# KEEPING THE PARK DARK

FACILITATING DARK SKY STATUS IN GLACIER NATIONAL PARK

EVAN DAPSIS | RYANN DIONNE | BRADY GARDNER | CHRISTIANA KEARNS | CARTER MELANSON

# Keeping the Park Dark

## Facilitating Dark Sky Status in Glacier National Park

***Glacier Dark Sky - Glacier National Park, Montana Project Center - IQP***

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# ABSTRACT



Light pollution threatens the exceptional dark night sky above Glacier National Park (GNP), endangering its International Dark Sky Park (IDSP) status. We assisted GNP in maintaining IDSP status by conducting a comprehensive ArcGIS lighting inventory of 1,516 lights. We found the Park had 64% dark sky compliant lighting. We also created a range of dark sky outreach material to increase enthusiasm in keeping the Park dark, including a citizen science program for employees and a pamphlet for electricians.

# ACKNOWLEDGEMENTS



We are so grateful to all of the people that have helped us through this project and our time in Glacier National Park. All of the park staff here in Glacier National park have been nothing but helpful, informative, and supportive.

We would like to thank **Sharolyn Anderson** for her dedicated support with the ArcGIS inventory system.

We would like to thank our sponsors **Mark Biel** and **Ed Eberhardy** for their committed support and encouragement throughout this entire project.

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Lastly, we would like to thank **Matthew Catuccio**, **James Kiefer,** and **Jonathan Wessler** for their stunning photographs of the night sky in the Park and allowing us to use them throughout our project.

# AUTHORSHIP



All members have fully contributed to the writing portions of this report. Even if a section was originally written by an individual, it was torn apart, rewritten, and edited by the entire team. We want to note certain achievements and contributions to our overall project, including **Evan Dapsis'** initial creation of the ArcGIS manual and "citizen science" staff program, **Ryann Dionne's** keen editing eye and great versatility across the many branches of our project, **Brady Gardner's** contribution to the initial creation and ideas for the StoryMap, **Christiana Kearns'** expertise in editing the ArcGIS dashboard and correcting GIS problems, and **Carter Melanson's** incredible design sense and dedication as the primary developer in the design of our report and deliverables.

# MEET THE TEAM



My name is **Evan Dapsis**, I am a junior studying Biochemistry. I grew up in Connecticut, however recently moved to Maine in the past few years. My time at Glacier National Park has been an absolutely amazing experience. From going on beautiful hikes, to seeing the Aurora Borealis and Milky Way, it has certainly been life changing. It is incredibly satisfying and motivating to see what my work is protecting. I am now a part of the dark sky effort, and will continue to be.

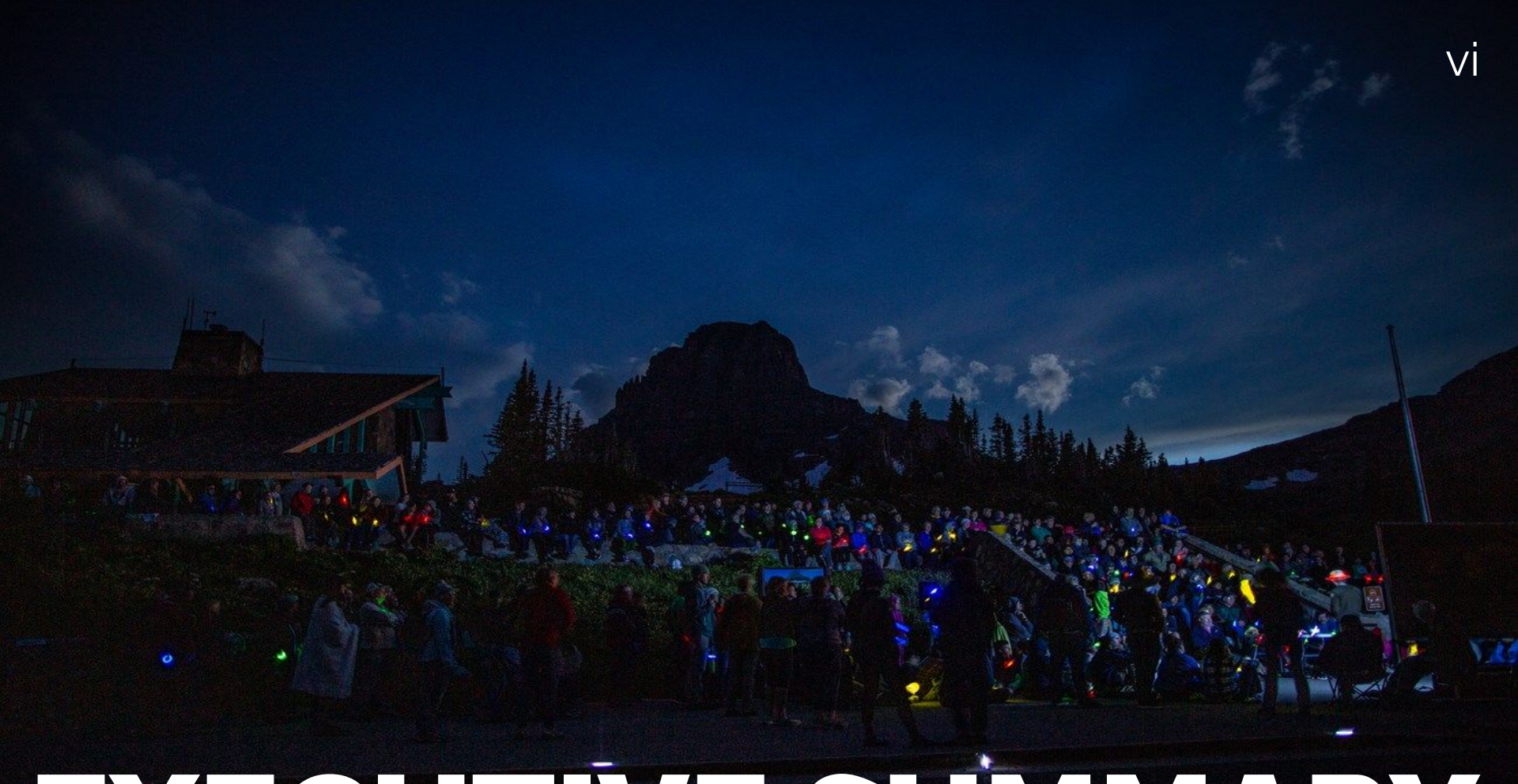
Hi! My name is **Brady Gardner**, and I am from Hudson, Massachusetts. I am majoring in Biomedical Engineering with a minor in Mechanical Engineering. I have had an amazing time working at Glacier National Park. It was a great experience getting to see everything Glacier National Park has to offer, especially the dark sky. Experiencing the Milky Way and Northern Lights for the first time through this project has motivated me to continue to be a part of the dark sky effort.

Hello! My name is **Ryann Dionne**, and I am a Civil Engineering student from Hudson, New Hampshire. I'm thankful for all the time I've been able to spend exploring this amazing national park and pushing myself to reach new limits. I have loved working in the Park and meeting so many kind and friendly park staff. This project and my experiences in Glacier have helped me realize how important the dark sky is to me personally, and I will cherish my newfound knowledge and appreciation for the dark sky at home.

# MEET THE TEAM

I'm **Christiana Kearns!** I am a Mechanical Engineering student from Marlborough, Massachusetts. I found this project so interesting to work on from the overall dark sky movement to the Park's efforts. I am excited to spread awareness of dark sky protection back home, and I will forever appreciate the time I've had to experience this beautiful region. The coolest part to me was the range and amount of wildlife inhabiting the area. Witnessing such natural beauty first hand is the ultimate inspiration for its preservation.

Hi! I'm **Carter Melanson**, and I am working towards a B.S. in Mechanical Engineering with a Manufacturing Engineering minor. I grew up in Manchester, New Hampshire. This is my second time in Glacier, and I know it won't be my last! I've seen my fair share of dark skies, but none have compared to the beautiful night skies I have been able to see through this project. Researching the dark sky effort has opened my eyes to the need to reduce light pollution so everyone can see the Milky Way. And of course, all my light fixtures will definitely be dark sky compliant from now on!



# EXECUTIVE SUMMARY

The unpolluted dark sky is a crucial cultural, social, and environmental asset (DarkSky International, n.d.c). It has become an increasingly rare natural resource due to light pollution (Falchi & Bará, 2023). Light pollution, defined as the "brightening of the night sky" from artificial lighting, diminishes the visibility of the stars and other celestial objects (National Geographic Society, 2022). Approximately 80% of Americans cannot see the Milky Way galaxy from where they live (Weber, 2021). Negative effects of light pollution include health disorders in humans and the disruption of wildlife's natural behaviors such as foraging, migration, reproduction, and communication (Longcore & Rich, 2004). National parks have become safe havens from the threat of light pollution, protecting expanses of wilderness and the darkness of night skies.

## The International Dark Sky Park Program

Glacier National Park has been recognized as an International Dark Sky Park (IDSP) for its exceptional dark night sky. DarkSky International coordinates the IDSP program. This organization is the world's authority on reducing light pollution by decreasing unnecessary artificial lighting, implementing dark sky-friendly lighting fixtures, and promoting the importance of the dark sky (DarkSky International, 2023).

To become an IDSP, Glacier National Park submitted an application to DarkSky International, demonstrating fulfillment of the three core requirements: dark night skies, efforts in dark sky compliant outdoor lighting, and educational programs on the night sky (National Park Service, 2022). IDSPs must then report annually on the progress of these requirements. Glacier National Park's application was accepted in 2017, and the Park received full certification as an International Dark Sky Park in 2021 (Biel, 2021).

DarkSky International logo.


International Dark Sky Park seal.

## The Problem

Since recognition as an IDSP, Glacier National Park has utilized a lighting inventory system consisting of multiple Microsoft Excel spreadsheets. Previous inventory gatherers had inconsistent methods and missed lighting fixtures. Also, the spreadsheets proved too disorderly for the large amounts of data required for IDSP certification, compromising the accuracy of the compliance percentage (E. Eberhardy, personal communication, April 19 2023). Our project sponsors, Mark Biel (Natural Resources Program Manager) and Ed Eberhardy (Physical Science Technician), along with Dr. Sharolyn Anderson (Physical Scientist in the Natural Sounds and Night Skies Division of the NPS), identified a need for a more standardized and user-friendly lighting inventory system. They also outlined an opportunity for more dark sky outreach material for park staff, especially for electricians and facilities staff whose work directly affects the dark sky.

Our project goal was to assist Glacier National Park in maintaining International Dark Sky Park status by implementing a standardized lighting inventory system and developing employee outreach material on Glacier National Park's dark sky. We divided this goal into three objectives with corresponding methods.

**GOAL**

Assist Glacier National Park in **maintaining** International Dark Sky Park Status by **implementing** a standardized lighting inventory system and **developing** employee outreach materials on Glacier National Park's dark sky

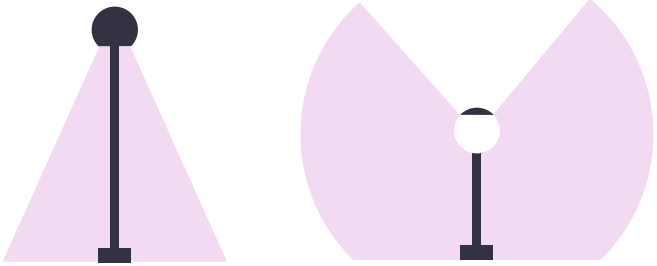
| OBJECTIVE 1 | OBJECTIVE 2 | OBJECTIVE 3 |
|---|---|---|
| **EXPLORE IDSP STATUS REQUIREMENTS** | **IMPLEMENT ArcGIS LIGHTING INVENTORY SYSTEM** | **DEVELOP DARK SKY STAFF OUTREACH MATERIALS** |
| ★ Thoroughly research DarkSky International compliance | ★ Establish ArcGIS system for Glacier National Park | ★ Analyze current outreach |
| ★ Perform sky quality measurements | ★ Populate and collect lighting inventory data | ★ Interview staff about dark sky knowledge |
| ★ Explore compliant lighting qualities | ★ Create GIS user manual | ★ Design citizen science and awareness material for staff |

## Explore Requirements for IDSP Status

We reviewed GNP's IDSP application and annual reports as well as DarkSky International's IDSP program guidelines. We studied DarkSky's webpage to determine the components of a compliant light fixture including the shielding status, correlated color temperature (CCT), and task (DarkSky International, n.d.a).

## Shielding

A fully-shielded fixture prevents light from escaping to the sides or above.



A properly shielded fixture (left) directing light strictly downwards. An improperly shielded fixture (right) that emits light upwards.

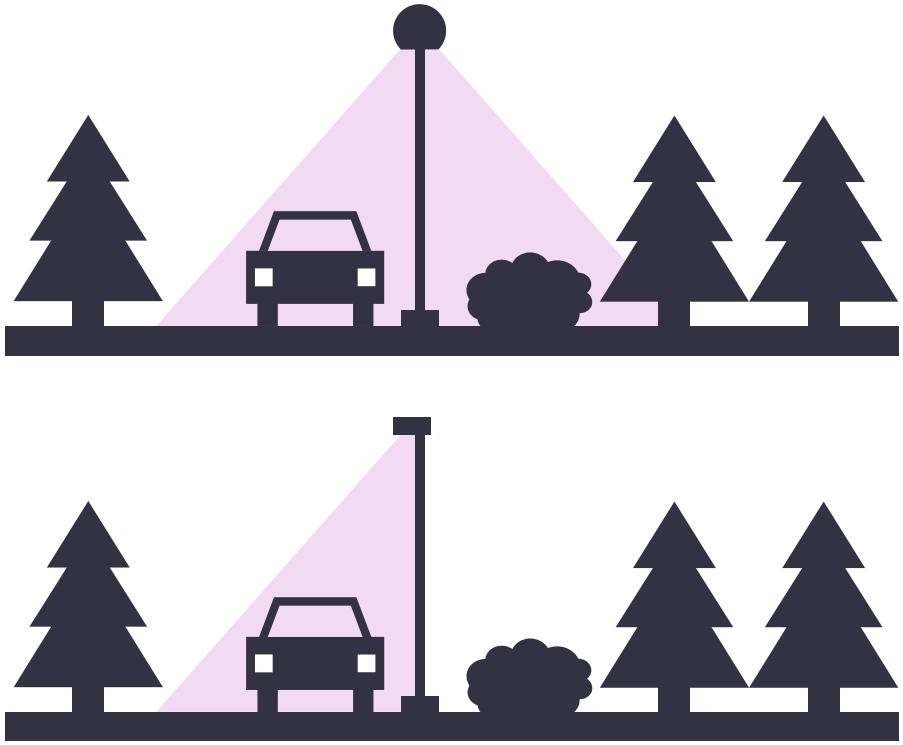
## Correlated Color Temperature (CCT)

DarkSky compliant bulbs have a CCT of less than 3,000 Kelvin.


Range of CCT values with their corresponding emitted colors. Compliant lights emit warm colored light ranging from amber to soft yellow.

## Task

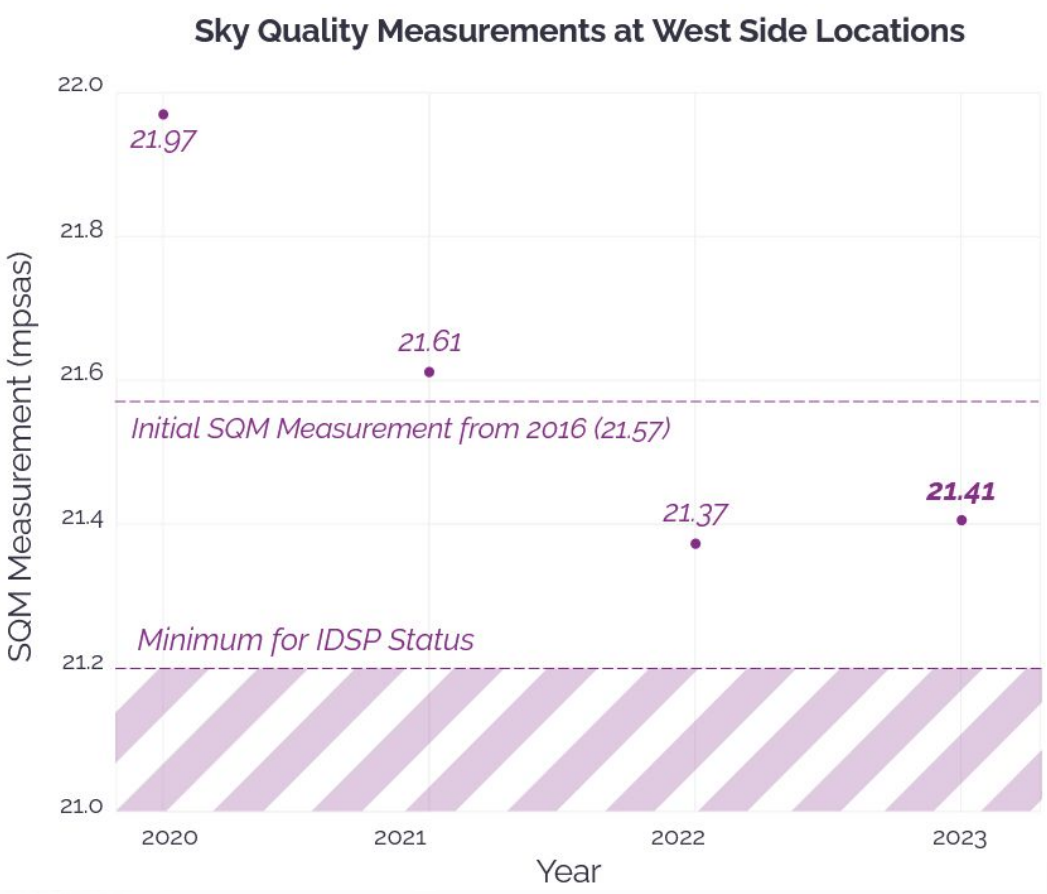
A DarkSky compliant light is on task, meaning it has a necessary purpose (such as illuminating roadways, parking areas, egresses, or pathways), and only illuminates the area needed to fulfill this task.



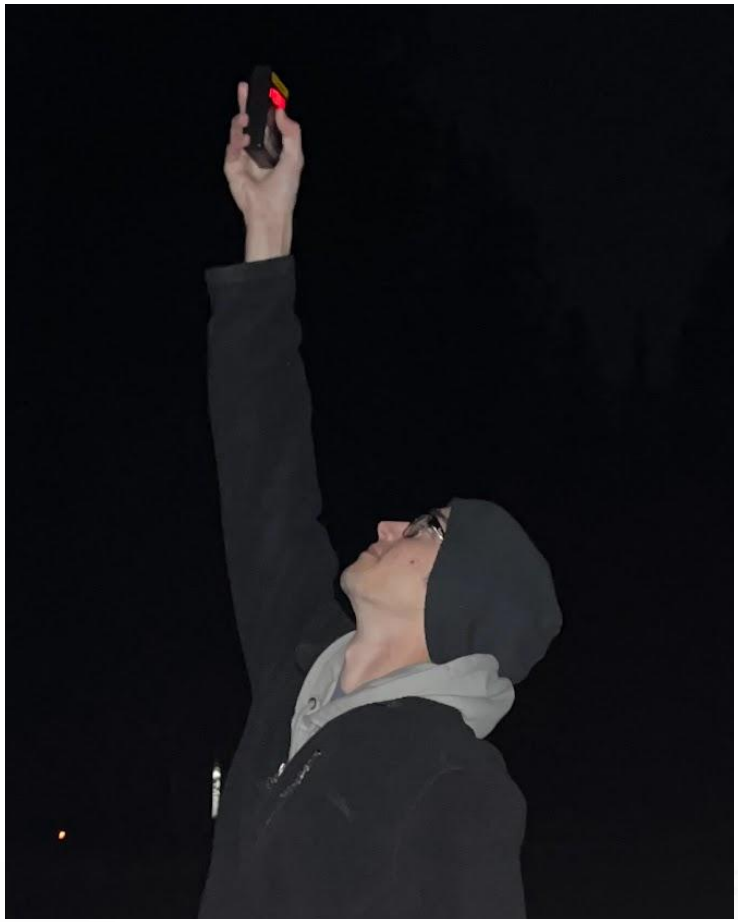
An off task light fixture (top) due to its illumination of the forest area, when its task is to illuminate the roadway. A retrofitted on-task light (bottom) that directs light only on its task area, the roadway, making it compliant.

## Sky Quality Measurements

We took the 2023 sky quality measurements on the west side of the Park on the night of a new moon with minimal cloud coverage. We used a Sky Quality Meter with lens (SQM-L), which measures sky darkness. We found that the west side of Glacier National Park darkened by 3.6% compared to the previous year. This could be due to lighting retrofits conducted within the past year.




Average reported sky quality measurements of the west side SQM locations in Glacier National Park from 2020 to 2023. The Park submitted their IDSP application in 2016 (Biel, 2022).



## Implement ArcGIS Lighting Inventory

Other national parks face similar challenges to Glacier National Park regarding inadequate lighting inventory systems. This led the National Park Service (NPS) to seek a standardized solution. The Natural Sounds and Night Skies Division of the NPS identified the need for parks to perform new lighting inventories in ArcGIS, a Geographic Information System (GIS) software, so they developed a standardized lighting inventory system utilizing this software. We implemented this system in Glacier National Park.

GIS software overlays layers of geospatial information. These layers can contain information such as terrain, buildings, and streets, as long as there are GPS coordinates attached to the data. This system provides the NPS with a highly organized lighting inventory for each park that can be easily analyzed and shared.

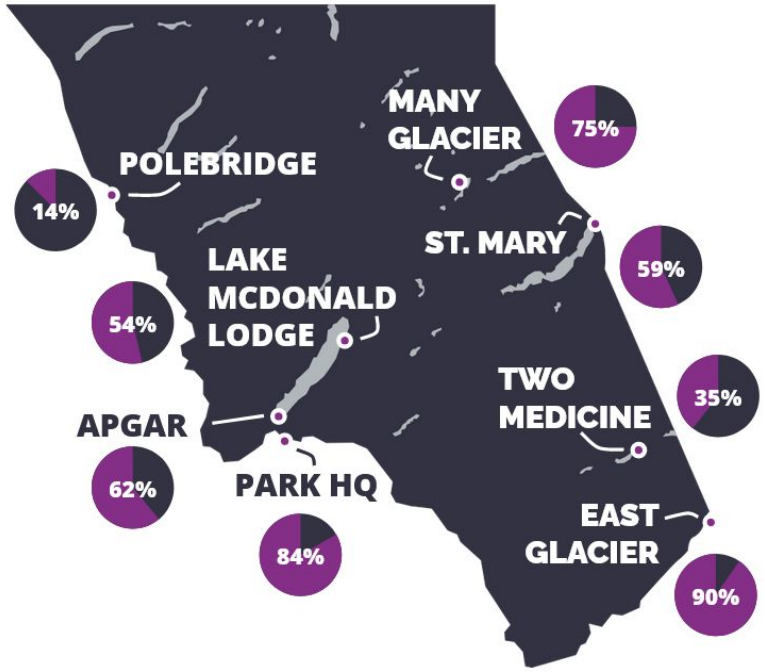

Dashboard screen and filter tab displaying the Headquarters area. Total number of luminaires, or light fixtures, on screen, dark sky compliance percentage, and percentage of fully shielded lights shown. The “No Shielding” option is activated, showing only lights with no shielding.

## Inventory and Analysis

We addressed concerns of inaccurate lighting inventory data by taking a new inventory through the NPS ArcGIS system. Our project logged 1,516 light fixtures in total, which was approximately 94% of the total light fixtures in Glacier National Park. Previously, different groups of people inventoried each location, leading to inconsistency in the attributes that were logged. To prevent this, we reviewed each data point in the inventory and analyzed the final data using the ArcGIS dashboard.

Using different functions in the dashboard, a user can filter and analyze lighting data by specific attribute. We configured the ArcGIS dashboard to determine compliance by calculating the percentage of lights that were fully shielded and had a CCT of less than 3,000 Kelvin. A separate percentage reflecting only light fixtures labeled as fully-shielded is shown below the compliance.

Logging light fixture data at St. Mary campground in Glacier National Park. Photo by Christiana Kearns.




Results of WPI student lighting inventory showing compliance percentages at major locations in Glacier National Park.

We found that, as of October 2023, Glacier National Park is 64% dark sky compliant. This is a 9.5% decrease from the previously calculated percentage in 2022 and does not meet the anticipated 90% compliance by the end of 2023 (Biel, 2022). This percentage discrepancy could be due to missed light fixtures on the last inventory. In some areas, we inventoried a greater number of light fixtures than the previous inventory. This likely led to more recorded non-compliant fixtures, lowering the compliance percentage. Also, inconsistencies in the initial inventory performed for the IDSP application may have led to an inflated compliance percentage.

## Staff Outreach Material

One of our key objectives was to create dark sky outreach material for Glacier National Park staff. We conducted interviews with park staff to determine knowledge and interest in Glacier National Park's dark sky efforts. We gained valuable insight into staff interest in the dark sky and what the dark sky means to them.

We deduced that a combination of digital and physical outreach material would be necessary to reach as many staff members as possible. Therefore, we created a "Defend the Dark" pamphlet for electricians and facilities workers, "The Astronomical Allure of Glacier National Park" poster promoting Glacier National Park's Astronomy Program, "Nightfall in Glacier" StoryMap for general staff to learn more about the dark sky, and a "Dark Sky Watch" staff "citizen science" program to involve staff in SQM measurements.

Discussing outreach material with Ed Eberhardy, Physical Science Technician and project co-sponsor. Photo by Ryann Dionne.


Two panels of the pamphlet geared towards electricians and facilities workers in the Park.

## Recommendations

We assisted Glacier National Park in maintaining International Dark Sky Park Status by **implementing a standardized ArcGIS lighting inventory system, collecting all new inventory data, and creating dark sky employee outreach material**. The approximate compliance percentage of 64% was lower than anticipated. We think previous inventory collectors counted some non-compliant lights as compliant, inflating the percentage, and may have missed some non-compliant lights. However, the Park can quickly identify where compliance can be raised using the ArcGIS system we implemented, facilitating a smooth path towards 100% compliance by 2027.

We recommend the Park:

- ★ **Complete the ArcGIS Inventory**
- ★ **Plan to Update the ArcGIS Inventory and StoryMap**
- ★ **Increase Staff Access to Dark Sky Compliant Bulbs**
- ★ **Switch to SQM-Ls**
- ★ **Increase Staff Access to Logan Pass Star Parties**
- ★ **Coordinate In-Person Dark Sky Events for Park Staff**

We hope the community of park employees enjoys defending the dark and fighting the light!

The Milky Way galaxy at Logan Pass in Glacier National Park. Photo by Jonathan Wessler.

# TABLE OF CONTENTS

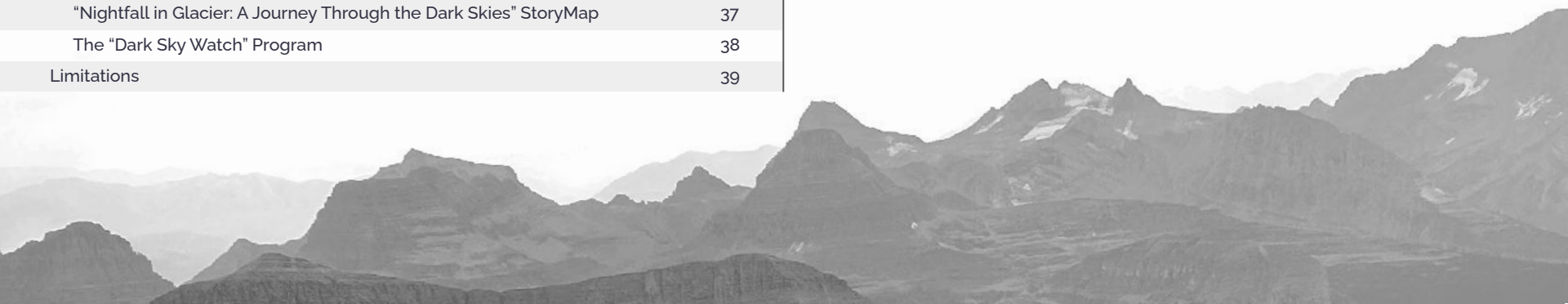




# TABLE OF CONTENTS







# LIST OF FIGURES AND TABLES

# LIST OF FIGURES AND TABLES

# LIGHT FIXTURE INVENTORY GLOSSARY



| | |
|---|---|
| **Attribute** | Data field(s) used to gather information about a light fixture |
| **Astronomical Twilight** | When the geometric center of the sun is 18 degrees below the horizon, the last phase before night |
| **Lamp** | A device for giving light, one electrical bulb |
| **Luminaire** | A light fixture that contains an electrical lamp and provides illumination |
| **Luminaire Control** | How the luminaire is controlled or operated |
| **Luminaire Type** | How the luminaire is mounted |
| **Measured CCT** | The correlated color temperature of the light measured with an instrument such as a spectrometer |
| **Operating at Night** | If the luminaire is emitting light |
| **Principle Investigator** | Group title of data collectors |
| **Rate of Backlight** | Light escaping the area of interest behind the light fixture |
| **Rate of Glare** | Light escaping the area of interest on the sides of the light fixture |
| **Rate of Uplight** | Light escaping the area of interest above the light fixture |
| **Shielding** | Physical barriers of the light fixture preventing uplight or sidelight (glare) |
| **Specified CCT** | The correlated color temperature of the light determined by labeled bulb specifications or electrical records |
| **Task** | The main purpose of the light or what the light is trying to light up |
| **Trespass** | Light present outside of the designated task area |

# LIST OF ACRONYMS



| | |
|---|---|
| **AGOL** | ArcGIS Online |
| **CCT** | Correlated Color Temperature |
| **GIS** | Geographic Information System |
| **GNP** | Glacier National Park |
| **IDA** | International Dark-Sky Association |
| **IDSP** | International Dark Sky Park |
| **mpsas** | Magnitudes per square arc second |
| **NPS** | National Park Service |
| **SQM** | Sky Quality Meter |
| **SQM-L** | Sky Quality Meter with lens |

# INTRODUCTION

All around the world, dark night skies are becoming an increasingly rare resource. A dark night sky allows the entire Milky Way galaxy and all observable astronomical elements to be visible to the naked eye. Light pollution, defined as the “brightening of the night sky” generated by artificial lights, threatens dark skies. (National Geographic Society, 2022). From 2011 to 2022, the sky brightened by 10% every year, decreasing the visibility of stars and astronomical objects around the globe (Falchi & Bará, 2023). Currently, only 20% of the world population, and only 1% of people in the United States and Europe, can see the Milky Way from where they live (National Geographic Society, 2022).

# INTRODUCTION



The dark sky is not only beautiful, it is also a cultural, historical, and environmental asset worth protecting (DarkSky International, n.d.c). The visible stars in a dark sky are highly valuable to many cultures, including Indigenous peoples such as the Blackfeet and Kootenai who have inhabited northwestern Montana for thousands of years (Glacier National Park, 2016). The dark sky holds historical value as well, revealing a starry night akin to that seen by ancient civilizations (Sovick, 2001). Furthermore, the dark sky holds deep environmental importance, allowing nocturnal animals to navigate, conceal, and hunt (Longcore & Rich, 2004).

