Wellesley Sports Lighting Findings and Recommendations
Revised 8/30/2021

Introduction
The following report is based on my analysis of the proposed lighting plans and an on-site investigation that was conducted 4/18/21 through 4/20/21, and questions that have come up in previous versions of the report. The goal of this analysis is to identify the potential adverse impacts of the proposed lighting installation and recommend a balanced approach to achieve the best possible lighting for the players and minimize the negative impacts on the environment and surrounding residential areas. The lighting of a sports field is one of the single largest sources of nighttime illumination within a community and has the potential to produce a great deal of glare, light trespass, and skyglow. In addition, the introduction of this amount of lighting into the nocturnal environment may result in significant adverse effects on species in the region. Here is a brief examination of these negative effects.

Light trespass
The most often cited negative impact of sports lighting is light trespass, which is defined as light that encroaches on neighboring properties. It can be measured with a light meter in lux or foot candles, but its negative impact is subjective, meaning that the same amount of light level can be perceived differently by different individuals. While light trespass can be mitigated by lighting design and blockage (manmade [walls, fabric, etc.] or natural [trees, buildings, etc.]), light trespass is primarily a matter of distance from the source and topography.

The range of impact varies from mild (noticeable glow on horizontal and vertical surfaces) to high luminance that creates a distraction, thereby reducing the enjoyment of being outdoors at night and requiring opaque drapes in bedrooms to sleep.

Glare
Glare is defined as a sensation of discomfort produced by a very high contrast light source. At night, this is commonly cause by looking at the pinpoint light source in a lighting fixture (a bulb or LED lens). It is characterized by its intensity and measured in candela. While there is no agreed upon metric for glare, it is categorized in a range from mild discomfort to disability. Like light trespass, it too can be mitigated by lighting design and blockage (manmade [walls, fabric, etc.] or natural [trees, buildings, etc.]). Unlike light trespass, glare's ability to be perceived as a nuisance at great distances can impact viewers in the direct line of sight far from its source.

Skyglow
Skyglow is the brightening of the night sky from artificial light sources. This occurs due to the scattering of light by particulate matter combined with moisture in the atmosphere and is exacerbated by elevated levels of both. Skyglow can be mitigated by focusing the light from fixtures below 90° of Nadir and reducing the total quantity of lumens emitted. While the majority of skyglow is created by light focused at or above the horizon, it can also be created by the reflection of light off surfaces like concrete and snow. The result of skyglow is the blotting out of stars and other celestial features like the Milky Way.

Ecological Impact

Ecological impact is much harder to quantify, but research shows that it is equally important. Light at night can significantly modify the nocturnal behavior of animals in foraging, migration, predation, mating, and the viability of offspring and mortality. It can simultaneously advantage some species while disadvantaging others and can create circadian disruption in all species of flora and fauna, including humans. Mitigation is difficult but can be reduced by using the proper spectrum of light and reducing the dose, timing, and duration. There are several specific negative impacts of artificial light at night that may affect the Wellesley ecosystem.

Trees conserve energy by shedding leaves in fall. They do this based on several factors, but length of daylight is most prominent. When artificial light at night tricks the tree into thinking it's day, it holds on to its leaves longer, expending energy that needs to be conserved for the winter. This can cause disease and lead to premature death. [1,2]

Wetlands are host to birds, insects, invertebrates, and amphibians, all of which have been shown to exhibit deleterious effects from light at night. [3,4,5,6,7,8]

Siting Concerns

The impacts enumerated above are exacerbated when a lighted sports field is in a suburban area without adequate separation from adjacent residential communities and/or significant blockage from natural or manmade structures. The combination will almost always ensure that residents close to the fields will experience some annoyance ranging from mild irritation to a tangible reduction in the quality of life. This is created by the point source glare from the lighting fixtures and/or elevated levels of ambient illuminance created by light trespass onto their property from the sports lighting.

