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To: United States Cities, Counties, and States
From: Ira Bell, CEO & Founder, Space Elements
Subject: Information and Analysis on Light Pollution

The following document is an analytical report on light pollution. The document has been written in format which informs the audience about the often-overlooked aspect of light pollution and its respective impact on humans, animals, and plant life. The document then provides methods which can be taken to address the challenges with existing infrastructure and governance for plans and projects in the future.

The document has been authored by Ira Bell, CEO & Founder at Space Elements. Space Elements is an organization which researches and develops space exploration technology. The mission of Space Elements is to contribute to the fields of space research and product design, space exploration, and extraterrestrial colonization.

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Information and Analysis on Light Pollution:

Prepared for: United States Cities, Counties, and States

Prepared by: Ira Bell, CEO & Founder, Space Elements

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Introduction

With the invention of the light bulb, humanity was forever changed. Previously, streets, homes and businesses were subject to the use of fire for light. Certainly, the invention and eventual mass production of the light bulb was an incredible technological advancement. In its many variations, it has enabled people to work longer hours, to read more, to be safer in medical procedures, and to have more visibility in the darkness generally whenever desired. However, with the ever-increasing production of light bulbs and devices that continually generate more and more light, there has been a very dramatic downside to astronomers and the general health of humans, animals (fauna) and plants (flora). This analytical report outlines the impacts of what the document author generally calls “Light Pollution” and provides examples of methods that can be taken against existing infrastructure as well as future infrastructure in an attempt to reverse the path that societies have unfortunately gone down.

Audience

This analytical report has been written for audiences such as United States cities, counties and states who collectively have the ability and power to make an actual impact toward correcting light pollution. Examples of individuals or groups who fall into this category are city councils, county commissioners, mayors, economic development councils, chambers of commerce, schools, governors, community colleges, and universities, etc. Often, individuals are unaware of the impacts of light pollution and as such the document has been written with a broad reach to maximize its exposure and to try and create and inspire positive change. In order to maximize the reach of this document, it has been written in a non-technical form (with the exception of two examples in the appendix which aren't necessarily required to interpret and understand the purpose of this document and the information contained within).

Light Pollution Explained

In the following sections, the document author explains light pollution from a broad perspective, but also its associated impacts on humans, animals (fauna), and plants (flora).

What is Light Pollution?

Light pollution is defined as artificial skylight (as from city lights) that interferes especially with astronomical observations (Merriam-Webster). It is further defined as “unwanted or excessive artificial light” which “is a form of waste energy that can cause adverse effects and degrade environmental quality” (Nathanson). Essentially, we can think of light pollution as light which competes with the natural physical property of the absence of light when the earth is in a position that has rotated away from the sun. Light pollution is created by humans in most cases, with the exception of naturally occurring events on earth such as volcanic activity or lightning. For the purposes of this document, light pollution is specifically referring to light that is created by humans through the installation or use of light generating sources created by mankind.

Impacts of Light Pollution?

There are a significant number of impacts of light pollution which are not often well known by society. In this section, the document outlines the impact of light pollution on humans, animals, and plants. Additionally, there are some miscellaneous impacts of light pollution identified.

Impacts of Light Pollution on Humans

To begin to understand the impact of light pollution on humans, we must first define **circadian rhythm**. The National Institutes of Health defines Circadian Rhythm as “physical, mental, and behavioral changes that follow a daily cycle” and that “they respond primarily to light and darkness in an organism’s environment” (NIH). People often confuse biological clock with circadian rhythm. However, biological clock is how scientists describe the management of time at the molecular level. Further, there is a master clock which occurs in the nervous system, controlling the biological clocks in the human body found in all tissue and organs. Essentially, factors that impact the biological clock and master clocks in humans produce circadian rhythms.

As humans evolved over time, human bodies learned to rest when the sun was down and to be active when the sun was present. Much debate has occurred about evolution over the years, but it’s generally agreed that humans were safer in the sunlight and able to be more productive, and less safe in the dark (even with the discovery of fires) and therefore more likely to rest. At the cellular level, the body’s biological clock(s) and master clock have been tuned generationally to follow the sun.

One of the factors that helps humans sleep is the release of a hormone called melatonin. The human master clock is what sends signals to release this hormone, which relaxes the body and mind and helps to allow a human to sleep. The primary factor in which the human master clock knows that it’s time to release melatonin is the absence of light (NIH). Therefore, we can

conclude that excess light has the potential to disrupt generational structure and process in the human brain and human biological clock(s).

