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Prepared in support of the DOE Solid-State Lighting Technology Program

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Executive Summary

The U.S. National Park Service (NPS) maintains and operates numerous park units along the Eastern Seaboard of the United States, extending into the Caribbean to Commonwealth territories like Puerto Rico and the U.S. Virgin Islands (USVI). Parks that dot the eastern shore of the United States are susceptible to damage from hurricane events. Several of these units were in the direct path of hurricanes Irma and Maria during the 2017 hurricane season and suffered considerable damage, including power outages, structural damage, and destroyed equipment.

In February 2018, a task force of four staff (including participants from the Natural Sounds and Night Skies Division [NSNSD] of the NPS, the U.S. Department of Energy's Pacific Northwest National Laboratory, and Seattle City Light) deployed to three locations in the Caribbean – San Juan, Puerto Rico; and St. John and St. Croix, USVI – to assess hurricane damage to the existing lighting systems and energy infrastructure. Information was gathered through site visits and face-to-face interviews with onsite NPS staff.

The primary objective of this trip was to provide recommendations for resiliency upgrades to the lighting and electrical supply systems, with special added emphasis on the numerous goals, objectives, and requirements of the NPS (such as protecting night skies, wildlife, wilderness character, cultural resources, etc.). This document is intended to be more of a "how to" tutorial than a "why do" justification and is divided into three primary sections: Outdoor Lighting, Electric Infrastructure, and Recommended Next Steps. The main body of the document concludes with a summarized list of specific recommendations based on opportunities the project team found and discussed with onsite staff during the site visits.

Recommended Next Steps (see Section 5.0)

- Define "resiliency" in the NPS context – this broad term applies at multiple scales.
- Define and quantify goals – establish priorities and rank them.
- Refine technical options – identification of best approaches may require an iterative process.
- Conduct research/education – investigate how well other systems (including those outside of NPS) have fared in challenging environments.
- Other actions – include pursuit of internal and external coordination necessary to maximize project effectiveness; consider pilot installations as an essential component of the process.

Specific Recommendations for NPS Caribbean Sites Visited (See Section 6.0)

A host of specific lighting and power system upgrades have been assembled from both comments made during discussions with onsite staff and from personal observations around each of the sites visited. In general, it is recommended that the NPS secure qualified people to assist with the development of requests for proposal and master plans for carrying out any associated work scope. Vital technical and practical factors are needed for successful implementation, and dedicated effort will be required to ensure that the desired goals are appropriately specified. The development of design guides and product and application mockups/pilots will help improve the likelihood that the resulting designs will fit these very specific application needs.

A set of general rules for lighting upgrades is as follows:

1. Install luminaires at the appropriate height and distance from one another (and this may differ from earlier lighting) so that areas are not over- or under-lighted and an appropriate uniformity of distribution is achieved.
2. Select luminaire systems that deliver the minimum amount of light necessary to satisfy the need (lowest brightness/luminance).
3. Give attention to selecting the appropriate color temperature for the application.
4. Consider spectral content that takes into consideration the area's primary animal, plant, or insect population in choosing parts of the spectrum to minimize.
5. Use luminaires that are downward facing and shielded where necessary.
6. Use motion detectors, dimmers, and timers to reduce environmental impacts, energy use, and costs.

Numerous opportunities exist for simultaneously increasing resiliency and preserving natural environments within these sensitive locations, from both a micro and macro perspective. The coming years are likely to bring additional severe weather events to the Caribbean, with accompanying consequences. In a sense, the properties in this region present an "acid test" for achieving the multifaceted goal of increased resiliency in parallel with other critical needs. Combined with their relatively "blank slate" of existing infrastructure, these properties comprise ideal locations for pilot testing new ideas and innovations. Technological approaches that work in the extreme conditions encountered here should readily translate to many other less complex sites across the greater park system. The NPS (and the federal government in general) could benefit from developing and testing resiliency in the challenging, but highly motivated and optimistic environment found in these locations. Ultimately, care and attention to detail in implementation are the most important underlying requirements for success across the myriad needs likely encountered at these sites, once commitment to resolving them has been secured.

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Acronyms and Abbreviations

BUG – Backlight, Uplight, Glare rating

CCT – Correlated Color Temperature

CRI – Color Rendering Index

HPS – High-Pressure Sodium

ICE – Internal Combustion Engine

IES – Illuminating Engineering Society

ILAC-MRA – International Laboratory Accreditation Cooperation – Mutual Recognition Arrangement

LCOE – Levelized Cost of Electricity

NPS – National Park Service

NREL – National Renewable Energy Laboratory

NSNSD – Natural Sounds and Night Skies Division

PREPA – Puerto Rico Electric Power Authority

PV – Photovoltaic

RGB – Red/Green/Blue

SAJU – San Juan

SHPO – State Historical Preservation Office

TM – Technical Memorandum

USVI – United States Virgin Islands

VIWAPA – Virgin Islands Water and Power Authority

Contents

Figures

1.0 Introduction

1.1 Background

The U.S. National Park Service (NPS) maintains and operates numerous park units along the Eastern Seaboard of the United States, extending into the Caribbean to Commonwealth territories like Puerto Rico and the U.S. Virgin Islands (USVI). Parks that dot the eastern shore of the United States are susceptible to damage from hurricane events. Several of these properties were in the direct path of named hurricanes Irma and Maria during the 2017 hurricane season and suffered considerable damage, including power outages, structural damage, and destroyed equipment. Some of these effects remained visible months after the hurricanes (Figure 1), and repairs continue as of this publication.

Figure 1. Visible damage remains in park facilities months after the hurricanes passed (photo taken March 2018).

The NPS Organic Act of 1916 established broad obligations to preserve the natural, cultural, and historic resources of national parks. In accordance with the Act, the NPS Natural Sounds and Night Skies Division (NSNSD) strives to preserve natural lightscapes and other exemplary features of parks to the greatest extent possible. For outdoor lighting, this means defining where, when, and how much light is needed; controlling the distribution of light to minimize light trespass into off-target areas that include the night sky; and mitigating associated impacts to nocturnal habitats while preserving opportunities for visitors to enjoy the park at night. The damage brought by the hurricanes presents an opportunity to improve not only the resiliency of various energy systems and services (like lighting), but also their adherence to this fundamental mission of the park service. NSNSD thereby contacted a variety of experts to gauge interest in participating on a task force to assess the impacted sites and provide recommendations for how to best achieve the collective desired ends.

In late February 2018, a task force of four staff (including participants from the NPS, the U.S. Department of Energy's Pacific Northwest National Laboratory, and Seattle City Light) deployed to three locations in the Caribbean – San Juan, Puerto Rico; and St. John and St. Croix, USVI – to assess hurricane damage to the existing lighting systems and energy infrastructure. Information was gathered through both site visits and face-to-face interviews with onsite NPS staff.

In addition to the existing storm-related damage, these sites have long endured a host of energy issues such as extraordinarily high prices for highly unreliable electrical service. Park managers therefore see potential upgrades as opportunities to address these critical issues as well.

This document provides some of the information obtained during this visit, describes means of addressing issues of interest with specific examples, and finally presents recommendations across all the sites visited.

1.2 Sites Visited

- San Juan, PR – (SAJU) San Juan National Historic Site including Castillo San Felipe del Morro and Castillo de San Cristóbal
- St. John, USVI – (VIIS) Virgin Islands National Park including NPS Headquarters, Cruz Bay; Caneel Bay Resort; Cinnamon Bay Campground
- St. Croix, USVI – (CHRI) Christiansted National Historic Site including Fort Christiansted, park housing and surroundings; (SARI) Salt River Bay National Historic Park and Ecological Preserve and the site of future NPS visitor center at this site.

In all cases, NPS staff were available to meet and discuss their needs and wants and provide guidance around the mission of each site. Information provided by managers was very forthcoming and engaged, leading to fruitful discussions. Their assistance proved extremely useful and is greatly appreciated.

The primary objective of this trip was to provide recommendations for resiliency upgrades to the lighting and electrical supply systems, with special added emphasis on the goals, objectives, and requirements of the NPS and NSNSD. The rest of this document focuses on this charge. This report is intended to be more of a “how to” tutorial than a “why do” justification. Several previous documents and presentations have been prepared for the NPS pertaining to the latter; a brief listing with descriptions is provided in Appendix B– Brief List of Recent Related Materials. The present document is divided into three primary sections: Outdoor Lighting, Electric Infrastructure, and Recommended Next Steps. The main body of the document concludes with a summarized list of recommendations based on specific opportunities the project team found and discussed with onsite staff during the site visits.

1.3 System Resiliency

The concept of “resiliency” has become a recent focus of government attention due to a variety of events that have compromised U.S. infrastructure over the last several years. Resiliency in the current context comes in multiple forms with a range of considerations.

Modern civilization relies heavily on a readily available supply of electric power, loss of which extends beyond modern convenience to health and safety. Risks of interruption to power supplies influence the level of resiliency for multiple systems, and their effects may be cascading. Interruption may result from destruction of power-generating equipment, damage to grid infrastructure connections between that equipment and the end-use, destruction of end-use componentry that converts power to services (such as lighting fixtures), or overreliance on unrealistic requirements of maintenance, knowledge, and availability of trained staff and related tools and supplies needed to perform such maintenance and repair. Each of these factors presents a potential vulnerability, and all of them, in different combinations, have influenced various installations observed during site visits.

Resiliency can involve electrical, structural, and temporal elements, often in combination. Electrical issues might arise from corrosion induced by salt in the air due to the proximity of the sea, for example, creating problems that worsen over time independent of emergency events (Figure 2, left). A system already weakened by corrosion, however, is much more vulnerable when an event occurs. Structural integrity of components can be similarly compromised over time by exposure to the elements, without visible indication, until such an event reveals it (Figure 2, right).

Figure 2. Left: Salt buildup visible on display lighting in interior of "El Morro" fort. After only a few years, most of these fixtures are inoperable. Right: Effect of high winds on a fiberglass streetlight pole likely weakened over time by exposure to ultraviolet rays in sunlight.

Improving resiliency in island locations is further challenged by their remoteness. It is difficult to maintain sufficient and readily-available inventories of fuel, new and replacement components, and emergency equipment for such large-scale events, as these are generally shipped as needed. Local contractors and staff might not be properly trained for the emergency maintenance duties necessary or may lack the equipment required. Access to remote regions introduces further difficulties – this factor alone has received much of the blame for the long-standing power outages in Puerto Rico. In general, all these issues are in play in the sites visited.

The area known as “The Biosphere” on St. John, for example, had at least two failed emergency generators onsite while new units remained on skids at the NPS maintenance facility (Figure 3). While not further investigated during this visit, combustion-based emergency generators require regular maintenance, such as frequent replacement of coolants, oil levels, and fuel filters. The failed units might reflect an inability to provide the necessary attention given numerous competing demands and/or scarce staff availability during the long power outage. Meanwhile, new units must be transported to the installation site using heavy equipment and installed and commissioned – a process likely challenged again by a shortage of available staff and equipment.

Figure 3. The Biosphere with two non-operating emergency generators (left; units are yellow), while new generating units (right) await installation back at the maintenance facility.

Improving resiliency over long-term emergency conditions such as those endured in these locations requires, in part, planning for additional attention and equipment that is specifically dedicated to this goal.

2.0 Part 1 – Outdoor Lighting

2.1 A Brief Introduction to Outdoor Lighting

2.1.1 Why Light in the First Place?

Where genuinely needed, lighting provides numerous safety and security benefits, most of which are apparent and need no further justification. However, excessive lighting is a significant issue for protecting natural dark night skies and associated national park resources and values. Over-illumination and light trespass can cause more disruption to park resources than benefits to park visitors and might be avoided entirely. In some cases, for instance, lighting alternatives such as reflective tape or posts can adequately serve wayfinding needs without adding light to the nocturnal environment. As previously defined, Zone 0 locations are those wanting no supplemental lighting infrastructure. The NPS has many such areas within its boundaries. The semi-urban settings and lighted surrounding environments of SAJU or CHRI, however, preclude this zone designation.

IES also suggests that roads with a posted speed limit of 30 mph or less may be sufficiently illuminated by vehicle headlights, with no supplemental lighting needed.[1] In other areas, night lighting may not be necessary due to exclusive operation during daylight hours. This is a valid consideration pertaining to the interior of St. Cristóbal, for example, where the display lighting fixtures have succumbed to salt corrosion and most have become inoperable after only a few years (Figure 2). With perhaps the exception of one or two individual units that lack adequate exposure to the exterior at this site, natural daylight may provide more than enough illumination in most cases.

The current corrosion issue at St. Cristóbal is likely to remain problematic in the future, while it appears that the supplemental lighting is mostly superfluous; here is an example where further evaluation is warranted. On the one hand, it might be preferable to eliminate this lighting altogether, while on the other, aging eyes that might be visiting this site need more light for adequate perception in dim lighting conditions. Similar tradeoffs are frequently involved in decisions regarding the need for lighting. A qualified lighting designer will consider all such factors when making recommendations in each situation.

Related questions as to when lighting is needed and at what level also arise in other areas. Such questions are again at the heart of thoughtful lighting design and planning. During the site visit, several discussions centered on the perceived need for lighting additions, in some cases requiring new installations such as in the parking lot at the Cinnamon Bay Campground. This is not a high traffic area for vehicles; rather, the perceived need for supplemental lighting stems from pedestrian safety issues related to insufficient visibility. Accordingly, this area could be illuminated at very low levels and still provide adequate visual acuity for pedestrians, while also incorporating dimming and occupancy sensors, or possibly reflective tape or posts specifically designed for wayfinding that might reduce light levels, even to zero, when no one is actively using the parking lot.

[1] As stated in IES RP-8-18. Due to the possible number of variables present, however, IES defers to the designer and governing authority to determine whether supplemental lighting is warranted in any given instance.

2.1.2 Design Criteria

Skilled lighting design incorporates many factors, some of which are basic standards established by the IES or longstanding practices that are adhered to for a specific need to the greatest extent possible. These typically include horizontal and vertical illuminance, uniformity, and glare (see definitions above). The need for lighting is determined by a combination of the lighting zone in which a given application resides and the level of activity and other perceived needs pertaining to that application. At Cinnamon Bay on St. John, for example, the parking lot has always been unlighted, but a tripping accident and resulting lawsuit have increased interest in providing illumination there.

