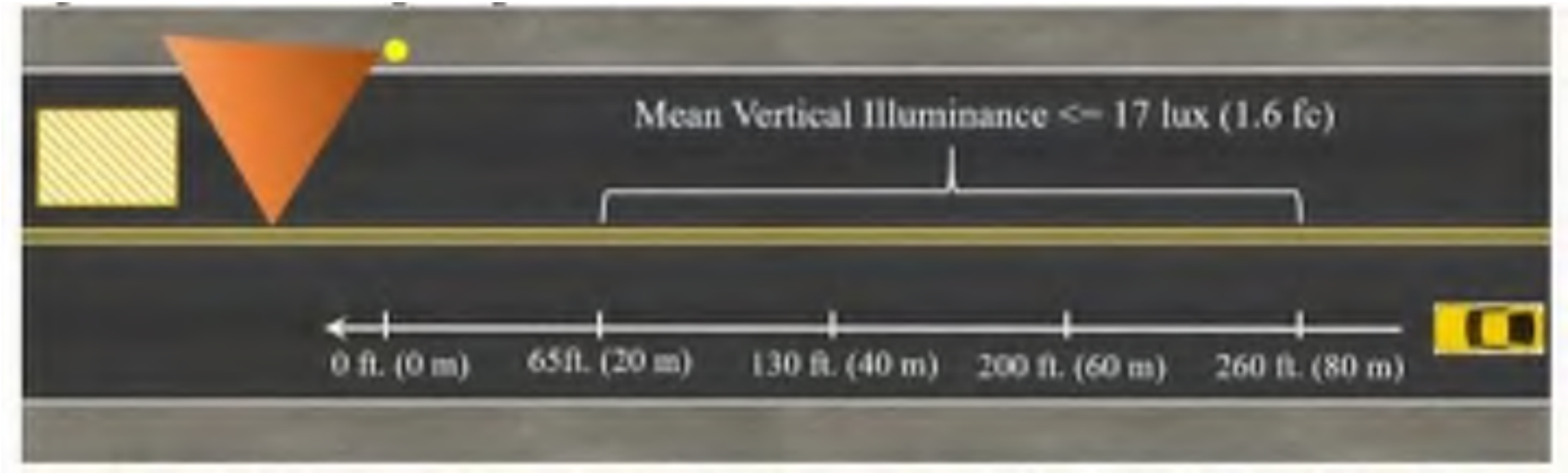
Lighting Limits



Maximum vertical allowed in the critical range = 50 lux

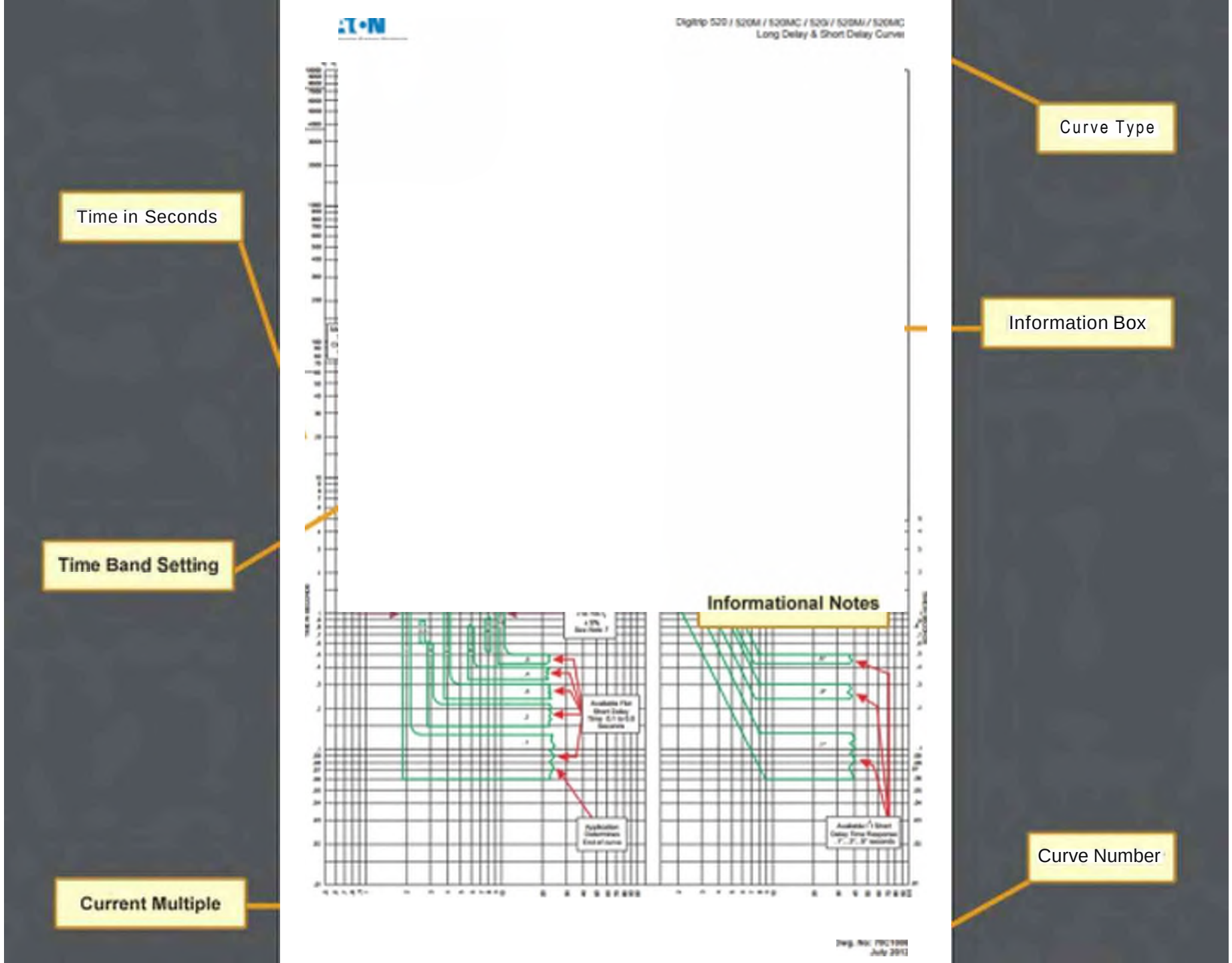
Electrical System Considerations

Key Issues

- Assess inrush starting currents during design considering all expected overcurrent devices.
- Consider over-voltages for solid state components.
- Assess allowable voltage drop against local requirements and benefit/cost.
- Consider an adaptive control system to control and monitor electrical conditions of the lighting system.
- Consider adding a surge protection device in the pole handhole.
- Consider additional TVSS at the electrical service panels feeding the lighting system.

Inrush Current

- LED luminaires have a significant inrush current upon starting.
- Depending on the product, inrush current can be more than 100 times the luminaire input current for a very short duration.
- Consider slow blow fuses in pole handholes or time delay circuit breakers
- Obtain in-rush info from luminaire supplier and match breaker and /or fuse trip rating


Time in Seconds
Time Band Setting
Current Multiple
Curve Type
Information Box
Curve Number
Informational Notes

Surge Protection

WHY?

- Protect critical and sensitive equipment (electronics)
- Increase equipment longevity
- Reduce downtime

HOW

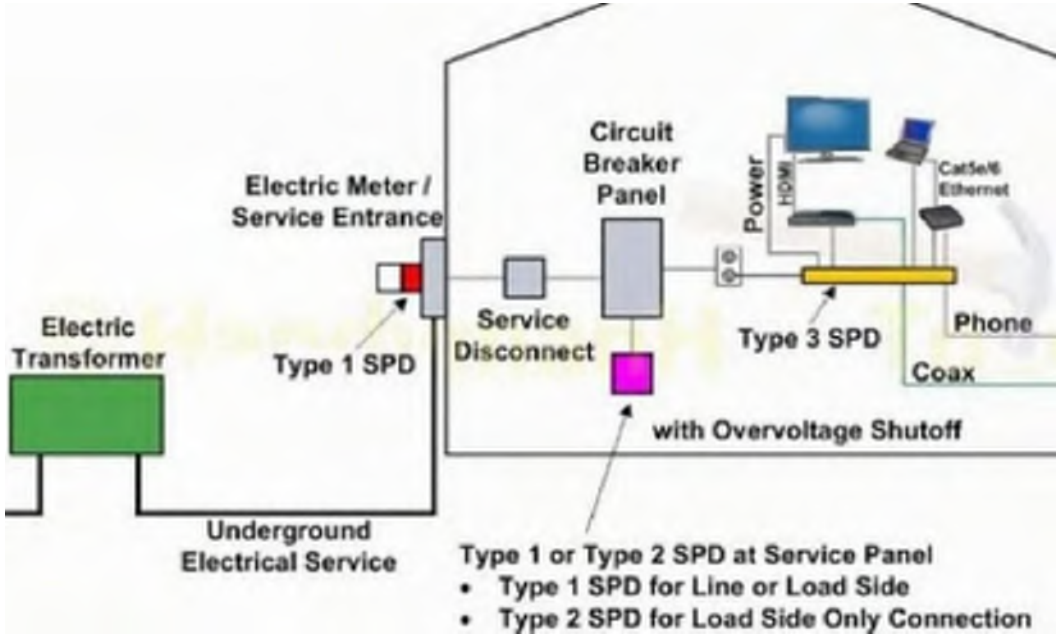
This is achieved by diverting and limiting damaging transient voltages and currents

Surge Protection Devices (SPD)

- Such a device should be approved to:
  - *UL 96A, Standard for Installation Requirements for Lightning Protection Systems (see UL 1449, Standard for Surge Protective Devices, 4th Edition)*
  - *IEEE C62.45-2002, IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and less) AC Power Circuits Standards for Surge Protective Devices*
- Recommend a surge capacity of at least 50 kA with a short-circuit current rating of 200 kA.
- The surge protection device must be installed within 6 inches of the breakers within the panel, and wiring must run in straight paths with minimal bends.

