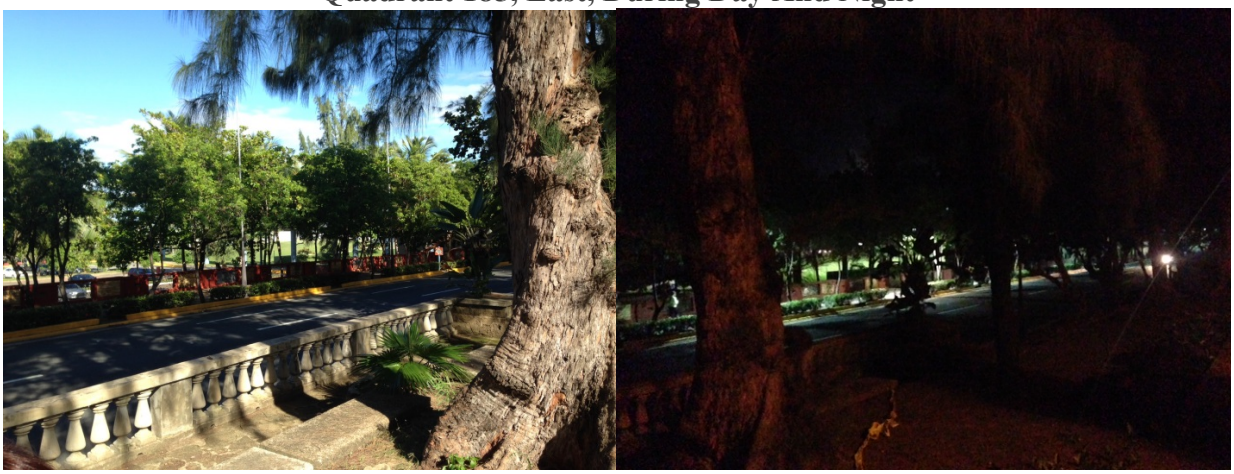
SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
185	12/3/2013	6:50pm	236112.0314	269998.9273	Luis Muñoz Rivera Park

Quadrant 185 Pictures

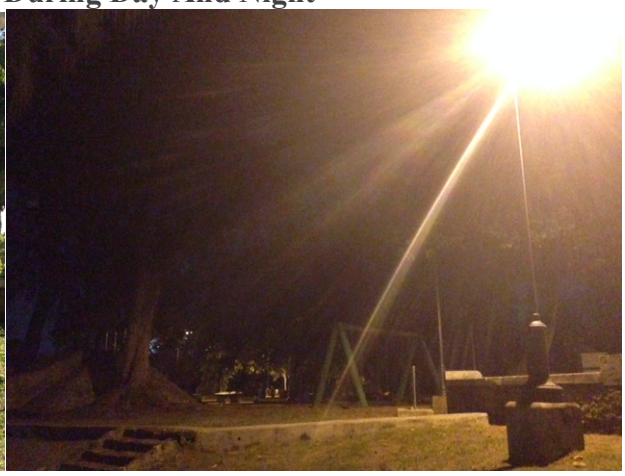
Quadrant 185, North, During Day And Night



Quadrant 185, East, During Day And Night



Quadrant 185, South, During Day And Night

Quadrant 185, West, During The Day And Night


The next table includes the observations we made in Quadrant 186, which was located in a baseball park. These observations were performed during the day.

	OBSERVATIONS AT 186 (DAY)
NORTH	Sidewalk lights, 3 park lampposts
EAST	6 focus lights, the biggest light being at the far end of the park
SOUTH	4 lights along a sidewalk
WEST	3 lights along a sidewalk

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION

186	11/20/2013	3:00PM	236222.0314	269998.9273	Inside a small baseball park

The next table includes the observations made at night in quadrant 186.

	OBSERVATIONS AT 186 (NIGHT)
NORTH	2 extremely bright park lights and a bridge.
EAST	There are 4 brilliant park lights
SOUTH	Many trees and no enabled lights
WEST	This area is brightly lit by the park lights

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
186	12/3/2013	7:05PM	236222.0314	269998.9273	On the sidewalk in El Escambrón Park, next to Muñoz Rivera Ave

Quadrant 186 Pictures

Quadrant 186, North, During Day And Night

Quadrant 186, East, During The Day And Night

Quadrant 186, South, During Day And Night

Quadrant 186, West, During The Day And Night

The next table includes the observations we made in Quadrant 187, which was located in the Sixto Escobar Stadium. These observations were performed during the day.

	OBSERVATIONS AT 187 (DAY)
NORTH	A park with 4 luminaries, and a large cement wall.
EAST	2 large stadium lights, as well as 5 lights within the bleachers.
SOUTH	More stadium lights and lampposts are in this direction.
WEST	There is one stadium light directed into the park

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
187	11/18/2013	3:05PM	236312.0314	269988.9273	Near Sixto Escobar Stadium

The following observations were made during the night at quadrant 187.

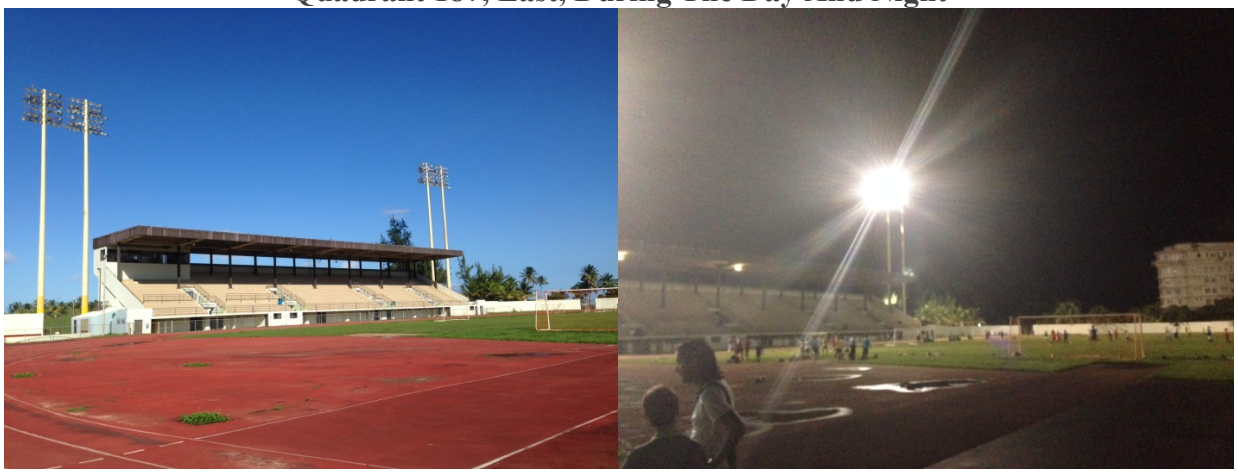
	OBSERVATIONS AT 187 (NIGHT)
NORTH	A floodlight here provides much glare
EAST	Stadium lighting
SOUTH	More stadium lights and apartment buildings
WEST	Lampposts facing the softball field and a large fence

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
187	12/3/2013	7:25PM	236312.0314	269988.9273	Inside the Escambrón Park

Quadrant 187 Pictures

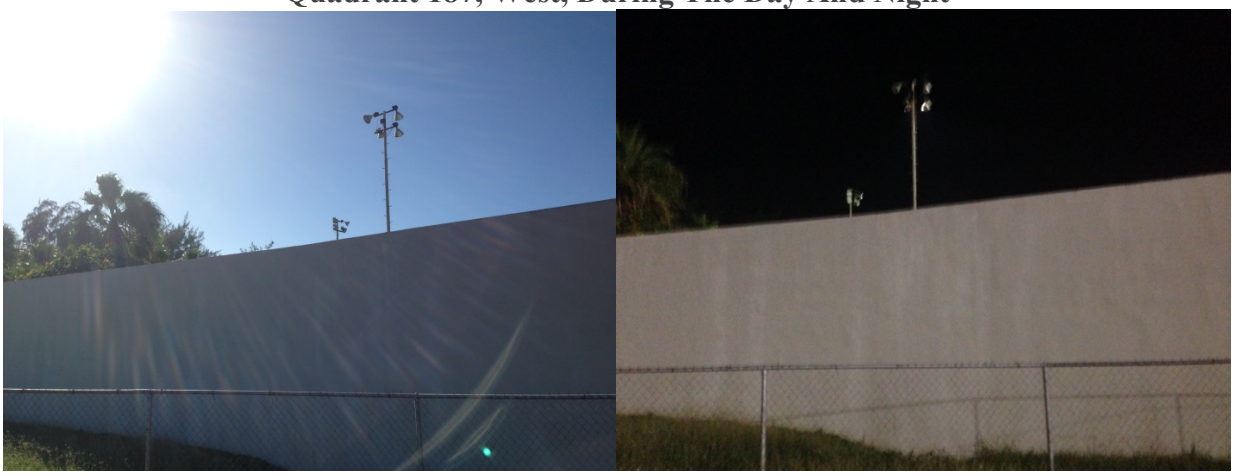
Quadrant 187, North, During The Day And Night

Quadrant 187, East, During The Day And Night



Quadrant 187, South, During The Day And Night

Quadrant 187, West, During The Day And Night



The next table includes the observations we made in Quadrant 195, which was located in the Parque de las Palomas. These observations were performed during the day.

	OBSERVATIONS AT 195 (DAY)
NORTH	A luminary on the wall, as well as an apartment building. There are many trees.
EAST	More trees and a few lights. There are shops in this direction, as well as La Capilla del Cristo.
SOUTH	A view overlooking the sea and apartments in Old San Juan. There is a large light directed at the water.
WEST	Many trees in this direction, as well as a small view of the ocean.

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
195	12/3/2013	2:50PM	233302.0314	269828.9273	Parque de las Palomas

The next table includes the observations we made in Quadrant 195 during the night.

	OBSERVATIONS AT 195 (NIGHT)
NORTH	A building that belongs to La Fortaleza, with many interior lights; trees
EAST	Capilla del Cristo, a wall lamp and 12 luminaries lighting La Capilla

SOUTH	The bay, well lit by the surrounding area
WEST	Many trees that could impact our photometer measurements
MISC	The Konica has begun to resist calibration recently, giving a constant “0.0” reading. If it were a problem with the sensor it would be reading an error or “0.000.”

SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
195	12/4/2013	7:07PM	233302.0314	269828.9273	Parque de las Palomas

Quadrant 195 Pictures

Quadrant 195, North, During The Day And Night

Quadrant 195, East, During The Day And Night

Quadrant 195, South, During The Day And Night

Quadrant 195, West, During The Day And Night

The next table includes the observations we made in Quadrant 195. These observations were performed during the day.

	OBSERVATIONS AT 222 (DAY)
NORTH	There are luminaries in the trees, as well as lights on the street that could impact the park
EAST	More tree lights and many lampposts
SOUTH	Multiple lamps, impacting the visibility of the area. There is an extremely lit building in this direction on Ave. Fernandez Juncos
WEST	Sidewalk lights and many trees

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
222	11/18/2013	6:00PM	236012.0314	269868.9273	Muñoz Rivera Park

The following observations were made during the night at quadrant 222.

	OBSERVATIONS AT 222 (NIGHT)
NORTH	Many trees that cover sky lighting, 2 round luminaries and 2 luminaries in the grass
EAST	Many trees and 8 lights directed at the sidewalk
SOUTH	An office building with 10 wall lamps, across Muñoz Rivera Ave
WEST	7 lampposts directed at the sidewalk
	Heavy traffic from Luis Muñoz Rivera Ave may effect readings

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
222	12/3/2013	6:30PM	236012.0314	269868.9273	Muñoz Rivera Park

Quadrant 222 Pictures

Quadrant 222, North, During Day And Night

Quadrant 222, East, During The Day And Night

Quadrant 222, South, During The Day And Night

Quadrant 222, West, During The Day And Night

The next tables include the observations we made in Quadrant 225, which was located across the street from the two stadiums in Old San Juan. These observations were performed during both the day and night.

	OBSERVATIONS AT 225 (DAY)
NORTH	Streetlights, as well as massive clustered floodlights inside the stadium
EAST	Headlights from oncoming traffic and 2 street lamps
SOUTH	Lights from a walled-off property
WEST	Few lights; in the direction of the Muñoz Rivera Park

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
225	11/15/2013	5:20PM	236362.0314	269878.9273	Underneath trees across the street (Ave de la Constitucion) from the two stadiums

The following observations at quadrant 225 were conducted at night.

	OBSERVATIONS AT 225 (NIGHT)
NORTH	Streetlights, as well as massive clustered floodlights inside the stadium that illuminate the sky, cause glare and more.
EAST	Headlights from oncoming traffic and 2 street lamps; a bright moon
SOUTH	4 lights along the wall at this property are directed upwards
WEST	3 different lights are at this site.

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
225	11/18/2013	8:30PM	236362.0314	269878.9273	Underneath trees across the street (Ave de la Constitucion) from the two stadiums

Quadrant 225 Pictures

Quadrant 225, North, During The Day And Night

Quadrant 225, East, During The Day And Night

Quadrant 225, South, During The Day And Night

Quadrant 225, West, During The Day And Night

The next 2 tables include the observations we made in Quadrant 228, which was located in a small park near the Normandie hotel and Morton's Steakhouse. These observations were performed during both the day and night, and are followed by the photos taken at night:

	DAYTIME OBSERVATIONS AT 228
NORTH	Road lights, as well as flood lights on the corner of a fence. 2 additional luminaries behind the Normandie hotel
EAST	Small lightings along the pathway. There is also a large hotel in this direction.
SOUTH	There are many lights lighting the ground and the trees in this area.
WEST	There are large lampposts lighting up the area beyond the fence.