At the very least, design criteria for a given installation will detail how much light is needed (e.g., “0.1 fc average horizontal illuminance”) and its required uniformity (e.g., “maximum to minimum variation of no more than six to one”) over the specified target area. The criteria may also include other relevant parameters such as allowable level of veiling luminance (i.e., intensity of the light impinging on someone’s vision using the target area), allowable CCT, and other desired attributes such as the boundaries of the area beyond which no light is intended to cross. Design criteria and planning enable a designer to identify suitable products and related equipment for a given application. For example, reflective tape or posts may be adequate for directional wayfinding in some areas, while in others with changing grades or contours it might be that low-level, low-light bollards (perhaps solar-powered and/or using motion detection) may provide enough illumination for adequate depth perception.

2.1.3 Adverse Effects of Lighting

In addition to mission-driven objectives such as the protection of dark night skies, visitor experience, cultural resources, wilderness character, and public health and safety; reductions in energy use and its associated cost savings are other important reasons park units would consider for converting older lighting technologies, including high-intensity discharge products like metal halide or high-pressure sodium and even compact fluorescent, to light-emitting diode (LED). Energy use is incurred even when providing the proper amount of light to the target space at the proper time(s) and depends on both the efficacy (lumens per watt) of the given lighting device and how well the lumens produced are delivered to the target area. Excess or wasted energy results when an installation:

- produces more light than needed,
- operates at times when light is not needed, or
- sends light into areas where it is not needed or intended.

Each of these practices represents an area of potential savings or mitigation that can be achieved without affecting the intended service the lighting provides. Absent such consideration, these practices not only waste energy and money but also cause impacts to national park resources and values (night skies, wildlife, cultural/historic resources, wilderness values, and visitor experience). Minimizing excess use of lighting helps to address all these issues simultaneously.

Wildlife – Most forms of life on the planet have evolved under a 24-hour diurnal cycle of light and dark. Light at night effectively changes the natural cycle and can disrupt numerous and varied phenomena like seasonal flowering, mating behaviors, migration patterns, and predator/prey behavior.

Cultural/Historic Resources – Many early structures maintained by the NPS were not historically illuminated beyond campfires or torchlight, so to an extent any new lighting is departing from original conditions. Despite applications of façade lighting like those illuminating the forts at the sites visited, however, there remains a desire to maintain subtlety and tasteful discretion in its use, avoiding results that evoke a commercial parking lot or sports arena. Well-aimed and shielded lighting that puts light of suitable color only where it is expressly wanted is of utmost importance at these culturally significant sites.

Wilderness – In the NPS context, "Wilderness" (capitalized) means Congressionally designated undeveloped public land. Lower case "wilderness" applies to a natural place that remains in its pristine, pre-human condition. Any human-based light at night, even visible via distant horizon, runs counter to these designations.

Night Skies – National parks remain one of the few areas within the continental U.S. where relatively unobstructed views of the night sky are still available, yet the number and size of those areas continue to diminish. Visibility of celestial objects is obstructed, and night sky visibility is reduced from increased brightness of the night sky, or *sky glow*, from large, brightly lit areas in the vicinity, as well as from localized sources of light such as a nearby parking lot. Sky glow often appears as a dome of light on the horizon typically associated with nearby cities but can also be observed from substantial distances. The presence of sky glow degrades the naturalness of the night sky in a national park. Even in the NPS units near urban centers where night skies suffer effects of sky glow, visitors are often guaranteed access to the best nearby night skies within park boundaries. Importantly, however, night skies are not only affected by large lighted areas or concentrations of lights; even a single incorrectly aimed light can cause significant annoyance glare and diminish views of the night sky.

2.2 Components of Sky Glow, Glare, and Light Trespass

Sky glow is caused by the scattering of wavelengths in the visible spectrum passing through the Earth's atmosphere. Most scattering is wavelength-dependent and results from a physical relationship between the frequency of the light wave and the size of airborne particles it encounters. Shorter wavelengths corresponding to blue and violet colors are the most affected by the molecular content of our atmosphere, primarily nitrogen and oxygen, and thus scatter the most readily. This phenomenon creates the apparent blue color of an unpolluted daytime sky that most humans observe. Larger particles, like humidity, may also cause scattering in a form that is not wavelength-dependent, which is why, for instance, clouds appear white or gray. Individual wavelengths of light emitted from electric or other sources at night scatter the same way in the atmosphere as those contained in sunlight at similar frequencies, albeit at much lower intensity.

Some amount of light propagating through the night sky is unavoidable if supplemental lighting sources are to be used: Light reflecting from objects is how we see them. Moreover, no single lighting technology (e.g., high-pressure sodium or LED) or end-use (e.g., street, area or architectural lighting) is exclusively responsible for light at night. All sources of light exposed to the exterior environment contribute to light entering the night sky, and this includes not only street, roadway, parking lot, and other lights installed for vehicular safety (including lights on the vehicles themselves), but also all manner of building lighting (exterior as well as any interior light allowed to escape to the outside), pathway lighting, landscaping, signage, sports lighting, and all others.

Concisely stated, the contributions towards sky glow from a singular light source typically include, in order of significance:

7. *Uplight from the source* – Uplight is the light emitted from a fixture at or above a horizontal plane level with the fixture. When present, uplight is the largest potential contributor to sky glow.
8. *Luminaire output* – The greater the amount of light emitted from a luminaire, the more light that is likely to wind up in the night sky through the variety of paths (usually a varying combination of direct, reflected, and scattered emissions) it follows to get there.
9. *Spectral content* – Shorter wavelength light scatters more readily than longer wavelength light in Earth's atmosphere and has greater magnitude near the source. Longer wavelength light travels farther and does eventually scatter, however, and thus also contributes to sky glow. The latter is commonly visible as the familiar orangish light dome over populated areas.

In a single sentence, the most effective lighting practice addressing the greatest number of collective concerns is limiting the correct amount of light to the target area of illumination, minimizing the escape of *all* light spectra to the surrounding environment.

2.3 Mitigation

Most light pollution can be avoided by thoughtful system design and selection of lighting equipment that has become widely available on the market. The ability to achieve this objective continues to improve with the evolution of both lighting technology and the means of digitally controlling it.

The best approach for simultaneously addressing energy, cost, and the various NPS environmental objectives referenced earlier is to avoid producing excess light in the first place. As previously noted, excess light includes illumination surpassing the level recommended for the given application and light emitted in unwanted directions. Considering that supplemental illumination is exclusively intended for the benefit of humans, the timing in which lights are energized should also coincide with human occupation in a space and reflect both the specific purpose and natural lighting levels presently available. Use of lighting alternatives such as reflective tapes and posts, and photoluminescent markers can help ensure that lighting design and specifications correspond to only the levels and locations needed. Appropriate use of adaptive lighting equipment and techniques provides similar function.

LEDs have an inherent advantage over conventional lamp-based sources that are omni-directional emitters, because they offer much more directional control from the moment of output. This means they do not require as many reflectors and secondary optics in the fixture to accurately reshape their light output to the target space (e.g., such as a rectangular road surface passing beneath the luminaire). A direct consequence of this is that LEDs do not usually need the same lumen output (or "lumen package") as the conventional product they are replacing (Figure 4). Lighting requirements can often be met with half (or less) the lumen output from an LED product compared to the incumbent product being replaced. This factor can be a significant component of their associated energy savings while offering marked improvement towards reducing light in the night sky (Figure 5) – at the same time, however, neglecting this improved distribution quickly leads to overlighting if an unfamiliar designer simply replaces an incumbent source with a like number of LED lumens.

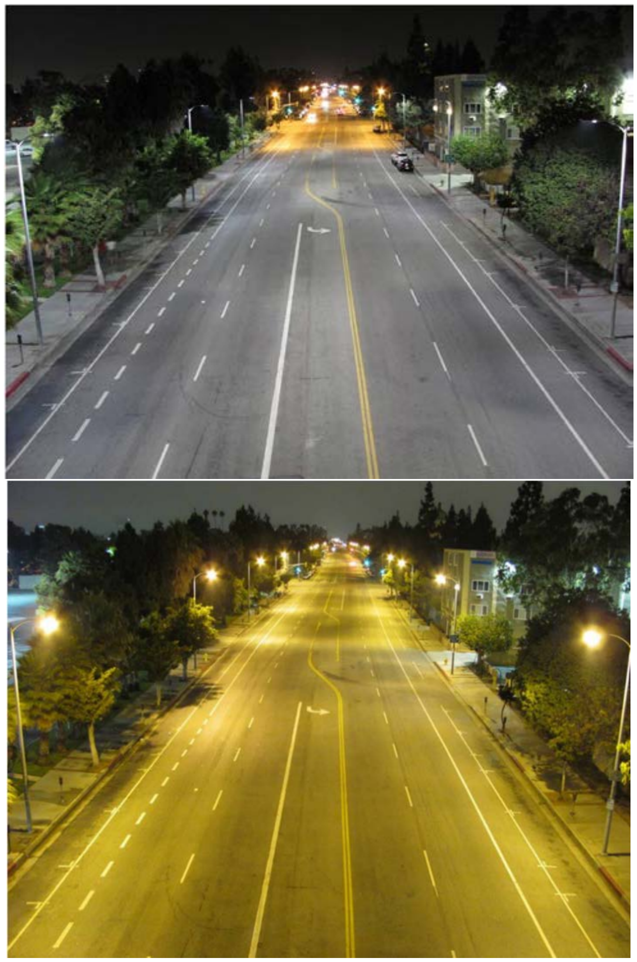

Figure 4. Top: LED lighting showing significant improvement in lumen delivery to the road surface compared with older, HPS lamp-based lighting (bottom). In this installation, the replacement LED luminaires are producing less than half the lumens of the HPS (Personal communication with Ed Ebrahimian, Director of the Los Angeles Bureau of Street Lighting). The substantial reduction in uplight achieved is also visible. Photo: LABSL

Figure 5. Tightly fitted distribution on a roadway minimizes off-target illumination. Photo: Chris Kyba

Finally, significant attention has recently focused on luminaire spectral content, with related recommendations of minimizing or eliminating shorter wavelength content, but such decisions introduce a variety of topics for consideration. Some recommendations, for example, involve filters to remove all wavelengths shorter than 500 nm (i.e., roughly beginning at cyan and continuing through blue and violet colors). Filtering out lumens that one has expended energy to produce is a less desirable approach than avoiding their production in the first place; a better approach may be selecting products that do not contain such wavelengths. An increasing number of LED products in the 2200 – 2400 K range have recently become commercially available for this purpose. Note that these products continue to incur energy penalties compared to higher color temperature products and their ability to render colors in other objects is also somewhat compromised.

The spectral content of a light source contributes to multiple objectives, including visual acuity, enhancing contrast of objects in the path or road, and improved ability to render natural colors in illuminated objects. All of these may bring benefits such as more rapid identification of animals in the roadway at night. Spectral content also drives other traits that may be either beneficial or detrimental depending on the context, such as apparent visibility/brightness of the source to different species, or relative ability to stimulate the human circadian response, or plant growth, etc. Unfortunately, CCT by itself is an imprecise measure of actual wavelength content and thus does not guarantee to satisfy objectives that fundamentally depend on that content (such as relative ability to stimulate a circadian response). Different CCT product versions or sometimes even siblings with the same CCT[1] may involve tradeoffs among one or more of the traits mentioned (refer to the visible variation among LED products at the same nominal CCT in Figure C.2, for example). The only certain way to know that impacts are being minimized is for the buyer/designer to understand which specific spectra are responsible for the given effect and to compare those against the spectral content of each product being considered. Marketing materials often treat such issues in general terms and cannot be relied on to provide the full story, especially as it pertains to a given LED sample in a range of products.

[1] Such as might occur, for example, in different generations of a product or when a luminaire manufacturer employs chips of the same nominal color from different suppliers.

Up to now, manufacturers have generally not been accustomed to providing full SPD information on their product lines but do have this information or access to it. (It is necessary for calculating CCT, for example.) Furthermore, IES has recently approved the development of a new technical memorandum (TM-33, which will subsume three earlier documents) for describing standardized data formats for electronic transfer of photometric data and related information. For the first time, TM-33 will also establish a standardized format for SPD, which should help make it more commonly available and encourage development of tools for its evaluation.

In the relatively near future, ongoing advancements in lighting technology may enable extremely precise selection and control of spectral content, but for reasons of cost and simplicity, most users presently wanting to reduce short wavelength content continue to rely almost exclusively on CCT. In the most basic sense, lower CCT products do tend to have lower overall levels of short wavelength content than their higher CCT counterparts. As noted, however, the variances possible even within a nominal CCT (e.g., 3000 K) can lead to a variety of associated tradeoffs. Comparisons based on CCTs should thereby also consider other desired characteristics of the products being evaluated, such as their relative efficacies and color rendering abilities, and light output.

2.4 Advantages of LEDs with Controls

LED products offer a wide range of characteristics and are becoming increasingly capable of dynamic adjustability to suit a wide spectrum of needs. “Adaptive” lighting is the term being used to describe systems that can be programmed to respond to user presence or other conditions via dimming or other behavior, employing motion detection or various other sensors to monitor that presence. Additional characteristics such as an ability to dynamically change the distribution of light or color temperature (non-RGB type systems) are now becoming available. The compatibility of LEDs with digital controls and their wide potential range in characteristics will make them increasingly appealing for the wide variety of park lighting needs and objectives.

Solid-state construction also substantially increases LED resistance to vibration and other shocks that can prematurely end the life of glass lamp-based products. In combination with the long operating life of the source (perhaps 15 or more years for LEDs compared to glass lamps that typically require replacement every 4-5 years), these products require much less maintenance and significantly improve reliability at sites that install them. For sites that are susceptible to severe weather or loss of grid connected power and want to increase resiliency, LEDs are the current technology of choice. Associated controls have not yet attained the same level of market readiness (not yet offering complete interoperability among systems, for example), but are the focus of much research and rapid development.