UL1449

- The SPD type refers to the location where the SPD can be used
- *Type 1 – before the service disconnect overcurrent device*
- *Type 2 – after service disconnect overcurrent device*
- *Type 3 – a minimum 10m (30 ft) of conductor between service disconnect overcurrent device and SPD*



Operations and Maintenance

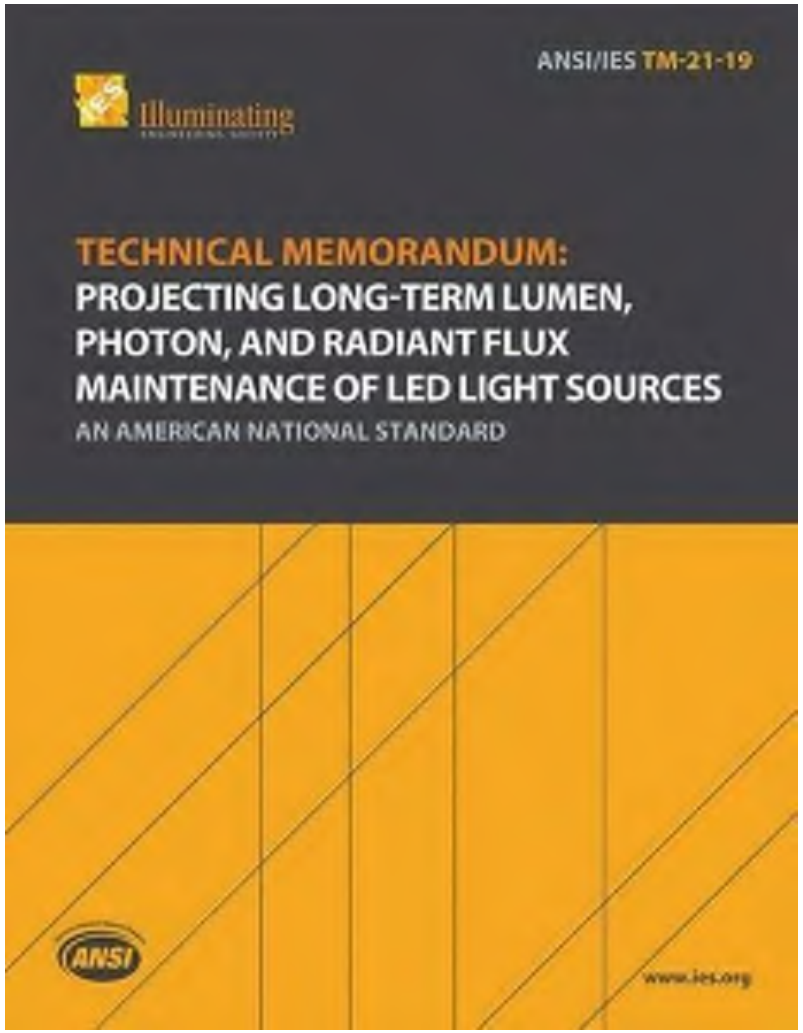
Key Issues

- Calculate light loss factors on a luminaire's expected service life determined by the DOT or agency installing the lighting system
- Consider an adaptive lighting system as part of an overall control and operation and maintenance cost reduction tool as well as an asset management tool
- Use benefit/cost analysis to help determine the best design approach for a proposed lighting system

Light Loss Factor

- Because an LED luminaire degrades differently than a HID luminaire and the LED will likely continue operating but at a steadily decreasing lumen output, therefore a light loss factor light loss factor (LLF) is applied:
- LLF = LLD × LDD × LATF where
  - *LLD = lamp lumen depreciation,*
  - *LDD = luminaire dirt depreciation, and*
  - *LATF = luminaire ambient temperature factor.*
- Design should be based end of life (say 20 years - 88,000 hours)

Lamp Lumen Depreciation (LLD) – IES TM-21



TM-21 Inputs

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Luminaire Dirt Depreciation (LDD)

- IES RES-1-16 Measure and Report Luminaire Dirt Depreciation (LDD) in LED Luminaires for Street and Roadway Lighting Applications.
- This document is available as a free download from the IES at: http://media.ies.org/docs/research/IES-RES-1-16.pdf .
- This report is the result of a project commissioned by the IES to quantify the impact of dirt accumulation on the light output of LED luminaires.
- Glass is easier to clean (example of optics which is harder clean on next side)

Luminaire Optical System	Dirt Depreciation Rate (per Year)	10-Year Cumulative Dirt Depreciation (LDD)	Impact to LLF
Flat Glass (protecting individual LED optics)	+1 %	10 %	
Exposed individual LED optics	+3 %	30 %	20% decrease

Cleaning Example

Steps for Cleaning Luminaire:

- Using a soft bristle brush, lightly brush away any debris that may be lying on the optic lens
- Spray the solution directly onto the scratch-free cloth while making sure the towel is damp.
- [redacted]
- Using the damp towel, clean the exterior surface of the optic lens
- Use the soft brush in conjunction with the towel to clean the optic lens in detail

Luminaire Ambient Temperature Factor (LATF)

- The luminaire ambient temperature factor is based on the temperature testing of the luminaire at 25° C.
- Given average nighttime ambient temperatures vary a LATF can be applied.
- Typically allow 1% for every 5° C above or below 25° C.

LED Conversions – Lessons Leaned

- Luminaire distribution and optical performance varies greatly from supplier to supplier.
- Product vary greatly in quality (you get what you pay for).
- Failure rates low - under 1% a year (service calls reduced). Most suppliers offer 10-year warranty. We request catastrophic failure requirement.
- Mass conversions typically have 5 to 8-year payback with a good return on investment (over say 20 years).
- Some conversions have resulted in public complaints (as result of luminaire brightness). Glare shields offered are typically of poor design.
- As result of optical control LED luminaires can create a tunnel of light on the roadway with reduced lighting off the roadway (poor surround ratio)

LED Conversions

- Most roads are well over-lit with high pressure sodium (HPS) luminaires. This is a result of HPS poor uniformity ratio. Some roads are underlit as result of pole spacing.
- LED's with improved optics can reduce over lighting and improve uniformity.
- Colour of the light source (CCT) can improve object detection distances (4000K vs 3000K).
- Simple wattage conversions (ie; 100W HPS for 50W LED) are not recommended. Best results obtained by reviewing GIS data and calculating lighting to ensure proper light levels are met. ***A conversion is huge cost investment so important to do the analysis!***

Potential Health and Environmental Impacts

Key Issues

Much research has been done in the area of health and environmental impacts of lighting at night, and much more research continues. Although impacts and considerations may further develop as more data are analyzed, the following key items are recommended for design.

