

Fade to Black

An Inventory of Publicly-Owned Lighting Fixtures in Moab and Grand County

ADAM DALTON & NATHAN JELLEN

University of Utah
City & Metropolitan Planning
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Cover image: Moab and Grand County's light emissions measured by the Suomi NPP satellite's Visible Infrared Imaging Radiometer Suite (VIIRS). Source: Light Pollution Map

Abstract

Urbanization has impacted night skies throughout the world. As of 2016, nearly one-third of Earth's population was unable to view the Milky Way due to widespread light pollution. Aside from diminishing the cultural and aesthetic value of night skies, light pollution impacts human health, ecosystem functionality, and economic well-being. Although study of the night sky has emerged as an area of applied research, many knowledge and implementation gaps still exist. This study aims to foster awareness, planning capacity, and night sky-friendly development in Moab, UT and the broader Grand County, UT area of the Spanish Valley. To this end, our project utilizes a pioneering, comprehensive, and streamlined lighting inventory procedure. Our lighting audit of publicly- and some privately-owned fixtures will provide a baseline that local decision-makers in the Moab area can use to evaluate the potential benefits of lighting-related capital investments, regulatory changes, and incentive programs. The baseline can also be used to benchmark on-the-ground changes over time. Because the lighting audit findings are available on Google Maps and through ESRI's ArcGIS system, the project also supports citizen science and public participation in local government. This paper contains the lighting audit procedures, findings, and policy recommendations, which may inform city and county efforts to protect and preserve local dark skies.

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Introduction

Across time and space, humans have looked toward the cosmos for religious rites, artistic inspiration, and navigational assistance. Nearly every culture throughout anthropocentric history has developed narratives and created unique constellations from the Earth's night skies (Smith & Osherson, 1995). While the starry night sky is undoubtedly part of humanity's collective history, in an increasingly developed and urbanized world, fewer persons are able to experience unimpeded views of the night sky. As of 2016, 80% of Earth's total land area was so polluted with artificial light that the Milky Way was fast becoming a rare sight to see globally (Donahue, 2016).

Within the Western context, sky glow—the phenomenon where atmospheric particles and clouds scatter light emissions from ground-based sources—prevents 99% of American and European citizens from observing the Milky Way from their homes (Donahue, 2016). Problematically, this sky glow phenomenon can be detected over hundreds of miles when unimpeded

by topography (Gaston et al., 2014) and allows for a singular city's poor lighting to potentially detract from the starry views of surrounding communities and ecosystems.

While the majority of modern Americans lack access to a clear view of the night sky, residents of the Colorado Plateau region (encompassing southeastern Utah, southwestern Colorado, northwestern New Mexico, and northeastern Arizona) enjoy some of the darkest night skies within the continental United States (Duriscoe & Ament, 2015). While the favorable combination of high elevation, low humidity, low cloud cover, and a lack of light pollution within the region contributes to these optimal night sky views, rising population growth, a burgeoning tourist industry, and general lack of awareness threaten the darkness of the region's night sky.

Because of these threats, the U.S. National Park Service (NPS) and other environmentally-focused organizations have begun to aim their respective efforts toward combating the growth of light pollution on the Colorado Plateau

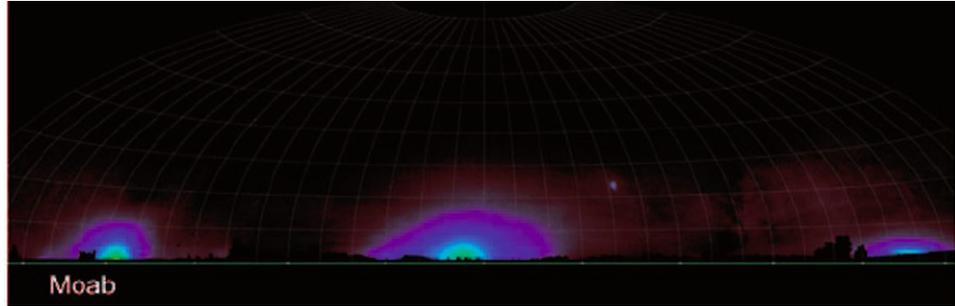


Figure 1: Moab's Sky Glow From Three Different Observation Points. Duriscoe et al. (2013) captured the following three images of Moab's anthropogenic sky glow from three different observation points to show how the city was impacting the surrounding nightscape. Source: Duriscoe et al. (2013)

through public education, lighting ordinance implementation, and scientific study (Duriscoe & Ament, 2015). These efforts have sparked interest in night sky conservation and have facilitated the growth of astro-tourism into a unique sector within tourism-based economic development for many areas located in the rural Colorado Plateau (Duriscoe & Ament, 2015). As a direct result, many communities on the Colorado Plateau are currently interested in pursuing International Dark-Sky Association (IDA) Dark Sky Place accreditation through enacting night sky-friendly lighting ordinances to preserve and improve local night sky quality (IDA, 2017). Although the topics of nighttime light pollution and astro-tourism are undoubtedly hot-button issues in the Colorado Plateau region, scant previous research on either topic currently exists due to the nascent nature of dark sky academic study.

Despite this lack of research, residents and local officials in the Spanish Valley area of Grand County, Utah, since 2016, have been active in expressing interest in preserving the darkness of their night sky. Their voices prompted a group of diverse stakeholders to form the

Moab Area Dark Skies Group in 2016. The following year, the group reached out to the University of Utah's Consortium for Dark Sky Studies (CDSS) for assistance in understanding and curbing their lighting emissions. After consulting with CDSS, Moab Dark Skies began to plan for a comprehensive inventory of local lighting in order to gauge the ecological, economic, public health, and cultural impacts of their exterior lighting stock. Our team, comprised of two graduate students in the University of Utah's City and Metropolitan Planning program, undertook a month-long survey of all of the publicly-owned exterior lighting fixtures to provide Moab Dark Skies with the following assessment.

The first section of the assessment contained in this report details the materials, methods, and findings from the comprehensive inventory conducted by our research team. The second section contains economic and environmental cost and savings estimates calculated on the assessment's findings. By conducting the baseline lighting inventory and providing supplementary analyses, this research aims to illuminate many

issues within the field of dark sky studies, with special emphasis placed upon the economic and environmental effects of dark sky preservation. Additionally, this paper serves to parse out the practicalities related to use, presentation, and analysis of urban baseline lighting inventories. It is our hope that together, our team's research may

yield valuable contributions to the field of dark sky studies and can serve to provide the basis for future night sky preservation. Without access to a dark night sky, we as humans may not, as Marcus Aurelius dreamed, "Dwell on the beauty of life, watch the stars, and see ourselves running with them" (Marcus Aurelius, 173).

Literature Review

History of Lighting Regulation

While the loss of Earth's night skies is a rapidly-developing issue, between 2012-16 the Earth's artificially lit area increased by 2% per year (Gill, 2017), it has not received the same attention as many other modern environmental concerns such as air and water pollution, among others. Due to various cultural factors and attitudes, the negative externalities related to light pollution have only recently began to emerge as a topic of scientific research and environmental concern. In many contemporary societies, especially those within the developing world, exterior lighting at night is often seen as economic and social progress; and thereby a phenomenon to be embraced wholeheartedly (Sebitosi & Pillay, 2007). Additionally, in both developing and developed contexts, the primal fear of dark holds still. When asked about the connections between lighting and safety, respondents across studies consistently equate artificial lighting at night (ALAN) with increased

perceived safety in urban, suburban, and rural environments (Haans & de Kort, 2012).

Essentially, light pollution is the product of poor lighting design. When left unchanged, it can have serious impacts on human health, especially when its correlated color temperature (CCT)—the color appearance of a light source—is on the cooler-colored (i.e. blueish-whitish) end of the visible light spectrum. The American Medical Association in 2016 cited numerous studies indicating that exposure to blue-rich lighting at night increases risks for cancer, diabetes, and cardiovascular disease (AMA, 2016). Additionally, ALAN can disrupt circadian rhythms and suppress melatonin, thereby impacting human's sleeping patterns, immune systems, and the healthy functioning of the pancreas, thyroid, and reproductive organs (IDA Human Health, 2018). With these health, safety, and public welfare concerns, light pollution falls within the jurisdictional powers of municipal leaders; therefore, light pollution is a planning problem.

Numerous studies have tied exterior lighting to urban planning practices. Lighting levels and intensities tend to relate to the prevalence of certain land uses, with the peak of night sky brightness typically occurring in the central business district (CBD) then decreasing with distance from the CBD (Biggs, Fouché, Bilki, & Zadnik, 2012). Streets, public service areas (schools, hospitals), and industrial and commercial areas tend to be brighter than residential areas, parks, and agricultural areas (Kuechly et al., 2012). Because of these close ties to land use, urban planners are positioned to address the challenges of light pollution and to propose and enforce exterior lighting codes that will protect human health, the environment, economic interests, and the cultural heritage of their local nightscape.

Efforts to curtail the negative impacts of lighting in the United States date back as early as 1958, when the city of Flagstaff, Arizona adopted the first known lighting ordinance, “The Searchlight Law.” This law banned the use of advertising searchlights within city limits (Portree, 2002). Since that time, Flagstaff and many other public entities both in the United States and abroad have adopted lighting codes and standards that address their concerns and needs. In 1989, Flagstaff and its surrounding Coconino County developed lighting codes that restricted the number of lumens per acre permitted by different land uses (Flagstaff Dark Skies Coalition, 2015). In 2001, Flagstaff received designation as the world’s first International Dark Sky Place (IDA Dark Sky Communities, 2018). Since that time, the IDA has recognized 17 additional American

and international cities for their efforts to curtail light pollution and has designated each of them as an International Dark Sky Communities. The most recent designation of an IDS Community went to Torrey, UT at the beginning of 2018 (IDA Dark Sky Places, 2018).

Larger public entities in the US and abroad have also made efforts to cut their lighting emissions. Currently, 18 states, the District of Columbia, and Puerto Rico have laws that strive to cut light pollution (NCSL, 2016). On March 22, 2018, Utah governor, Gary R. Herbert, signed the legislative concurrent resolution “Encouraging the Use of Shielded Light Fixtures on Outdoor Lights” which “recognizes the harmful effects of light pollution, identifies the benefits of shielded outdoor lighting and dark skies, and encourages the transition from unshielded to shielded outdoor lighting” throughout the state (S.C.R. 2, 2018). According to dark skies advocates throughout the state of Utah, including for those within the study’s scope in the Moab area, the aforementioned resolution is a move in the right direction regarding dark-sky preservation.

Although the U.S. has yet to pass legislation protecting the night sky, other countries have made critical steps toward protecting the night sky. In 2002, the Czech Republic was the first country in the world to enact a lighting law. It required all residences, businesses, and government agencies to fully shield all outdoor light fixtures (Lockwood, 2004). Countries like Canada, the United Kingdom, the U.S., New Zealand, Ireland, France, Germany, and Namibia have IDA-designated Dark Sky Reserves that

make up large land areas of several thousand kilometers dedicated to the protection of the night sky (IDA Dark Sky Places, 2018). Additionally, the IDA has granted dark sky park designation to many national parks in the U.S., as well as to other protected areas in the U.S. and abroad. But cities, states, and countries have cultural footprints that emerge through how they regulate and distribute their lighting as well.

The divided lighting management of the city of Berlin, Germany during the Cold War years is still visible today; American cities tend to have more lights per capita than German cities, with Los Angeles and Chicago having an estimated 9 lights per capita (Kyba et al., 2015). These cultural dynamics introduce a new level of sophistication in addressing light pollution as preferences, cultural interests, and spiritual dynamics may impact how a city or nation may desire to light itself at night. While sensitivity to these factors is critical, they do not necessarily have to interfere with the study of light pollution and its myriad impacts. In striving to understand where and how we light our urban and rural areas at night, we can increase our general accountability for our lighting and reintroduce intentionality to our nocturnal lightscape.

Accounting for Light Pollution

Accounting for light pollution is an emerging field with many researchers focusing their efforts

on the quantification of urban light emissions. As discussed below, there are many methods for accounting for lighting and for calculating light pollution, but in the most general sense, these methods have typically involved either a “sky-down” approach or a “ground-up” approach to understanding how sky brightness is affected by ALAN (Luginbuhl, Lockwood, Davis, Pick, & Selders, 2009). As their name implies, sky-down approaches involve measuring light in the atmosphere and drawing conclusions about the processes on the ground that are creating that light. In the reverse sense, ground-up approaches begin with measurements of lighting on the surface and deduce how that lighting is impacting sky glow (Luginbuhl et al., 2009).

Three principal approaches to quantifying light pollution have been identified: 1) using images of nighttime lighting at different scales captured by satellites, the International Space Station, and airplanes; 2) modeling light pollution patterns based on the earth’s contours as captured by LiDAR technologies; and 3) by using ground-based assessments taken with spectral readings and digital photography. While each of these approaches has advantages and disadvantages which we will examine below, it is important to note that recent studies have combined approaches to create more holistic estimations of how light pollution is experienced from different vantage points (Katz & Levin, 2016).

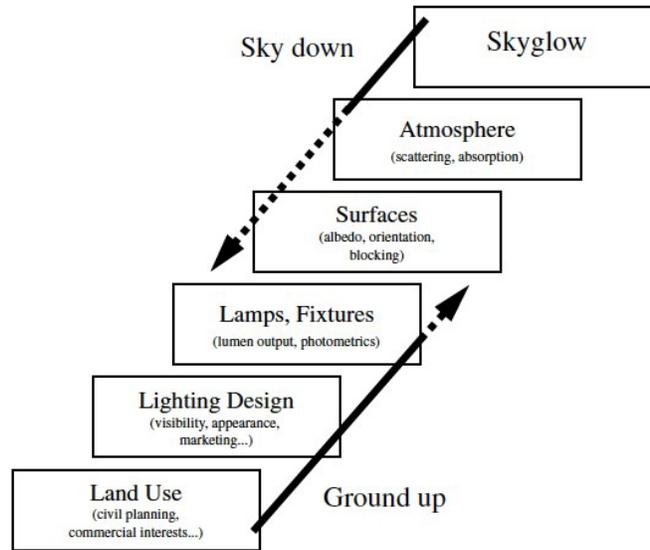


Figure 2: Flowchart linking sky glow to artificial light use. This chart illustrates the different approaches to considering light pollution impacts. Source: Luginbuhl et al. (2009)

Space-Based and Aerial Assessments

While satellites have been taking images of nighttime lighting around the globe for decades, a consistent digital record of ALAN began in 1992 with the launch of the Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS). Images from this satellite program provided data for nearly one hundred different publications on ALAN and light pollution. However, these images were often considered too coarse to differentiate between sources of light pollution. While space-based monitoring of ALAN markedly improved with the launch of the Suomi National Polar-orbiting Partnership (NPP) satellite and its Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) system in 2012, studies of ALAN still argued that the resolution of the imagery was suboptimal. Consequently, some

studies have resorted to taking aerial photographs captured by airplanes (Kuechly et al, 2012). By using high resolution imagery, such studies argue they are able to distinguish between lighting sources with greater clarity.

The disadvantage of nighttime lighting as captured from an aerial perspective is that it quantifies light as it is projected upwards, thusly measuring pollution as experienced in the sky and in space. While this upwardly-emitted light has implications for night sky visibility and astronomical observations, it neglects the impacts of light pollution as it is experienced on the ground by humans, fauna, and flora (Katz et al., 2016). Additionally, imagery captured within space is limited in its ability to continuously monitor light pollution, unlike ground-based cameras (Dobler et al., 2015). Aerial photographs of ALAN also require use of expensive airplanes

and pilot services, which thereby makes continual monitoring of ALAN limited to both funding constraints and airplane availability.

Despite these disadvantages, the ability to survey ALAN from a sky-based point of view is necessary insofar that it allows for the evaluation of light's impact on nightscapes and sky glow. Such measurements can also help distinguish relationships between light pollution and different land use and development types, can analyze population density, and serve as a proxy for economic wellbeing. It also enables studies of species migration barriers, identifies sources of over-pollution, gauges the effectiveness of mitigation strategies, and can help to estimate energy use analyses of ALAN (Kuechly et al., 2012).

Model-Based Assessments

Another approach to conceptualizing light pollution has been developed through the use of computer modeling. The first models were developed in the 1980s by Roy Garstang and sought, through simple calculations, to predict the brightness of the night sky for use at observatories while accounting for the curvature of the earth (Garstang, 1989). Even these early models demonstrated the value of reducing light emissions through use of fully shielded street lamps and other outdoor light sources (Garstang, 1986).

Garstang's models were eventually refined to include the use of satellite imagery (Cinzano, Falchi, Elvidge, & Baugh, 2000) until the first world atlas of artificial night sky brightness was published in 2001 (Cinzano,

Falchi, Elvidge, 2001). These modelling systems eventually were incorporated into a Light Pollution radiative TRANSfer (LPTRAN) software system to predict the distribution of artificial brightness on a given night in a given place by measuring photonic densities in the atmosphere and by accounting for light scattering caused by air pollutants, clouds, and topographic features (Cinzano & Falchi, 2014).

While this improved LPTRAN modelling technique has allowed for more efficient and accurate modeling of light pollution, it still can benefit from combination with satellite assessments to chart light spectral readings. As they stand, photonic measurements and other findings derived through light pollution modelling systems are even less accessible to public officials and the public than the more familiar, traditional methods of quantifying light pollution like calculating total night sky brightness, the number of visible stars, and even color correlated temperatures. Unfortunately, the aforementioned reality makes light pollution modeling software systems impractical for use by most public agencies and other entities which lack the human capital (astronomers and physicists) to run them. While not stated to discount the value of their findings for policymakers, it is simply not necessary to have a computer modeling system in order to enact dark sky-friendly regulations within a municipality.