Unfortunately, this is the situation with all the fields currently being considered for new or retrofitted sports lighting fields in Wellesley.

Proposed Sports Field Lighting Retrofits

Warren Field and Tennis Courts

The Musco Light Structure 2 system currently installed for this area is approximately 20 years old and uses older Metal Halide, High Intensity Discharge (HID) lamp technology in parabolic aluminum fixtures. While these fixtures have some opaque louvers added to block glare, the aiming angles (~20° to 40° from nadir) required to light the field adequately produce high levels of glare, skyglow, and light trespass by today's standards. This was confirmed by horizontal illumination measurements of adjacent properties on Linden Street (backing to Washington Street) that often exceed 4 lux and, more importantly, vertical illumination measurements of >6 lux in many cases at 100' from the fields.

While there isn't an approved glare metric to describe the point source luminance intensity at the adjacent properties, Candelas Per Square Meter (cd/m^2) is currently the only measurement that is possible to do with a luminance meter in the field. (These are not the same or as accurate as Candela which are specified in the Musco computer-generated lighting plans and the IDA Community Friendly Outdoor Sports Lighting Program.) I took extensive measurements during my visit to gauge the current conditions and to be used in before/after comparisons.

Typically, measurements of >1000 cd/m^2 taken from the affected properties are a good indicator of potential problems. The specific fixtures that were measured and subjectively deemed objectional are located on the far side of the playing fields and are aimed to cover the near side of the field. Each field

and court have at least two fixtures per pole that project a great deal of light at higher angles. In these cases, using a Minolta LS-110 luminance meter with a 1/3° acceptance angle at the adjacent residential properties, measurements ranged from 1000 to 3000 cd/m^2. From my experience, I would categorize the glare from these specific fixtures on the Warren Field and Tennis Courts to be potentially objectionable.

I've included images that better illustrate the current conditions, but the light trespass and glare measured across the railroad tracks from Warren Field and Tennis Courts were high enough to be considered a nuisance to these properties. Replacement of the lights for these fields/courts — with the newer LED technology specified in the Musco proposals using the "TLC LED" system — should significantly reduce the negative off-site impacts to these properties.

My on-site meeting with Mike Berry of Musco revealed a real desire to install a system that will minimize off-site impact. The designs provided are good and, in my opinion, are as good as can be implemented for the space at this time. The low aiming angles of the TLC LED fixtures also improve the chances that the point source glare from the fixtures opposite Washington Street will be reduced to <=1000 cd/m^2 and directed to a lower elevation at the adjacent homes than it is now.

During my on-site inspection I inspected the impact a large white oak tree on the first base line was having on infield lighting. I have discussed this with Mike Berry of Musco and he agrees that it is substantial and will probably continue to reduce lighting levels more each year. The only mitigation possible, without substantial trimming, would be to move the affected pole approximately 20 feet towards the outfield and an equal amount in towards the first base line. This will require a new foundation and electrical work that could cost $15,000 or more. The existing pole should be reusable, but this option will need an on-site inspection and evaluation by Musco before further consideration.

Reidy Field

The Musco Light Structure Green system was installed approximately 15 years ago. While also using Metal Halide, High Intensity Discharge (HID) lamps in aluminum parabolic fixtures, the shielding used was the probably the best sold at that time for older technology softball fields. It reduced skyglow, light trespass, and glare compared to other HID systems, including the Light Structure 2 installed at Warren Field and Tennis Courts. The off-site measurements of both glare and light trespass were approximately 50% lower than those taken of Warren Field and Tennis Courts.

This system is still under the original Musco 25-year warranty and performs well. While replacing it with a Musco TLC LED system may reduce the offsite impact, it may not be as noticeable to the residents adjacent to the field as a retrofit to Warren Field and Tennis Courts. The primary improvement gained from the replacement at this time would be the ability to adjust the lighting level to the class of play. However, if the decision is made not to use the reduced lighting levels, it would be difficult to recommend the replacement of lighting on Reidy Field at this time.