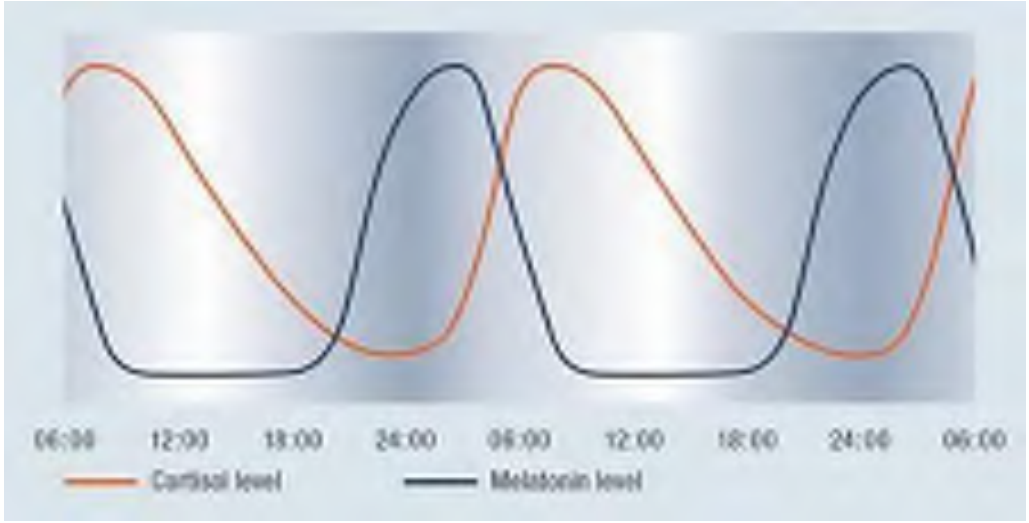
- Research does not show that a well-designed roadway lighting system using recommended light levels, meeting glare limits, and meeting light trespass values included in the AASHTO guide has any health effect using typical 3000K or 4000K LED sources.
- Although LED sources are likely to cause greater light scatter and sky glow, this is often offset by reduced total lumens and limited light trespass.
- Impacts on wildlife and plants vary by species. Research for some species is limited. For system design, lighting should be at the lowest level recommended, light trespass should be limited, and sensitive species in the area of the lighting system should be studied and mitigation, if any, should be documented if recommended (e.g., for turtle nesting grounds).

Consider the Negative Impacts of Roadway Lighting

- The is some evidence that Solid State Roadway lighting has:
  - Higher Health Impacts
    - Sleep and General Health
  - Sky glow
  - Impact on Flora and Fauna
    - Bugs, Buds, Bears and Bass

Health Impacts and Subjective Color

- Circadian rhythm, hormone secretion: The hormones responsible for the circadian rhythm in humans are melatonin, which is released in response to increasing levels of darkness and which promotes sleep, and cortisol, which is the biological opposite of melatonin and an indicator of the level of human activeness.

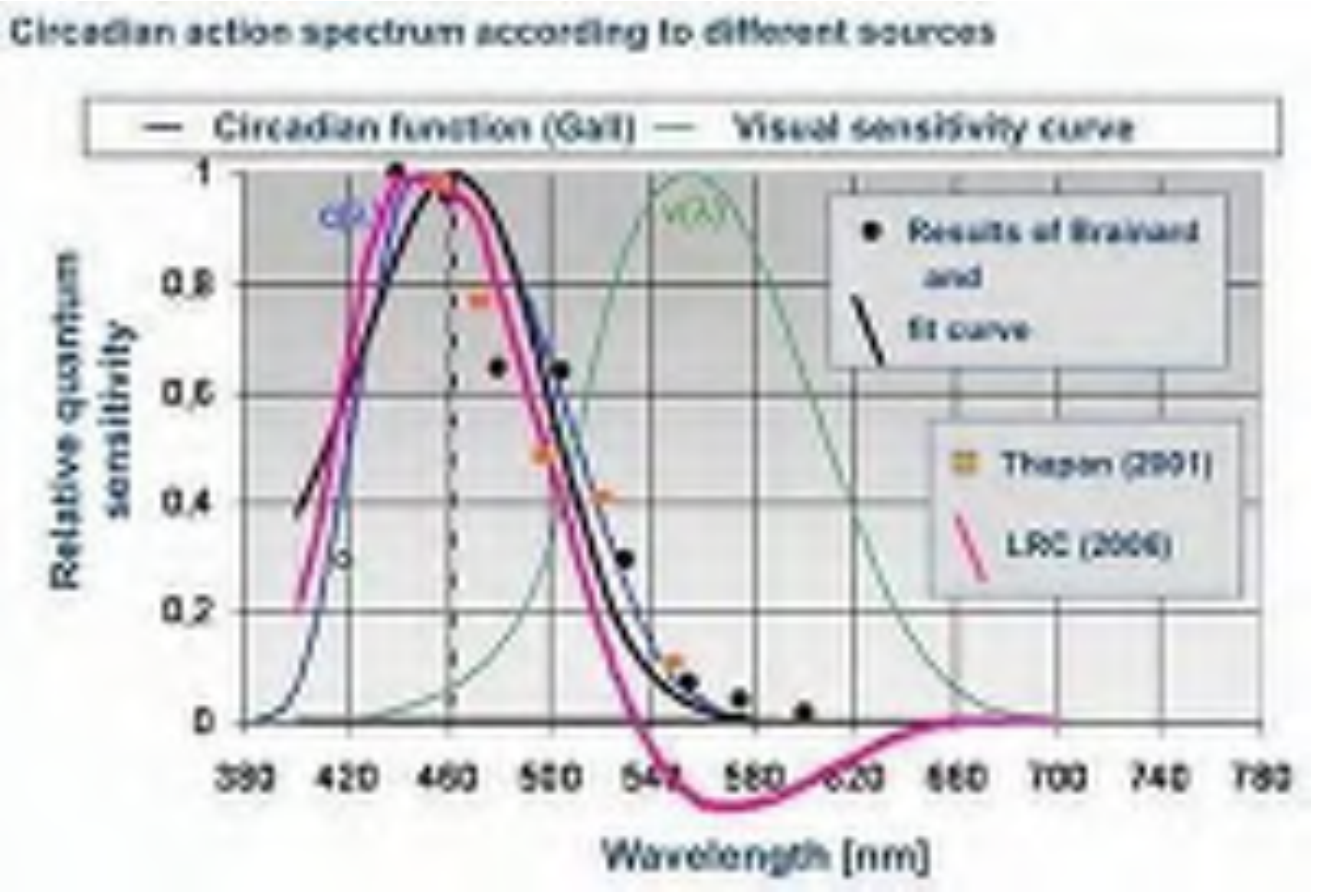


Light and Health

- Light Impacts the human
  - Melanopsin Response
    - Peaks around 480 nm
    - Impacts circadian rhythms, alertness
    - Sleeping etc.
  - Same in all mammals

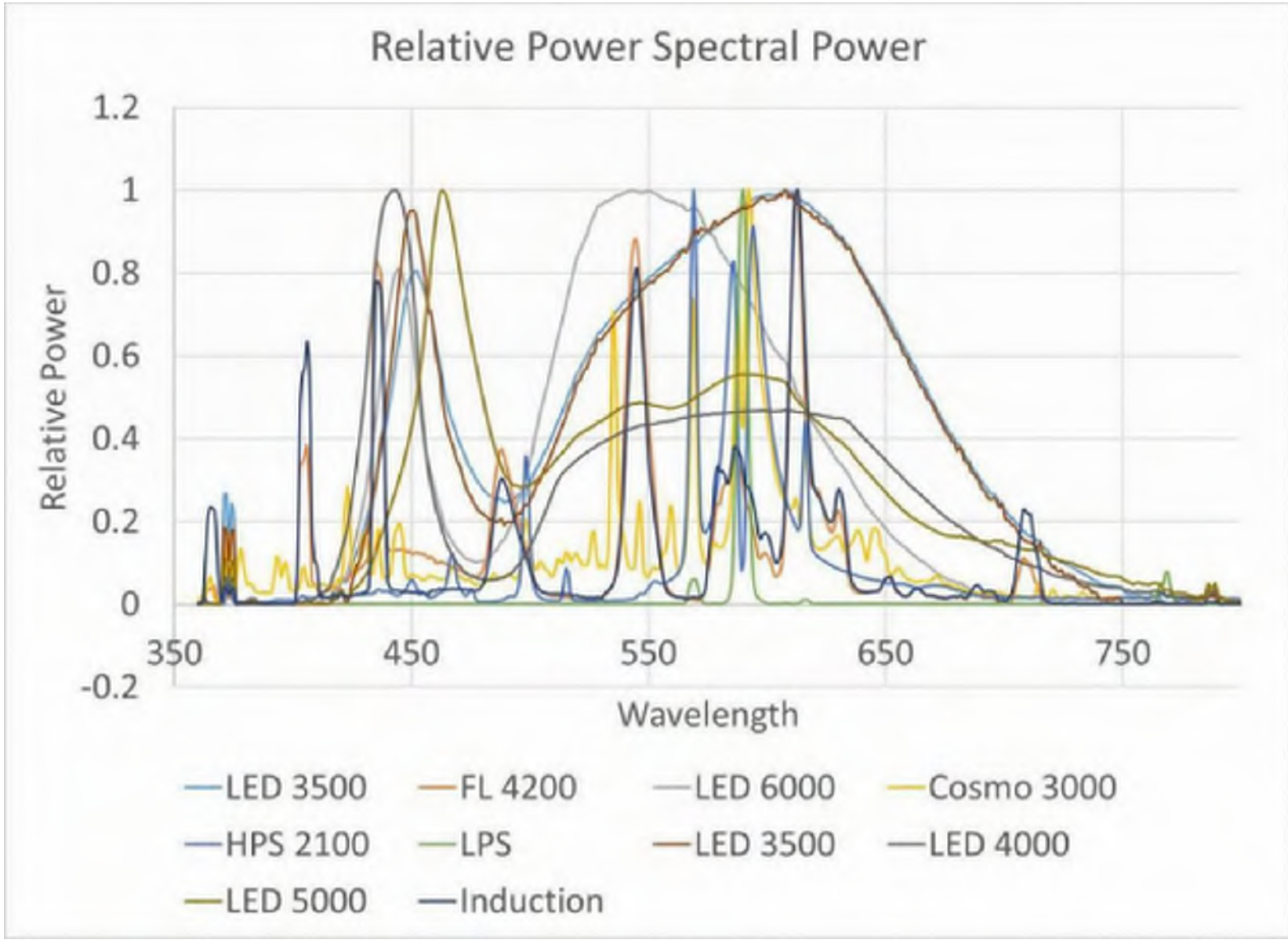
- Interesting – Circadian Response
  - Light can keep you awake and alert
  - Is that good or bad for a driver?