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
228	11/15/2013	5:15PM	2336612.0314	269818.9273	A small park outside of The Normandie and Morton's Steakhouse

The following tables display the nighttime observations at quadrant 228.

	OBSERVATIONS AT 228 (NIGHT)
NORTH	4 lampposts along a fence, as well as 4 lights lighting the ground
EAST	6 lights along the sidewalk, as well as a hotel. Bright lighting from the moon.
SOUTH	7 trees with lights, as well as 4 sidewalk lights
WEST	A tall fence with 5 bright luminaries

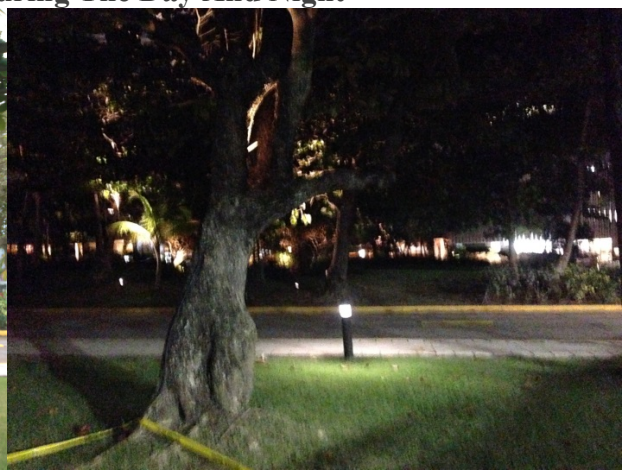
SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
228	11/18/2013	8:50PM	2336612.0314	269818.9273	A small park outside of The Normandie and Morton's Steakhouse

Quadrant 228 Pictures

Quadrant 228, North, During The Day And Night


Quadrant 228, East, During The Day And Night


Quadrant 228, South, During The Day And Night

Quadrant 228, West, During The Day And Night

The next tables include the observations we made in Quadrant 297, which was located next to two large apartment buildings near the Marina. These observations were performed during both the day.

	OBSERVATIONS AT 297 (DAY)
NORTH	A road, with several small lights lighting the sidewalks
EAST	2 street lights and a large apartment building
SOUTH	2 streetlights, as well as the bright lighthouse outside of the marina
WEST	A hotel surrounded by many round, unshielded luminaries- potentially unwanted

	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION
297	11/15/2013	4:55PM	236472.0314	269618.9273	Outside of 2 large apartment buildings

The following observations were done at night in quadrant 297.

	OBSERVATIONS AT 297 (NIGHT)
NORTH	A state road with 4 luminaries
EAST	Trees with moderate indoor lighting
SOUTH	Many trees, as well as 2 lampposts 100 meters away
WEST	A hotel surrounded by many round, unshielded luminaries- potentially unwanted

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
297	11/18/2013	8:02PM	236472.0314	269618.9273	Outside of 2 large apartment buildings

Quadrant 297 Pictures

Quadrant 297, North, During The Day And Night

Quadrant 297, East, During The Day And Night

Quadrant 297, South, During The Day And Night

Quadrant 297, West, During The Day And Night

The next 2 tables include the observations we made in Quadrant 322, which was located in the Muelle Frontier docks. These observations were performed during both the day.

	OBSERVATIONS AT 322 (DAY)
NORTH	Trees, a building and a road with no evident lights
EAST	1 light post
SOUTH	A light on the side of a building
WEST	2 lights pointing away and a large fence
MISC	We requested night access from Nelson Maldonado-Eucagardo, from the Navy Frontier

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
322	11/20/2013	4:00PM	236012.0314	269578.9273	Muelle Frontier

The next table includes all the observations at night.

	OBSERVATIONS AT 322 (NIGHT)
NORTH	One building, 2 trees and a fence.
EAST	1 light post; extremely bright and about 25 feet away.
SOUTH	A very bright light on the side of a building
WEST	2 lights pointing away, a large fence and a third light pointing North
MISC	We requested night access from Nelson Maldonado-Eucagardo, from the Navy Frontier Too many clouds to take a SQM reading

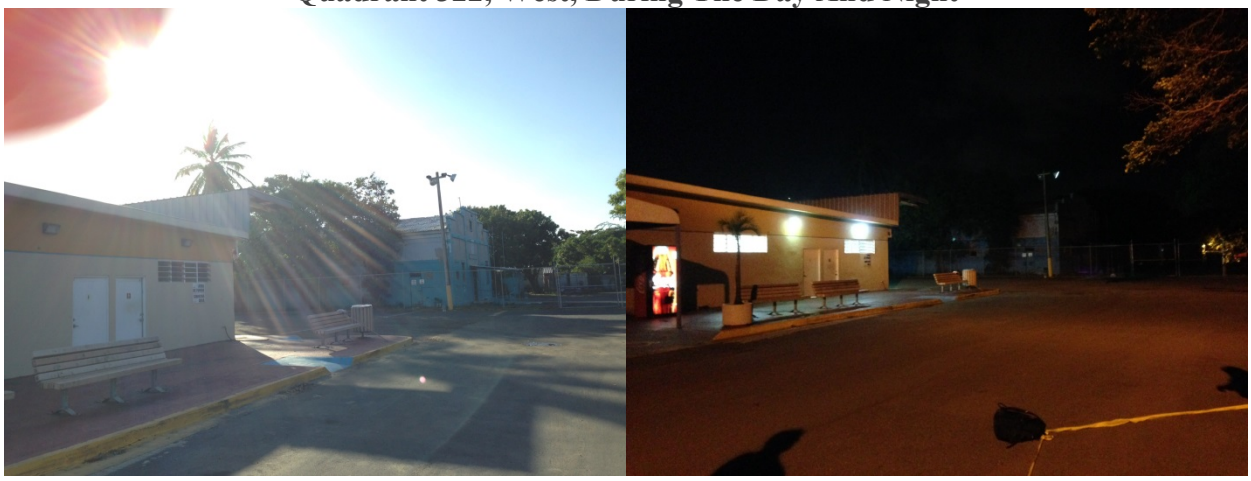
Quadrant 322 Pictures

Quadrant 322, North, During The Day And Night

Quadrant 322, East, During The Day And Night

Quadrant 322, South, During The Day And Night

Quadrant 322, West, During The Day And Night



The next 2 tables include the observations we made in Quadrant 323, which was also located in the Muelle Frontier docks. These observations were performed during both the day and night, and are followed by the photos taken at during those times:

	OBSERVATIONS AT 323 (DAY)
NORTH	There is a luminary on the corner of a building.
EAST	There is a radio tower, various buildings and apartment buildings
SOUTH	San Juan Bahia and the many buildings across the water
WEST	3 lampposts on a building
MISC	We requested night access from Nelson Maldonado-Eucagardo, from the Navy Frontier

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
323	11/20/2013	4:20PM	236152.0314	269548.9273	Muelle Frontier

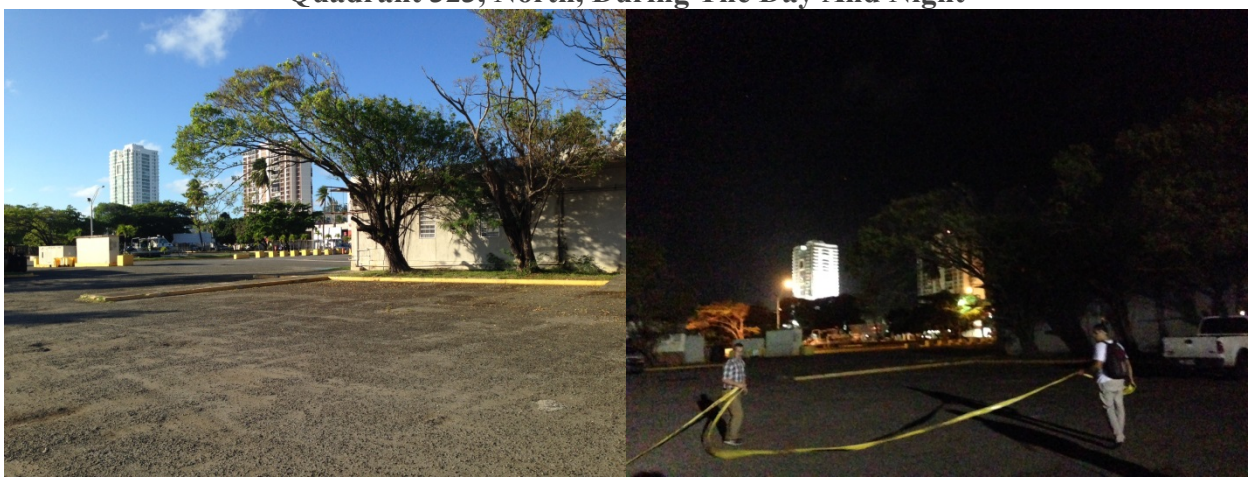
The following tables show the nighttime observations

	OBSERVATIONS AT 323 (NIGHT)
NORTH	3 lampposts and 3 buildings
EAST	An extremely bright light and an apartment building
SOUTH	San Juan Bahia and the many buildings across the water
WEST	3 lampposts on a building
MISC	We requested night access from Nelson Maldonado-Eucagardo, from the Navy Frontier

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
323	11/20/2013	4:20PM	236152.0314	269548.9273	Muella Frontier

Quadrant 323 Pictures

Quadrant 323, North, During The Day And Night



Quadrant 323, East, During The Day And Night

Quadrant 323, South, During The Day And Night

Quadrant 323, West, During The Day And Night

The next 2 tables include the observations we made in Quadrant 344, which was located in the interior parking lot Nautical Club of San Juan. These observations were performed during both the day and are followed by the photos taken.

	OBSERVATIONS AT 344 (DAY)
NORTH	Streetlights and headlights from oncoming traffic
EAST	4 lampposts lighting the parking lot
SOUTH	Lampposts, possible lighting from docked boats
WEST	5 lampposts lighting the parking lot
MISC	We needed to obtain special permission from the manager of the marina here, Odette. We needed to be careful due to wet cement near the site.

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
344	10/15/2013	4:40PM	236322.0314	269498.9273	The parking lot of the Club Náutico de San Juan

The following observations are done at nighttime in Quadrant 344.

	OBSERVATIONS AT 344 (NIGHT)
NORTH	Focus lamps, the area is well lit by 8 light fixtures
EAST	4 lampposts lighting the parking lot
SOUTH	Lampposts. Some of our measurements were performed directly underneath one of these.
WEST	6 lampposts lighting the parking lot and a building bordered with wall lights
MISC	We needed to obtain special permission from the manager of the marina here, Odette. We needed to be careful due to wet cement near the site.
SOUTH-EAST	These lights had a direct impact on our measurements

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
344	10/18/2013	7:15PM	236322.0314	269498.9273	The parking lot of the Club Náutico de San Juan

Quadrant 344 Pictures

Quadrant 344, North, During The Day And Night

Quadrant 344, East, During The Day And Night

Quadrant 344, South, During the Day And Night

Quadrant 344, West, During The Day And Night

The next table includes the observations we made in Quadrant 346, which was located on a fairly large median on Avenue Fernandez Juncos. These observations were performed during the day.

	OBSERVATIONS AT 346 (DAY)
NORTH	Cars driving along Avenue Fernandez Juncos
EAST	Street Lights
SOUTH	Parking lot with many lit signs; 18+ individual sources
WEST	A large, white and blue building- possibly housing; somewhat more to the NW corner

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
346	11/15/2013	4:05PM	236512.0314	269498.9273	On a road median on Avenue Fernandez Juncos, next to 2 unlit billboards

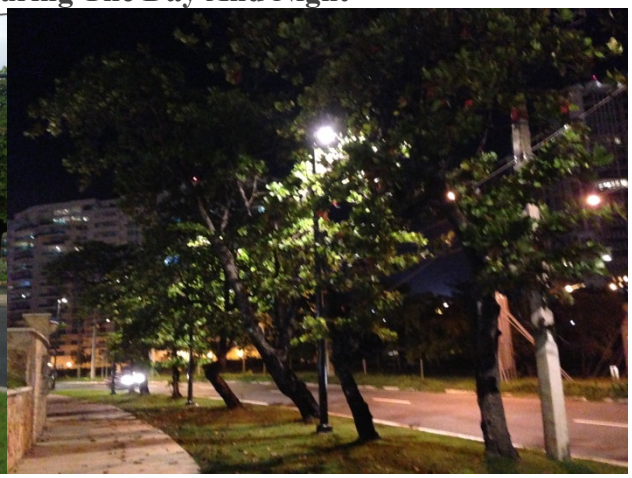
The following tables show the nighttime measurements at quadrant 346.