Class of play lighting levels/LED Dimming

LED lighting can be dimmed, whereas HID cannot. The Illuminating Engineering Society RP-6-20 recommended practice is the lighting standard that most sports fields in North America are designed to meet. In RP-6-20, the lighting levels prescribed are defined by the type of sport being played and the class of play. In the past, prior to LED technology, a field was designed to meet the highest level of play expected and couldn't be adjusted.

The difference in recommended lighting levels for Class IV Baseball/Softball (practice) and Class III (Competition) are approximately 40% lower. When practice level lighting can be used there would be a proportional reduction in of-site impact in addition to the additional energy savings.

Retrofit Cost/Benefit Analysis

Energy Savings for Warren Field and Tennis Courts

Musco estimates that the 25-year energy costs of operation for the Warren Field and Tennis Courts is $410,400. The conversion to LED technology will reduce energy consumption by around 55%, and a 25-year savings of $226,848, or roughly $13,000 per year. Using practice or scrimmage lighting levels for Warren Field can reduce this by approximately 30% more ($3,900).

Table 1: Cost of Operation over 25 Years

	Existing				Proposed			
COST (over 25 years)	**Energy**	**Maintenance**	**Controls**	**Total**	**Energy**	**Maintenance**	**Controls**	**Total**
Warren	$207,360	$39,217	$9,720	$256,297	$100,832	$0	$0	$100,832
Tennis	$203,040	$30,350	$16,200	$249,590	$82,720	$0	$0	$82,720
High School Field	$0	$0	$0	$0	$75,790	$0	$0	$75,790

Energy use includes demand charges.

Maintenance & Control Costs

Now out of warranty, you can also expect to pay approximately $96,000 over the next 25 years/ or $3,819 per year for maintenance and controls for the current system.

New Lighting Installation Cost Estimates

With the cost estimate provided by Musco of $300,000 to $340,000 for materials and labor to replace the lighting for Warren Field and Tennis Courts combined, the operational cost savings for the new LED system, using reduced lighting levels for scrimmage, would take about approximately 20 years to recoup these costs.

CO_2 Considerations

As outlined in Table 2 At the current estimated usage for both Warren and the Tennis courts, the CO_2 savings over 25 years would be approximately 672 tons, or ~44% by converting to LED. This is roughly equivalent to taking 143 cars off the road for one year. The calculations in Table 2a are those provided by MUSCO. Calculations in Table 2b identify the CO2 estimates using Wellesley-specific

Table 2a: CO2 Savings/Creation

C02 (tons)	Existing	Proposed	Change	Notes
Warren Field	447	217	-230	Based on 400 Hours Use/year for 25 years
Tennis Courts	745	303	-442	Based on 1000 Hours Use/year for 25 years
High School Field	0	108	108	Based on 100 Hours Use/year for 25 years
High School Field 6/1 Update	0	80	80	Based on 100 Hours Use/year for 25 years

TONS of CO2/100 hour of field use over 25 years

	Existing	Proposed	Change
Warren Field	111.75	54.25	-57.5
Tennis Courts	74.5	30.3	-44.2
High School Field	0	108	108
HS 6/1 Update	0	80	80

Table 2a: CO2 Savings/Creation using Wellesley CO2 estimates.

C02 (tons)	Existing	Proposed	Change	Notes
Warren Field	186	90	-96	Based on 400 Hours Use/year for 25 years
Tennis Courts	310	126	-184	Based on 1000 Hours Use/year for 25 years
High School Field	0	45	45	Based on 100 Hours Use/year for 25 years
High School Field 6/1 Update	0	33	33	Based on 100 Hours Use/year for 25 years

TONS of CO2/100 hour of field use over 25 years

	Existing	Proposed	Change
Warren Field	47	23	-24
Tennis Courts	31	13	-18
High School Field	0	45	45
HS 6/1 Update	0	33	33