Response to Spectral Content



Lighting Application for Non-Visual Effects of Light
Andreas Wojtysiak, Alfred Wacker and Dieter Lang, Osram AG

Comparison of SPDs



AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights

Foi immediate release: Jun 14, 2016

AMA Report

- AMA has stated –
  - Use 3000k
    - Reduces Sky Glow
    - Reduces impact in Humans
    - Reduces impact on Migratory Animals
    - Reduces impact on Sea Turtles
    - Etc.
- Is it an unbiased recommendation?

Limitations in the Melanopic Research

- Performed at extremely high lighting levels as compared to roadways
- So what is the impact at street lighting levels?
  - The ratio would be the same
  - But does the magnitude make a difference?

Impacts (Dosage and Duration)

PNNL data

Combined subset* of readings taken by Naomi Miller, Bruce Kinzey, Rita Koltai, Terry McGowan, Derry Berrigan (*note: not all participants provided readings in every category; not all categories listed)	Reading (Lux)
Vert illuminance from window facing street light, if avail., interior lights off	
-- blinds open	≤0.1
-- blinds closed	0
Vert illuminance from window not facing street light	0-1
Kitchen	30-340
TV from 10 feet away, room light off	0-10
TV from 10 feet away, room light on	2-30
Phone/tablet at reading distance, other room lighting off	0-5
Phone/tablet at reading distance, room lighting on	15-45
Bedside lamp(s) reflecting on magazine/book page	35-350
Max horizontal illuminance at street light nadir - no vegetation interference	5-10
Max horizontal illuminance at street light nadir - some interference	0-5

Health Impacts and Subjective Color

Table 2: Predicted Human Nocturnal Melatonin Suppression from Incandescent and Daylight Illumination [46] of Varying Corneal Illuminances and Durations, Based on Rea et al. [37]

Incandescent

Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	0%
1	0%	1%	1%
3	1%	2%	2%
10	3%	5%	5%
30	8%	11%	13%
100	19%	25%	27%
300	35%	42%	45%
1000	54%	59%	60%
3000	65%	68%	69%

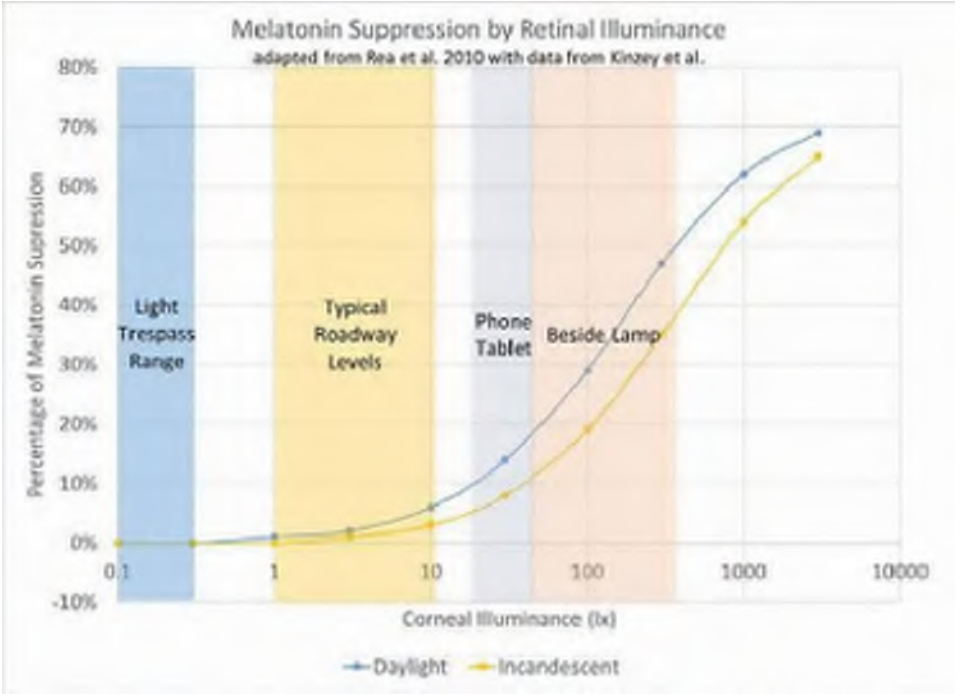
Daylight

Illuminance (lx)	Melatonin suppression after 30 minutes	Melatonin suppression after 60 minutes	Melatonin suppression after 90 minutes
0.1	0%	0%	0%
0.3	0%	0%	1%
1	1%	1%	1%
3	2%	3%	4%
10	6%	9%	10%
30	14%	19%	20%
100	29%	36%	39%
300	47%	53%	55%
1000	62%	65%	66%
3000	69%	71%	71%

Marianna Figueiro, et al, 2006 research reported in the Journal of Carcinogenesis

Potential Impact on Human Health

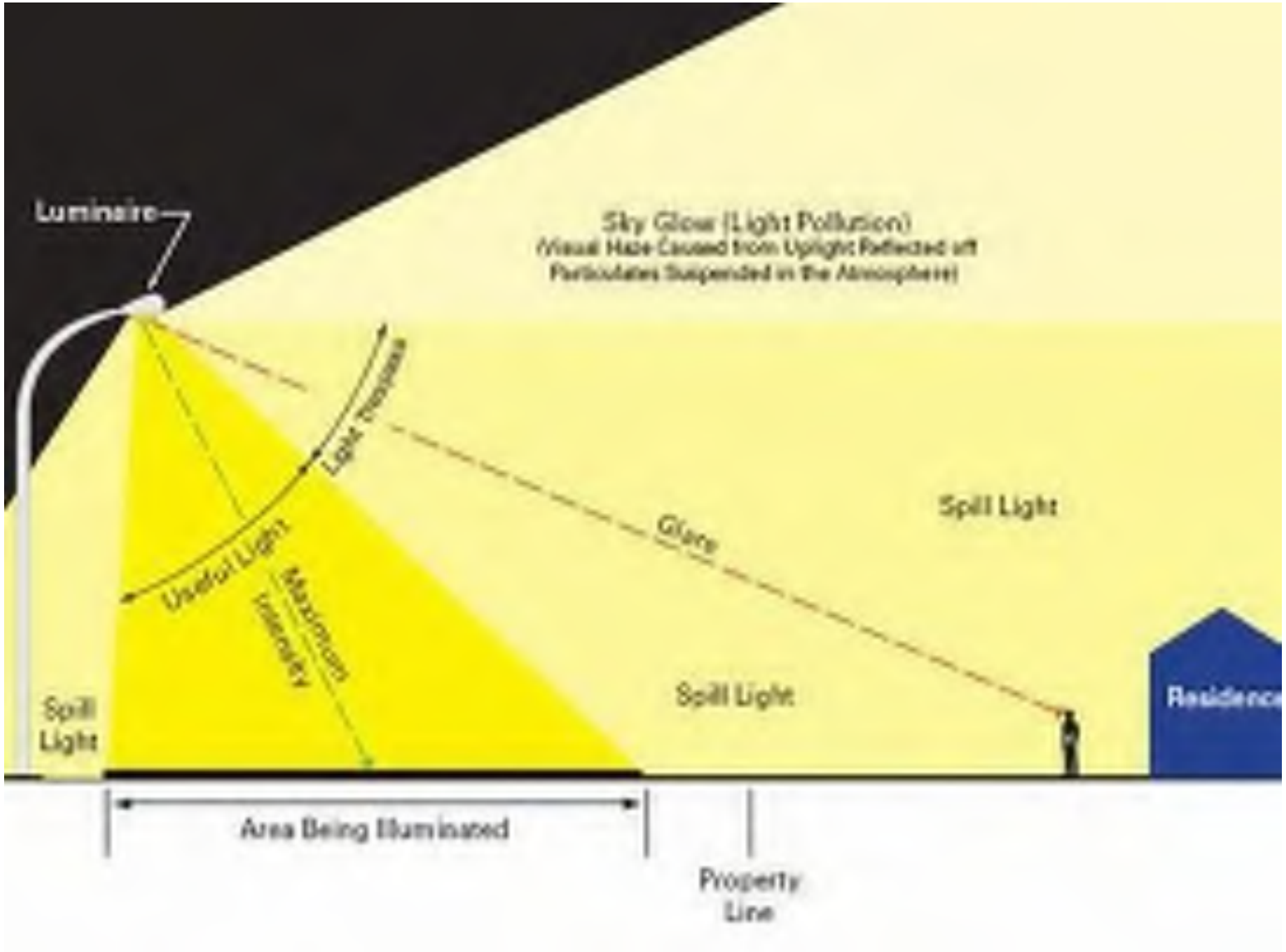
- Preliminary there may be an impact
  - Correlation but no causation
- Roadway Lighting Levels are below thresholds
  - Research is on-going