2.5 Specification

The characteristics sought for a given lighting application are most reliably obtained through a well-articulated specification document. Special needs such as the required resistance to highly-corrosive marine environments and high wind speeds potentially encountered on the islands are unlikely to be satisfied by products procured unless these are clearly called out in the performance specification.

Contracting and procurement specialists must understand that because LEDs differ significantly from earlier incumbent technologies, they often require a dedicated version of the lighting specification from the boilerplate language that agencies have used in the past. In recognizing this need among cities, the U.S. Department of Energy’s Solid-State Lighting Program previously prepared a Model Luminaire Specification through its Municipal Solid-State Street Lighting Consortium, with many sections relevant to municipal use already provided in draft form. In some cases, default values have been inserted where the user may not have either knowledge of available choices or preference among them, but any or all values can be simply modified as desired. Given the somewhat broader mission scope of the NPS compared to a typical municipality, a variety of corresponding sections will likely need to be added for its use. However, this document can be a useful starting point for sites that lack a dedicated LED specification document.

In some instances, a site might also want to take a simpler approach and develop a specification similar to those used in the past. For example, after the site visits in this effort, the project team was provided with a draft lighting specification addressing a requested upgrade for which funding had just been approved and was asked to provide review and feedback. The project team identified several areas where the draft could be strengthened to improve the suitability of resulting proposals (see Appendix). An equally important job of a good specification is to effectively discourage submission of unsuitable proposals, while not precluding proposals that miss on a minor or even unintentional point but are still worth considering.

The recommended modifications apply to issues common among specification documents and thus extend beyond an individual instance. The following list pertains to all types of lighting specifications.

2.6 General Suggestions – Lighting Specifications

- Consider providing an Introduction that clearly states the goals of the project, explaining why lighting is warranted to begin with, and justifying important aspects (e.g., white light versus amber, color changing versus fixed spectrum).
- Sites should fully characterize the existing lighting systems intended for replacement (e.g., luminaire make/model, lamp make/model, ballast make/model) and luminaire-target geometries (e.g., site plan, building elevations, luminaire spacing, luminaire setback, luminaire mounting height).
- When existing luminaires are being replaced, do not assume that the original luminaires provided the ideal characteristics. It's important to reevaluate the appropriate light distribution and levels. Mock-ups are the best way to visually establish/verify that light levels, CCT, etc., are appropriate.
- Once minimum light level is specified appropriately, it is best to simply set a limit on input power and refrain from redundantly specifying other parameters that may inadvertently exclude optimal products – the combination of minimum light level and maximum input power will naturally ensure sufficient illumination, energy savings, and efficacy.
- Use a checklist specification format to ensure all important characteristics are addressed.
- Structure the specification to avoid duplication and conflict among sections – for example, create dedicated sections for each luminaire type (e.g., with different ingress protection [IP] ratings for bollards than for uplights), and consolidate all overlapping items (e.g., warranty) in a "general" section.
- Ensure that specifications for any given item (e.g., CCT) are appropriate for the given application; complete, consistent, and unambiguous; and not in conflict with specifications for other items

- When occasional color-changing is required, but luminaires will generally operate in “white” mode, consider specifying the two modes separately – their power consumptions are likely to be different, for example.
- The more items in a specification, the higher the odds that an approved product (i.e., one that satisfies the specification) will prove acceptable, but the lower the odds of finding an off-the-shelf product that meets all requirements – some flexibility is often needed (and justified) in approving products.
- Insist that vendors submit documentation supporting their performance claims – it is one thing for a manufacturer to claim their product produces 800 lumens with 5.5W input power, and another to demonstrate this with an IES LM-79 report from a test laboratory that is accredited by an ILAC MRA signatory to do the testing.
- Consider good/better/best alternate bids, but keep in mind that the matrix can grow quickly in size and complexity.
- Use mock-ups and table-top examination (i.e., where units can be closely inspected by facilities staff) to verify that products meeting specifications also meet with visual approval.

3.0 Part 2 – Electrical Infrastructure Assessment and Recommendations

3.1 Distributed Energy Resources and Microgrids for Enhancing Resiliency

Like most NPS units, the Caribbean park systems appear to be almost exclusively served by local utility grid power (Puerto Rico Electric Power Authority [PREPA] for Puerto Rico and Virgin Islands Water & Power Authority [WAPA or "VIWAPA"] for the USVI) on a distribution system that spans each property. As described previously, there are a few fossil fuel emergency backup generators at the various properties and a few roadway lights with photovoltaic (PV) panels attached (though ownership may be unclear, Figure 6). Besides these limited examples, there appears to be no local or onsite generation within the park properties – various PV and wind generation facilities were spotted elsewhere on the islands; however, many of them appear to be privately owned. A thoughtfully designed system equipped with resilient and redundant equipment could reduce out-of-service time for park properties while increasing safety for employees and visitors.

Figure 6. Roadway lights with grid-tied PV panels located inside Christiansted housing area, likely owned by the utility.

A variety of locally sustainable distributed energy resource options could potentially serve this purpose for park properties, including:

- Renewable energy generation (wind and solar)
- Generation and battery storage (off-grid)
- Microgrid (islanded [i.e., temporarily or permanently electronically isolated from the grid] and/or grid-tied or "-connected")

Moreover, these options are entirely modular and thus can be easily implemented at various scales. Small installations can be used to supply a subset of park loads, for example, or a larger installation (or combination of smaller installations) can be used to supply all loads within the property.

The following provides a summary of each option and how it should be evaluated for NPS purposes, along with design requirement considerations.

3.2 Renewable Energy Generation

Local renewable generation is a relatively "easy" onsite addition within each park campus. Adding this local generation essentially offsets the energy purchased from the utility. In a net metering arrangement, the utility meters customer generation in addition to customer use. The customer only pays the utility for the additional electricity above what was locally generated. The utility may provide a customer credit for excess generation. Metering configurations vary among utilities and are based on utility options.[1]

Both PREPA[2] and USVI WAPA[3] offer net metering programs to their customers for small wind and/or PV systems (solar). Both utility programs allow customers to carry over net excess generation as a kilowatt-hour credit to the following month. Customers with an excess at the end of a 12-month cycle will be compensated financially, but at different rates, depending on the utility.

In this report, "local renewable energy" refers to the readily accessible solar or wind resources at these sites; however, the models can also be applied to locally-generated hydro energy, thermal energy, and other renewables. These can be installed at park facilities *off-grid* (dedicated and islanded), *grid-tied only* (net metered), or in combination. In all cases, checking with the local utility regarding the availability of demand response or other incentives to help offset costs is worthwhile.

Off-grid – This type of generation has many advantages, including the ability to partially or fully offset the cost of energy at a site for a portion of the day, depending on the site and system size. Adding energy storage to these systems extends the savings to times when generation is limited or not possible – say, at night or on a windless day. Obviously, since the system is not tied to the grid, utility credits are not possible. However, the demand from the utility is still reduced with a commensurate cost savings.

Grid-tied – Power generation systems connected to the utility grid are typically net metered by the utility to measure how much energy (in kilowatt-hours) is placed on the grid. Such systems also offset the energy purchased from the utility and thereby reduce the power bill, but also enable the site to get credit for any excess generation, and possibly at the higher rate available during peak demand periods, an advantage over energy storage that may be offsetting usage during off-peak periods. When switching equipment is used to allow onsite use, the owner receives direct benefits. Another consideration for systems with enough storage reserve can be to apply as much generated and stored electricity towards the grid as possible (i.e., over and above supplying their internal use) to obtain peak shaving credits if/when they are available and NPS is able to take advantage of them, and recharging storage during off-peak periods.

[1] See Section 6 of VIWAPA's Net Metering Agreement for Small Wind and/or Photovoltaic Systems: (http://www.viwapa.vi/Libraries/PDFs/Net_Metering_Agreement_2-2013.sflb.ashx)
[2] PREPA Net Metering: https://www.energy.gov/savings/puerto-rico-net-metering | https://www.aeepr.com/medicionneta/
[3] VIWAPA Net Metering: http://www.viwapa.vi/OurEnergyFuture/NetMetering.aspx

A grid-tied system enables continuous operation, with lapse in service only when the grid and onsite generation are down simultaneously. However, some systems may not produce power for the site during a grid outage, regardless of the state of local production. This is often the case in very reliable utility service areas, for example, where some systems are designed to feed all local generation to the grid while using only grid (i.e., utility-provided) energy for onsite use – in other words, a "buy all, sell all" system. Yet other systems are purposely designed to stop production during a grid outage as a safety measure, to protect utility workers conducting repair work.

For utility worker and customer safety, VIWAPA requires the customer to install a "readily accessible and visible" manual disconnect "to provide a separation point" between the AC power output of the customer system and the utility grid system. To prevent back feeding in either direction, this equipment needs to be operable and lockable by the utility to isolate the utility electrical grid from the customer generation. (At the time of this writing, it is unclear how PREPA addresses this safety concern.)

3.2.1 Sizing

Sizing a local generation system is often based on maximizing system size against the local load (energy usage) and space constraints. For example, a rooftop system would ideally use as much of the available roof space as possible, typically up to the point where system generation equals the building load. During different times of day, a system may generate more or less energy than is needed. During those times, the grid compensates for the excess flows to the grid or the shortage, illustrating the benefits of being grid-tied.

Initial sizing of a local generation system generally requires only the annual load of the building(s) to be supplied and the estimated annual production of the generation system. The National Renewable Energy Laboratory (NREL) PVWatts[1] tool provides a good first cut at estimating annual solar energy production. Optimizing the system design may require an iterative process, however, as it could be that a system above a certain size will be less financially attractive than a smaller system. The size of the system should be fine-tuned using financial analysis.

3.2.2 Design Requirements

The subsections below describe various design requirements or considerations for local renewable generation.

3.2.2.1 Solar PV

There are a range of factors to consider when installing a solar PV system. General guidelines are included here but site-specific considerations should be included as well.

- Major Equipment:
  - **Modules[2]**: The main design choice when selecting solar modules is between polycrystalline (lower efficiency, lower cost) and monocrystalline (higher efficiency, higher cost). For areas with ample solar resources and/or space constraints, the higher-efficiency modules become cost effective.

[1] http://pvwatts.nrel.gov/

[2] https://www.pv-tech.org/editors-blog/top-10-module-suppliers-in-2017

– **Mounting[1]:** The type of mounting chosen is largely informed by local wind speeds and building codes, as well as structural considerations (e.g., existing roofs/structures, soil types)
  - ○ Rooftop: Solar panels can be mounted to roofs with various penetrating attachments, or by being ballasted (weighted). Mounting systems often combine these approaches.
  - ○ Ground mount: Ground mount systems can be drilled pier foundations, spread footing, or ballasted.
  - ○ Building integrated solar: Building integrated photovoltaic (BIPV) refers to solar that is integrated into the design and materials of a building in various forms. Examples include:
    - Solar roof tiles: Solar panels can be integrated into the roofing material of a building or house. Tesla[2] has come out with a version of this. Note that the project team is not aware of any installations of the Tesla product that have any length of data to prove performance, and therefore recommends further investigation before considering this option.
    - Solar-integrated sun shades and window treatments: Shades or blinds are available and can be designed into the building architecture. These can reduce the air conditioning requirements while providing additional PV generation.

– **Inverter[3]**: There are distinct types of inverters (e.g., central, string, and micro). Central inverters are typically used for larger systems where there is space for a large inverter. String or micro inverters are typically used for smaller systems or systems that are more likely to be impacted by shading.

[1] http://www.panelclaw.com/products/
http://sunlink.com/#!/products
https://www.s-5.com/products/
[2] https://www.tesla.com/solarroof?redirect=no
[3] https://www.sma-america.com/products/solarinverters.html
http://www.fronius.com/en-us/usa
http://solarenergy.advanced-energy.com/solar-inverters

- Notes:
  - **W/ft^2 Rule of Thumb:** At a high level, it can be estimated that roofs can accommodate 10 W of solar for every square foot. This is a high-level estimate that changes depending on the solar panel wattage used, the tilt of the system, the design of the roof, compass orientation of the panel, shading, and other factors. Ground mount solar panels are expected to have a higher wattage per square foot from optimal placement.
  - **Tilt**: To maximize solar production annually, the tilt of the system should equal the latitude of the site, although structural considerations often outweigh this rule-of-thumb. Tilts typically range from 10-20 degrees.
  - **Azimuth**: To maximize energy production, systems should face the Equator. Thus, systems in the Northern Hemisphere should face south. When mounted on roofs, this is often infeasible and therefore systems have slightly off-south azimuths. Also, if trying to maximize energy production in the morning, the systems should face more towards the east; similarly, when trying to maximize afternoon production, systems should face more west.
  - **Shading**: Depending on the vintage of the solar equipment and how the system is installed, solar energy production can be heavily impacted by shading. However, shading is less of a concern in newer systems where decreases in production are not linearly related to the area of a panel shaded, nor does shading of one panel necessarily affect the output of other panels to which it is connected. Nevertheless, trees, buildings, and even other solar panels can shade parts of a system and reduce its output, and for that reason, siting and spacing of panels relative to other objects should be a top consideration.
  - **Balance of System (BOS)**: Balance of system components include conduit, wire, and other infrastructure required to physically and electrically make the system work. General considerations for BOS components include their exposure to elements such as sunlight and rain, as well as their physical appearance. For roof-mounted solar, architectural considerations for conduit are often included in the design and routing of BOS components.
  - **Operations and Maintenance (O&M)**: The maintenance of a solar system is generally very minimal. Washing of solar panels can increase production; however, the benefits are minimal and therefore the maintenance cost to wash should be assessed against the gain in production. A general rule of thumb is one or two washes per year with slight adjustments for local conditions.

3.2.3 Strengths and Limitations of Renewable Energy Generation: Solar

The table below summarizes the strengths and limitations of local renewable generation with respect to some of the parks' lighting goals.

Goals	Strengths	Limitations
Resiliency		No improvement to resiliency unless the utility allows islanding.
Cost	Energy costs can be reduced if the system is designed with payback or levelized cost of electricity (LCOE) in mind.	The systems will require onsite O&M. These expected costs should be factored into the economic analysis, but there may be unexpected costs.