	OBSERVATIONS AT 346 (NIGHT)
NORTH	Cars driving along Avenue Fernandez Juncos; focus lamp
EAST	Street Lights
SOUTH	Parking lot with many lit signs; 18+ individual sources
WEST	A large, white and blue building- possibly housing; somewhat more to the NW corner

SITE NUMBER	DATE	TIME	COODINATES X	COORDINATES Y	LOCATION
346	11/18/2013	7:45PM	236512.0314	269498.9273	On a road median on Avenue Fernandez Juncos, next to 2 unlit billboards

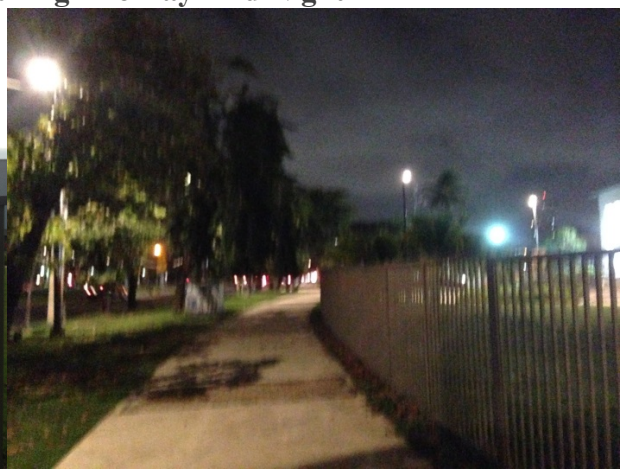
Quadrant 346 Pictures

Quadrant 346, North, During The Day And Night

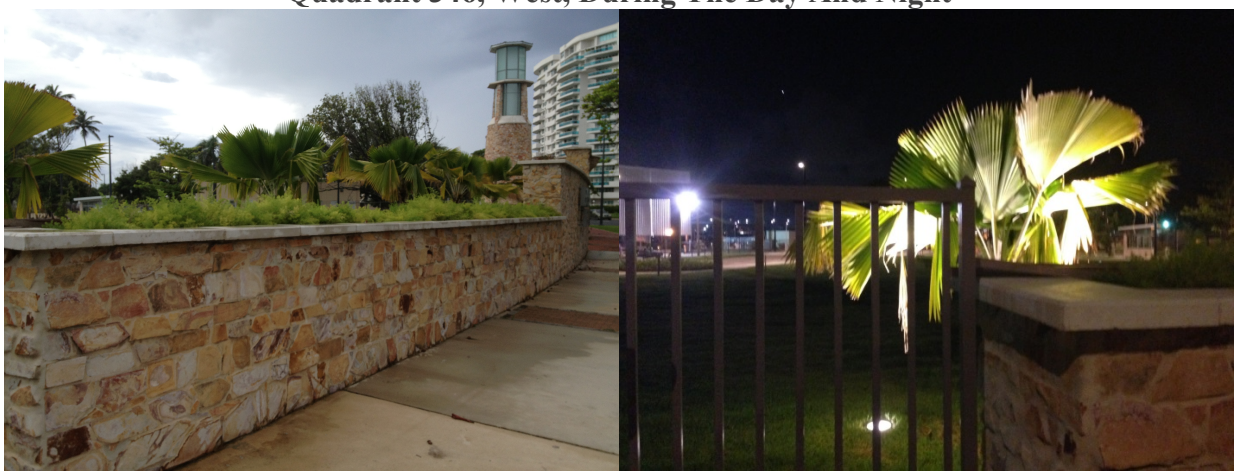



Quadrant 346, East, During The Day And Night


Quadrant 346, South, During The Day And Night

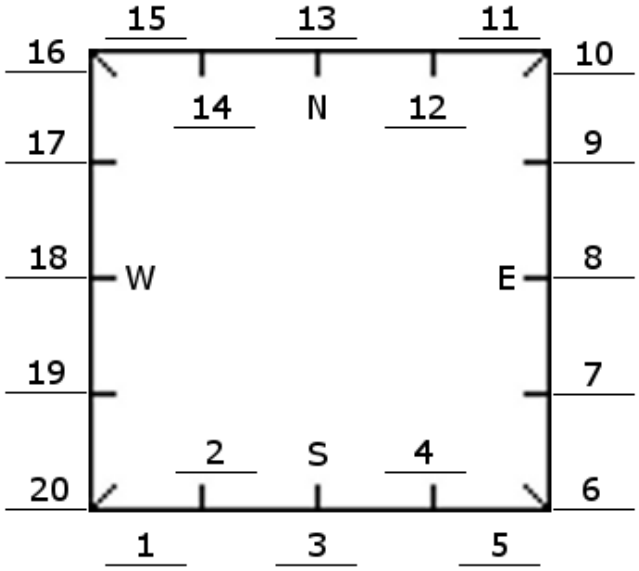
Quadrant 346, West, During The Day And Night



APPENDIX F: NUMERICAL DATA SHEETS

Quadrant 12 Data

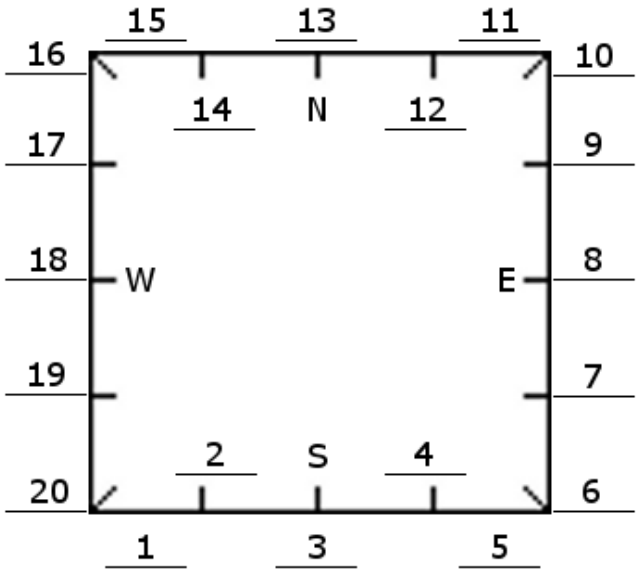
SITE NUMBER	DATE	COODINATES ◦N	COORDINATES ◦W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (◦F)	REGULATION (15/20/21)	Lunar Phase
12-31	11/7	232792.0314	270568.9273	Clear Post-Rain	In the park outside of El Morro	78	N/A	22% Waxing, 4 Days



1	.004	X	X
2	.000	X	X
3	.002	X	X
4	.000	X	X
5	.002	X	X
6	.003	X	X
7	.000	X	X
8	.003	X	X
9	.002	X	X
10	.002	X	X

11	.010	X	X
12	.009	X	X
13	.012	X	X
14	.012	X	X
15	.013	X	X
16	.007	X	X
17	.009	X	X
18	.007	X	X
19	.006	X	X
20	.005	X	X

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase
20-100	11/7	232882.0314	270408.9273	Clear Post-Rain	In the park outside of El Morro	78	N/A	22% Waxing, 4 Days

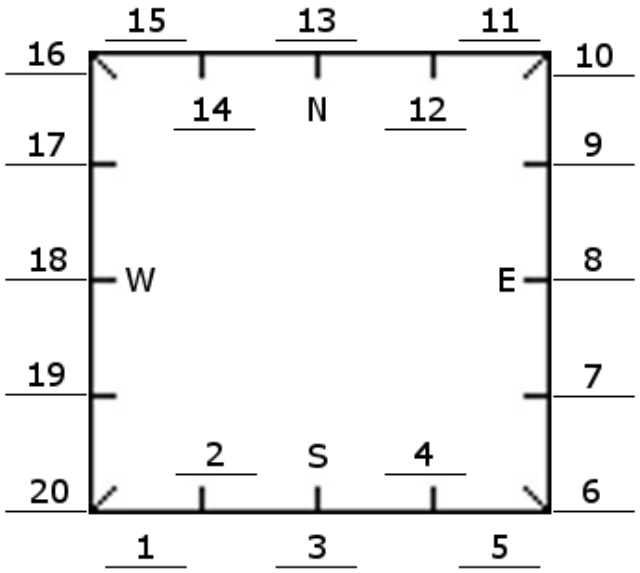


1	.002	X	X
2	.002	X	X
3	.002	X	X
4	.002	X	X
5	.002	X	X
6	.004	X	X
7	.003	X	X
8	.002	X	X
9	.002	X	X
10	.003	X	X

11	.020	X	X
12	.018	X	X
13	.019	X	X
14	.017	X	X
15	.021	X	X
16	.013	X	X
17	.015	X	X
18	.012	X	X
19	.012	X	X
20	.011	X	X

Quadrant 22 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase
22-48	11/7	233062.0314	270458.9273	Clear Post-Rain	In the park outside of El Morro	78	N/A	22% Waxing, 4 Days

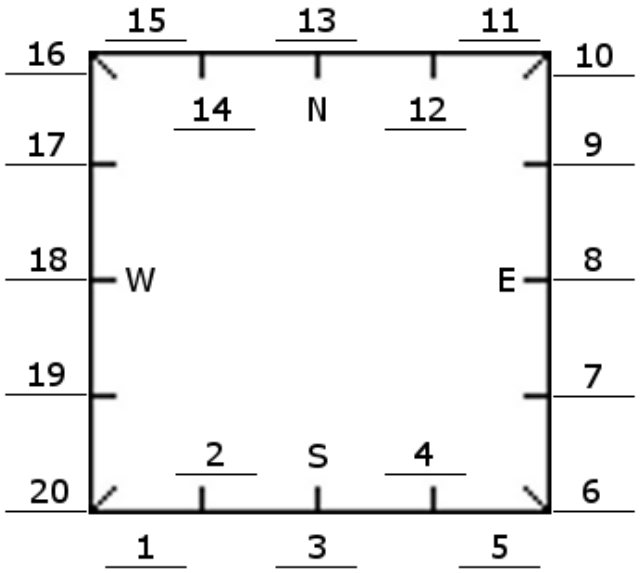


1	.000	X	X
2	.000	X	X
3	.000	X	X
4	.000	X	X
5	.000	X	X
6	.002	X	X
7	.005	X	X
8	.005	X	X
9	.003	X	X
10	.005	X	X

11	.030	X	X
12	.026	X	X
13	.028	X	X
14	.029	X	X
15	.027	X	X
16	.013	X	X
17	.012	X	X
18	.016	X	X
19	.013	X	X
20	.012	X	X

Quadrant 52 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase
52-24	11/7	232822.0314	270278.9273	Clear Post-Rain	In the park outside of El Morro	78	N/A	22% Waxing, 4 Days

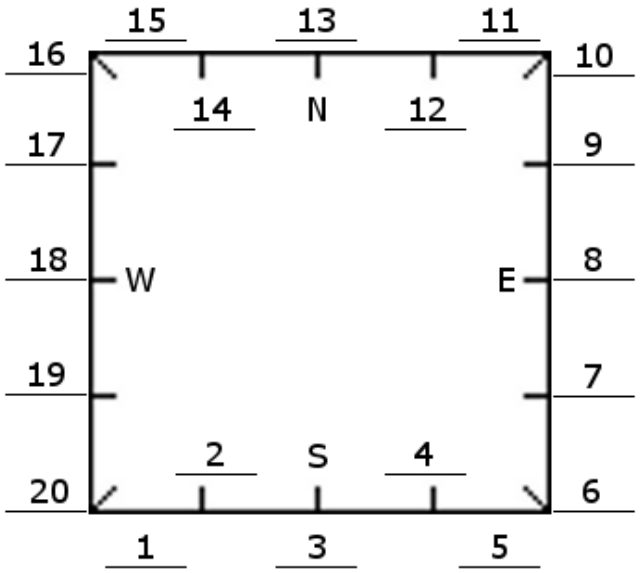


1	.001	X	X
2	.001	X	X
3	.001	X	X
4	.001	X	X
5	.001	X	X
6	.005	X	X
7	.004	X	X
8	.005	X	X
9	.004	X	X
10	.005	X	X

11	.010	X	X
12	.011	X	X
13	.011	X	X
14	.012	X	X
15	.010	X	X
16	.012	X	X
17	.013	X	X
18	.013	X	X
19	.013	X	X
20	.013	X	X

Quadrant 54 Data

SITE NUMBER	DATE	COODINATES N	COORDINATES W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (F)	REGULATION (15/20/21)	Lunar Phase
54-7	11/12 8:52p	233052.0314	270298.9273	Partly Cloudy	Sidewalk near El Morro	82	N/A	75% Waxing, 9 Days



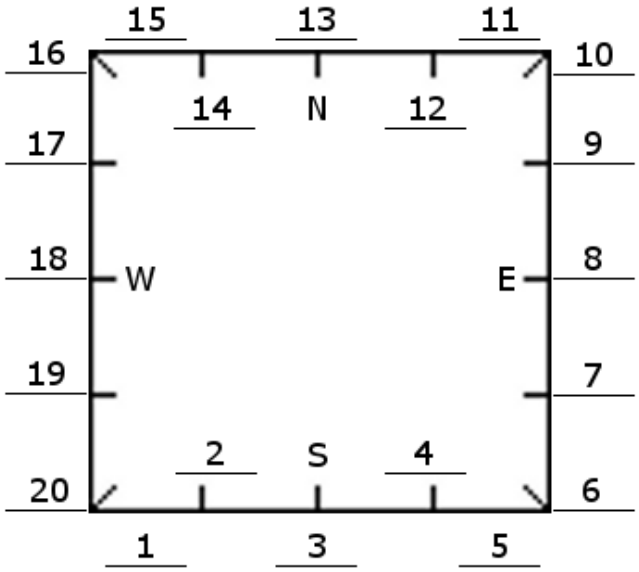
1	.230	X	X
2	.240	X	X
3	.240	X	X
4	.224	X	X
5	.185	X	X
6	.058	X	X
7	.082	X	X
8	.163	X	X
9	.293	X	X
10	.331	X	X