On-going Project

- DOE Sponsored project considering all roadway users
  - Pedestrians
  - Sleepers
  - Drivers
- Looking at the impact of lighting under 5 different light sources (5000K, 4000K 3000K, 2200K, HPS) as compared to no lighting.
- Next Summer

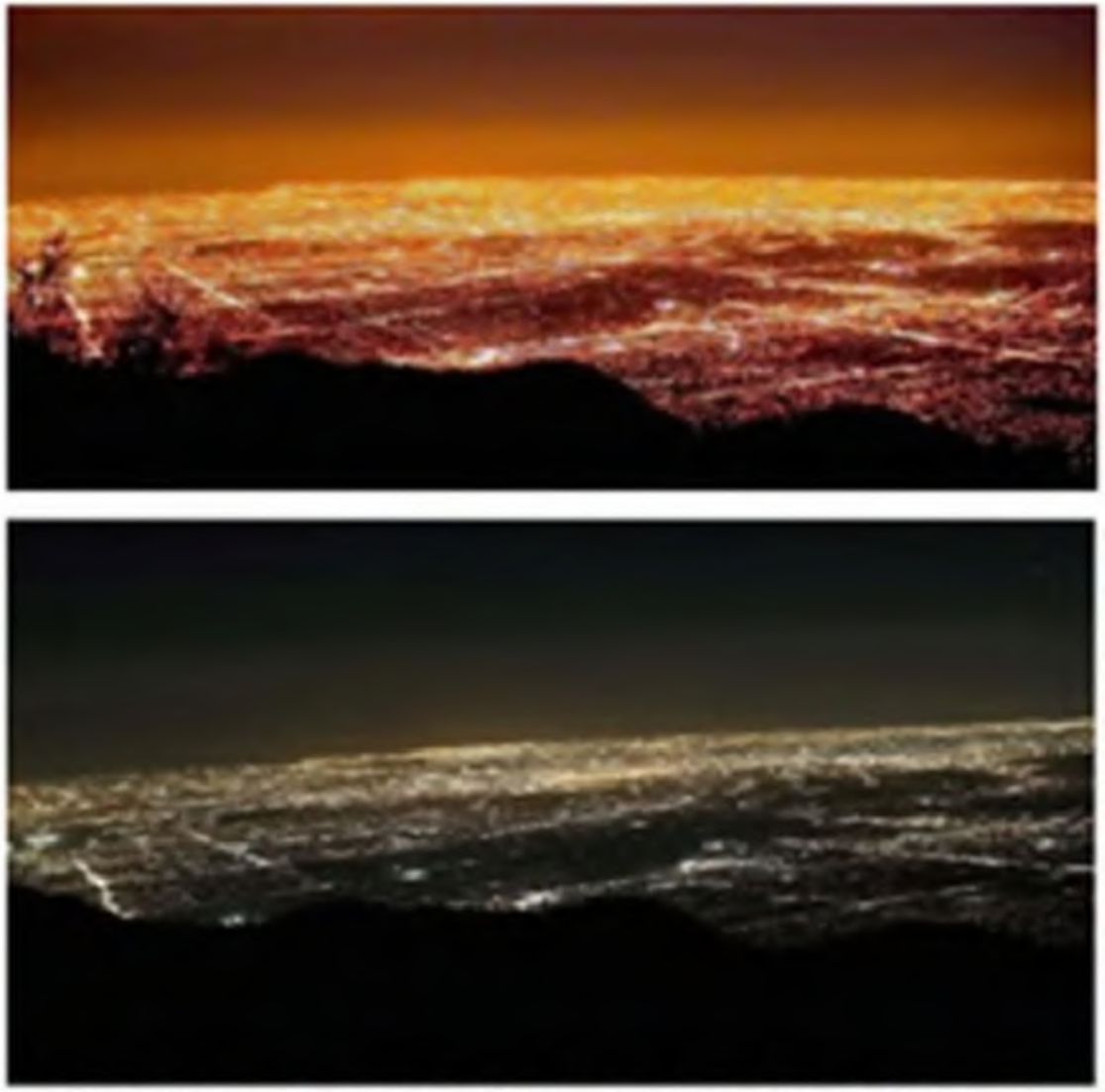
Light Trespass



Sky Glow

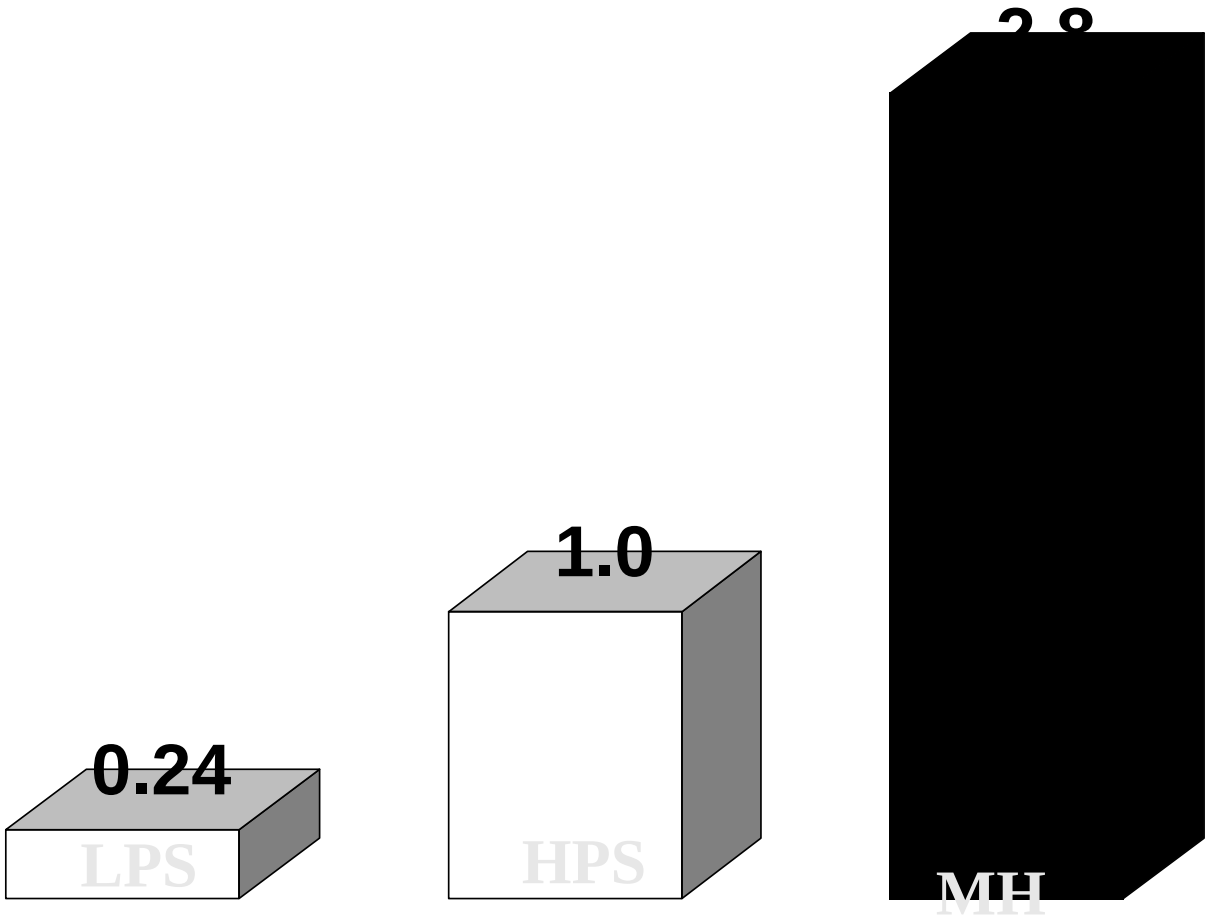
- Sky Glow
  - Blue Light Scatters more than amber light
- Rayleigh Scattering
  - Molecular Scattering – Molecule are about the same size as the wavelength for blue light
  - Blue Light Scatters more
  - Low angle blue content light is particularly bad
- Mie Scattering
  - Aerosol Scattering – Particles are much bigger than wavelength
  - Not Spectrally Selective