DarkSky International is an organization formed to preserve the dark sky. Their mission is to "restore the nighttime environment and protect communities from the harmful effects of light pollution through outreach, advocacy, and conservation" (DarkSky International, 2023a). DarkSky International coordinates the International Dark Sky Park (IDSP) program, which allows parks, defined as publicly or privately owned conservation areas, around the globe to show their commitment to dark sky efforts. The IDSP program holds certified parks to standards including maintaining dark skies, implementing dark sky compliant outdoor lighting, and committing to dark sky community outreach (DarkSky International, 2023a).

Waterton-Glacier International Peace Park was fully certified as an IDSP in 2021 and reports annually on their current status regarding IDSP requirements (Biel, 2022). Since 2017, Glacier National Park has used a lighting inventory system composed of Excel spreadsheets. Due to a multitude of spreadsheets and an inconsistent inventory process, it has been difficult to calculate an accurate lighting compliance level (E. Eberhardy, personal communication, April 19, 2023).

Figure 1. The night sky at Lake McDonald in Glacier National Park. Photo by Ryann Dionne.

Figure 2. The Northern Lights at Lake McDonald in Glacier National Park. Photo by Matthew Catuccio.

Other national parks faced similar issues regarding inadequate lighting inventory systems, leading the National Park Service to develop a standardized ArcGIS lighting inventory system (S. Anderson, personal communication, April 6, 2023). ArcGIS is a Geographic Information System software that can be used to connect data to GPS locations. This is especially useful for a lighting inventory because it is imperative to know where each light fixture is located in the event that a retrofit, removal, or replacement is required.

Another important aspect of International Dark Sky Park recognition is dark sky community outreach. Glacier National Park holds many visitor-focused interpretive events, including “Half the Park Happens After Dark” and Star Parties. There is an opportunity, though, for more dark sky outreach material focused on park staff.

The goal of this project was to assist Glacier National Park in maintaining International Dark Sky Park Status by implementing a standardized lighting inventory system and developing employee outreach materials on Glacier National Park’s dark sky. This was completed by understanding IDSP requirements, implementing a standardized ArcGIS lighting inventory system, and developing employee outreach material for park staff. We hope the results of this project help to promote dark sky enthusiasm and awareness in Glacier National Park and beyond.

# BACKGROUND

The dark night sky has become an increasingly rare natural resource. This resource is an important and endangered cultural, social, and environmental asset. National parks around the globe have implemented an array of strategies and programs to preserve the darkness of the night sky. One such park is Waterton-Glacier International Peace Park, a combination of Glacier National Park (GNP) in Montana, U.S.A. and Waterton Lakes National Park in Alberta, Canada (DarkSky International, n.d.b).

Glacier National Park has been committed to dark sky conservation since 2006. The Park was officially named an International Dark Sky Park (IDSP) in 2017 and received full certification in 2021 (Biel, 2021). The IDSP program "certifies communities, parks, and protected areas around the world that preserve and protect dark sites through responsible lighting policies and public education" (DarkSky International, n.d.c). This designation correlates with the National Park Service's mission to "preserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations (Glacier National Park, 2016, p. 1).

## Dark Night Skies

A true dark sky is a night sky minimally affected by artificial lighting, allowing people to witness the brightness of the stars and see the Milky Way galaxy (Figure 3).

Figure 3: A view of the stars and the Milky Way galaxy taken at Logan Pass. Photo by Jonathan Wessler.

## Dark Skies as a Resource

The dark sky in Waterton-Glacier International Peace Park is recognized as both a cultural and historical resource. Indigenous peoples including the Blackfeet and Kootenai have cherished the dark sky above the region for thousands of years and maintain a deep emotional and cultural connection to it (Many Grey Horses, 2021; Carbaugh & Grimshaw, 2021). Rebecca Many Grey Horses, a Blackfoot member, recounted the importance of the night sky to Blackfoot culture in a video titled "Blackfoot Legends of the Cosmos with Rebecca Many Grey Horses." She highlighted the connection between the cosmos and the Blackfoot tribe saying, "legends have been passed down from generation to generation. The stories transfer the knowledge and skills of the Blackfoot culture, language, and traditions" (Many Grey Horses, 2021).

Maintaining the night sky to be as dark as possible for historical purposes is a part of the National Park Service's mission (National Park Foundation, n.d.). According to Joe Sovick of the National Park Service's Intermountain regional office in Santa Fe, New Mexico (2001), the dark night sky is "associated with so many facets of history, philosophy, religion, societal development, poetry, song, mathematics and science" (p. 15). As skies around the world brighten, Waterton-Glacier International Peace Park's dark sky has become a staple of the visitor experience. According to a news report in the Tribune Content Agency (Weber, 2021), as many as 80% of Americans cannot see the Milky Way where they live. Dark sky protection in Glacier National Park is vital to preserve the opportunity for visitors to experience a truly dark sky and the countless connections and stories forged by it.

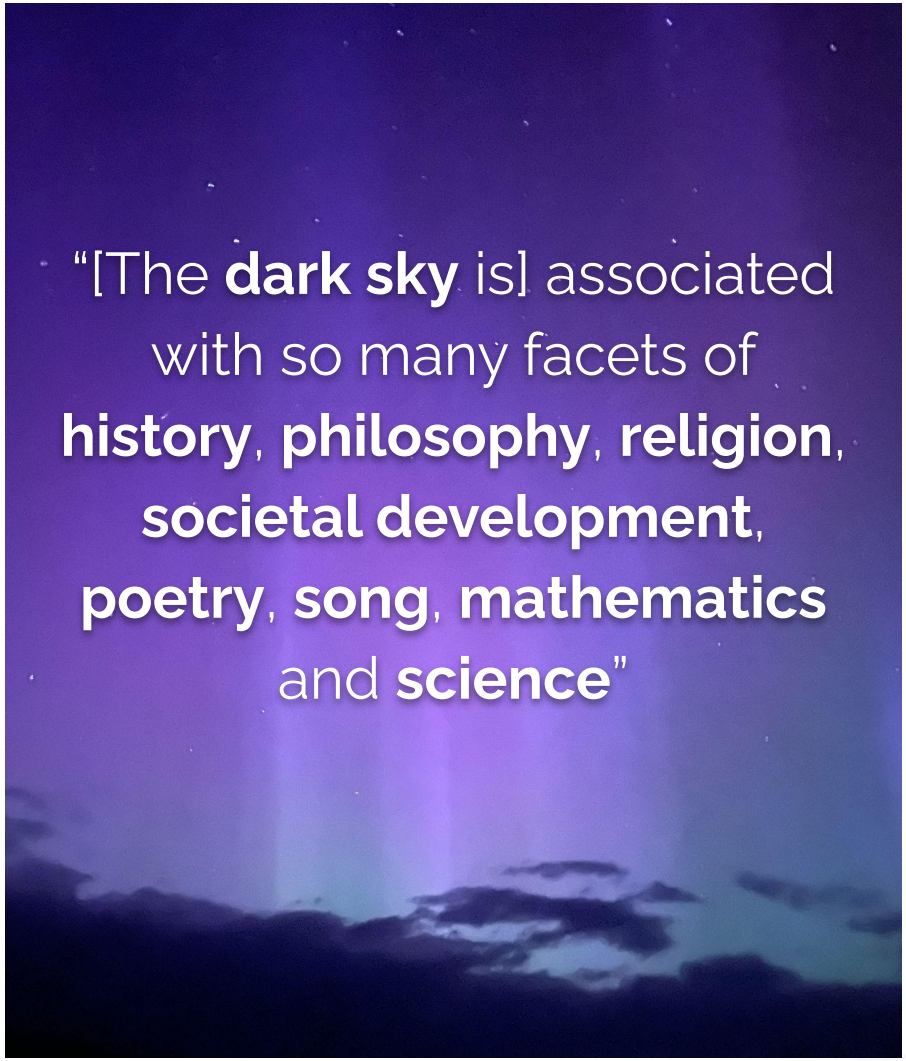



Figure 4. The Northern Lights at Lake McDonald in Glacier National Park. Photo by James Kiefer. Quote by Joe Sovick, (2001, p. 15).

## Spotlight on Light Pollution

One major impact humans have on the world is pollution, or the introduction of contaminants into natural settings. Light is a prevalent pollutant in today's society (National Geographic Society, 2022). Light pollution is defined as the "brightening of the night sky, mostly over urban areas, due to electric lights of cars, street lamps, offices, factories, outdoor advertising, and buildings" (National Geographic Society, 2022). In a decade-long citizen science study conducted by physicists and light pollution experts at the University of Santiago de Compostela, tens of thousands of citizens around the world recorded the dimmest stars they could see with the naked eye. Researchers determined that there was a 10% brightening of the sky every year from 2011 to 2022 due to light emissions from human-made sources (Falchi & Bará, 2023).

## Harmful Effects of Light Pollution

Light pollution causes natural sources of light to be drowned out by artificial sources. Poor air conditions such as fog, haze and smog also worsen visibility of these dimmer stars as light scatters due to the particles in the air (National Park Service, 2023).

In addition to the diminished visibility of the night sky, light pollution also negatively affects the environment, human health, wildlife, and behavior (National Geographic Society, 2022; Tatro, 2020). Light pollution from artificial sources has a series of physical and mental effects on humans and animals (Chepesiuk, 2009). Light pollution negatively affects the circadian clock, also known as the natural day/night cycle. For humans, disruption of this clock is linked to health disorders (Chepesiuk, 2009).

Light pollution affects wildlife natural behaviors including foraging, migration, reproduction, and communication (Longcore & Rich, 2004). Light pollution is particularly disruptive to the habitat of nocturnal species. Nocturnal animals such as the mountain lions in Glacier National Park need darkness to conceal, hunt, reproduce, and navigate (Figure 5). Light pollution interferes with all of these processes (National Park Service, 2022). Combating light pollution is crucial to Glacier National Park for the preservation of the wildlife's natural behaviors, as well as maintaining the Park's status as an International Dark Sky Park (National Park Service, 2022).

Figure 5. A mountain lion, one of the nocturnal predators in GNP. Light pollution interferes with the natural survival processes of these animals (National Park Service, n.d.b).

## International Dark Sky Places Program

DarkSky International, formerly known as the International Dark-Sky Association (IDA), coordinates the International Dark Sky Places program. DarkSky International is the world's authority on reducing light pollution. The International Dark Sky Places program recognizes places around the world as exceptional in protecting the night sky (International Dark-Sky Association, 2018). DarkSky International is motivated to uphold the cultural, spiritual, and recreational value of the dark sky (DarkSky International, 2023a). The association aims to limit light pollution by decreasing unnecessary artificial lighting, implementing dark sky-friendly lighting fixtures, and promoting the importance of the dark sky (DarkSky International, 2023a).


Figure 6. DarkSky International Logo (DarkSky International, 2023a).


Figure 7. International Dark Sky Park Logo (DarkSky International, n.d.c).

## Earning International Dark Sky Park Status

To become an International Dark Sky Park (IDSP), which is one subset of the International Dark Sky Places program, a publicly or privately owned conservation area, which the program labels 'park,' must submit an application to DarkSky International and fulfill three core requirements: dark night skies, dark sky compliant outdoor lighting, and educational programs on the night sky (National Park Service, 2022). After an application is accepted and a park is certified as an IDSP, a yearly report is required to track the Park's steps towards 100% compliance.

## Measuring the Dark Sky for IDSP Status

The "dark night skies" requirement means that IDSPs must measure the sky brightness at least once a year and affirm that the night sky is either staying dark or getting darker. The best method to measure the darkness of the night sky is by using a Sky Quality Meter (SQM) device (Figure 8).

To be an IDSP, any park must have an overall sky darkness that reads above 21.2 magnitudes per square arcsecond (mpsas) when measured with an SQM (International Dark-Sky Association, 2018). A magnitude per square arcsecond is an astronomer's unit and it represents the magnitude of light that is in one square arcsecond of the sky (Unihedron, n.d.).

## Dark Sky Education Programs for IDSP Status

Another requirement of the International Dark Sky Park program is that parks must initiate educational and interpretive programs on the importance of protecting the night sky (International Dark-Sky Association, 2018). In many cases, IDSPs have astronomy programs for park visitors that foster curiosity about the night sky. IDSP recognition can help increase the number of park visitors who seek a starry night sky.


Figure 8. A Sky Quality Meter with lens, or SQM-L, displaying the recorded magnitudes per square arcsecond (mpsas) (Astronz, n.d.).

## Dark Sky Compliant Outdoor Lighting for IDSP Status

Along with educational programs, DarkSky International requires that IDSPs have compliant outdoor lighting and a Lighting Management Plan, which details how a park plans to achieve 90% compliance five years after the initial application and 100% compliance 10 years after the initial application (International Dark-Sky Association, 2018). Alongside this plan, a park must annually report an updated dark sky compliance percentage. Dark sky compliance is calculated from the amount of dark sky compliant exterior lighting fixtures in the Park. DarkSky International provides guidelines on what makes a light fixture dark sky compliant (DarkSky International, 2023b). The association requires that each fixture in a park, regardless of where it is installed, must be fully shielded, on task, and warm colored (S. Anderson, personal communication, April 6, 2023).

## Dark Sky Compliant Color Temperature

DarkSky International requires bulbs with color temperatures less than 3,000 Kelvin [K], which ranges from yellow to amber colored light (Figure 9) (DarkSky International, 2023b). This value is called the correlated color temperature, referred to as the CCT.

Around the world, energy inefficient older-style lights such as sodium vapor lights are slowly being replaced by LEDs and metal halide lights, which generally emit cooler colored light (4,000K or above) compared to the warmer older styles (4,000K or below) (Figure 10) (Boyes, 2021) (DarkSky International, 2023b). Despite this, some manufacturers make "amber LEDs," which are LEDs with a warmer color temperature (3,000K or below) (E. Eberhardy, personal communication, September 3, 2023).

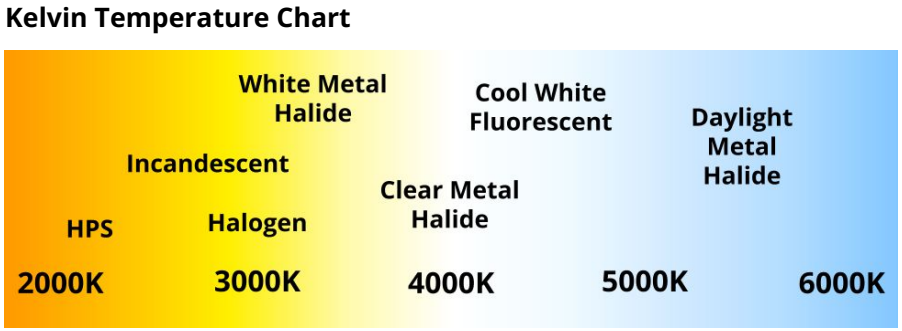



Figure 9. Examples of light bulbs and their respective color temperatures (DarkSky International, 2023b).

Figure 10. Comparison of warm sodium light (left) to cool LED light (right) (Boyes, 2021).

## Dark Sky Compliant Shielding

According to the Natural Sounds and Night Skies Division of the National Park Service (2023), a fully shielded light fixture prevents light from spilling into unwanted areas. To be considered fully shielded, a fixture must prevent light from escaping to the sides, known as glare, or above, known as uplight. Bulbs that have shielding built into their casing can turn a non-compliant fixture into a compliant one (Figure 11).

## Additional Dark Sky Compliant Attributes

Additional attributes crucial to determining lighting compliance are the task, luminaire control, and trespass of a light fixture (Natural Sounds and Night Skies Division, 2023). Lighting tasks include roadways, parking, egresses, and pathways (Natural Sounds and Night Skies Division, 2023). The control of the luminaire is how a lighting fixture turns on and off. This can be by a switch, a motion sensor, a timer, or a photo sensor which turns the light on depending on the brightness outside (Alvarez del Castillo et al., 2001). According to IDSP compliance requirements, the luminaire control should be in accordance with the task of the bulb so the light is only when necessary to serve its purpose (DarkSky International, 2023b). Trespass occurs when a light fixture illuminates an area not necessary to complete its task (Figure 12) (Natural Sounds and Night Skies Division, 2023). Compliant lighting provides the minimum amount of light directed where needed to create a safe work area.

Figure 11. Example of a fully shielded bulb, able to turn a non-compliant lighting fixture into a compliant one. Photo by Christiana Kearns.

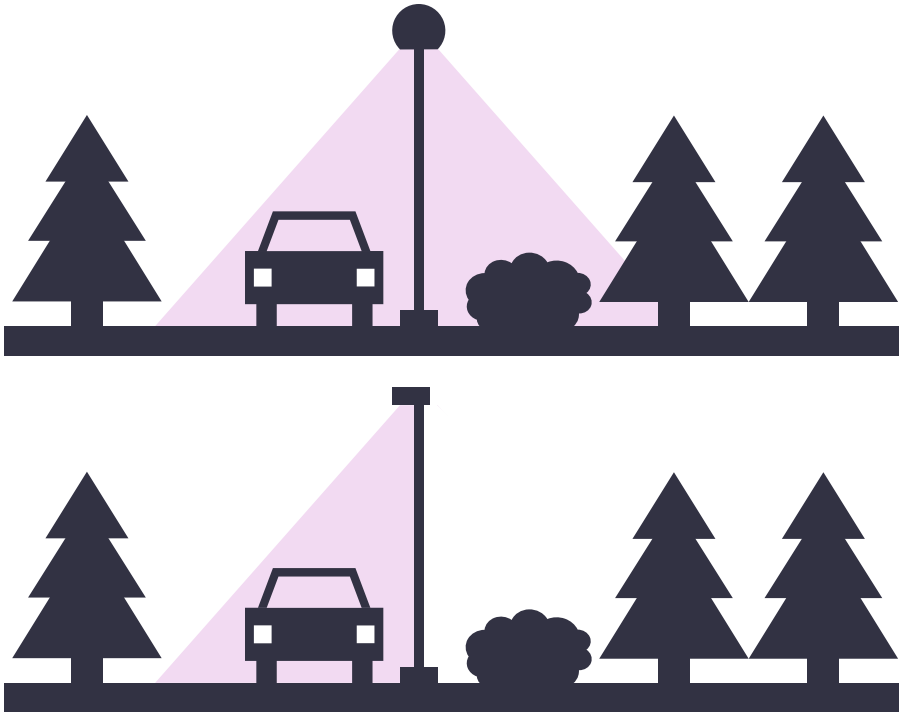


Figure 12: An off task light fixture (top) due to its illumination of the forest area, when its task is to illuminate the roadway. A retrofitted on task light (bottom) that directs light only on its task area, the roadway, making it compliant.

## Bolstering Glacier National Park's Dark Sky Efforts

Glacier National Park has continued to bolster dark sky efforts since being certified as an IDSP in 2017. In order to remain an International Dark Sky Park, three components must be maintained: possessing dark skies, having compliant outdoor lighting, and hosting dark sky educational programs.

## IDSP Component: Dark Skies

Glacier National Park staff measure sky brightness levels each year with a Sky Quality Meter (SQM) (Wheeler, 2017). In 2022, recorded sky darkness in Glacier National Park was 21.36 mpsas, while darkness was 21.66 mpsas in the original application. Since the mpsas scale is exponential, a seemingly small change of 0.30 mpsas is significant. As noted in Glacier National Park's 2022 IDSP annual report, increasing light pollution outside of the Park affected many of the measuring sites, particularly on the East and West park boundaries (Biel, 2022).

## IDSP Component: Compliant Outdoor Lighting in the Park

The DarkSky Association requires that 100% of GNP's lighting must be dark sky compliant by the year 2027 (Buckley et al., 2020). Glacier National Park has been retrofitting old light fixtures to obtain the highest possible level of compliance in the Park. In addition, the Park's Lighting Management Plan includes steps to replace old light fixtures with shielded fixtures, replace old bulbs with amber LEDs, and avoid the installation of new lights unless necessary (Wheeler, 2017).

According to Glacier National Park's 2022 IDSP annual report, the level of lighting compliance was 73.5% in 2022, up from 29% in the original application (Biel, 2022; Wheeler, 2017). This is due to the Park having purchased many compliant light fixtures and dark sky compliant bulbs to replace old lights with (E. Eberhardy, personal communication, September 12, 2023). The Park anticipates at least 90% compliance by the end of 2023 (Biel, 2022).

## Lighting Fixture Inventory

Since 2017, GNP has utilized a lighting inventory that consisted of multiple spreadsheets in Microsoft Excel (Figure 13, 14) (Wheeler, 2017). According to Ed Eberhardy, a Physical Science Technician at GNP, this lighting inventory system was too disorderly for the large amounts of data required for IDSP certification (E. Eberhardy, personal communication, April 19, 2023). These spreadsheets contain photos of each light that inventory volunteers found, the building number, light number, type of luminaire, light control mechanism, shielding status, wattage, bulb type, purpose, notes, and a recommendation. Many national parks faced similar challenges regarding inadequate inventory systems, leading the NPS to seek a standardized solution. Dr. Sharolyn Anderson, a Physical Scientist in the Natural Sounds and Night Skies Division of the NPS, suggests that parks perform new lighting inventories in ArcGIS, a Geographic Information System (GIS) software (S. Anderson, personal communication, April 6, 2023).

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | Building Number | Number of Lighting Fixtures | Number of Compliant Fixtures | Number of Non-Compliant Fixtures | Unknown Compliance | | This page updates automatically!!! Do not modify! |
| 2 | | | | | | | |
| 3 | Grand Totals | 93 | 25 | 71 | #VALUE! | | |
| 4 | | | | | | | |
| 5 | 0008 | | 2 | 1 | #VALUE! | | |
| 6 | 0010 | 1 | 0 | 1 | 0 | | |
| 7 | 0011 | 2 | 0 | 2 | 0 | | |
| 8 | 0012 | 2 | 0 | 2 | 0 | | |
| 9 | 0014 | 2 | 0 | 2 | 0 | | |
| 10 | 0015 | 2 | 0 | 2 | 0 | | |
| 11 | 0035 | 2 | 0 | 2 | 0 | | |
| 12 | 0035_Shed | 0 | 0 | 0 | 0 | | |
| 13 | 0036 | 3 | 3 | 0 | 0 | | |
| 14 | 0037 | 1 | 0 | 1 | 0 | | |
| 15 | 0066 | 2 | 0 | 2 | 0 | | |
| 16 | 0196 | 0 | 0 | 0 | 0 | | |
| 17 | 0200 | 0 | 0 | 0 | 0 | | |

Figure 13. The old lighting inventory summary page that counts total compliance.

| | A | B | C | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 |  | | | | | | | | | |
| 2 | Picture (Wide) | Picture (Detail) | Light No. | Shielded? | Wattage | Bulb Type | Purpose / Application | Compliant? | Notes | REC |
| 3 |  |  | 1 | N | | Compact Fluorescent | Entry Way Light | N | Built in 1928- Not original fixture, replace with period appropriate fixture and new lightulb | Raymond RB-8W with PAR 16 Amber LED |

Figure 14. The previous lighting inventory sheets of an individual building and the respective lighting data.

## Exploring ArcGIS for a Lighting Inventory

Geographic Information System, or GIS, software overlays layers of geospatial information, such as terrain, buildings, and streets, to be analyzed, shared, and used to solve problems (Doré, 2020). These 'layers' can contain many types of information as long as there are coordinates attached to the data. For instance, a layer can contain boundaries of properties, or a layer can contain the location and purpose of buildings. As of 2023, The NPS has been implementing a standardized lighting inventory system utilizing ArcGIS in multiple national parks, including Acadia National Park (Demanche et. al, 2023). This system provides the NPS with a highly organized inventory for each park that can be easily analyzed and shared.

Figure 15. The Northern Lights at Lake McDonald in Glacier National Park. Photo by Matthew Catuccio.

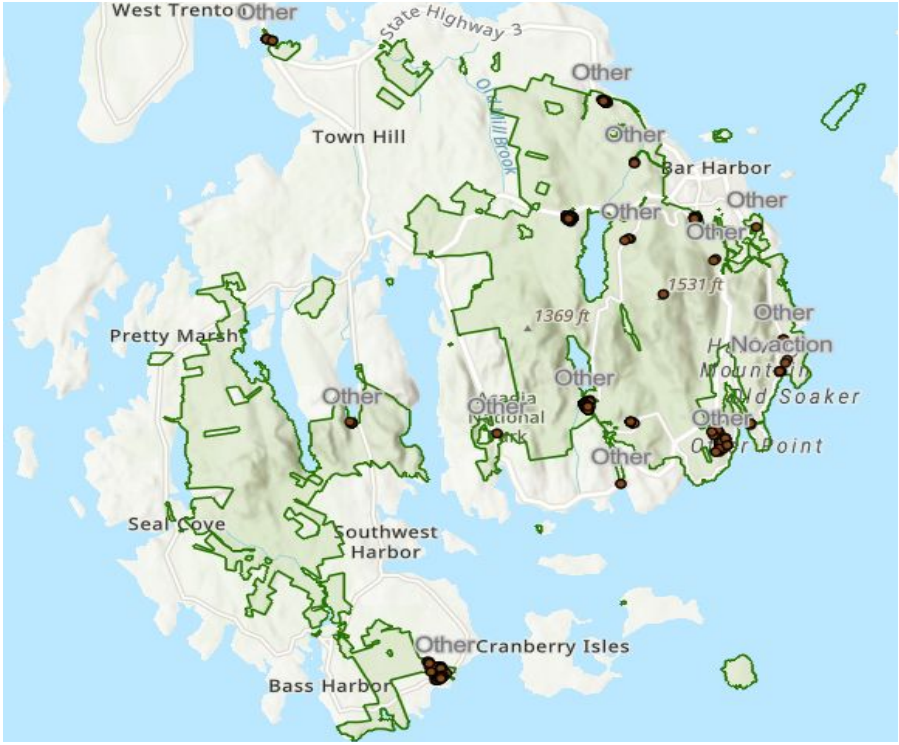



Figure 16. ArcGIS Lighting inventory Webmap for Acadia National Park (Demanche et. al, 2023).

## ArcGIS Online

ArcGIS Online (AGOL) is the online version of the ArcGIS software. There are many benefits of AGOL, including the ability to view spatial data on web maps, accessibility by smartphone, tablet, and web browser, and ease of publishing and sharing data across organizations (Doré, 2020). ArcGIS Field Maps is a user-friendly mobile phone application designed to record data with GPS coordinates in the field, even without internet access (ArcGIS Field Maps, n.d.).

## ArcGIS StoryMaps

ArcGIS StoryMaps is a tool to create interactive maps (Figure 17) (ESRI, n.d.). StoryMaps allows users to insert ArcGIS maps, videos, photos, and text to turn their raw data into a visual story (ESRI, n.d.). These maps are easy to share and access (ESRI, n.d.).

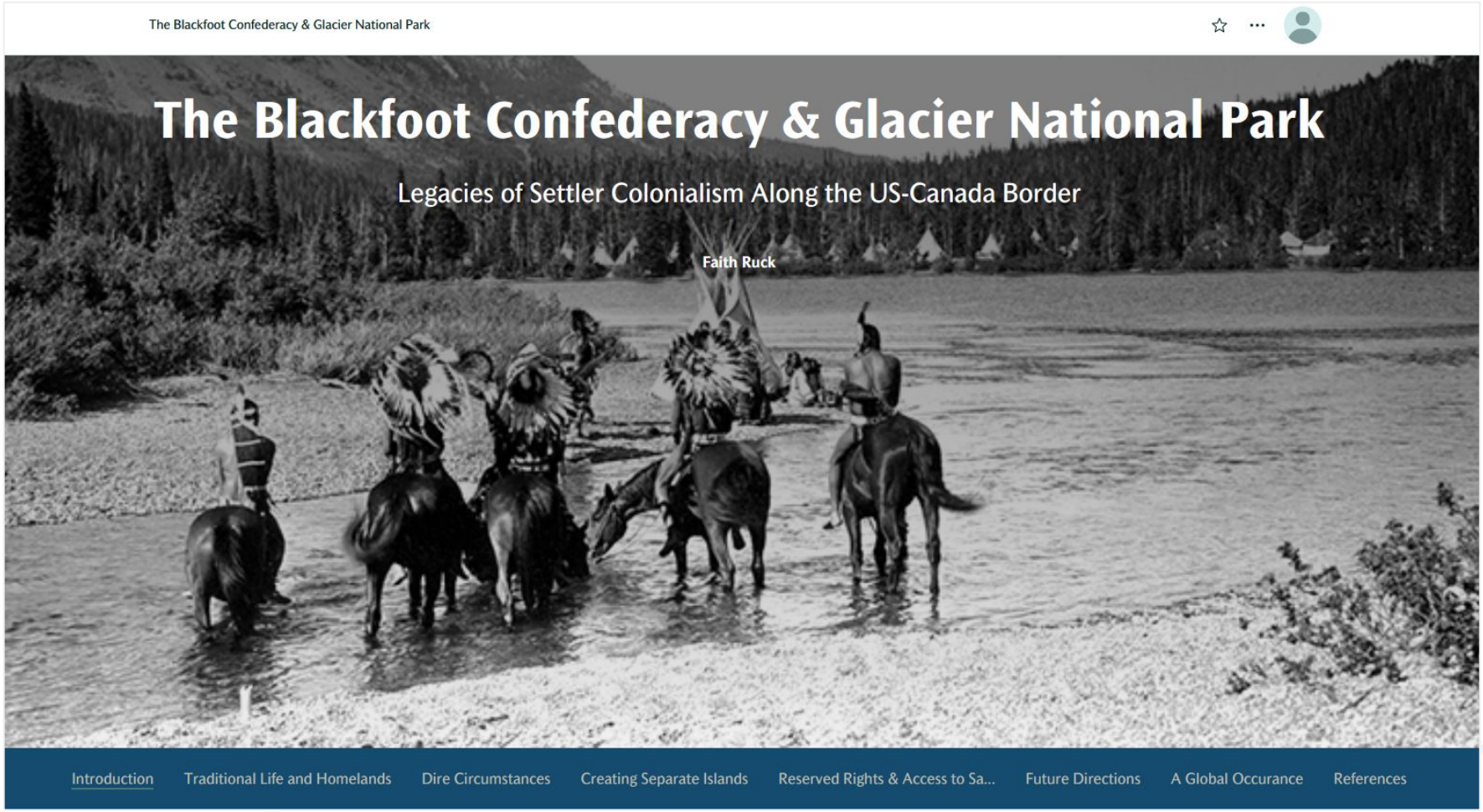



Figure 17. StoryMap exhibiting the deep history of Indigenous Homelands, specifically the Blackfoot Confederacy land and history (Ruck, n.d.).

## IDSP Component: Dark Sky Education in GNP

The Glacier National Park Conservancy, the non-profit partner of Glacier National Park, raises money to support the Park's mission, including the funding for all of GNP's educational astronomy programs (Glacier National Park Conservancy, 2023). In 2022, nearly 10,000 people attended 134 dark sky events, including the "Half the Park Happens After Dark" program and the "Logan Pass Star Parties" (Figure 18) (Biel, 2022). In addition, the Park operates the Dusty Star Observatory in St. Mary to offer visitors the opportunity to observe stars and other celestial objects nightly (Dusty Star Observatory, n.d.). Events encourage visitors to view Glacier's dark skies through telescopes while volunteer astronomers talk about stars, constellations, and the dark sky (Glacier National Park, 2016).