Goals	Strengths	Limitations
Sustainability	By using renewable generation, parks will offset a portion of the largely carbon-based grid power.	
NPS Organic Act		
Wildlife	Installing small-scale PV systems on existing structures would not modify wildlife habitat and may reduce the amount of fossil fuels and/or electricity imported to the islands. Both of the latter are typically associated with negative impacts to wildlife.	Few studies exist on the ecological effects of small-scale solar energy systems, but depending on design specifications, plant populations, wildlife habitat, and terrestrial wildlife may be disturbed or displaced (especially during construction phase).
Cultural Resources	Ballasting renewable energy rooftop installations (or other building-integrated installations) could secure equipment without permanent alteration of cultural resources. Solar panels on a historic property in a location that cannot be seen from the ground will generally meet the *Secretary of the Interior's Standards for Rehabilitation*. [1]	Solar arrays have the potential to disrupt the cultural landscape by altering the sense of place and the perception of historic or cultural authenticity of an area. Solar panels requiring roof-mounted penetrating attachments would likely modify historic structures, triggering State Historic Preservation Office (SHPO) review.
Noise	May reduce need for use of noisy emergency power supplies.	Consider noise produced during construction phase of installation.
Visitor Enjoyment	Installing off-grid renewable energy systems ensures that park facilities are self-sufficient and available to visitors during outages. This could also provide the opportunity to bury unsightly power distribution lines.	Scenic viewsheds, and the visitor experience of an undeveloped or non-industrial landscape, may be adversely impacted by visible solar arrays and related equipment. Arrays can be oriented so as not to disrupt viewsheds.
Water	Currently, the primary source of energy on the islands is imported fossil fuels. Reducing reliance on this energy source will reduce boat traffic to the islands and water use associated with burning and transporting fossil fuels.	Solar array construction activities and operations have the potential to impact water quality through ground disturbance and sedimentation, or through runoff from washing off panels. Implementing best practices can help avoid impacts from ground disturbance, sedimentation, or runoff.
Air	Renewable energy sources do not create criteria pollutant or greenhouse gas emissions. Local air clarity, contributions to climate change, as well as environmental and human health may be improved by a shift to renewable energy sources.	Emissions from construction equipment and dust from large ground-disturbing activities can negatively affect short-term air quality during the construction phase of a renewable energy project. Low emitting vehicles and dust management practices can reduce impacts.

[1] The NPS has developed guidance on installing solar panels on historic properties. See https://www.nps.gov/tps/sustainability/new-technology/solar-on-historic.htm

Goals	Strengths	Limitations
Night Skies		No significant issues arise if installation and maintenance on systems is performed during the day without artificial illumination.

3.2.3.1 Wind

The project team's internal expertise in wind power is minimal. Various resources[1] are available and various consulting firms can provide extensive knowledge on whether wind is a good option for a specific application. Some general considerations for wind:

- Wind resources often become more powerful the higher a turbine is placed. However, this can create challenges in urban environments when mounting a turbine too high results in structural, safety, or aesthetic challenges.
- Wind resources are very site specific. The wind resource can be impacted by site topography, buildings, trees, and other objects, so the resource at a given location may be quite different than another within proximity. Local conditions must be assessed completely when siting wind turbines.

3.2.4 Strengths and Limitations of Renewable Energy Generation: Wind

Goals	**Strengths**	**Limitations**
Resiliency		No improvement to resiliency unless the utility allows islanding.
Cost	Energy costs can be reduced if the system is designed with payback or LCOE in mind.	The systems will require onsite O&M that will partly be a function of the wind resource available. These expected costs should be factored into the economic analysis, but there may be unexpected costs.
Sustainability	By using renewable generation, parks will offset a portion of the largely carbon-based grid power.	
NPS Organic Act		
Wildlife	Will reduce the amount of transportation and use of fossil fuels on the islands, both of which are commonly associated with negative impacts to wildlife.	Few studies exist on the ecological effects of small-scale wind energy systems, though several avian mortality considerations[2] from utility-scale wind energy are relevant. In addition, depending on design specifications, plant populations, wildlife habitat, and terrestrial wildlife may be disturbed or displaced (especially during construction phase).

[1] https://www.energy.gov/energysaver/installing-and-maintaining-small-wind-electric-system

[2] Potential concerns may include effects on low-flying, migratory songbirds, passerines, pheasants, bats, etc. as applicable. Issues may also arise not only from the overall magnitude of impact but because of impact on individual species, especially any threatened or endangered species in the region.

Goals	Strengths	Limitations
Cultural Resources		Wind turbines have the potential to disrupt the cultural landscape by altering the sense of place and the perception of historic or cultural authenticity of an area.
Noise	May reduce need for use of noisy emergency power supplies.	Wind turbines, through the blade movement of air, emit sounds that are audible to both humans and wildlife. Modeling should be done to mitigate this issue.
Visitor Enjoyment	In some areas, the Federal Aviation Administration may allow the use of audio-visual warning systems, such as those deploying radar technology, as an alternative to night lighting, or the use of blinking red lights that may be less intrusive to the nocturnal environment or attractive to birds. Developing new renewable energy generating facilities could provide the opportunity to bury unsightly power distribution lines.	Scenic viewsheds, and the visitor experience of an undeveloped or non-industrial landscape, may be adversely impacted by wind turbines. Depending upon the location and height of turbine, night lighting of turbine towers may be required for aircraft safety (current regulations begin at a blade tip height of 200 feet). Alternatively, selecting turbines that do not exceed the height restrictions avoid the requirement for night lighting.
Water	Currently, the primary source of energy on the islands is imported fossil fuels. Reducing reliance on this energy source will reduce boat traffic to the islands and water use associated with burning and transporting fossil fuels.	Wind turbine construction activities and operations have the potential to impact water quality through ground disturbance and sedimentation, or potential oil spills from the turbines. Construction best practices and spill response plans can help avoid impacts.
Air	Renewable energy sources do not create criteria pollutant or greenhouse gas emissions. Local air clarity, contributions to climate change, as well as environmental and human health may be improved by a shift to renewable energy sources.	Emissions from construction equipment and dust from large ground-disturbing activities can negatively affect short-term air quality during the construction phase of a renewable energy project. Low emitting vehicles and dust management practices can reduce impacts.
Night Skies		Anti-collision lighting placed on wind turbines would detract from the natural nighttime environment, but impacts could be reduced with radar detecting or other mitigation technologies.

3.3 Renewables and Battery (Off-Grid)

When properly sized, off-grid renewable and battery systems supply site loads while using any excess generation to charge the battery. At times when renewable generation isn't sufficient to cover the load, the battery supplies the difference.

3.3.1 Sizing

The size of a renewable and battery system is dictated by typical local weather conditions and the anticipated load. The system size must be sufficient to feed loads locally and provide enough charge to the battery such that local loads can be met during any solar condition (at night, or during cloudy periods, still air conditions, etc.).

HOMER[1] is a microgrid modeling software that can be used to size a renewable and battery off-grid system and may also offer financial analysis. This software is becoming increasingly user friendly but is probably still best implemented by a consultant.

3.3.2 Design Requirements

Design considerations must account for both the renewable technology and the battery technology, separately and as a system. For renewable generation, see Design Requirements under Renewable Generation, above. This section addresses battery considerations.

- **Battery[2]**: There are several battery technologies available. Typically, larger battery systems with faster discharge times to meet the needs of an off-grid system are lithium Ion or some type of flow battery. These types of technologies have environmental and fire safety considerations that need to be accounted for in a system design. Typical mitigation approaches include containment of chemicals in the event of a leak (moat, concrete covert, etc.), fire protection (e.g., walls), and barriers (walls, fences, etc.) for access. State and local codes often determine the most appropriate approach in a given instance.

3.3.3 Strengths and Limitations Renewables and Battery (Off-Grid)

The main benefit of an off-grid system is the enhanced or exclusive use of renewable energy generation.

Goals	Strengths	Limitations
Resiliency	Operates independently of whether the grid is operating. The present systems on the islands are notably unreliable. The user/owner may have greater ability to protect its operation or return to operation following an event than the conventional grid. The extent of improved resiliency achieved correlates to how many loads must be powered and for how long when the renewable source is limited or unavailable. Tiering loads according to priority helps extend the resiliency of those most critical.	Depending on the condition of the utility grid and the design of an off-grid system, these systems can be viewed as either improving or decreasing resiliency. If the utility grid is susceptible to failure, and an off-grid system is more resilient, overall the system becomes more resilient. However, if the off-grid system is similarly or more susceptible to failure, or if just through happenstance (e.g., a tree falling) the off-grid system is compromised, the system is less resilient since the utility grid is not available as backup. In general, redundancy improves resiliency. For the parks application, the project team therefore recommends off-grid systems be considered a reduction in resiliency.

[1] https://www.homerenergy.com/products/pro/index.html

[2] http://www.sandia.gov/ess/publications/SAND2015-1002.pdf

Goals	Strengths	Limitations
Cost	Energy costs can be reduced if the system is designed with payback or LCOE in mind.	Cost-effectiveness is more challenging given that an off-grid system requires greater investment in larger equipment and likely higher O&M costs.
Sustainability	By using renewable generation, parks will offset a portion of the largely carbon-based grid power, along with any associated transportation fuel use.	Battery technologies can often have environmental or safety considerations that could negatively impact the sustainability of the system. Generally speaking, if proper mitigation options are implemented, this impact will likely go away.
NPS Organic Act		
Wildlife	Reduces power lines that may disturb birds and bats. Reduces fossil fuels being transported to the islands, which may impact wildlife and their habitat.	Construction activities required to establish off-grid systems could disturb wildlife habitat or displace wildlife.
Cultural Resources		If not adequately buried or hidden, battery systems have the potential to disrupt the cultural landscape by altering the sense of place and the perception of historic or cultural authenticity of an area.
Visitor Enjoyment	Park facilities may or may not be more self-sufficient and available for visitors to enjoy during outages, depending on the specifics of the installation. Developing new off-grid renewable energy generating facilities provides an opportunity to eliminate unsightly power distribution lines and other unnatural elements like required utility easements.	Local wind and solar energy production and storage facilities can have significant visual impacts with the potential to negatively affect visitor enjoyment. Thoughtful site selection and project design can help to minimize this limitation.
Water		Battery chemical leaks could harm hydrologic resources, but standard mitigation protocols should help prevent this.
Air	Renewable energy sources do not create criteria pollutant or greenhouse gas emissions. Local air clarity, contributions to climate change, as well as environmental and human health may be improved by a shift to renewable energy sources.	Emissions from construction equipment and dust from large ground-disturbing activities can negatively affect air quality, especially during the construction phase of a renewable energy project. Low emitting vehicles and dust management practices can reduce construction impacts.
Night Skies		No significant issues arise if installation and maintenance on systems is performed during the day without artificial illumination.

3.4 Microgrid (Islanded and/or Grid-Connected)

There are many variations of microgrids, but essentially the term refers to an electrical system, containing both loads and generation, that is typically connected to a larger (e.g., utility) grid. More importantly, a microgrid can function autonomously, connecting and disconnecting from the utility to best service local needs. In disconnected mode, the microgrid is islanded but can supply power locally to all or some loads. While connected, the microgrid can behave very much like local generation, described above.
Microgrids become beneficial when the use cases or combination of use cases is economically attractive. Typical use cases for microgrids include:

- Increased sustainability, as described above under "Local Generation"
- Added resiliency
- Added grid benefits (utility load balance, improved ancillary services like frequency response and reactive power/voltage control, integration of green power into generation, diversification of risk, etc.)

3.4.1 Sizing

As with a renewable and battery system, the size of a microgrid system is dictated by the local weather conditions and the loads. Microgrid systems may also be used to provide grid benefits. In this case, a larger system size can be used and potentially monetized.

As with renewable and battery systems, HOMER software can be used to calculate the size and financial attractiveness of a microgrid.

3.4.2 Design Requirements

In addition to the local generation and battery systems described in the sections above, there are a few additional components for microgrids:

- **Microgrid Controller**[1]: A control system is a key component of a microgrid. The complexity of a microgrid controller scales with the various use cases desired from the microgrid, and the use cases are typically associated with what makes a microgrid an attractive option as described in the "Evaluating Options" section below (e.g., local generation, resiliency and grid benefits).
  - Improving resiliency at the local level – Critical elements of a resilient system include:
    - Identifying critical loads in the event of an emergency
    - Designing reliability and durability into the system
    - Providing for storage and availability of spare parts and equipment to restore the system quickly
    - Investing in team knowledge and the ability to independently operate the system
  - Grid benefits – If grid benefits are being explored as a use case for the microgrid, then a discussion with the local utility is needed. This discussion includes determining if there is a way to monetize this "service." (Note: This is an emerging area in microgrids and it is

[1] There are various microgrid controllers available on the market. Batteries typically come with their own control system and in some cases may be sufficient to play the role of a microgrid controller as well.

unlikely the local utilities have yet formalized a way of dealing with it. But they will need to eventually.)

- **Internal Combustion Engine (ICE) Generator (optional)**: In some cases where reliability and resiliency are very important, a diesel, biofuel or propane generator may be added to a system, although note that fossil-fueled varieties have emissions that could offset the benefits from local renewable generation, and all versions contribute significant noise to the environment. Additionally, a reliable supply of liquid fuel is required.

3.4.3 Strengths and Limitations Microgrid (Islanded and/or Grid-Connected)

The strengths and limitations for microgrids parallel those of local generation (renewable), with a few additional items.