Sky Glow



View from Mt Wilson of light pollution in Los Angeles, before and after LED deployment

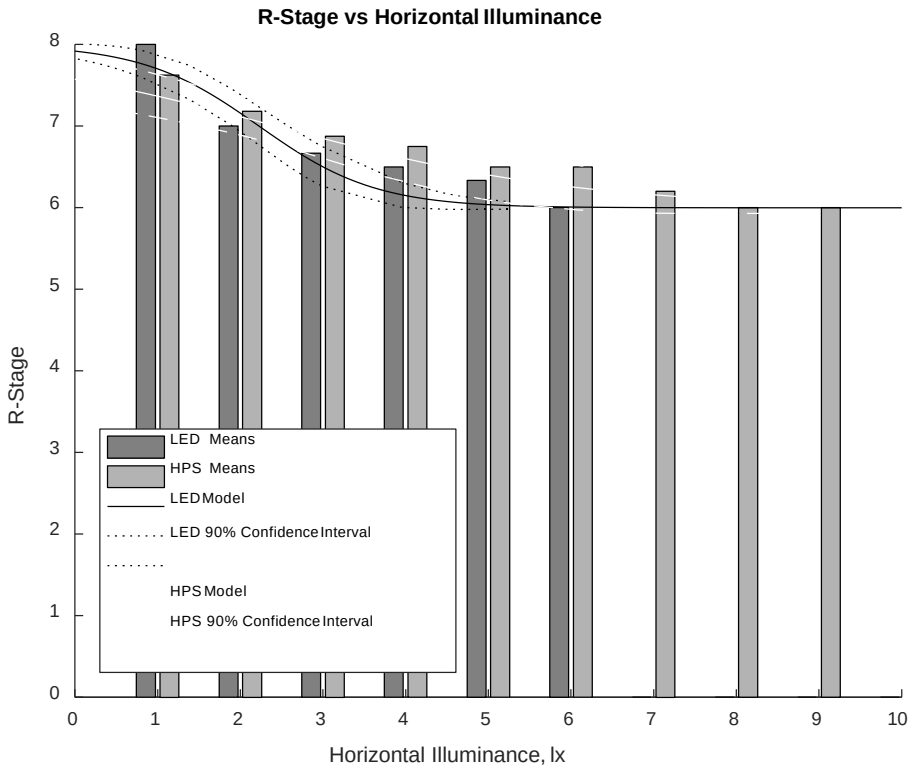
Relative Sky Glow

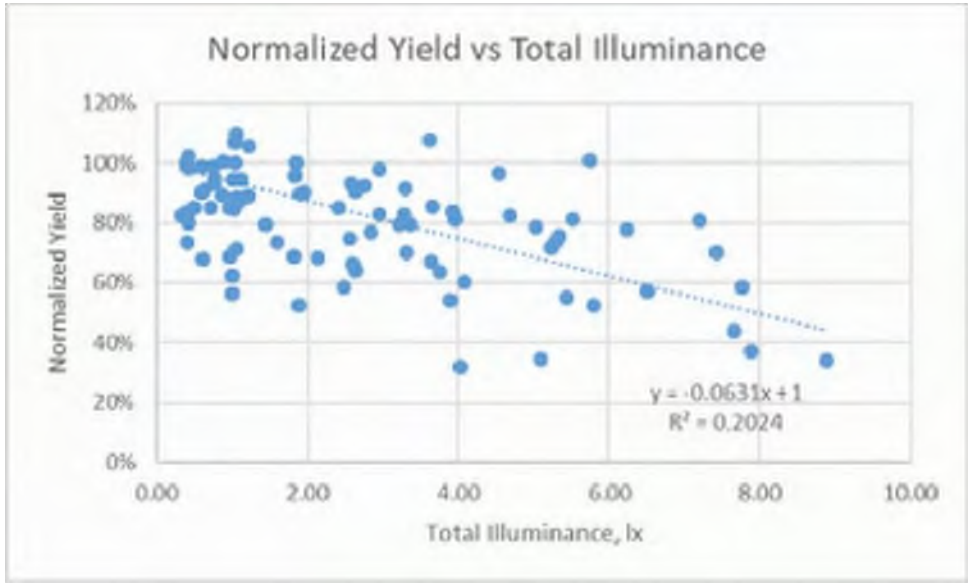


From CORM 2008, Luginbuhl, Keith & Knox

Impact on Soybean Growth

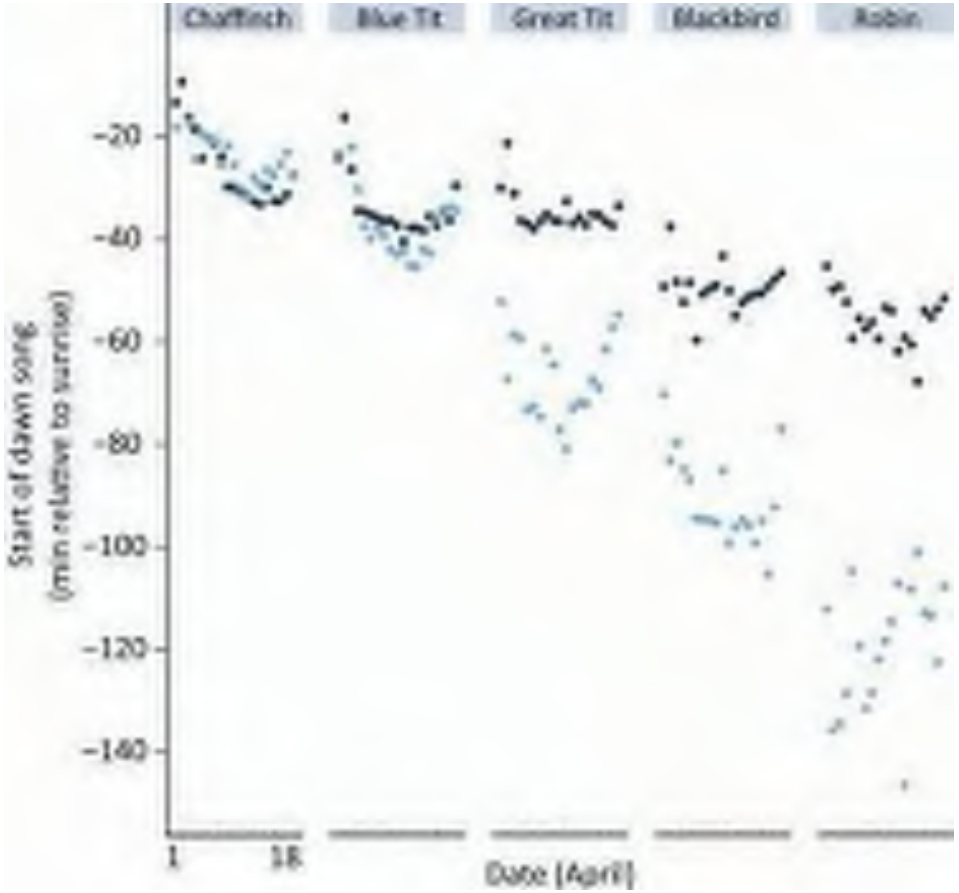
Yield and Moisture





Maximum Values	
Illuminance	Maximum, lx
Horizontal	2.2
Vertical	1.8

Birds, Bass, Bears and Bees

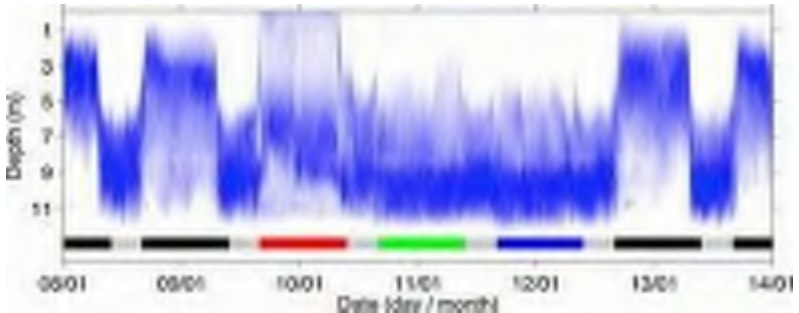


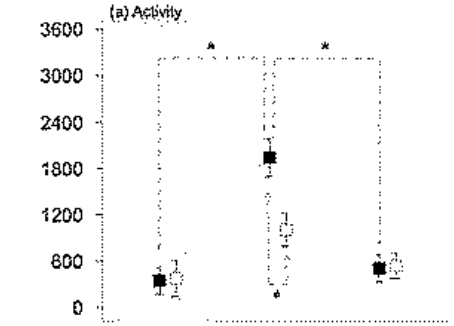
Lighting influences anything with eyes that are sensitive to visible light