But what is the impact of a disruption in the circadian rhythm for humans? The National Institutes of Health states that there are an incredible number of alarming impacts. “Sleep-wake cycles, hormone release, eating habits and digestion, body temperature” are some of the body functions that can be impacted by an impact on circadian rhythm (NIH). Yet, it gets worse as the NIH also describes that “disrupted or abnormal circadian rhythms...have been linked to various chronic health conditions, such as sleep disorders, obesity, diabetes, depression, bipolar disorder, and seasonal affective disorder.”

Impacts of Light Pollution on Animals (Fauna)

As described in the section above, light pollution is known to disrupt the biological systems of humans which lead to several negative conditions. Scientists have studied cellular organisms, leading to an understanding of prokaryotic and eukaryotic cells. The easiest way to think about the difference between prokaryotic cells is to generally think of eukaryotic cells as those which are often multicellular and most specifically have a ‘division of labor’. Eukaryotic cells are what we find in humans and animals. Therefore, it is not surprising to discover that light pollution affects animals negatively at the biological clock and master clock level, disrupting circadian rhythms.

Animals and wildlife often use their clocks to know when it’s time to mate, or search for food, or hide from predators. The presence of light pollution has likely had more of an impact on earth’s decline in the count of total species than humanity is able to truly understand. Some of the examples of animal species who are directly impacted by light pollution are described as follows.

Sea turtles lay their eggs at night on land. And when the eggs eventually hatch, the young turtles lose their compass to get them to the safety of the ocean as they often follow the artificial light instead (Dark-Sky Wildlife). Many migratory species such as the Bar Headed Goose use the moon to navigate away from the cold or away from the heat, so they can survive. Artificial light produced by humanity causes them to lose their way and die in great numbers (Dark-Sky Wildlife). But it’s not just individual animal species that are impacted. Animals typically live off other animals or plants (flora). As mentioned above, many animals use their master and biological clock(s) to know when to hide or hunt. Artificial light impacts animals’ ability to eat or survive.

Impacts of Light Pollution on Plants (Flora)

In this section, the author of the document is using the word plants for simplicity. However, plans mean any type of Flora such as trees, cacti, flowering plants, succulents, foliage, herbage, vegetation, as well as bacterial or fungal life. Plants are fairly well known for their relationship with the sun. Too much sun can kill certain plants, whereas too little sun can kill others. Each plant has developed in its region and ecosystem based upon the rhythm of the sun, the weather patterns, and the animals and insects that they interact with.

Some plants only bloom at night, which when blooming attracts insects that can pollinate them (and thus allow the plant to have continuity and reproduce). For example, the *Selenicereus Grandiflorus* (Queen of the Night) is a cactus that only fully blooms for two hours in the nighttime. Moths and bats are the only two types of animals and insects which are able to pollinate this species of cactus, which happen to be nocturnal (FAU Physics). Studies have shown that artificial light impacts the ability of the *Selenicereus Grandiflorus* to detect the correct time to bloom, and thus the species begins to die off in regions with artificial light.

Studies have also shown that trees are susceptible to light pollution. Trees have a clock that regulates their 'perception' of the day length. Trees use this biological system to regulate many things, such as stomatal pores in leaves. Trees open and close these pores regulating the gas exchange that occurs. When the pores are open longer than normal, trees are more susceptible to air pollution which damages the tree health (FAU Physics).

Miscellaneous Impacts of Light Pollution

As described above, humans, animals and plants are all impacted by light pollution. Everything is connected on earth. But there are some miscellaneous impacts of light pollution that are both quantitative and qualitative that aren't necessarily well known.

As mentioned in the introduction of this document, astronomers are greatly impacted by the affects of light pollution. Even in the rare circumstances (e.g. locations) where light pollution doesn't exist, an astronomer must compete with the earth's atmospheric conditions to conduct their research and science. As with the biological impacts above, this leads to many connected situations which make an astronomer's life much more challenging.

For example, when an astronomer wants to build an observatory, she must first evaluate a location which will be suitable. Examples qualities astronomers look for in suitable locations for observatories are things such as dark skies, high elevation, dry air (lower humidity/moisture), and better weather patterns. To find dark skies and areas which meet these requirements, astronomers typically must look in areas that are far from cities. Sadly, in these remote locations there is often a lack of infrastructure such as electricity, water, and internet. Further, these remote locations are often more subject to crime as there are generally not many police officers patrolling empty land or mountainous regions. The idea of building an observatory in a remote location which contains extremely expensive and sensitive equipment is quite terrifying for many astronomers and leads to requirements such as enhanced privacy and permanent residences at the location (creating extreme solitude in many cases). The alternative isn't really an alternative. Building observatories closer to cities would lead to better infrastructure, but the light pollution would prevent astronomers from doing their best research as they look upward to the sky.