CO2 calculations are as follows: # Hours x Total kW per lamp x years in Warranty * coefficient

Off-Site Negative Impact Reduction

The reduction in energy costs and carbon from retrofitting are easier to document than the potential reduction of off-site impact from skyglow, light trespass, and glare, or ecological disruption. The reduction in light trespass and glare may be noticed by residents directly across Washington Street, and drivers and pedestrians passing by, but it probably won't be reduced enough to quell complaints. There is no way to estimate or document any reduction in ecological disruption without extensive research over a period of years. As outlined in Table 3, Total Luminance will be reduced by 3,420,000 Lumens by replacing the existing Metal Halide Lighting system.

Table 3: Luminance for Warren and Tennis Courts

Tennis and Warren			
Existing Fixtures	**Quantity**	**Lumens**	**Total**
TLC 1500W MH	36	155,000	5,580,000
TLC 1000W MH	30	100,000	3,000,000
			8,580,000

Tennis and Warren				
Proposed Fixtures	**Quantity**	**Lumens**	**Total**	**Change**
TLC-LED-1200 LED	35	136,000	4,760,000	
TLC-BT-575 LED	8	52,000	416,000	
TLC-LED-900 LED	4	89,600	358,400	
TOTAL	47		**5,534,000**	**-3,045,000**

Glare and Light Trespass Reduction

My estimates for glare and light trespass presuppose that Reidy Field is not being upgraded at this time. Estimates for the reduction off-site impacts are impacted by several factors.
Reidy is currently used approximately 200 hours, while Warren Field and Tennis Courts are used about 400 and 1000 hours per year respectively.
Secondly, without taking field measurements of each field with the lighting on and off, any estimate will be just an educated guess. With field measurements taken a matrix could be developed showing the impact with number of scenarios:

- Tennis Courts Only
- Reidy Field Only
- Warren Field Only
- All on
- Tennis Courts plus Warren Field
- Warren Field plus Reidy Field
- Reidy Field plus Tennis Courts

I have reviewed the predicted off-site impact plans provided by Musco for both the existing and proposed lighting of Warren Field and Tennis Courts. I must state as a matter of record that I have no reason to question their projections, however I have no way of validating them. A reduction of 90% for both candela and vertical illumination at 150' is a stunning improvement. However, if Reidy Field lighting is not being replaced, it will significantly reduce the net effect of the improved lighting for of Warren Field and Tennis Courts when it is being used. As stated earlier, it is extremely difficult to determine the exact reduction for candela and vertical illumination, but I estimate that it might be closer to 50% near Reidy Field in when Reidy Field on. This would improve as you move towards the Tennis Courts; maybe approaching 75%.

If Reidy Field is upgraded in the future, you may likely be able to approach the 90% reduction estimated by Musco. I do want to make clear that while Musco guarantees the on-field performance specified in their proposal, they do not make the same guarantee regarding off-site impact.

Skyglow Reduction

Musco has not provided any estimate of reduction to skyglow in any of the information that I have reviewed. There are several elements that contribute heavily to local skyglow: the first is

total lumen output; the second is fixture shielding; and the last is the blue spectral power density of the light source. The new designs reduce total lumens by approximately 33% and the fixture shielding is far superior to the existing system. Skyglow is most impacted by the quantity of light directed 5-20° above the horizon, but reflected light can also contribute, especially on light colored surfaces (especially snow). The last factor, which is difficult to model, is the amount of moisture and particulate matter in the atmosphere. This ultimately has an outsized influence on the total skyglow (night sky brightness).

As indicated in the initial report, I was unable to make baseline night sky brightness measurements during my first visit due to weather conditions. I am still planning to perform them, and they will be the most definitive factor in determining how much of a reduction in night sky brightness is possible. Bear in mind, Wellesley will already have significant skyglow from all the existing exterior lighting. Therefore, this factor by itself will "mute" the overall reduction possible by improving the sports lighting.