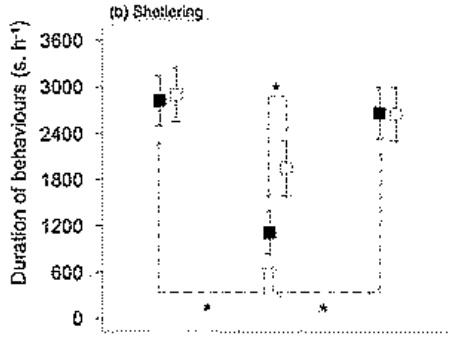
- Eg. Robin Song will start as much as 2 hours early in areas adjacent to Roadways (Kempenaers et al, 2010)

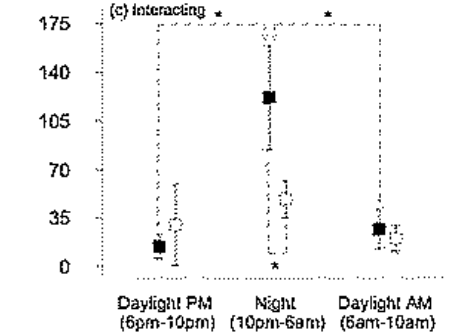
We are changing the Ecology

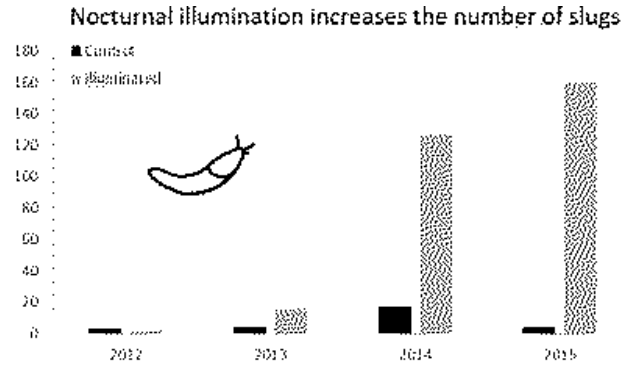
- Crayfish hide and do not interact as significantly under roadway lighting
- Bats now hunt under light fixtures
- Slugs are on the rise
- Salmon change their swimming depth





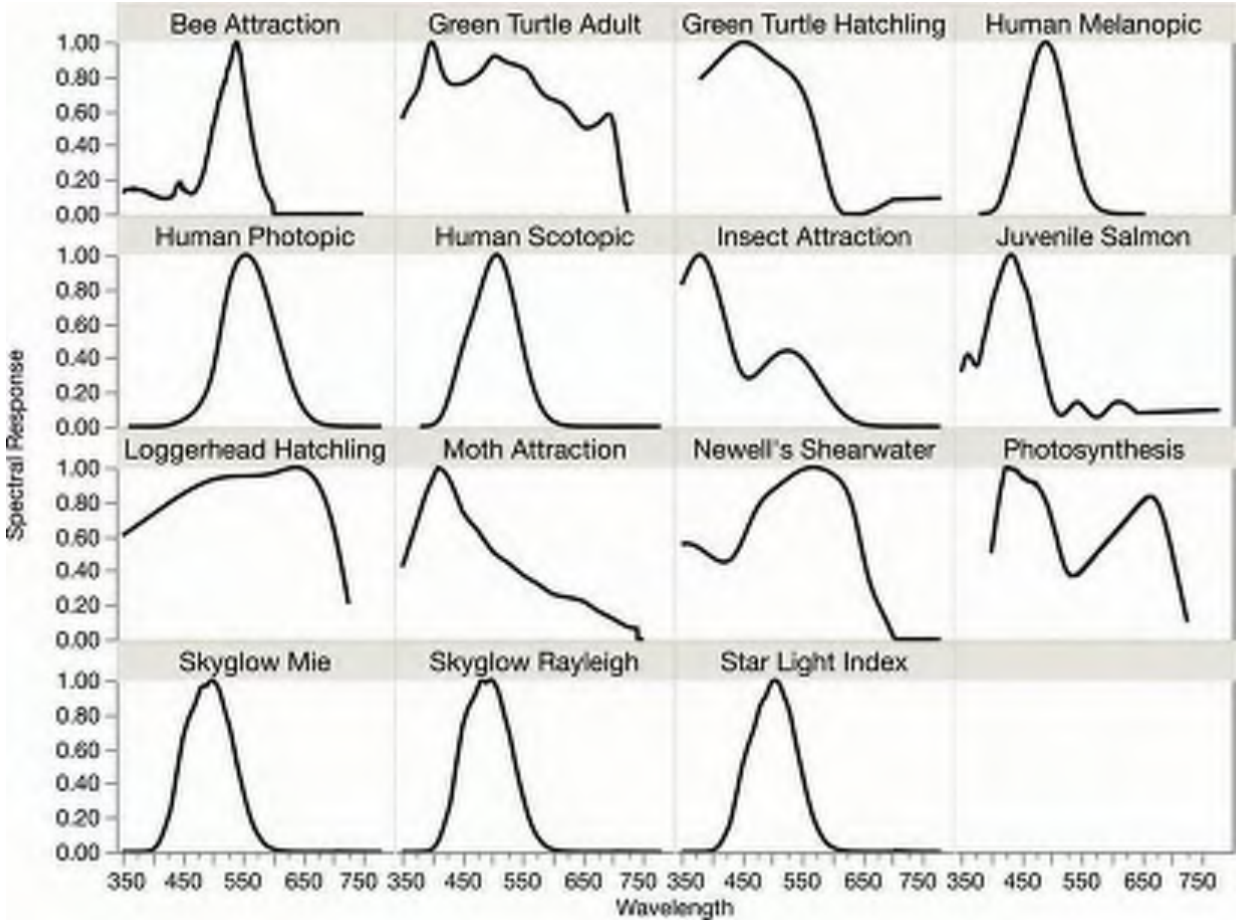


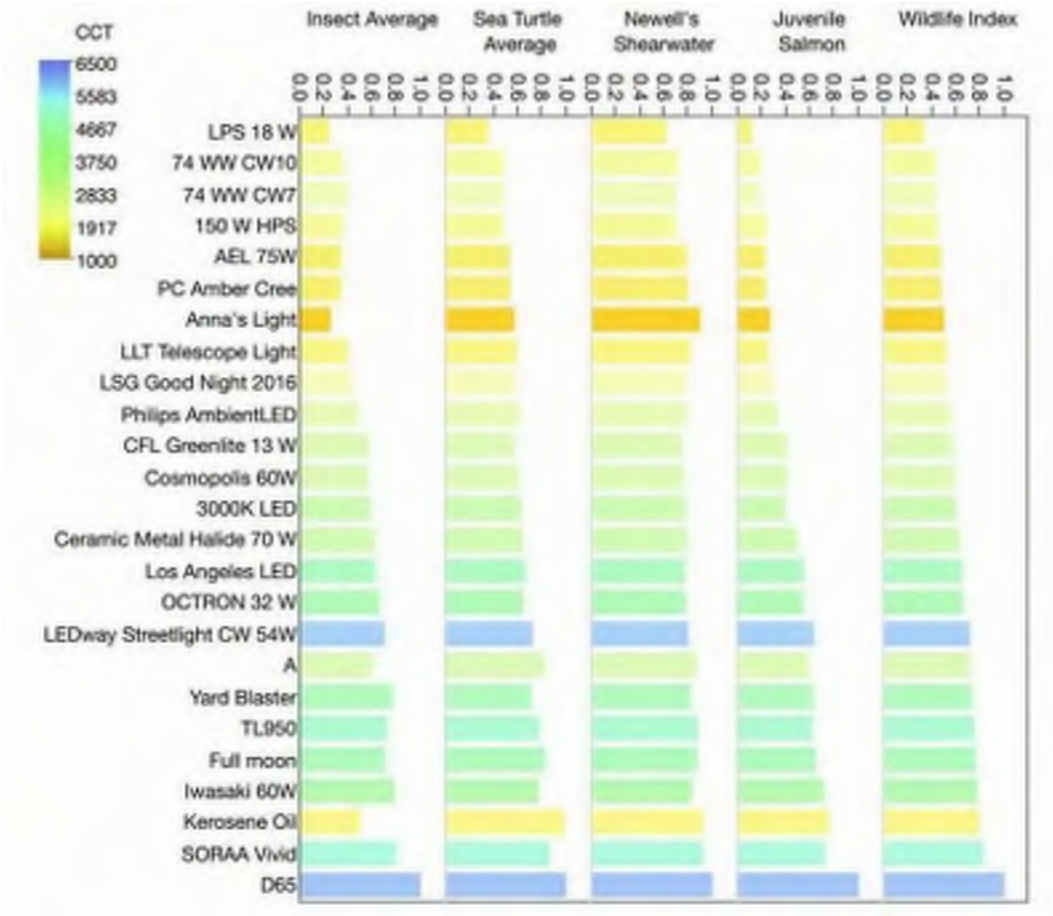




Bridges

Actinic Curves (Longcore et al)





$$E_{eff} = \int E_\lambda S_i(\lambda)\, d\lambda$$

$$E_{lux} = \frac{\int E_\lambda S_i(\lambda)\, d\lambda}{\int E_\lambda V(\lambda)\, d\lambda}$$