Ground Assessments

While light pollution was first a concern of the astronomical sciences community, literature on the field has

of late taken a growing interest in ground-based indicators that assess the impacts of light pollution on the environment and public health (Cinzano et al., 2014).

One recent approach to completing ground-based assessments of light fixtures has involved taking nighttime photographs of cityscapes. High-resolution cameras set at fixed vantage points are demonstrated to assist with monitoring light emissions from privately-owned areas provided they are set at a reasonable distance from their target areas so as to protect the privacy of those within their field of view (Dobler et al., 2015). Such an approach can be less intrusive than visiting individual fixtures on-site as was necessary in our present study. However, using cameras over spectrometers trades the value of having individual correlated color temperature (CCT), illuminance, and footcandle readings for general identification of sleep patterns and behaviors in turning light sources on and off at night. Nevertheless, monitoring public activity patterns at night can help local officials identify appropriate hours to regulate nighttime lighting through dark sky ordinances.

Since hand-held sky quality meters (SQMs) became available commercially in the early 2000s, many studies have deployed them for data collection related to sky brightness at zenith (Biggs, Fouché, Bilki, & Zadnik, 2012). These measurements are helpful in assessing how ALAN impacts the visibility of a nightscape, and thus are an asset for astronomical observation as their values represent what a person on the ground can see looking up at the stars.

SQM measurements fit on a basic spectrum brightness, ranging from 16 magnitudes per square arc second (mpsas), very bright, to 23 mpsas, very dark. This basic spectrum of bright-to-dark makes SQM values accessible to the public and to local government officials, as it provides a general sense of how impacted a specific nightscape is by local lighting. At the time of this study, the standard Unihedron SQM cost 120 USD, making the tool relatively inexpensive for communities interested in preserving their night skies. SQMs, however, are limited in the data they provide. While helpful for astronomers and other observers of the night sky, they are not enabled with CCT-, illuminance-, or footcandle-measurement systems. This restricts their usefulness in assessing the environmental, economic, and public health impacts of light pollution.

Carrying out inventories of ALAN is an alternative approach some studies have taken to better understand urban light emissions. These inventories have taken different forms, but generally involve counting or estimating the number of different fixture types distributed throughout an urban area and using spectrometers or knowledge of lamp types to quantify energy use and the amount of light emitted. As suggested above, inventories can be invasive; our team, as an example, limited its inventory scope to publicly-owned fixtures and still was stopped by police and other public employees on several occasions. This reiterates the need for clear *and constant* coordination with law enforcement, government agencies, and the wider public during the study period.

Ultimately, the value of an inventory lies in the resultant lighting baseline upon which regulations can be built and against which future assessments can be compared. Narisada et al. (1998) found pedestrian area lighting and signs accounted for an average of 57% of all upward flux in the areas they inventoried and were able to recommend lighting restrictions accordingly. Luginbuhl et al. (2009) conducted a survey of all exterior lights (public and private) in Flagstaff, AZ focusing on illuminance and its relationship to land use. Their findings estimated that, in the time since the adoption of the city's 1989 lighting codes, the city had succeeded in reducing the expected 43% growth in sky glow to just 17%, despite population growth from around 44,000 in 1990 to 55,000 when they conducted their inventory. These findings reiterate the comprehensive exterior lighting inventory's value as a tool to measure the effectiveness of lighting codes over time.

Combining Approaches

While consideration of light pollution has generally been limited to one of the three approaches listed above, recent efforts at combining approaches to maximize understanding of the night sky have been pursued. In 2016, Katz et al. attempted to refine their ability to estimate light pollution in urban settings by combining nighttime imagery captured by the EROS-B satellite with ground-based Unihedron SQM data. They evaluated light pollution as it was experienced from three angles—upwards, downwards, and horizontally—in order to better understand how sky glow and shielded lighting is

perceived by organisms at ground level. While our present study is more focused on creating a lighting baseline for Moab, Grand County, and the other entities our team worked with, we fully acknowledge that a more scientific study of light pollution in the Moab area could benefit from a combination of our inventory with aerial and space-based imagery and computer-based modelling systems. This is an area of potential future study.

Economic Effects of Light Pollution

Over the past century, the academic field of natural resource economics has developed a rich and diverse body of literature. However, until the 2010s, very little attention within the field has been directed towards the concept of dark skies as an economic resource. Nevertheless, with increased public support and awareness of dark sky resources, in 2010 mainstream natural resource economists began to tackle the complex issue of assigning an economic value to activities related to the dark night sky (Galloway & Olsen, 2010). While it is understandable that some readers of this paper may find the concept of valuation and commodification of the culturally invaluable night sky to be an objectionable pursuit, I reiterate the following: the studies highlighted below serve to estimate the monetary benefits of astrotourism and energy savings related to dark sky-friendly practices, not to place a value upon the dark sky itself. Unlike water or land resources, the night sky is truly a public resource

and rightfully cannot be bought by any person, corporation, or nation-state.

Conducted in 1991 but not published until 2017, Hunter and Crawford's paper *Economics of Light Pollution* serves as the seminal example of a dark-sky natural resource economics study (Hunter & Crawford, 1991). Within their study, the authors found 2.5% of overall U.S. energy consumption is directed towards nighttime artificial lighting at night (ALAN), of which 30% is projected into the night sky (Hunter & Crawford, 1991). Going further, the authors analyzed utility rates and fossil fuel consumption metrics to estimate the United States spends over 8.2 million pounds of coal and \$1 billion yearly to cause light pollution (Hunter & Crawford, 1991)! Owing to the rapid proliferation of light pollution on the North American continent during the past two decades, if the authors were to re-conduct their study in 2018, they would most likely ascertain higher values regarding fossil fuel usage

and monetary losses related to light pollution.

Published in 2014, the book *Urban Lighting, Light Pollution, and Society* was the first compilation of scientific discussions related to urban lighting and light pollution (Meier et. al, 2014). Split into three distinct sections: perceptions of lighting, lighting as conflict and resolution, and evaluations of lighting, the book's mixed social science and humanities perspective allows readers to grapple with and explore the intricacies of the many complex issues related to light pollution (Meier et. al, 2014). Particularly valuable with respect to natural resource economics, Terrel Gallaway's chapter, *The Value of the Night Sky*, considers methods to evaluate the economic value of the night sky.

Beginning with an explanation that the night sky is functionally invaluable, Gallaway's chapter goes on to explain the economic value of the night sky stems wholly from its



Image 1: Natural Bridges. Natural Bridges National Monument was the Colorado Plateau's first International Dark Sky Park. Source: Utah Tourism Office

potential for astro-tourism (Gallaway, 2014). The author states the aforementioned economic potential occurs because truly dark night skies are quickly diminishing yet remain a sought-after natural resource within the United States (Gallaway, 2014). Basic economics dictate when a desirable resource is in short order, its perceived value and people's consequent willingness to pay for it increase. While the chapter's explanation of night sky valuation tactics follows sound economic principles, the author generally fails to address social justice concerns related to dark sky access tied to the ability to pay and travel. In my overarching analysis of resource economics articles pertaining to dark skies, I failed to find a single mention of night sky access related to the ability to pay framed in terms of a social justice issue. I would urge future researchers to consider this intersection of natural resource access and monetary availability.

Turning to the unique context of the Colorado Plateau, Gallaway (as mentioned above) teamed up with David Mitchell in 2014 to estimate the potential economic value of the night skies above the Colorado Plateau (Gallaway & Mitchell, 2014). The scientists' team correspondingly found the economic potential of dark skies over the Colorado Plateau was, in short, enormous. With 65% of visitors to the region's natural areas stating dark skies were "important" or "very important", the authors estimated between 2014-2024 local economies inside of the Colorado Plateau would see an additional \$1.6 billion of revenue and 50,000 jobs related to dark-skies tourism (Gallaway & Mitchell, 2014). Furthermore, Gallaway and Mitchell

found astro-tourists were more likely to visit the Colorado Plateau during the region's traditional "off season" and make at least one overnight stay; thereby helping to dually smooth and increase revenue streams for areas with boom/bust seasonal tourism-based economies (Gallaway & Mitchell, 2014). Even more impressive in terms of economic prospects, in their conclusion Gallaway and Mitchell stated, "...our reported figures assume simply the continuation of existing trends, with no increase in efforts to promote night sky tourism..." (Gallaway & Mitchell, 2014). Therefore, if communities and citizens within the Colorado Plateau work together to consciously develop dark-skies related businesses and promote astro-tourism, the reported figures could be greatly increased.

Following the release of the aforementioned study, governments, academics, and dark-sky activists located within the Colorado Plateau took notice. As of April 2017, the State of Utah led all world jurisdictions regarding number of International Dark Sky Association (IDA) Places, with nine (IDA, 2017). Adding to the State of Utah's actions related to dark skies, in 2015 the University of Utah established the first-ever academic Consortium for Dark Sky Studies (CDSS) and the Utah Office of Tourism released the 2017 "Dark Sky Parks" tourism campaign (Utah Office of Tourism, 2017). In spite of the rural Colorado Plateau's current socio-political wariness of environmental conservation movements, dark sky preservation has enjoyed citizen's bipartisan support thus far (Potter, 2017). By couching the issue of night sky preservation

as important to Western heritage and rural economic development, persons who normally fail to see eye-to-eye on conservation-related issues are consistently working together to promote and preserve the Colorado Plateau's night skies; a truly remarkable feat considering the politically-polarized nature of environmental issues in the modern American West (Potter, 2017).

Ecological Effects of Light Pollution

Among many concerns related to artificial lighting at night (ALAN), the adverse effects which ALAN imposes on ecological systems have been well-studied in various contexts. Longcore's groundbreaking article, *Ecological Light Pollution* (2004), illuminated numerous environmental systems concerns germane to wildlife and light pollution exposure. For example, select species of sea turtles and migrating birds are attracted to ALAN (Longcore, 2004). According to Longcore, the aforementioned phenomena can result in disorientation and increased death rates in affected populations (2004). Following the publication of Longcore's article, a diverse group of environmental scientists began to undertake research pertinent to the environmental consequences of light pollution.

In 2005, the American Ornithological Society published an influential study which found populations of breeding American Robins exposed to light pollution commenced birdsong significantly earlier than robins who lacked exposure to ALAN (Miller, 2005). This unique research

served to highlight the effects light pollution can impose upon critical reproductive behaviors within avian populations and inspired further ALAN-based ecological research; including Kempenaers & Borgstrom's *Artificial Night Lighting Affects Dawn Song and Lay Date in Songbirds* (2010). The above paper built upon previous songbird and ALAN research and ascertained songbirds exposed to light pollution began egg-laying before their unexposed peers (Kempenaers & Borgstrom, 2010). While these behavioral changes may appear nonconsequential, if birds began breeding and nesting behaviors earlier each year, they may have less reproductive success due to weather and other extraneous effects (Kempenaers & Borgstrom, 2010).

Moving into the nocturnal sphere, studies conducted upon bats in 2009 found the animals' commuting behaviors were altered in the presence of light pollution, with no evidence of habituation (Stone & Jones, 2009). As noted, an extremely concerning aspect of Stone & Jones' findings was the observation that bats did not adjust to light pollution, but instead avoided it permanently (Stone & Jones, 2009). Since the bats' commuting paths were affected by ALAN, bug population structures changed in response; populations boomed in lit areas which were less prone to bat predation (Stone & Jones, 2009). Such conclusions parse out the alarming ecosystem "domino-effects" which may occur when light pollution affects a select species' behavior. Although some nocturnal species, such as bats, are repelled by light pollution, moths and others are conversely attracted to ALAN. Interestingly, the wavelength of lighting which moths are exposed

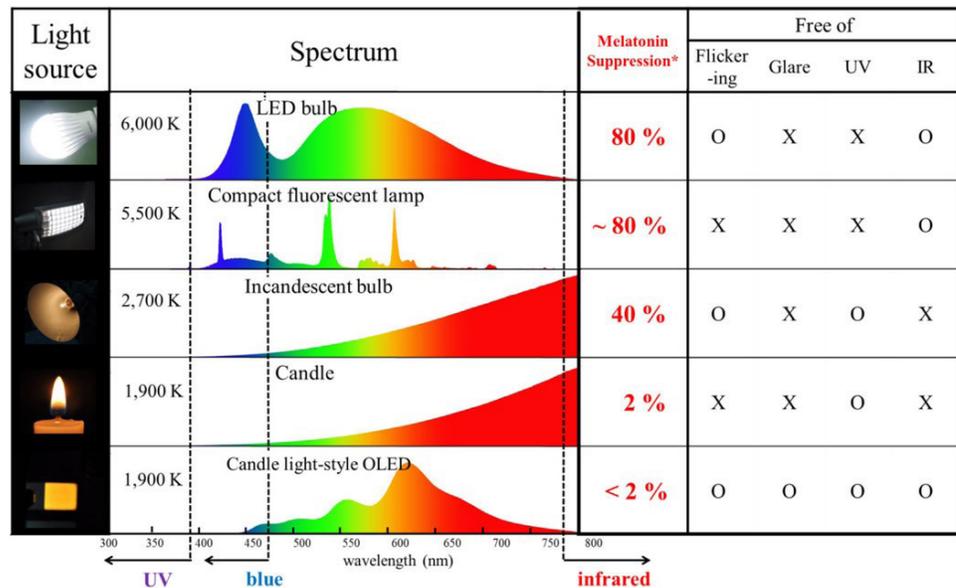


Figure 3: Visible Light Spectrum Wavelengths. This chart indicates light wavelengths as identified by a spectrometer. Source: Garmin OLED

to affects their attractive tendencies (Langevelde & Ettema, 2011). Moths exposed to shorter wavelength light sources (i.e. bright blue/white LEDs) experienced greater rates of overall light attraction (Langevelde & Ettema, 2011). With many contemporary municipalities and homeowners choosing to install bright blue/white LED lighting, plant species reliant on moth pollination and animal species which predate moths may therefore see population declines due to increased moth deaths (Langevelde & Ettema, 2011).

Formerly considered a fringe area of scientific inquiry, the body of literature related to circadian rhythm effects and light pollution has now become a trendy topic of study. In 2013, *The Ecological Impacts of Nighttime Light Pollution: A Mechanistic Appraisal*, concluded exposure to any level of ALAN, regardless of wavelength, inhibits normal melatonin production in birds, fish, and various mammals (Gaston & Bennie, 2013). With

melatonin production affected, fauna exposed to light pollution experience altered sleep/wake cycles as well as related issues which stem from the disruption of the sleep/wake cycle (Gaston & Bennie, 2013). To conclude their article, the authors of *The Ecological Impacts of Nighttime Light Pollution: A Mechanistic Appraisal* express grave concern regarding the rapid proliferation of light pollution by claiming, “At given latitudes, natural light regimes have been relatively consistent through evolutionary time...rapid growth in artificial light represents a potentially significant perturbation to the natural cycles of light and darkness” (Gaston & Bennie, 2013). While the full effects of animal circadian rhythm disruption due to ALAN are not currently known, as of 2017, countless scientific studies exploring the intricacies of circadian rhythm-related health effects in fauna are underway. Ideally, these studies will eventually help shed light upon this multifaceted and confounding ecological issue.

Owing to the rapid proliferation of ALAN coupled with technological and lighting design developments during the past decade (2008-2018), recent studies have attempted to parse out the ecological systems effects stemming from differences in lighting color temperature/wavelength. In *Artificial Light Pollution: Are Shifting Spectral Signatures Changing the Balance of Species Interactions*, the authors assess how the different light spectrums present within four lighting typologies (low-pressure sodium, high-pressure sodium, metal halide, and LED) affect the visual abilities of 213 species including arachnids, insects, birds, reptiles, and mammals (Davis & Bennie, 2013). After conducting their analyses, the authors find three broad spectrum lighting technologies (high-pressure sodium, LED, and metal halide) create larger disparities between animal groups' sight abilities compared with narrow spectrum low-pressure sodium lamps (Davis & Bennie, 2013). Since broad-spectrum lighting technologies have a greater effect upon faunal vision, their potential to alter the balance of interspecific interactions in the environment likely exceeds that of low-pressure sodium lighting (Davis & Bennie, 2013). In summary, environmental research and evaluation directed at the ecological impacts of ALAN, especially with respect to different lamp types, is undoubtedly essential in a world where the artificially lit night environment is increasing at unparalleled pace. On a final note, while there have been countless germane studies regarding the effects of ALAN in relation to human health, we do not focus upon these studies in our inventory.

Policy Tools

With recent emphasis placed upon the positive economic benefits of dark skies and negative environmental externalities pertaining to light pollution, many municipalities and their leaders have begun to consider various mechanisms to mitigate light pollution. Originally spearheaded by communities containing light-sensitive astronomical observatories (such as Tucson, AZ and Flagstaff, AZ), dark-skies lighting ordinances have generated recent interest within a larger social and governmental context. In order to help communities interested in preserving dark skies through ordinances, the non-profit International Dark Sky Association (IDA) curates a publicly-available and legally-defensible municipal model lighting ordinance (IDA, 2011). Common elements within community-scale lighting ordinances include: lighting design standards, lighting brightness standards, requirements for replacement of non-conforming lighting, enforcement mechanisms, among others (IDA, 2011). Within the past year alone, the Colorado Plateau communities of Torrey, UT and Moab, UT have adopted lighting ordinances (Alberty, 2018). Concurrently, many other municipalities within the United States' Intermountain West region are considering ordinance adoption (Alberty, 2018).