Goals	Strengths	Limitations
Resiliency	Resiliency is improved with microgrids and the redundancy they offer. The extent of the resiliency improvement correlates to how many loads are powered and for how long when the microgrid is islanded. Tiering loads according to priority helps extend the resiliency of those most critical.	
Cost	Energy costs can be reduced if the system is designed with payback or LCOE in mind.	The systems will require onsite O&M. These expected costs should be factored in to the economic analysis, but there may be unexpected costs. The battery system will require additional space that could otherwise be used for another purpose. The cost impact of this should be considered in the analysis.
Sustainability	By using renewable generation, parks will offset a portion of the largely carbon-based grid power.	Battery technologies often have environmental or safety considerations that may negatively impact the sustainability of the system. Generally speaking, if proper mitigation options are implemented, then this impact becomes negligible. ICE backup generation may introduce negative impacts to sustainability.
NPS Organic Act		
Wildlife	Will reduce the transportation and use of fossil fuels on the islands, both of which are commonly associated with negative impacts to wildlife.	Construction activities required to establish micro grid systems could disturb wildlife habitat or displace wildlife. Construction best practices and careful site selection can help avoid impacts.
Cultural Resources		Microgrids have the potential to disrupt the cultural landscape by altering the sense of place and the perception of historic or cultural authenticity of an area.

Goals	Strengths	Limitations
Noise	May reduce need for use of noisy emergency power supplies.	Optional ICE generators produce much noise when running. Mitigation options such as noise curtains or enclosures are available to reduce noise impacts.
Visitor Enjoyment	Developing new renewable energy generating facilities could provide the opportunity to bury unsightly power distribution lines.	Local wind and solar energy production and microgrid infrastructure can have significant visual impacts with the potential to negatively affect visitor enjoyment. Thoughtful site selection and project design can help to minimize this limitation. During an outage in grid-tied systems, park facilities powered by renewable energy might be unavailable, due to regulations protecting utility workers.
Air	Renewable energy sources do not create criteria pollutant or greenhouse gas emissions. Local air clarity, contributions to climate change, as well as environmental and human health may be improved by a shift to renewable energy sources.	Local ICE electricity generation can produce harmful levels of air pollution and may require an air quality permit for operation. Emissions from construction equipment and dust from large ground-disturbing activities can negatively affect air quality, especially during the construction phase of a renewable energy project. Low emitting vehicles and dust management practices can reduce construction impacts.
Night Skies		No significant issues arise if installation and maintenance on systems is performed during the day without artificial illumination.

3.5 Evaluating Options

Selecting among local generation, renewable, and battery or microgrid options at a given location requires an analysis to quantify the relative value of each approach with respect to NPS goals. Something like the table below might serve to compare options against one another. Note that the cost analysis is expected to be fairly straightforward and is discussed in the following subsection. The resiliency and sustainability analyses are less straightforward because quantifying those benefits potentially involves a greater range of considerations, not all of which may be as readily defined or even as easily identifiable as cost. The NPS will need to define the quantification of these goals.

	Local Gen Option 1	Local Gen Option X	RE & Batt Option 1	RE & Batt Option X	Microgrid Option 1	Microgrid Option X
Resiliency						
Cost						
Sustainability						
NPS Organic Act						
TOTAL						

3.5.1 Cost

A system of any type is financially advantageous if there is a cost benefit, such as when a system pays itself back in a reasonable amount of time[1] (e.g., before the warranty is expired) or the LCOE is less than the utility rate.
Cost analysis includes the following considerations:

- Installation Cost (Capital Cost) – Current solar cost information for U.S. installation is available in a Lawrence Berkeley National Laboratory report *Tracking the Sun*.[2] This report predated the hurricanes and does not discuss Puerto Rico or USVI explicitly but provides costs that can be used with adders for additional local labor expenses and transport costs for materials. These adders would be typical for most projects performed in Puerto Rico/USVI and therefore may be readily available from previous documentation.
- O&M – Mostly comprised of the costs of performing general maintenance of the system and panel washings. The NREL LCOE tool offers default values that could be used for estimating O&M. As each project progresses, this number could be refined.
- Offset generation – Represents the amount of energy that would have otherwise been purchased from the utility.
- Utility Electricity Price – Electricity rates often vary depending on the end-user. Residential users pay one price while different-sized commercial and industrial users pay different prices and may add demand charges on top of those. Street lighting is often billed at a flat bulk commercial rate; the still nascent but growing trend of dimming street and area lights combined with the greatly increased range of available luminaire wattages is putting pressure on utilities to develop more precise, but complex, sets of rates for street lights too. Depending on the range of rates offered by the utility and the range of end-uses being supplied by, for example, a microgrid system, adequately representing this seemingly simple input in a cost analysis can become quite complex.
- Life of the System – For solar PV systems, a lifetime of 20 years is typically assumed. This value is based largely on the typical warranty offered on solar panels.

[1] Simple Payback: Cost of Renewable Energy Installation + Operations & Maintenance Costs for the Lifetime of Project – Money Saved (e.g. offset utility bills, other O&M). Discount rate can be applied to account for time value of money.
[2] http://eta-publications.lbl.gov/sites/default/files/tracking_the_sun_ix_briefing.pdf

4.0 High-Level Example

This section provides one approach that the NPS could take to evaluate two options:

- Local generation at the Administration and Discovery Center at San Cristobal as described in an earlier NREL report reviewing the viability of PV at SAJU.[1]
- Hypothetical solar and diesel microgrid at the Administration and Discovery Center that powers all load of these two buildings for 48 hours, with a hypothetical 11-year payback.

Goal Definition: The bullets below illustrate examples of more detailed goals that the NPS may develop:

- Resiliency: the NPS may consider it a goal to have all lighting loads be locally powered when the utility grid goes offline for up to 48 hours.
- Cost: the NPS may desire that all infrastructure investment pay itself back within 10 years.
- Sustainability: the NPS may desire that all new generation be renewable/carbon-free.

All of the above items can be scored based on the following guidelines:

- Meets Goal – 10 points
- Partially Meets Goal – 5 points
- Does Not Meet Goal – 0 points

Example Analysis:
Based on values in the NREL SAJU report, the following table evaluates solar PV installation on the Administration and Discovery Center in San Cristobal (with incentives) against another hypothetical option of a solar microgrid with diesel generator and an 11-year payback.

	Local Gen: Admin & Discovery Center with Solar	Microgrid: Renewable & Diesel Microgrid at Admin & Discovery Center
Resiliency	0	10
Cost	10	5
Sustainability	10	10
NPS Organic Act*	11	5
Wildlife	*2*	*1*
Cultural Resources	*1*	*1*
Noise	*2*	*0*
Visitor Enjoyment	*2*	*0*
Water	*2*	*2*
Air	*2*	*1*
Night Skies	*2*	*2*
TOTAL	33	32

*Organic Act criteria were not considered in the earlier NREL report. Arbitrary value of up to 2 points assumed in this example for each subcategory under the Act.
The above table/scoring illustrates that overall the two options are very similar, with local generation slightly edging out the microgrid option. Additional scenarios may also warrant consideration, for instance, the addition of battery storage to the PV system, which likely will add greatly to its resiliency score but also increases costs. Such additional costs might be justified, however, depending on the relative importance assigned to goals, such as the example given for sustainability above.

[1] "Renewable Energy Assessment for San Juan National Historic Site," February 2015. National Renewable Energy Laboratory. Prepared for the Federal Energy Management Program.

5.0 Part 3 – Recommended Next Steps

These general recommendations are intended to help the NPS define what they are looking for and the best paths for getting there.

- Define resiliency in the NPS context: Resiliency is a broad term that applies at multiple scales. How does the NPS want to apply the concept to operations within their properties? For example:
  - What are the key roles that lighting plays in the park properties and how do they rank among the relative priorities following an event? Security lighting plays a different role than wayfinding for visitors; often, a single lighting installation provides both. But what areas of the property have critical needs for lighting following (or during) an event, even if the park is closed? These might be categorized among operational tiers such as ASAP (or even Never Out), High Priority Security, High Priority Visitor, and Low Priority. The corresponding tier for a given installation helps define the type of system and associated expense that can be justified.
  - Is there a preference to rely on the grid except during periods of outage, in which case the renewable energy backup system steps in? Or would the preference be for the main power supply to be provided by renewables? Perhaps the preference is to be entirely standalone (off-grid)?
  - In many situations, a mix of approaches will best address the overall set of concerns – remote areas of an island may mean a standalone system offers significant cost advantages compared to bringing the grid to those locations, for example, whereas areas with the grid already available are better served with only a backup system. From the NPS perspective, what corresponding resiliency criteria might determine whether a given location prefers grid-connected vs. standalone power?
  - What is the relative prioritization of different loads in the event of a power outage (e.g., lighting, communications, refrigeration)?
  - What additional measures does the NPS need to consider in system selection? An example might include restrictions imposed by the Cultural Resources division regarding what installations are acceptable and where. Another might be the allowable level of additional commitment required in terms of staffing, maintenance training, or supplemental inventories to ensure a satisfactory return to reliable service following an event.
- Define and quantify goals: Establishing priorities and their relative importance is necessary for identifying the most appropriate approaches going forward. Goals fall under specific topic areas and should have easily quantifiable/comparable metrics. There may be many of these and they may also fall into tiers, which furthermore may change based on the severity of the event. A hypothetical example under the rubric of resiliency might be to keep selected electrical systems running without interruption for up to 48 hours following failure of the grid. For longer outages, this goal might shift to having these resources serve as a reservoir of emergency power for staff and local residents, e.g., to charge cell phones or other portable electronic or medical devices.

  Likewise, a corresponding sustainability goal might be to become 100% carbon-free for all new power generation. A wildlife impacts goal might be to prevent any new noise generation beyond 20 yards of new construction from rising above 50 db. Such goals, as illustrated in the high-level example provided, weigh heavily into the selection of equipment deployed.

- Refine technical options: Identifying the best options may involve an iterative process where, for example, initial options are later found in the cost analysis to be oversized, with a smaller system having a more attractive payback or better meeting the goals otherwise. In such cases, the options are modified as necessary to meet payback or other requirements and reevaluated against the other options.
  - For San Juan, the NPS could update analysis done by Mactec[1] and NREL with current assumptions (e.g. cost of renewable generators, cost of electricity). Investigation of incentives and their applicability need to be updated (e.g., federal investment tax credit, net metering).
  - The NPS could also include options for renewable, battery and microgrid options for evaluation (e.g., addition of battery storage was not included in the earlier NREL analysis).
  - The NPS might consider soliciting "out of the box" ideas to address particular issues that present difficult challenges for conventional approaches. An example might be the challenge of providing sufficient structural integrity of a light pole to withstand wind gusts of 175 mph, a speed reportedly observed during Hurricane Maria. Perhaps rigid strength of the pole is not the only means of resisting such forces; perhaps some level of flexibility to bend with the wind (e.g., like palm trees) or capability for quick disassembly/reassembly so that lights or PV panels can be removed and stored somewhere safe during the event could provide better alternatives.
- Conduct research/education: the NPS should investigate how well other renewable energy systems on the islands withstood the hurricanes.
  - The St. Thomas airport has a large solar array that appears to have suffered considerable damage from the hurricanes. The NPS might consider speaking to representatives of the airport/solar array about the condition of the system post-storm to better inform their own future designs.
  - Other resources for solar system's ability to withstand wind storms/hurricanes:
    - https://www.nrel.gov/news/features/2015/16488.html
    - https://spectrum.ieee.org/green-tech/solar/rooftop-solar-stood-up-to-sandy
- Other actions: Additional items that could be pursued immediately or after identifying a future project:
  - Internal review: Review existing Project Management Information System (PMIS) materials to see how proposed projects align with lighting and electrical infrastructure goals. Consider where aspects of improving lighting and electrical infrastructure can be embedded into existing PMIS, or where a new PMIS is required.
  - Utility engagement: Engage local utilities (PREPA[2] and WAPA) to discuss their incentives/programs and concerns regarding proposed options.
  - Understand the local renewable resources: Installation of local weather stations will provide invaluable data for fully vetting the solar or wind resources at the different sites

[1] The Mactec report indicates that solar power is not a good option given the long payback period. The Team recommends this analysis be revisited to confirm assumptions used in analysis and updated with current solar costs, energy costs, and other current information.
[2] Article regarding PREPA's concerns with microgrids: https://microgridknowledge.com/microgrids-puerto-rico-rules/

of potential interest. This is less important for smaller solar projects due to the smaller financial commitment and the quality of readily available solar resource datasets. However, for larger solar and wind installations, onsite measurements are often very helpful in informing a go/no-go decision and design. Typically, a years' worth of data is desired for estimating resources at a site to account for seasonal variations. Smaller increments of data are also useful, but more data means less uncertainty in the estimated value of a facility.

– Conduct one or more pilot installations: The coming years are likely to bring many more severe weather events to the Caribbean, with accompanying consequences that may be more or less severe than those of 2017. In a sense, the islands in this region present an "acid test" for achieving the desired goal of increased resiliency; technological approaches that work in these extreme conditions should readily translate to other, less complex situations. The islands are an ideal location for pilot testing such approaches given the many challenges noted in this document, particularly when considered in aggregate. The NPS (and the larger federal government) might highly benefit from developing and testing innovative approaches in this difficult environment.
  That said, the NPS might do best to consider a variety of smaller-scale installations, followed by an update of their merits and related lessons learned from a couple of years of actual field experience, prior to embarking on a major investment.

6.0 Part 4 - List of Recommendations for Puerto Rico and the USVI

The following recommendations arose from observation of the respective sites and from information provided by NPS staff onsite. Recommendations are grouped by site and then further categorized by lighting application or microgrid application.

Overall, it is recommended that the NPS secure qualified people to assist with the development of requests for proposal and master plans for carrying out any associated work scope. Vital technical and practical factors are needed for successful implementation, and dedicated effort will be required to ensure that the desired goals are appropriately specified.

Such effort should include developing design guides and conducting product and application mockups/pilots to assist in their development, which improve the likelihood that the resulting designs will fit these very specific application needs. Physical mockups are invaluable for gaining buy-in or identifying needed changes to proposed designs before they are locked in, helping minimize future complaints that stem from excessive glare, light trespass, inappropriate CCT, and other avoidable errors.

The recommendations in all cases below assume use of LED luminaires that have been appropriately designed and selected; however, first consideration should always be given to whether supplemental lighting is really needed at all, or whether other materials like retroreflectors or self-luminous materials might adequately serve the need.