The last factor to consider is that although the lumens are being reduced, the correlated color temperature (CCT), and more specifically the blue spectral power density, is increased. The current metal halide lamps are 4200K and the new LED will be 5700K. Musco does not release spectral power density specifications for the LED system, but a big factor in the ability to reduce lumens by ~33%, is the increase in spectral power density in the blue spectrum. This increase helps the players be able to see objects in motion better, but it also increases what is called Rayleigh scatter[1]. It's a very complex issue, but it means that blue light will scatter more when it contacts moisture and particulate matter in the atmosphere, thus increasing skyglow and night sky brightness.

I am "guesstimating" that a large percentage of the reduction in lumens will be offset by the increase in blue spectral power density. Exactly how much is incredibly hard to calculate, but I will say that if all fields were being retrofitted, the overall reduction in skyglow probably would not exceed 30%, taking in all the factors discussed above. With Reidy Field not being upgraded, it will most likely be more like a 10-20% reduction when it is in use. This may seem small, but there is probably no other location in Wellesley that could contribute to an overall reduction in skyglow by being upgraded.

The off-site negative impacts of glare and light trespass will be much more obvious to the residents in the immediate vicinity far more acutely.

1. https://en.wikipedia.org/wiki/Rayleigh_scattering

Proposed New Sports Field Lighting

WHS Track and Field

Unlike the retrofit of Warren Field and Tennis Courts, the installation of lighting for the WHS Track and Field will introduce new skyglow, glare, and light trespass near the high school. The impact will be felt most acutely by the residents on Smith Street across from the school. Like Warren Field and Tennis Courts, the closest houses are approximately 120' from the field, and you can expect similar levels of glare and light trespass with the new Musco TLC LED there as you will get with the proposed Warren Field and Tennis Courts retrofit. The key difference will be that it will be all new to the residents of Smith Street.

On 6/2/2021 Musco submitted a new lighting design for this field. By reducing the lighting associated with track use, they have reduced the peak candela reading on Smith Street by ~60% (359 vs. 888 candela) and vertical footcandles to <= 0.01. This is a substantial reduction that should improve both glare and light trespass.

As discussed in the previous section, the only other way to mitigate the adverse impact of the proposed new lighting will be to use the appropriate lighting levels for the class of play and only using lighting when needed. To ensure that the field is only lighted when needed will require regular communication with the WHS staff, coaches, and updates to the web-based scheduling app provided by Musco.

As previously discussed, the introduction of 5,024,600 lumens (see table 4) of new lighting directly adjacent to a residential community may present significant intrusion into the peaceful enjoyment of their properties at night. While not in the scope of this report, the additional traffic and noise associated with night games also must be carefully considered. In the end, the decision must be made if the good of the community at large is best served by enabling sports to be played at night, as well as the enjoyment by those participating, both students and family.

Table 4: Luminance

Proposed

High School Field

Fixtures	Quantity	Lumens	Total
TLC-LED-1500 LED	22	156,100	3,434,200
TLC-LED-900 LED	8	89,600	716,800
TLC-LED-1200 LED	10	136,000	1,360,000
TLC-LED-400 LED	2	46,500	93,000
TLC-BT-575 LED	8	52,000	416,000
			6,020,000

High School Field 6/1 Update

Fixtures	Quantity	Lumens	Total
TLC-LED-1500 LED	22	156,100	3,434,200
TLC-LED-900 LED	4	89,600	358,400
TLC-LED-1200 LED	6	136,000	816,000
TLC-LED-400 LED	0	46,500	0
Balltracker	8	52,000	416,000
			5,024,600

IDA Sports Lighting Certification
All of the lighting designs provided by Musco appear on paper to meet the International Dark-Sky Association's Community Friendly Outdoor Sports Lighting Program requirements. To have a field certified by the IDA, an application must be submitted to them with a $1000 fee. If approved, the design will receive a phase one IDA Certification Letter. After construction is complete, you may apply to have the field validated by IDA with an on-site inspection. The validation fee is $3000 plus travel expenses for IDA staff. If it meets the specifications of the design in phase one, the field will IDA Certified with a plaque, and listed on the IDA website.