However, not all locations wishing to pursue dark sky preservation through policy-focused efforts fall under a municipal jurisdiction. A growing number of federal and state-managed land management agencies have aimed to protect their lands' minimally-polluted night skies

through policy-based designations. For example, beginning in 2014 the US National Parks Service (NPS) released their “Starry, Starry Night”, action item aimed at understanding the impacts ALAN posed to the service’s parks (NPS, 2016). After analysis concluded in 2016, the Parks Service realized light pollution posed a threat the ecological integrity and visitor experience within their managed lands and thereby vowed to retrofit existing outdoor lighting within the parks system to use night sky-friendly lighting (NPS, 2016). In a context local to the Colorado Plateau, the State of Utah Parks Department maintains a “Dark Sky Initiative” aimed at protecting their State Parks’ night skies for current enjoyment and the posterity of future generations (Utah State Parks Department, 2018).

In closing, compared to efforts focused on alternate forms of pollution, future proposed light pollution mitigation policies face a unique basket of challenges due to the overarching nature of light itself. Unlike water, ground, or noise pollution; light pollution, at peak times, can travel up to 250 miles away and adversely affect areas with little to no natural light pollution (Petersen, 2017). Henceforth, while individual municipal and park efforts undertaken thus far to reduce light pollution are undeniably valuable; they will ultimately fail to maintain a truly dark night sky unless a regionalized model of dark sky

preservation is adopted. Owing to the rapid spread of ALAN worldwide, it is therefore imperative to break away from a place-focused model of fighting light pollution in favor of a more regionally-based approach. In the context of the United States, the 1,400 square mile Central Idaho Dark Sky Reserve serves as a fantastic model of regional-scale collaborative planning regarding dark-sky preservation. To facilitate the Reserve’s creation, numerous land management agencies including the National Park Service (NPS) and National Forest Service (NFS) worked with local communities to establish mutually-agreed upon core values stemming from dark sky conservation including: economic development, ecological preservation, support of scientific study, and preservation of community character (Idaho Dark Sky, 2017). Once the majority of entities within the Reserve’s proposed area were on-board with dark sky preservation, each community and land management agency adopted dark-sky friendly ordinances and policies (Idaho Dark Sky, 2017). While such regional and cross-organizational environmental planning ventures are uncommon within the context of the United States’ Intermountain West region, the success of the Central Idaho Dark Sky Reserve provides an exemplary blueprint for communities and land management agencies aiming to achieve a sustainable regionalized model of dark sky preservation.

The Inventory

Objective

Formed in 2016 with a stated mission of: “Promoting the appreciation and preservation of Moab’s unique and rare dark skies”, the Moab Area Dark Skies Group is comprised of elected and appointed Moab City and Grand County officials [Utah], Utah State and National Park Service representatives, and community members (Moab Dark Skies, 2018). In the summer of 2016, the group formulated a plan to protect Moab’s unique dark skies through implementation of a comprehensive city lighting ordinance aimed at curbing light pollution. As part of that plan, Grand County’s Director of Community and Economic Development, Zacharia Levine, contacted the University of Utah’s City and Metropolitan Planning Department (CMP) to request the assistance of our team of two graduate students, Adam Dalton and Nathan Jellen, to complete a baseline lighting inventory of Moab, UT and the adjacent unincorporated Spanish Valley, UT. Once completed, the baseline inventory would serve as a tool for local decision makers

to adopt and implement dark sky-friendly lighting ordinances that would meet the particular needs of their jurisdictions.

This study describes that baseline inventory, which sought to map and evaluate all of the publicly-owned exterior lighting fixtures in the Grand County section of the Spanish Valley in southeastern Utah. This inventory was made accessible to local officials, administrators, staff, and the Moab Area Dark Skies Group in KML format for use in Google Maps, a widely available and user-friendly web mapping service.

Additionally, this report describes the environmental and economic implications of the Moab area’s exterior lighting by calculating associated greenhouse gas emissions along with the monetary costs of maintaining the lighting at this 2017 baseline.

Materials & Methods

After defining its study area, the research team employed a lighting

inventory protocol pioneered by Dr. Bryan Boulanger at Ohio Northern University in cooperation with the United States National Park Service (NPS). Boulanger had previously conducted similar lighting inventories in Yellowstone and Grand Teton National Parks. With Boulanger's permission and guidance, the team adopted his protocol to create a similar inventory for the Moab area. It was one of the first instances of a comprehensive lighting inventory of its kind being carried out in an urban area in the United States. The team had previously trained with Boulanger to conduct inventories using the same protocol in Grand Teton National Park (WY), Helper (UT), Torrey (UT), and Bluff (UT). But the Moab area was logistically the largest urban area the team had inventoried to date.

Study Area and Timeframe

The study area for the inventory comprised the Grand County section of the Spanish Valley in Utah (see Figure 4). All fixtures owned by Moab City and Grand County were surveyed to the best of the team's knowledge. As no official record existed of the exterior lighting owned by the city or the county, the team collected city and county maps to ensure that all local public buildings and streets were visited for assessment of their exterior lights.

The inventory was conducted between June 14, 2017 and July 14, 2017. As the research protocol required daytime and nighttime visitations of each fixture, the team would typically work in the early morning between the hours of 06:00

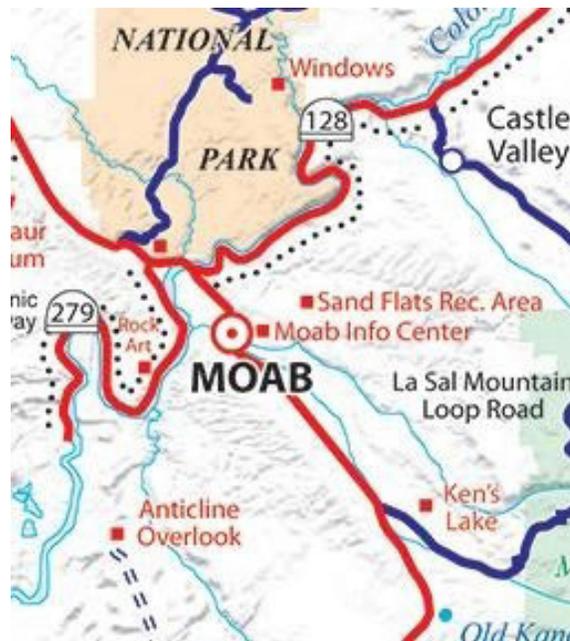


Figure 4: Inventory Study Area. Our inventory was geographically limited to the Grand County portion of the Spanish Valley (including the city of Moab) in southeastern Utah. Source: Discover Moab

and 11:00 and during the nighttime hours from 21:30 to 00:30. The decision to work in the early morning was largely made to avoid the extreme heat temperatures incident to the area's climate in the middle of summer.

Materials

The research team utilized a number of tools to complete the inventory. The decision to use these materials was centered around their use in earlier protocols conducted by Boulanger. They are also relatively inexpensive and are easily available for purchase online through certified vendors.

AsenseTek Lighting Passport Spectrometer

The AsenseTek Lighting Passport Spectrometer is a Bluetooth-enabled device that works in tandem with a smartphone application to determine and display lighting measurements related to correlated color temperature (CCT), illuminance, footcandles, and light wavelength ranges and spectra (see Figure 5)

Suaoki D5T Laser Distance Measurer

Two Suaoki D5T laser distance measurers were used to measure the heights of the different fixtures visited. The measurers are accurate to within 1/12 inches (+/- 2 mm) up to 65.61 feet (or 20 meters) according to their vendors (see Figure 6).

ESRI's Collector Application for ArcGIS Online

ArcGIS is a powerful commercial software package originally



Figure 5: AsenseTek Lighting Passport Spectrometer. This is the Bluetooth-enabled spectrometer that our team used to gather CCT, illuminance, and footcandle measurements. Photo: Nathan Jellen



Figure 6: Suaoki D5T Laser Distance Measurer. Laser distance measurers allowed us to measure the heights of different fixtures to gauge how they might be wasting light. Photo: Amazon

developed by ESRI Corp. in 1999 for geospatial analysis (ESRI, 2016). It allows users from various backgrounds to collect, analyze, and store geospatial data—defined as data which contains a spatial location and may contain a variety of numerical or type-based attributes like cost, height, color, etc. While two versions of ArcGIS currently exist (ArcGIS Desktop and ArcGIS Online), our method employs ArcGIS Online for a variety of reasons. By utilizing the online version of ArcGIS, individuals or groups conducting baseline lighting inventories are easily able to share their results in real time with the general public as well as remote project collaborators. Once data is placed in the online inventory, it is accessible to edit, review, and filter, allowing users to create maps, analyze lighting trends and patterns, identify areas of concern, and conduct energy and costs analyses.

Collector by ESRI is a smartphone application that can be used in the field to geo-locate features in an ArcGIS Online database. Using the GPS capability of their smartphones, the team used the Collector app to map data points for every publicly-owned exterior lighting fixture in the study area. Included with each data point were specific measurements for inclusion in the inventory. In the event of a poor connection to mobile data services or WiFi networks, the Collector app allows for manual positioning of the data points on a base map to ensure they are properly located geographically.

Methods

As previously mentioned, the research team utilized a lighting protocol developed by Dr. Bryan Boulanger at Ohio Northern University in cooperation with NPS. This protocol required the students to locate and visit each publicly-owned exterior lighting fixture within the study area to take daytime and nighttime measurements and photographs.

The bulk of the assessment was carried out during the daytime. The research team would visit a previously determined street or public building to identify the location of different fixtures. Each fixture was then inputted into the Collector app on a smartphone. Consistent with the protocol, the students took the following daytime fixture data points.

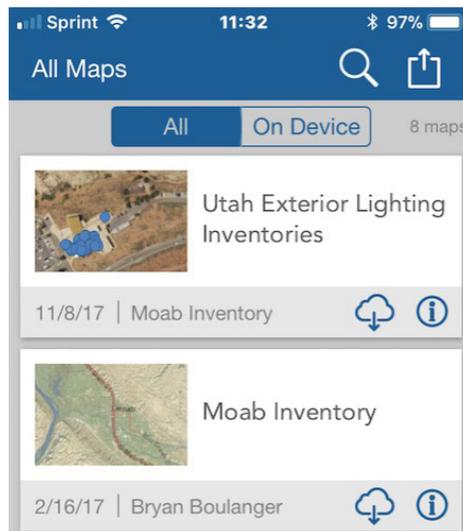


Figure 7: Snapshot of ESRI’s Collector Application. The app uses the GPS capability of a smartphone to geo-locate fixtures on a map. It also stores all data collected for each fixture. Source: ESRI

Daytime and Nighttime Data Points

Visit date. The date and time of the daytime assessment were indicated with the data points for the purpose of keeping an accurate record of fixture visitation.

Fixture height. Using the Suaoki D5T laser distance measurers, the research team was able to gather measurements of the heights of all of the fixtures from the ground. As other city lighting ordinances specify a maximum height limit for their fixtures (particularly street lights), the research team identified the heights of all fixtures in the study area for inclusion with their recommendations.

Fixture lighting purpose. The team identified eight principal purposes for which each fixture existed: area, entrance/egress, pathway, parking, roadway, sign, stairway, and other. These identifiers distinguish the function each fixture exists to fulfill and allowed the team to filter the inventory's findings accordingly.

Fixture type. The team identified 15 principal fixture types by which each fixture could be classified: barn, bollard, ceiling mount, flood, hanging light, lamp post, phone booth, recessed can, spotlight, tin hat, tube, vending machine, wall pack, wall sconce, and other.

Number of fixtures. As some fixtures, like lamp posts, have multiple fixtures attached to one post, the team determined to indicate the number of fixtures per post.

Lamps per fixture. Occasionally, one fixture would contain multiple lamps. In such instances, the team made note of the number of lamps per fixture.

Historic fixture. If the fixture was historic in nature—thus potentially adding historic value to the fixture itself—the team made note accordingly. Historic fixtures are very rare, but usually exist in the form of building signs (neon signs, old hotel signs, etc.) that may add aesthetic value to buildings or streets. As the team focused on publicly-owned exterior lighting (and not privately-owned lighting), it only identified 15 lights as potentially having historic value at the county courthouse.

Fixture power. Three power sources were identified as potential suppliers of energy to each fixture. Each fixture was characterized as either solar powered (with solar panels attached to the fixture), utility powered, or other. As expected, almost all fixtures were powered by a utility, but the team accounted for other possibilities in its economic and environmental cost estimates (Dalton, 2018).

Fixture adaptive controls. As some fixtures were operated by a motion sensor, photocell, switch, or timer switch, the team attempted to account for each of these circumstances in the inventory.

Lamp type. When the team could not visually identify the type of lamp utilized in each fixture, it determined lamp type based on the nighttime spectral readings obtained with the lighting passport spectrometer. The team identified 12 possible lamp types for classification in the inventory: compact fluorescent lamp (CFL), fluorescent tube, halogen, high pressure sodium (HPS), incandescent, induction, light-emitting diode (LED), low pressure sodium (LPS), mercury vapor, metal halide, other, and empty socket.

Shielding. The team identified the shielding component of each fixture. These were classified as fully shielded fixture, partially shielded fixture, fully shielded by eye, partially shielded by eye, fully shielded lamp lens, partially shielded lamp lens, and unshielded fixtures.

After the team gathered these measurements for their daytime assessment of each fixture, they took daytime photos of each fixture to include with the inventory. This would allow for easy identification of the fixture by local government staff for future retrofitting or replacement efforts to conform with eventual improvements to local exterior lighting codes.

After completing a daytime assessment, the team revisited each geo-located fixture again during a nighttime visit. If the fixture was on at night, the nighttime visit involved selecting each geo-located fixture in the Collector app and editing the data to add the following data points.

Visit Date. The date and time of the nighttime visit were recorded.

Passport filename. Each fixture was given a filename by which it could be identified. The team used the same name for fixtures that were identical to one another (thus, the name “Road1” was used for roadway fixtures with the same lamp type, power source, adaptive controls, lamp type, and shielding).

Correlated color temperature (CCT). Correlated color temperature is the color appearance of a light source measured in Kelvin. It is an important reading for determining lighting impacts on public health and wildlife. Using the lighting passport spectrometer, the team identified and recorded the CCT of each fixture that was on at night.

Illuminance (lux). Illuminance is the brightness of a light source and is measured in lumens. The lighting passport spectrometer identified the illuminance of each lamp, which the team determined

could be beneficial in calculating lumens per acre measurements for consideration in drafting local lighting codes.

Footcandles (fc). Footcandles indicate the intensity of light as it falls on a surface, like a road or the ground. The lighting passport spectrometer identified the footcandle measurements that the team included in their assessment.

These measurements were only taken when the light source was on at night. In the event that a lamp was off at night, no nighttime measurements were taken. The daytime data was still included with the fixture, but a note was made to indicate the fixture was off at night.

The team utilized a form (see Appendix A) that was converted to digital format for use within the Collector application. Each time the team recorded a fixture within the application, a page would open up requesting the data for the points listed above. Where the same fixture

typology was utilized repeatedly (as in the instance of street lights of the same type being used along a road), the team was able to copy-paste data within the app for each fixture. This meant that measurements for CCT, illuminance, and footcandles for one fixture were used for all fixtures of its same typology. The findings in this report related to CCT, illuminance, and footcandles are, therefore, estimations of the study area's lighting emissions and are intended to provide local officials and administrators with a sense of what the status of their publicly-owned lighting is.