Figure 18. A crowd gathering at dusk for a Logan Pass Star Party, one of the GNP's dark sky events (National Park Service, n.d.a).

# METHODS

This project assisted Glacier National Park in maintaining International Dark Sky Park Status by implementing a standardized lighting inventory system and developing employee outreach materials on Glacier National Park's dark sky (Figure 19). To accomplish this goal, we pursued three objectives: exploring the requirements of International Dark Sky Park status, implementing an ArcGIS lighting inventory system, and developing dark sky outreach materials for park staff.

**Dark Sky Team Goal Chart**

## GOAL

Assist Glacier National Park in **maintaining** International Dark Sky Park Status by **implementing** a standardized lighting inventory system and **developing** employee outreach materials on Glacier National Park's dark sky

## OBJECTIVE 1

**EXPLORE IDSP STATUS REQUIREMENTS**

- ★ Thoroughly research DarkSky International compliance
- ★ Perform sky quality measurements
- ★ Explore compliant lighting qualities

## OBJECTIVE 2

**IMPLEMENT ArcGIS LIGHTING INVENTORY SYSTEM**

- ★ Establish ArcGIS system for Glacier National Park
- ★ Populate and collect lighting inventory data
- ★ Create GIS user manual

## OBJECTIVE 3

**DEVELOP DARK SKY STAFF OUTREACH MATERIALS**

- ★ Analyze current outreach
- ★ Interview staff about dark sky knowledge
- ★ Design citizen science and awareness material for staff

Figure 19. Our goal statement and project objectives, accompanied by our methods.

## **Objective 1:** Exploring Requirements for IDSP Status

DarkSky International has many requirements for a park to become and remain an IDSP. Our team reviewed Glacier National Park's 2017 IDSP application and annual reports to understand IDSP requirements and the Park's current status. We analyzed GNP's current lighting inventory to get a sense of what has been done before and to find gaps in what is currently known. We also reviewed the Park's Lighting Management Plan to determine the strategies the Park intended to use to increase lighting compliance.

### Determining Dark Sky Compliance

To understand dark sky compliant lighting, we studied DarkSky International's website to determine compliant light bulbs and fixtures as well as other lighting parameters such as luminaire control, task, and trespass (DarkSky International, n.d.a).

### Measuring GNP's Sky Darkness

Measurement of the sky's darkness is required for Glacier National Park's annual IDSP report. We measured sky darkness with a Unihedron Sky Quality Meter with lens (SQM-L) obtained from Worcester Polytechnic Institute. These measurements require strict weather and moon conditions as well as specific measuring procedures. We conducted the measurements on a night with minimal cloud coverage, coinciding with the night of a new moon. The procedure used for taking SQM measurements involved determining the locations, setting up and normalizing the instrument, and using the instrument to take five reportable readings at each location (Figure 20).

We then calculated and recorded the average of these readings. This average was the sky quality value we reported for that location. We noted the estimated cloud cover and the air quality. The team determined the air quality based on purpleair.com, an online resource recommended by Ed Eberhardy, a Physical Science Technician involved in monitoring air quality in Glacier National Park.

Figure 20. Gathering a sky quality measurement. Photo by Ryann Dionne.

## **Objective 2:** Implementing an ArcGIS Inventory System

The National Park Service (NPS) developed a standardized lighting inventory system in ArcGIS. With a GIS-based lighting inventory, all inventoried lighting fixtures are displayed based on their location on a map. In the ArcGIS lighting inventory, users can identify each lighting fixture's corresponding attributes by selecting its data point in the system.

## Establishing ArcGIS Lighting Inventory in Glacier National Park

We met with Dr. Sharolyn Anderson, a Physical Scientist in the Natural Sounds and Night Skies Division of the NPS, who has successfully implemented lighting inventories using ArcGIS in several national parks. Dr. Anderson created and sent the team an ArcGIS map specific to GNP, as well as the lighting attribute map layer that the NPS uses. This attribute layer is where we logged the lighting data in ArcGIS (Figure 21).


Figure 21. The lighting inventory map is composed of three layers: topographic world map (left), Glacier National Park building data layer (middle), and luminaire data layer (right). The luminaire data layer is where the lighting inventory data is logged.

## Understanding Lighting Attribute Data

In the ArcGIS lighting inventory, each light fixture is recorded as a singular data point with several attributes describing the light and its compliance (Figure 22, 23). GNP chose a selection of desired attributes based on the required attributes for IDSP compliance and the preferences of the Park. The attributes specific to determining IDSP compliance are the correlated color temperature (CCT), shielding, task, luminaire control, and trespass (International Dark-Sky Association, 2018).


Figure 22. In the ArcGIS system, photos of each light fixture are included with the logged attributes for each data point.

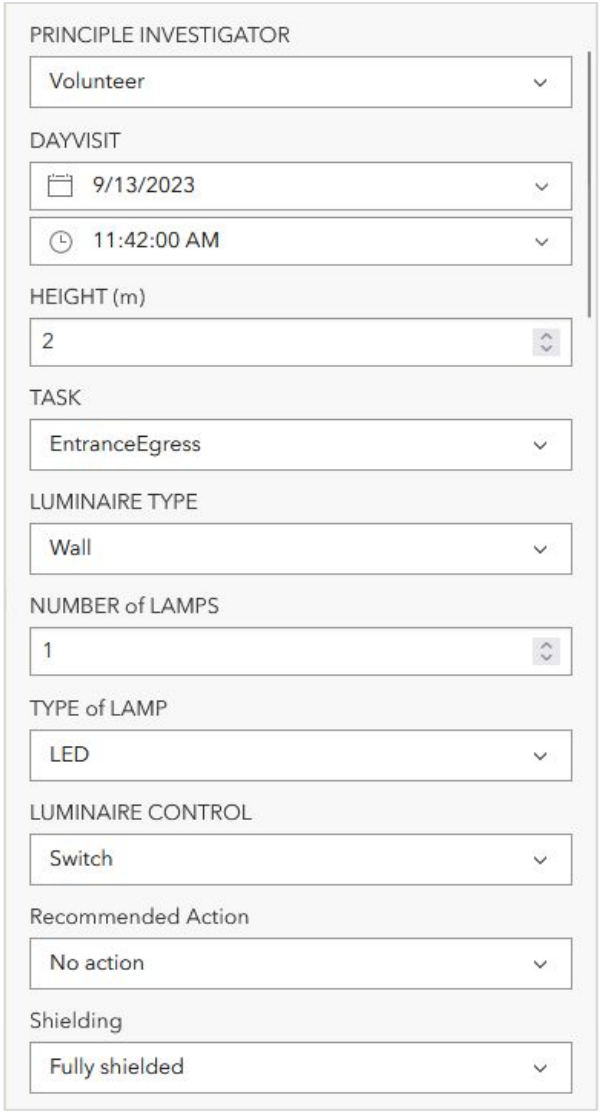



Figure 23. Attributes fieldworkers collect during day visits.

## Finding The CCT

The correlated color temperature (CCT) of any light bulb is a value on a color spectrum expressed in units of Kelvin. There are two methods to find the CCT of a light (Natural Sounds and Night Skies Division, 2023). The most accurate method of finding CCT is to measure the light during a night visit using a spectrometer, which disperses the emitted light into a spectrum and is then translated into the CCT value (OpenStax, n.d.). The CCT can also be found in the written specifications of the bulb, which are often located on the bulb itself. We gathered the specified CCT when possible, as we collected lighting inventory data during the daytime only.


Figure 24. Some light bulbs have specified CCT labeled on the bulb itself (3,500K). Left photo by Carter Melanson, right photo by Christiana Kearns.


Figure 25. Spectrometer used to measure CCT (left). Measurements are required to be taken at night, pointing the sensor toward the light (right). Photos by Ryann Dionne.

Nighttime lighting inventory visits provide more complete data about the performance of a light. We conducted one night visit at Headquarters to serve as an example for the Park. Dr. Sharolyn Anderson, Physical Scientist in the National Park Service, sent Glacier National Park a UPRtek MK350 N Premium Spectrometer to gather the measured CCT value. We collected data after astronomical twilight, which allows for the darkest skies and thus the most accurate CCT values.

## Collecting Lighting Inventory

We were able to download maps of areas to be used offline through the Field Maps app (Figure 27). Dr. Anderson recommended this application. We mapped out each inventorying location on paper and split it up into sections, depending on overall area size and number of buildings (Figure 26). We would proceed to each lighting fixture's position, mark its location in the app, take a picture, and log the relevant attributes. Once connected to Wi-Fi, we synced the data from Field Maps into ArcGIS online. A step by step guide on logging light fixture data is available in the ArcGIS Lighting Inventory User Manual for Dark Sky Parks (Appendix F).

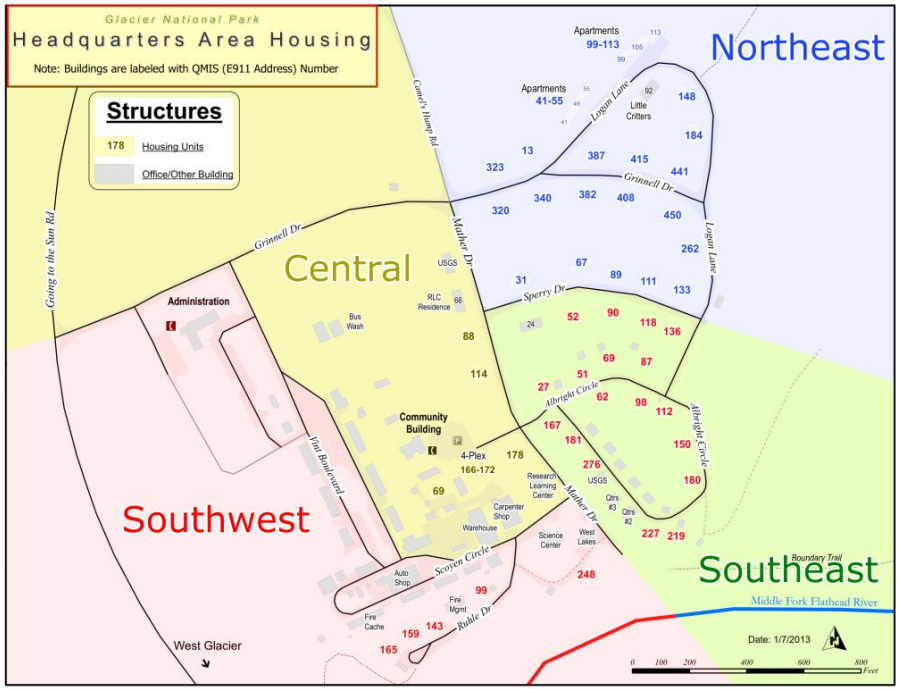



Figure 26. Color-coded headquarters map used to divide luminaires into manageable regions (T. Carolin, personal communication, August 29, 2023).

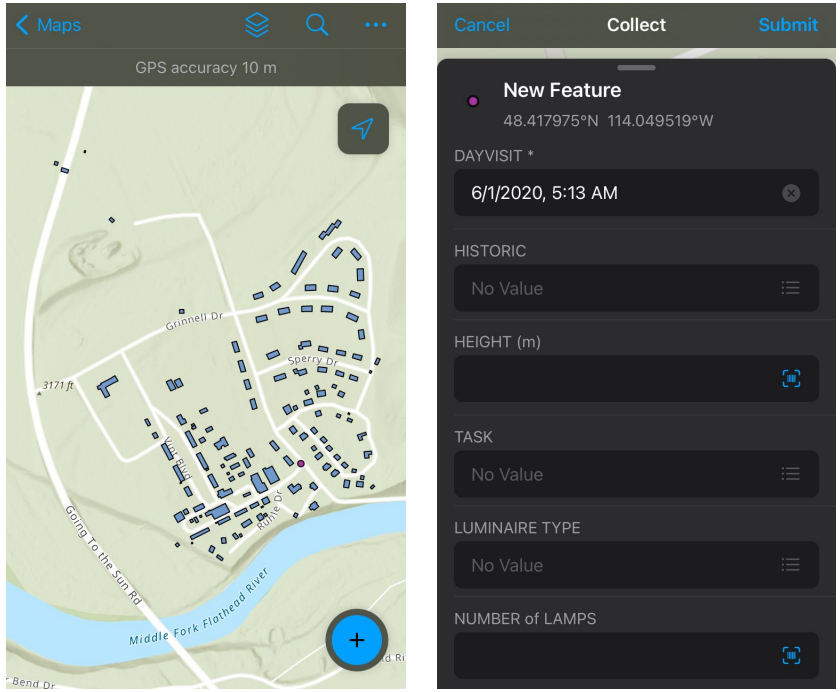



Figure 27. Screenshots of ArcGIS Field Map application on an IPhone, showing the displayed map and then attributes to be logged for a lighting fixture.

## Analyzing Data

After we logged all lighting data possible, we manually reviewed the data, looking for any discrepancies in the attribute options selected and then correcting as necessary by editing the data points. We did this by filtering data by a specific attribute, such as shielding, and sorting through all the points that had a "null" value for that attribute, meaning it had been left blank because we were unsure what to select while in the field. As a team, we then agreed what to select for that data point based on the pictures we took of that light. After this, we went through every single data point and compared the attributes to the photos we took to verify the gathered data. We then filled out the 'Recommended Action' attribute under each data point in order to upgrade the compliance of each light fixture if non-compliant. The attribute options included *replace*, *retrofit*, *remove*, and *no action*.

## Developing GNP Lighting Inventory Manual

We developed the ArcGIS Lighting Inventory User Manual for Dark Sky Parks (Figure 28) regarding usage of the ArcGIS lighting inventory system to assist future inventory takers with accurately and efficiently inputting lighting data for outdoor light fixtures in the Park. This manual was written based on our experience with the system and inventory taking. The manual is crucial to the park staff who will help complete logging lighting data for the areas we did not get to (such as Goat Haunt and Rising Sun). It is also crucial for those who are responsible for editing the inventory with any retrofits or new fixtures.

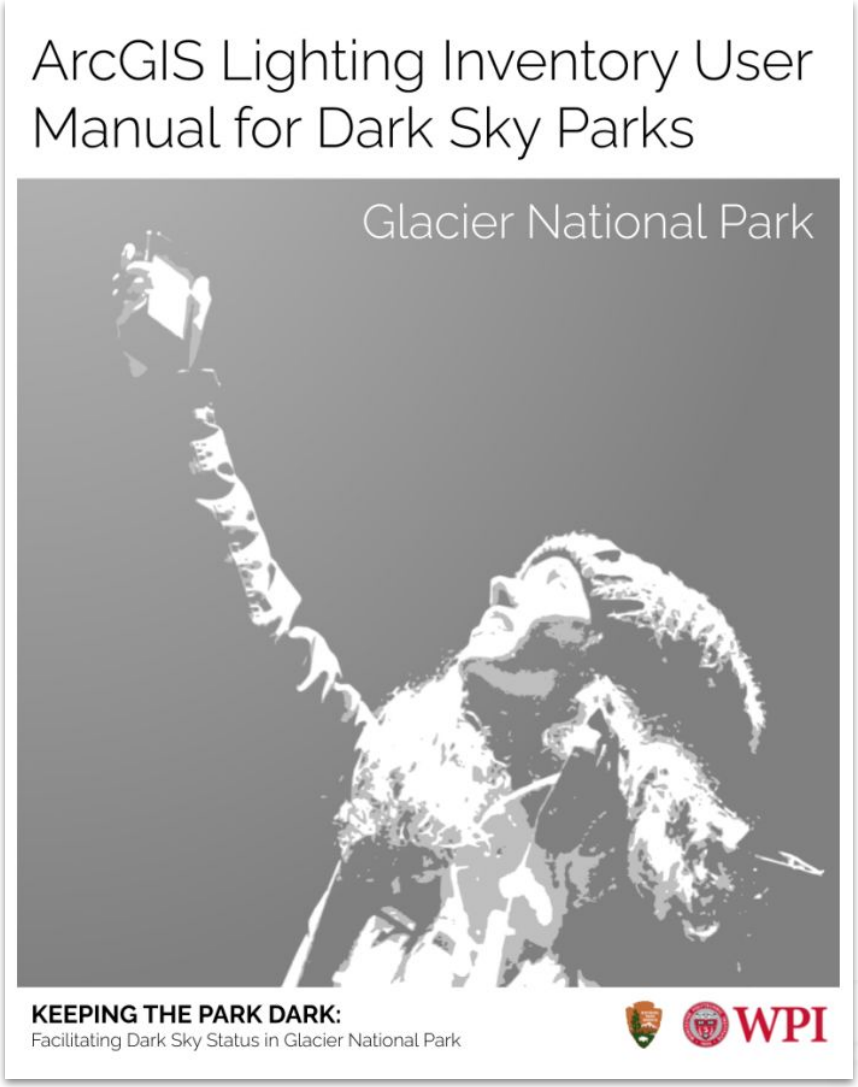



Figure 28. Cover page of the ArcGIS Lighting Inventory User Manual for Dark Sky Parks. See Appendix F.

## **Objective 3:** Developing Dark Sky Outreach Material for Park Staff

We first used a participant-observation method of learning about Glacier National Park's dark sky by attending some of the Park's dark sky events. Then, we organized semi-structured interviews to gain an understanding of the dark sky's meaning to different park personnel. Key informant interviews were pre-planned and up to an hour long, while other interviews were ad hoc and lasted 15 minutes (Appendix B contains our interview questions). One informal focus group occurred spontaneously with personnel involved in wildlife research in the Park. After analyzing the responses from dark sky staff interviews, we decided on four forms of outreach material. These are: two physical, one digital, and one engagement program.

Figure 29. Discussing outreach material with Ed Eberhardy, Physical Science Technician and project co-sponsor. Photo by Ryann Dionne.

# FINDINGS

Over the course of this seven week project, we addressed the three components of International Dark Sky Park status: the quality of Glacier's dark night sky, the compliance of the Park's external lighting, and interpretive outreach on the Park's dark sky. **Our measurements revealed that the sky in west Glacier National Park was darker in Fall 2023 than it was in Fall 2022, while lighting compliance was 64%**, which is lower than reported in the 2022 annual report. **The dark sky interpretive programs for park visitors informed the development of outreach material** specific to electricians and facilities staff. **We also found that many park personnel were interested in learning more about Glacier National Park's dark skies**, so we developed programs for the wider community of park personnel.

## The Darkness of Glacier's Sky

As a requirement of IDSP status, the Park must take annual sky quality measurements (National Park Service, 2022). The Park has utilized a Sky Quality Meter (SQM) in previous years to collect these measurements. We utilized the more precise Sky Quality Meter with lens (SQM-L) provided by WPI. The SQM-L has a smaller field of view by 30 degrees compared to the SQM, ensuring that trees and nearby lights do not affect the measurement (Figure 30) (Unihedron, n.d.). **We found the SQM-L to be more useful in Glacier National Park because at all sky quality measurement sites there are nearby trees that could negatively affect the accuracy of the measurement.**

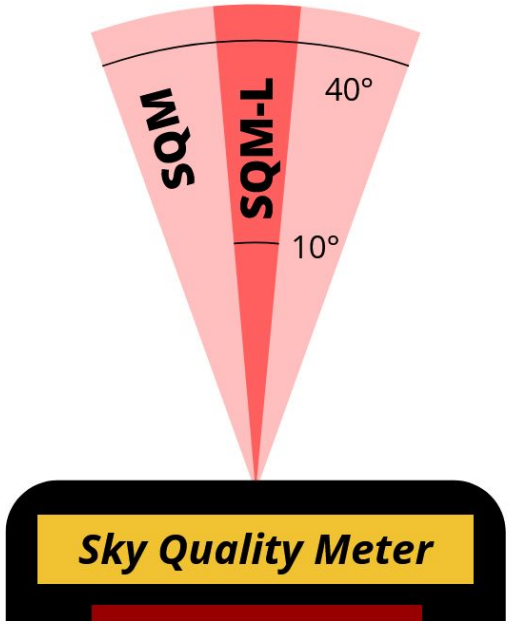



Figure 30. Difference between an SQM-L with a 10 degree field of view, and an SQM with a 40 degree field of view.

Polebridge Ranger Station, Huckleberry Lookout Trailhead, Apgar Boat Dock, and Lake McDonald Lodge were the previous sky quality measurement locations for the west side of the Park. The previously established locations on the east side of the Park were: the St. Mary Visitor Center, One Mile Gate at St. Mary, Many Glacier Sherburn Dam, and Chief Mountain. Ed Eberhardy briefed the team on the specifics of where exactly to take the measurements at each location.

**GNP's Established Sky Quality Measurement Locations**


Figure 31. Previously established locations around Glacier National Park for annual sky quality meter measurements.

We were not able to measure the east side locations due to time, weather, and moon phase constraints. For accurate sky quality measurements, we needed to take measurements within a day of a new moon (meaning the day before, of, or after), after astronomical twilight, and in a sky with minimal cloud coverage. Astronomical twilight reflects when the "geometric center of the sun is eighteen degrees below the horizon" (National Weather Service, n.d.). For SQM measurements, the researcher can estimate cloud coverage by the naked eye. We measured all four sites on the west side of the Park on September 14th, 2023, the night of a new moon with 0% estimated cloud coverage (Table 1).

### West Side Sky Quality Measurements

| | Polebridge | Huckleberry Lookout | Lake McDonald Lodge | Apgar Boat Dock |
|---|---|---|---|---|
| **2020** | 21.13 | – | 21.90 | 21.87 |
| **2021** | 21.66 | 21.57 | 21.66 | 21.53 |
| **2022** | 21.39 | 21.45 | – | 21.27 |
| **2023** | 21.36 | 21.39 | 21.43 | 21.44 |

Table 1. Data collected at each west side sky quality measurement location. All measurements are in magnitudes per square arcsecond (mpsas) (Biel 2022).

**We found the average sky quality of the sites on the west side of Glacier National Park was 21.41 magnitudes per square arcsecond (mpsas) in Fall 2023, an improvement from the year before by 0.04 mpsas** (Figure 32). This is approximately 3.6% darker than the previous year. This could be due to lighting retrofits conducted within the past year.

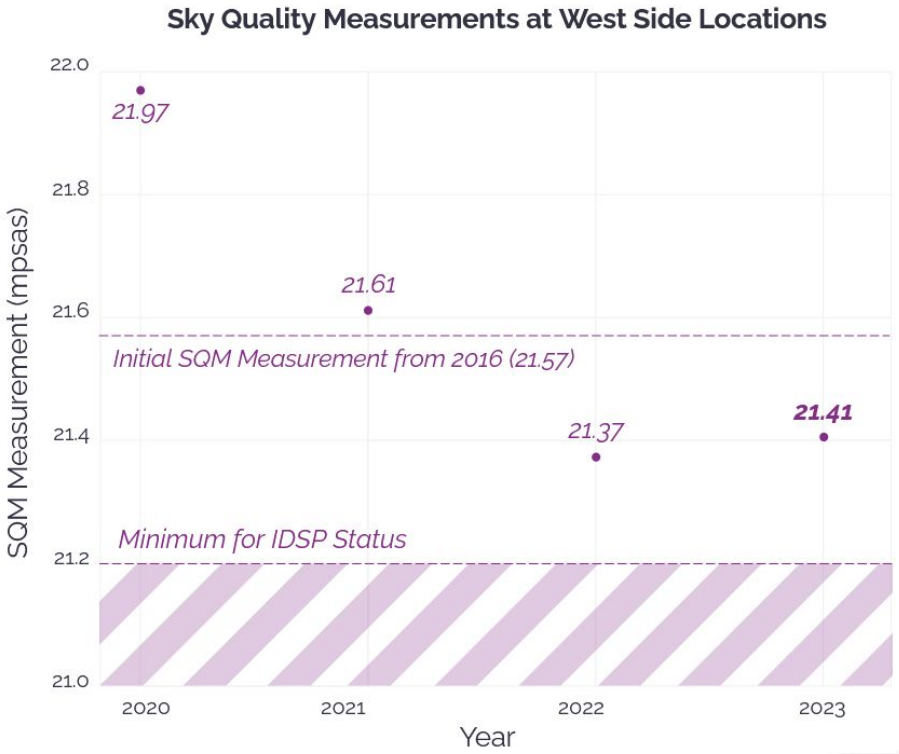



Figure 32. Average SQM measurement for the west side locations in Glacier National park from 2020 - 2023. The minimum measurement for maintaining IDSP status is 21.2 mpsas. 2016 was the year the Park submitted their IDSP application (Biel, 2022).

**We were surprised that the sky was darker at the Apgar boat dock than it was in Polebridge (21.43 mpsas and 21.36 mpsas respectively)**. In the Park, there were 242 light fixtures in Apgar Village and Campground and only 29 light fixtures in Polebridge (Figure 33). We observed that the Northern Lights Saloon, a restaurant located outside of park boundaries, 1.4 miles south of the Polebridge Ranger station, had non-compliant outdoor lighting, including a set of unshielded string lights (Figure 34). These lights could have had a negative impact on the SQM measurements. Regarding outdoor lighting fixtures, Polebridge was 14% compliant, whereas Apgar Village and Campground was 62% compliant (Figure 37). The lower compliance at Polebridge could have also caused the lower sky quality measurement at that location.

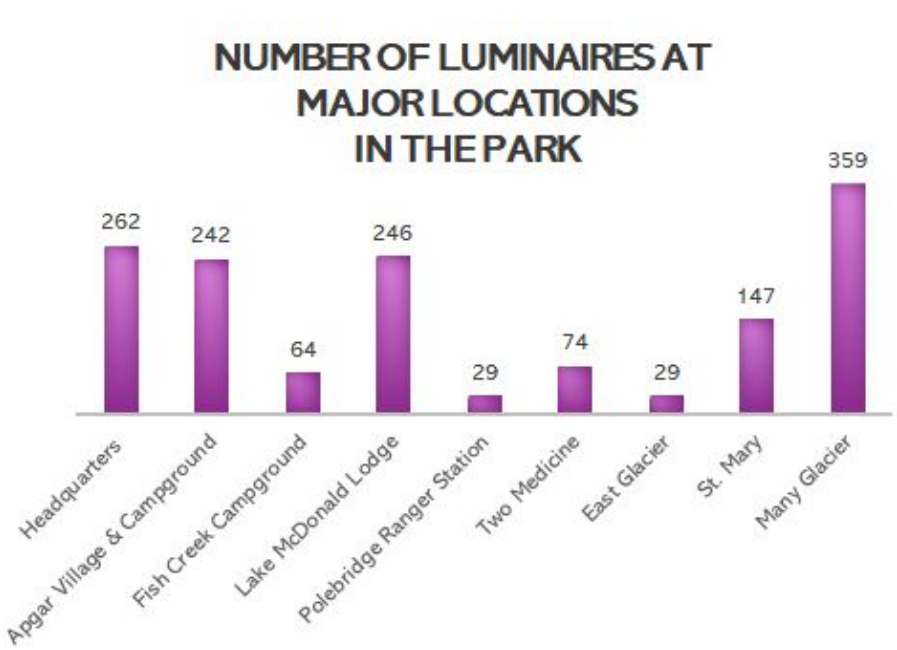



Figure 33. Individual locations around Glacier National Park along with the number of luminaires, or lighting fixtures, present at that location.

Figure 34: The Northern Lights Saloon with non-compliant string lights (R., 2021).

## Findings Related to Inventory Taking

Our second objective was to implement an ArcGIS lighting inventory system and obtain an accurate lighting inventory of the Park. Ed Eberhardy, a Physical Science Technician and co-sponsor of this project, was concerned that inventory takers missed some light fixtures during the initial inventory for their IDSP application (E. Eberhardy, personal communication, April 19, 2023). To address this, we conducted a new inventory and collected data at locations not included in the old inventory, such as Lake McDonald Lodge. We identified locations of previously collected data from the spreadsheets.

We completed the lighting inventory of the 262 light fixtures in the Headquarters area of the Park in approximately three hours on September 13th, 2023. We used this timing information along with an estimate of the number of lights in each area (from the original inventory) to plan out our other inventory days.

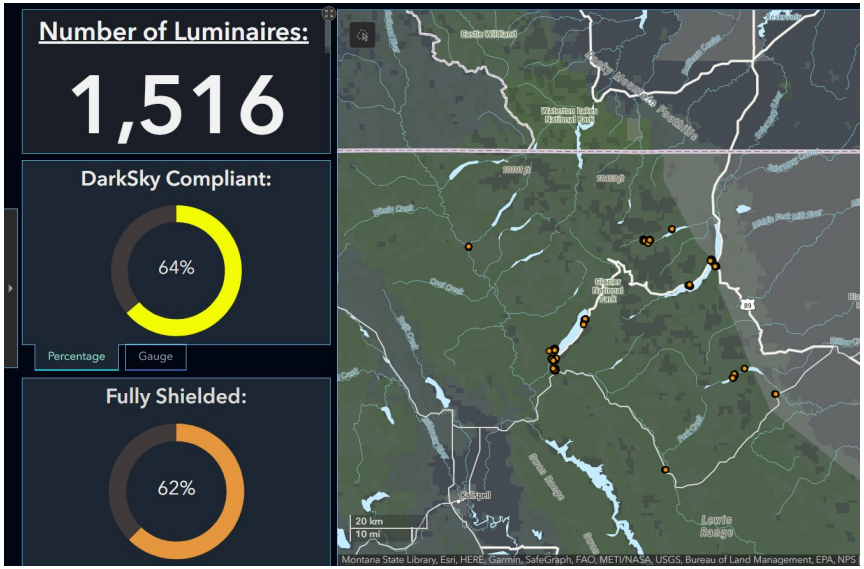



Figure 35. The main ArcGIS dashboard shows the total number of luminaires visible on the map as well as the compliance percentage and fully-shielded percentage.

## Reviewing and Analyzing Attributes

**We logged a total of 1,516 luminaires, or light fixtures, in Glacier National Park, accounting for approximately 94% of the Park's total fixtures**. After our first inventory trip, we found discrepancies in data taken by different team members and agreed upon a standardized way to interpret lighting attributes. This consisted of readdressing how we determined attributes such as shielding status. We ensured that fields were filled out with "Unknown" rather than left blank if we did not know an attribute value (such as bulb type or luminaire control) so that we collected accurate and comparable data. In the previous inventory, different groups of people inventoried each location, leading to a lack of consistency in logged attributes. This led to uncertainties when calculating compliance each year.

**We found that the ArcGIS dashboard made it straightforward to analyze the lighting inventory** (Figure 35). After working with it, we were able to change the formula that calculated compliance in order to count emergency lights as compliant, even if they were not shielded, since DarkSky International counts emergency lights as compliant. Ed Eberhardy, who leads many of the Park's dark sky efforts, found the height attribute important to determine if a ladder was needed to retrofit or replace a light. Thus, we created a filter that allows users to sort light fixtures via height range. **We also found that users can filter data utilizing other collected attributes, such as shielding status, bulb type, task, fixture type, recommended action, and luminaire control** (Figure 36). The Park can use these filters to analyze data in the ArcGIS inventory system.