The approach to dealing with the drug varies:

Issue	Solution
Roadway User Safety	Depends
Energy Consumption	Lower Light Levels and use Solid State
Public Perception and Acceptance	Depends
Environmental Impact	Reduce or Remove Lighting
Impact on Surrounding Areas	Control Lighting, Reduce or Remove Lighting
Impact on user health	Use Warmer Colors / Reduce Lighting

New Standards for Safety

- We are getting much closer to understanding the issues of a safe roadway:
  - Trying to control driver behavior and the components of the crash trifecta
  - Likely not a broad brush approach to lighting
  - Lighting requirements may be segment based
    - Lower levels on tangents
    - Higher levels at conflict points

- Issues for agencies:
  - Huge inventory?
  - Changing needs?

Evolution of Roadway Lighting Design

Move from This

To This

Our approach is to slather light around the roadway

We now need to use fine brush strokes to put light when and where we need it

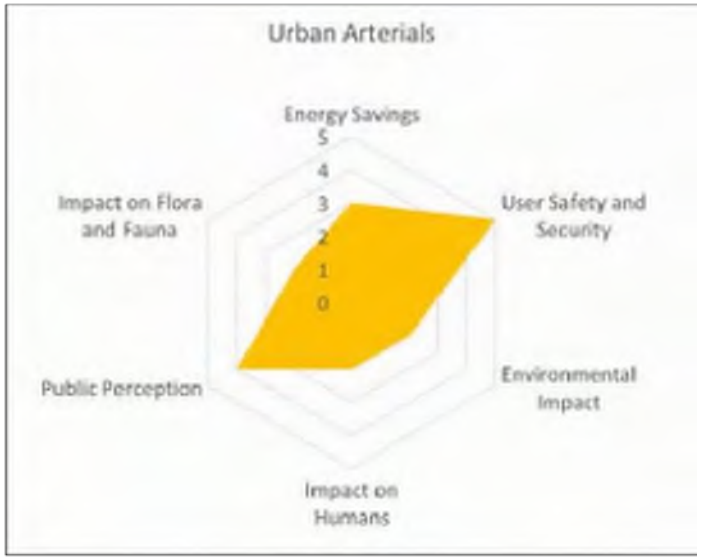
Looking for “Just right” in Lighting

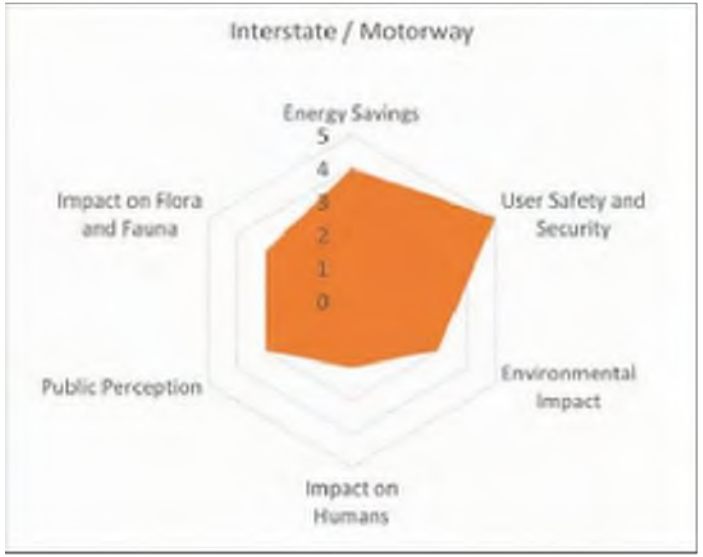
- So what is “Just Right”?
- We judge this by a variety of Dimensions
  - Roadway User Safety
  - Energy Consumption
  - Public Perception and Acceptance
  - Environmental Impact
  - Impact on Surrounding Areas
  - Impact on user health
- Our current approach is Adaptive Lighting

Light Source Selection Criteria

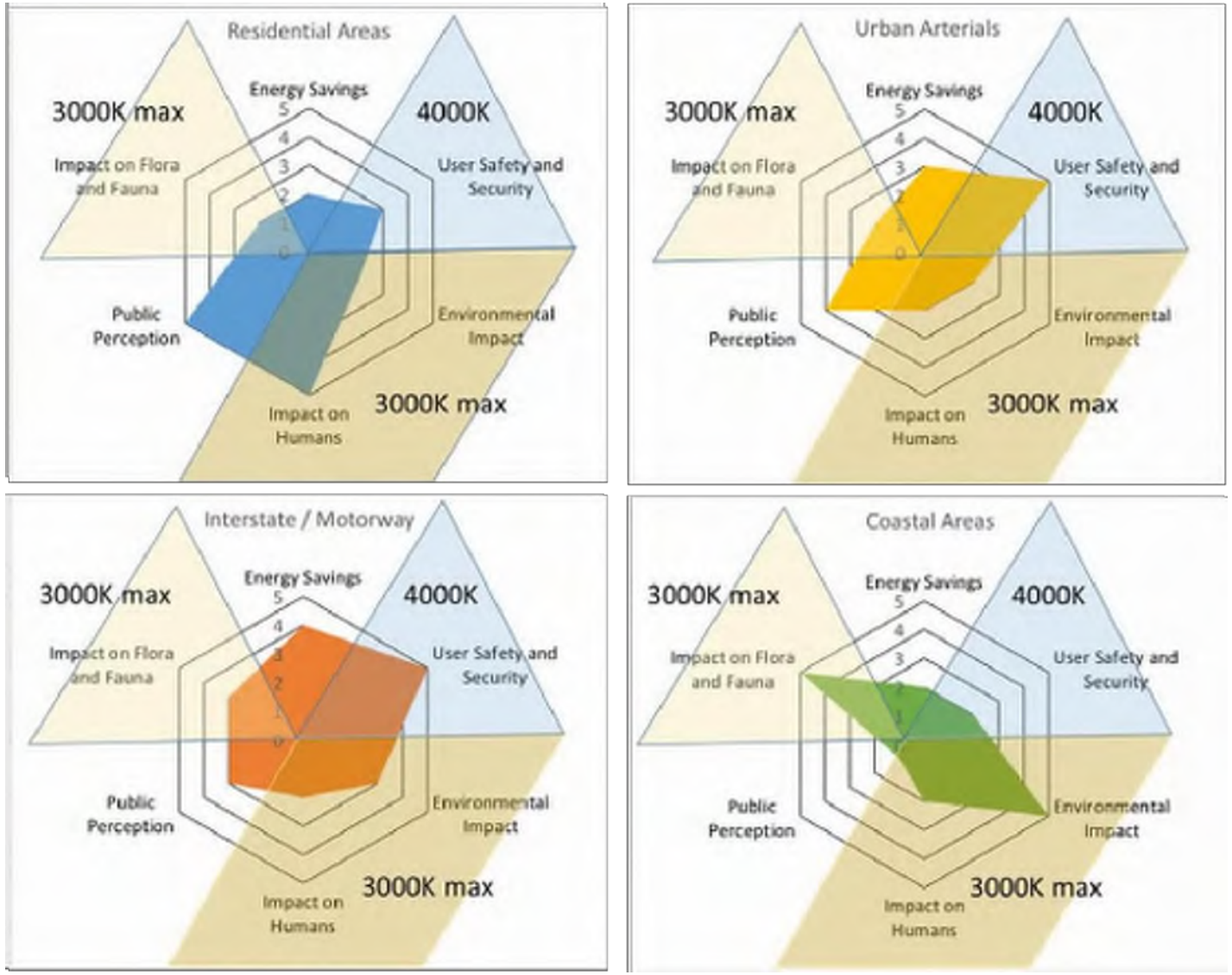
- Each of lighting valuation criteria can be weighted to provide guidance on how to approach the light source and lighting level selection.

Weighing the Impacts





Weighing the Impacts



Today's Panelists

- Paul Lutkevich, paul.lutkevich@wsp.com
- Don McLean, don@dmdeng.com
- Ron Gibbons, rgibbons@VTTI.VT.edu
- Rajaram Bhagavathula, RBhagavathula@vtti.vt.edu

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