Alternative Vendors
Wellesley has also obtained lighting proposals from Eaton using Ephesus lighting fixtures.
The designs proposed by Eaton do not include off-site measurements for glare or light trespass. While using LED technology, the Ephesus fixture design in this proposal is more like the older Musco Light Structure 2 system and uses a hood with many exposed individual LED lenses. The aiming angles are greater than the Musco TLC LED system and would most likely result in elevated levels of skyglow, glare, and light trespass compared to the Musco TLC LED system. The 10-year fixture warranty provided by Ephesus is inferior to the 25-year warranty from Musco. It is highly unlikely that Eaton could provide a system that would meet the IDA Community Friendly Outdoor Sports Lighting Program Design requirements. For these reasons, I cannot recommend the Eaton proposal for this project.

Closing
Musco LED sports lighting fixtures are a significant improvement in controlling off-site light trespass over any currently available alternatives, but any direct view of the light sources at the close distances involved will be problematic and may be perceived as nuisance glare. This is another reason to strive to reduce the lighting levels to meet the required class of play and only have them on when needed.

While I was able to collect a great deal of the required information to start this investigation, the lack of clear skies hindered my ability to take accurate baseline night sky brightness measurements. I also need to take a series of geo-located luminance and illuminance measurements to be used for reference after any installations. If the decision is made to move forward on construction, I will plan a second visit to finish that part of the investigation.

Please refer to the included Q&A that was provided earlier for additional detail.

Regards,

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Definitions

Candela	the SI unit of luminous intensity. One candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian.
Candelas Per Square Meter	Is the derived SI unit of luminance. The unit is based on the candela, the SI unit of luminous intensity, and the square meter, the SI unit of area.
Footcandle	The unit of measure expressing the quantity of light received on a surface. One footcandle is the illuminance produced by a candle on a surface one foot square from a distance of one foot.
Glare	Lighting entering the eye directly from lighting fixtures or indirectly from reflective surfaces that causes visual discomfort or reduced visibility.
High Intensity Discharge	A type of electrical gas-discharge lamp which produces light by means of an electric arc between tungsten electrodes housed inside a translucent or transparent fused quartz or fused alumina arc tube.
Iluminance	The amount of luminous flux per unit area.
Lamp	A generic term for a source of optical radiation (i.e. “light”), often called a “bulb” or “tube”. Examples include incandescent, fluorescent, high-intensity discharge (HID) lamps, as well as light-emitting diode (LED) modules and arrays.
Lighting Fixture	A light fixture, light fitting, or luminaire is an electrical device containing an electric lamp that provides illumination.
LED	Light Emitting Diode.
Light Pollution	Any adverse effect of artificial light including, but not limited to, glare, light trespass, sky- glow, energy waste, compromised safety and security, and impacts on the nocturnal environment.
Light Trespass	Light that falls beyond the property it is intended to illuminate.
Lumen	The unit of measure used to quantify the amount of light produced by a lamp or emitted from a luminaire (as distinct from “watt,” a measure of power consumption).(e.g., a 60-watt incandescent lamp produces approximately 800 lumens.)
Luminance	The intensity of light emitted from a surface per unit area in a given direction.
Lux	The SI unit of illuminance, equal to one lumen per square meter.
Nadir	Is the direction pointing directly below a particular location; that is, it is one of two vertical directions at a specified location, orthogonal to a horizontal flat surface there.
Skyglow	The brightening of the nighttime sky that results from scattering and reflection of artificial light by moisture and dust particles in the atmosphere. Skyglow is caused by light directed or reflected upwards or sideways and reduces one's ability to view the night sky.

Map of Area (areas in yellow are primarily impacted)

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