6.1 Park Site – El Morro / St. Cristobal Fort, San Juan, Puerto Rico

- Replace ground-based wall washers and flood lights around inner wall with better targeted (i.e., appropriate beam angle, distance, height, etc.) units. (Figure 7, A)
- Replace flood lights around outer wall with suitable corrosion-resistant units with U0 uplight rating. (Figure 7, B)
- Continue LED bollards on to currently unlighted path for forthcoming expanded visitor schedule. (Figure 7, C)
- Replace current floodlights in inner courtyard with downward-facing linear wall washers with U0 uplight rating. (Figure 7, D)
- Consider removing lighting / occupancy sensor electronics from interior display boards –
  - Is lighting really needed during open hours given the continued problem from salt buildup/corrosion?
  - Related question: Are all inner areas going to be open for the expanded schedule (i.e., 9:00 PM)?
- On the far east end of St. Cristobal, add security area lighting with dimming and motion detectors (intended to prevent marring of walls and trench by graffiti). (Figure 8, E)
- Replace St. Cristobal ground lights with units better targeting the walls, after reevaluating the required illuminance. (Figure 8, F)
- Replace exterior wall lights in St. Cristobal with lights matching those on El Morro.

Figure 7. El Morro, San Juan, PR. Imagery ©2019 Google, Map data ©2019 Google

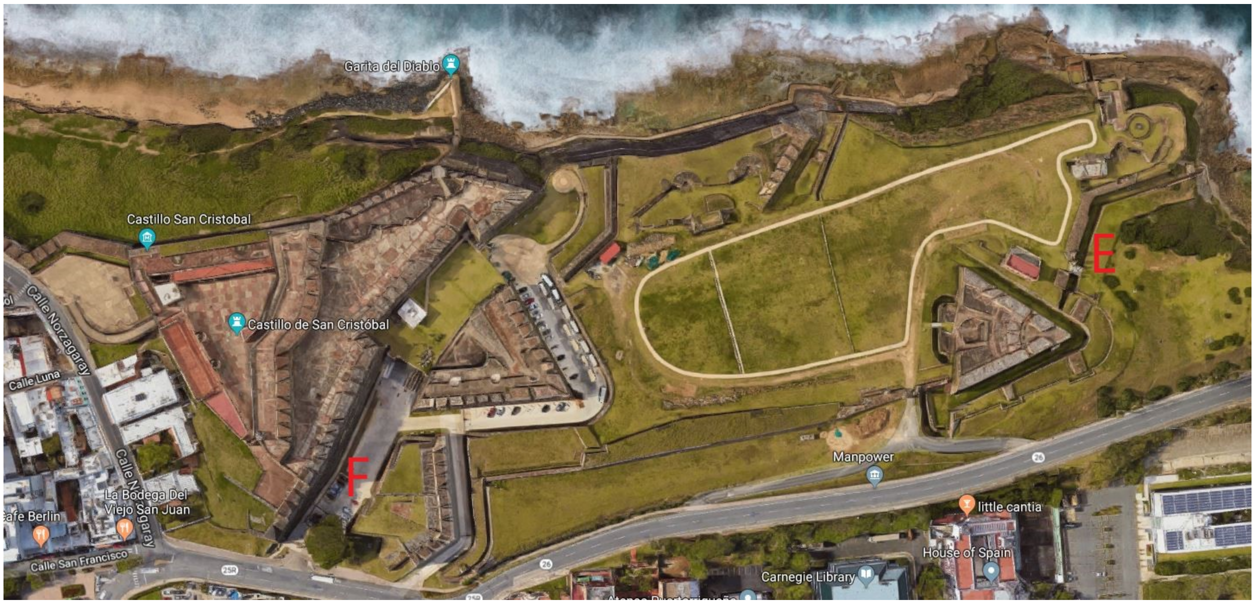

Figure 8. St. Cristobal, San Juan, PR. Imagery ©2019 Google, Map data ©2019 Google

6.2 Park Site – St. John, USVI

- NPS Visitor Center – Add downward facing (U0 uplight rating) security lighting around perimeter of main building, with motion detectors and significant dimming.
- Maintenance facility – Add downward facing security lighting along front of building facing parking lot area, with motion detectors and dimming down to 10% or less after hours.
- The Biosphere – Interior and exterior LED lighting and the refrigerator can probably be supplied by PV panels on buildings coupled with battery storage.
- Cinnamon Bay Campground – Lighting in parking lot is needed for pedestrian visibility rather than for vehicles; consider reflective taping or install low illumination wayfinding bollards or similar products with motion detectors; consider PV power.
- Cinnamon Bay Campground – Install PV-powered low-level wayfinding bollards for guest access along pathways to tent area.

6.3 Park Site – St. Croix, USVI

The exterior of this fort has already been partially converted to LED, in general providing appropriate, well-targeted levels of light at suitable and consistent color temperature. However, a few large metal halide products remain around the back of the building, with noticeably cooler and less controlled output (likely directing much more into the sky), along with significantly higher energy use. It was also reported that some incandescent lamps are still in use within the building. At the reported (exceedingly high) electricity price of $0.52/kWh, a replacement LED product for a 60 W incandescent bulb could easily repay its purchase price in less than a month, depending on its usage. The metal halide will take longer but is still easily justified. All remaining lighting should be converted to LED as soon as possible. This will quickly repay its investment and reduce burden on the limited (two-person) maintenance crew.

- Harmonize the appearance of all exterior (grassy park area) lighting by installing the same CCT throughout.

- Complete conversion of exterior flood lights (matching CCT with other exterior lights).
- Tighten flood lights around the fort exterior so they cannot be easily redirected.
- Replace all non-LED interior lighting with LED drop-in replacements.
- Replace maintenance garage lighting fixtures with U0-rated, motion sensor activated LED luminaires.
- Consider using roof-mounted PV power for exterior and interior lighting in maintenance facilities.

General Rules for LED Use

1. Install luminaires at the appropriate height and distance from one another (may differ from the previous lighting) so that areas are not over- or under-lit and an appropriate uniformity of distribution is achieved.
2. Select luminaire systems that deliver the minimum amount of light necessary to satisfy the need (lowest brightness/luminance).
3. Give attention to selecting the appropriate color temperature for the application.
4. Consider spectral content that takes into consideration the area's primary animal, plant, or insect population in choosing parts of the spectrum to minimize.
5. Use luminaires that are downward facing and shielded where necessary.
6. Use motion detectors, dimmers, and timers to reduce environmental impacts, energy use, and costs.

Appendix A – Lighting Specification Example

A.1 Background:

Following the site visits, the project team was forwarded a draft lighting specification addressing a requested upgrade for which funding had just been approved and was asked for review and feedback.

The project team identified several areas where the draft could be strengthened to improve the suitability of resulting proposals likely to be received. An equally important job of a good specification is effectively discouraging submission of vendor proposals clearly unsuitable in one or more key aspects, while not precluding proposals that miss on a minor or even unintentional point but remain worth considering.

The recommended modifications apply to issues commonly seen in other specification documents and thus extend beyond this individual instance. These examples can thereby serve as useful illustrations for all specification developers.

An initial table lists several examples from the original draft specification and briefly details the relevant issues and suggested remedies. Following the table are sections from the original draft specification as submitted, and a modified version containing the recommended edits.

A.2 Tabulated Examples of Issues and Proposed Solutions

Issue with Draft Specification	Proposed Solution
Specified "light fixtures and bulbs" (as was previously done for high-intensity discharge) and "Manufactured for LED bulbs."	Specify complete LED luminaires, rather than LED bulbs or retrofit kits. When a luminaire is provided with integrated LED light source(s), the luminaire manufacturer cannot simply blame the light source manufacturer if/when problems arise. This helps to ensure the light source is compatible with the luminaire and enables an apples-to-apples comparison between LED luminaires using IES LM-79 photometry.
Some product specifications were given in the SCOPE section (e.g., "Lights shall be tamper-proof and rated for outdoor use and certified for wet locations") and TASKS (e.g., "Light housings shall be metal, either stainless steel or aluminum").	Create separate section(s) for product specifications and consolidate this content there.
Some work requirements were given in SCOPE (e.g., "All work shall be completed in compliance with OSHA standards and regulations") and TASKS (e.g., "All electrical work shall be completed by a licensed electrician or under the direct supervision of a licensed electrician").	Create separate section for site work and consolidate this content there.
Ambiguous Specification: "Lights shall be [...] rated for outdoor use and certified for wet locations."	Better to specify in an enforceable manner – for example, "listed or certified for wet locations by a U.S. Occupational Safety Health Administration (OSHA) Nationally Recognized Testing Laboratory (NRTL)."

Issue with Draft Specification	Proposed Solution
Ambiguous Specification: “Weather-tight.”	Better to specify in an enforceable manner – for example, “Luminaire shall have a minimum ingress protection (IP) rating of 68, as defined in IEC 60529.”
Some specifications lacked required detail (e.g., “Operate on single phase electric service”).	Specify nominal values and tolerances as required (e.g., “Luminaires shall accept 60 Hz single-phase 120 V electric service and operate normally with input voltage fluctuations of ±10%”).
Some specifications were contradictory (e.g., “Emit amber or yellow light” and “Correlated color temperature of ≤3500K”).	Specify white light sources in terms of standard ANSI bins – for example, “Warm white light, with a nominal correlated color temperature (CCT) value that is ≤ 3000 K, measured CCT and Duv values within ANSI C78.377-2017 tolerances for the nominal CCT value.”
Specified “Each light shall be supplied with color filter lenses of red, blue, green, and amber [...] New fixtures shall be placed in the same location as existing fixtures.”	If a luminaire must be unsealed to change a lens, it provides an opportunity for contaminants to enter the optical cavity and lose/damage optical components or compromise the sealing mechanism. It is preferable to specify dynamic color tuning – for example, “Tunable (i.e., selectable or changeable) color. Luminaire shall be capable of producing any of a wide variety of saturated colors (e.g., blue or pink) for holidays and other special occasions. Control of color-tunable luminaires must be wireless (e.g., Bluetooth or wireless DMX) or utilize existing electrical wiring (i.e., powerline carrier).”
Specified “product examples” with make/model information from other potentially unrelated projects.	Do not specify make/model information for specific products unless these products are known to be ideal for the particular application. Instead, specify the desired performance characteristics (e.g., “IP-68”).
Specified “Each pedestal light shall be supplied with field-interchangeable lenses of Narrow Spot lense (15°), Flood lense (40°), and Elliptical (30°x60°) [...] Fixtures shall be selected to provide the most consistent wash of light across the [...] walls as possible.”	Combinations like this are known as “spec-lockers,” where such specificity may mean only one commercially available product meets them – a product that may not be the best choice in other respects. In this instance, the user should first consider whether beam angle (or field angle) is the best metric for the job; it’s generally better to specify luminaire-target geometry (e.g., wall height, luminaire spacing, luminaire setback) and desired uniformity of illuminance (e.g., “average-to-minimum uniformity ratio of ≤ 3:1”). The responding proposals should achieve precise fits to this specified target area.
Specified “Façade lighting from floodlights shall provide no more than 5.0 lumens per square foot of the illuminated walls.”	Specify minimum or target illumination levels, rather than maximum. For example, although a product providing 0.01 lumens per square foot (0.01 footcandle) would meet the spec, it would presumably be deemed inadequate in practice.
Specified “Upon completion of installation, measure lumen output on [...] walls at intervals not	Calculation grid placement should be unambiguous, and of sufficient resolution to

Issue with Draft Specification	Proposed Solution
exceeding 20 feet, capturing brightest and dimmest wall areas.”	capture bright and dark spots – for example, “Calculation grid points shall be spaced 4 feet apart on each 32-foot height wall sloped 15 degrees away from luminaires (8 horizontal rows of points spaced 4 feet apart horizontally, centered on each wall segment). Luminaire locations are as shown in plan; in-ground luminaires are spaced approximately 18 feet apart and setback __ feet from wall, on average.”
No specification for luminaire maximum input power.	Maximum input power should be specified as required to ensure realistic energy savings requirements are met. (Don’t set this limit so low that no products can meet it, however.) Notably, it is best to specify maximum input power in unison with minimum illuminance. Luminaire efficacy is less useful if some luminaire lumen output misses the target.
No specification for flicker.	Specify per current standards (e.g., “Luminaire light output shall not exhibit flicker exceeding the low-risk limits in Figure 18 of IEEE Standard 1789-2015. Specifically, the quotient of percent flicker (i.e., modulation depth) and flicker frequency shall be < 0.08 at flicker frequencies ≥ 90 Hz, and the quotient percent flicker / flicker frequency shall be < 0.025 at flicker frequencies < 90 Hz.”
No specification for luminaire useful lifetime.	It is best to specify minimum warranty in conjunction with lumen maintenance—for example, “Lumen maintenance for warm white light mode at 60,000 hours operation shall be ≥ 85% of initial, supported by IES TM-21 calculations based on IES LM-80 data and in-situ temperature measurement (ISTMT) testing, in accordance with the DesignLights Consortium methodology. Luminaires shall have a minimum warranty of 5 years.”
Only product submittals required were “Floodlight product specification sheet” and “Flush mount in-ground light product specification sheet.”	To help separate the wheat from the chaff, request documentation supporting all performance claims – for example, “IES LM-80 test report(s), In-Situ Temperature Measurement Test (ISTMT) report, and IES TM-21 spreadsheet calculations per DesignLights Consortium requirements for Option 1 (https://www.designlights.org/solid-state-lighting/submit-a-product/lumen-maintenance/) with luminaire operating in warm-white mode.”

A.3 Original draft specification as submitted

BACKGROUND

The existing exterior lights were installed to provide security [...]. Their operation has a major impact on the park’s electricity bills. The park is seeking to reduce the cost of operating external lights by replacing them with energy efficient bulbs and fixtures.

1. OBJECTIVES:

Replace existing exterior lights with energy efficient lighting fixtures, while minimizing light spillage.

Purpose of exterior lighting is for decoration and security.

2. PLACE OF PERFORMANCE:

[...] Work days and hours: 7:00am to 3:00pm Monday through Friday, excluding Federal Holidays. Access to jobsite and electrical panels will be gained through the COR and/or park maintenance staff.