11	.085	X	X
12	.078	X	X
13	.082	X	X
14	.071	X	X
15	.069	X	X
16	.576	X	X
17	.379	X	X
18	.254	X	X
19	.164	X	X
20	.109	X	X

Quadrant 80 Data

SITE	DATE	COODINATE	COORDINATE	WEATHER	LOCATION	TEMPERATUR	REGULATIO	Lunar Phase

NUMBER		S □N	S □W	CONDITIONS		E (□F)	N (15/20/21)	
80-75	11/12 8:35p	232932.0314	270128.9273	Partly Cloud	Basketball Court near El Morro	82	N/A	75% Waxing, 9 Days



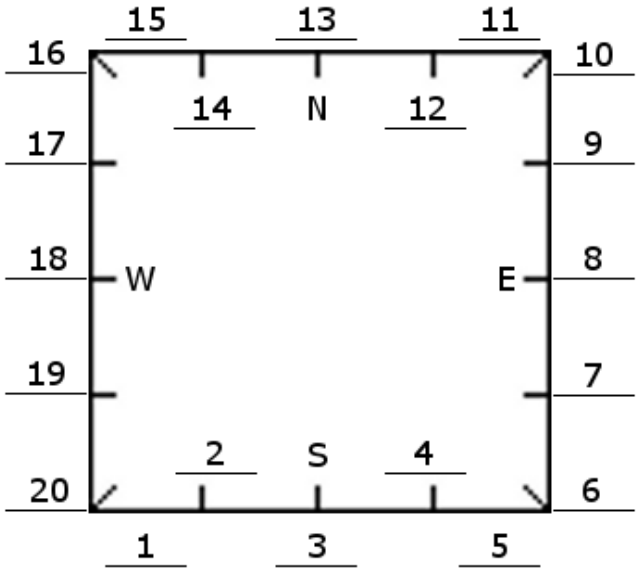
1	1.099	X	X
2	1.109	X	X
3	.997	X	X
4	1.055	X	X
5	.872	X	X
6	.997	X	X
7	1.249	X	X
8	1.511	X	X
9	1.793	X	X
10	2.176	X	X

11	.057	X	X
12	.056	X	X
13	.058	X	X
14	.069	X	X
15	.078	X	X
16	1.527	X	X
17	.857	X	X
18	.280	X	X
19	.203	X	X
20	.058	X	X

Quadrant 98 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION	Lunar Phase

							(15/20/21)	
98-92	11/14	234702.0314	270108.9273	Cloudy	On the sidewalk North of Route 25	81	N/A	91% Waxing, 11 Days



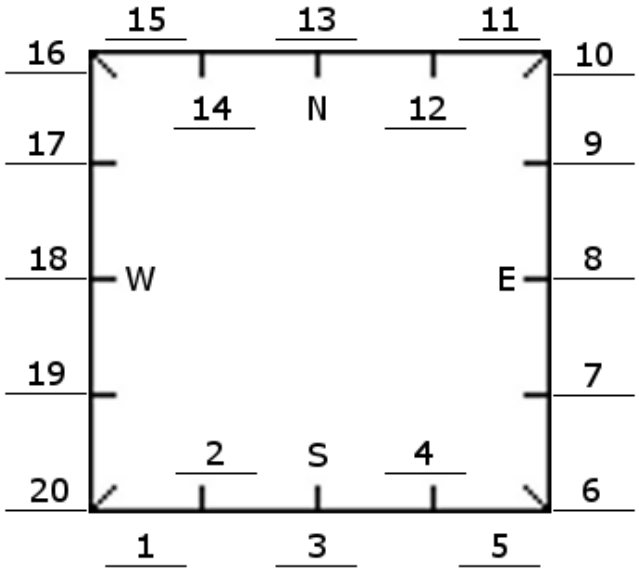
1	.212	.210	.198
2	.259	.258	.249
3	.329	.323	.329
4	.281	.286	.273
5	.247	.262	.243
6	.464	.473	.465
7	.244	.258	.260
8	.373	.406	.433
9	.404	.363	.375
10	.519	.499	.496

11	.284	.267	.260
12	.232	.289	.291
13	.344	.355	.340
14	.244	.221	.240
15	.124	.126	.145
16	.437	.452	.359
17	.415	.397	.396
18	.425	.426	.435
19	.520	.481	.490
20	.533	.673	.726

Quadrant 99 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

99-43	11/14 7:28p	324812.0314	270158.9273	Cloudy Misty Rain	On the sidewalk north of Route 25	81	N/A	91% Waxing, 11 Days



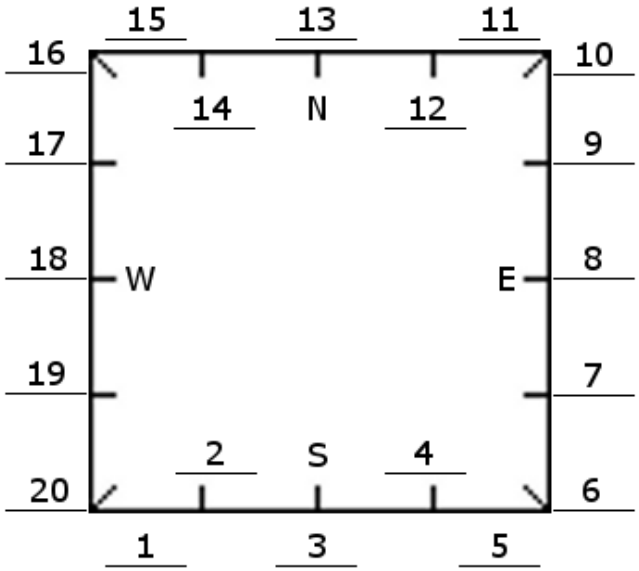
1	.103	.104	.109
2	.126	.122	.128
3	.128	.125	.119
4	.104	.108	.113
5	.103	.106	.108
6	.072	.082	.042
7	.065	.050	.049
8	.058	.060	.055
9	.058	.057	.050
10	.058	.066	.047

11	.556	.584	.608
12	.438	.432	.433
13	.377	.359	.364
14	.292	.307	.307
15	.250	.231	.236
16	.284	.289	.302
17	.263	.274	.291
18	.327	.335	.320
19	.389	.384	.381
20	.435	.449	.435

Quadrant 117 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

117-25	11/12 8:18p	233032.0134	270078.9273	Partly Cloudy	Along Paseo del Morro	82	N/A	75% Waxing, 9 Days



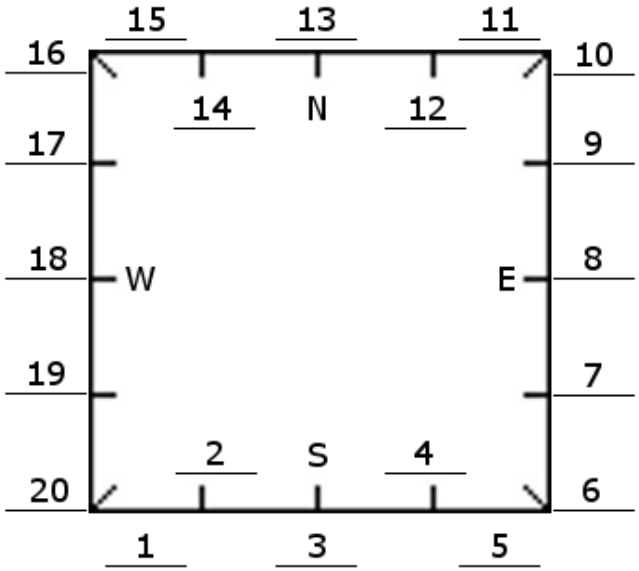
1	1.188	X	X
2	2.640	X	X
3	2.707	X	X
4	2.201	X	X
5	1.069	X	X
6	4.190	X	X
7	4.640	X	X
8	2.332	X	X
9	1.074	X	X
10	.368	X	X

11	1.108	X	X
12	1.360	X	X
13	1.341	X	X
14	1.231	X	X
15	.806	X	X
16	.478	X	X
17	.283	X	X
18	.642	X	X
19	1.869	X	X
20	3.250	X	X

Quadrant 136 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

136-80	11/14 7:48p	234982.0314	270028.9273	Cloudy	On the sidewalk South of Route 25	81	N/A	91% Waxing, 11 Days



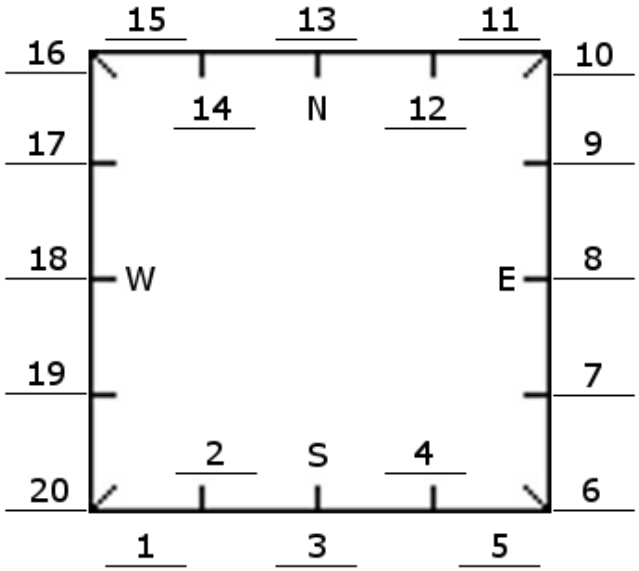
1	.261	.247	.238
2	.282	.267	.267
3	.067	.117	.132
4	.208	.206	.189
5	.483	.480	.487
6	.110	.096	.103
7	.159	.177	.183
8	.118	.124	.125
9	.160	.256	.360
10	.442	.403	.412

11	.085	.103	.091
12	.080	.077	.079
13	.069	.063	.058
14	.046	.044	.048
15	.047	.049	.048
16	.348	.359	.324
17	.297	.132	.169
18	.081	.085	.081
19	.058	.066	.067
20	.054	.042	.041

Quadrant 155 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

155-51	12/4	233092.0314	269948.9273	Cloudy, Drizzly	The beginning of El Paseo la Princesa	75	N/A	4% Waxing, 2 Days



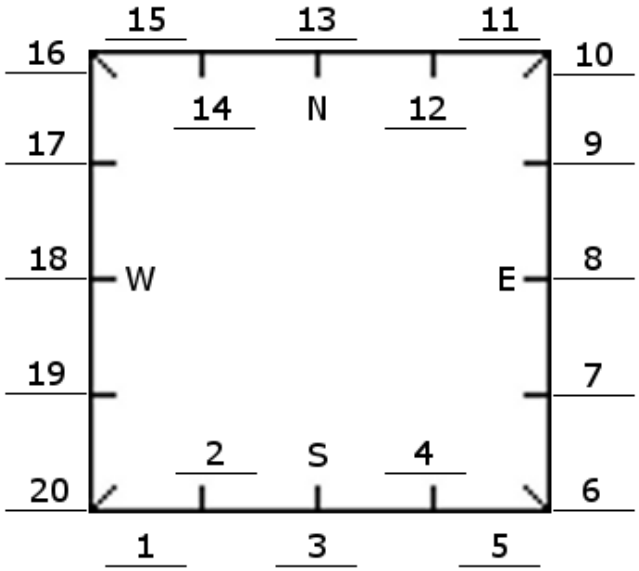
1	1.132	1.098	1.125
2	.418	.404	.404
3	.325	.321	.312
4	.409	.425	.395
5	.473	.451	.430
6	3.530	3.030	2.990
7	.669	.667	.667
8	.269	.267	.277
9	.307	.306	.298
10	.272	.261	.261

11	.424	.407	.394
12	.330	.313	.305
13	.438	.422	.422
14	.265	.274	.262
15	.235	.210	.199
16	.741	.752	.791
17	.432	.441	.428
18	.431	.455	.440
19	1.429	1.291	1.222
20	2.368	2.521	2.629

Quadrant 182 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

182-70	11/20 7:09p	235882.0314	269938.9273	Partly Cloudy	Muñoz Rivera Park	78	N/A	91% Waning, 17 Days



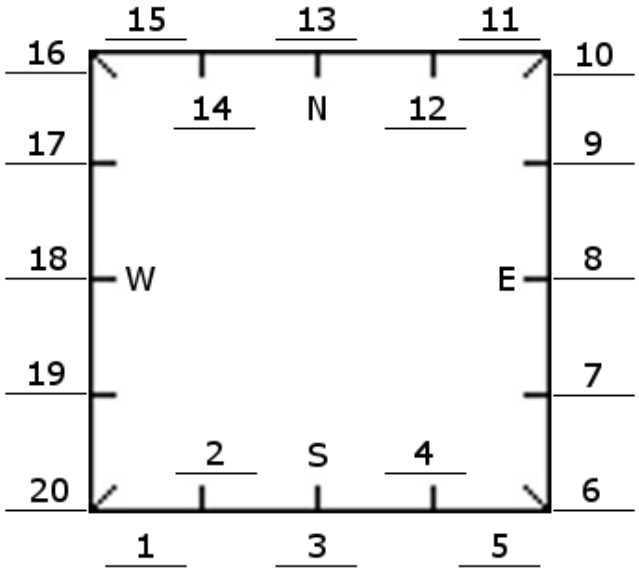
1	.038	.038	.040
2	.050	.053	.048
3	.085	.062	.069
4	.129	.115	.126
5	.211	.211	.213
6	.078	.063	.074
7	.069	.068	.069
8	.111	.109	.107
9	.108	.097	.105
10	.087	.098	.086