And with looking upward, most children today have no perception of what the night sky is really meant to look like. There is a great sense of awe and wonder that occurs when a child first sees the seemingly infinite number of stars in the sky. Today's children rarely have the opportunity to see a shooting star (meteorite). While this is a qualitative type of discussion and that of which is extremely difficult to prove or measure, the author of this document challenges the reader to contemplate this idea around why children (and adults) aren't allowed to see the stars above.

Addressing Light Pollution

In this section, topics are covered such as understanding how to detect and measure light pollution, actions that can be taken on existing infrastructure, and suggestions for helping society mitigate, reduce, or remove light pollution in the future through the implementation of policies and procedures.

Evaluating Whether Light Pollution Exists

There are many ways to measure light pollution. From a precise scientific perspective it can be measured through the use of globally accepted commercial devices, such as the **Sky Quality Meter** or the **International Year of Astronomy Lightmeter** (*note*: in the appendix of this document, examples of the device output for each of these commercial devices has been shown, as well as links to the URLs of each of the respective device web pages).

From a less precise method, there are mobile applications that can be downloaded to help evaluate light pollution. One of the great things about this approach is that it's less costly, and these apps crowdsource user data to formulate conclusions about given areas. There are also websites which use content rich maps to show the light pollution in each area. For example, Dark Site Finder is a website which maintains an interactive map for the entire world (<https://darksitefinder.com/maps/world.html>).

Lastly, light pollution can be evaluated based upon observations and feelings. When an individual looks up at night, is there something such as a streetlight impacting their ability to clearly see? Is there a glow on the horizon from a nearby car dealership?

Existing Infrastructure

This section provides a brief overview of the methods that can be taken to correct existing infrastructure completely – or methods to make small and incremental changes in existing infrastructure which do not fully solve the light pollution issue – but at least make improvements against light pollution overall.

Documenting Light Sources

After measuring light pollution overall, through the use of commercial devices, the use of mobile and web applications and their data, and general observations and feelings – it is recommended to document all permanent light sources in an area. For example, the individual or team (documenting team) who are documenting light sources might use Microsoft Excel to document all of the streetlights within a city, noting their location, model number, what time they typically turn on and off, and more. Privately held businesses should also be evaluated, such as car dealerships, factories, and restaurants. If evaluating a car dealership, the documenting team should note the count of light sources, their location, their model number, and what time they typically turn on and off. Lastly, it's important to evaluate which direction the light sources are shining towards and whether they have any type of shield above them that aids in the prevention of light going upward.

Completely Correcting Existing Infrastructure

When a city, county or state is able to completely correct existing infrastructure, solving light pollution is easily done. This will mean that all objects documented (as described in the above section) are replaced with lights that do not pollute the night skies. This would typically mean the total replacement of all streetlights and creating law and ordinances that require businesses and homes to change their existing infrastructure. This can be a monumental task, as homeowners may feel that they purchased or built the home when such laws didn't exist and that they shouldn't be required to make such changes. One opportunity for the city, county or state would be for paying for the equipment and installation of such for homes and businesses, in addition to the mandates. This would likely result in better compliance overall. The following sections of this document articulate other suggestions for attaining compliance from citizens in the fight against light pollution.

Partially Correcting Existing Infrastructure

The author of this document understands that a complete correction of existing infrastructure is rarely possible, though strongly encouraged. Cities, counties, and states can evaluate areas which are on the edge of less bright areas and begin to work on those first. For example, it would be incredibly difficult to convince the owners and tenants of Times Square in New York City that they were all meant to comply with new light pollution ordinances. However, further out on Long Island – for example – in the areas known as the Hamptons (North and South Forks) – Suffolk County and the individual towns (e.g. East Hampton) could fund the replacement of the street lights and any government buildings or structures which required changes for a positive impact against light pollution (*note*: the author of this document does not know what the light pollution is in Suffolk County, New York and provided this location only as a reference to the absolute brightness of Times Square and the likely darker areas toward the end of Long Island, New York).

Prevention Through Policies and Procedures

Although taking specific action against existing infrastructure is the quickest way to remove light pollution, it is extremely important that there is public awareness of light pollution and its impacts, as well as policies and procedures that are in place to prevent the incorrect infrastructure growth in the future.