3. PERIOD OF PERFORMANCE:

Period of performance is 90 calendar days from issuance of Notice to Proceed.

4. SCOPE:

Replace exterior lighting with energy efficient fixtures and bulbs, manufactured to operate on single phase electrical service. Lights shall be tamper proof and rated for outdoor use and certified for wet locations. Remove and dispose of existing fixtures and concrete bases.

All work shall be completed in compliance with OSHA standards and regulations.

5. TASKS:

Contractor is responsible for the following items:

- Replace (44) exterior light fixtures
  - (24) in ground, flush mounted lights, round
  - (17) pedestal mounted flood lights
  - (3) wall mounted flood lights
- Fixture Requirements
  - Weather-tight
  - Rated for outdoor use
  - Manufactured for LED blubs
  - Operate on single phase electric service
  - Product example, floodlight: Ecosense Rise F380
  - Product example, wall mounted floodlight: LSI-industries, XBAL LED Bullet Floodlight, large
  - Product example, in-ground light: LSI-Industries XIG-B-LED-19-350-WW-SP10
- Light requirements
  - LED
  - Emit amber or yellow light

- Correlated color temperature of ≤3500K
- Color rendering index (CRI) ≥80

Light housings shall be metal, either stainless steel or aluminum. Lighting shall be resistant from wind loads from hurricanes.

Each light shall be supplied with color filter lenses of red, blue, green, and amber. Lenses shall be supplied by the lighting manufacturer and suitable for use with their product.

Each pedestal light shall be supplied with field-interchangeable lenses of Narrow Spot lense (15º), Flood lense (40º), and Elliptical (30ºx60º).

The contractor shall install new concrete support bases for each pedestal mounted flood light. All hardware (bolts, anchors, washers, etc…) shall be stainless steel.

All junction boxes shall be potted using a insulating and sealing polymeric potting compound with fast crosslinking at room temperature, sticky, adhesive, re-enterable, suitable for filling. The potting compound shall be suitable for anticorrosion protection, non-toxic, and safe. In suitable cases, it shall give a degree of protection of IP 68.

Floodlights shall be properly aimed upon installation, then secured to prevent tampering of the light's aim. Fixtures shall be aimed to minimize light spillage over the top of the walls or other items to which they're aimed. The use of shields to limit light spillage is approved.

For fixtures flush with the earth, notify COR three work days prior to ground disturbance.

Coordinate with park to shut off power to buried light fixtures prior to ground disturbance. Uncover fixtures using hand tools, minimizing the volume of ground disturbance around the fixture. All soils shall remain on site. Installation may require some gravel to allow for drainage away from the buried fixture. Fixtures shall be installed per manufacturer's recommendations. Remove existing fixture; install, wire and connect new fixture. New light fixtures shall allow for changing of bulb without excavation. All conduit, wiring, and boxes shall be sealed to prevent water entry.

Façade lighting from floodlights shall provide no more than 5.0 lumens per square foot of the illuminated walls. Upon completion of installation, measure lumen output on [...] walls at intervals not exceeding 20 feet, capturing brightest and dimmest wall areas. Provide measured lumen per square foot data to COR prior to final inspection.

New fixtures shall be placed in the same location as existing fixtures. Fixtures shall be selected to provide the most consistent wash of light across the [...] walls as possible.

All electrical work shall be completed by a licensed electrician or under the direct supervision of a licensed electrician.

Coordinate shutting off electrical service to fixtures with COR prior to demolition and installation of fixtures.

6. DELIVERY:

Provide product specification sheets to CO or his/her representative for approval for each light fixture and bulb type.

Provide (1) spare floodlight and (3) spare in-ground light fixtures and bulbs. Pre-Construction Submittals (due at precon):

- Letter designating Project Superintendent
- Proof of insurance
- Project Schedule
- Schedule of Values
- Signed SF-1413's for each sub-contractor
- Safety Plan
- Quality Control Plan
- Electrician's license

Pre-Mobilization Submittals:

- Floodlight product specification sheet
- Flush mount in-ground light product specification sheet

Close-Out Submittals

- Lumen per square foot data, measured post installation
- Operation and maintenance information for each type of fixture installed
- Certified payrolls
- Release of Claims Spare parts:
- Any spare parts sent with fixtures shall be turned over to COR at project completion.
- (1) spare floodlight and bulb
- (2) spare in-ground lights and bulbs

7. GOVERNMENT-FURNISHED PROPERTY, MATERIAL, EQUIPMENT, OR INFORMATION (GFP, GFM, GFE, OR GFI):

Schematic of light fixture locations [...] attached.

8. SECURITY:

Contractor is responsible for securing any equipment, parts, tools, etc. left on site. NPS cannot be held liable for damage or theft to items retained on NPS property.

COR will provide Contractor with access to building spaces necessary to complete the required tasks.

9. TRAVEL:

Travel fees related to this contract shall be included in the contractor's bid proposal. Do not include travel costs as a separate line item. Contractor is not authorized to bill the government for travel as a unique expenditure.

10. SPECIAL MATERIAL REQUIREMENTS:

Materials shall be corrosion resistant.

11. OTHER UNIQUE REQUIREMENTS:

None.

12. QUALITY ASSURANCE REQUIREMENT:

The contractor shall develop and maintain a quality program to ensure services are performed in accordance with commonly accepted commercial practices. The contractor shall develop and implement procedures to identify, prevent, and ensure non-recurrence of defective services. As a minimum the contractor shall develop quality control procedures addressing the critical areas identified in this statement of work. The government will periodically evaluate the contractor's performance in accordance with the statement of work.

A.4 Updated specification with proposed edits

BACKGROUND

The existing exterior lights were installed to provide security [...]. Their operation has a major impact on the park's electricity bills. The park is seeking to reduce the cost of operating external lights by replacing them with long-life energy-efficient LED luminaires.

1. OBJECTIVES:

Replace existing exterior lights with energy efficient lighting fixtures, while minimizing light spillage and enabling color changing for special events.

Purpose of exterior lighting is for decoration and security.

2. PLACE OF PERFORMANCE:

[...] Access to jobsite and electrical panels will be gained through the COR and/or park maintenance staff.

3. PERIOD OF PERFORMANCE:

Period of performance is 90 calendar days from issuance of Notice to Proceed.

4. SCOPE:

Contractor is responsible for the following items:

Remove existing exterior lighting and replace with long-life energy-efficient LED luminaires.

- (24) in-ground, flush-mounted color-tunable uplights, round
- (17) pedestal-mounted color-tunable floodlights
- (3) wall-mounted floodlights

Add control system for the new color-tunable luminaires; existing electrical wiring to luminaires shall be retained, and no new control wiring may be run to luminaires.

Install new concrete support bases for each pedestal-mounted floodlight.

Properly dispose of existing light fixtures and concrete bases.

5. SPECIFICATIONS FOR ALL LUMINAIRES:

Light housings shall be metal, either stainless steel or aluminum. Lighting shall sustain wind loads from hurricanes. All fasteners (bolts, anchors, washers, etc.) shall be stainless steel.

Luminaires shall be tamper-proof and listed or certified for wet locations by a U.S. Occupational Safety Health Administration (OSHA) Nationally Recognized Testing Laboratory (NRTL).

Luminaires shall accept 60 Hz single-phase 120 V electric service and operate normally with input voltage fluctuations of ±10%.

Except where noted, luminaire shall have light output of electronically tunable color, and be capable of both of the following operating modes:

a. Warm white light, with a nominal correlated color temperature (CCT) value that is ≤ 3000 K, measured CCT and Duv values within ANSI C78.377-2017 tolerances for the nominal CCT value, and color rendering index (CRI) of ≥ 65.
b. Tunable (i.e., selectable or changeable) color. Luminaire shall be capable of producing any of a wide variety of saturated colors (e.g., blue or pink) for holidays and other special occasions.

Control of color-tunable luminaires must be wireless (e.g., Bluetooth or wireless DMX) or utilize existing electrical wiring (i.e., powerline carrier). No new wiring may be run to luminaires.

Luminaire light output shall not exhibit flicker exceeding the low-risk limits in Figure 18 of IEEE Standard 1789-2015. Specifically, the quotient of percent flicker (i.e., modulation depth) and flicker frequency shall be < 0.08 at flicker frequencies ≥ 90 Hz, and the quotient percent flicker / flicker frequency shall be < 0.025 at flicker frequencies < 90 Hz.

Combined illumination from in-ground and pedestal-mounted luminaires shall provide an average illuminance of ≥ 3.0 footcandles (fc, or lumens per square foot) on each of the seven illuminated wall segments when operating in warm-white mode, measured perpendicular to wall surface (i.e., with back of typical illuminance meter pressed to wall), with average-to-minimum uniformity ratio of ≤ 3:1. Calculation grid points shall be spaced 4 feet apart on each 32-foot height wall sloped 15 degrees away from luminaires (8 horizontal rows of points spaced 4 feet apart horizontally, centered on each wall segment). Luminaire locations are as shown in plan; in-ground luminaires are spaced approximately 18 feet apart and setback ___ feet from wall, on average.

Luminaires shall be selected with appropriate optical control to minimize light spillage.

Lumen maintenance for warm white light mode at 60,000 hours operation shall be ≥ 85% of initial, supported by IES TM-21 calculations based on IES LM-80 data and in-situ temperature measurement (ISTMT) testing, in accordance with the DesignLights Consortium methodology.

Luminaires shall have a minimum warranty of 5 years.

6. SPECIFICATIONS FOR IN-GROUND LUMINAIRES:

Luminaire shall allow for replacement of LED light engine (or LED light source and driver) in luminaire without excavation.

Luminaire shall have a minimum ingress protection (IP) rating of 68, as defined in IEC 60529.

Color-tunable luminaire input power shall not exceed 60 W in any mode.

If luminaire intensity distribution is circular (i.e., X° beam) or oval (i.e., X° by Y° beam) in cross-section, luminaire must have minimum 10° internal tilt capability, and minimum initial light output is 700 lumens. If the intensity distribution is instead of asymmetric design to wash or graze walls (i.e., does not exhibit quadrilateral symmetry) and lumens in quarter-sphere oriented toward wall are at least four times (4x) lumens in quarter-sphere oriented away from wall, then no tilt mechanism is required and minimum initial light output is 350 lumens. Resulting accent on wall shall have a natural “scallop” appearance with gradual fade from point of maximum illuminance, demonstrated via computer-generated grayscale rendering subject to COR approval.

Luminaire must be flush with ground surface (cannot protrude above) and rated to support the weight of industrial riding lawnmowers.

7. SPECIFICATIONS FOR PEDESTAL-MOUNTED LUMINAIRES:

Luminaire shall have a minimum IP rating of 66.

In warm-white mode, color-tunable luminaire shall have minimum initial light output of 6300 lumens; input power shall not exceed 220 W in any mode.

8. SPECIFICATIONS FOR WALL-MOUNTED LUMINAIRES:

Luminaire shall have a minimum IP rating of 66.

Luminaire shall operate in warm-white mode only, and have maximum input power of 220 W.

Luminaire shall be mounted at existing location __ feet above grade. Coordinate with COR to determine necessary hardware for attaching to historic structure.

Luminaires shall provide a combined average horizontal illuminance of ≥ 3.0 fc at grade, with average-to-minimum uniformity ratio of ≤ 4:1 (excluding points not in luminaire line-of-sight), measured on a grid with points spaced 10 feet apart.

9. SITE WORK:

All work shall be completed in compliance with OSHA standards and regulations. All electrical work shall be completed by a licensed electrician or under the direct supervision of a licensed electrician.

All junction boxes shall be potted using a insulating and sealing polymeric potting compound with fast crosslinking at room temperature, sticky, adhesive, re-enterable, suitable for filling. The potting compound shall be suitable for anticorrosion protection, non-toxic, and safe. In suitable cases, it shall give a degree of protection of IP 68.

For fixtures flush with the earth, notify COR three work days prior to ground disturbance.

Coordinate shutting off electrical service to fixtures with COR prior to demolition and installation of fixtures.

Coordinate with park to shut off power to buried light fixtures prior to ground disturbance. Uncover fixtures using hand tools, minimizing the volume of ground disturbance around the fixture. All soils shall remain on site. Installation may require some gravel to allow for drainage away from the buried fixture. Fixtures shall be installed per manufacturer's recommendations. Remove existing fixture; install, wire and connect new fixture. All conduit, wiring, and boxes shall be sealed to prevent water entry.

Coordinate with COR to determine suitable location for color-tuning control system equipment.

Except where noted otherwise, new fixtures shall be placed in the same location as existing fixtures. Luminaires shall be properly aimed upon installation, then secured to prevent tampering of the light's aim. Fixtures shall be aimed for uniformity of illumination and to minimize light spillage over the top of the walls or other items to which they're aimed.

Upon completion of installation, measure warm-white mode illuminance on representative portion of wall segment to be selected by COR post-installation. Measurement grid shall consist of 8 horizontal rows 4 feet apart, with 4 points 4 feet apart in each row, centered on the wall between in-ground uplights. The illuminance meter shall be calibrated by an ILAC MRA Signatory-accredited laboratory over a range of illuminance values inclusive of 0.3 fc and 30 fc using CIE Standard Illuminant A (incandescent). Provide illuminance measurement data to COR prior to final inspection.

10. DELIVERY:

Provide the following to CO or his/her representative for approval.