11	.305	.279	.284
12	.169	.171	.180
13	.182	.181	.181
14	.187	.172	.170
15	.195	.192	.183
16	.077	.080	.081
17	.100	.099	.095
18	.058	.043	.044
19	.129	.122	.124
20	.144	.134	.140

Quadrant 185 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

185-3	12/3	236112.0314	269998.9273	Partly Cloudy	A basic park	82	N/A	1% Waxing, 1 Day



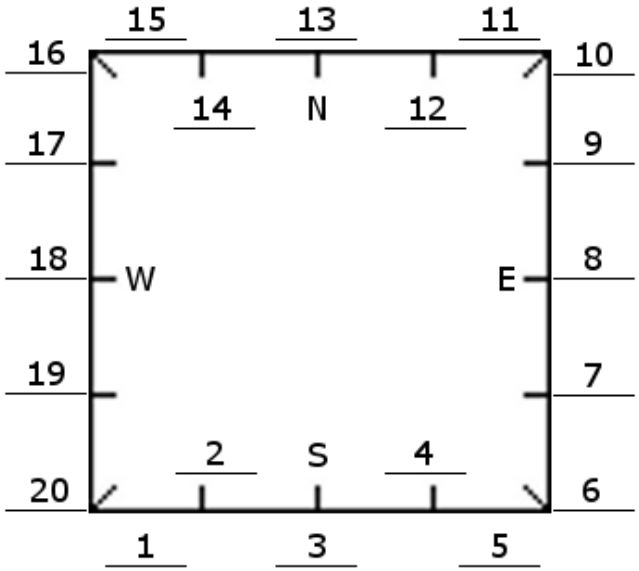
1	.040	.061	.052
2	.045	.049	.026
3	.023	.020	.025
4	.016	.016	.007
5	.013	.013	.012
6	.343	.347	.324
7	.279	.265	.254
8	.098	.098	.096
9	.093	.079	.087
10	.06	.082	.078

11	.132	.133	.148
12	.113	.101	.076
13	.215	.222	.213
14	.269	.266	.274
15	.316	.333	.319
16	.103	.147	.098
17	.105	.070	.095
18	.287	.225	.226
19	.271	.311	.283
20	.571	.754	.839

Quadrant 186 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

186-4	12/3	236222.0314	269998.9273	Partly Cloudy	Inside a small baseball park	79	N/A	1% Waxing, 1 Day



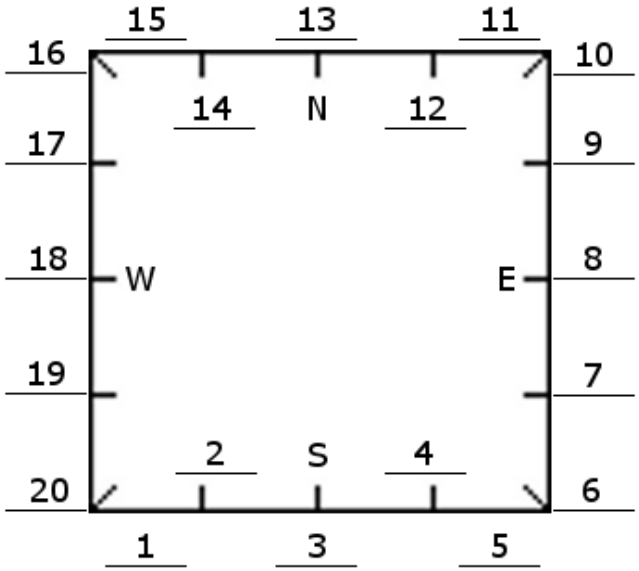
1	1.200	1.160	1.188
2	1.191	1.228	1.205
3	1.232	1.264	1.108
4	1.351	1.389	1.373
5	1.476	1.435	1.444
6	.344	.345	.364
7	.266	.307	.291
8	.152	.210	.231
9	.128	.208	.183
10	.311	.345	.351

11	.411	.425	.374
12	.383	.324	.416
13	.274	.325	.329
14	.307	.253	.266
15	.278	.299	.311
16	1.070	1.109	1.030
17	1.308	1.238	1.243
18	1.449	1.429	1.421
19	1.450	1.382	1.366
20	1.333	1.319	1.232

Quadrant 187 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

187-13	12/3	236312.0314	269988.9273	Partly Cloudy	Near Sixto Escobar Stadium	79	N/A	1% Waxing, 1 Day



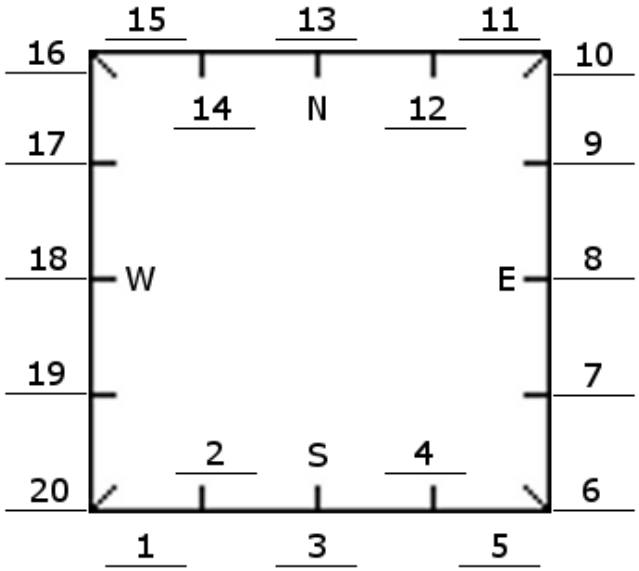
1	1.133	1.165	1.188
2	1.221	1.144	1.202
3	1.133	1.187	1.137
4	1.111	1.088	1.013
5	1.316	1.302	1.373
6	.099	.103	.095
7	.108	.105	.103
8	.112	.113	.127
9	.116	.125	.123
10	.121	.118	.116

11	.196	.193	.203
12	.193	.196	.190
13	.178	.181	.180
14	.195	.189	.176
15	.173	.177	.174
16	1.508	1.316	1.410
17	1.242	.947	1.283
18	1.232	1.257	1.230
19	1.157	1.252	1.109
20	1.205	1.208	1.207

Quadrant 195 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

195-96	12/4 7:28p	233342.0314	269808.9273	Cloudy, Drizzly	Parque de las Palomas	75	N/A	4% Waxing, 2 Days



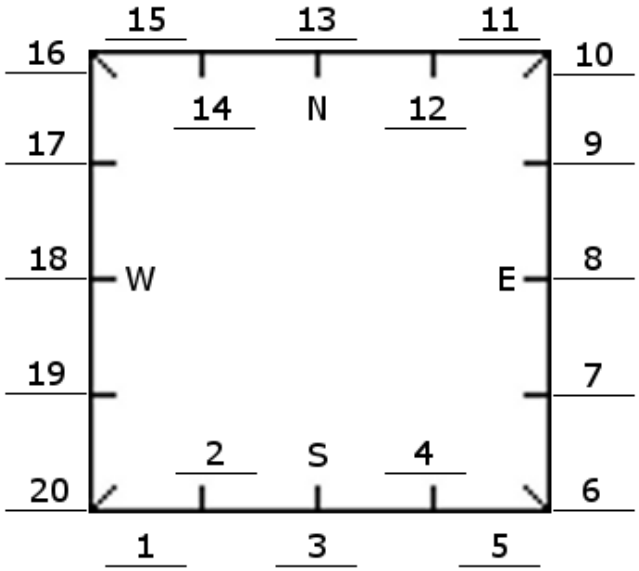
1	.065	.063	.054
2	.082	.080	.078
3	.124	.137	.112
4	.060	.061	.057
5	.071	.045	.062
6	.019	.020	.016
7	.025	.024	.013
8	.045	.051	.052
9	.043	.046	.032
10	.037	.044	.043

11	.019	.004	.003
12	.020	.012	.001
13	.034	.020	.041
14	.017	.016	.018
15	.040	.005	.031
16	.041	.052	.034
17	.084	.095	.092
18	.098	.097	.092
19	.085	.083	.088
20	.085	.093	.094

Quadrant 203 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

203-100	11/12 7:25p	234183.0314	269808.9273	Partly Cloudy	The entrance of the San Juan Cruise Port	82	N/A	75% Waxing, 9 Days



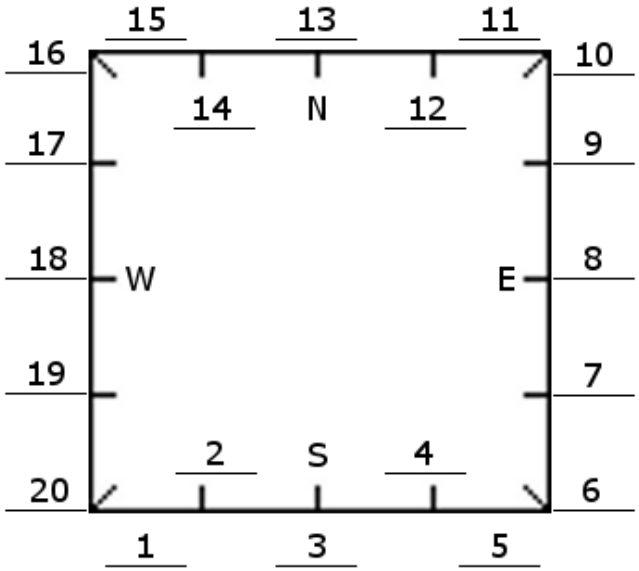
1	.417	X	X
2	.440	X	X
3	.430	X	X
4	.448	X	X
5	.396	X	X
6	.163	X	X
7	.117	X	X
8	.133	X	X
9	.136	X	X
10	3.680	X	X

11	.146	X	X
12	.131	X	X
13	.131	X	X
14	.111	X	X
15	.071	X	X
16	.360	X	X
17	.258	X	X
18	.298	X	X
19	.358	X	X
20	.424	X	X

Quadrant 222 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

222-33	12/3	236012.0314	269868.9273	Cloudy	Muñoz Rivera Park	79	N/A	1% Waxing, 1 Day



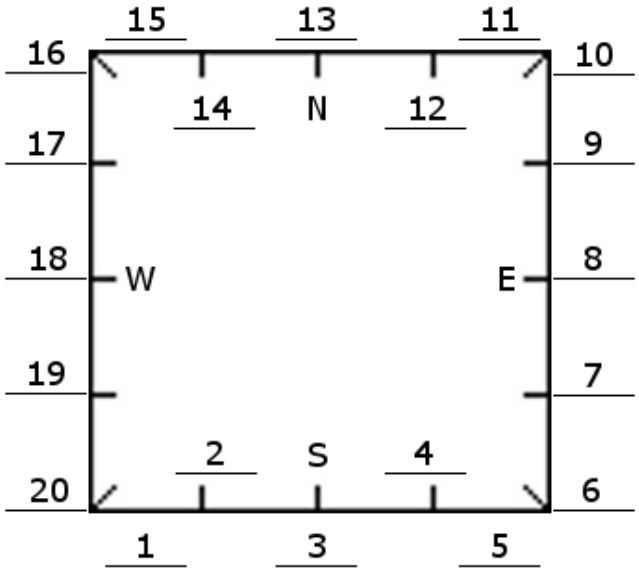
1	.010	.011	.011
2	.019	.018	.011
3	.019	.022	.026
4	.019	.019	.019
5	.022	.020	.021
6	.070	.061	.060
7	.054	.056	.082
8	.036	.045	.027
9	.032	.038	.026
10	.070	.019	.020

11	.082	.062	.054
12	.156	.154	.133
13	.113	.114	.099
14	.100	.103	.109
15	.095	.072	.101
16	.042	.042	.039
17	.067	.072	.075
18	.061	.049	.062
19	.164	.159	.161
20	.210	.205	.126

Quadrant 225 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

225-28	11/18	236362.0314	269878.9273	Cloudy	Underneath trees across from 2 stadiums	78	N/A	99% Waxing, 15 Days



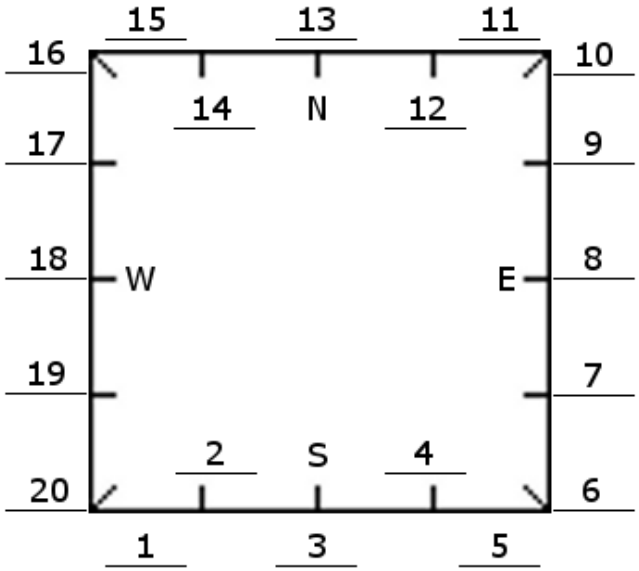
1	.289	.266	.273
2	.240	.247	.196
3	.548	.538	.526
4	.551	.585	.592
5	.583	.594	.600
6	.170	.174	.165
7	.194	.174	.188
8	.150	.150	.138
9	.132	.135	.115
10	.162	.181	.180