**Filtering Options of ArcGIS**

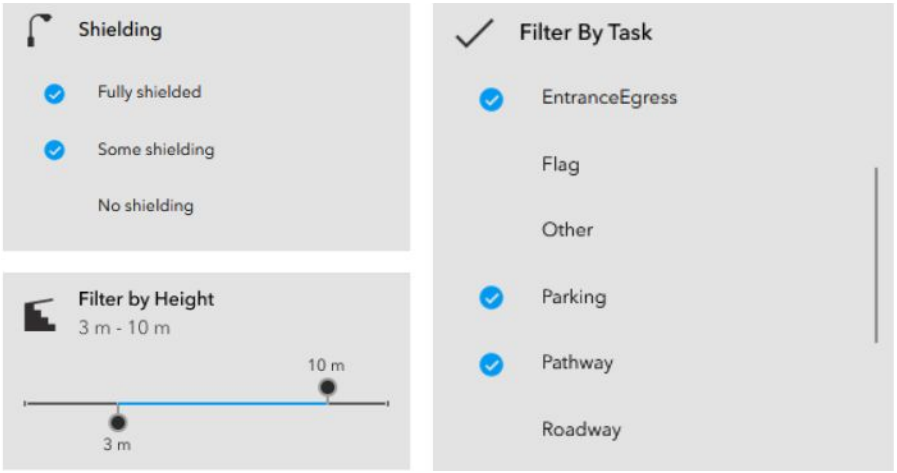



Figure 36. The ArcGIS dashboard is capable of filtering lighting data by each attribute.

## Lighting Compliance Analysis

**Given the 1,516 lights we inventoried, we found that Glacier National Park was 64% compliant as of October 2023** (Figure 35). **This is a decrease from the previous lighting compliance percentage of 73.5% in 2022, and is lower than the anticipated 90% compliance by the end of 2023**. One possible reason for this discrepancy is that the last inventory missed a number of non-compliant lights. For example, in the Headquarters area, the old lighting inventory had a total of 225 inventoried lighting fixtures, while during our inventory, we found 261 lighting fixtures in the area. With more fixtures being logged, this could lead to an increase in recorded non-compliant fixtures, lowering the overall recorded compliance. Additionally, compliance may have been previously inaccurate due to inconsistency within the data logged.

**Compliant Light Across Glacier National Park**

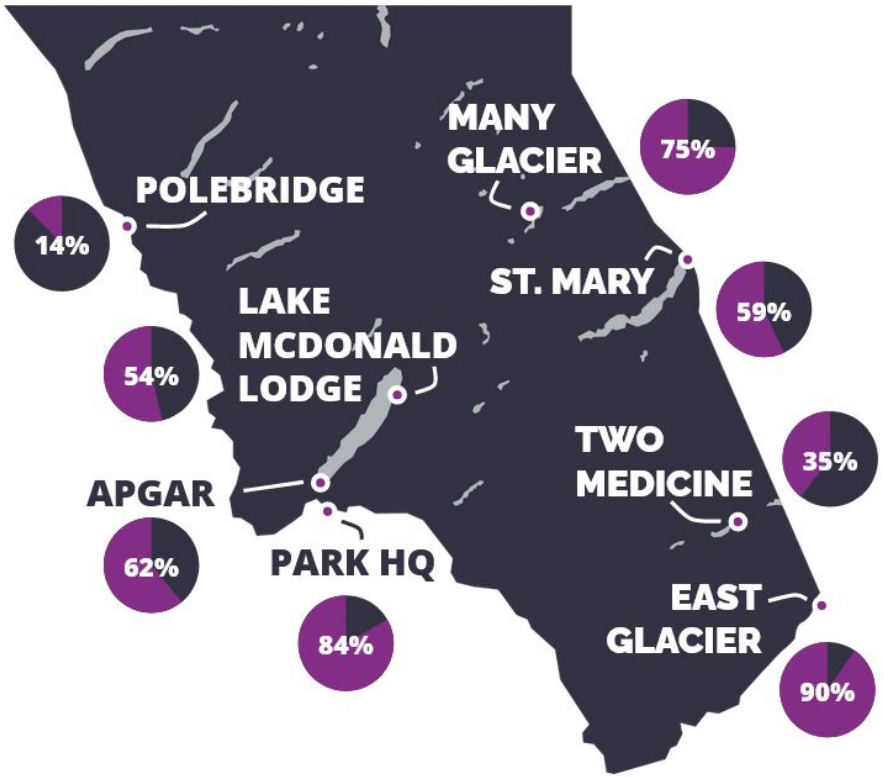



Figure 37. Display of percentages of compliant lighting at each major location around the Park, with East Glacier being the most compliant and Polebridge being the least compliant.

## Lighting Ownership

Jim Willis, the West Side Electrician, and Mark Biel, Natural Resources Program Manager and co-sponsor of this project, informed us that in the Headquarters area, 18 of the Park's lights are property of Flathead Electric, an electrical company the Park contracts for lighting, including road lighting (Biel, 2021). They recalled that since becoming an International Dark Sky Park in 2017, park staff have tried to contact Flathead Electric to urge them to retrofit the non-compliant lights in the Park that they own, but to no avail. The Electrician and Natural Resources Program Manager say **these non-compliant lights decrease Glacier National Park's compliance rate because the Park cannot retrofit lights owned by Flathead Electric**.

## Findings from Park Staff Interviews

We conducted twelve semi-structured interviews with park staff from different work groups and held one focus group with wildlife technicians who work in our sponsor's office. Each of these staff members were aware that Glacier National Park had been recognized as an IDSP. Five key informant interviews with Debby Smith (Hudson Bay District Interpreter), Lee Rademaker (Grand Teton Supervisory Park Ranger), Kylie Caesar (Science Communication Specialist), Jim Willis (West Side Electrician), and Erin Madsen (Housing Manager), were especially helpful for gaining an understanding of personal experiences, emotions associated with the dark night sky, and feedback on staff outreach material (Key informant interview questions are in Appendix B).

| Key Informant | Title | Relation to Dark Sky |
|---|---|---|
| **Erin Madsen** | Housing Manager | Has insight on increasing dark sky compliance in the housing area. |
| **Debby Smith** | Hudson Bay District Interpreter | Runs Glacier National Park's dark sky interpretive events. |
| **Lee Rademaker** | Supervisory Park Ranger at Grand Teton National Park | Helped establish many of Glacier National Park's current astronomy programs. |
| **Jim Willis** | West Side Electrician | Has retrofitted some streetlights in the Park and will likely retrofit many more lights in the future. |
| **Kylie Caesar** | Science Communication Specialist | Has expertise in reaching park staff on important scientific efforts. |

Table 2. Key Informants, their title, and relation to our project. Lee Rademaker is a former Park Astronomer at Glacier National Park.

We conducted seven interviews that were semi-structured ad hoc interviews. These interviews occurred when conducting field work where we interviewed any willing staff we came across (Interview questions are in Appendix B). We asked park staff about their emotional connection to the night sky. Staff described how the night sky makes them feel, showcasing the deep impact the dark sky has on Glacier National Park employees. **Interviewees described the dark sky as "amazing," "magical," "calming," and "overwhelming"** (Figure 38).

The majority of our interviewees recalled a significant experience with the dark sky that they wished to share with us. They described experiences, saying "the sky dances" when discussing the Northern Lights and feeling as though "this cannot be real" when witnessing all the stars an unpolluted night sky holds (Figure 38).


Figure 38. Dark sky experiences gathered from staff interviews.

Interviews also brought to light a problem with employee access to the Star Party at Logan Pass. Four employees we interviewed mentioned having **difficulty getting tickets to attend the Star Party**, or they knew of colleagues that ran into similar issues. Erin Madsen, the Glacier National Park Housing Manager, explained the high interest in the Logan Pass Star Party. She believed that the **ten reserved car spots for park staff were not an adequate number of spaces for interested staff**. Matthew Applegate, the West Glacier Housing Assistant, explained his inability to attend the Star Party due to a lack of reserved employee spots. Five park staff were in favor of the idea of a staff shuttle to the Star Party.

Figure 39. The Northern Lights at Lake McDonald in Glacier National Park. Photo by James Kiefer.

The Glacier National Park Housing Manager also discussed increasing tenant access to dark sky compliant bulbs. Tenants are often responsible for changing their own light bulbs. **Currently, compliant bulbs are not available at the housing supply location for tenants in the Headquarters area.**

## Staff-Based Outreach Material

Dr. Sharolyn Anderson, Ed Eberhardy, and Mark Biel highlighted that dark sky outreach **material for park staff would be beneficial to the Park, with an additional focus on material for electricians and facilities staff.**

## Inspiring Staff with Outreach

Debby Smith and Kylie Caesar, key informants who work directly with interpretive material, provided insight on how to reach park staff as a whole and electricians and facilities staff specifically. Debby Smith, the Hudson Bay District Interpreter, said that since facilities workers and electricians are out in the field often, "old-school printing and posting" is likely a better way to reach them with material on Glacier National Park's dark sky. Kylie Caesar emphasized the importance of easy-to-access material for electricians and facilities workers due to their often busy schedules. Three interviewees, Matthew Applegate, Erin Madsen, and Debby Smith, mentioned that **paper-based outreach material could be an effective way to spread information amongst park staff about the dark sky.** Wildlife Biologist Lisa Bate and Wildlife Technicians Megan Potter, Gabriella Eaton, and Kaile Kimball, also agreed that paper-based material would be effective in reaching park staff. The West Glacier Housing Assistant said having a physical reminder in the form of paper material, which can be quickly referenced, is better than receiving an email which is easy to forget about.

Alternatively, Erin Madsen, Lee Rademaker, Jim Willis, and Megan Potter recommended **interactive digital material as an effective method of dark sky outreach.** Conversely, Kylie Caesar, Science Communication Specialist, made the point that it is important to connect to park staff through in-person dark sky experiences and events. This feedback helped us develop two paper-based forms of outreach, one interactive webpage, and a staff-engagement program.

Figure 40. The Northern Lights at Lake McDonald in Glacier National Park. Photo by Jonathan Wessler.

## "Defend the Dark" Pamphlet

We developed a pamphlet, called "Defend the Dark," geared towards electricians and facilities personnel. Dr. Sharolyn Anderson, a Physical Scientist of the NPS, highlighted the **importance of facilities workers and their role in protecting the dark sky. They are the work group most directly involved in lighting retrofits and replacements, which is vital to increasing the Park's lighting compliance**. The primary goal of the pamphlet was to emphasize the importance and impact of electricians and facilities workers and to generate more awareness among these professionals about the importance of dark sky compliance. The pamphlet includes a brief summary of dark skies and light pollution, an overview of lighting compliance, a section on how the dark sky is meaningful to park staff, and a section highlighting the vital role electricians and facilities employees play in protecting Glacier National Park's dark sky (Figure 41).


Figure 41. "Defend the Dark" pamphlet targeted towards electricians and facilities employees of Glacier National Park.

## "The Astronomical Allure of Glacier National Park" Poster

We developed a poster, titled "The Astronomical Allure of Glacier National Park," to be displayed in staff high-traffic areas (break room, refrigerator, and building entrances and exits) to **catch staff's attention and generate more interest in the dark sky and Glacier National Parks efforts.** This poster includes dark sky photos taken in the Park, GNP dark sky fun facts, and astronomical information (Figure 42). We also highlighted the interpretive staff's willingness to share their expertise with other park staff on astronomy and the Park's astronomical capabilities. Debby Smith, the Hudson Bay District Interpreter, offered to show park staff the telescope in the Dusty Star Observatory.

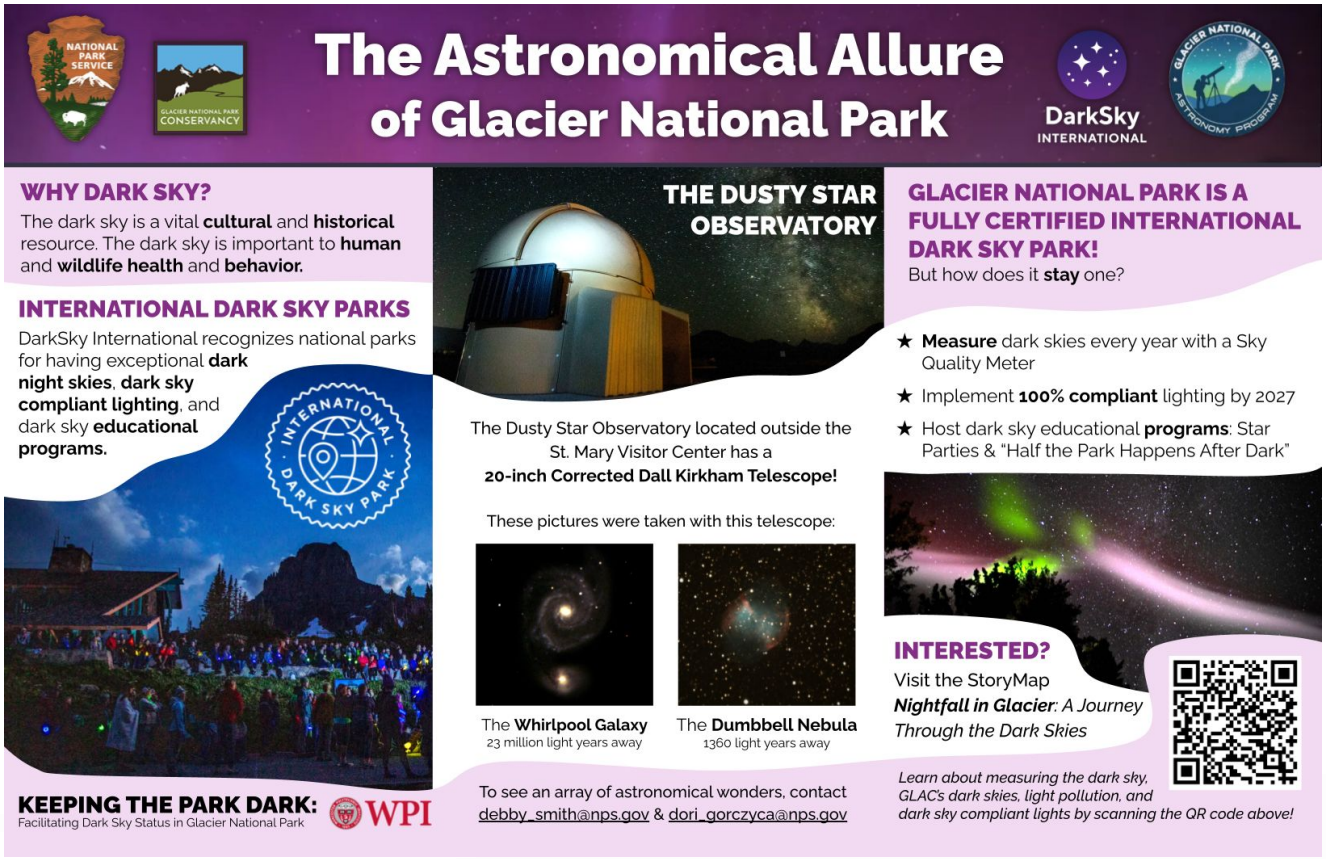



Figure 42. Awareness-raising poster highlighting the Dark Sky, International Dark Sky Parks, the Dusty Star Observatory, and Glacier National Park's dark sky efforts.

## "Nightfall in Glacier: A Journey Through the Dark Skies" StoryMap

Along with the hard-copy educational materials, we created a StoryMap about the Park's dark sky efforts. ArcGIS StoryMaps allow users to insert ArcGIS maps, videos, photos, and text to turn their data into a visual story (ESRI, n.d.). Our StoryMap, "Nightfall in Glacier: A Journey Through the Dark Skies," includes a time-lapse image of the Northern Lights taken at Apgar Village, photos of the Park's dark skies, an interactive map showing information about sky quality measurement locations, and the Park's ArcGIS lighting inventory (Figure 43). It also includes informative sections on the importance of the dark sky, DarkSky International, the IDSP program, and resources for users to learn more. **The StoryMap allows a greater amount of information to be shared compared to paper-based outreach material**. A scannable QR code located on the poster and pamphlet allows any interested readers to explore the StoryMap.

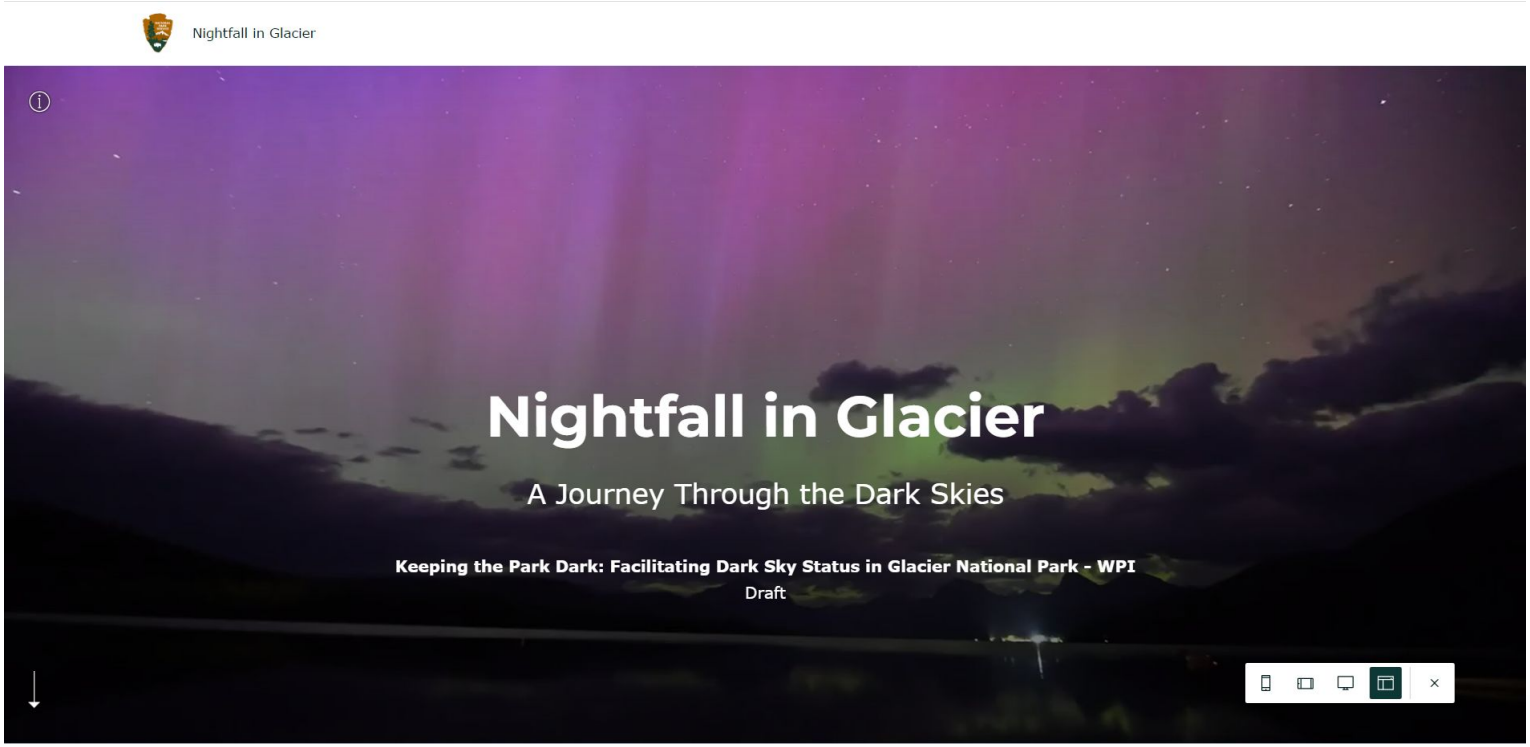
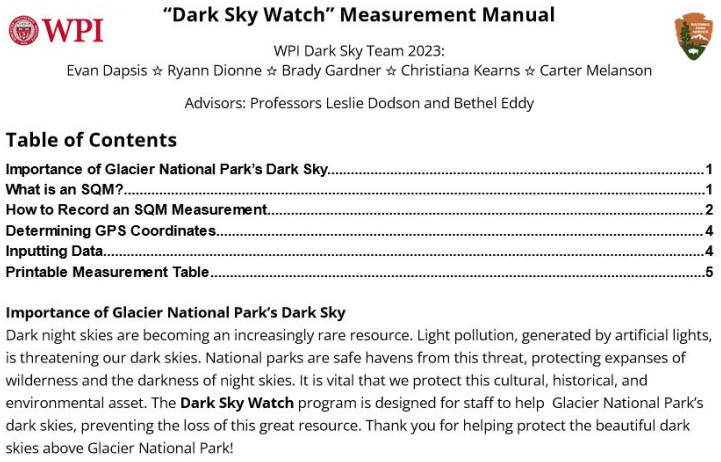



Figure 43. Cover page of the StoryMap featuring a timelapse of the Northern Lights. See Appendix E. Timelapse by Jeffrey Whelehon.

## The "Dark Sky Watch" Program

We also developed the **"Dark Sky Watch" citizen science program to cultivate more excitement about the dark sky among staff and for the Park to collect data on the darkness of the sky in backcountry locations**. We created material that the Park can use to initiate this sky quality measurement program. Ed Eberhardy had proposed setting up backcountry sky quality meter (SQM) locations two years ago, and Debby Smith brought forth the idea of a program in which staff who are going on backcountry trips in the Park can borrow an SQM and take measurements. We created a user manual (Figure 44) on how to use the SQM and included a printable data table that volunteers can use to fill out measurements while in the field (Figure 45). We also created a Microsoft form that volunteers can use to submit their measurements upon returning to Wi-Fi connection or cellular service. The "Dark Sky Watch" program invites interested staff who are going on backcountry trips during a new moon to participate. These staff members could take measurements at any backcountry site or campground, however, Mark Biel, Natural Resources Manager who submits the IDSP report annually, suggested that there be some consistency in backcountry locations. He suggested two specific backcountry sites, Goat Haunt and Belly River, where staff could take measurements (M. Biel, personal communication, September 28, 2023). These measurements are intended to be used by the Park as data points to compare to SQM measurements along the Park borders and can be used to better understand the Park's dark sky dynamics.



WPI

**"Dark Sky Watch" Measurement Manual**

WPI Dark Sky Team 2023:
Evan Dapsis ☆ Ryann Dionne ☆ Brady Gardner ☆ Christiana Kearns ☆ Carter Melanson

Advisors: Professors Leslie Dodson and Bethel Eddy

**Table of Contents**



**Importance of Glacier National Park's Dark Sky**

Dark night skies are becoming an increasingly rare resource. Light pollution, generated by artificial lights, is threatening our dark skies. National parks are safe havens from this threat, protecting expanses of wilderness and the darkness of night skies. It is vital that we protect this cultural, historical, and environmental asset. The **Dark Sky Watch** program is designed for staff to help Glacier National Park's dark skies, preventing the loss of this great resource. Thank you for helping protect the beautiful dark skies above Glacier National Park!

Figure 44. Portion of first page of "Dark Sky Watch" Measurement Manual. See Appendix G.

| Date | Time | Location | Latitude | Longitude |
|---|---|---|---|---|
| | | | | |
| SQM Readings: | | % Cloud Cover: | | |
| 1 | | % Moon Visibility: | | |
| 2 | | Temp [˚F]: | | |
| 3 | | Notes: | | |
| 4 | | | | |
| 5 | | | | |

Figure 45. A printable measurement table intended to be taken with an SQM to measure sky quality at backcountry locations.

## Limitations

We encountered limitations while gathering lighting inventory data. We faced challenges gaining access to inventory sites during inventory collection. For example, the only means of getting to the Goat Haunt Ranger Station was via ferry from Waterton Lakes National Park in Canada or by a multi-day backpacking trip in northern Glacier National Park. We were unable to take inventory there. Additionally, we could not access the Lake McDonald Ranger Station because of a road closure. We tried to complete the inventory at Rising Sun but were not able to finish due to bear activity.

Due to general time constraints, we were not able to perform night visits for the entire lighting inventory. We also faced challenges with our mobile phone batteries. Our mobile phones usually lost significant charge over the course of the inventory on days where collecting data took longer than four hours. We combated this challenge with portable chargers.

Figure 46. Taking a CCT measurement of a lamppost at night with a Spectrometer. Photo by Evan Dapsis.

# RECOMMENDATIONS

Key informants and interviewees have illuminated some of the Park's dark sky challenges, and we utilized their feedback to determine recommendations for the Park. Through discoveries and experiences during our fieldwork, we also generated recommendations on what park staff can do to boost the Park's progress toward 100% dark sky compliance. We recommend that the Park increase staff access to Logan Pass Star Parties with shuttles and a carpool program, increase access to compliant lighting for housing, coordinate in-person dark sky events and information sessions, switch from SQMs to SQM-Ls, complete the ArcGIS inventory, and determine a plan to update the ArcGIS inventory and StoryMap.

## **Recommendation 1**: Increase Staff Access to Logan Pass Star Parties with Shuttles and a Carpool Program

Our interviews with park employees illuminated a strong interest in attending these Logan Pass Star Parties but difficulty getting to them due to a lack of reserved staff spots and ease of transportation. We suggest that the Park implement an employee shuttle to the Logan Pass Star Party as well as a carpool program to increase the number of employees able to attend the event. The ten car spots set aside for park staff can transport approximately fifty park employees at most, with the average car having five seats. Going-to-the-Sun Road shuttles reserved for park employees to and from the Star Party could drastically increase that number, since one shuttle can fit 12 to 15 people.

We recommend that the Park reserve Going-to-the-Sun Road shuttles from both Headquarters and the St. Mary Visitor Center to drive park staff to and from Logan Pass Star Parties. The number of shuttles required could change based on employee interest for the event. We recommend that the Park advertise the shuttle service by email and posters set up in break rooms and other common areas. Interpretive staff might also email out an online sign-up sheet to register for the Star Party shuttles.

A carpool program would allow drivers willing to take fellow employees to the Star Party to sign-up as a driver for the program. The sign-up sheet could be an online form advertised by the Park through email and posters around the Park. Drivers could enter their vehicle's passenger capacity, updating the total number of passengers able to sign up. Employees who want to attend but not drive could sign-up as a passenger.

The carpool program could allow for 10 drivers and approximately 40 passengers, maximizing the total number of employees able to attend the Star Party program within the 10 reserved car tickets. An employee Star Party shuttle system and carpool program could allow more employees to learn about the requirements for the Park to maintain its International Dark Sky Park status, increasing general excitement and spreading awareness of dark sky compliance.

Figure 47. Going-to-the-Sun Road Shuttle. (Glacier National Park, n.d.).

## **Recommendation 2**: Increase Access to Compliant Lighting for Housing

Currently, the housing supply location in the Headquarters area does not carry compliant light bulbs for tenants. Since many tenants replace their own bulbs, it is essential that they know about the Park's dark sky compliance efforts to replace inoperable bulbs with compliant ones. Currently, the housing supply stores non-compliant light bulbs which could be replaced with compliant light bulbs once depleted. For the time being, the Park could store dark sky compliant bulbs in an easily accessible location and notify tenants.

Figure 48. Dark sky compliant shielded bulb installed on a house in Headquarters. Photo by Christiana Kearns.

We recommend the Park make new tenants and seasonal employees aware of this resource with their move-in instructions, and the Park could send out information regarding dark sky compliance in the park staff newsletter to inform current tenants. Our "Defend the Dark" pamphlet could be included in these instructions so that tenants are aware of dark sky compliant lighting, and they can recognize the importance of bulb type when replacing their light bulbs. This effort would aid in maintaining the Park's lighting compliance, preventing it from decreasing when tenants replace bulbs.

## **Recommendation 3**: Coordinate In-Person Dark Sky Events and Information Sessions

Kylie Caesar, the Science Communication Specialist of Glacier National Park, as well as our sponsor Ed Eberhardy, Physical Science Technician, noted the impact of in-person educational experiences. Speakers from the NPS, experts in dark sky protection, or Glacier National Park's volunteer astronomers could be invited as speakers for events such as the brown bag lunch program and "Nerd Nights." In-person gatherings could be paired with the "Defend the Dark" pamphlet, "Nightfall in Glacier: A Journey Through Glacier National Park's Dark Skies" StoryMap, or the Staff Citizen Science Program, "Dark Sky Watch," so that interested employees can become more involved. The Science Communication Specialist also recommended incorporating the "Defend the Dark" pamphlet in facilities and electrician orientation programs. Pairing the dark sky outreach material with in-person experiences could result in more staff who are aware and excited about the Park's dark sky efforts and goals.

## **Recommendation 4**: Switch to SQM-Ls

The Sky Quality Meter with lens (SQM-L) is more accurate than the SQM the Park currently uses due to the SQM-L's 30 degree narrower field of view. Nearby lights and trees affect the SQM-L reading less because of this narrower field of view (Unihedron, n.d.). We recommend that park staff switch to SQM-Ls. This would help the Park acquire more accurate and precise sky quality measurements, allowing a better understanding of its dark sky dynamics. More accurate measurements would also aid with the annual IDSP report and thus the Park's overall IDSP status.

As of October 2023, the retail price of the SQM-L was $155.00 per unit, only $17.00 more than the SQM ($138.00). We hope the Park can find room in the budget to purchase the SQM-Ls. If there is no room in the budget, we suggest that the Park appeal to the Glacier National Park Conservancy for funding. We recommend the Park purchase at least four SQM-Ls, so each side of the Park (East and West) possesses two. These four could be used for the annual sky quality measurements and the number could increase depending on the interest in the "Dark Sky Watch" program.

## **Recommendation 5**: Complete the ArcGIS Inventory

Having both day and night visit data for every light fixture would increase analysis ability of compliance and prepare the Park for stricter DarkSky International standards if implemented. Inventory takers can refer to the "ArcGIS Lighting Inventory User Manual for Dark Sky Parks" for both day and night visit data collection procedures.

We recommend that staff at Glacier National Park complete the day visits to areas we were unable to get. We were unable to get to Goat Haunt, the Lake McDonald Ranger Station, and a portion of Rising Sun.

We also recommend interns or volunteers gather night visit data on all lighting fixtures for the Park. We conducted one night visit to Headquarters to understand the night visit data collection process and to serve as an example for future night visits. Gathering night visit data aids in fully understanding the performance of each light fixture, and the NPS recommends that parks collect this data.

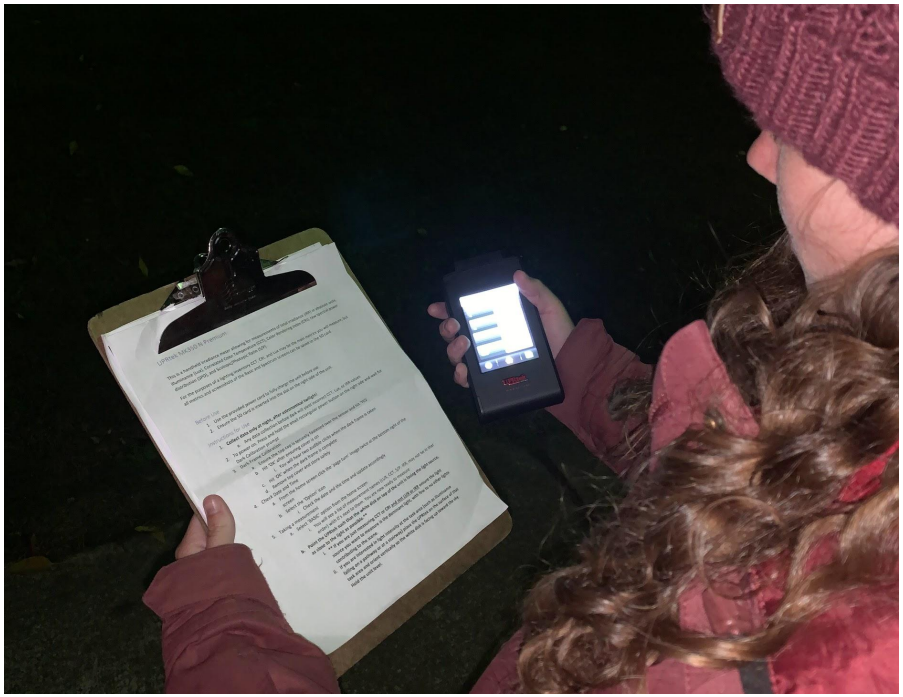


Figure 49. Looking at directions for how to use the spectrometer. Photo by Evan Dapsis.