Public Awareness

Cities, counties, and states should take steps to facilitate public awareness of light pollution and its impacts. Examples might include social and marketing campaigns which promote dark skies at night, designated professionals who visit elementary, middle, and high school students to teach them about light pollution, and direct mail or home and business visits by well-informed individuals who can spread the awareness on light pollution.

Policies and Procedures

The author of this document is not well informed on creating public policy or procedures for cities, counties, or states. However, the author of this document intends to suggest a few examples of things which might help and inspire the document audience in beginning to explore various policies and procedures for combatting light pollution.

One example that might be taken is after public awareness has generally been reached, cities, counties, or states might provide a discount on electric or utility services for homes and businesses which have declared that they are compliant. Depending on the resources available, home and business visits in terms of inspections or evaluations could occur by the city, county, or state to certify said location.

Another example might be the introduction of dark sky at night compliant light requirements for building codes. As plans are submitted to the planning and zoning office (or permitting office), the plans must be compliant to be approved. This would mean that the planning and zoning office (or permitting office) would generally need to understand what was and wasn't acceptable in terms of model numbers of lights and their respective locations for installation, etc.

Another approach might be to declare that the city, county, or state will be dark sky friendly by a certain date – thereby giving homes and businesses the ability to have some time to reach compliance. Throughout this process, campaigns aiming for an increase in public awareness should take place and an evaluation of homeowners and businesses that might not become compliant without conflict. Steps could be taken to inform them that fines will be issued and gradually increased for lack of compliance.

Lastly, cities, counties and states might consider a relief in taxes – such as property taxes for businesses that are compliant against light pollution. Perhaps the idea of rewarding those who are compliant with less tax liability would motivate more individuals to comply.

The Document Author's Position

The position of the document author is clear. The document author intends to lobby the audience to reduce light pollution by correcting existing issues and by implementing guidelines to slow the spread of light pollution in the future. This means that to comply with this position, funds will have to be allocated from cities, counties, or states toward combatting light pollution. In some cases, this may mean replacing existing infrastructure with new infrastructure that does not cause light pollution. Aside from correcting existing issues, the document author strongly encourages cities, counties, and states to implement ordinances by way of building codes and permitting that prevents light pollution from expanding further in the future. In order for this to have an impact, the codes will need to be enforceable, and the cities, counties, or states will need to prioritize such enforcement.

It should be noted that the document author is in the Space industry and therefore likely has an unintentional bias. However, the document author believes that even if he wasn't in the Space industry he would have the same opinion on light pollution – specifically its negative impacts on humans, animals and plants.

Opposition

As with any environmental regulation or material change in what is considered to be the 'norm', the document author expects there to be significant opposition. For example, cities, counties, or states will probably encounter individuals and groups who don't necessarily care about or agree with the negative impacts of light pollution and declare that there is no reason they should make any changes. There will also be individuals who declare that making the nighttime darker is generally more unsafe. For example, certain individuals, groups, or businesses might declare that crime is likely to be more rampant if auto dealerships are required to remove their excessively bright lights that run through the night. Other groups might believe that sidewalks will become more unsafe for individuals walking or jogging at night if the streetlights are adjusted in any way. Lastly, there will likely be individuals who don't care about our ability to see the stars and will either be an opposition vote or generally not get behind the reduction of light pollution initiative.

Conclusion

As described in this analytical report, the technological advances in lighting have been incredible but extremely impactful. The impact of this lighting has taken a toll on the ability for people to see the stars in the night sky. This means that many children today grow up having never experienced the awe and wonder of the great infinity they might see when they look upward. There are also very drastic effects on circadian rhythms which impact humans, fauna and flora. The author of this document believes that the financial impact of correcting the current infrastructure which causes light pollution is quite insignificant when compared to the issues it causes.