11	.155	.146	.170
12	.043	.055	.039
13	.148	.170	.258
14	.161	.171	.158
15	.284	.221	.227
16	.206	.244	.263
17	.162	.176	.158
18	.301	.341	.314
19	.078	.080	.083
20	.245	.233	.224

Quadrant 228 Data

SITE NUMBER	DATE	COODINATES N	COORDINATES W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (F)	REGULATION (15/20/21)	Lunar Phase

228-23	11/18	236612.0314	269818.9273	Cloudy	Small park outside of the Normandie	78	N/A	99% Waxing, 15 Days



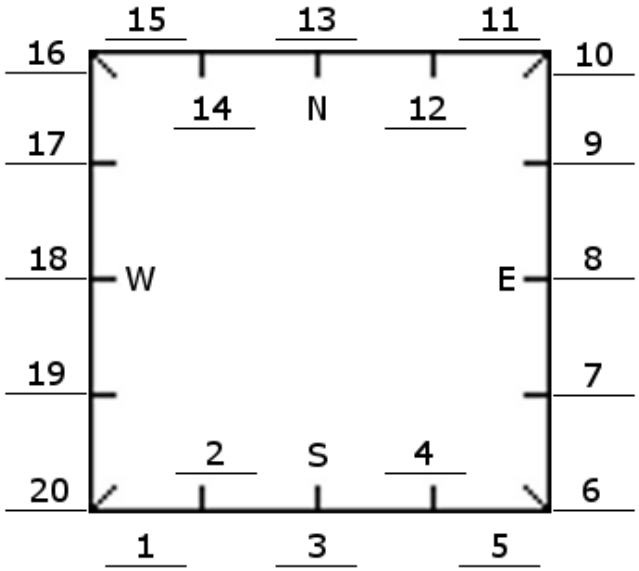
1	.671	.701	.718
2	.325	.389	.275
3	.307	.322	.272
4	.173	.197	.228
5	.156	.167	.135
6	.731	.748	.761
7	.758	.758	.740
8	.719	.731	.751
9	.700	.694	.693
10	.666	.664	.660

11	.211	.196	.276
12	.266	.256	.213
13	.414	.355	.432
14	.408	.446	.361
15	.584	.580	.580
16	.093	.105	.105
17	.079	.091	.081
18	.085	.086	.075
19	.075	.071	.083
20	.091	.112	.113

Quadrant 234 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

234-37	11/12 7:55p	233452.0314	269768.9273	Partly Cloudy	Along Paseo de la princesa	82	N/A	75% Waxing, 9 Days



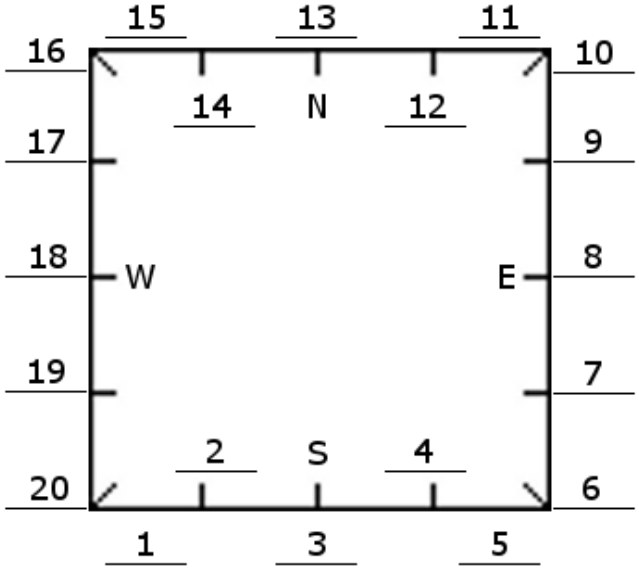
1	.269	X	X
2	.277	X	X
3	.228	X	X
4	.251	X	X
5	.220	X	X
6	.801	X	X
7	.401	X	X
8	.284	X	X
9	.254	X	X
10	.304	X	X

11	.926	X	X
12	1.073	X	X
13	.357	X	X
14	.379	X	X
15	.421	X	X
16	.242	X	X
17	.206	X	X
18	.439	X	X
19	.581	X	X
20	.537	X	X

Quadrant 284 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

284-30	11/14	235182.0314	269678.9273	Cloudy	In a private dock area South of Route 1	81	N/A	91% Waxing, 11 Days



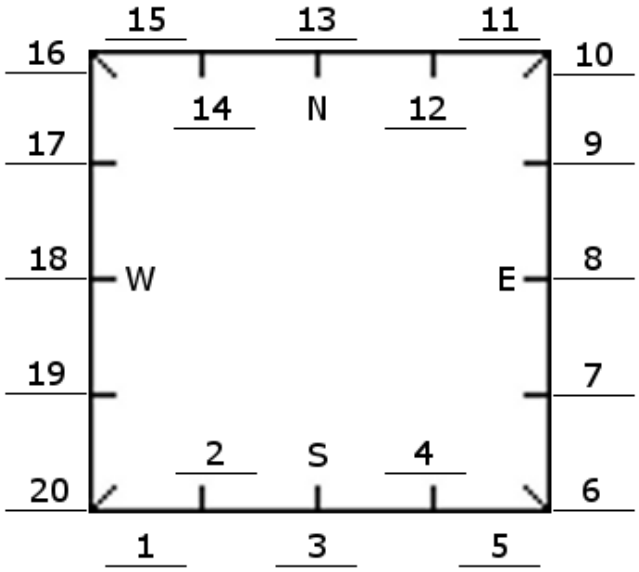
1	.034	.034	.044
2	.017	.017	.016
3	.041	.035	.022
4	.026	.024	.009
5	.065	.047	.024
6	.023	.007	.007
7	.023	.022	.022
8	.019	.017	.018
9	.021	.021	.019
10	.020	.007	.007

11	.022	.027	.027
12	.020	.024	.021
13	.021	.009	.023
14	.022	.020	.019
15	.020	.004	.005
16	.034	.032	.014
17	.034	.035	.024
18	.048	.047	.038
19	.090	.089	.084
20	.101	.099	.082

Quadrant 297 Data

SITE NUMBER	DATE	COODINATES N	COORDINATES W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (F)	REGULATION (15/20/21)	Lunar Phase

297-89	11/18	236472.0314	269618.9273	Cloudy	Outside of 2 large apartment buildings	78	N/A	99% Waxing, 15 Days



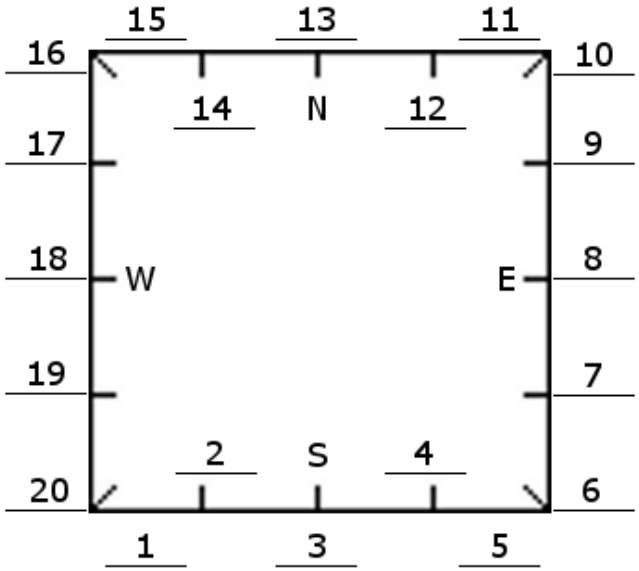
1	.209	.223	.210
2	.214	.220	.216
3	.043	.041	.041
4	.202	.202	.201
5	.245	.231	.221
6	.142	.152	.146
7	.300	.176	.204
8	.180	.185	.200
9	.178	.305	.160
10	.118	.107	.105

11	.116	.130	.126
12	.101	.104	.081
13	.091	.111	.095
14	.103	.092	.095
15	.100	.102	.116
16	.240	.270	.438
17	.095	.084	.086
18	.063	.062	.060
19	.045	.052	.058
20	.108	.116	.127

Quadrant 322 Data

SITE NUMBER	DATE	COODINATES N	COORDINATES W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (F)	REGULATION (15/20/21)	Lunar Phase

322-23	11/20 8:20p	236012.0314	269578.9273	Partly Cloudy	Muelle Frontier	78	N/A	91% Waning, 17 Days



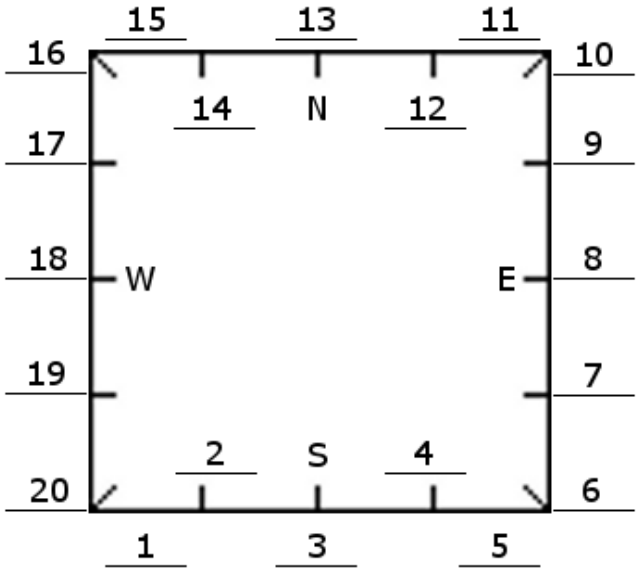
1	.128	.177	.152
2	.209	.184	.197
3	.158	.181	.184
4	.211	.221	.226
5	.271	.270	.448
6	.263	.281	.282
7	.255	.244	.254
8	.232	.226	.223
9	.209	.209	.202
10	.184	.185	.180

11	1.741	1.511	1.629
12	1.863	1.687	1.568
13	2.439	1.707	1.819
14	2.548	2.673	2.389
15	1.619	1.502	1.666
16	2.920	2.800	2.670
17	2.370	3.200	3.180
18	3.530	3.520	3.520
19	3.220	3.020	2.980
20	2.512	2.434	2.505

Quadrant 323 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

323-57	11/20 7:48	236152.0314	269498.9273	Partly Cloudy	Muelle Frontier	87	N/A	91% Waning, 17 Days



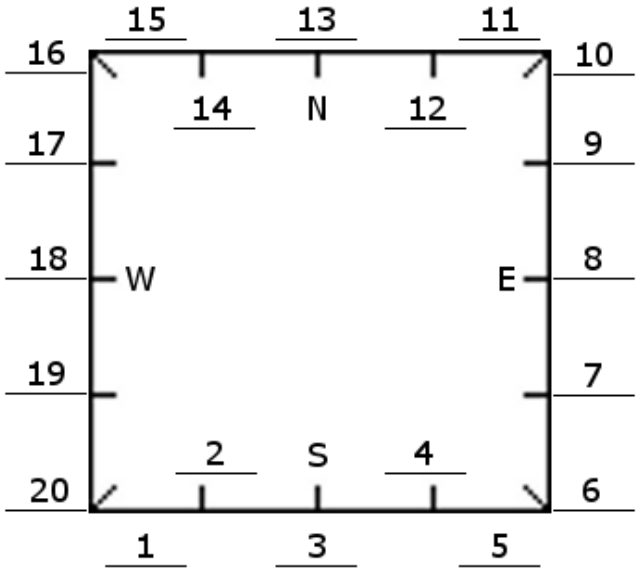
1	.039	.043	.028
2	.038	.022	.037
3	.038	.021	.037
4	.038	.022	.038
5	.035	.037	.036
6	.048	.047	.047
7	.049	.054	.036
8	.041	.041	.040
9	.032	.035	.023
10	.038	.039	.039

11	.349	.354	.328
12	.358	.386	.376
13	.399	.355	.384
14	.406	.385	.390
15	.313	.341	.297
16	.323	.334	.369
17	.313	.358	.389
18	.432	.463	.374
19	.412	.428	.418
20	.542	.520	.518

Quadrant 344 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

344-4	11/18	236322.0314	269498.9273	Cloudy	Parking lot of Club Naúica de San Juan	78	N/A	99% Waxing, 17 Days



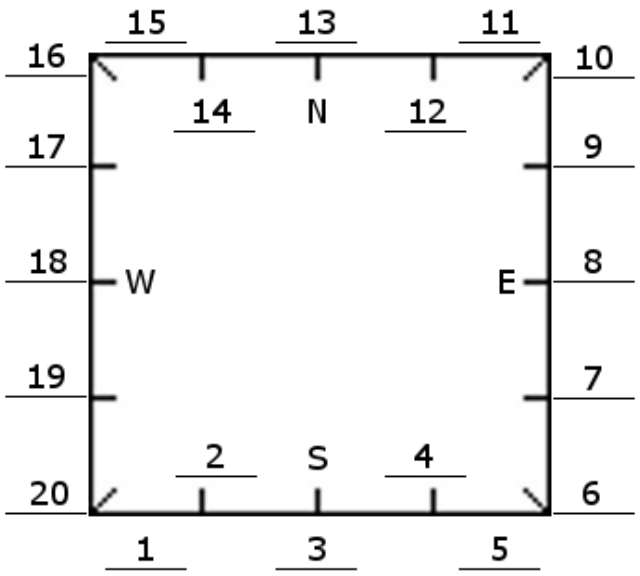
1	1.573	1.584	1.590
2	2.070	2.050	2.061
3	2.040	2.052	2.043
4	2.077	2.095	2.110
5	1.842	1.825	1.775
6	2.346	2.322	2.357
7	3.010	3.240	3.280
8	2.853	2.885	2.915
9	2.505	2.425	2.441
10	2.815	2.619	2.946