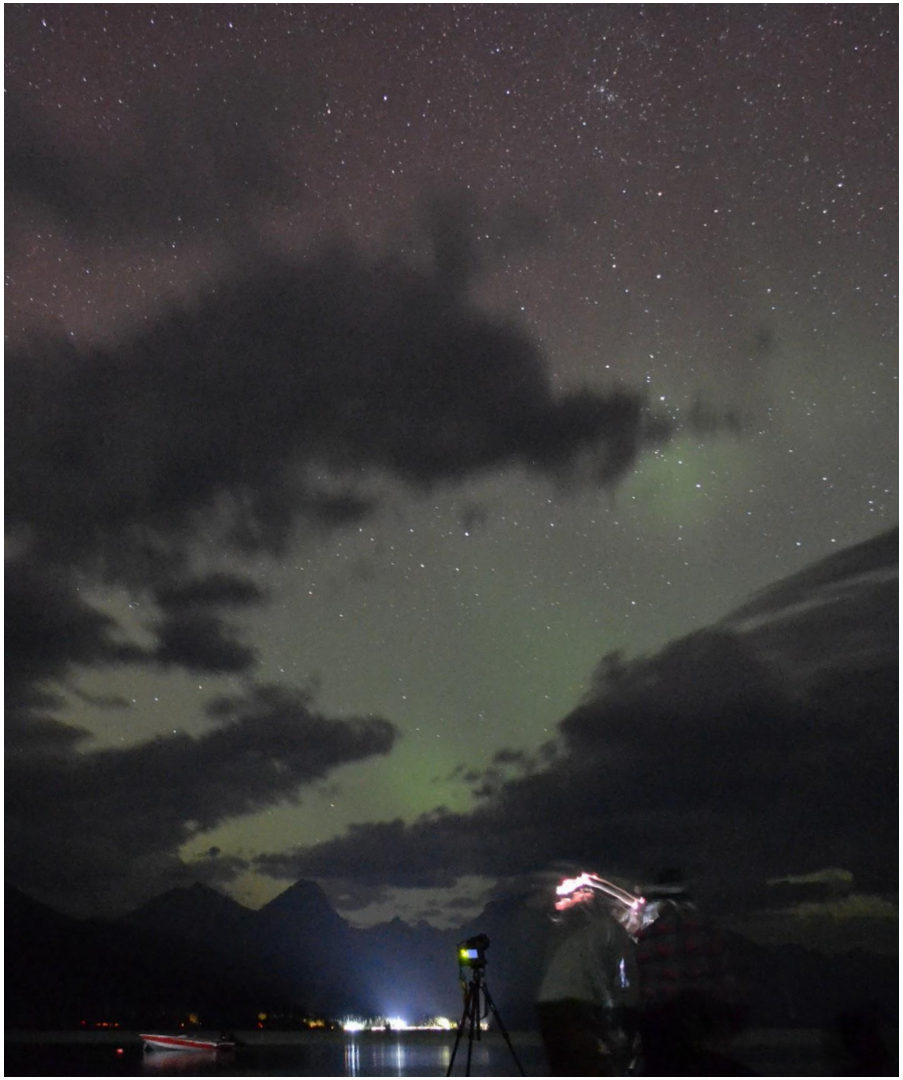


Figure 50. The Northern Lights above Lake McDonald. Photo by Jonathan Wessler.

## **Recommendation 6**: Determine a Plan to Update ArcGIS Inventory and StoryMap

The ArcGIS lighting inventory system will likely continue to be a useful resource for the Park to determine lighting compliance. However, the system will require a manager to make updates when electricians and concessionaires perform lighting retrofits in the Park. We recommend Glacier National Park assign a person to be the manager of the ArcGIS inventory who will know when any changes are required to be made.

Additionally, we suggest that a semiannual tenant survey be sent out to request that tenants submit any bulb changes they have made to their housing unit. These responses can then be used to update the current ArcGIS data points.

Alternatively, the housing supply location could keep a bulb replacement log that tenants fill out when retrieving a bulb. This log would keep track of what bulb is being used and the tenant's housing number. The ArcGIS lighting inventory manager could refer to this log and update the altered data point accordingly.

Awareness of lighting retrofits around the Park is also vital: we recommend that the lighting inventory manager update the ArcGIS inventory accordingly after retrofits.

Furthermore, we recommend this manager make updates to the "Nightfall in Glacier: A Journey Through the Dark Skies" StoryMap. We recommend that if any new SQM locations are added, the ArcGIS manager updates the StoryMap. We suggest someone spearhead these endeavors in order to preserve the accuracy of the Park's dark sky status.

# ETHICAL CONSIDERATIONS



There is one significant ethical consideration we pondered during this project. A notable study showed that people feel safer when there is more lighting present (Painter, 1988). Part of the lighting inventory is to determine attribute values for each light, and one such attribute that we had to determine was “recommended action.” The options for this attribute were: “retrofit,” meaning to replace the entire light fixture, “replace,” meaning to replace the bulb, “remove,” meaning to get rid of the light, or “no action.” Since people feel safer with more lighting, we have made sure to only select “remove” on the recommendation attribute of the lighting inventory when there was enough lighting redundancy that we thought people would still feel safe. Lighting redundancy means that there is more than one light performing the same task. For example, many lights for which we selected “remove” were non-compliant entrance lights that had compliant entrance lights for the same entrance. Our focus when determining the recommendation attribute was geared more toward identifying lights that were not shielded or had a high correlated color temperature and recommending that the Park retrofit or replace those lights. We did not suggest that the Park remove as many lights as possible. Especially in bear country, it is important to make sure that there is adequate visibility at night so campers and other park guests feel safe.

Figure 51. Stars above Apgar Village. Photo by Jonathan Wessler.

# TEAM REFLECTION

Our entire dark sky team is grateful that we were able to work on this project. Dr. Sharolyn Anderson told us: “You will look at lights differently forever,” and we have found this statement to be true. We are elated to see fully shielded lights that are yellow, and we cringe at the sight of blue-light LEDs that emit an immense amount of glare. As we worked in the Park on this project, we came to the realization that the dark sky effort is much more substantial than we initially thought, and it was inspiring to be a part of something that is so meaningful to people who visit and work in the Park. We originally thought dark sky played a much smaller part in Glacier National Park, but after attending the Star Party and talking to staff, we saw how the demand for dark sky programs exceeds the Park’s capacities.

# TEAM REFLECTION



This project has helped us reflect on our own dark sky experiences and appreciation of the night sky. We were in pure awe when we got the privilege to see the Northern Lights so clearly from the beach at Apgar Village, and we never expected to have such an amazing night sky experience here. We went to the beach at Apgar Village multiple times at night to look at the stars and greatly enjoyed learning about constellations and astronomy at the Logan Pass Star Party and the "Half the Park Happens After Dark event." Ryann even bought a night-sky themed deck of cards from the Logan Pass Visitor Center. We also joined DarkSky International's monthly newsletter to stay updated on all things dark sky.

Furthermore, we found it inspiring to work with the National Park Service. We encountered so many people who were enthusiastic about the night sky and so passionate about their own work. It was a remarkable experience to work with such kind professionals who were willing to help us with this meaningful project.

Figure 52. Collage of hiking pictures of the team and other Worcester Polytechnic Institute students in Glacier National Park. Left photo by Sophie Brochu, top middle photo by Carter Melanson, bottom middle photo by Christiana Kearns and right photo by unknown hiker.

# CONCLUSION



In this project, we assisted Glacier National Park in maintaining International Dark Sky Park status by implementing a new ArcGIS lighting inventory system, collecting all new inventory data, and creating dark sky employee outreach material. These developments aim to facilitate a smooth path to 100% dark sky lighting compliance by 2027. As of October 2023, the Park has 64% compliance, and for the most accurate compliance percentage, we suggest that Park personnel complete day visits to any light fixtures unaccounted for. Along with substantial groundwork for an accurate inventory, we created staff-centered outreach material, including a pamphlet, a poster, a StoryMap, and a staff "citizen science" program.

Glacier National Park staff and visitors greatly value the Park for its dark sky. We hope the outreach material will cultivate staff interest in the dark sky for years to come, bolstering the Park's dark sky programs as well as increasing compliance efforts. Furthermore, the outreach material created for electricians and facilities staff aims to give this work group a deeper understanding of the impact and meaning of their work. If everyone in the National Park Service finds meaning in the dark sky, it can be more easily preserved for cultural and personal enjoyment for generations to come. Fewer people are able to see the Milky Way from their homes each year, demonstrating the rarity of a dark night sky like that of Glacier National Park. Protecting this sky is just one notable step in the overall goal of dark sky awareness, allowing the preservation and protection of our deep-rooted human connections to the stars.

Figure 53. The Logan Pass Star Party (D. Smith, personal communication, September 30).

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## Focus Group Questions For Park Staff

We used these questions to understand current knowledge about GNP's dark sky initiative.

## Introduction

Hello! We are a student team from Worcester Polytechnic Institute in Massachusetts, and we are working with GNP on a project regarding dark sky preservation. We are working with Mark Biel and Ed Eberhardy. We are implementing a new lighting inventory system and will be taking external light fixture data throughout the park. Thank you for agreeing to talk with us today! We want to better understand the experiences of park staff, specifically regarding dark sky preservation efforts to gain more insight into our overall approach. There is potential that you will be quoted in our project report, do we have your permission? Would you like to remain anonymous? Are you comfortable if we take notes throughout? Feel free to reject any question or end the interview at any time. Once again we really appreciate you speaking with us today.

## Questions

- What is your name and title?
- Could you give us a brief overview of what you've been working on recently?
- What is your favorite thing about Glacier?
- Have you been able to experience the dark sky in the park at night?
- Does having a dark sky affect your field of work?
- Have you been to any of the park's dark sky programs?
    - If so, which ones and what did you think?
- Are you aware that Glacier National Park has been recognized as an International Dark Sky Park by the International Dark-Sky Association?
    - If yes, do you know what requirements the park must meet to maintain this status?
    - If yes, how did you learn this information?
- Do you know what dark sky compliant lighting entails?
- Has this information affected you to change personal property lighting fixtures or bulbs?
- Would you be interested in learning more about the park's dark sky efforts?
- What types of educational material do you find most engaging?
- That's all the questions we have, do you have any questions for us?
- Is there anyone else we can talk to that you recommend?
- Can we reach back out to you?

## End of Interview

- Ask about anonymity
- Ask about cutting out any information the interviewee is not comfortable sharing
- Thank interviewee again
- Ask for contact information

## Interview Questions For Park Staff

We used these questions to understand current knowledge about GNP's dark sky initiative.

## Introduction

Hello! We are a student team from Worcester Polytechnic Institute in Massachusetts, and we are working with GNP on a project regarding dark sky preservation. We are working with Mark Biel and Ed Eberhardy. We are building a new lighting inventory system and will be taking external light fixture data throughout the park. Thank you for agreeing to talk with us today! We want to better understand the experiences of park staff, specifically regarding dark sky preservation efforts to gain more insight into our overall approach. There is potential that you will be quoted in our project report, do we have your permission? Would you like to remain anonymous? Are you comfortable if we take notes throughout? Feel free to reject any question or end the interview at any time. Once again we really appreciate you speaking with us today.

## General Questions

- What is your name and title?
- Could you give us a brief overview of what you've been working on recently?
- Have you been able to experience the dark sky in the park at night?
- Do you have any star/dark sky stories and experiences?
- What is the value of the dark sky to you personally?
- Have you been to any of the park's dark sky programs?
    - If so, which ones and what did you think?
    - Have you experienced any difficulties attending or getting info about programs?
- Would you be interested in learning more about the park's dark sky efforts?
- Were you previously aware that Glacier National Park is an International Dark Sky Park?
    - If so, when did you find out?

## Additional Questions for Debby Smith

- What is your job title, and what does that include?
- Do visitors seem engaged with the dark sky programs?
- Do staff ever attend these events?
  - Do they seem to enjoy it?
- What is your favorite dark sky event?
- Are there currently any educational materials or programs for park staff?
  - Yes
    - What are those materials?
  - No
    - Would any visitor educational materials translate well to park staff?
- Do you like the idea of an ArcGIS StoryMap as a form of dark sky educational material?
- How would you go about increasing enthusiasm for electricians and facilities people in GNP?

## Additional Questions for Erin Madsen and Matthew Applegate

- Does having a dark sky affect your field of work?
  - If so, how?
- Do you know what dark sky compliant lighting entails?

## Additional Questions for Lee Rademaker

- What was your role when you worked in Glacier?
- What is your role now?
- What types of educational materials would you recommend we create for park staff dark sky education?

## Additional Questions for Kylie Caesar

- What types of educational materials would you recommend we create for park staff dark sky education?
- Could you give us an example of one of your favorite methods of science communication and how it was used?

# DEFEND THE DARK

Above the great expanse of **GLACIER NATIONAL PARK** lies an exceptional

## DARK NIGHT SKY... THAT'S IN DANGER!

## YOU CAN HELP

## THE THREAT? LIGHT POLLUTION

The sky is getting **BRIGHTER** and **OBSCURING STARS.**

## 80% OF AMERICANS CANNOT SEE THE MILKY WAY

## YOU HAVE THE POWER TO

## FIGHT THE LIGHT

## HOW? USE DARK SKY COMPLIANT LIGHTING



# APPENDIX C: "DEFEND THE DARK" PAMPHLET (BACK)



**ELECTRICIANS AND FACILITIES WORKERS ARE AT THE FOREFRONT OF REVERSING LIGHT POLLUTION.**

**THEY RETROFIT REPLACE & REMOVE NON-COMPLIANT LIGHTING FIXTURES.**

**THANK YOU FOR ALL YOU DO TO PROTECT**

**DARK SKY**

**KEEPING THE PARK DARK:**

Facilitating Dark Sky Status in Glacier National Park

WPI

"A sense of **PEACE**, **CALM**, **WONDER** and **CURIOSITY**"

"The sky **DANCES**"

"It's **AMAZING**–it just opens up the world"

"This cannot be **REAL**"

**ELECTRICIANS LIGHT THE WAY FOR THESE EXPERIENCES**

FASCINATING
BEAUTIFUL
GORGEOUS OVERWHELMING
**AMAZING**
AWESOME
MAGICAL
CALMING

**GLACIER NATIONAL PARK HAS BEEN AN INTERNATIONAL DARK SKY PARK SINCE**

**2017**

**TO MAINTAIN INTERNATIONAL DARK SKY PARK STATUS, THE PARK NEEDS**

**100% COMPLIANCE BY 2027...**

**BUT AS OF LATE 2023, THE PARK IS ONLY AT**

**64%***

*This percentage reflects the compliance for approximately 94% of GNP's outdoor lighting fixtures.

# APPENDIX D: "THE ASTRONOMICAL ALLURE OF GLACIER NATIONAL PARK" POSTER



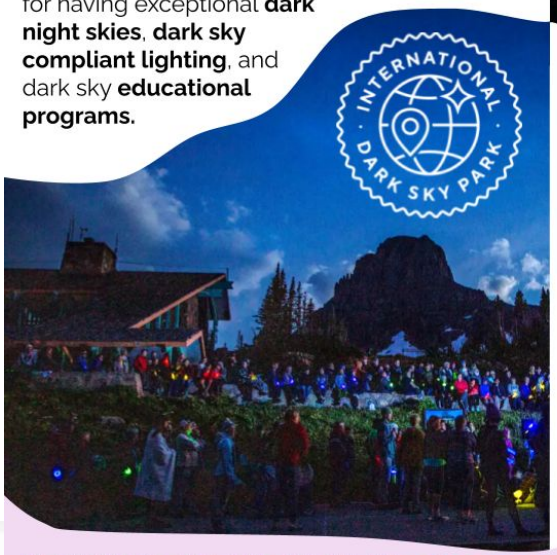
# The Astronomical Allure of Glacier National Park

## WHY DARK SKY?

The dark sky is a vital **cultural** and **historical** resource. The dark sky is important to **human** and **wildlife health** and **behavior.**

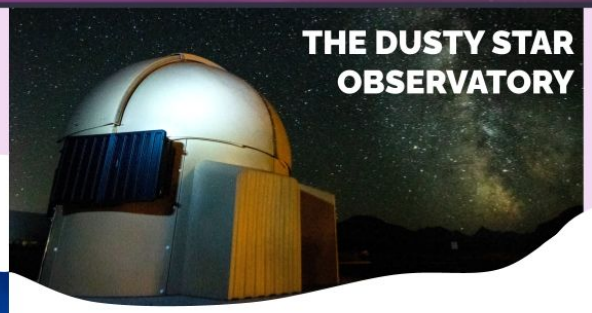
## INTERNATIONAL DARK SKY PARKS

DarkSky International recognizes national parks for having exceptional **dark night skies**, **dark sky compliant lighting**, and dark sky **educational programs.**




**KEEPING THE PARK DARK:**
Facilitating Dark Sky Status in Glacier National Park

WPI



## THE DUSTY STAR OBSERVATORY

The Dusty Star Observatory located outside the St. Mary Visitor Center has a **20-inch Corrected Dall Kirkham Telescope!**

These pictures were taken with this telescope:

The **Whirlpool Galaxy**
23 million light years away

The **Dumbbell Nebula**
1360 light years away

To see an array of astronomical wonders, contact debby_smith@nps.gov & dori_gorczyca@nps.gov

## GLACIER NATIONAL PARK IS A FULLY CERTIFIED INTERNATIONAL DARK SKY PARK!

But how does it **stay** one?

- ★ **Measure** dark skies every year with a Sky Quality Meter
- ★ Implement **100% compliant** lighting by 2027
- ★ Host dark sky educational **programs**: Star Parties & "Half the Park Happens After Dark"

## INTERESTED?

Visit the StoryMap ***Nightfall in Glacier**: A Journey Through the Dark Skies*

*Learn about measuring the dark sky, GLAC's dark skies, light pollution, and dark sky compliant lights by scanning the QR code above!*

# APPENDIX E:

"Nightfall in Glacier: A Journey Through The Dark Sky" StoryMap

# Nightfall in Glacier

## A Journey Through the Dark Skies

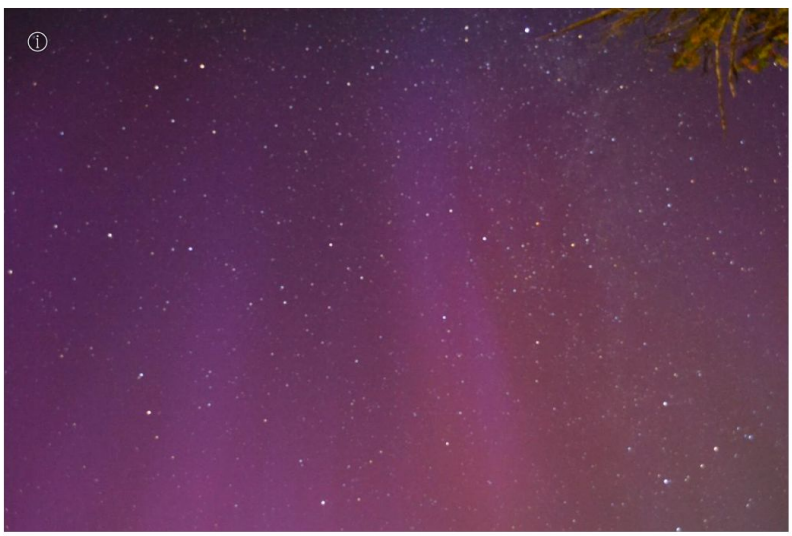
**Keeping the Park Dark: Facilitating Dark Sky Status in Glacier National Park - WPI**
October 11, 2023



## The Importance of Dark Skies

People have long apppreciated the allure of the unpolluted sky in Waterton-Glacier International Peace Park. The dark sky is recognized as a cultural and historical resource. Indigenous peoples including the Blackfeet and Kootenai have cherished the dark sky for generations.

> ***"I get this feeling that I'm standing in heaven."***
> *Rising Wolf, a member of the Blackfeet tribe*
> *(*Carbaugh, D., & Grimshaw, E., 2021*)*



The northern lights at Lake McDonald in Glacier National Park

DarkSky International is motivated to uphold the **cultural**, **spiritual** and **recreational** value of the dark sky. The Association aims to limit light pollution by reducing unnecessary artificial light and by implementing dark sky-friendly lighting around the world.

# DarkSky International

DarkSky International, formerly known as the International Dark Sky Association, is dedicated to protecting the night sky through their mission:

***"To restore the nighttime environment and protect communities and wildlife from light pollution"***(DarkSky International, 2023).

DarkSky International Logo

DarkSky International is motivated to uphold the **cultural**, **spiritual** and **recreational** value of the dark sky. The Association aims to limit light pollution by reducing unnecessary artificial light and by implementing dark sky-friendly lighting around the world.

## International Dark Sky Parks

DarkSky International coordinates the International Dark Sky Park (IDSP) program, which recognizes parks around the world as **exceptional in protecting the night sky**. International Dark Sky Parks are defined as "publicly or privately owned conservation areas that implement good outdoor lighting and provide dark sky programs"(DarkSky International, 2023).

International Dark Sky Park Seal

To become an IDSP, a park must submit an application to DarkSky International and fulfill three core requirements:

1. **Dark night skies**
2. **Responsible outdoor lighting**
3. **Educational and interpretive programs on the night sky**

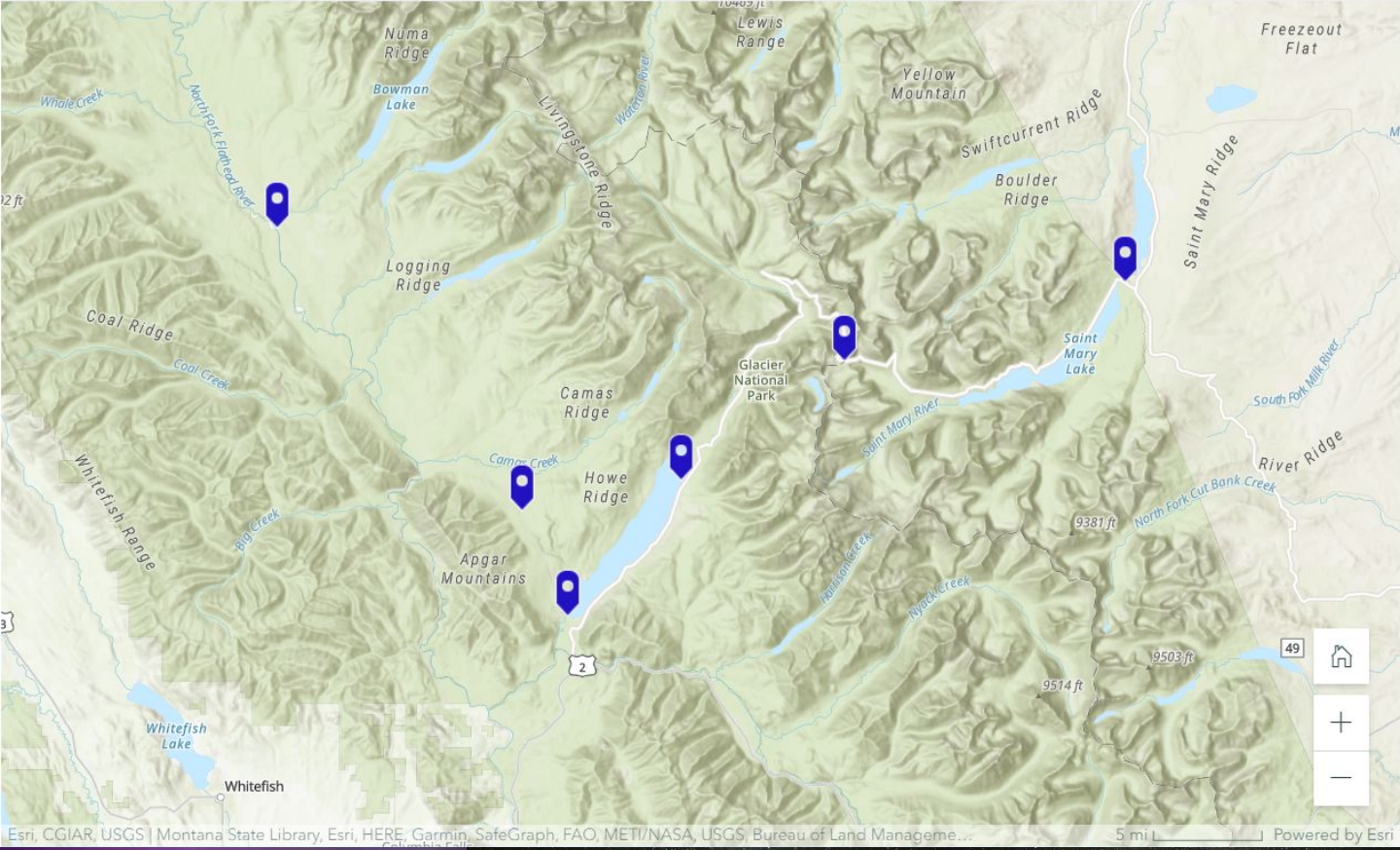
After the application is accepted, an annual report is required to track the park's progress regarding the three requirements above. Glacier National Park received provisional International Dark Sky Park status in 2017 and full certification in 2021.

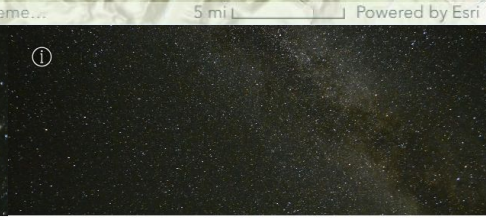


# Measuring The Dark Sky


A Sky Quality Meter with lens, or SQM-L, displaying the recorded magnitudes per square arcsecond

IDSP's "dark night skies" requirement means that Glacier National Park must measure the sky darkness at least once per year to affirm that the night sky is **staying dark or getting darker**. A **Sky Quality Meter with lens (SQM-L)** is a device that measures the darkness of the sky. The device measures sky quality such that the closer the reading is to 22 magnitudes per square arcsecond (mpsas), the darker the sky. To be an IDSP, the Park must have an overall measurement between 21.2 and 22 mpsas.



## Apgar Village

The Apgar Visitor Center holds "Half the Park Happens After Dark." A program where volunteer astronomers speak about the Park's dark sky program, IDSP certification, importance of dark night skies, and a deep dive on a specific astronomical topic such as the moon. Then, astronomers guide a dark sky tour.

The Park takes annual sky quality measurements here. This year's (2023) measurement was 21.43 mpsas, an improvement from last year's (2022) measuremnt of 21.27 mpsas.

## Huckleberry Trailhead

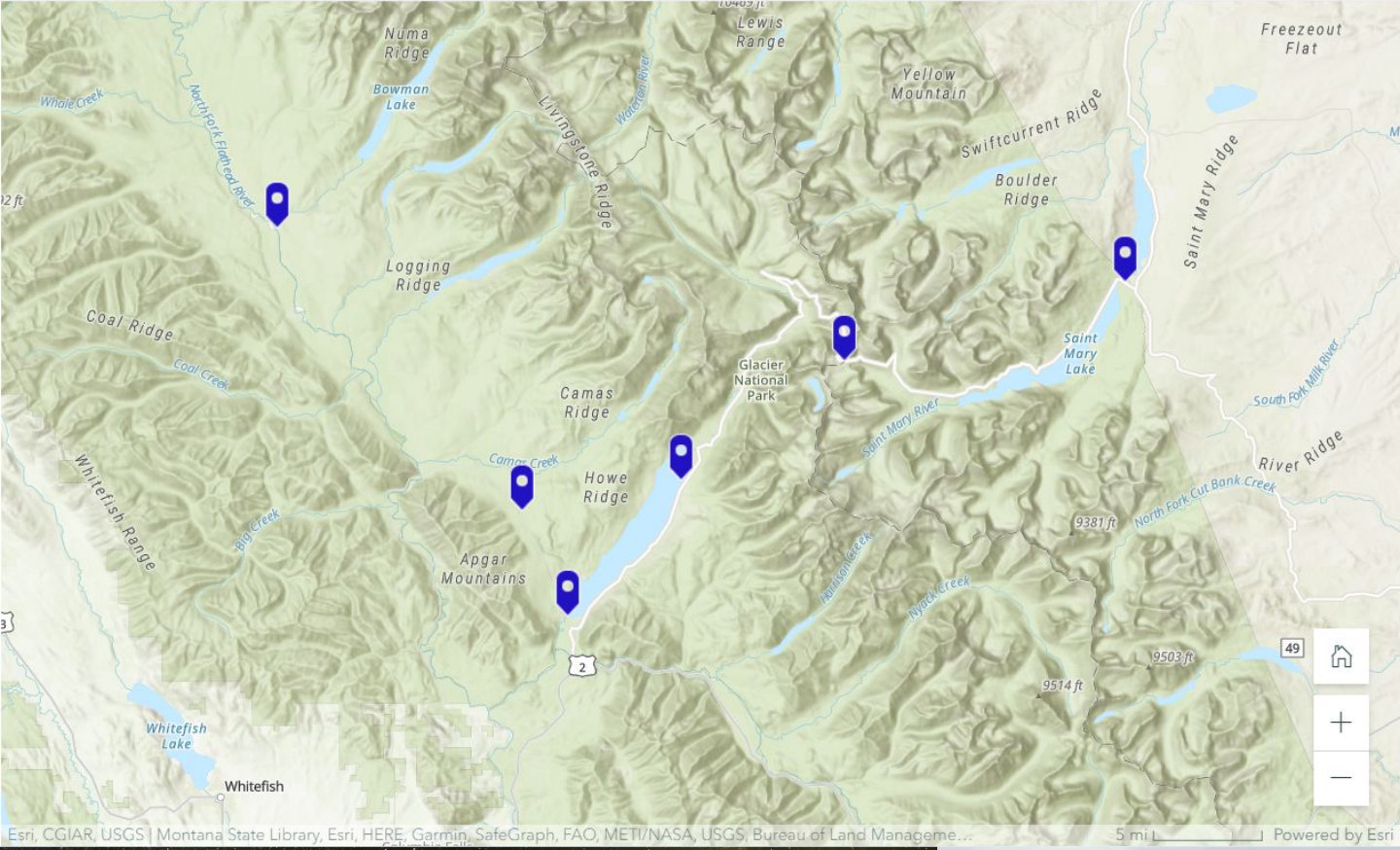
Huckleberry Trail is located bewteen Polebridge and Apgar Village. It is a popular trail that leads to the Huckleberry lookout.