References

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Appendix

The Sky Quality Meter

URL: <http://unihedron.com/projects/darksky/>

Example Data from the Sky Quality Meter

The following example has been borrowed from the International Dark-Sky Association website (Dark-Sky Measuring).

```
# Community Standard Skyglow Data Format 1.0
# URL: https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/47_SKYGLOW_DEFINITIONS.PDF
# Number of header lines: 35
# This data is released under the following license: ODbL 1.0
http://opendatacommons.org/licenses/odbl/summary/
# Device type: SQM-LE
# Instrument ID: Dahlem_tower_le
# Data supplier: Christopher Kyba / Freie Universitaet Berlin
# Location name: Germany-Berlin-Dahlem
# Position (lat, lon, elev(m)): 52.4577, 13.3107, 91
# Local timezone: Europe/Berlin
# Time Synchronization: GPS
# Moving / Stationary position: STATIONARY
# Moving / Fixed look direction: FIXED
# Number of channels: 1
# Filters per channel: HOYA CM-500
# Measurement direction per channel: 0., 0.
# Field of view (degrees): 20
# Number of fields per line: 6
# SQM serial number: 1687
# SQM firmware version: 4-3-21
# SQM cover offset value: -0.11
```

```

# SQM readout test ix: i,00000004,00000003,00000021,00001687
# SQM readout test rx: r, 18.73m,0000000004Hz,0000130978c,0000000.284s, 031.2C
# SQM readout test cx: c,00000019.69m, 0000300.000s, 023.2C,00000008.71m, 029.3C
# Comment: SQM installed on a tower.
# Comment: last cleaned on 20120511
# Comment:
# Comment:
# Comment:
# blank line 30
# blank line 31
# blank line 32
# UTC Date & Time, Local Date & Time, Temperature, Counts, Frequency, MSAS
# YYYY-MM-DDTHH:mm:ss.fff;YYYY-MM-DDTHH:mm:ss.fff;Celsius;number;Hz;mag/arcsec^2
# END OF HEADER
2012-05-10T22:00:04.000;2012-05-11T00:00:04.000;31.2;130978;4;18.73
2012-05-10T22:00:09.000;2012-05-11T00:00:09.000;31.2;130978;4;18.73
2012-05-10T22:00:14.000;2012-05-11T00:00:14.000;31.2;130978;4;18.73
2012-05-10T22:00:19.000;2012-05-11T00:00:19.000;31.2;130978;4;18.73
2012-05-10T22:00:24.000;2012-05-11T00:00:24.000;31.2;130978;4;18.73
}

```

[International Year of Astronomy Light Meter](http://hms.sternhell.at/lightwiki/index.php/Main_Page)

URL: http://hms.sternhell.at/lightwiki/index.php/Main_Page

[Example Data from the International Year of Astronomy Light Meter](https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/47_SKYGLOW_DEFINITIONS.PDF)

The following example has been borrowed from the International Dark-Sky Association website (Dark-Sky Measuring).

```
# Community Standard Skyglow Data Format 1.0
```

```
# URL: https://www.darksky.org/wp-content/uploads/bsk-pdf-manager/47_SKYGLOW_DEFINITIONS.PDF
```

Number of header lines: 35

This data is released under the following license: ODbL 1.0
<http://opendatacommons.org/licenses/odbl/summary/>

Device type: IYA Lightmeter (Mark 2.3)

Instrument ID: DE_BERLIN_4

Data supplier: Christopher Kyba / Freie Universitaet Berlin

Location name: Germany-Berlin-Dahlem

Position (lat, lon, elev(m)): 52.4577, 13.3107, 91

Local timezone: Europe/Berlin

Time Synchronization: NTP

Moving / Stationary position: STATIONARY

Moving / Fixed look direction: FIXED

Number of channels: 1

Filter per channel: None

Measurement direction per channel: 0., 0.

Field of view (degrees): 180

Number of fields per line: 4

IYAL serial number: n/a

IYAL firmware version: n/a

IYAL readout test: 23.3.2012;15:24:58;27,6;Å°C;2984760;0;0;ok;

Comment: The shadow of our building falls on the lightmeter around noon

Comment: contact: christopher.kyba@wew.fu-berlin.de

Comment:

Comment:

Comment:

blank line 27

blank line 28

blank line 29

blank line 30

```
# blank line 31
# blank line 32
# UTC Date & Time, Local Date & Time, Temperature, Counts
# YYYY-MM-DDTHH:mm:ss.fff;YYYY-MM-DDTHH:mm:ss.fff;Celsius;number
# END OF HEADER
2012-03-23T15:24:59.000;2012-03-23T16:24:59.000;27.5;2984520
2012-03-23T15:25:01.000;2012-03-23T16:25:01.000;27.5;2984640
2012-03-23T15:25:02.000;2012-03-23T16:25:02.000;27.5;2984280
2012-03-23T15:25:03.000;2012-03-23T16:25:03.000;27.6;2984520
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2012-03-23T15:25:06.000;2012-03-23T16:25:06.000;27.6;2984760
2012-03-23T15:25:07.000;2012-03-23T16:25:07.000;27.5;2984760
2012-03-23T15:25:08.000;2012-03-23T16:25:08.000;27.5;2985000
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2012-03-23T15:25:11.000;2012-03-23T16:25:11.000;27.6;2984760
```