11	.962	.986	.982
12	1.042	1.035	1.023
13	1.128	1.126	1.113
14	1.175	1.159	1.186
15	.805	.845	.726
16	2.329	2.848	2.753
17	2.395	2.326	2.356
18	1.668	1.755	1.742
19	1.503	1.434	1.457
20	1.131	1.270	1.213

Quadrant 346 Data

SITE NUMBER	DATE	COODINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE (□F)	REGULATION (15/20/21)	Lunar Phase

346-3	11/18	236512.0314	294498.9273	Cloudy	Median of Avenue Fernandez Juncos	78	N/A	99% Waxing, 15 Days



1	.576	.588	.591
2	.526	.653	.521
3	.349	.284	.271
4	.986	.773	.860
5	1.087	1.032	1.425
6	.325	.458	.414
7	.483	.462	.466
8	.394	.383	.390
9	.369	.361	.416
10	.376	.380	.380

11	1.422	1.419	1.519
12	1.277	1.418	1.456
13	.642	.573	.737
14	.439	.450	.481
15	.423	.399	.408
16	.484	.241	.235
17	.533	.547	.597
18	.648	.665	.640
19	.616	.604	.603
20	.142	.123	.386

APPENDIX G: LAB MANUAL

JCA Light Pollution Measurement Handbook

TABLE OF CONTENTS

EQUIPMENT

-Compass
-Photometer
-GPS
-Caution Tape

-Site Assessment Sheets
-Data Collection Sheets
-Writing Utensils
-Metric Tape Measure
-Digital Photo/Video Camera
-Watch/Clock

CHAPTER 1

USING THE PHOTOMETER

Each model of photometer is slightly different; however, they all assemble in similar fashions and perform relatively the same functions. Each device has an external light sensor that connects to the meter through a short cable.

Before powering the devices on, it is necessary to note the calibration of the device. Most light meters are factory calibrated and must be sent to the manufacturer annually to be recertified and calibrated. To see whether the meter requires this or not, see the manual for the meter and/or any Certificates of Calibration provided with the device. Other meters are factory calibrated, but perform a "zero adjustment" each time they are started and at certain intervals while they are running. To perform this "zero adjustment", you usually need to connect the light sensor and start the device; however, it is important that you read the manual for your light meter to understand any device-specific instructions.

The standard unit for measuring light pollution is the foot-candle. This is usually changed by either toggling through a variety of units through a "Units" button or switch. The LCD interface generally indicates which unit has been selected.

There are many different buttons for performing different operations on different varieties of meters. For this methodology, however, only the "Hold" function of the light meter is necessary. This button is standard on nearly all instantaneous photometers. The measurements must be performed in the standard illuminance measurement mode, not a tangential or differential mode that may be provided on the meter.

In terms of accuracy of data, there are a few things to keep in mind. Firstly, one must note the difference in range of light levels measured by each meter. It is best to have a light meter that can measure low levels of light, so the more decimal places the device can capture on its lowest range option the more preferable it is to use the device. It is also preferable to have a device that performs a zero-adjustment, as it increases the precision of the results.

CHAPTER 2

CHOOSING THE QUADRANTS

The first step in selecting points is to divide the area of study into 100x100 meter quadrants, then divide each quadrant into 10x10 meter sub-quadrants. This can easily be completed using the computer program ArcGIS, or through the aid of a local cartographer

with ArcGIS experience. The number of quadrants that must be sampled for statistical significance of the study will vary based on the total area. ArcGIS can then randomly select the quadrants, giving GPS coordinates as well as a blown up image of each.

Once each point is chosen by ArcGIS, it must then be located in person. To do this, use a handheld GPS and input the coordinates of the point, which are typically given in meters north and meters east. Moving with the GPS will give a heading to follow and lead to the point. Most modern GPS units have a margin of error of 5 meters. This means that if the GPS says the researcher is on the point, but they cannot take measurements at that exact location because of some obstruction, it is acceptable to move the point up to 5 meters in any direction without altering the randomness of the procedure. If measurements cannot be taken within 5 meters of the located point because of obstructions or safety concerns, the point must be cancelled and a replacement point must be selected by the computer software.

CHAPTER 3

DAYTIME AND NIGHTTIME SITE ASSESSMENTS

Once a quadrant has been successfully located, the team must make observations about the site. These observations will be used to help draw conclusions about the perceptions of light sources during the day and night and to determine which sources of light are the brightest or most problematic. The assessment is performed during the night and day, and both procedures are similar but slightly different.

Once the point is discovered during the day, the researchers must note the number of the site, the date and time, the coordinates of the site and the relative location, noting any distinguishable landmarks. The compass can be used to determine the 4 cardinal directions- North, East, South and West. After this, observations are made concerning light sources and obstacles that may affect the photometer readings during the night. Photos are taken in each direction in case any observations were missed. If any special permission was required to access the site, or if there are any interesting observations in any of the intercardinal directions (northeast, northwest, southeast, and southwest), that information must be recorded in the extra space provided in the Site Assessment Sheet (see Appendix A).

When the researchers return at night, this information must be filled out again on another Site Assessment Sheet. Another 4 photographs must also be taken. After the data has been successfully gathered, one member of the research team must stand at the center of the site and take a video of the area. Standing at the same point and facing directly north, they will speak the site number and then begin to spin, slowly, in a clockwise direction. Once they have completed the rotation they will again read the site number and end the recording.

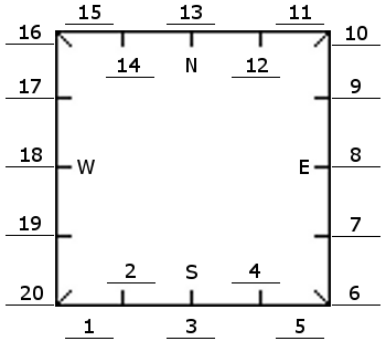
CHAPTER 4

PERFORMING NIGHTTIME MEASUREMENTS

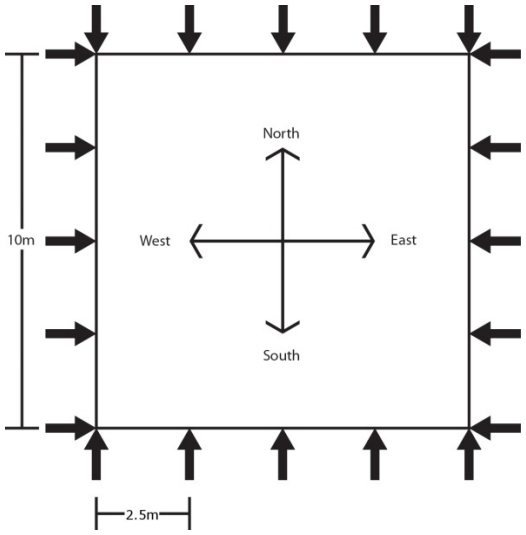
All measurements must not be taken during the period known as “astronomical twilight.” This is the range of time between when the sun’s altitude falls below the point 18º below the Western horizon and when the sun’s altitude rises above the point 18º below the Eastern horizon. This time period can be determined mathematically, however there are many online resources that can provide this range of time for a given date, latitude, longitude, and elevation. Readings can be performed between the end of astronomical twilight, at night, and the beginning of astronomical twilight, in the morning.

Once astronomical twilight has ended, the measurement quadrant must be prepared. From the center of the quadrant, located using the GPS, the researchers must measure 7.071 meters to the northeast, northwest, southeast and southwest, placing markers at each. These markers can be anything, as long as they are recognizable to the researchers. Next, the researcher will connect each corner to the others, forming a 10 meter by 10 meter square around the perimeter of the quadrant. This denotes the area to be measured.

The measurements must begin at the southwestern corner of the square, facing north. The researcher must stand with the photometer held 1.5 meters above the ground, wait several seconds, and then hold the result. Once it has been recorded by another member of the measurement tame on the Data Collection Sheet (see Appendix B), they will release the measurement, wait several seconds, and then press “Hold” again. This will continue until 3 data points have been measured at that point on the square. Then, with the aid of a tape measure, the researcher will move 2.5 meters east along the edge of the square and take another 3 measurements at that point. Once the corner has been reached, the researcher will take 3 points facing north, then an additional 3 facing west. They will then repeat this procedure along the eastern side of the square, facing west. This creates a pattern in which the researcher moves along the edge of the quadrant in a counter-clockwise direction, taking measurements in the following order:



In the end, the research team should possess 60 data points for each quadrant. The final square, with points where measurements should be taken marked, should resemble this:



CHAPTER 5

DIGITALLY STORING THE DATA

Data storage all begins in the field. As previously mentioned, there should be a daytime site assessment sheet, a nighttime site assessment sheet and data collection sheet filled out at each quadrant. These sheets are all provided in a digital format and handwritten comments can be entered on the computer when storing data.

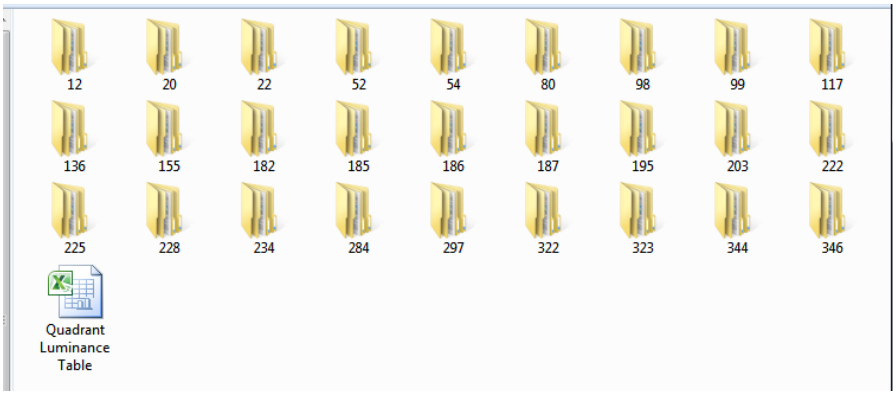
After populating all of these sheets, the researcher will then begin digitalizing the collected data in the excel workbook. This workbook contains two sheets. The first sheet is strictly for populating with the photometer data gathered in the field. In this sheet the researcher will place a name for the site in the yellow cell located at the top of the column. From there, he/she will populate that same column with each location's respective measurements. Please note that all values are to be input in footcandles for the workbook to function properly.

W25

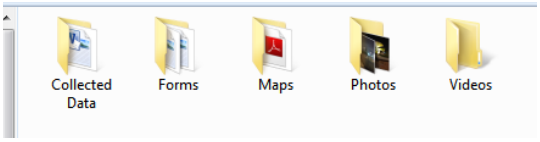
	A	B	C	D	E	F	G	H	I	J	K
1	Ambient Light Data Collection Table										
2		Site Number									
3	**Quadrant Location**										
4	SW, Facing North										
5											
6											
7	SSW										
8											
9											
10	S										
11											
12											
13	SSE										
14											
15											
16	SE, Facing North										
17											
18											

Once this sheet has been successfully populated, the researcher will navigate to the second sheet by clicking the tab labeled “RESULTS” on the bottom of the workbook. This page has formulas pre-loaded that calculate the average luminance for each location around the quadrant as well as averaging these values to find the mean luminance for the interior of the entire quadrant. The highlighted cells in each column signify the lowest and highest values in each quadrant (Reference table legend for significance of each color). If it is necessary to include more points than provided in the workbook, the researcher can copy the formatting from one of the existing columns into an additional one; however it may be necessary to alter certain functions to reflect the correct columns.

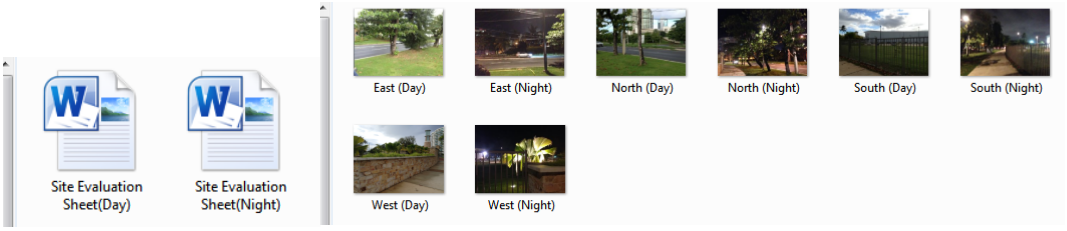
For convenience, there is a folder hierarchy that can be used to organize all of the data in an easy-to-find format. Inside a folder made to contain all of the data, there should be one folder for each point to be measured and the Excel file which contains the measurements at each quadrant combined. Inside each site folder, named after the quadrant it is located in, should be a “Collected Data” folder that contains the data collection sheet, a “Forms” folder that contains the site assessment sheets (labelled as day or night in their file names), a “Maps” folder that contains the relevant ArcGIS maps with included coordinates, a “Photos” folder where each photo is labelled in terms of direction and whether it was taken during the day or night, and a “Videos” folder that contains the site video. The following images are examples of folders that illustrate the correct formatting:



The master folder contains the quadrant folders and the master excel file.