Inventory Findings

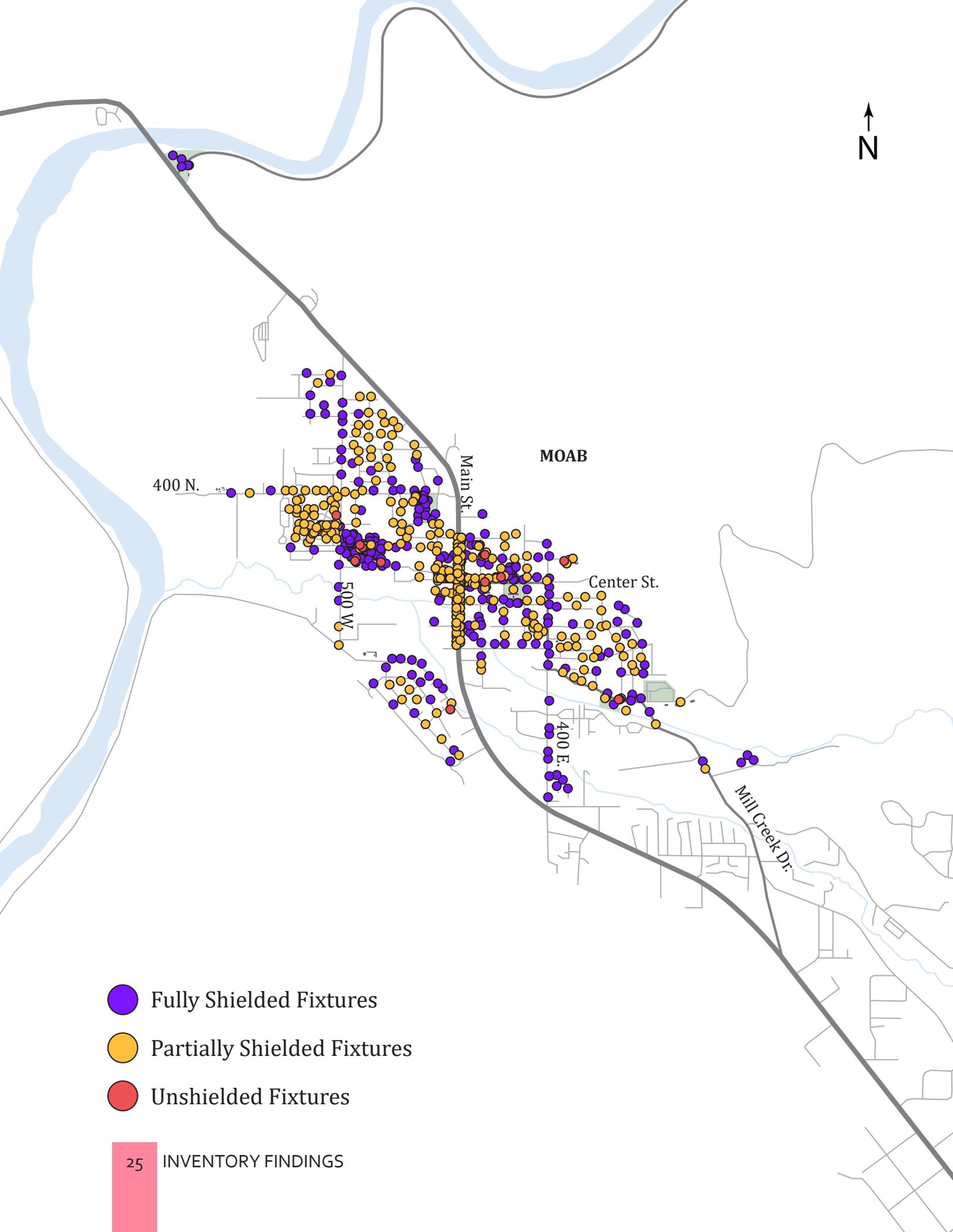
Total Fixtures Assessed

Over the study’s month-long timeframe, data were collected for 2,102 fixtures. The ownership profiles of these different fixtures were mixed. The majority of the fixtures belonged to the city of Moab and to Grand County. However, at the request of local officials and administrators, data were gathered on several fixtures belonging to federal, state, and private entities (see Table 1). The purpose for

gathering this additional data was to provide policymakers with local examples of “dark sky-friendly” lighting and to demonstrate areas where lighting ordinances might help guide local residents, businesses, and public employers in improving the exterior lighting of their homes, businesses, and facilities. Additionally, the team assessed the fixtures at the Bonderman Field Station on nearby Rio Mesa as part of its funding agreement through the University of Utah’s Young Scholar Grant.

Total Number of Fixtures				
Ownership Profile	Fixtures, on at night	Fixtures, off at night	Total Fixtures	Percentage, on at night
Moab City	696	289	985	70.7%
Grand County	372	382	754	49.3%
Utah Department of Transportation (UDOT)	123	14	137	89.8%
Arches National Park	43	69	112	38.4%
U.S. Postal Service (USPS)	8	12	20	40%
University of Utah	7*	2	9	77.8%
Private (13 entities)	70	15	85	82.4%
Total	1319	783	2102	62.7%

Table 1: Total Number of Fixtures. The total number of fixtures assessed for each ownership profile are shown along with the number of fixtures that were either on or off at night during the study timeframe. *The lights at Bonderman Field Station (owned by the University of Utah) are usually turned off at night, but the station’s on-site director, Hau Truong, turned the lights on so the team could assess their impact.



- Fully Shielded Fixtures
- Partially Shielded Fixtures
- Unshielded Fixtures

While Table 1 provides a general breakdown of the total number of fixtures assessed by the team from June 14-July 14, 2017, details for each owner's fixture heights, fixture purposes, fixture adaptive controls, lamp types, shielding, and CCT are provided in Appendix B of this report. However, a summary of our findings for each ownership profile are included above.

City of Moab Assessment

Left: Moab's illuminated lighting stock by shield type

The city of Moab owned the most exterior lighting fixtures of any other entity in or around the Spanish Valley. This finding is not particularly surprising, given that the city's urban area and population dominate the valley. The research team gathered data on a total of 985 fixtures belonging to the city, with 696 (70.7%) of those fixtures illuminated during the nighttime hours (see Table 1). The bulk of the city's illuminated lighting at night is used for vehicle-related purposes, like roadway and parking lot lighting (see Table 2). Other major uses include area lighting, entrance/egress lighting, and pathway lighting, while publicly-owned internally-lit signs are quite few in number. The research team also created an "other" use option in their inventory, though for the city of Moab, the only "other" use was for upward-directed flagpole lighting.

Regardless of whether the publicly-owned lighting fixtures were on or off at night, in the team's visual assessments, it appeared that none of the 985 fixtures belonging to the

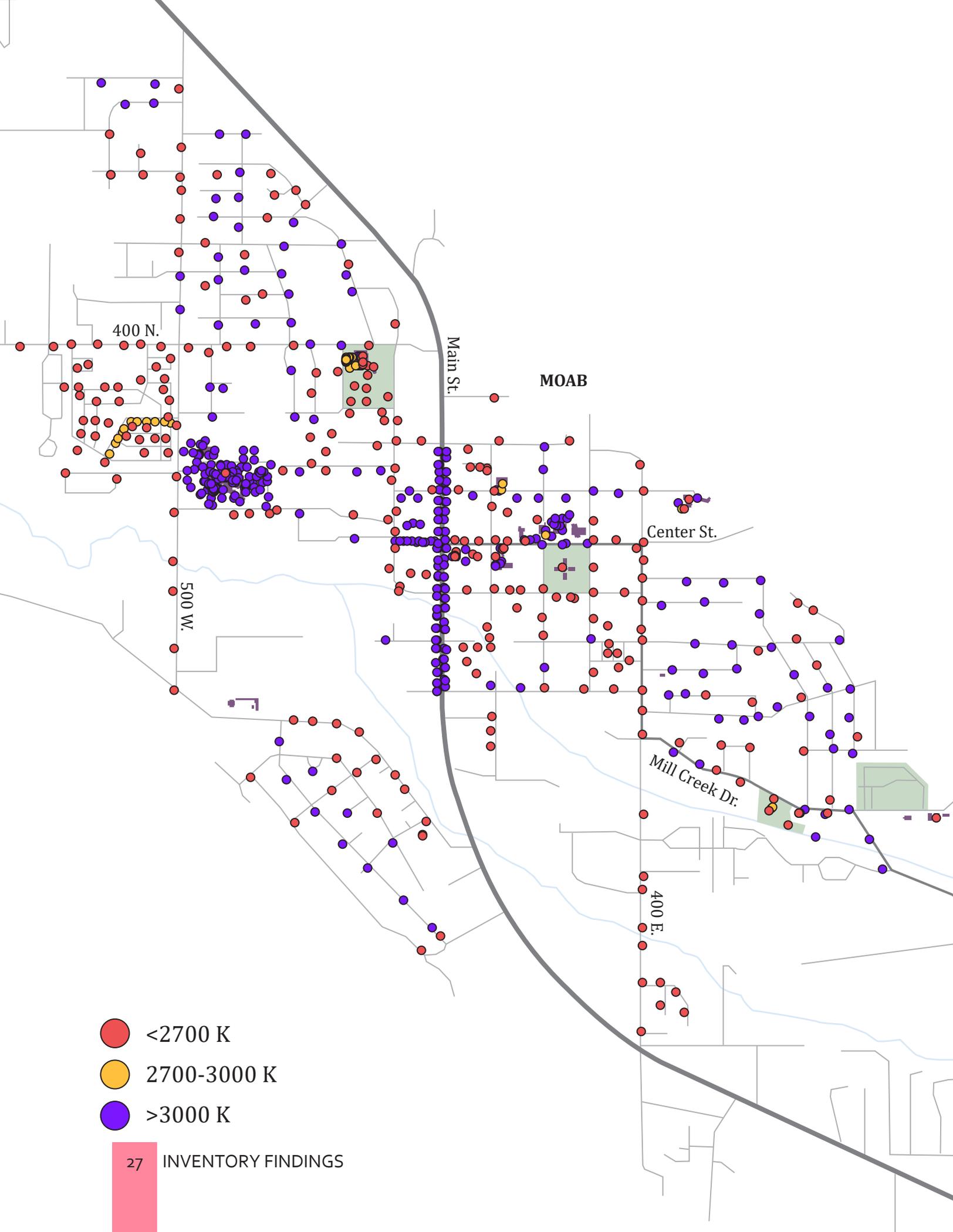
city were connected to solar panels or other non-utility power sources. As such, the team concluded that all exterior lighting sources were powered by a utility.

Roadway and Parking Lot Lighting Evaluations

Of Moab's 696 illuminated fixtures, 369 (53%) and 51 (7.3%) were being used to light roadways or parking areas respectively. These two vehicle-related uses constituted the bulk of the inventory's findings for the city, making up 60.3% of the city's illuminated-at-night lighting stock.

Of the city's 369 illuminated fixtures for roadway uses, 156 (42.3%) fixtures were fully shielded and the remaining 213 (57.7%) fixtures were partially shielded. Many of these partially shielded fixtures were drop-lens cobra head fixtures which would be considered fully shielded if their drop-lenses were removed (see Figure 6). This is a fairly quick and inexpensive fix for many of these fixtures, and for those with a high pressure sodium (HPS) lamp would bring them into compliance with International Dark-Sky Association (IDA) guidelines as their CCTs rarely exceed 2700K. Most of Moab's 188 HPS roadway fixtures have a CCT range of 1700K-1900K.

Of Moab's remaining 181 non-HPS roadway fixtures, 166 have metal halide lamps with a CCT range of 3200-5000K. While many of these lamps also have drop-lenses, removing the lens to fully shield the fixtures can only be considered a temporary fix to the issues these lamps create. Ultimately, the fixtures will need to be retrofitted for lamps of a warmer and lower CCT (like HPS



-  <2700 K
-  2700-3000 K
-  >3000 K

27 INVENTORY FINDINGS

Total Fixtures On at Night and Total Fixtures by Fixture Purpose (Moab)				
Fixture Purpose	Fixtures, On at Night	Percentage, Of On at Night	Total Fixtures	Total Percentage, Of Total Fixtures
Roadway	369	53%	401	40.7%
Area	128	18.4%	281	28.5%
Entrance/Egress	79	11.4%	150	15.2%
Pathway	58	8.3%	62	6.3%
Parking	51	7.3%	65	6.6%
Sign	6	0.9%	18	1.8%
Other	5	0.7%	8	0.8%
Total	696		985	

Table 2: Total Fixtures On at Night and Total Fixtures According to Fixture Purpose (Moab). Here, all illuminated fixtures are arranged by their purpose and are compared to all of Moab’s fixtures (on and off at night) according to their purpose. Roadway fixtures dominate Moab’s lighting stock, especially when only the illuminated fixtures are considered.



Figure 8: A Side-by-Side Comparison of Two Cobra Head Fixtures. These two cobra head fixtures are currently in use throughout Moab and the Spanish Valley. On the left, the fixture features a drop-lens which refracts light up into the sky and creates light trespass. A simple technique to remediate the problem is to pop the lens out, creating a fully shielded fixture. Photo: Nathan Jellen

Left: Moab’s illuminated lighting stock by CCT

or LPS lamps). The remaining 15 roadway fixtures have LED lamps that also need to be retrofitted with shields or low-temperature LEDs.

The city has also installed 96 dual purpose roadway-pathway lighting fixtures (see Figure 8) along Main Street, which have a metal halide lamp with CCTs between 3200-

3400K. These fixtures are all partially shielded on account of their drop-lenses, causing glare, light trespass, and sky glow. In considering the aesthetic appeal of these particular fixtures along Main Street, city officials and administrators may wish to retrofit the fixtures with HPS or LPS lamps and remove the drop-lens from the fixture.

Parking lot lighting constitutes a small portion of the city's exterior lighting stock, but with roadway lighting, creates a citywide lighting program more focused on cars than it is on people. Most publicly-owned parking lot lighting in Moab uses metal halide lamps, which tend to have high CCTs. Other lamps used are HPS and LEDs. The bulk of parking lot lighting is fully shielded, meaning that retrofits for more HPS, LPS, or lower-temperature LEDs will be needed to transition away from metal halides lamps.

Publicly-Owned Facility and Neighborhood Lighting Evaluations

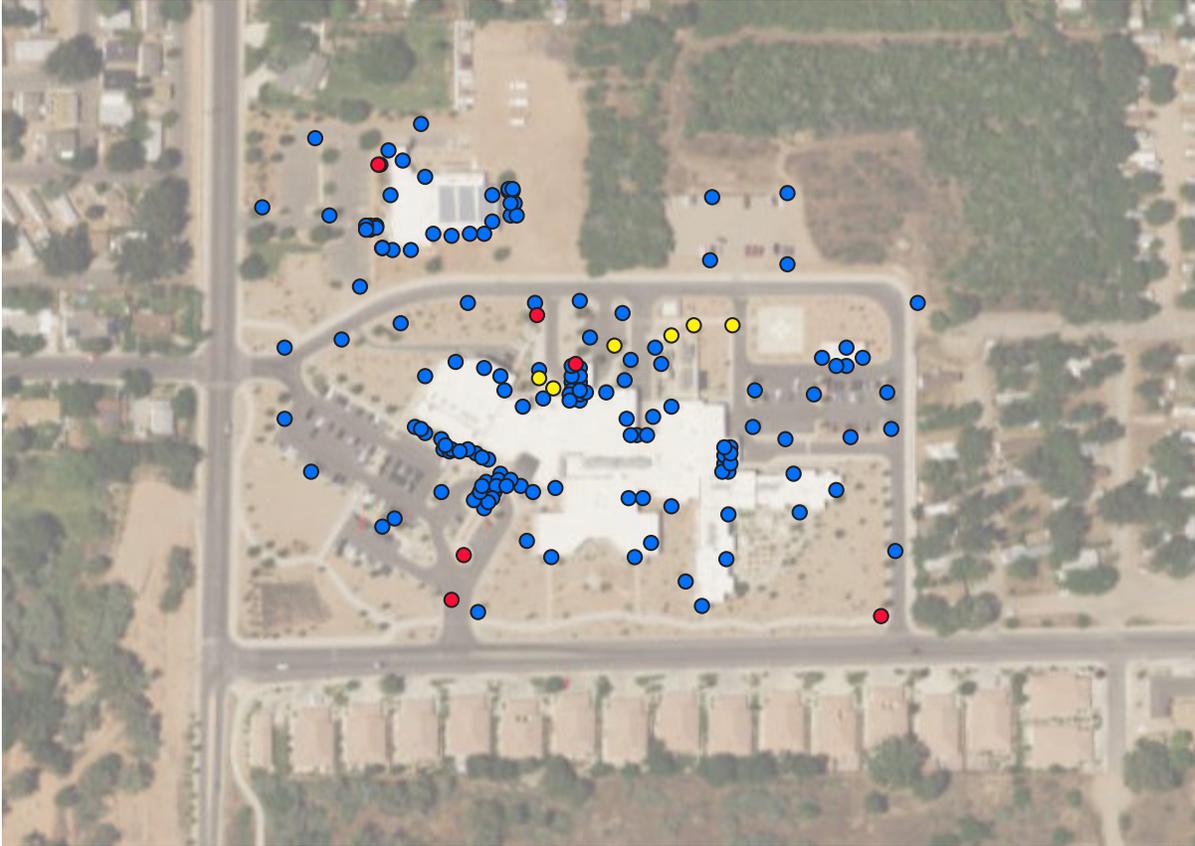
The Moab Regional Hospital, with its 130 illuminated fixtures, was the most lit building owned by the city during the nighttime hours. While almost all of the lighting on the hospital was fully shielded (there were only 6 partially shielded fixtures and 5 unshielded fixtures for internally illuminated signs and for flagpole lighting), only one light source—the internally-illuminated “Emergency” sign on the north side of the building—had a CCT lower than 3000K. The rest exceeded the 2700-3000K guideline set by the IDA, and 30 of those ranged from 4384-5964K. This presents an opportunity for hospital administrators and city officials to reconsider the public health implications of their lighting for patients at the hospital and residents living in the surrounding neighborhoods.

The Moab Recreation and Aquatic Center with its surround public park areas was the next most lit vicinity managed by the city. It had a total of



Figure 9: Moab's Dual Purpose Roadway-Pathway Lighting Fixtures Along Main Street. These fixtures are only partially shielded on account of their plastic drop-lens. Photo: Adam Dalton

42 fixtures illuminated at night, almost all of which were fully shielded fixtures. The exception were 8 ground-level fixtures that were pointed skyward to illuminate a series of columns at the northwest corner of the building. While the columns were supporting an eave that, in turn, was partially shielding the upward-directed lights, nearby upward-directed fixtures were actually burnt out at night, begging the question of whether these 8 fixtures ought to be illuminated in the first place. That said, most of the lighting on the facility and its premises had CCTs lower than 3000K with only 6 metal halide lamps on



Above: The hospital's lighting stock by shielding

Right: The rec center's lighting stock by shielding



- Fully Shielded Fixture
- Partially Shielded Fixture
- Unshielded Fixture

the building's northern and southern walls exceeding 3000K (they were measured at 5198K).

The Grand Oasis Manufactured Home Community to the south west of the intersection of 400 North and 500 West in Moab had a total of 30 area lights. While all of the fixtures were

entirely comprised of HPS lamps with a CCT below 2700K, the fixtures were also all barn lamps, which offer only partial shielding. Metal shields for barn lamps have been used in other parts of Moab and are a potential solution to the shielding issues created by this particular fixture type (see Figure 10).