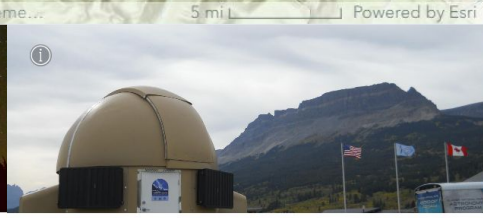
The Park takes annual sky quality measurements here. This year's (2023) measurement was 21.39 mpsas, a slight decrease from last year's (2022) measurement of 21.45 mpsas.

## Polebridge

Polebridge is located in the northwest region of the Park. Here you can visit the Polebridge Mercantile.

The Park takes annual sky quality measurements here. This year's (2023) measurement was 21.36 mpsas, a slight decrease from last year's (2022) measurement of 21.39 mpsas.



## Lake McDonald Lodge

In the northern part of Lake McDonald lies the Lake McDonald Lodge.

The Park takes annual sky quality measurements here. This year's (2023) measurement was 21.44 mpsas, a decrease from the last (2021) measurement of 21.66 mpsas.

## Logan Pass

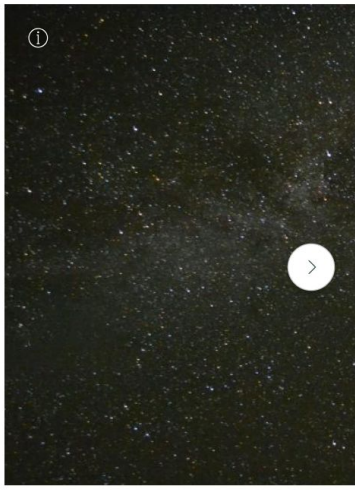
At Logan Pass Star Parties, volunteer astronomers talk about the constellations, planets, and galaxies visible in the dark sky above. Representatives of the Blackfeet tribe tell their Star Stories and astronomers focus telescopes on different planets, stars, and galaxies for viewing.

## St. Mary

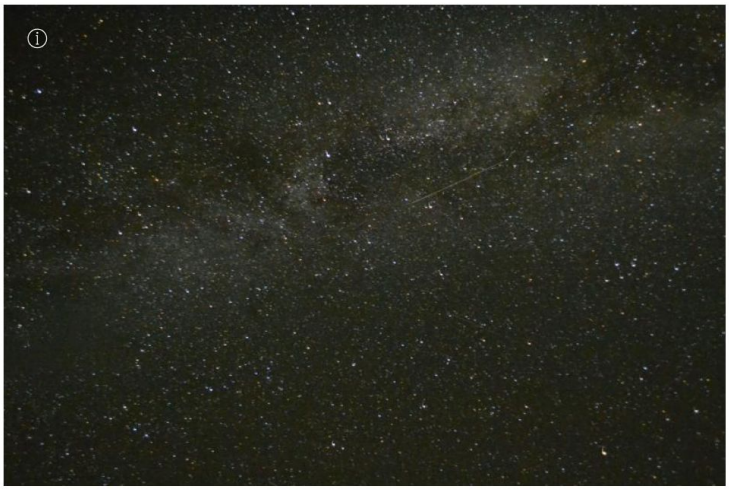
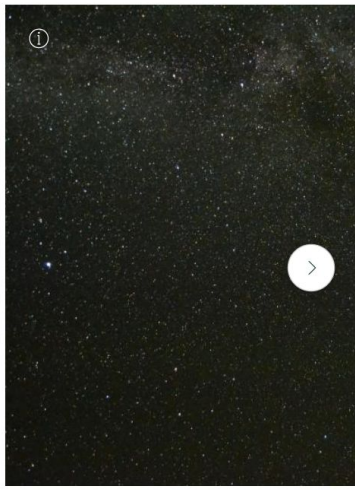
At the St. Mary Visitor Center, you can visit the Dusty Star Observatory and attend the "Half the Park Happens After Dark" program. The St. Mary Visitor Center holds many presentations on astronomical topics such as the Fermi Paradox, Deadly Stars, and Venus.


Glacier National Parks Dark Skies





Glacier National Parks Dark Skies

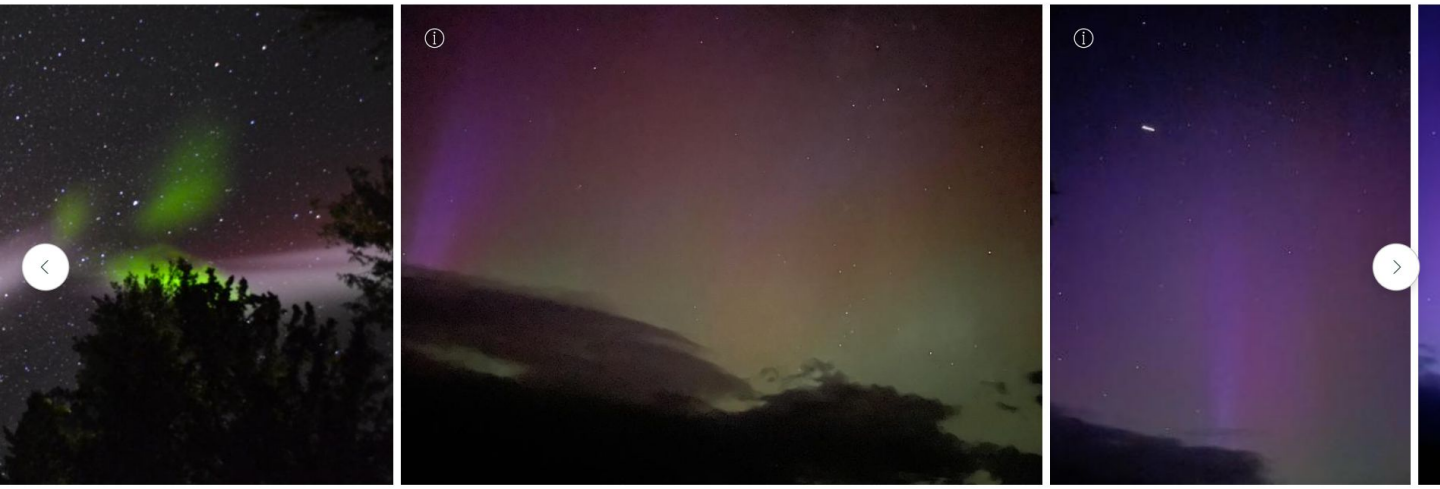




Glacier National Parks Dark Skies

Glacier National Parks Dark Skies

Glacier National Parks Dark Skies

Glacier National Parks Dark Skies



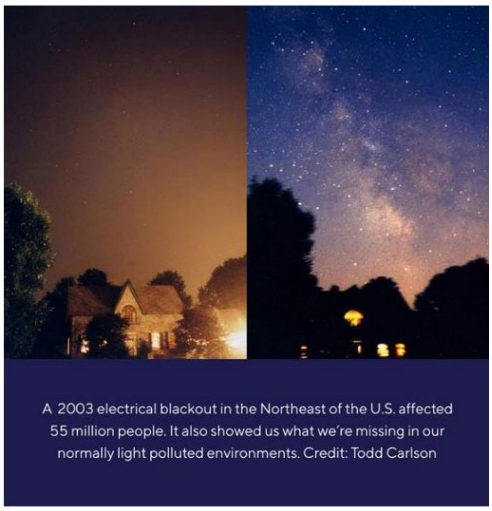
Glacier National Parks Dark Skies

Glacier National Parks Dark Skies

# Light Pollution

Light pollution is defined as the

***"brightening of the night sky, mostly over urban areas, due to electric lights of cars, street lamps, offices, factories, outdoor advertising, and buildings"*** *(National Geographic Society, 2022).*




An image demonstrating the effects of light pollution on the night sky (DarkSky International, 2023)

Light pollution causes natural sources of light, such as stars, to be drowned out by artificial sources. Aside from obscuring star visibility in the night sky, light pollution negatively affects human health and wildlife behavior.

**The circadian clock**, or the natural day/night cycle, is disrupted by light pollution. In humans this is linked to many health disorders in humane health life and heltsuch as **obesity**, **depression**, **sleep disorders**, **diabetes**, and **breast cancer**.

For wildlife, light pollution affects natural behaviors including foraging, migration, reproduction, and communication. Nocturnal animals need darkness to conceal, hunt, reproduce and navigate - all processes light pollution can interfere with.

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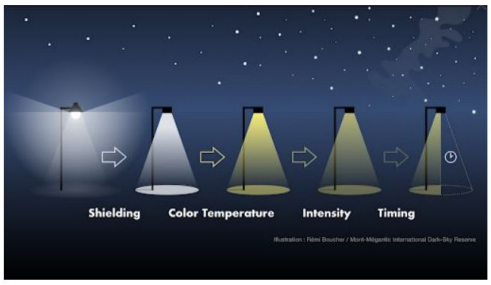
# Dark Sky Compliant Lights




Demonstrating the effects of shielding, the CCT of the bulb, brightness, and the luminaire control (if the light had a timer).

DarkSky International provides guidelines on what makes a light fixture dark sky compliant. DarkSky International requires that fixtures in IDSPs are:

- **Fully shielded**
- **Warm-colored**
- **On task**

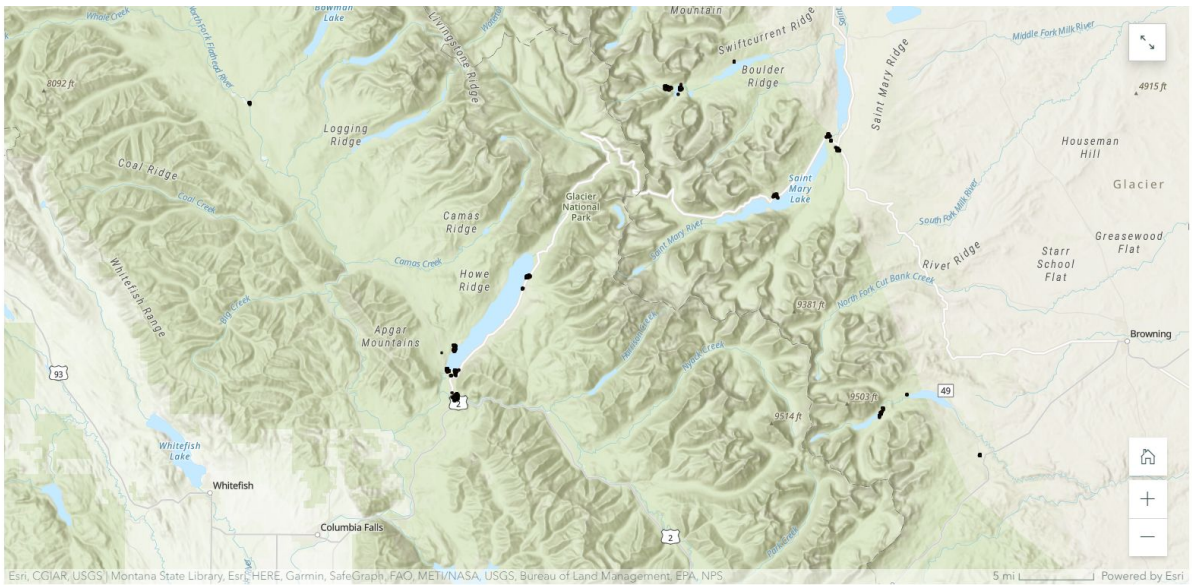
**A fully shielded fixture prevents light from escaping to the sides or above.**

DarkSky International requires light bulbs to have a **correlated color temperature (CCT)** of **less than 3000 Kelvin [K]**, which produces yellow to amber colored light. Glacier National Park is aiming to replace all lights with warmer colored lights that have a CCT of **less than 2700K**.

### On Task Lighting


A compliant light must be on task. A light's task describes its **purpose**, such as lighting a roadway, parking area, egress, or pathway. The control of the luminaire is **how a lighting fixture turns on and off**; a switch, motion sensor, timer, or photo sensor. The luminare control must make sure the light is only on when necessary. Trespass occurs when a light fixture **illuminates an area not essential to its task**.

Below is a map of Glacier National Park's lighting inventory displaying the locations of outdoor light fixtures and their attributes. There is also a link to the **lighting inventory dashboard** where you can see the Park's current compliance. The dashboard is an element of the Park's ArcGIS lighting inventory system. Using different functions in the dashboard, you can filter and analyze the data by specific attributes or by location.




Map of Glacier National Park Outdoor Lights

**Glacier Lighting Inventory**

# Importance of Retrofits

Non-compliant lighting causes light pollution, obscuring the view of the Milky Way and other celestial objects. Thus, working towards 100% compliant lighting by replacing and retrofitting lights is fundamental to preserving Glacier National Park's dark sky.

The dark sky at a Logan Pass Star Party

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# Importance of Electricians

Electricians and facilities workers who replace light bulbs and fixtures are at the **forefront of reversing light pollution** in Glacier National Park.

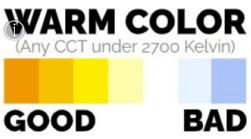
Next time you see an electrician or facilities worker, thank them for their work preserving the night sky!



# How Can I Keep the Park Dark?

- **Check your outdoor light fixtures**
  Is the light fixture necessary?
  Is the light fixture on only when I need it to be?
  Is the light fixture fully shielded/directing light only downwards?


- **When changing light bulbs, verify the compliance of the bulb**
  Is your light shielded, only emitting light downwards?
  Does this light have a warm amber to yellow color (CCT of 2700K or less)?




- **Going backpacking? Take an SQM and measure the dark sky!**
  Check out the "Dark Sky Watch" program

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# Want to Know More?

See these resources!

### DarkSky International

DarkSky International restores the nighttime environment and protects communities from the harmful effects of light pollution...

https://darksky.org

### Partners - Glacier National Park (U.S. National Park Ser...


Glacier National Park Volunteer Associates non-profit partner with no paid staff. Their mission is "to bring together people interested in th...

https://www.nps.gov

### Night Sky - Glacier National Park (U.S. National Park S...

Dark night skies are environments undisturbed by light and air pollution. Dark night skies have natural, cultural, and scenic...

https://www.nps.gov

### Night Skies - (U.S. National Park Service)

The night sky has inspired us for generations. Nighttime views and environments are among the critical park features the National Park...

https://www.nps.gov

### Unihedron


The Unihedron CapSelector provides an inexpensive way to tune a VLF loop over a wide range (120 - 5510 pF) of capacitances. It...

http://www.unihedron.com

### Light Pollution - National Geographic Society

People all over the world are living under the nighttime glow of artificial light, and it is causing big problems for humans, wildlife, a...

https://education.nationalgeographic.org

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# Acknowledgements


- **Glacier Institute**
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- **Glacier National Park Volunteer Associates**
- **Mark Biel (Natural Resources Program Manager)**
- **Ed Eberhardy (Physical Science Technician)**
- **Sharolyn Anderson (Physcial Scientist, Natural Sounds and Night Skies Division)**
- **Professor Leslie Dodson**
- **Professor Beth Eddy**




# Photography Credits

**Dark Sky Photos** - Matthew Catuccio

**Dark Sky Photos** - James Kiefer

**Dark Sky Photos** - Jonathan Wessler

**Apgar Northern Lights Timelapse** - Jeffrey Whelehon (Instagram: _jeffrey_wheels)



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Christiana Kearns

Carter Melanson

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# APPENDIX F:

ArcGIS Lighting Inventory User Manual for Dark Sky Parks

# ArcGIS Lighting Inventory User Manual for Dark Sky Parks


**KEEPING THE PARK DARK:**
Facilitating Dark Sky Status in Glacier National Park

WPI

# ArcGIS Lighting Inventory User Manual for Dark Sky Parks

Glacier National Park

2023 WPI Dark Sky Team:

Evan Dapsis ☆ Ryann Dionne ☆ Brady Gardner ☆ Christiana Kearns ☆ Carter Melanson

Advisors: Professors Leslie Dodson and Bethel Eddy

## Table of Contents



This work was produced by undergraduate students in the Worcester Polytechnic Institute (WPI) Global Projects Program. For more information: https://www.wpi.edu/project-based-learning/project-based-education/global-project-program

## LIGHT FIXTURE INVENTORY GLOSSARY

| | |
|---|---|
| Attribute | Data field used to gather information about a light fixture |
| Astronomical Twilight | When the geometric center of the sun is 18 degrees below the horizon, the last phase before night |
| Lamp | A device for giving light: one electrical bulb |
| Luminaire | A light fixture that contains an electrical lamp and provides illumination |
| Luminaire Control | How the luminaire is controlled or operated |
| Luminaire Type | How the luminaire is mounted |
| Measured CCT | The correlated color temperature of the light measured with an instrument such as a spectrometer |
| Operating at Night | If the luminaire is emitting light during a night visit |
| Principle Investigator | Group title of data collector |
| Rate of Backlight | Light escaping the area of interest behind the light fixture |
| Rate of Glare | Light escaping the area of interest on the sides of the light fixture |
| Rate of Uplight | Light escaping the area of interest above the light fixture |
| Shielding | Physical barriers of the light fixture preventing uplight or sidelight (glare) |
| Specified CCT | The correlated color temperature of the light determined by labeled bulb specifications or electrical records |
| Task | The main purpose of the light/what the light is trying to illuminate |
| Trespass | Light present outside of the designated task area |

# OVERVIEW OF INVENTORY PROCESS

The overall inventory process includes three main steps:

1. Preliminary planning and preparation
2. Gathering day data
3. Gathering night data

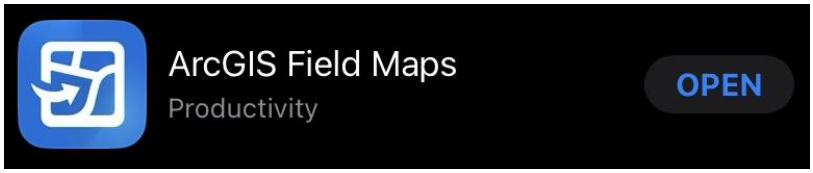
Using ArcGIS for a Lighting Inventory

Geographic Information Systems, or GIS, software overlays layers of geospatial information, such as buildings, terrain, and streets, to be analyzed and shared. These 'layers' can contain many types of information as long as there are GPS coordinates attached to the data. This gathered data can be utilized as an inventory system and can relay important attributes used to determine a park's compliant lighting percentage. ArcGIS utilizes and overlays lighting fixture GPS points over a building layer of Glacier National Park.

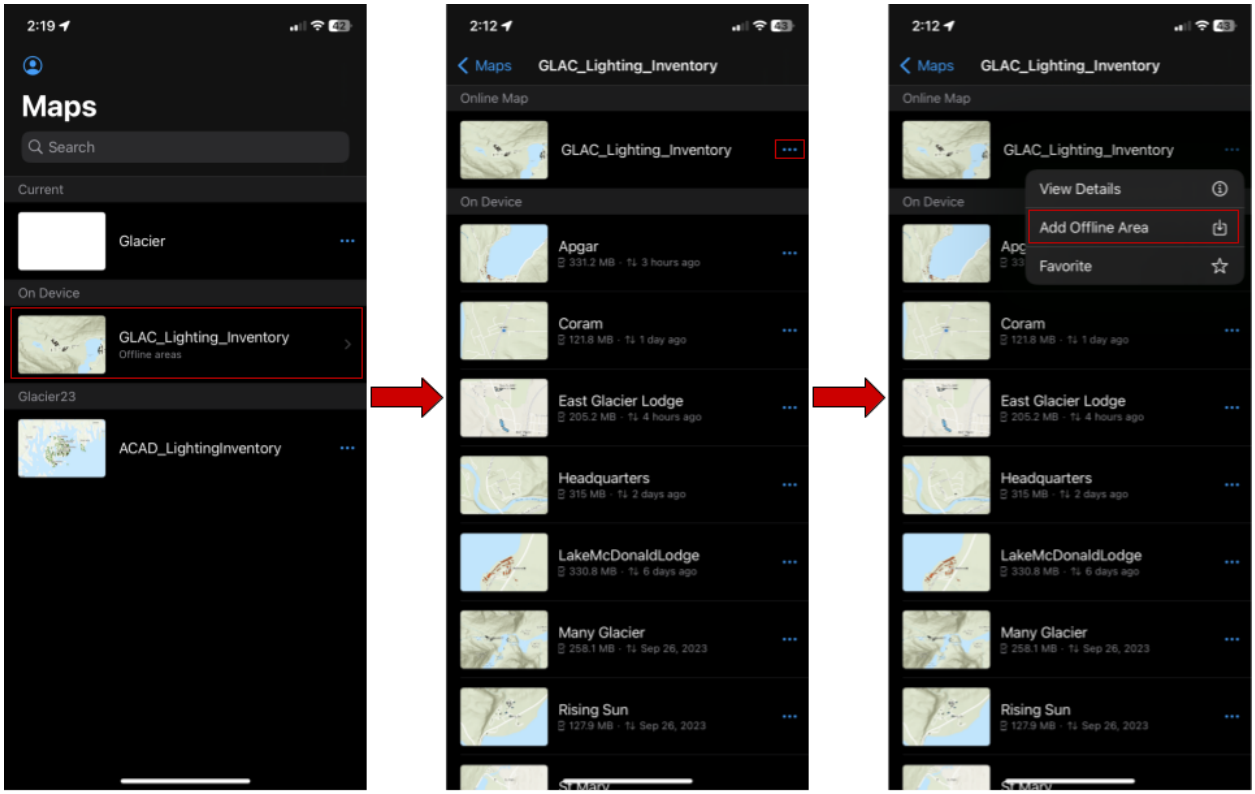
# PRELIMINARY PLANNING AND PREPARATION

Download Offline Map Area

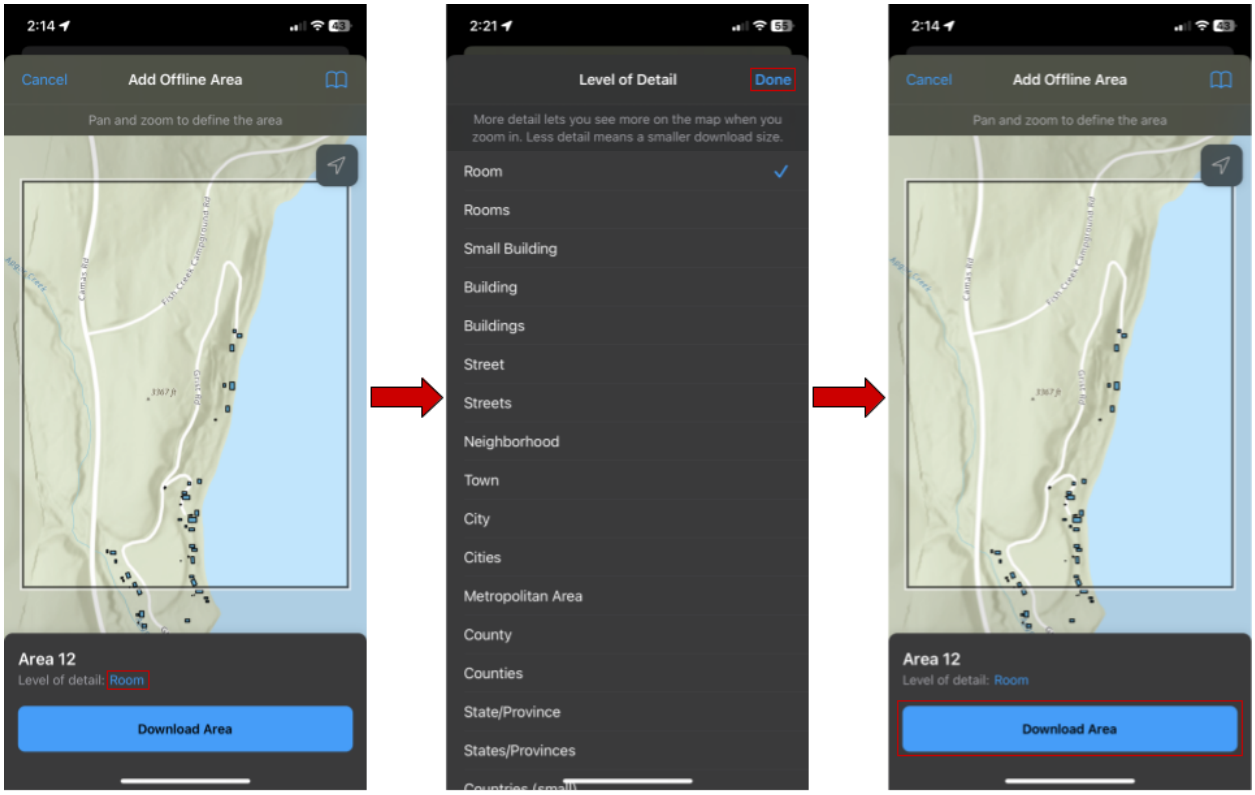
1. Choose a device to use and download the "ArcGIS Field Maps" app. The best devices to use are smartphones or tablets, but a laptop could be used if necessary. Ensure that your device is connected to wifi or cellular data. Open the ArcGIS Field Maps app and log in using your ArcGIS account provided by Glacier National Park.



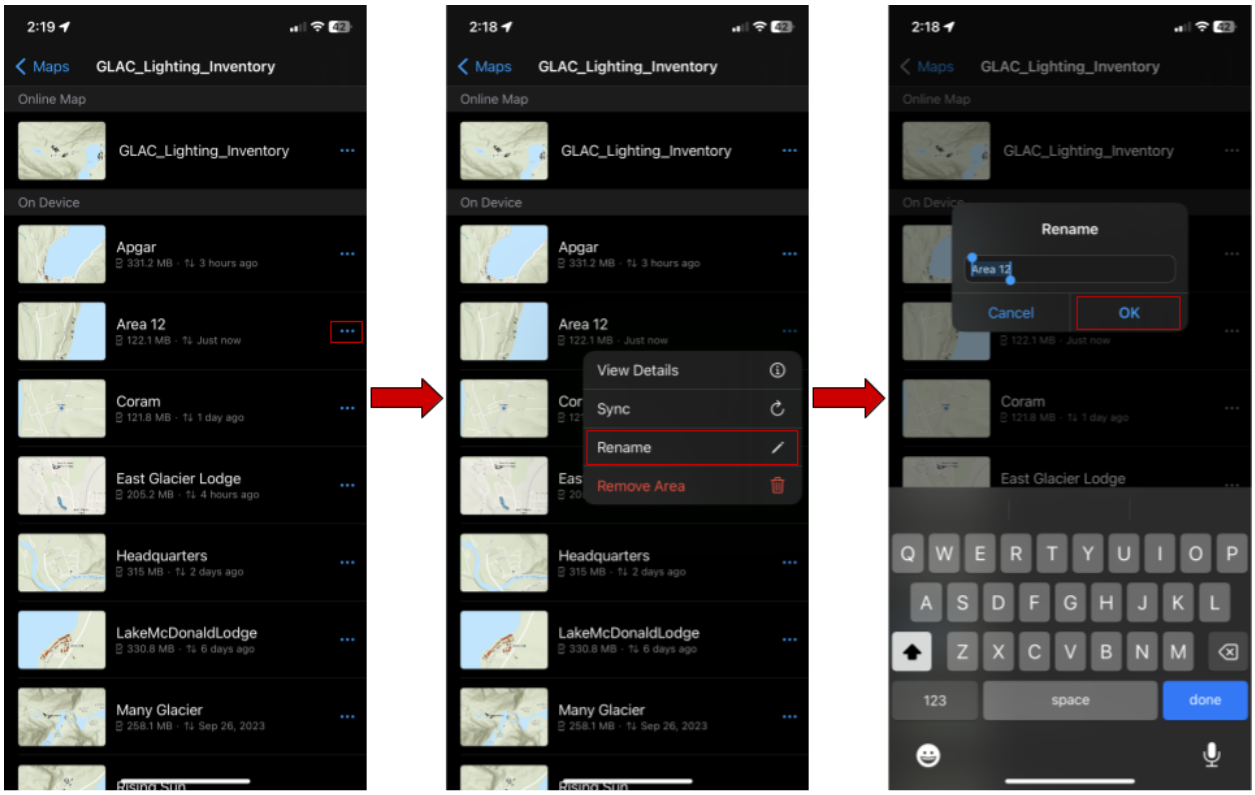
2. After logging in, the “Maps” section will be displayed. Click on the map labeled “GLAC_Lighting_Inventory.” This map will show up on your phone automatically as long as you are a member of the ArcGIS group and are authorized to edit.
3. The ArcGIS map of Glacier will be displayed under “Online Map''. Click on the three dots next to “GLAC_Lighting_Inventory”, and press “Add Offline Area” to load a new area onto your device.



4. Once in the “Add Offline Area” tab, move the displayed box to the planned inventorying location.
5. Click on “Level of detail” and select one of the listed options depending on the size of the area you are inventorying to change the size of the downloaded area. For most of the areas in the Park, the default “Room” option can encompass the entire area.
6. Move the box to encompass the entire area that you are planning to inventory. Once the area to be inventoried is fully encompassed in the box, press “Download area.”



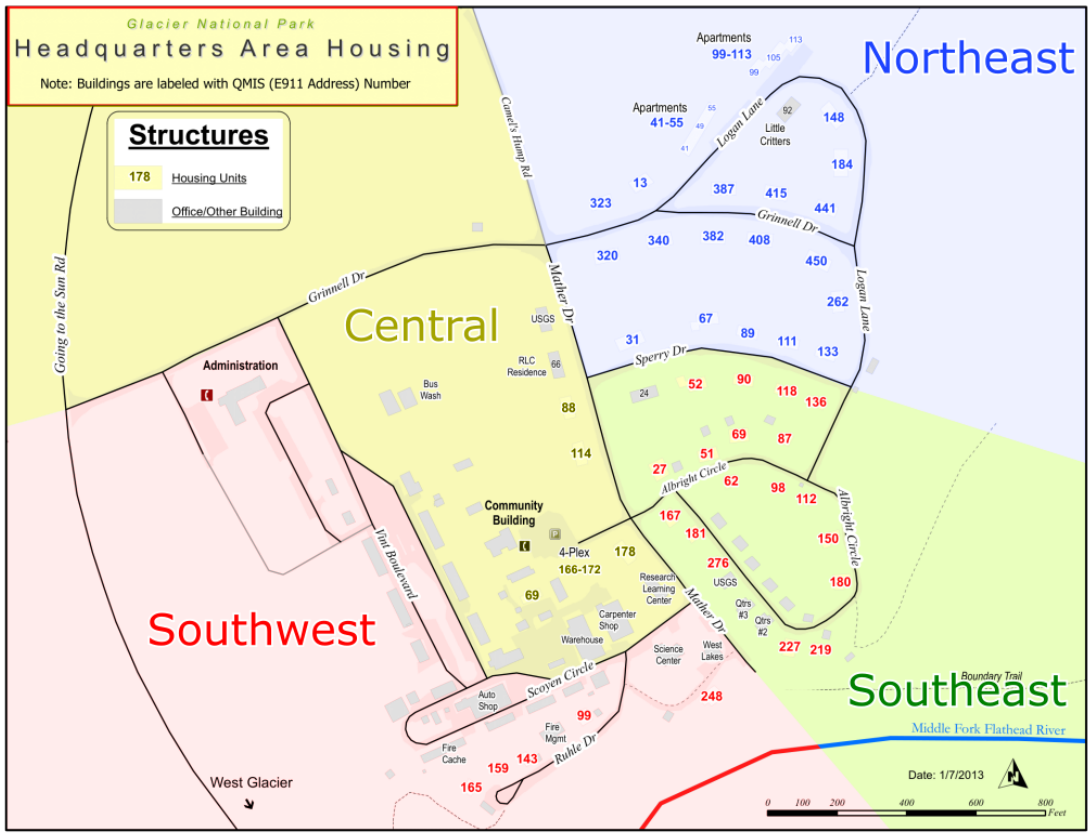
7. Once the area to be inventoried has been downloaded, the offline map will be accessible under “On Device” of the GLAC_Lighting_Inventory map.
8. To rename the downloaded map, press the three dots next to Area_x (which is the area you just downloaded.) Press “rename”. Finally, type in the name of the location and press “OK.”