Pre-Construction Submittals (due at precon):

- Letter designating Project Superintendent
- Proof of insurance
- Project Schedule
- Schedule of Values
- Signed SF-1413's for each sub-contractor
- Safety Plan

- Quality Control Plan
- Electrician's license

Pre-Mobilization Submittals:

- For each luminaire type (in-ground, pedestal-mount, wall-mount)
  - Luminaire spec/cut/data sheets, with project-specific configuration(s) and complete model number (catalog ordering information) indicated
  - Data sheets for LED light sources, LED drivers, and any surge-protection devices
  - Instructions for luminaire installation, operation, and maintenance
  - OSHA NRTL luminaire safety certification and file number indicating compliance with UL 1598
  - Luminaire warranty
  - IES LM-79 test report and corresponding LM-63 luminous intensity data file from an ILAC MRA Signatory-accredited laboratory (luminaire in warm-white mode)
  - IES LM-80 test report(s), In-Situ Temperature Measurement Test (ISTMT) report, and IES TM-21 spreadsheet calculations per DesignLights Consortium requirements for Option 1 (https://www.designlights.org/solid-state-lighting/submit-a-product/lumen-maintenance/) with luminaire operating in warm-white mode
- Computer-generated point-by-point photometric analysis of maintained light levels, using a light loss factor (LLF) of 0.85 and lumen output in warm-white mode.
- Computer-generated grayscale rendering for each of the 7 illuminated wall segments
- Site plan drawn to scale with table/schedule indicating complete model numbers of luminaires to be used at each location (e.g., input power and optic/beam may vary), complete with aiming angles (horizontal orientation and vertical tilt) and any available locations not needed/utilized
- For each color-tunable luminaire type, a table of CIE 1931 (x, y) or CIE 1976 (u', v') chromaticity diagram coordinates defining the polygon containing the set of distinct colors that can be produced via the control system
- For each color-tuning control system, complete datasheets and instructions/manuals/warranty

Close-Out Submittals

- Post-installation illuminance (footcandle) measurement data
- Operation and maintenance information for each type of fixture installed
- Certified payrolls
- Release of Claims Spare parts:
- Any spare parts sent with fixtures shall be turned over to COR at project completion
- (1) spare wall-mount luminaire
- (2) spare pedestal-mount floodlight luminaires

- (2) spare in-ground uplight luminaires
- (2) spare in-ground uplight luminaire replaceable LED light engines

11. GOVERNMENT-FURNISHED PROPERTY, MATERIAL, EQUIPMENT, OR INFORMATION (GFP, GFM, GFE, OR GFI):

Schematic of light fixture locations [...] attached.

12. SECURITY:

Contractor is responsible for securing any equipment, parts, tools, etc. left on site. NPS cannot be held liable for damage or theft to items retained on NPS property.

COR will provide Contractor with access to building spaces necessary to complete the required tasks.

13. TRAVEL:

Travel fees related to this contract shall be included in the contractor's bid proposal. Do not include travel costs as a separate line item. Contractor is not authorized to bill the government for travel as a unique expenditure.

14. SPECIAL MATERIAL REQUIREMENTS:

Materials shall be corrosion resistant. [Once an adequate corrosion standard is issued by an appropriate standards body, it should be cited here.]

15. OTHER UNIQUE REQUIREMENTS:

None.

16. QUALITY ASSURANCE REQUIREMENT:

The contractor shall develop and maintain a quality program to ensure services are performed in accordance with commonly accepted commercial practices. The contractor shall develop and implement procedures to identify, prevent, and ensure non-recurrence of defective services. As a minimum the contractor shall develop quality control procedures addressing the critical areas identified in this statement of work. The government will periodically evaluate the contractor's performance in accordance with the statement of work.

Appendix B – Brief List of Recent Related Materials

Benya, James. Yosemite National Park Lighting Guidelines, 2011. Prepared by Benya Lighting Design for the U.S. National Park Service, May 6, 2011.

Longcore, Travis and Catherine Rich, 2017. Artificial Night Lighting and Protected Lands – Ecological Effects and Management Approaches (Revised August 2017). Natural Resource Report NPS/NRSS/NSNS/NRR – 2017/1493. U.S. Dept of Interior, National Park Service.

Puerto Rico Energy Resiliency Working Group, 2017. Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico. Prepared for Governor Andrew Cuomo, New York, Governor Ricardo Rossello, Puerto Rico, and William Long, FEMA Administrator. December 2017.

Rocky Mountain Institute, 2017. Insight Brief: The Role of Renewable and Distributed Energy in A Resilient and Cost-Effective Energy Future for Puerto Rico. December 2017.

U.S. Department of Energy, Federal Energy Management Program, 2010. Exterior Lighting Guide for Federal Agencies. Prepared by Lawrence Berkeley National Laboratory and the California Lighting Technology Center. August 2010.

Walker, A. and E. Elgqvist, 2015. Renewable Energy Assessment for San Juan National Historic Site. National Renewable Energy Laboratory. DOE/GO-102015-4622, February 2015.

Appendix C – Definitions[1]

Adaptive lighting – A method of controlling a lighting system according to parameters that vary or are initially uncertain. Examples of relevant varying parameters for outdoor lighting systems include ambient light or traffic (e.g. pedestrian, bike, automobile) levels that vary periodically (predictably or unpredictably) over the course of a day.

Atmospheric scattering/attenuation – Light waves traveling through the atmosphere are either transmitted, absorbed, or scattered by constituents within the atmosphere (gaseous molecules, aerosols, and particulate matter). Because different wavelengths interact differently with particles of varying size, the spectral content of a given beam of light often changes as it propagates through the atmosphere, with some portions eventually attenuated by a long enough travel path and/or high enough level of atmospheric constituents. Sky glow is caused by the portion of light scattered in the specific direction of the observer's location, with its associated spectral content generally a combined function of the original content and distance from the source.

BUG rating – Backlight, Uplight, and Glare ratings that may be used to evaluate luminaire optical performance related to light trespass, sky glow, and high-angle brightness control. These ratings are based on lumen output calculations (i.e., brightness) for a given luminaire in various zones (Back, Up, and Forward) surrounding it, as shown in Figure C.1.

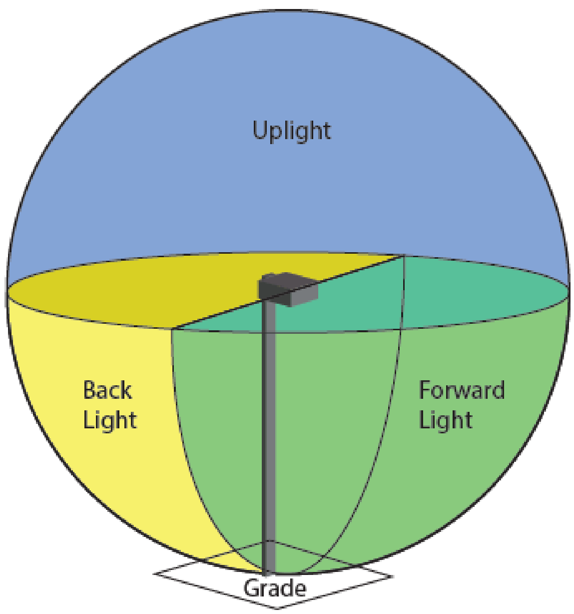

Figure C.1. Solid angle depiction of zonal lumens used in calculating BUG rating. Reprinted with permission from Illuminating Engineering Society.

Backlight – The percent of lamp lumens or the luminaire lumens distributed behind a luminaire between zero degrees vertical (nadir) and 90 degrees vertical.

[1] Sources include ANSI/IES RP-16-10 "Nomenclature and Definitions for Illuminating Engineering"; IESNA TM-15-07, "Luminaire Classification System for Outdoor Luminaires"; Model Lighting Ordinance.

Uplight – The percent of lamp lumens or the luminaire lumens distributed above a luminaire between 90 and 180 degrees vertical.

Glare – The sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance or visibility.

Brightness – Attribute of a visual sensation according to which an area appears to emit more or less light.

Color rendering index (CRI) – A measure of the degree of apparent color shift that objects undergo when illuminated by the light source, as compared to a reference source (e.g., sunlight). The effect of CRI is noticeable in comparing colors of objects under the light source vs. their appearance under the reference. Narrow-band wavelength sources like low-pressure sodium provide the extreme example, where many hues may no longer even be identifiable.

Correlated color temperature (CCT) – The absolute temperature of an ideal (blackbody) radiator whose associated chromaticity most resembles that of the light source. Note that this definition refers to a perceived *appearance* of the light source; significant variations in combinations of spectral content can produce a similar overall appearance in terms of CCT (Figure C.2); therefore, CCT provides only a general indication of the actual spectral content. *Nominal* CCT refers to a naming convention for binning groups of CCTs within specified ranges under a single value, e.g., 3895 K, 4002 K, and 4072 K chips would all be *nominally* referred to as 4000 K.

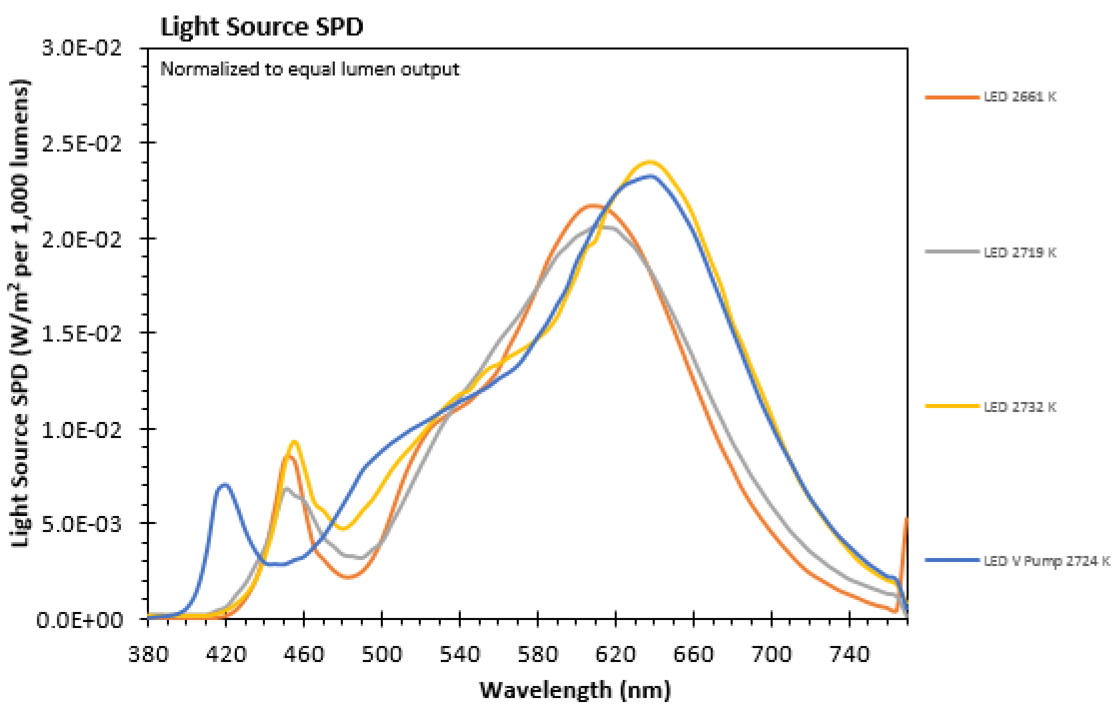

Figure C.2. Graphed spectral power distributions (SPDs) of four nominal 2700 K LED sources.

Horizontal and vertical illuminance – The areal density (e.g., lumens/m^2) of light incident on a horizontal or vertically-oriented surface at a specified location.

Illuminating Engineering Society (IES) – An accredited standards development organization under American National Standards Institute (ANSI)-approved procedures. The IES publishes recommended practices on a variety of applications, design guides, technical memoranda, and publications on energy management and lighting measurement, and is the industry's principal source for lighting knowledge. Although IES does not currently address outdoor lighting specific to protected areas, the NPS and IES are planning a partnership to develop such standards that will acknowledge the unique mission of the NPS and its numerous different lighting needs and objectives.

Light pollution (or sky glow) – The added night sky brightness caused by the scattering of light from human-made sources of radiation (e.g., outdoor electric lighting), including radiation that is emitted directly upward and radiation that is reflected from surfaces.

Lighting zones – The base or ambient light levels desired by a community, establishing a target set of criteria for designing a lighting system. The Model Lighting Ordinance (MLO)[1] provides five zone definitions:

> LZ0: No ambient lighting – Areas where the natural environment will be seriously and adversely affected by lighting. Impacts include disturbing the biological cycles of flora and fauna and/or detracting from human enjoyment and appreciation of the natural environment. Human activity is subordinate in importance to nature. The vision of human residents and users is adapted to the darkness, and they expect to see little or no lighting. When not needed, lighting should be extinguished.
>
> LZ1: Low ambient lighting – Areas where lighting might adversely affect flora and fauna or disturb the character of the area. The vision of human residents and users is adapted to low light levels. Lighting may be used for safety and convenience, but it is not necessarily uniform or continuous. After curfew, most lighting should be extinguished or reduced as activity levels decline.
>
> LZ2: Moderate ambient lighting – Areas of human activity where the vision of human residents and users is adapted to moderate light levels. Lighting may typically be used for safety and convenience, but it is not necessarily uniform or continuous. After curfew, lighting may be extinguished or reduced as activity levels decline.
>
> LZ3: Moderately high ambient lighting – Areas of human activity where the vision of human residents and users is adapted to moderately high light levels. Lighting is generally desired for safety, security, and/or convenience, and it is often uniform and/or continuous. After curfew, lighting may be extinguished or reduced in most areas as activity levels decline.
>
> LZ4: High ambient lighting – Areas of human activity where the vision of human residents and users is adapted to high light levels. Lighting is generally considered necessary for safety, security, and/or convenience, and it is mostly uniform and/or continuous. After curfew, lighting may be extinguished or reduced in some areas as activity levels decline.

[1] A joint effort of the International Dark Sky Association and the IES, this guidance document allows communities to dramatically reduce light pollution and glare and reduce excessive light levels. The recommended practices can be met using readily available, reasonably priced lighting equipment.

Spectral content – The collection of wavelengths within the visible spectrum (generally between 380 and 770 nm) contained in a light beam or emitted by a specific light source. Spectral content is often reported in a spectral power distribution (SPD) table in units of radiant flux (i.e., power output) per unit wavelength interval at each wavelength, e.g., watts per nanometer.

Target area/Off-target area – The area intended for illumination versus its surroundings where illumination is not desired. Off-target illumination may sometimes be referred to as light trespass or spillover.

Uniformity – A characterization of the range of illumination values within a visual scene. Different measures are used for different applications. For example, a specification might set acceptable range limits for maximum-to-minimum values or average-to-minimum values within a targeted design space.

Veiling luminance – Brightness of light superimposed on the retinal image that reduces its contrast.

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