Figure 10: A Side-by-Side Comparison of Barn Fixture Shielding. These are two barn fixtures currently being used in Moab, UT. On the left is a barn fixture with a transparent plastic shield that only offers partial shielding for its light emissions. The barn fixture on the right has an opaque metal shield that offers full shielding, preventing light trespass, sky glow, and glare. Photos: Nathan Jellen

Shielding and CCT Evaluations of All Illuminated Fixtures

Half of all of the city's exterior lighting that is on at night is fully shielded either by the fixture (48.7%) or by an eve (1.4%). The other half of the city's lights are either partially shielded by their fixture (46%), partially shielded by an eve (1.7%), or unshielded (2.2%). However, even among the fully

shielded fixtures, there are many that emit a CCT higher than 3000K. Table 3 breaks down shielding and CCT by the number of fixtures that are on at night, indicating that 157 (22.5%) of the city's fixtures are currently within the shielding and CCT guidelines set by the IDA. Of the remaining fixtures, 343 (49.3%) are near compliance and only require a CCT retrofit or proper shielding. The remaining 196 (28.2%) are noncompliant and require both a CCT retrofit and proper shielding.

Number of Fixtures on at Night by Shielding and CCT (City of Moab)						
CCT (Kelvin)	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Eve	Partially Shielded Fixture	Unshielded	Total
<2700K	3	135	3	119	6	266
2701-3000K	2	17	8	15	-	42
3001-4000K	5	103	1	113	4	226
4000K +	-	84	-	73	5	162
Total	10	339	12	320	15	696

Table 3: Illuminated Fixtures at Night Arranged by Shielding and CCT (Moab). Here, fixtures are arranged according to their shielding and their CCT. White boxes indicate the number of fixtures that are currently in compliance with the standards set by the IDA. Yellow boxes indicate fixtures that are nearly in compliance with those standards and orange boxes indicate the number of fixtures that are noncompliant. These figures are only for the 696 fixtures owned by Moab that were on at night during the study period.

Adaptive Control Evaluations of All Illuminated Fixtures

Adaptive controls designate when a light source turns on or off. In most households, fixtures are turned on and off using a light switch, but other control options are available for designating when a light source is on or off. Photocells are a common adaptive control and make up the majority of Moab’s exterior lighting controls. Using the brightness of daylight as its guide, a photocell will turn a fixture on once the brightness of the day begins to fade into sunset. Photocells work well for roadway lighting, but are also commonly used for exterior building lighting, parking lot lighting, and park lighting.

Other adaptive control options include motion sensors, light switches, timer switches, and automatic timers. With the exception of timer switches, which involve turning a dial to a specific amount of time that then counts down until switching the lights off, all of these other adaptive controls are currently being used in Moab, but to a considerably smaller degree than

photocells. Not surprisingly, in the instances where these other controls are being used, the lights are typically off at night.

Lions Club Park, in the northernmost part of the city has most of its fixtures on automatic timers. As soon as night begins to fall, the 49 fixtures in the park all turn on. But at 11 pm every night, 40 of the 49 fixtures turn off automatically, leaving only a few essential fixtures on. This sort of a control allows for areas to go dark after hours, limiting light emissions to the hours when people are typically awake and may have use for them.

Motion sensors are another effective tool for keeping fixtures on only when they’re needed. The city currently has 15 fixtures operating on motion sensors, though only 3 were functioning during our assessment. Though motion sensors should not be used in heavily trafficked pedestrian areas at nighttime, they can be helpful at low-trafficked building entrances and exits, as was the case with all of Moab’s motion-activated fixtures.

The research team also documented 56 fixtures requiring operation by a light switch. Of all of these fixtures, only 4 were noted to be on at night, reiterating that switches can also be effective tools in keeping lights on only when they are serving a specific, temporary purpose.

Employing a variety of adaptive controls can be a helpful method for controlling light pollution and its effects. It can reintroduce intentionality to the urban lightscape by lighting only when and where it is needed.

Grand County Assessment

Grand County was the second largest owner of exterior lighting in the Spanish Valley. The research team gathered data on a total of 754 fixtures belonging to the county, with 372 (49.3%) of those fixtures illuminated during the nighttime hours (see Table 1 above). The majority of the county’s illuminated

fixtures at night is used for area lighting in and around buildings and for illuminating entrances/egresses (see Table 4). Other major uses are for roadway and parking lot lighting. Pathways involve a small use of light, while there are only three upward-pointed flagpole lights at the Helen M. Knight Elementary School and two fixtures used for illuminating a sign at the Old Spanish Trail Arena (OSTA).

Regardless of whether the publicly-owned lighting fixtures were on or off at night, in the team’s visual assessments, it appeared that only two fixtures belonging to the county were solar powered. One was located on the main entry gate to the recycling center and was intended to light a sign. The other was at the OSTA on one of the horse pens and was intended to power a spotlight. However, neither of these solar powered fixtures was on when the team came by to assess them. As no other solar paneling was visible for the other lights assessed by the team, we concluded that all other exterior lighting owned by the county was powered by a utility.

Total Fixtures On at Night and Total Fixtures by Fixture Purpose (Grand County)				
Fixture Purpose	Fixtures, On at Night	Percentage, Of On at Night	Total Fixtures	Total Percentage, Of Total Fixtures
Area	108	29%	314	41.6%
Roadway	108	29%	133	17.6%
Entrance/Egress	103	27.7%	208	27.6%
Pathway	25	6.7%	39	5.2%
Parking	23	6.2%	47	6.2%
Sign	2	0.5%	3	0.4%
Other	3	0.8%	10	1.3%
Total	372		754	

Table 4: Total Fixtures On at Night and Total Fixtures According to Fixture Purpose (Grand County). Here, all illuminated fixtures are arranged by their purpose and are compared to all of the county’s fixtures (on and off at night) according to their purpose. Area lighting dominates the county’s lighting stock, but most of that lighting remains off at night.

Publicly-Owned Facility and Neighborhood Lighting Evaluations

Grand County School District

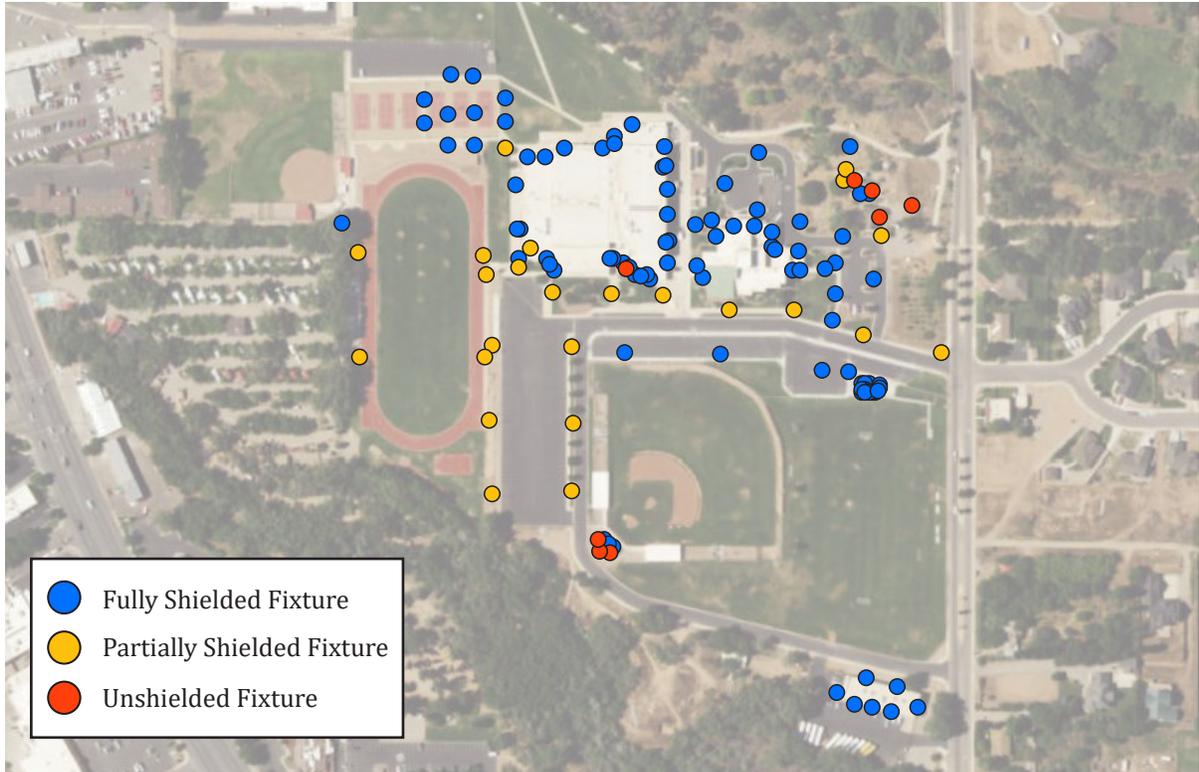
Grand County School District operates several prominent buildings within the Spanish Valley, including Helen M. Knight Elementary School, Grand County Middle School, and Grand County High School. In carrying out our lighting assessment, we found that, among the county-owned facilities, the high school and elementary school had the most illuminated fixtures at night. The high school, including the bus shed at the southern end of the school's premises) had 91 fixtures illuminated at night (making up 24.5% of Grand County's total illuminated fixtures) and the elementary school had 66 fixtures illuminated at night (or 17.7% of all of Grand County's illuminated fixtures). By contrast, the middle school only had 14 fixtures on at night (3.8% of all of the county's illuminated fixtures).

Grand County High School had the highest illuminated lighting stock of any other building in the county during our assessment. Of its 91 illuminated fixtures at night, 75 of them were fully shielded by their fixture, 15 were partially shielded by their fixture, and one—a flagpole light—was unshielded. The bulk of the school's lighting was composed of LED lamps. Only the tennis courts used metal halide lamps (with CCTs of 3900K), though they were controlled by a timer switch and shut off after some late-night tennis enthusiasts had finished their game. The LEDs on the rest of the school

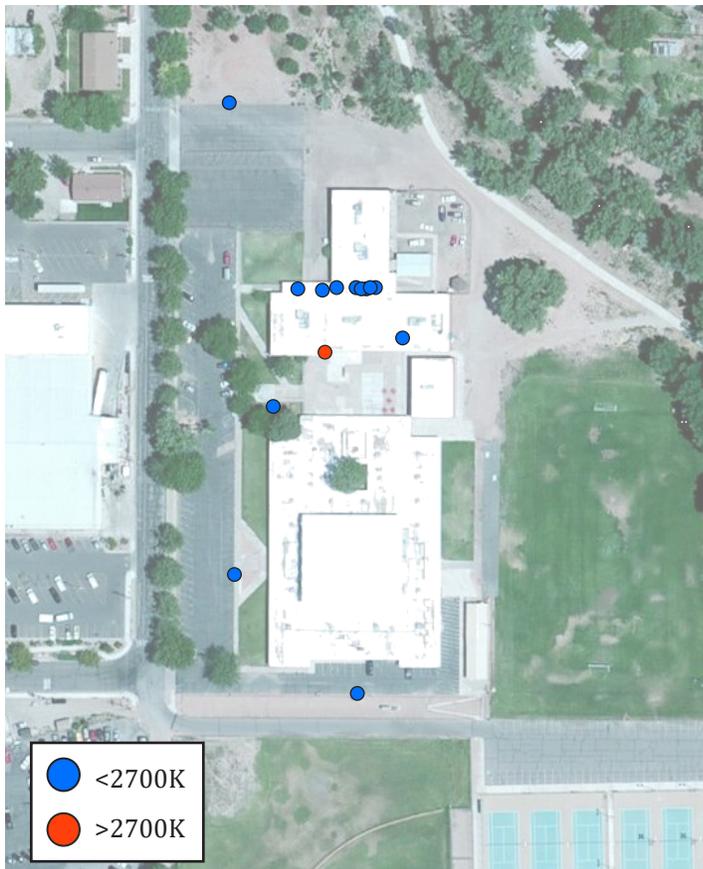
were measured with CCTs between 4100-6000K, which is outside the CCT guideline of 2700-3000K (maximum) set by the IDA. This presents an opportunity for school district administrators and county officials to reconsider the public health and environmental implications of their lighting and to consider alternative lighting designs.

All but three of the 66 illuminated fixtures at Helen M. Knight Elementary School were fully shielded by their fixtures. The other three were unshielded, but were being used to illuminate flagpoles at the school's entrance. Additionally, 27 of the school's parking lot fixtures shut off automatically at 10 pm, leaving 39 fixtures illuminated. Of these remaining 39 fixtures, 20 used LED lamps with CCTs ranging from 3400K-7450K and the other 19 used compact fluorescent (CFL) lamps with CCTs of 3500K.

Grand County Middle School had the lowest illuminated lighting stock of the three schools in the Spanish Valley. With the exception of one unshielded metal halide (with a CCT of 5000K) being used to illuminate the courtyard between the school's three buildings, the rest of the school's HPS and CFL lighting fell below the 2700K guideline set by the IDA. Nine of the 14 fixtures were fully shielded, while the four HPS barn fixtures (see Figure 8 above) were partially shielded. If metal shields replace the transparent shields on these four barn fixtures and the school reconsiders its unshielded courtyard light, the school's exterior lighting program will meet dark sky-friendly practices.

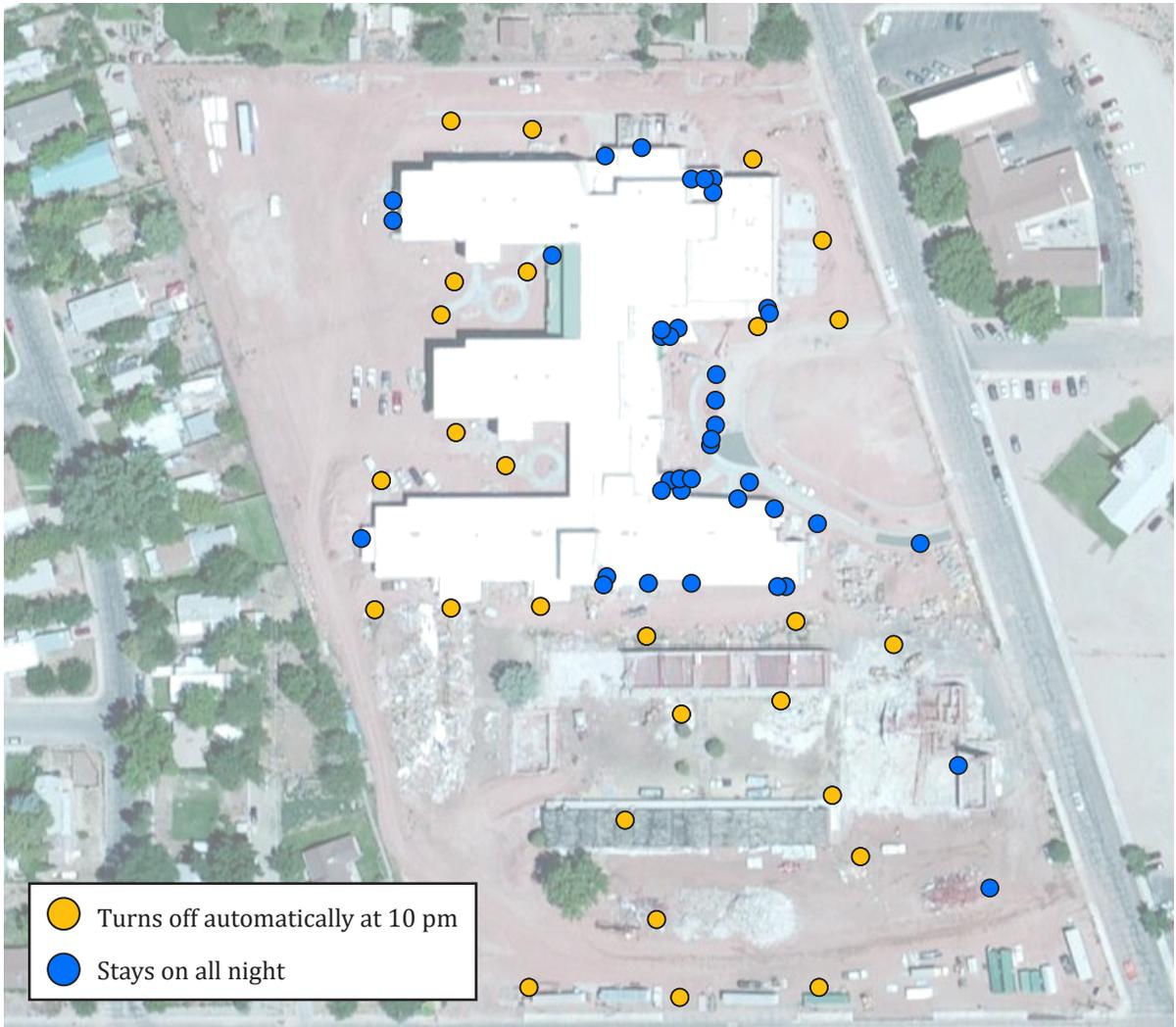


Above: Grand County High School's lighting stock by shielding type.



Left: Grand County Middle School's lighting stock by CCT. Only one lamp had a CCT higher than 2700K.

Right: Helen M. Knight Elementary School's lighting stock by adaptive control type. Twenty-seven of the school's fixtures shut off automatically every night at 10 pm.



Our team also evaluated the Grand County School District offices on 400 East. Only two fully shielded fixtures were illuminated at night, and both were using HPS lamps with CCTs of 1700K.

Other County Buildings

In addition to the school district's facilities, our team assessed the exterior lighting for other prominent

county buildings throughout the valley. Other major sources of artificial light at night (ALAN) included the county library, the county courthouse, and the Old Spanish Trail Arena (OSTA).

The library had a total of 38 illuminated fixtures, but was one of the most dark sky-friendly buildings within our study area. All 38 fixtures used HPS lamps with CCTs of 1700K



Figure 11: Grand County Library. Grand County Library's lighting program involves using recessed cans like the one pictured on the right. Combined with HPS lamps, these fixtures direct the light beam downward, while maintaining an aesthetic that is dark sky-friendly. Left image: Moab Library Twitter; right image: Nathan Jellen



Figure 12: HPS lamps at the Grand County Courthouse. These two lamps, while technically complying with the IDA's guidelines for CCTs lack the shielding to prevent light trespass, sky glow, and glare. Image source: Nathan Jellen

and each was a recessed can, meaning it was fully shielded. The library’s lighting program can serve as an example for other lighting programs in the valley as it complies with IDA standards (see Figure 11).

Though the county courthouse had fewer illuminated fixtures than the library, most of its fixtures were only partially shielded. In total, the building had 27 fixtures that were on at night. Of those fixtures, 14 were LEDs with CCTs of 3800-5000K, one was a CFL with a CCT of 3300K, and the other 12 were HPS lamps with CCTs of 1700-1800K. While the HPS lamps complied with IDA guidelines for CCTs, only one was fully shielded. The other HPS lamps were only partially shielded by their fixtures (see Figure 12). As the Grand County Courthouse is the base for county government operations, its example of establishing dark sky-friendly lighting could help launch a county-wide initiative to preserve the night sky.

While our team counted 139 fixtures on the premises of the Old Spanish Trail Arena (OSTA), our nighttime assessment found that only 24 of

those fixtures were actually illuminated after dark. However, our survey found a variety of lamp types and shielding types were being used on and around the building. Table 5 displays the breakdown of different illuminated fixture typologies currently utilized by the facility. Although the facility’s 60-foot ballfield floodlights were not illuminated on the night of our visit, it should be noted that they are only partially shielded and may cause light trespass into the adjacent (and dark sky-friendly) Rim Village neighborhood.

Grand County Neighborhood Lighting

Rim Village has already been mentioned above as a dark sky-friendly neighborhood in the study area. The subdivision has adopted a uniform street lighting program comprised of twenty-five 10-foot tall lamp posts that are fully shielded (see Figure 13). The lamp posts use a CFL bulb with a CCT of 2400K. The subdivision has a small tennis court with six 30-foot tall fixtures that utilize metal halide lamps with CCTs of 4340K, but the fixtures are

OSTA Lighting Typologies			
Lamp Type	Shielding	CCT (Kelvin)	Number of fixtures
HPS	Fully Shielded Fixture	4340	4
Fluorescent Tube	Fully Shielded Eve	3443	2
CFL	Fully Shielded Eve	1748	1
CFL	Partially Shielded Fixture	1748	8
Metal Halide	Partially Shielded Fixture	3525	7
LED	Unshielded	4769	2

Table 5: Lighting Typologies at the Old Spanish Trail Arena (OSTA). The lighting program at OSTA involved a large variety of lamp types. While many of these lamps had CCTs higher than the 2700K-3000K guideline set by the IDA, many fixtures were either fully or partially shielded.



Figure 13: Rim Village Street Lights. The street lights in the Rim Village neighborhood in Grand County are only 10 feet high and are outfitted with 2400K CFL lamps. Photo: Nathan Jellen & Adam Dalton

controlled by a timer switch, which allows visitors to set a time limit for the lights before they turn off. To further minimize impacts on the neighborhood, each of the tennis court fixtures is fully shielded, preventing light trespass and sky glow. These lighting features within the subdivision have made it dark sky-friendly through effective implementation of best practices in exterior light design.

Roadway and Parking Lot Lighting Evaluations

Grand County owns 133 roadway fixtures, of which 108 are illuminated at night. It also owns 47 parking lot fixtures, of which only 23 are actually on during the nighttime hours. Together, these uses represent 35.2% of the county's total illuminated exterior lighting stock at night.

Of the county's 108 illuminated fixtures for roadway uses, 85 fixtures were fully shielded and the remaining 23 fixtures were partially shielded. Many of these partially shielded fixtures were drop-lens cobra head fixtures which would be considered fully shielded if their drop-lenses were removed (see Figure 6). This is a fairly quick and inexpensive fix, and for those fixtures with a low temperature lamp, like an HPS or CFL bulb, would bring them into compliance with International Dark-Sky Association (IDA) guidelines. Table 6 breaks down Grand County's roadway lighting according to lamp type, shielding, and CCT.

Illuminated parking lot fixtures owned by Grand County, though scarce, exhibit some variety in their lamp types and shielding. The bulk of the 23 illuminated parking fixtures are made up of LED lamps, with 9

LEDs fully shielded by their fixture and 7 LEDs partially shielded by their fixture. All of these LEDs have a CCT value that falls in the range of 4300K-6000K. Additionally, there are three, fully shielded metal halide fixtures with CCTs of 3300K and there is one partially shielded HPS lamp with a CCT of 2000K. With these values, there are opportunities for Grand County to improve its dark sky-friendly lighting practices in its parking lots.

Shielding and CCT Evaluations of All Illuminated Fixtures

A total of 72.3% of Grand County’s exterior lighting that is on at night is

fully shielded either by the fixture (69.9%) or by an eve (2.4%). The other quarter of the county’s lights are either partially shielded by their fixture (24.5%) or unshielded (3.2%). However, even among the fully shielded fixtures, there are many that emit a CCT higher than 3000K. Table 7 breaks down shielding and CCT by the number of fixtures that are on at night, indicating that 110 (29.5%) of the county’s fixtures are currently within the shielding and CCT guidelines set by the IDA. Of the remaining fixtures, 210 (56.5%) are near compliance and only require a CCT retrofit or proper shielding. The remaining 52 (14%) are noncompliant and require both a CCT retrofit and proper shielding.

Grand County Street Lighting Typologies			
Lamp Type	Shielding	CCT (Kelvin)	Number of fixtures
LED	Fully Shielded Fixture	4000-5000K	34
HPS	Fully Shielded Fixture	1800K	26
CFL	Fully Shielded Fixture	2400K	25
HPS	Partially Shielded Fixture	1800-2400K	19
Metal Halide	Partially Shielded Fixture	4300-4600K	3
LED	Partially Shielded Fixture	4800K	1

Table 6: Grand County Street Lighting Typologies. This table lists the different types of illuminated street lighting in Grand County and the number of fixtures corresponding to each typology.

Number of Fixtures on at Night by Shielding and CCT (Grand County)					
CCT (Kelvin)	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Fixture	Unshielded	Total
<2700K	7	102	51	-	160
2701-3000K	-	1	-	-	1
3001-4000K	2	36	11	3	52
4000K +	-	121	29	9	159
Total	9	260	91	12	372

Table 7: Illuminated Fixtures Arranged by Shielding and CCT for Grand County. Here, fixtures are arranged according to their shielding and their CCT. White boxes indicate the number of fixtures that are currently in compliance with the standards set by the IDA. Yellow boxes indicate fixtures that are nearly in compliance with those standards and orange boxes indicate the number of fixtures that are noncompliant. These figures are only for the 372 fixtures owned by Grand County that were on at night.

Adaptive Control Evaluations of All Illuminated Fixtures

Adaptive controls designate when a light source turns on or off. In most households, fixtures are turned on and off using a light switch, but other control options are available for designating when a light source is on or off. Photocells are a common adaptive control and make up the majority of Grand County's exterior lighting controls. Using the brightness of daylight as its guide, a photocell will turn a fixture on once the brightness of the day begins to fade into sunset. Photocells work well for roadway lighting, but are also commonly used for exterior building lighting, parking lot lighting, and park lighting.

Other adaptive control options include motion sensors, light switches, timer switches, and automatic timers. All of these other adaptive controls are currently being used by Grand County, but to a considerably smaller degree than photocells. Not surprisingly, in the instances where these other controls are being used, the lights are typically off at night.

As has been mentioned previously, Helen M. Knight Elementary School has 27 of its parking lot fixtures on automatic timers. As soon as night begins to fall, these fixtures all turn on in order to illuminate the parking lot. But at 10 pm every night, after all employees are likely to have gone home, these 27 fixtures turn off automatically. This sort of a control allows for areas to go dark after hours, limiting light emissions to the hours when people are most likely to need them.

Motion sensors are another effective tool for keeping fixtures on only when they're needed. The county currently has 21 fixtures operating on motion sensors, though none were actually functioning during our assessment. Though motion sensors should not be used in heavily trafficked pedestrian areas at nighttime, they can be helpful at low-trafficked building entrances and exits, as was the case with all of Grand County's motion-activated fixtures.

Our research team also documented 124 fixtures requiring operation by a light switch. Of all of these fixtures, only 5 were noted to be on at night, reiterating that switches can also be effective tools in keeping lights on only when they are serving a specific, temporary purpose.

We also noted 77 fixtures requiring operation by a timer switch throughout the county. Of these many fixtures, only 24 were being used on the nights we were assessing them. Most of these timer switch-activated fixtures were concentrated around sporting facilities (tennis, baseball, basketball)—a purpose that suits their use well.

Employing a variety of adaptive controls can be a helpful method for controlling light pollution and its effects. It can reintroduce intentionality to the urban lightscape by lighting only when and where it is needed.

Environmental and Economic Assessments

Estimating Light Pollution Impacts

Once our research team had completed its ArcGIS online baseline lighting inventory maps and data spreadsheets, we aimed to parse out the ecological and economic consequences of Moab City and Grand County's current lighting choices. With respect to ecological impacts, we generated greenhouse gas (GHG) emission estimates based upon city and county lighting stocks. These GHG estimates fit within the broader context of the city of Moab's recent legislation aimed at reducing citywide GHG emissions by 80% by 2040 (Moab City, 2017). We also conducted an economic assessment focused on municipal energy costs stemming from publicly-owned exterior lighting.

Admittedly, it is somewhat reductionist and limiting to package ecological and cost estimates into a single set of numbers. The economic and ecological effects of light pollution are complex and multifaceted. However, given the time and resource constraints

inherent within our research study, we consider the following estimates to be the most representative of relevant ecological and economic effects arising from present city and county lighting situations.

Regarding ecological GHG analyses, our protocol followed best practices outlined by the State of California Institute for Local Governments (Bay Area Air Quality District, 2009). First, our research team filtered the baseline lighting inventory data in ArcGIS online to separate Grand County and Moab City data. Once completed, we downloaded the dataset and created new Moab City and Grand County spreadsheets where each lighting type was given a unique spreadsheet tab (for example: CFL, LED, etc.). Next, we utilized the *Ameren Energy Lighting Wattage Guide* to ascertain the approximate power consumption of each measured lighting type in watts and entered those figures into the GHG calculations spreadsheets (Ameren Illinois, 2011). The final step before completing any calculations was to assume lighting which was on at night was lit an average of 11 nighttime hours per night.

With energy and time approximations for each lighting type in both municipal jurisdictions, GHG calculation could thereby commence. To begin, wattage data was divided by 1,000 to convert watts into kilowatts (kW), since energy usage data is generally presented as kW. After conversion, kW data was multiplied by the number of hours lighting was on per night (11 hours) to yield kWh—the standard measure of energy usage for electric companies within the United States. Next, the physical number of light fixtures within each category was multiplied by kWh to determine the total daily energy usage for each subcategory of lighting stock for the city and then for the county. Once the calculations were finished, daily usage was multiplied by 365 to estimate the yearly kWh impact of each subtype of lighting present within the datasets. Annual kWh estimates for the unique lighting subtypes were plugged into the U.S. EPA’s Greenhouse Gas Equivalencies Calculator; which then yielded yearly CO₂ impacts in Metric tons (U.S. EPA, 2017). To conclude, all discrete GHG estimates for Moab City and Grand County were added

together to create a final yearly Metric T estimate of the ecological GHG impact of each entities’ lighting stock.

Thankfully, by completing a thorough GHG estimation process, most steps required to undertake economic cost analyses had previously been conducted. With data regarding daily and yearly energy usage already available in kWh, the only element missing to conduct an economic cost estimate was utility price rates per kWh. However, owing to the nontransparent nature of utility company data, finding utility rates per kWh happened to be the most singularly difficult task undertaken during either analysis processes. Numerous hours of online searches solely provided aggregated residential energy rates for the State of Utah, \$0.113 per-kWh, courtesy of Rocky Mountain Power (Rocky Mountain Power, 2018). As municipal utility rates commonly fall below residential rates, we conservatively subtracted roughly two cents from the above residential rate of \$0.113 per-kWh. Our cost rate, therefore, equated to roughly \$0.094 per-kWh.

A	B	C	D	E	F	G	H	I	J	K
# of Lights	CCT	Watts	Days/Year	# Hrs On	KW/Hr. Daily	Cost Per KW/Hr.	Total \$\$\$ Day	GHG Day	Total \$\$\$ Year	GHG Year
20	< 4000	175	365	11	1.925	0.0941	3.62285	38.5	1322.34025	14052.5
10	> 4000	250	365	11	2.75	0.0941	2.58775	27.5	944.52875	10037.5
HALIDE TOTALS							6.2106	0.049 Metric T	2266.869	17.885 Metric T

Table 8: GHG Spreadsheet. This table indicates energy costs and GHG emissions data for metal halide fixtures owned by Grand County. Source: Adam Dalton

A	B	C	D	E	F	G	H	I	J	K
# of Lights	CCT	Watts	Days/Year	# Hrs On	KW/Hr. Daily	Cost Per KW/Hr.	Total \$\$\$ Day	GHG Day	Total \$\$\$ Year	GHG Year
49	< 3000	70	365	11	0.77	0.0941	3.550393	37.73	1295.893445	13771.45
24	> 3000	110	365	11	1.21	0.0941	2.732664	29.04	997.42236	10599.6
CFL TOTALS							6.283057	0.05 Metric T	2293.315805	18.25 Metric T

Table 9: Cost Spreadsheet. This table indicates energy costs and GHG emissions data for compact fluorescent fixtures owned by Grand County. Source: Adam Dalton

In the same vein as the ecological GHG analyses, within our economic analyses Grand County and Moab City, data were parsed by lighting type. Each subtype of lighting underwent the following calculation to estimate yearly energy costs:

$$\text{kWh of energy used per-year} \times \text{utility rate per-kWh}$$

With cost estimates for each lighting type completed, dollar estimates were added together to determine a total monetary cost to each jurisdiction emanating from their respective publicly-owned exterior lighting situations. Once conducted, the previously-mentioned baseline GHG and cost estimates serve as a baseline from which to measure the impacts of future lighting decisions. In our recommendations to Moab City leaders, our team completed numerous estimates which referenced our baseline GHG and cost estimates to understand energy and cost savings which could be derived from lighting upgrades in the City. Going further, it is indeed possible to break down and apply estimation techniques to smaller entities; for example, we conducted GHG and cost estimates for the Grand County School District.

Estimating energy and cost savings with respect to baseline numbers is a relatively straightforward process. To start, parameters for lighting replacement are set based on previously-established best practices (such as: replacing all CFL exterior building lights with 2,700K amber LED lighting). Once a new lighting stock is established, theoretical GHG and cost estimates based on the new lighting parameters are to be undertaken. As a note, whereas theoretical GHG estimates are

identical to baseline estimates, cost analyses differ as theoretical estimates are to include the cost of purchasing new bulbs and may also include labor costs to replace said lighting. Upon completion of the theoretical GHG and cost estimates, results are to be compared with the baseline calculations in order to recognize potential GHG and cost savings which occur as a result of select lighting changes. However, depending on chosen lighting, sometimes costs associated with lighting replacement and energy usage exceed current yearly energy costs. In such a scenario, divide the newly-calculated energy and replacement costs by the baseline yearly energy costs. In doing so, estimations can be calculated for the payoff window within which energy savings related to new lighting will pay for the costs of lighting replacement.

Once completed, our team's Moab inventory economic analysis estimated the City currently spends roughly \$42,300 yearly in utility costs related to powering publicly-owned exterior lighting. Our first proposed alternate scenario, within which Moab City would solely replace non-compliant street and building lighting fixtures over 3000K CCT with low-pressure sodium and low-CCT LED lighting, yielded utility costs of \$29,450. This equates to \$12,850 of monetary savings yearly. A more aggressive second alternate scenario within which Moab City would uniformly replace all lighting with low-pressure sodium and low-CCT LED bulbs resulted in utility costs of \$26,350 and savings of \$15,950.

<i>Lighting Option</i>	<i>Yearly Cost (\$)</i>	<i>Yearly GHG (Metric T)</i>	<i>Cost Savings (\$)</i>	<i>GHG Savings (Metric T)</i>	<i>Replace Costs (\$)</i>	<i>Payoff Time</i>
Current	42,292.21	334.71	N/A	N/A	N/A	N/A
Replace Above 3K	29,457.96	232.87	12,834.26	101.84	16,271	1 Year, 3 Months
Replace All	26,346.68	208.42	15,945.53	126.29	32,914	2 Years, 1 Month

Table 10: Financial and GHG Comparison Chart for Moab City. This table compares estimates for energy costs and GHG emission reductions based on two scenarios proposed for the city of Moab. In scenario 1, only exterior lighting presently with a CCT above 3000K would be replaced with low-temperature lighting. In the more ambitious scenario 2, all exterior lighting in the city would be replaced with low-pressure sodium and below-2700K LED lighting. Source: Adam Dalton

With respect to GHG emissions, the Moab inventory analysis indicated energy produced to light the city’s contemporary lighting stock causes an estimated 335 Metric Tons of GHG emissions yearly. Under the proposed scenarios one and two above, total emissions fall to 233 and 208 Metric Tons respectively, equating to GHG reductions of 102 and 127 Metric Tons yearly.

When estimating theoretical cost payoff times—defined as the timeframe within which utility savings outweigh lighting replacement cost—proposed alternate scenario number one (replacement of lighting above 3000K CCT) generated a cost payoff period of one year and three months. Going further, alternate scenario number two (replacement of all lighting) had a marginally longer payoff period, two years and one month.

Before concluding, it is critical to note two shortcomings related to our payoff period analyses. First, our payoff analyses lack labor costs associated with lighting replacement as data related to lighting

replacement and labor time does not exist. Any estimates within this realm would therefore be entirely speculative. Consequently, our payoff time estimates likely underestimate what would be considered as true cost payoff time frames. Second, the above estimates assume all lighting to be replaced simultaneously so as to ease estimation of energy and GHG savings associated with the alternate proposed lighting stocks. Needless to say, the assumption that all lights are replaced at the same time is far from realistic. Lighting replacement generally occurs based on obsolescence or on a facility-by-facility basis. This being the case, our theoretical payoff times are exactly that: theoretical. While they serve as a useful baseline regarding the benefits of lighting stock alteration, they may not entirely reflect real-life conditions. For future research, investigation of the dynamics within the realms of labor and lighting fixture replacement times would improve the accuracy of total cost and payoff timeframe estimates related to lighting changes at a municipal level.

<i>Lighting Option</i>	<i>Yearly Cost (\$)</i>	<i>Yearly GHG (Metric T)</i>	<i>Cost Savings (\$)</i>	<i>GHG Savings (Metric T)</i>	<i>Replace Costs (\$)</i>	<i>Payoff Time</i>
Current	15,575.28	123.37	N/A	N/A	N/A	N/A
Replace Above 3K	13,204.51	104.39	2370.77	18.98	3,212	1 Year, 4 Months
Replace All	11,991.74	94.9	3583.54	28.47	10,945	3 Years, 1 Month

Table 11: Financial and GHG Comparison Chart for Grand County. This table compares estimates for energy costs and GHG emission reductions based on two scenarios proposed for Grand County. In scenario 1, only exterior lighting presently with a CCT above 3000K would be replaced with low-temperature lighting. In the more ambitious scenario 2, all exterior lighting in the city would be replaced with low-pressure sodium and below-2700K LED lighting. Source: Adam Dalton

Owing to the fact that Grand County’s publicly-owned nighttime-lit exterior lighting fixtures are far fewer in number than Moab City (371 to 986), the following GHG and economic cost estimates are noticeably smaller in magnitude than those conducted for the city of Moab. In terms of economic costs, we projected the associated utility costs regarding the County’s current publicly-owned exterior lighting stands at \$15,575 annually. In parallel with the Moab City estimates, our team presented identical alternate proposed lighting scenarios (replacement of only lighting above 3K CCT and replacement of all lighting with low-pressure sodium and low-CCT LED lighting). By our calculations, if Grand County were to replace only lighting above 3000K CCT, they would be presented with a yearly utility bill related to exterior lighting of \$13,204—representing savings of \$2,370. Furthermore, if the County were to pursue the more ambitious alternative of uniformly replacing all lighting, we estimate they would see \$3,583 of yearly utility savings stemming from their hypothetical \$11,992 utility bill.

Branching into GHG calculations, we ascertained the County’s current lighting choices facilitate the release of 123 Metric Tons of GHG yearly. Matching trends previously seen in the Moab inventory GHG analyses, decisions to implement scenario number one (replacement of above 3000K CCT) and scenario two (replacement of all) result in GHG emissions reductions of 19 and 28 Metric Tons respectively. Finally, given the caveats previously mentioned regarding payoff time analyses, we found scenario number one to present a cost payoff window of one year and four months and scenario two to have a three year and one-month payoff window.

After conducting economic cost and GHG analyses, it can be said with a high degree of certainty that by simply altering their respective publicly-owned exterior lighting stocks to include dark-sky friendly bulbs and fixtures, both Moab City and Grand County would be triply benefited with darker skies, lowered utility bills, and lowered municipally-related greenhouse gas emissions.

Discussion

While conducting a comprehensive exterior lighting inventory requires careful planning and coordination, it can be a powerful tool for establishing a lighting baseline within a community. This baseline provides a starting point against which the effectiveness of lighting regulations can be measured and monitored, enabling public officials and administrators to understand how new lighting programs and designs are functioning.

The baseline created by our inventory provides city and county officials, planners, and staff with an extensive view of where their jurisdictional lighting presently stands. As both entities work to curb their lighting emissions, the inventory will help them identify areas of immediate need for dark sky-friendly lighting. They will be able to consider the different uses for their lighting stock and adapt new policies accordingly. They will also be able to estimate the impacts these new policies will have on the economic and environmental costs of their exterior lighting (see Dalton, 2018).

That the process of carrying out an inventory requires constant communication and coordination cannot be emphasized strongly enough. Over the course of our month-long inventory, our team interacted with many local residents in the streets, in parks, and around public buildings. People took a genuine interest in what we were doing and wanted to learn more about the project. Thankfully, we had been working closely with the local Moab Area Dark Skies Group, which had provided us with flyers we could distribute to interested parties about the dark sky initiative in the area. Our project also brought us into close contact with the city and county planning departments. The directors of these departments were able to secure access for our team to visit restricted areas for daytime and nighttime assessments, ensuring that a full inventory of all publicly-owned fixtures could be achieved. Without the guidance and support of these local stakeholders, we would not have been able to conduct our assessment.

Naturally, there are shortcomings associated with the inventory our

team carried out. Most obviously, it provides only a moment-in-time view of Moab and Grand County’s lighting, specifically for the timeframe between June 14 and July 14, 2017. Unless it is kept up to date as each local government entity maintains, replaces, or permanently shuts off different fixtures, it can only speak to the lighting in the Moab area for the specified 2017 timeframe. In the event the inventory is not kept up to date, future inventories may need to be conducted for comparison with the findings in this study.

Another shortcoming lies in the limited scope of the inventory. As it only accounts for publicly-owned exterior lighting, with some very specific exceptions, our assessment does not account for all of the lighting in the Moab area. In working with local officials, administrators, and the Moab Area Dark Skies Group, we collectively determined that the most effective place to start the assessment was by focusing on local government lighting infrastructure. This was largely based on the observation that inventorying private lighting can be invasive and requires coordination beyond the capability of our small group at the time. However, in order for the community to fully understand and account for its lighting stock, a complete inventory of all local lighting—perhaps similar to the one conducted by Luginbuhl et al. (2009)—would be beneficial.

As noted, the inventory also only accounts for exterior lighting. This was due to the interest locally to preserve and protect the darkness of the night sky. While following the recommendations in this study will certainly help curb the effects of poor exterior lighting, it should be noted

that because people spend the bulk of their time indoors, the city and county may consider conducting an assessment of their indoor lighting as well. Such an assessment could help local government agencies better understand the negative impacts poor interior lighting has on public health (American Medical Association, 2016).

In spite of these shortcomings, this exterior lighting assessment opens a door for local government entities in the Moab area to move forward with their dark skies initiative. It paves the way for the next steps to be taken—local officials and administrators now know where, in their publicly-owned infrastructure, their lighting falls short of compliance with the standards set by the IDA. By adding shields, removing lenses, changing lamp types, and retrofitting high-temperature lighting fixtures, can mitigate the harmful impacts of poor lighting. In this way, the inventory is operational. It can help local government entities find the best strategies to cut costs associated with energy use. It takes local GHG reduction goals and creates tangible opportunities to cut those emissions.

The inventory is also accessible. The whole database is available for use by Esri’s ArcGIS system as well as by Google Maps. By making it available on these two platforms, we hope that local officials, administrators, staff, and even residents will be able to access the lighting files and track improvements to the local lighting stock.

Furthermore, this lighting inventory was relatively inexpensive to conduct. Total costs for the tools (lighting passport spectrometer,

sky quality meter, and distance measurers), food for the two-member team, and transportation amounted to \$2,500 for the month-long period. This sum was the total we received in our Bonderman Field Station Young Scholars Grant. It should be noted that while the team was able to housesit for a local resident free of charge, housing costs may be another factor to consider in inventory costs. Additionally, the team was made up of two graduate students who were not being paid. With careful arrangements, costs can be minimized and an inventory can be carried out with minimal to no spending on the local government's part.

Thanks to efforts by the Moab Area Dark Skies Group, the inventory has received a degree of publicity locally.

News of our study and its findings appeared in local newspapers and magazines, including the Moab Times-Independent (Times-Independent, 2017), Moab Happenings Magazine (Dalton & Jellen, 2018), and Moab Area Real Estate Magazine (Talbott & Sullivan, 2017). After the inventory was complete, the Moab Area Dark Skies Group was able to reserve a time for our team to present our preliminary findings to city and county officials, administrators, and residents in a public forum setting. This allowed us to raise awareness of our project, to advance public appreciation for the local night sky, and to present feasible light design alternatives for the city and county for future implementation and enforcement through possible lighting ordinances.



Our team presenting the preliminary findings of our inventory to local officials, administrators, staff, and residents from Moab and Grand County on September 29, 2017. Our findings were well received and the Moab City Council voted to pursue our recommendations in October 2017. (Photo: Bettymaya Foott)

Conclusion

A product of the area's high elevation, low humidity, and sparse population density, the Colorado Plateau region encompassing the four corners sub-region of Arizona, Colorado, New Mexico, and Utah, boasts among the darkest night skies in the developed world (Duriscoe & Ament, 2015). Owing to recent trends of expanded interest in outdoor recreation opportunities, increased scientific research, and targeted tourism campaigns; as of 2018, dark-skies awareness and appreciation has begun to proliferate into the public consciousness and no longer solely occupies a sphere of niche interest within the astronomy and conservation communities (IDA, 2017).

Recognizing their unique position within the burgeoning dark-skies and related astrotourism movements, many municipal leaders along the Colorado Plateau have started to consider their incredible night skies as a critical cultural, economic, and environmental resource for their communities going forward (Foott, 2017). However, societal-level tourism trends which have fueled dark-skies interest ironically

threaten dark skies themselves. In the past decade, the Colorado Plateau has seen immense infrastructural, housing, and commercial growth; corresponding with the area's increase in tourism. Highlighting the aforementioned trend, Moab, UT is expected to double in population between 2020-2030 (Herndon, 2018). Faced with previously-unseen development and tourism pressures coupled with dark-skies interests; communities throughout the Colorado Plateau are searching for ways to facilitate growth in a way which respects night sky quality.

Accordingly, in 2016 the Moab [Utah] Dark Skies working group founded and formulated a plan to protect their community's picturesque dark skies through enactment of a comprehensive City lighting ordinance aimed at mitigating light pollution. Following, Grand County, UT's planner, Zacharia Levine, contacted the University of Utah's City and Metropolitan Planning Department (CMP) to enquire about the feasibility of our team's ability to complete a baseline lighting inventory of Moab, UT and the adjacent unincorporated Spanish

Valley, UT. Once completed, the baseline inventory would showcase a snapshot of existing lighting conditions and thusly serve as a tool for local decision makers to utilize when considering dark sky-friendly lighting ordinance adoption and implementation within the context of rapid projected future growth.

Fortunately, within the past five years, the process of undertaking baseline lighting inventories has become substantially more streamlined, accessible, and comprehensive. Whereas previous inventories were taken by hand utilizing paper/pencil spreadsheets followed by manual entry into a computer database; Prof. Bryan Boulanger's innovative mobile-based ArcGIS collection methodology allows everyone, from experts to citizen scientists, to collect multi-point data related to publicly-owned exterior lighting fixtures and upload in real-time to an online map. Such data may include: fixture height, bulb type, CCT, fixture purpose, fixture shielding, among many others. Once uploaded, anyone with authorized permission may view the baseline inventory maps, update them to reflect current conditions, create maps which focus on a specific lighting attribute (for example, CCT), and henceforth use them as a relevant decision-making tool regarding creation and implementation of informed dark-sky related policy actions.

After spending the months of June-July 2017 inventorying all publicly-owned exterior lighting fixtures within Moab City and unincorporated Grand County, UT, we found select notable patterns related to each entities' discrete

lighting makeup. In our assessment of 2,102 exterior lighting fixtures in the Moab area of southeastern Utah, tallied 1,739 fixtures which belonged to either the city of Moab or to Grand County, UT. Of the 985 belonging to Moab City, 696 were illuminated at night. Meanwhile, of the other 754 belonging to Grand County, 372 were illuminated at night. While 50% of Moab's illuminated fixtures were fully shielded, the other half were either partially shielded or unshielded, meaning that the city will need to take action to ensure its lighting fixtures are directing their light toward the ground. Additionally, the city will need to address the 56% of its illuminated fixtures with a CCT over 3,000 Kelvin. As the IDA is currently considering changing its CCT limit from 3,000K to 2,700K, the city may wish to consider retrofitting its lighting with lower color temperatures (such as low-pressure sodium lamps and warm-colored LEDs) if it wishes to be designated as a dark sky community by the IDA.

Grand County's fixtures also can be improved to be more dark sky-friendly. While 72% of its fixtures are fully shielded—leaving only 28% of its fixtures partially shielded or unshielded—approximately 57% of its illuminated fixtures emit light with a CCT over 3,000K. As with the city of Moab, Grand County may wish to consider retrofitting its fixtures with warmer-colored bulbs. We also recommend where publicly-owned lighting is already off at night or where fixtures have burnt out, the city and county carefully consider whether or not turning on or replacing such fixtures is necessary. While retrofits are relatively affordable, the best method for preserving the night

sky is to turn unnecessary lights off. Keeping unnecessary fixtures off at night saves more money and cuts lighting and GHG emissions much more drastically than replacement by energy-efficient fixtures.

Intuitively, as the population center of Grand County, Moab City had nearly three times as many exterior lighting fixtures as the County; a fact which likely stems from the City's high density of streetlights and governmental buildings. Aside from magnitude differences, the City and County serve as an intriguing natural experiment regarding the efficacy of lighting ordinance implementation in relation to affecting behavioral change. Whereas Grand County required full-cutoff light fixture shielding within their development codes before our baseline inventory began, Moab City lacked such regulations (Grand County, 2017). Fascinatingly, nearly $\frac{3}{4}$ of Grand County's public exterior light fixtures were fully shielded whereas slightly less than $\frac{1}{2}$ of Moab City's were; indicating the possible efficacy of municipal policy as an effective tool to achieve dark-sky related actions.

Branching out, once initial baseline inventory analyses and data collection were complete, at the request of Moab City and Grand County; our team conducted in-depth greenhouse gas (GHG) emissions and economic utility cost estimates regarding each municipality's public lighting stock. After establishing current baseline cost and GHG estimates, we developed two alternate lighting scenarios which conformed with the International Dark-Sky Association (IDA) dark-sky community best practices. As seen in the previous section, both alternate

scenarios established greater cost-efficiency and emissions reductions compared to either jurisdiction's current lighting stock. Amazingly, based on our team's findings, the Moab City Council voted to not only adopt a comprehensive lighting ordinance which complied with current IDA dark-sky community guidelines with respect to light fixture shielding, CCT, among others. Additionally, they decided to begin pursuit of an IDA dark-sky community designation; thereby cementing the City's status as a model leader in the growing dark-skies movement.

In considering future ordinances and a new lighting program for their jurisdictions, both city and county officials have many local examples of dark sky-friendly lighting to which they can turn for reference. These examples include the county library, Rim Village neighborhood, and Moab's recreation center. Each of these examples are distinguishable for their efforts to fully shield their exterior lighting fixtures and for their wide use of low-CCT lamps. These two design features ensure that nighttime lighting programs are deliberately addressing the functional needs of urban areas at night while also maintaining a harmony with the area's world-renowned night sky views. As an additional point of reference for local officials, administrators, and staff are the notable exterior lighting initiatives presently being undertaken by private entities in the area. While our team limited the scope of its study to publicly-owned lighting fixtures, through our own assessments, we were impressed by the exterior lighting programs of Moab Giants Dinosaur Museum, of

the bollards at the Fairfield Marriott Hotel, of the Village Market grocery store, and of a local Zion's Bank branch. By drawing on the findings of our inventory and by looking to local examples of dark sky-friendly lighting, we are confident that local residents and officials in Moab and Grand County will be able to curb their lighting emissions to ensure that the Spanish Valley maintains its pristine night sky views.

From an academic perspective, one of the main goals of our research is to contribute valuable methodological, practical, and result-based insights to the nascent yet quickly-developing field of dark sky studies. Undeniably, our papers expound on many relevant developing dark sky concepts and practices within the contemporary moment; nevertheless, there are many questions which we were unable to fully explore as a result of funding, scope, and time constraints. Therefore, we have identified the following sub-topics as worthy of further scrutiny. Leading off, future researchers should fully investigate different variations of dark-skies lighting policies in order to determine the efficacy of specific policy tools in facilitating specific dark sky-related actions. Since little is currently known about the aforementioned subject, current policymakers have minimal knowledge of which dark-sky tools are especially effective to enact within their specific contexts.

Secondarily, as light pollution can travel over two hundred miles if unimpeded, the possibility of establishing and studying the efficacy and dynamics of dark-skies coordination between regions is a vital next step within the field of dark

sky studies (Petersen, 2017). While the Idaho Dark Sky Reserve currently embodies principles of regional dark sky coordination, no other regional dark sky efforts currently exist within the United States as of Spring 2018. If the dark-skies movement continues to gain momentum, regional-scale efforts are the logical next step owing to the wide-reaching nature of light pollution. Another important future dark-sky consideration is further exploration of the link between private, public, and academic entities regarding action and preservation. While most current and past dark skies efforts have linked municipalities and academics (usually through the lens of astronomy); in the coming years it will be of great importance to understand and encourage other public and private participation in the dark skies realm. As the number and diversity of persons involved in dark skies work inevitably rises, academics should aim to understand their working dynamics and encourage participation within dark skies. By delving into the intricacies of the aforementioned spaces, academic studies would ideally help create more resilient and sustainable dark-sky partnerships which also respect the needs and wishes of traditionally-marginalized communities.

Penultimately, it is imperative for academic institutions to establish more interdisciplinary collaborations related to dark skies. While city planning, biology, and astronomy remain at the forefront of dark skies research, additional collaborations between other disciplines such as: economics, policy studies, law, visual arts, among others will undoubtedly help to facilitate sustainable, multi-

faceted, and innovative solutions to various dark sky-related issues. Finally, owing to the relatively-recent and previously-underground nature of the modern dark-skies movement; few funding opportunities currently exist related specifically to dark sky-specific work. In forthcoming years, various non-profits and

other granting organizations should consider the numerous economic, ecological, among other benefits emanating from dark-sky preservation efforts and thusly fund grants and other various mechanisms to support the dark-skies cause.

Appendices

Appendix A: Inventory Form

To the right is a copy of the form that was digitally adapted for use within ESRI's Collector application. Using this form ensured that all fixtures were measured for the same components. Where the fixtures were off at night, the team left the "Nighttime Visit" portion of the digital form blank.

The team would like to thank Bryan Boulanger (Ohio Northern University) for creating this form and adapting it for digital use.

DAYTIME VISIT	
Visit Date	Fixture Power
Fixture Height (ft)	<input type="checkbox"/> Solar
Fixture Lighting Purpose	<input type="checkbox"/> Utility
<input type="checkbox"/> Area	<input type="checkbox"/> Other
<input type="checkbox"/> Entrance/Egress	Fixture Adaptive Controls
<input type="checkbox"/> Pathway	<input type="checkbox"/> MotionSensor
<input type="checkbox"/> Parking	<input type="checkbox"/> None
<input type="checkbox"/> Roadway	<input type="checkbox"/> Photocell
<input type="checkbox"/> Sign	<input type="checkbox"/> Switch
<input type="checkbox"/> Stairway	<input type="checkbox"/> TimerSwitch
<input type="checkbox"/> Other	<input type="checkbox"/> Other
Fixture Type	Lamp Type
<input type="checkbox"/> Barn	<input type="checkbox"/> CFL
<input type="checkbox"/> Bollard	<input type="checkbox"/> EmptySocket
<input type="checkbox"/> CeilingMount	<input type="checkbox"/> FluorescentTube
<input type="checkbox"/> Flood	<input type="checkbox"/> Halogen
<input type="checkbox"/> HangingLight	<input type="checkbox"/> HPS
<input type="checkbox"/> LampPost	<input type="checkbox"/> Incandescent
<input type="checkbox"/> PhoneBooth	<input type="checkbox"/> Induction
<input type="checkbox"/> Recessed	<input type="checkbox"/> LED
<input type="checkbox"/> Spotlight	<input type="checkbox"/> LPS
<input type="checkbox"/> TinHat	<input type="checkbox"/> MercuryVapor
<input type="checkbox"/> Tube	<input type="checkbox"/> MetalHalide
<input type="checkbox"/> VendingMachine	<input type="checkbox"/> Other
<input type="checkbox"/> WallPack	Shielding
<input type="checkbox"/> WallSconce	<input type="checkbox"/> FullyShieldedEve
<input type="checkbox"/> Other	<input type="checkbox"/> FullyShieldedFixture
Number of Fixtures	<input type="checkbox"/> FullyShieldedLampLens
Lamps per Fixture	<input type="checkbox"/> PartiallyShieldedEve
Historic Fixture?	<input type="checkbox"/> PartiallyShieldedFixture
<input type="checkbox"/> Yes	<input type="checkbox"/> PartiallyShieldedLampLens
<input type="checkbox"/> No	<input type="checkbox"/> Unshielded

NIGHTTIME VISIT
Visit Date
Passport Date Filename
CCT (Correlated Color Temperature)
Illuminance (@ y=0, lux)
Footcandle (@ y=0, fc)

ADDITIONAL NOTES
Notes:

MITIGATION
Mitigation Required
<input type="checkbox"/> Yes
<input type="checkbox"/> No
Mitigation Date

Appendix B: Additional Findings by Ownership Profile

City of Moab Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose								
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Roadway	Sign	Other	Total
At ground level	8	-	-	-	-	-	-	8
0.5-9.9	10	15	6	-	11	4	4	50
10-15	34	53	49	19	14	1	1	171
15.1-20	13	-	-	-	56	1	-	70
20.1-25	50	11	1	29	166	-	-	257
25.1-30	11	-	2	-	50	-	-	63
30.1-34.9	-	-	-	3	71	-	-	74
35+	2	-	-	-	1	-	-	3
Total	128	79	58	51	369	6	5	696

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
15	810	56	-	34	70

City of Moab Assessment, continued

Number of Fixtures on at Night by Adaptive Controls and CCT						
CCT (Kelvin)	Motion Sensor	Photocell	Switch	Automatic Timer	Unknown	Total
<2700K	-	264	2	-	-	266
2701-3000K	2	38	2	-	-	42
3001-4000K	1	225	-	-	-	226
4000K +	-	162	-	-	-	162
Total	3	689	4	-	-	696

Number of Fixtures on at Night by Lamp Type and Shielding						
Lamp Type	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Eve	Partially Shielded Fixture	Unshielded	Total
CFL	6	117	9	7	1	140
Fluorescent Tube	-	1	-	-	-	1
Halogen	-	-	1	-	-	1
HPS	2	128	2	118	1	251
Incandescent	-	-	-	2	-	2
LED	2	10	-	13	8	32
LPS	-	-	-	-	3	3
Metal Halide	-	83	-	180	2	266
Total	10	339	12	320	15	696

Number of Fixtures on at Night by Shielding and CCT						
CCT (Kelvin)	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Eve	Partially Shielded Fixture	Unshielded	Total
<2700K	3	135	3	119	6	266
2701-3000K	2	17	8	15	-	42
3001-4000K	5	103	1	113	4	226
4000K +	-	84	-	73	5	162
Total	10	339	12	320	15	696

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	11	27	101	1	140
Fluorescent Tube	-	-	1	-	1
Halogen	-	-	1	-	1
HPS	251	-	-	-	251
Incandescent	-	2	-	-	2
LED	1	12	6	13	32
LPS	3	-	-	-	3
Metal Halide	-	1	117	148	266
Total	266	42	226	162	696

Grand County Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose								
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Roadway	Sign	Other	Total
At ground level	-	-	-	-	-	2	2	4
0.5-9.9	6	24	12	1	25	-	-	68
10-15	52	62	8	4	1	-	1	128
15.1-20	24	17	-	-	27	-	-	68
20.1-25	4	-	5	4	25	-	-	38
25.1-30	20	-	-	3	21	-	-	44
30.1-34.9	-	-	-	5	8	-	-	13
35+	2	-	-	6	1	-	-	9
Total	108	103	25	23	108	2	3	372

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
21	422	124	77	27	83

Number of Fixtures on at Night by Adaptive Controls and CCT						
CCT (Kelvin)	Photocell	Timer Switch	Switch	Automatic Timer	Unknown	Total
<2700K	154	6	-	-	-	160
2701-3000K	1	-	-	-	-	1
3001-4000K	42	10	-	-	-	52
4000K +	118	8	5	27	1	159
Total	315	24	5	27	1	372

Grand County Assessment, continued

Number of Fixtures on at Night by Lamp Type and Shielding					
Lamp Type	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Fixture	Unshielded	Total
CFL	7	54	12	-	73
Fluorescent Tube	2	-	-	-	2
HPS	-	71	43	-	114
LED	-	114	26	10	150
LPS	-	2	-	-	2
Metal Halide	-	19	10	1	30
Other	-	-	-	1	1
Total	9	260	91	12	372

Number of Fixtures on at Night by Shielding and CCT					
CCT (Kelvin)	Fully Shielded Eve	Fully Shielded Fixture	Partially Shielded Fixture	Unshielded	Total
<2700K	7	102	51	-	160
2701-3000K	-	1	-	-	1
3001-4000K	2	36	11	3	52
4000K +	-	121	29	9	159
Total	9	260	91	12	372

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	48	1	24	-	73
Fluorescent Tube	-	-	2	-	2
HPS	110	-	-	4	114
LED	-	-	5	145	150
LPS	2	-	-	-	2
Metal Halide	-	-	20	10	30
Other	-	-	1	-	1
Total	160	1	52	159	372

Arches National Park Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose						
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Sign	Total
At ground level	-	-	-	-	-	-
0.5-9.9	-	-	5	-	6	11
10-15	30	1	-	-	-	31
15.1-20	-	-	-	-	-	-
20.1-25	-	-	-	1	-	1
25.1-30	-	-	-	-	-	-
30.1-34.9	-	-	-	-	-	-
35+	-	-	-	-	-	-
Total	30	1	5	1	6	43

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
3	64	45	-	-	-

Number of Fixtures on at Night by Adaptive Controls and CCT				
CCT (Kelvin)	Motion Sensor	Photocell	Switch	Total
<2700K	-	5	-	5
2701-3000K	-	23	-	23
3001-4000K	-	10	2	12
4000K +	-	1	2	3
Total	-	39	4	43

Arches National Park Assessment, continued

Number of Fixtures on at Night by Lamp Type and Shielding						
Lamp Type	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
CFL	-	6	-	-	-	6
Fluorescent Tube	2	4	-	-	-	6
Halogen	-	-	-	-	-	-
HPS	-	-	-	-	-	-
Incandescent	-	5	-	-	-	5
LED	22	2	-	1	-	25
LPS	-	-	-	-	-	-
Metal Halide	-	1	-	-	-	1
Total	24	18	-	1	-	43

Number of Fixtures on at Night by Shielding and CCT						
CCT (Kelvin)	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
<2700K	-	5	-	-	-	5
2701-3000K	22	-	-	1	-	23
3001-4000K	2	10	-	-	-	12
4000K +	-	3	-	-	-	3
Total	24	18	-	1	-	43

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	-	-	6	-	6
Fluorescent Tube	-	-	6	-	6
Halogen	-	-	-	-	-
HPS	-	-	-	-	-
Incandescent	5	-	-	-	5
LED	-	23	-	2	25
LPS	-	-	-	-	-
Metal Halide	-	-	-	1	1
Total	5	23	12	3	43

Utah Department of Transportation (UDOT) Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose								
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Roadway	Sign	Other	Total
At ground level	-	-	-	-	-	-	-	-
0.5-9.9	-	-	-	-	-	-	-	-
10-15	-	-	-	-	-	-	-	-
15.1-20	-	-	-	-	-	-	-	-
20.1-25	-	-	-	2	6	-	-	8
25.1-30	-	-	-	-	81	-	-	81
30.1-34.9	-	-	-	-	-	-	-	-
35+	-	-	-	-	34	-	-	34
Total	-	-	-	2	121	-	-	123

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
-	137	-	-	-	-

Number of Fixtures on at Night by Adaptive Controls and CCT						
CCT (Kelvin)	Motion Sensor	Photocell	Switch	Automatic Timer	Unknown	Total
<2700K	-	82	-	-	-	82
2701-3000K	-	-	-	-	-	-
3001-4000K	-	40	-	-	-	40
4000K +	-	1	-	-	-	1
Total	-	123	-	-	-	123

UDOT Assessment, continued

Number of Fixtures on at Night by Lamp Type and Shielding						
Lamp Type	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
CFL	-	-	-	-	-	-
Fluorescent Tube	-	-	-	-	-	-
Halogen	-	-	-	-	-	-
HPS	-	38	-	44	-	82
Incandescent	-	-	-	-	-	-
LED	-	40	-	-	-	40
LPS	-	-	-	-	-	-
Metal Halide	-	1	-	-	-	1
Total	-	79	-	44	-	123

Number of Fixtures on at Night by Shielding and CCT						
CCT (Kelvin)	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
<2700K	-	38	-	44	-	82
2701-3000K	-	-	-	-	-	-
3001-4000K	-	40	-	-	-	40
4000K +	-	1	-	-	-	1
Total	-	79	-	44	-	123

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	-	-	-	-	-
Fluorescent Tube	-	-	-	-	-
Halogen	-	-	-	-	-
HPS	82	-	-	-	82
Incandescent	-	-	-	-	-
LED	-	-	40	-	40
LPS	-	-	-	-	-
Metal Halide	-	-	-	1	1
Total	82	-	40	1	123

U.S. Postal Service Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose								
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Roadway	Sign	Other	Total
At ground level	-	-	-	-	-	-	-	-
0.5-9.9	-	-	-	-	-	-	-	-
10-15	2	5	1	-	-	-	-	8
15.1-20	-	-	-	-	-	-	-	-
20.1-25	-	-	-	-	-	-	-	-
25.1-30	-	-	-	-	-	-	-	-
30.1-34.9	-	-	-	-	-	-	-	-
35+	-	-	-	-	-	-	-	-
Total	2	5	1	-	-	-	-	8

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
1	13	6	-	-	-

Number of Fixtures on at Night by Adaptive Controls and CCT						
CCT (Kelvin)	Motion Sensor	Photocell	Switch	Automatic Timer	Unknown	Total
<2700K	-	3	-	-	-	3
2701-3000K	-	4	-	-	-	4
3001-4000K	-	1	-	-	-	1
4000K +	-	-	-	-	-	-
Total	-	8	-	-	-	8

U.S. Postal Service Assessment, continued

Number of Fixtures on at Night by Lamp Type and Shielding						
Lamp Type	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
CFL	-	-	-	-	-	-
Fluorescent Tube	-	5	-	-	-	5
Halogen	-	-	-	-	-	-
HPS	-	2	-	1	-	3
Incandescent	-	-	-	-	-	-
LED	-	-	-	-	-	-
LPS	-	-	-	-	-	-
Metal Halide	-	-	-	-	-	-
Total	-	7	-	1	-	8

Number of Fixtures on at Night by Shielding and CCT						
CCT (Kelvin)	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
<2700K	2	-	-	1	-	3
2701-3000K	-	4	-	-	-	4
3001-4000K	-	1	-	-	-	1
4000K +	-	-	-	-	-	-
Total	2	5	-	1	-	8

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	-	-	-	-	-
Fluorescent Tube	-	4	1	-	5
Halogen	-	-	-	-	-
HPS	3	-	-	-	3
Incandescent	-	-	-	-	-
LED	-	-	-	-	-
LPS	-	-	-	-	-
Metal Halide	-	-	-	-	-
Total	3	4	1	-	8

University of Utah Field Station at Rio Mesa Assessment

Number of Fixtures on at Night by Fixture Height and Fixture Purpose								
Height (feet)	Area	Entrance/ Egress	Pathway	Parking	Roadway	Sign	Other	Total
At ground level	-	-	-	-	-	-	-	-
0.5-9.9	4	3	-	-	-	-	-	7
10-15	-	-	-	-	-	-	-	-
15.1-20	-	-	-	-	-	-	-	-
20.1-25	-	-	-	-	-	-	-	-
25.1-30	-	-	-	-	-	-	-	-
30.1-34.9	-	-	-	-	-	-	-	-
35+	-	-	-	-	-	-	-	-
Total	4	3	-	-	-	-	-	7

Adaptive Controls (All Fixtures)					
Motion Sensor	Photocell	Switch	Timer Switch	Automatic Timer	Unknown
-	-	9	-	-	-

Number of Fixtures on at Night by Adaptive Controls and CCT						
CCT (Kelvin)	Motion Sensor	Photocell	Switch	Automatic Timer	Unknown	Total
<2700K	-	-	3	-	-	3
2701-3000K	-	-	1	-	-	1
3001-4000K	-	-	-	-	-	-
4000K +	-	-	3	-	-	3
Total	-	-	7	-	-	7

U of U Field Station at Rio Mesa Assessment, continued

Number of Fixtures on at Night by Lamp Type and Shielding						
Lamp Type	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
CFL	-	-	1	1	-	2
Fluorescent Tube	-	-	-	-	-	-
Halogen	-	-	-	-	-	-
HPS	-	-	-	-	-	-
Incandescent	-	-	-	-	-	-
LED	4	-	-	1	-	5
LPS	-	-	-	-	-	-
Metal Halide	-	-	-	-	-	-
Total	4	-	1	2	-	7

Number of Fixtures on at Night by Shielding and CCT						
CCT (Kelvin)	Fully Shielded Eye	Fully Shielded Fixture	Partially Shielded Eye	Partially Shielded Fixture	Unshielded	Total
<2700K	1	-	1	1	-	3
2701-3000K	1	-	-	-	-	1
3001-4000K	-	-	-	-	-	-
4000K +	2	-	-	1	-	3
Total	4	-	1	2	-	7

Number of Fixtures on at Night by Lamp Type and CCT					
	<2700K	2701-3000K	3001-4000K	4000K +	Total
CFL	2	-	-	-	2
Fluorescent Tube	-	-	-	-	-
Halogen	-	-	-	-	-
HPS	-	-	-	-	-
Incandescent	-	-	-	-	-
LED	1	1	-	3	5
LPS	-	-	-	-	-
Metal Halide	-	-	-	-	-
Total	3	1	-	3	7

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