## Planning an Inventory Route

Prior to departing to collect lighting inventory data, the inventory team should plan a collection route to efficiently and accurately gather all light fixtures in the area. If there is a large amount of light fixtures in a location (such as Headquarters or St. Mary), the area should be split up relatively evenly to divide up the data points into manageable amounts, assuring all light fixtures are accounted for in each area. Dividing up an area is a subjective task. See the figure below as an example.

Sample Inventory Route of Glacier National Park Headquarters Area




Note. Example map of the Headquarters area divided into four sections, with an estimated similar number of lighting fixtures and buildings in each region. These four regions are labeled Northeast (blue), Southeast (green), Central (yellow), and Southwest (red).

## GATHERING DAY VISIT DATA

"Day Visit" Equipment

- Data collection devices (smartphone, tablet) with the downloaded offline ArcGIS Field Maps area
- Paper map of inventory area (optional)
- Clipboard and pen/pencil (optional)
- Safety vest
- Bear spray
- Portable battery charger for data collection devices

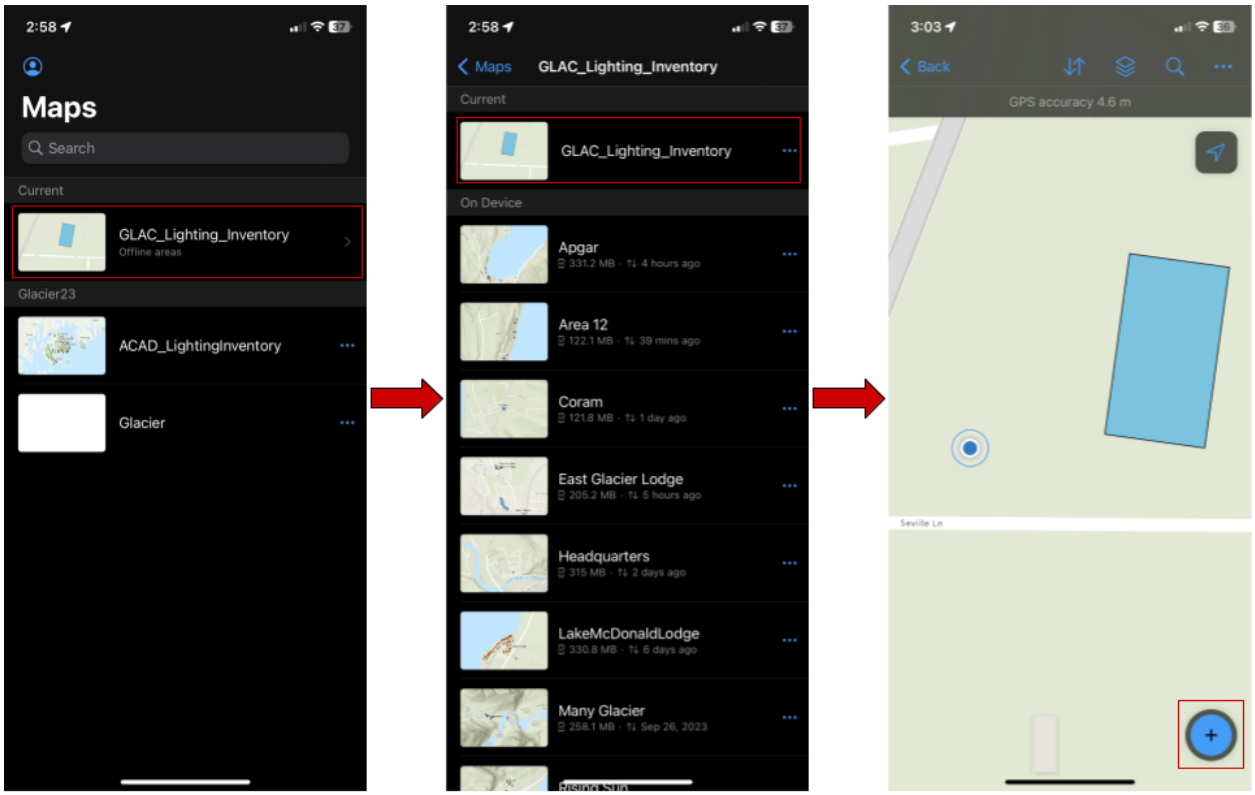
"Day Visit" Attributes

The main light fixture data collected during the day includes:

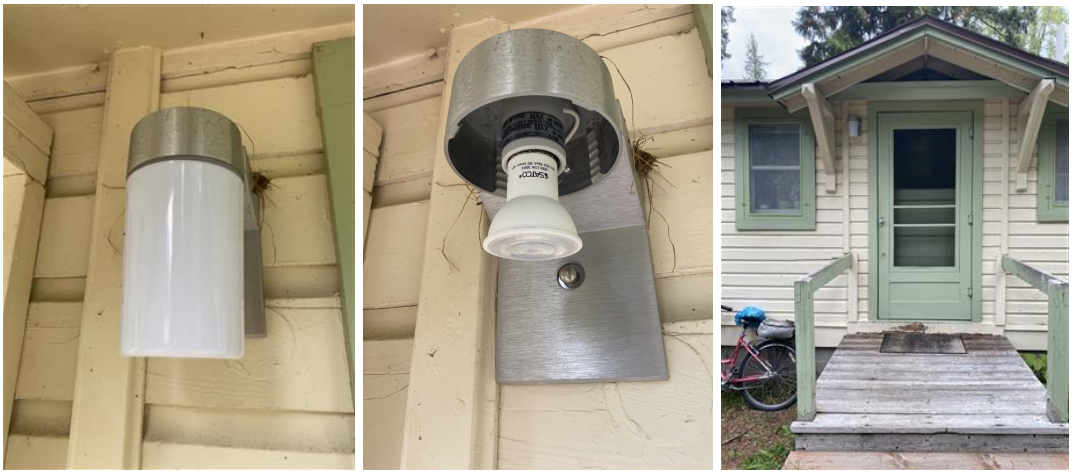
- The GPS coordinates of the fixture
- Photographs of the light fixture (and bulb if possible)
- The principle investigator
- Time and date of day visit
- Height of light fixture in meters (m)
- Task of the light fixture
- Luminaire type
- Number of lamps
- Type of lamp
- Luminaire control
- Shielding
- Specified CCT
- Recommended Action
- Notes about the light fixture.

The stepwise instruction for gathering day data are as follows:

1. Open the “Field Maps” app on your recording device.
2. Under “Current,” press “GLAC_Lighting_Inventory.”
3. Under “On Device” press the offline map where the light fixture is located
4. Stand directly under the light fixture being gathered (if standing under the fixture is not possible, stand as close as you can) and press the “+” button located in the bottom right corner of the map.

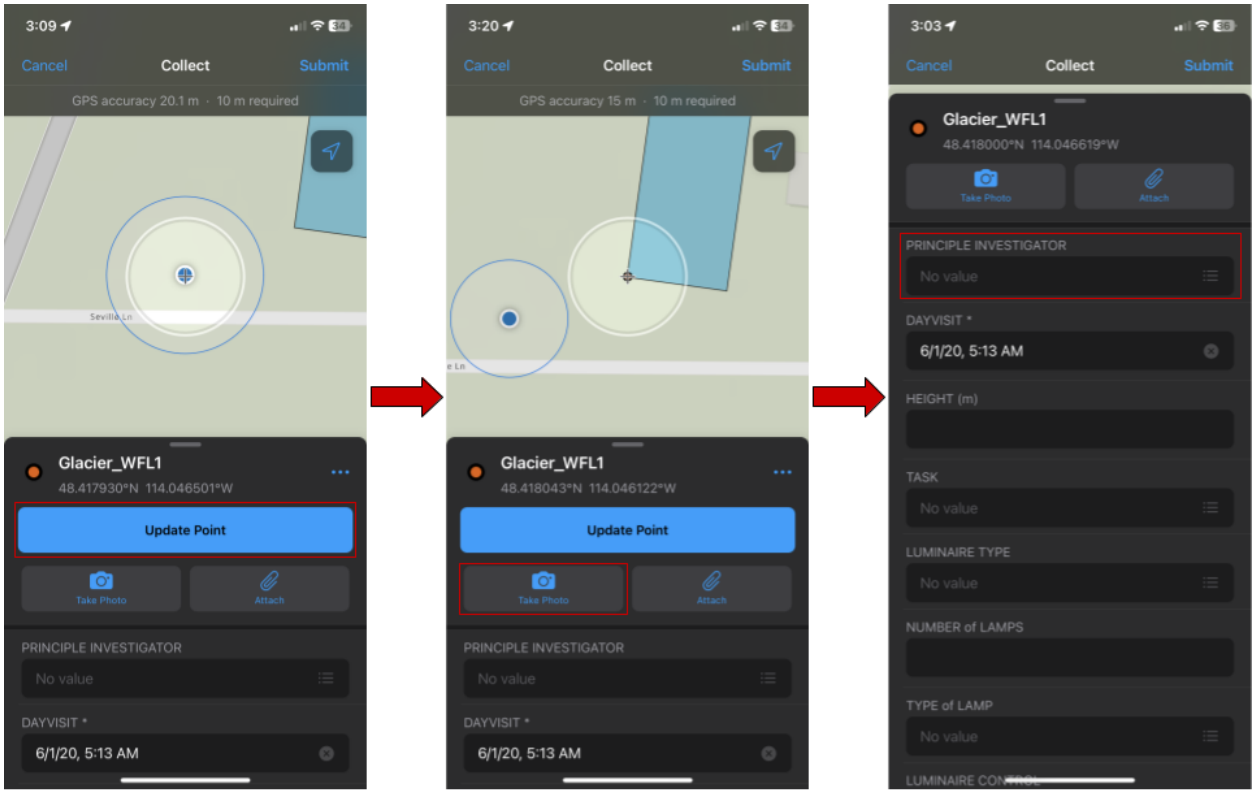



5. If unable to stand directly under the light to get the exact GPS location, move the cursor to the position where the fixture is located on the building layer and press “Update Point.”
6. Press “Take Photo”, and take a close-up picture of the bulb (if possible), a close-up picture of the light fixture, and finally a picture of the light fixture displaying the task of the fixture.

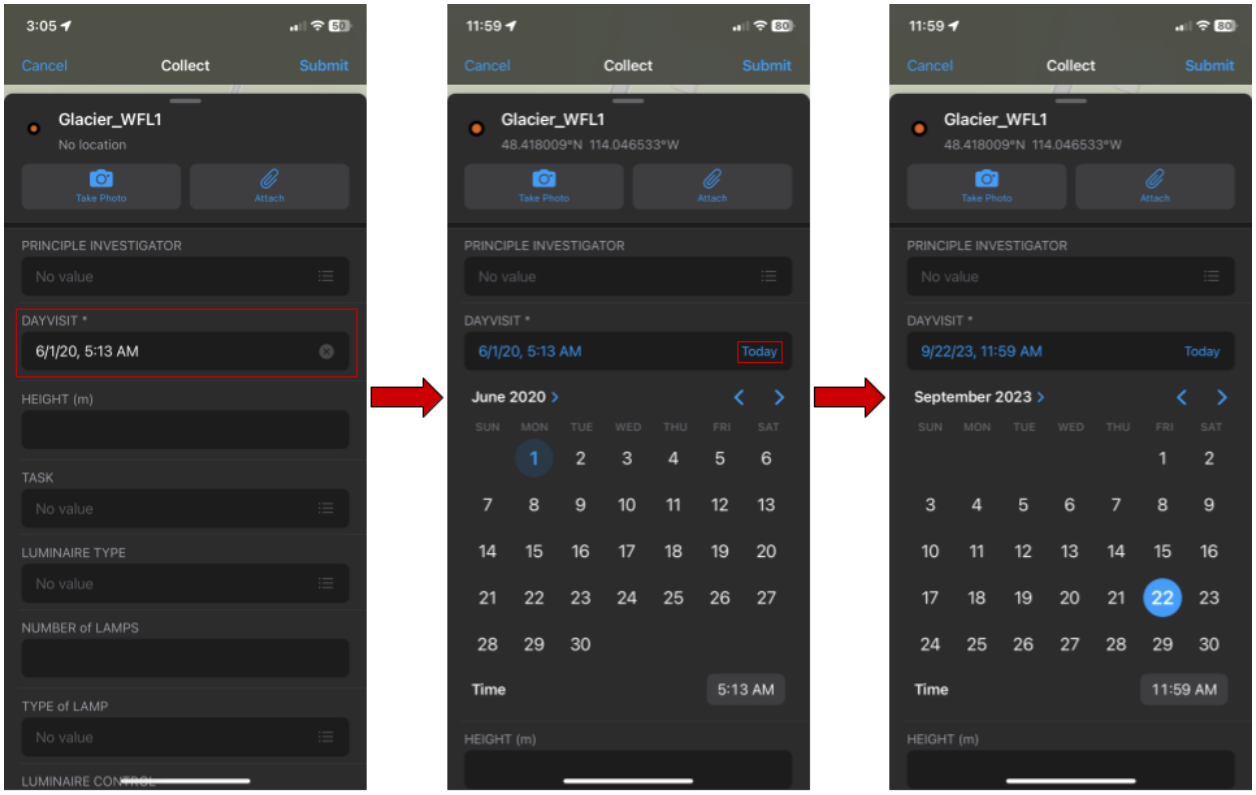


Examples of pictures of light fixtures, displaying a close up of the fixture (left); one a closeup of the bulb (center); and the fixture and its task area (right).

7. Under “Principle Investigator” enter the correct value. If you are a National Park Service Employee, select NPS. If you are a student or volunteer, select volunteer.



8. For “DAYVISIT,” press the displayed date and time, then press the blue “Today” text to update the value to the correct time and date.



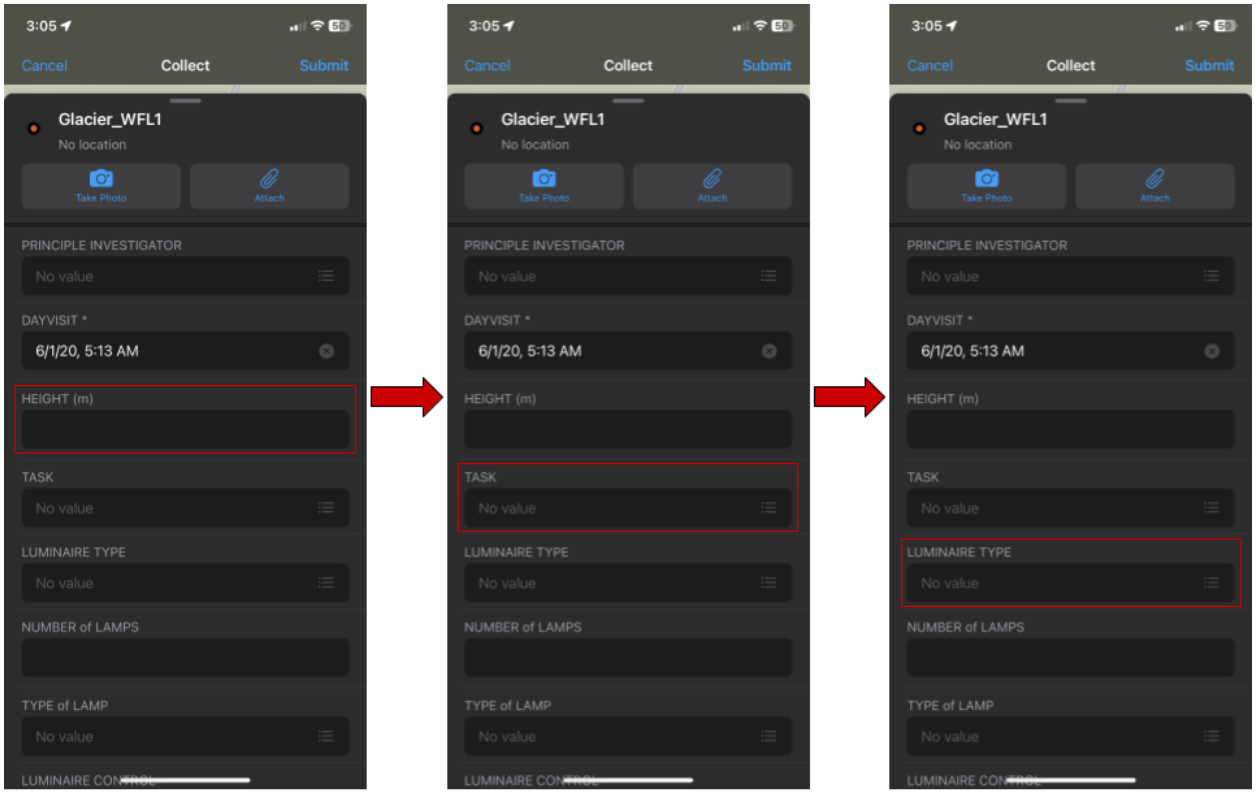

9. Press “Height (m)” and estimate the height to the nearest half meter value. If the light fixture is above a porch or set of stairs, estimate the height from the base of the porch or stairs, not the ground.

10. Enter the task, or the light fixture's purpose, under "Task."

| Option | Example | Option | Example |
|---|---|---|---|
| **Decorative** | Holiday lights | **Other** | |
| **Roadway** | Road without sidewalks | **Monument** | Lighting up a monument |
| **Wayfinding** | Lights at end of docks, buoy | **Signage** | Lighting up a sign |
| **Area** | Lighting up a seating area, or sport court | **EntranceEgress** | Lighting up a doorway for Safety (prevent tripping) |
| **Unknown** | | **Interpretive** | |
| **Parking** | Parking lot | **Pathway** | Lighting up a pathway (not connected to a road) |
| **Hazard** | OSHA required lighting (fueling stations, propane tank storage) | **StreetLighting** | Lighting with pedestrian focus (streets with sidewalks or crosswalks) |
| **Flag** | Illuminating a flag | | |

*Note.* Table depicting the different options under the "Task" attribute and examples of when to select each.

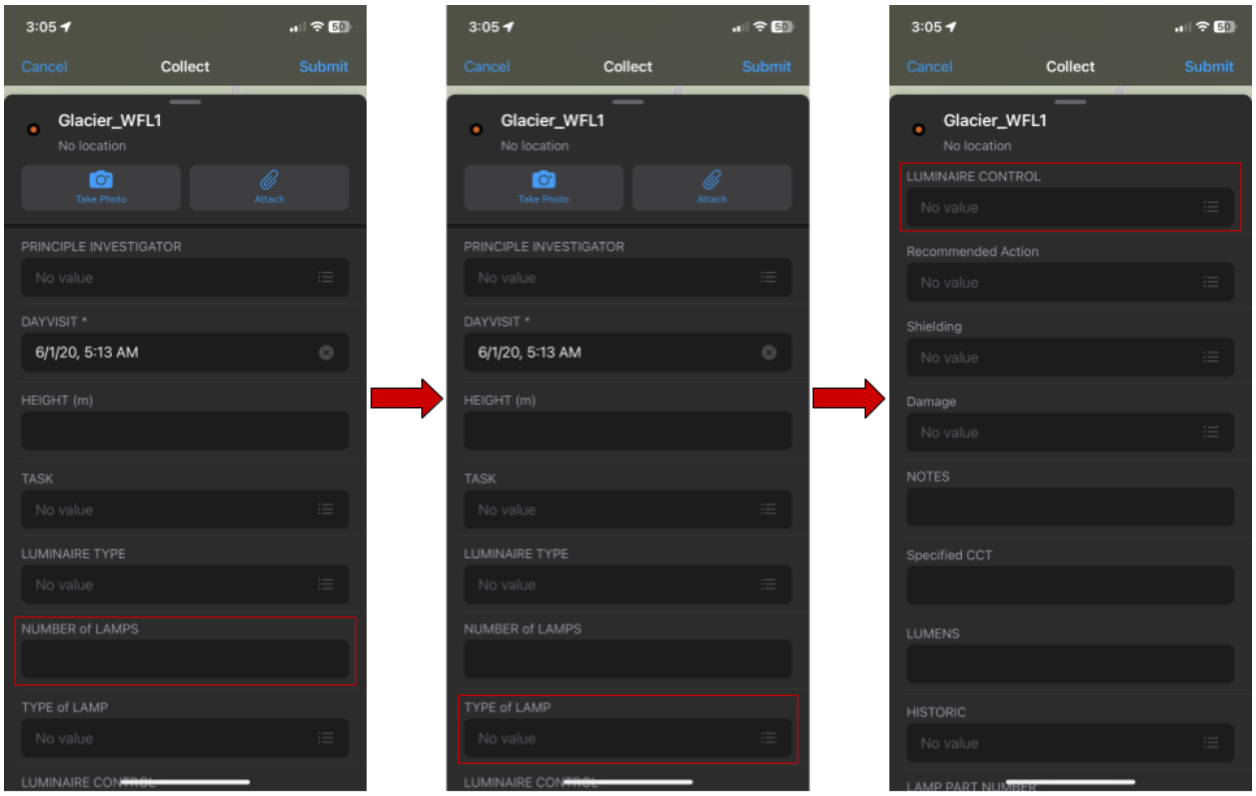
11. Under "Luminaire Type" enter the type of light fixture.



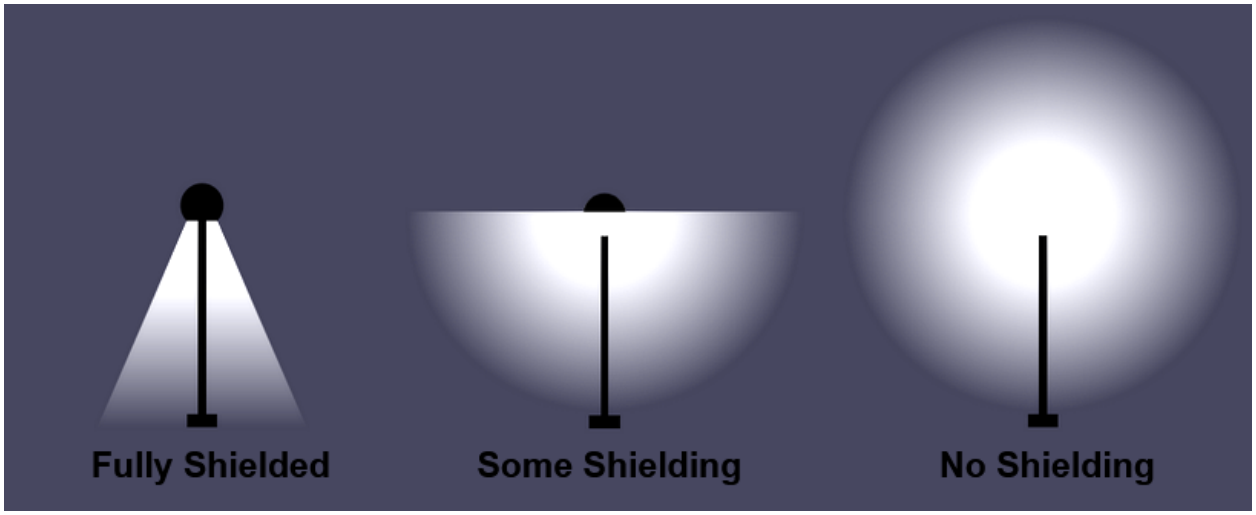

12. Enter the number of bulbs under “Number of Lamps.”
13. Under “Type of Lamp” enter the correct bulb type. If unsure, select “Unknown.”


*Note.* Examples of different bulb types (*Types of Lightbulbs*, 2023).

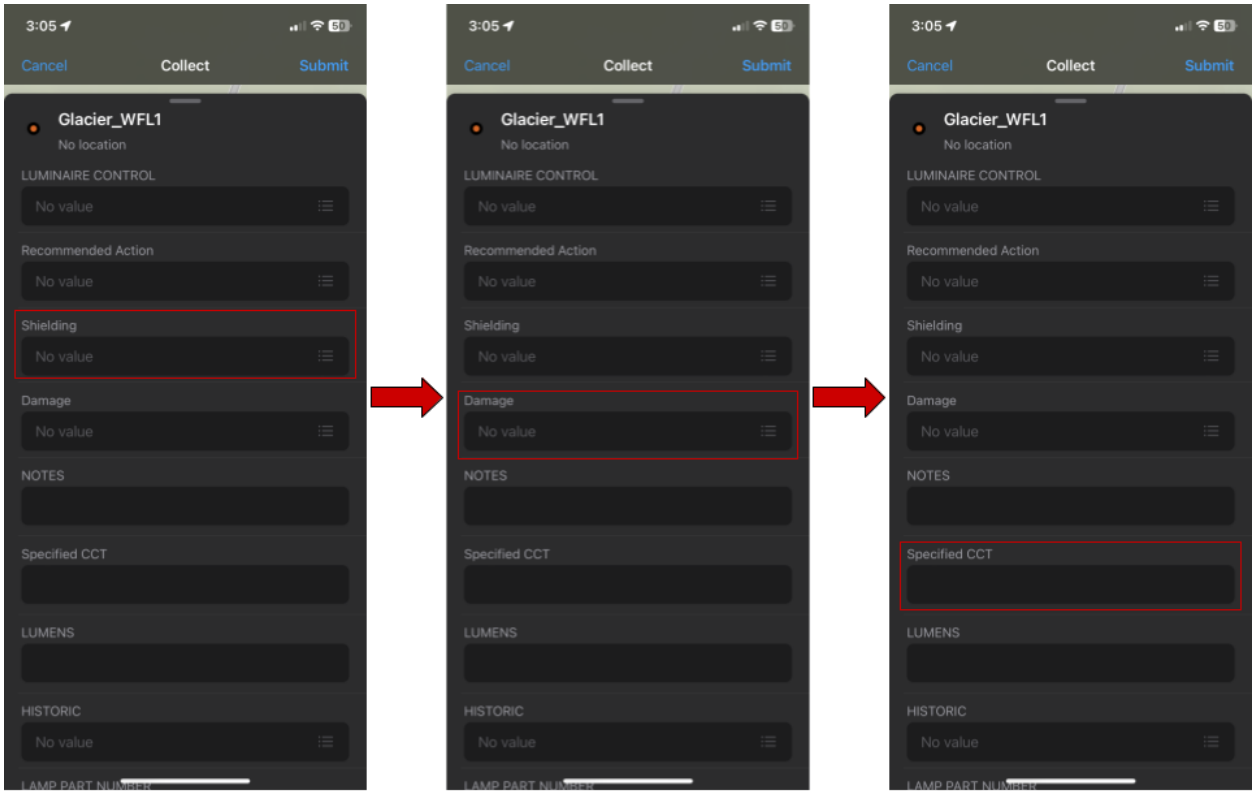
14. Enter how the light fixture is controlled: either by a motion sensor, a solar (photo) sensor (commonly on light posts), a switch (if it's on a house), or another control listed under “Luminaire Control”. If you are unsure, select “Unknown.”



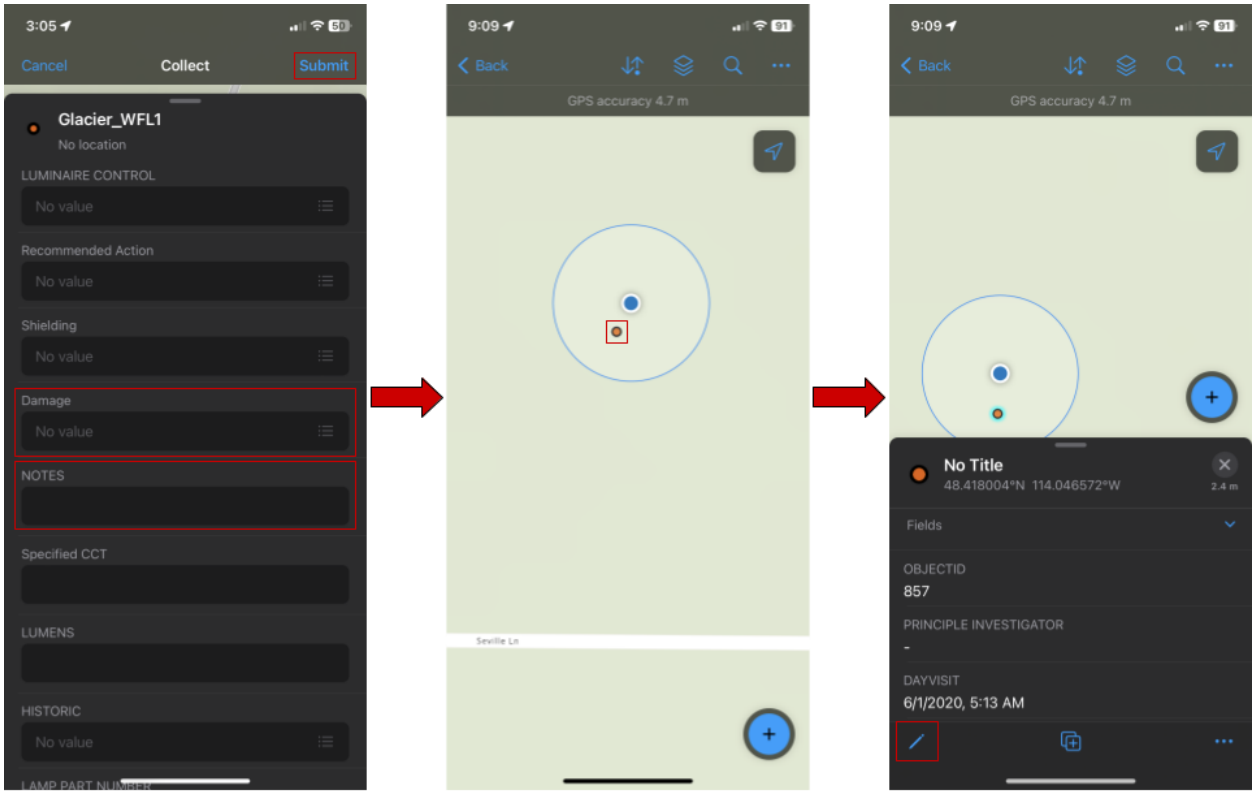

15. Enter the shielding status of the light fixture. A shielded light is a bulb that is not visible at eye level of the light fixture.



16. Enter the correct value under “Damage.”
17. Enter the CCT value labeled on the bulb under “Specified CCT.” If you cannot reach the bulb or cannot find the CCT on it, leave this attribute blank.




18. If necessary, enter other important observations into “Notes.” If you have a recommendation for the fixture, select “retrofit”, “ replace”, or “remove.” If you have no recommendation, select “no action.”
19. Press “Submit” to add the data point to the offline map.
20. If necessary, click on the data point, and then click on the pencil symbol “ ” to edit.