Each quadrant folder should contain these 5 folders for containing the data.



Each filename should be detailed if multiple files are in the same folder.

APPENDIX A

SITE ASSESSMENT SHEET

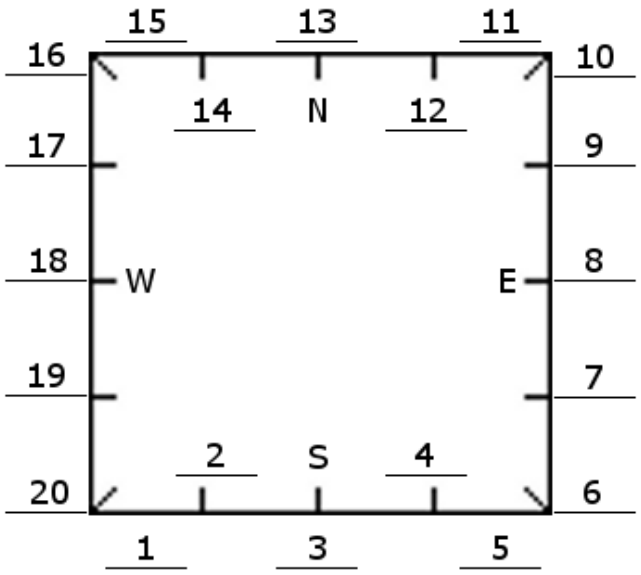
SITE NUMBER	DATE	TIME	COORDINATES X	COORDINATES Y	LOCATION

	OBSERVATIONS	PHOTOGRAPHS
NORTH		
EAST		
SOUTH		
WEST		

APPENDIX B

DATA COLLECTION SHEET

SITE NUMBER	DATE/ TIME	COORDINATES □N	COORDINATES □W	WEATHER CONDITIONS	LOCATION	TEMPERATURE	REGULATION (15/20/21)	LUNAR PHASE



2			
3			
4			
5			
6			
7			
8			
9			
10			

11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

APPENDIX H: EXAMPLES OF LUMINAIRE EFFECTS

Maximum Reading at Site 186

This picture is facing North at point 186-4 (See Quadrant 186, North, During Day And Night). It is located on a walking path adjacent to a ballpark to the North and a road to the South. The ambient light level was measured to be 0.759 fc. The highest value recorded was 1.452 fc, and was generated by an angled, unshielded field luminaire. This type of lighting is one of the worst contributors to glare and light trespass. The area of illumination is very uncontrolled and often spills over into areas other than the desired field. In addition, the light is angled directly into the eyes of viewers which causes discomfort. Although we did not take any pertinent measurements in this study, this type of luminaire is also a known contributor to sky glow.

Maximum Reading at Site 185

This picture is taken facing South from point 185-3, which is located just north of a playground. The ambient light level is 0.175 fc, which is relatively low (See Quadrant 185, South, During Day And Night). The highest luminance reading was 0.721 fc and was generated by this unshielded lamp. While this is significantly lower than the light reading from the previously discussed luminaire at point 186-4, there was a similar amount of discomfort to the viewer. This illustrates that glare is relative to the contrast between the ambient light level and the light produced by a single luminaire.

Maximum Reading at Site 322

This picture is facing East at point 322-23, in a parking lot for the port authority. The ambient light level at this point was 1.323 fc (See Quadrant 322, East, During The Day And Night). The maximum luminance measurement was 3.523 fc and was produced by this angled parking lot light. This type of light is usually horizontal, aiming the light directly towards the ground. For reasons unknown, this one was angled which greatly increased the glare for viewers.

Maximum Reading at Site 182

This picture is facing North from point 182-70, which is on a grass lawn next to a parking lot. The ambient light level was 0.122 fc (See Quadrant 182, North, During The Day And Night


).

The parking lot to the North of the point was illuminated using semi-cutoff lights. Semi-cutoff

luminaires direct most of the light produced at the ground, only a small amount of light is shone outside of the desired area, and almost none is wasted into the atmosphere. The highest measurement recorded facing this parking lot was 0.132 fc, which is very low and produced no uncomfortable glare. This demonstrates why most lighting experts and light-conservation groups are pushing for the use of semi and full cutoff lights.

References:

Amendment to the Light Pollution Control and Prevention Program, La Oficina de Servicios Legislativos de la Asamblea Legislativa de Puerto Rico, 29 Stat. (2012).

Astro-tourism set for star turn with grant of Dark Sky Reserve status to Beacons; NATIONAL PARK JOINS ONLY FIVE OTHER SITES IN THE WORLD. (2013) (pp. NEWS; Pg. 2,3).

Aubrecht, C., & Elvidge, C. D. (2008). Satellite observed nighttime lights as an indicator of human induced stress on coral reefs. *Keynote at Darksky, 2008*, 8th.

Biggs, J. D., Fouché, T., Bilki, F., & Zadnik, M. G. (2012). Measuring and mapping the night sky brightness of Perth, Western Australia. *Monthly Notices of the Royal Astronomical Society, 421*(2), 1450-1464.

BLINDED BY THE LIGHTS. (2008) (pp. FOCUS; Pg. 92).

Brons, J.A., Bullough, J.D., & Rea, M.S. (2008). Outdoor site-lighting performance: A comprehensive and quantitative framework for assessing light pollution. *Lighting Research and Technology*, 19. doi: 10.1177/1477153508094059

Cheney, I. (2011). The City Dark. http://www.pbs.org/pov/citydark/full.php - .Uktc2WTwJO4, Wicked Delicate Films**:** 83 Minutes.

Chepesiuk, R. (2009). Missing the dark: health effects of light pollution. *Environmental Health Perspectives, 117*(1), A20.

Cinzano, P., Falchi, F., & Elvidge, C. D. (2001). The first world atlas of the artificial night sky brightness. *Monthly Notices of the Royal Astronomical Society, 328*(3), 689-707.

Claudia, K. (2011). L.B. law aims to cut light pollution: Ordinance, which limits holiday lighting, goes into effect in February, after public-education effort, *Orange County Register*. Retrieved from http://wpi.summon.serialssolutions.com/link/0/eLvHCXMwY2BQsDQzT7EANhxSTSwsE5MSLU2NEy2TLI3SElMNjE2TDVJQbohAKs3dhBiYUvNEGeTcXEOcPXRhRWN8Sk5OvJGJMaiyMwfmTTEG3kTQ6u-8EvAusRRxBtY0YFSlioOKT3GgUeIMHBGWzpF-UT5uEK4QjKtXDN7KpFdYIg4srcExrWukZwAA9rcr_ghttp://wpi.summon.serialssolutions.com/link/0/eLvHCXMwY2BQsDQzT7EANhxSTSwsE5MSLU2NEy2TLI3SElMNjE2TDVJQbohAKs3dhBiYUvNEGeTcXEOcPXRhRWN8Sk5OvJGJMaiyMwfmTTEG3kTQ6u-8EvAusRRxBtY0YFSlioOKT3GgUeIMHBGWzpF-UT5uEK4QjKtXDN7KpFdYIg4srcExrWukZwAA9rcr_g

Czechs against light pollution. (2002). *Chemical & engineering news, 80*(16), 56-56.

Duriscoe, Dan M, Luginbuhl, Christian B, & Moore, Chadwick A. (2007). Measuring Night-Sky Brightness with a Wide-Field CCD Camera. *Publications of the Astronomical Society of the Pacific, 119*(852), 192-213.

Galbraith, B. K. (2012). Progress in Fight to Keep Night Skies Dark (pp. Section ; Column 0; Business/Financial Desk; GREEN; Pg.).

Gaston, K. J., Bennie, J., Davies, T. W., & Hopkins, J. (2013). The ecological impacts of nighttime light pollution: a mechanistic appraisal. *Biological Reviews*.

González, O. M. R. (2009). *Light Pollution in the Shining Star of the Caribbean*. Recovering the nightscape for future generations in island of Puerto Rico. USDA Forest Service. International Institute of Tropical Forestry. Tuscon, Arizona. Retrieved from http://cohemis.uprm.edu/prysig/pdfs/pres_oramos.pdf

Hölker, F., Moss, T., Griefahn, B., Kloas, W., Voigt, C. C., Henckel, D., . . . Schwope, A. (2010). The dark side of light: a transdisciplinary research agenda for light pollution policy.

IESNA. (2000). IESNA Technical Memorandum on Light Trespass: Research, Results, and Recommendations (pp. 15). 120 Wall Street, New York, New York 10005: Illuminating Engineering Society of North America.

Kinsbruner, Jay (01/01/2008). "San Juan, Puerto Rico" in *Encyclopedia of Latin American History and Culture (0-684-31590-4, 978-0-684-31590-4)*, (p. 718).

Kolláth, Z. (2010). *Measuring and modeling light pollution at the Zselic Starry Sky Park.* Paper presented at the Journal of Physics: Conference Series.

Liberia; Mangroves Protection Awareness in Buchanan. (2012).

Light Pollution Control and Prevention Program, La Oficina de Servicios Legislativos de la Asamblea Legislativa de Puerto Rico, 218 Stat. (2008).

Lombardy Law no. 17/00 (2000).

Longcore, T. and C. Rich (2004). "Ecological Light Pollution." Frontiers in Ecology and the Environment **2**(4): 191-198.

Mediatek. (2013). PRO Billboards Home Page. Retrieved November 1, 2013, from http://www.probillboards.com/

Mitchell, L. E. (2005). Developing a GIS of the bioluminescent bays on Vieques, Puerto Rico. *Retrieved March, 18*, 2007.

No lights in an area big as Switzerland. (2013) (pp. CANADA; Pg. A6)

Officials urge guidelines on light pollution; Laws would be difficult and inappropriate to enforce, environment department says. (2011) (pp. NEWS; Pg. 01).

Pollution, Royal Commission on Environmental. (2009). Artificial Light in the Environment (pp. 48). United Kingdom: The Stationery Office Limited.

Protect night skies plead stargazers; Light pollution is blotting out our views of the stars. (2009) (pp. NEWS; Pg. 13).

Pro Billboards. Advertisement. *PRO Billboards*. Mediatek, 1 May 2013. Web. 15 Sept. 2013.

Rabaza, O., Galadí-Enríquez, D., Estrella, A. E., & Dols, F. A. (2010). All-Sky brightness monitoring of light pollution with astronomical methods. *Journal of environmental management, 91*(6), 1278-1287.

Ramanath, Rajeev, Snyder, Wesley E, Yoo, Youngjun, & Drew, Mark S. (2005). Color image processing pipeline. *Signal Processing Magazine, IEEE, 22*(1), 34-43.

Rydell, J. (1992). "Exploitation of Insects around Streetlamps by Bats in Sweden." Functional Ecology **6**(6): 744-750.

Taylor, H. and J. Cozens (2010). The effects of tourism, beachfront development and increased light pollution on nesting Loggerhead turtles Caretta caretta (Linnaeus, 1758) on Sal, Cape Verde Islands. http://193.136.21.50/handle/10961/1547: 100-111.

Tom, A. (2006). Urban light pollution to be outlawed: First Edition, *The Independent on Sunday U6 -*
ctx_ver=Z39.88-2004&ctx_enc=info%3Aofi%2Fenc%3AUTF-8&rfr_id=info:sid/summon.serialssolutions.com&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&rft.genre=article&rft.atitle=Urban+light+pollution+to+be+outlawed&rft.jtitle=The+Independent+on+Sunday&rft.au=Tom+Anderson&rft.date=2006-01-08&rft.spage=22&rft.externalDBID=INSD&rft.externalDocID=959439441&paramdict=en-US U7 - Newspaper Article U8 - FETCH-proquest_dll_9594394411, p. 22. Retrieved from http://wpi.summon.serialssolutions.com/link/0/eLvHCXMwY2BQsDQzT7EANhxSTSwsE5MSLU2NEy2TLI3SElMNjE2TDVJQbohAKs3dhBiYUvNEGWTdXEOcPXRhRWN8Sk5OvKWpJXgPp6GhGANvImjxd14JeJNYijgDaxowplLFQaWnONAkcQaOCEvnSL8oHzcIVwjG1SsG72TSKywRBxbW4IjWNdIzAADTEivV

Walker, M. F. (1970). *Publications of the Astronomical Society of the Pacific, 82*, 672.

Where did all the stars go? (2012).

Walls, Varlamova, M. I., Ng, M., Karol, D. S., Klein, A. G., & Peet, R. C. (2010). The Effects of light pollution in Hong Kong. *Technology and Environment*, 1 , xii ,171 leaves col. ill. 128 cm.

Witherington, B. E. (1992). "Behavioral Responses of Nesting Sea Turtles to Artificial Lighting." Herpetologica **48**(1): 31-39.

WRITTEN QUESTION E-1207/02 by Antonio Tajani (PPE-DE), Guido Podesta (PPE-DE) and Amalia Sartori
(PPE-DE) to the Commission. Light pollution.

WRITTEN QUESTION No. 514/96 by Robin TEVERSON to the Commission. Light pollution. (1996).