21. Refer to **SYNCING OFFLINE MAPS TO ONLINE MAPS** to sync the offline data.

# GATHERING NIGHT DATA

"Night Visit" Equipment

- Data collection device with downloaded offline map
- Fully charged UPRtek MK350 N Premium Spectrometer
- Printed out map of planned and sectioned route (Optional)
- Headlamp/Flashlight
- Clipboard (Optional)
- Safety vest
- Bear spray
- Portable charger

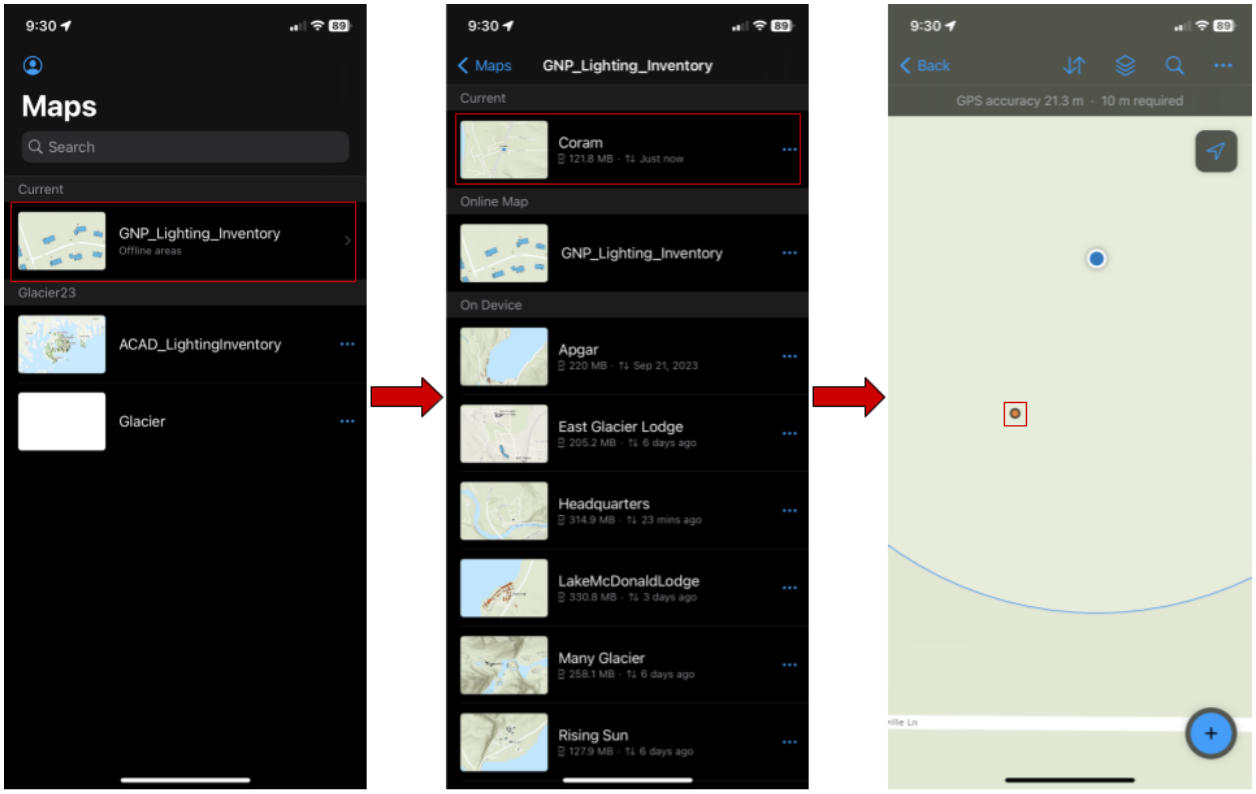
"Night Visit" Attributes

The main lighting attributes collected during the night include:

- Determining if the light operates at night
- Rate of glare
- Rate of backlight
- Rate of uplight
- Trespass
- Measured CCT of the light fixture

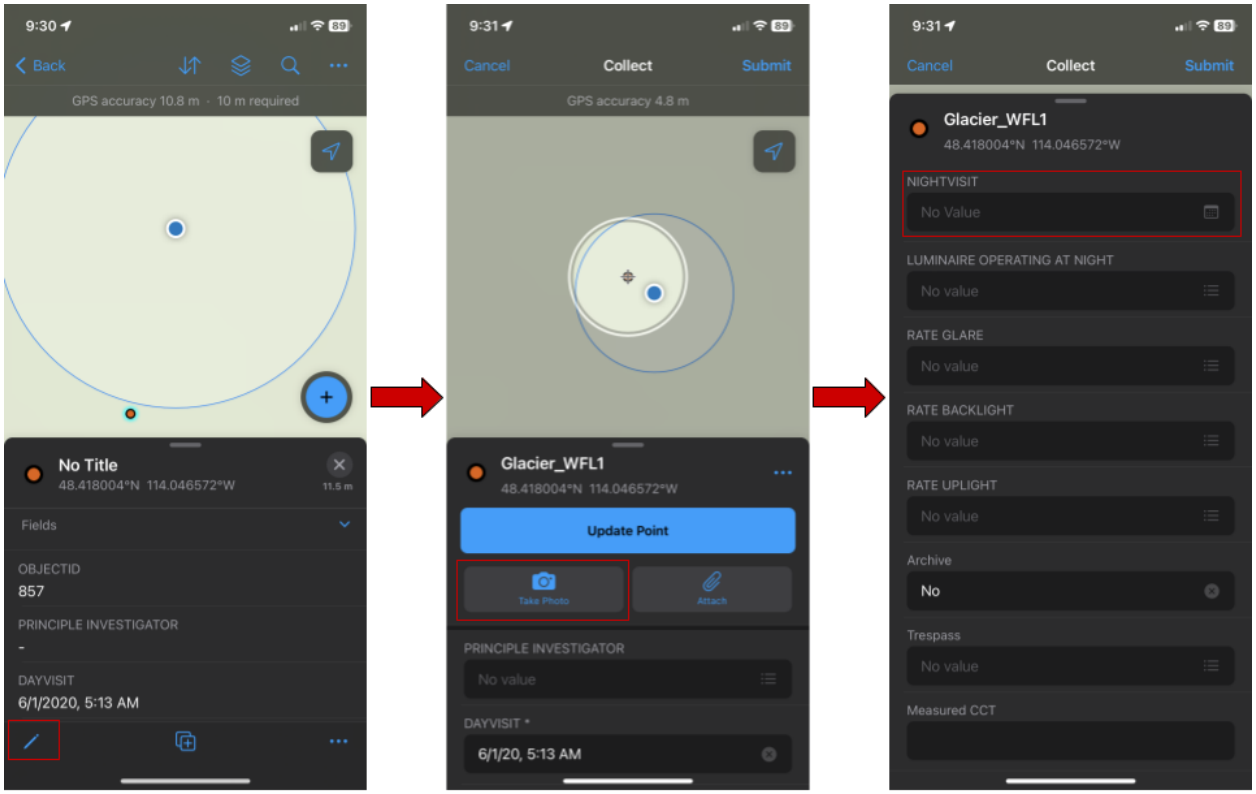
The stepwise instruction for gathering night data are as follows:

1. Open the "ArcGIS Field Maps" application once in the field on the data collection device.
2. Press "GLAC_Lighting_Inventory."
3. Under "On Device" press the offline map where data is being collected in the park.
4. Once you are near the light fixture being inventoried, press the data point of the light fixture on the map.




5. Once the attributes of the data point are on the screen, press the “ ” icon located in the bottom left of the screen to edit the data point.
6. Take a photo displaying the light fixture completing or failing its task.

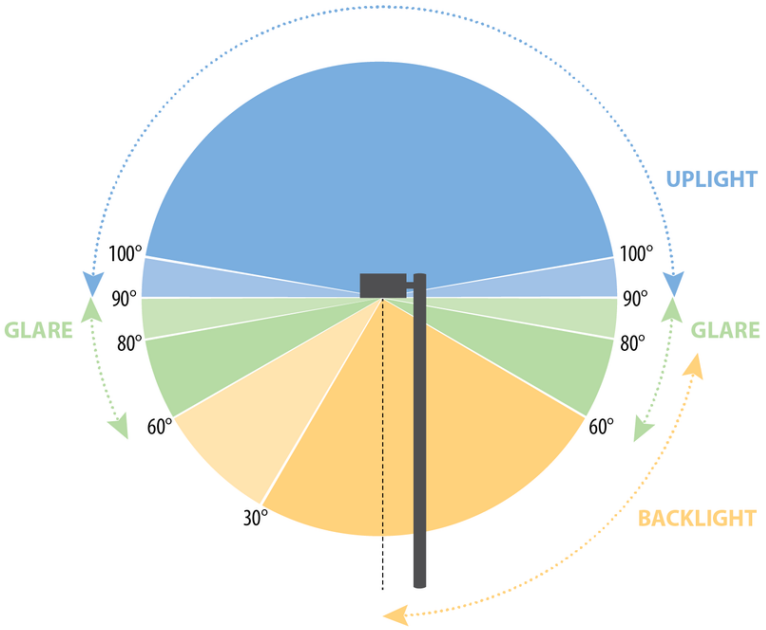
7. Once a photo is taken, edit the “NIGHTVISIT” value by pressing the attribute. The date and time should update automatically.




8. Enter whether the luminaire is on or off under the attribute “Luminaire Operating at Night”. If the luminaire isn’t operating at night, skip to step 11.
9. Enter a value for “Rate Glare”, “Rate Backlight”, and “Rate Uplight” as observed.
    9.1. The options for “Rate Glare” are “None,” “Task Area,” or “Beyond Task Area.” Glare is defined as light shining between 60 and 90 degrees up from the point on the ground directly below a light. Select “None” if there is no glare, “Task Area” if glare is limited to the task area, and “Beyond Task Area” if glare goes further than the light’s task area.
    9.2. The options for “Rate Backlight” are “Unknown,” “Negligible,” “Moderate,” and “Severe.” Backlight is defined as light falling behind the task area. Select “Unknown” if you are unsure of the rate backlight. Select “Negligible” if there is no backlight or if backlight is blocked by

an object such as a building. Select “Moderate” if backlight is present but not extreme. Select “Severe” if backlight is extreme.

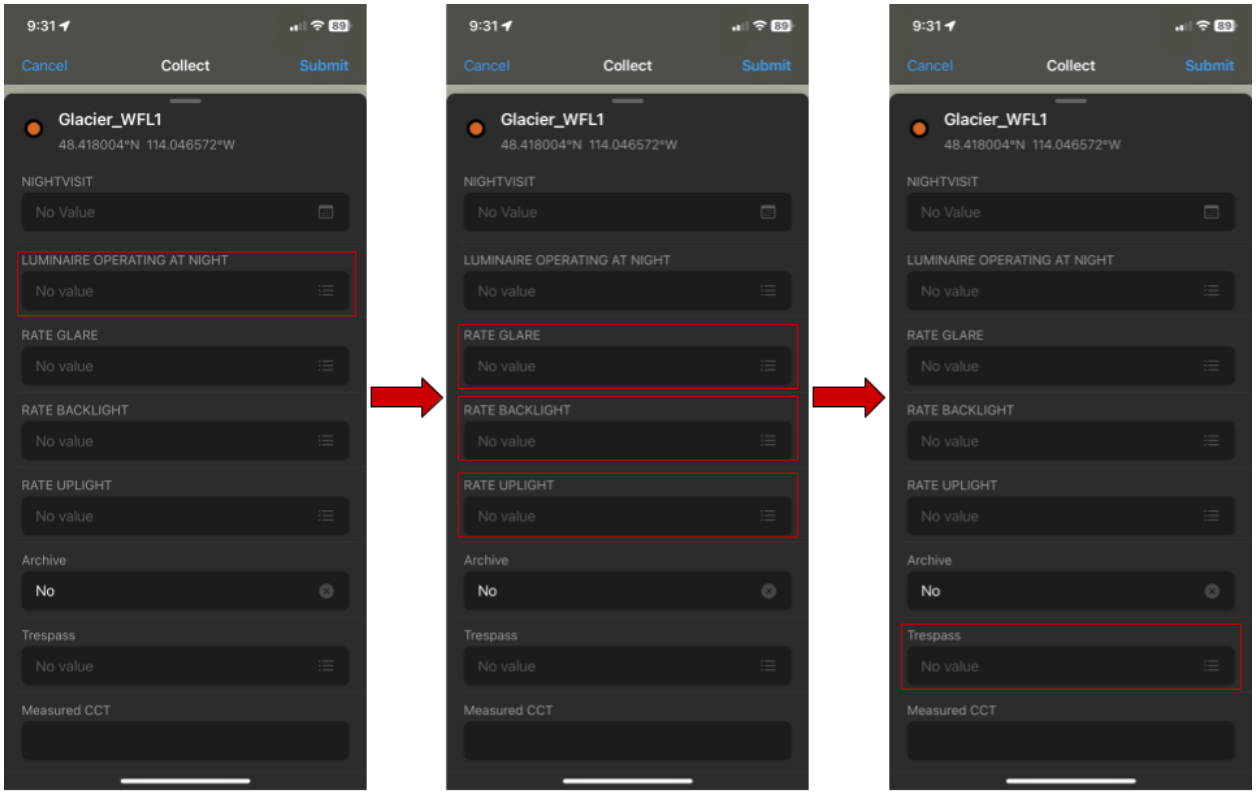
9.3. The options for “Rate Uplight” are “Unknown,” “Negligible,” “Moderate,” and “Severe.” Uplight is light that falls above the task area. Select “Unknown” if you are unsure of the rate uplight. Select “Negligible” if there is no uplight. Select “Moderate” if uplight is present but there is some shielding. Select “Severe” if uplight is extreme and there is no shielding.



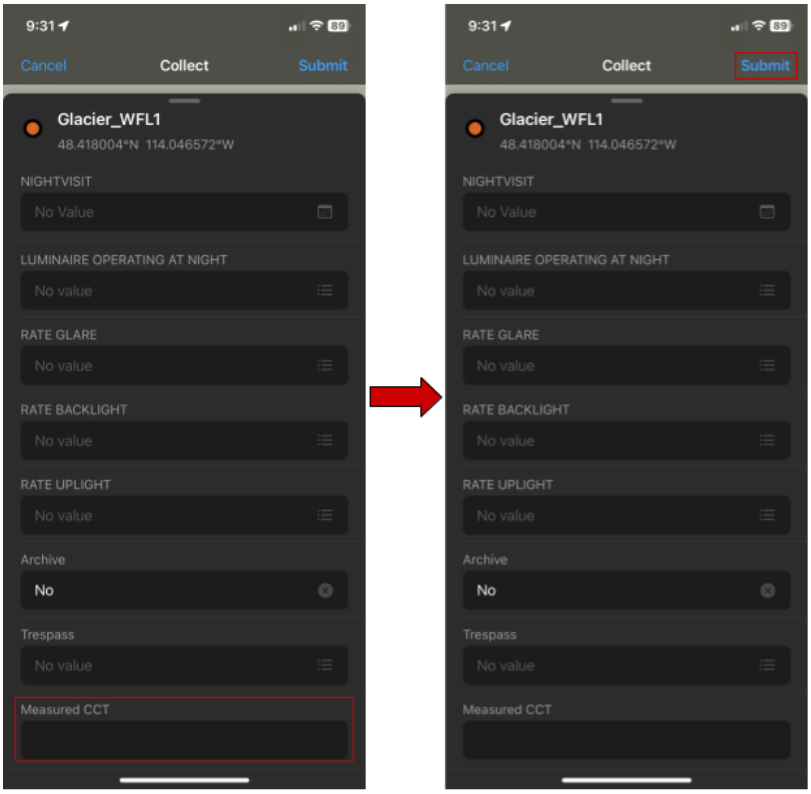

Note. Diagram displaying three attributes of the ArcGIS system, the backlight, glare, and uplight (Sullivan, 2023).

10. Enter a value for “Trespass”, referring to the area the light is illuminating, and if it is on task or not.

*Note.* Diagram displaying an “off task” trespass value, as the main task of the light is to illuminate the roadway and walkway, however it also illuminates the surrounding environment, not required by its task.




11. Measure the CCT of the light fixture, entering the value gathered into the attribute labeled “Measured CCT”. For instructions on using the spectrometer, refer to **Measuring CCT** below.
12. Press “Submit.” The night attributes are now added to the offline map data point.




13. Refer to **SYNCING OFFLINE MAPS TO ONLINE MAPS** to sync the offline data.

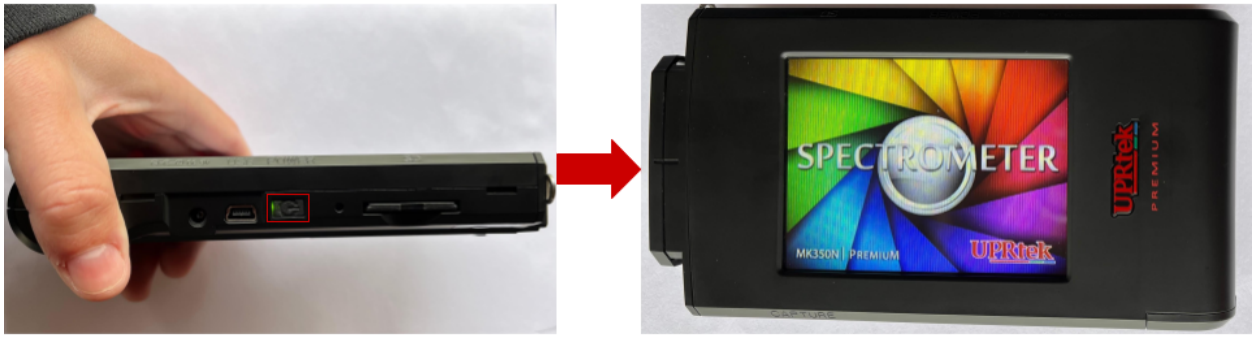
Measuring CCT

You'll need to charge the spectrometer, and ensure an SD is in the device (located in the right side of the unit). The spectrometer can only gather accurate data after astronomical twilight to ensure the most accurate measurement. To determine when astronomical twilight is, refer to [meteogram.org](meteogram.org).

**Anatomy of the UPRtek MK350 N Premium Spectrometer**

**To measure the CCT of a light fixture:**

1. Power on the spectrometer device by holding the small rectangular power button on the right side. A screen that says “Spectrometer” with colors around it will appear. Wait for a Dark Calibration prompt.




2. Complete the Dark Calibration:
   - 2.1. Ensure the top cap is securely fastened over the sensor and hit “OK.”
   - 2.2. Hit “OK” again, resulting in two audible clicks.
   - 2.3. Hit “OK” when the dark frame is complete, then remove the top cover and store the cover in a secure place.

3. Check the Date and Time

3.1. From the home screen click the “page turn” image twice at the bottom right of the screen.



4. Select the “option” icon, check and update the time and date accordingly.

1. Take a CCT measurement:

1.1. Select the “BASIC” option from the home screen.

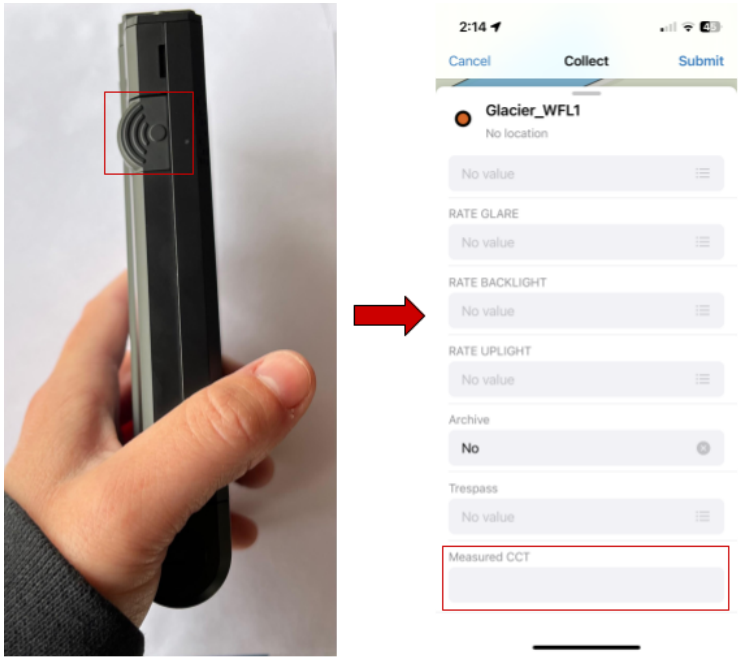
1.1.1. A list of measurements including LUX, CCT, S/P and IRR with zeros next to them will be displayed.


1.2. Point the spectrometer such that the light sensor (the white disk) on top of the unit is facing the light source and is as close to touching the bulb as possible while standing.

1.3. Ensure that the light source being measured is the dominant light source with no other/few lights contributing to the measurement.

1.4. Hit the large shutter button on the left hand side of the unit: values should populate the CCT row.

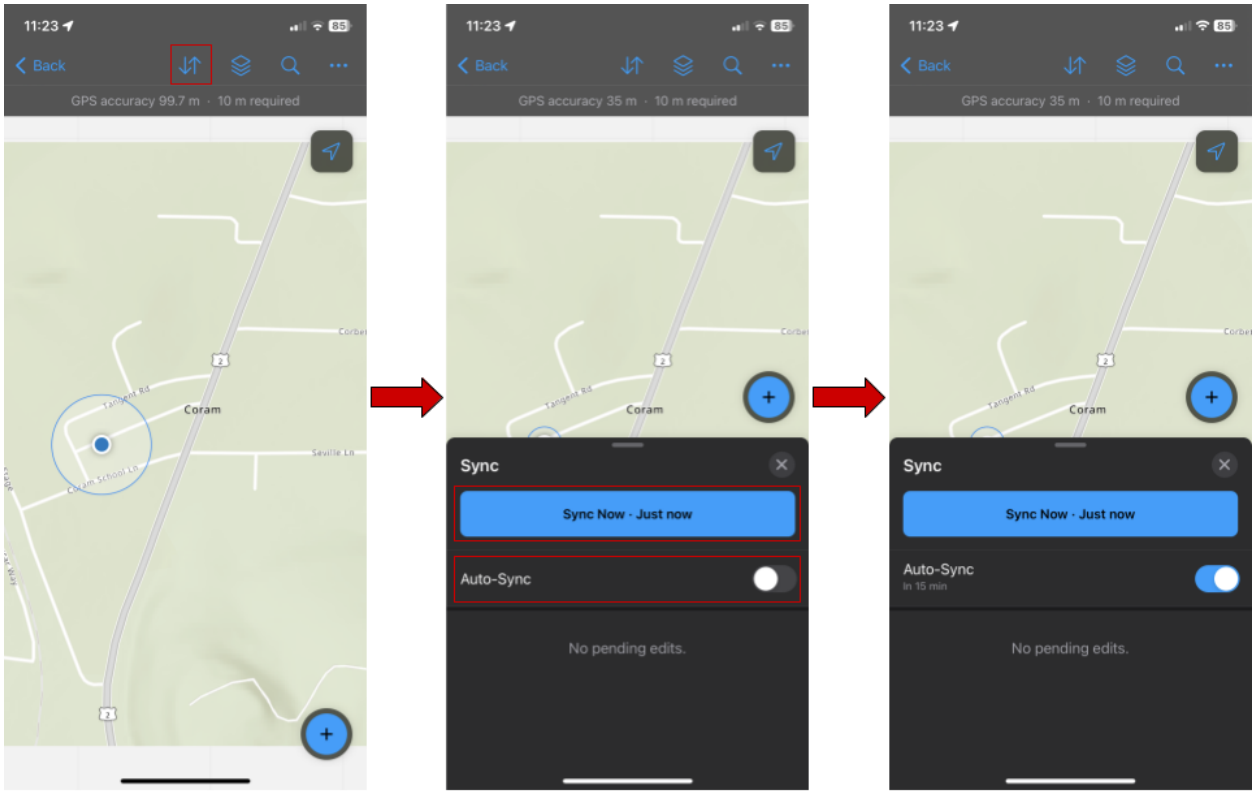
1.5. Manually enter the CCT value into the “Measured CCT” attribute for that light on ArcGIS Field Maps.



## SYNCING OFFLINE MAPS TO ONLINE MAPS

After collecting light fixture data points, make sure the offline map successfully syncs to the online map once a stable wifi or cellular connection is found.

1. While on the offline map, press the "⇅" symbol located at the top of the screen.
2. Press "Sync Now" located to the left of the last time the data was synced.
3. Toggling "Auto-Sync" to on will automatically upload offline data to the online map without manual syncing.
4. Ensure that the data was successfully synced. If the sync was completed successfully, next to "Sync Now" will be a label that says "Just now."



## Image Credits

Sullivan, R.G. (2023). *Diagram of the backlight, uplight, and glare (BUG) rating system.* ResearchGate. https://www.researchgate.net/figure/Diagram-of-the-backlight-uplight-and-glare-BUG-rating-system_fig1_372574389

*Types of Lightbulbs.* (2023). Wayfair. https://www.wayfair.com/sca/ideas-and-advice/renovation/types-of-lightbulbs-how-to-choose-the-right-one-T5256.

# APPENDIX G:

# “Dark Sky Watch” Measurement Manual

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This work was produced by undergraduate students in the Worcester Polytechnic Institute (WPI) Global Projects Program. For more information:
https://www.wpi.edu/project-based-learning/project-based-education/global-project-program

## Table of Contents



### Importance of Glacier National Park’s Dark Sky

Dark night skies are becoming an increasingly rare resource. Light pollution, generated by artificial lights, is threatening our dark skies. National parks are safe havens from this threat, protecting expanses of wilderness and the darkness of night skies. It is vital that we protect this cultural, historical, and environmental asset. The **Dark Sky Watch** program is designed for staff to help  Glacier National Park’s dark skies, preventing the loss of this great resource. Thank you for helping protect the beautiful dark skies above Glacier National Park!

### What is an SQM?

A sky quality meter (SQM) is a small handheld device. An SQM measures the darkness of the sky in magnitudes per square arcsecond (mpsas). SQM measurements have a range of 7-23 mpsas. 23 is the darkest measurement possible. 7 is the brightest measurement possible. The SQM-L (right) has a 30 degree smaller field of view than the normal SQM, decreasing the impact  foliage and other lights fixtures have on the accuracy of the data gathered.


Front panel of the Sky Quality Meter with lens, the only control is the “start” button on the front [1].

**Night Sky Requirements for an SQM Reading:**

Taking accurate sky quality measurements requires three important conditions:

1. **Low cloud coverage -** You  estimate cloud coverage by eye. Only take measurements when there is minimal cloud coverage (so there are no clouds in the reading).
2. **Low moon visibility -**  You can determine moon visibility using online sources, such as phasesmoon.com . Measurements must be taken within a day of a new moon (meaning the day before, the day of, or the day after) and moon visibility should be below 2.0%.
3. **Measurements are taken after astronomical twilight -** You can find this using online sources such as [www.almanac.com/astronomy/sun-rise-and-set](www.almanac.com/astronomy/sun-rise-and-set).

Example of utilizing the Sky Quality Meter with lens, pointed directly up at the skies zenith.

**How to Calibrate the SQM**

Recording an SQM requires the user to:

- Normalize the SQM's temperature to the outside temperature.
- Discard the first SQM measurement (for calibration due to a temperature increase when the device powers on.
- Take 5 other reportable SQM Measurements.

**How to Record an SQM Measurement**

1) Once you are ready to measure, normalize the device to the outside temperature by placing it outside for ten minutes.

2) Record the Date in the "Date" column.Record the Time in the "Time" column in military time (i.e. 2300 or 0200).Record the nearest named location to your position under the "Location" column, for example, a nearby campground, trailhead, mountain, or any named geographical feature, such as "Iceberg Lake."

3) Determine your current GPS coordinates (latitude and longitude). See **Determining GPS Coordinates,** and record GPS coordinates in the correct columns**.** Visually estimate cloud coverage. Record the "Cloud Coverage %" in the correct column.

4) Visually estimate cloud coverage. Record the "Cloud Coverage %" in the correct column.

5) Record the Moon Visibility % under the correct column. This can be determined before or after taking an SQM measurement or later using the website: www.phasesmoon.com.

6) Record Air Temperature in Fahrenheit by using a thermometer, weather app, or the Sky Quality Meter by pressing and holding the “start” button after pressing and releasing the button once.

7) Record Air Quality. This can be determined before or after measuring. Visit www.map.purpleair.com.

8) Calibrate the SQM by pointing the top of the SQM towards the zenith of the sky (directly above the measurer).

9) Press the “start” button on the face of the SQM. *Disregard the first measurement!* It is only a calibration.

10) To take a measurement press the “Start” button again. Record this result in “SQM #1”. Repeat this step four more times, filling the fields “SQM #2-#5.”

11) After recording the 5 reportable measurements, jot down any other important notes under the “Notes” column.

**Determining GPS Coordinates**

You can determine GPS coordinates by either collecting the value while at the measurement location, or after returning from your measuring trip. To determine GPS coordinates (with an iPhone) while at the measuring location (Wi-Fi and Cellular not required):

1) Enter the Apple Maps app.

2) Press the “my location” button indicated by an arrow in the top right of the screen .

3) Once you see a blue dot showing your current location, press and hold that dot until a box labeled “My Location” appears.

4) Press the box labeled “My Location” until details of your location appear on the bottom of the screen.

5) Drag the box upwards, revealing your current coordinates. Enter these values into the correct columns.

If you don’t have an iPhone or aren’t able to complete the steps listed above while you’re at the measurement location, you can use a GPS coordinate location website (www.gps-coordinate.net) to determine the GPS coordinates from a point on a map. Follow the instructions labeled “Map

coordinates of any GPS location.” When your coordinates of the measurement location are displayed, enter these values into the “Latitude” and “Longitude” columns.

**Inputting Data**

Once you have collected SQM data and have access to Wi-Fi or cellular data you’ll need to input the data into the Glacier National Park SQM database. This database is automatically updated once filling out a Microsoft form. Scan the QR code to access the form.

**Printable Measurement Table**

| Date | Time | Location | Latitude | Longitude |
|---|---|---|---|---|
| | | | | |
| SQM Readings: | | % Cloud Cover: | | |
| 1 | | % Moon Visibility: | | |
| 2 | | Temp [ ° F]: | | |
| 3 | | Notes: | | |
| 4 | | | | |
| 5 | | | | |

| Date | Time | Location | Latitude | Longitude |
|---|---|---|---|---|
| | | | | |
| SQM Readings: | | % Cloud Cover: | | |
| 1 | | % Moon Visibility: | | |
| 2 | | Temp [ ° F]: | | |
| 3 | | Notes: | | |
| 4 | | | | |
| 5 | | | | |

# Dark Sky Watch Staff Citizen-Science Form

* Required

1. Full Name *

2. Email *

3. What was the date of the SQM measurement? *

4. What time was the measurement taken? (24-Hour Clock, enter as [xxxx]) *

5. Measurement Location *

6. Latitude (If Available)

7. Longitude (If Available)

8. SQM Reading #1 (mpsas) *

9. SQM Reading #2 (mpsas) *

10. SQM Reading #3 (mpsas) *

11. SQM Reading #4 (mpsas) *

12. SQM Reading #5 (mpsas) *

13. Estimated Cloud Cover Percentage (%) *

14. Moon Visibility Percentage (%) *

15. Air Temperature (°F) *

16. Air Quality Index *

17. Other comments or notes: