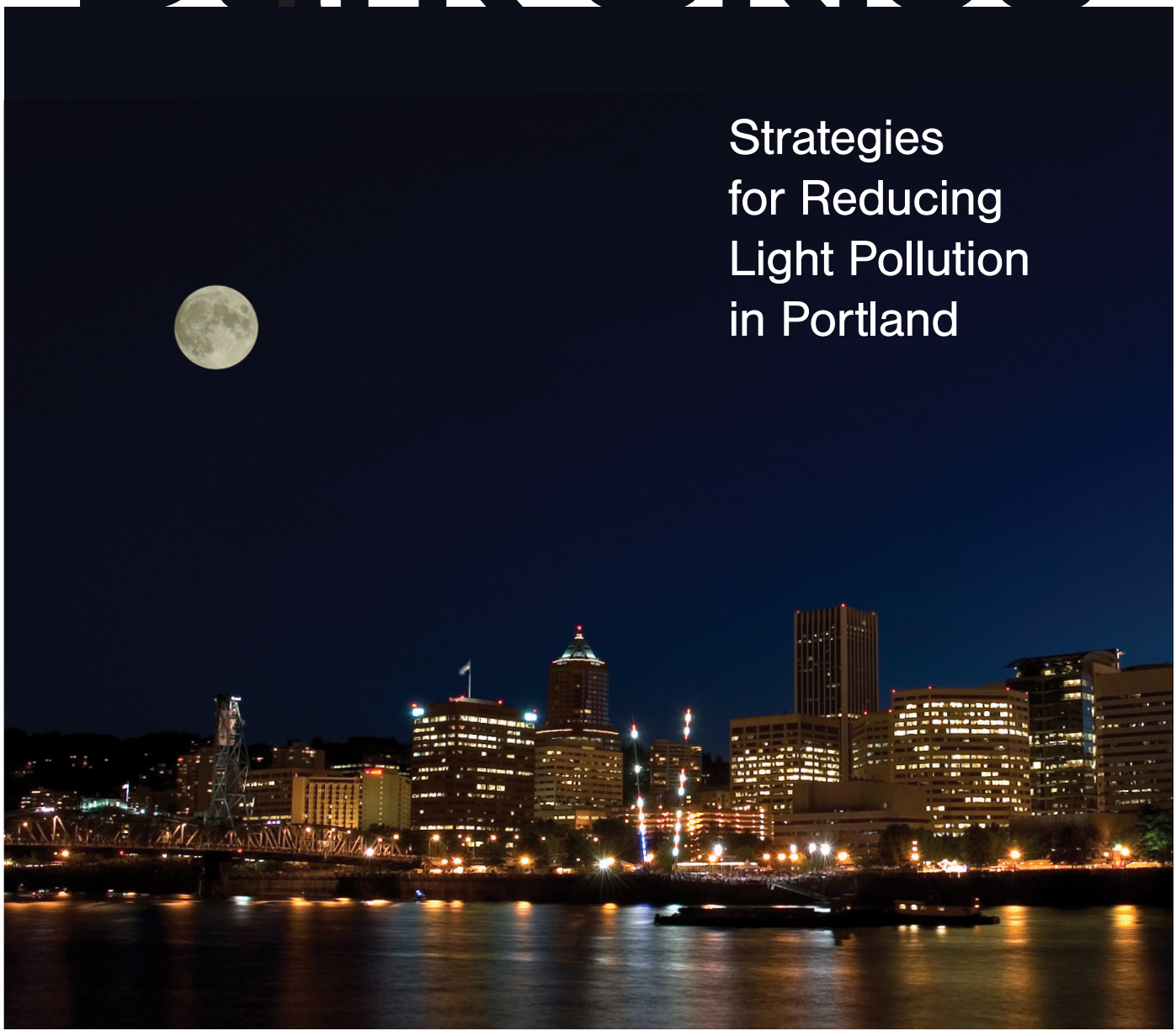
Dark Skies

Strategies for Reducing Light Pollution in Portland



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City of Portland, Oregon

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Section I: Introduction

Project Summary

The proliferation of excessive artificial light produced by a variety of sources of outdoor lighting has been shown to affect human health in the form of impaired sleep quantity and quality as well as impacts to the human eye. Excessive or overly bright outdoor light is also known to cause glare and reduce the safety of pedestrians and drivers at night. A growing body of research also demonstrates the widespread and deleterious impacts on ecosystems, including predator-prey behavior as well as foraging, mating, migrating, pollinating, and blooming habits of plants and animals including birds, mammals, amphibians, fish, and invertebrates.

In addition, with the global trend toward urbanization, an excess of light pollution prevents most of Earth's population from having the opportunity to observe the stars. According to a 2016 study on artificial night sky brightness published in the periodical *Science Advances*, light pollution has caused roughly one-third of the world, including nearly 80% of North Americans, to be unable to see the Milky Way—the band of stars the make up our galaxy. *(Falchi, et. al., June 2016; Science Advances)*

While good intentional lighting is an essential element of our urban landscape, the proliferation of excessive artificial light produced by poorly designed and poorly shielded outdoor fixtures drives these negative consequences. The good news is the problems can be addressed, as demonstrated by other cities and counties across Oregon and North America that have adopted clear regulatory guidance and outreach efforts to reduce light pollution in their communities (see Local and National Approaches; page 17). Today Portland has a relatively moderate light pollution problem relative to other North American cities, but without intentional action, light pollution will continue to proliferate. This report lays a foundation for how Portland can take the next steps in preventing and reducing light pollution.

This issue of light pollution was recognized by the City in 2003 when developing the Bird Agenda to frame goals and strategies for fulfilling the City's responsibility as a U.S Fish and Wildlife Service (USFWS) Urban Bird Treaty City. The issue was raised again in 2011 when the City collaborated with Portland Audubon and the USFWS to develop a *Resource Guide for Bird-Friendly Building Design*, which identifies artificial light as a hazard for humans and wildlife. It was further acknowledged when City Council adopted Resolution 37034 in October 2013, which directed the City to advance bird-friendly building and lighting design and management practices through City plans, policies and programs, including the Green Building Policy, Comprehensive Plan and other future planning efforts.

In July 2019, City Council allocated funding to the Bureau of Planning and Sustainability to research current best practices for reducing light pollution and develop recommendations for implementing the best practices citywide within the next five years. The direction for the project stems from action item EN13 of the adopted Central City 2035 plan, which directs the Bureau of Planning and Sustainability to "initiate a Dark Skies project and implement best practices to reduce the impacts of nighttime lighting and sky glare on human health and well-being, wildlife and energy consumption." The City Council's direction also helps meet goals and policies in Portland's recently adopted Comprehensive Plan (2018) and the Climate Action Plan (2015).

The goals of this project are to make recommendations to reduce the amount of poorly aimed, poorly shielded and overly bright light in our community, reduce negative impacts on human and ecosystem health and safety, reduce energy waste, and increase our ability to see the night sky. Meeting these goals is achievable and is intended to complement and support other City goals to improve lighting where needed to make the City safer, and to ensure lighting approaches are equitable across the

community. It is possible to have a vibrant, safe, pleasant city at night that has well-designed lighting that keeps light on the ground where it is needed without directing light skyward where it is not.

Process Overview

Phase 1: Research. The first phase of this project—Dark Skies: Strategies for Reducing Light Pollution in Portland—took place between July and December 2019 and was focused on fact finding. During this phase, staff conducted research into:

- The causes and implications of excessive light at night;
- The recommendations of experts for best practices to reduce excessive artificial light at night;
- Information on how other cities and counties have addressed the issues; and
- Existing City policy, practice and regulation related to reducing light pollution.

Outreach during phase 1 included meetings with stakeholders and bird safe experts from Portland Audubon and interviewing city staff in five City bureaus to obtain feedback on the scope of the project and get a deeper understanding of existing City policy and practice around exterior lighting and design.

Phase 2: Developing the report and recommendations. The second phase—January through early March 2020—was focused on developing recommendations and writing the first draft of the report. During this time project staff met with BPS equity and public outreach staff and began developing a public outreach strategy including steps to evaluate the equity implications of the draft recommendations.

Phase 3: Early review. The third phase took place between late March and the end of June. An early draft of the report was sent to over 20 internal and external stakeholders and experts who had been consulted or interviewed regarding the scope of the project. Internal reviewers include city staff from the Portland Bureau of Transportation, Portland Parks and Recreation, Bureau of Development Services, and the Office of Community and Civic Life. External reviewers include lighting experts from Portland Audubon, Rose City Astronomers, the International Dark-Sky Association, and lighting engineers from the Pacific Northwest National Laboratory. Equity and outreach staff in PBOT and BPS were also provided the opportunity to review and comment on the internal draft. In all, BPS received written comments on the report and recommendations from seven organizations. Project staff also convened two virtual meetings with the reviewers to discuss the comments and obtain additional feedback. At the end of Phase 3 the Internal Review draft was revised to be the Public Review draft.

Phase 4: Public review and outreach. The public review draft will be available for review and comment on the BPS website for three weeks between July 13, 2020 and July 31, 2020. Public outreach to publicize the opportunity to comment on the report and recommendations will include notification via the BPS e-news, social media postings and other forms of electronic outreach. Due to the COVID-19 crisis, in person open houses will not be possible. Staff have developed a survey, which will be available on the website, to gauge public support and obtain feedback.

In addition to encouraging public comments on the report and recommendations, staff is also convening two facilitated equity focus groups sessions to discuss and assess the potential benefits and burdens of the recommendations. The focus group events will be conducted virtually via Zoom.

Feedback from the equity focus groups and other public outreach will inform revisions to the report and recommendations.

City Council review and resolution

City Council consideration of the *Dark Skies—Strategies for Reducing Light Pollution in Portland* report and recommendations will take place on September 17, 2020 starting at 2:00 pm time certain. Staff will bring the report before council for a public hearing, discussion and vote. More information on the hearing will be available closer to the date.

At the same time staff will also bring a resolution to City Council declaring September 19, 2020 as Lights Out Portland Night. The resolution will declare support for the Portland Audubon's public outreach campaign encouraging people to "Take the Pledge to Go Lights Out" by turning off or shielding unnecessary external lighting from dusk until dawn from August 25 through November 15, and March 15 through June 7.

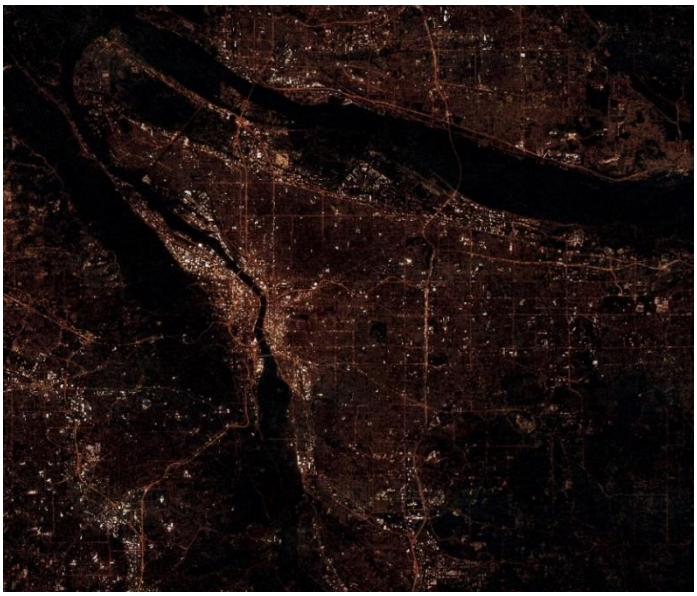
Section II: Background

What is light pollution?

The International Dark-Sky Association (IDA) defines light pollution as "the inappropriate or excessive use of artificial light." Not all artificial outdoor light at night causes light pollution. Light pollution is caused by outdoor lighting that is unshielded, overly bright or poorly directed. It is also be caused by indoor lighting that spills out of buildings, especially from tall buildings. The components of light pollution include:

- **Glare** – excessive brightness that causes visual discomfort or a reduction in visibility and can present a public safety hazard. Glare is created by light that shines into the observer's eyes. The closer it is to the observer's direction of gaze, the greater the reduction in visibility and comfort.
- **Skyglow** – brightening of the night sky over inhabited areas. Sky glow is the bright halo that appears over urban areas at night, a product of light being scattered by water droplets or particles in the air.
- **Light trespass** – light falling where it is not intended or needed. Light trespass occurs when artificial light from, for instance, a floodlight or streetlight spills onto another property, lighting an area that would otherwise be dark.
- **Over-illumination** –the use of artificial light well beyond what is required for a specific activity, such using more light for a longer period of time than is necessary in a parking lot.
- **Color** – blue vs warmer color quality. *(Chepesiuk, 2009; Environmental Health Perspectives)*

In 2016, scientists estimated that 99 percent of the population of the continental United States and Europe experience some amount of light pollution. *(Falchi, et al., June 2016; Science Advances)*



Light pollution causes ecological consequences, poses public health issues, and wastes energy and money. "Light pollution needs to be addressed because, even though it can be instantly mitigated..., its consequences cannot (for example, loss of biodiversity and culture)." (*Falchi, et. al., June 2016; Science Advances)* Lighting is an important element of our urban areas at night to allow for safety and circulation, to allow for extended activity beyond daylight hours, and to help create a sense of place. But we need to rethink the way we light our nights, and the use of warmer, shielded LED outdoor luminaires delivering tailored light levels for the benefit of dark skies, energy cost, and safety considerations.

There are several types of lighting in Portland that can contribute to light pollution:

- ⇨ **Street lighting** - lights installed by the City for the purpose of lighting the right-of-way (such as streets, sidewalks, and multi-use paths);
- ⇨ **Area Lighting** – publicly- or privately-owned exterior lighting systems installed to light a general area (such as a parking lot or park area);
- ⇨ **Building lighting** - interior and exterior lights affixed to buildings; and
- ⇨ **Outdoor lighting** – all exterior lighting.

Light pollution has documented negative impacts:

Studies are indicating that excessive artificial light endangers ecosystems by harming animals whose life cycles depend on cycles of light and dark. Excessive light at night has the potential of harming humans by altering the biochemical rhythms that normally ebb and flow with natural light levels. And, as described in National Geographic magazine "in a primal sense, we've lost our connection to nighttime skies, the tapestries into which our ancestors wove their star-studded stories, timed the planting and harvesting of crops, and deduced the physical laws governing the cosmos." *(Drake, 2019; National Geographic)*

The following briefly describes research and findings on the impacts from light pollution:

- Human health and safety

Excessively lit outdoor storage area.
Photo courtesy of Mary Coolidge, Portland Audubon

Growing evidence suggests that exposure to artificial light at night (ALAN) has unintended health consequences. Multiple studies have linked ALAN with suppressed melatonin, a key hormone in circadian regulation, and various diseases, including cancer, obesity, cardiovascular disease, and depression. Additionally, there is some indication that outdoor ALAN could, directly or indirectly, play a role in negative health outcomes. Travis Longcore, an Associate Adjunct Professor at the UCLA Institute of Environment and Sustainability, suggests that "the effect of outdoor lighting on indoor exposure could be either direct or indirect. In the direct impact scenario, the artificial light from outside reaches people inside at night at levels that affect production of hormones. In an indirect impact it would disturb people inside, who then turn on lights and expose themselves to more light." *(Chepesiuk, 2009; Environmental Health Perspectives)*.

Several recent studies have shown a connection between outdoor ALAN and risks to human health, specifically obesity and impacts on sleep quality and quantity. A 2016 epidemiological study of over 8,000 Korean adults revealed a significant association between high outdoor ALAN and obesity. *(Koo, et. al., March 2019; Chronobiology International)* A 2016 Stanford University observational study looked at the sleep habits of over 15,000 people over an eight-year period and overlaid the observations with information on outdoor ALAN from the Defense Meteorological Satellite Program. The study found that living in areas with greater outdoor ALAN was associated with delayed bedtime and wake-up time, shorter sleep duration, increased daytime sleepiness, increased dissatisfaction with sleep quantity and quality, and the likelihood of having symptoms associated with circadian rhythm disorder. The study adjusted for the effects of population density, age, sex, occupation, living with children, bright bedroom, sleeping with light on, noise level in bedroom, watching TV in bed, and type of bed. *(Ohayon and Milesi, June 2016; Sleep)* And, a 2019 study looked at outdoor ALAN in relation to short and long sleep duration in more than 300,000 middle-to-older aged men and women participating in the NIH-AARP Diet and Health Study. The investigation also included whether education and neighborhood poverty affect the relationship between outdoor ALAN and sleep duration. The study found that men and women living in areas with higher outdoor ALAN were more likely to report short sleep, and this finding appeared to be stronger among people living in neighborhoods with higher poverty levels. *(Xiao, et. al., January 2020; Environmental Research)* This

last study raises equity questions as well. For example, lower income populations may have fewer resources available to purchase window coverings that adequately block the light from nearby streetlights, vehicles, businesses, or other residential developments.

Additionally, there are concerns about the effects of blue-rich white light in particular. Not all colors of light have the same effect. Blue wavelengths—which are beneficial during daylight hours because they boost attention, reaction times, and mood—seem to be the most disruptive at night. Studies show that exposure to bright light at night suppresses melatonin and shorter wavelength blue-rich white light is most effective at melatonin suppression. According to Harvard sleep researchers, blue light suppresses melatonin for about twice as long as green light and shifts circadian rhythms by twice as much. *(2012; Harvard Health Publishing—Harvard Medical School)*

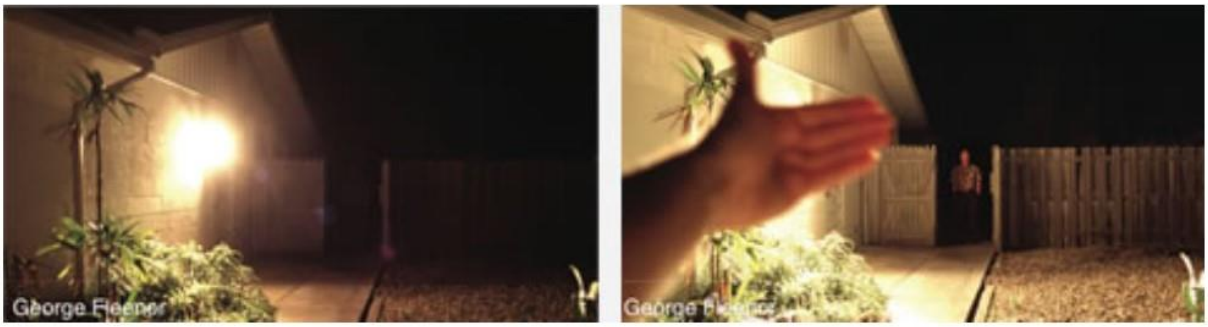
As mentioned above, some studies suggest a link between exposure to ALAN to some types of cancer, diabetes, heart disease, and obesity. For example, a 2018 population based multicase-control study of over 5,000 people in Spain found an association between exposure to outdoor ALAN, particularly blue-rich white light, and breast and prostate cancer. *(Garcia-Saenz, et. al., April 2018; Environmental Health Perspectives)* Further research on the effects of outdoor ALAN is necessary as these studies are not sufficient to be considered conclusive. However, the concerns are pervasive enough that the American Medical Association has recognized the potential harmful health effects of blue-rich white light and recommends that communities exercise caution when it comes to outdoor area and street lighting.

There are also some indications that light pollution may increase the spread of disease. As reported in a 2019 article in the online newsletter CityLab, a recent University of South Florida study found that artificial light may increase the risk of vector-borne diseases such as the West Nile virus. The research shows that birds infected with the West Nile virus remain infectious longer when exposed to artificial light, specifically blue-rich white LED light, at night. “As with humans, blue light (with shorter wavelengths) suppresses the production of melatonin in birds, which can weaken their immune response to diseases...”. *(Poon, January 2019; CityLab)* West Nile virus is transmitted from birds to humans via mosquitos. Birds that remain infectious longer may result in as much as doubling the number of infected mosquitoes that can then go on to bite humans.

Well designed, adequate outdoor lighting is critical to community safety and security. Poorly lit areas face higher incidence of vehicular accidents and pedestrian deaths, as well as feelings of insecurity while walking at night. For example, we know from the 2018 Portland Bureau of Transportation (PBOT) Walking While Black focus group findings that poor lighting is a key characteristic of what makes the focus group participants feel unsafe walking in Portland. As a result of these findings, PBOT has incorporated specific policy and investment recommendations into the recently adopted citywide pedestrian plan (PedPDX), recommendations that emphasize lighting needs and infrastructure deficiencies in communities of color.

However, light pollution, especially glare, also pose safety and security risks particularly relating to pedestrian and driver safety and comfort levels, and crime. Overly bright and poorly designed lighting contributes to glare. High intensity lighting that causes glare can create unsafe driving conditions. According to the American Medical Association “discomfort and disability from intense, blue-rich LED lighting can decrease visual acuity and safety, resulting in concerns and creating a road hazard.” *(AMA press release; June 14, 2016)* And, according to the International Dark-Sky Association, “vision science shows that bright white lighting increases the likelihood of glare and interferes with the ability of the eye to adapt to low light levels, a particular concern for older people.” *(International Dark-Sky Association, May 2010; Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting)*

Good lighting design using light that is no brighter than necessary is key to reducing the negative effects of glare. A recent study by Monash University in Australia describes "consistent and layered



Too much and poorly shielded light causes glare which can obscure objects outside the area where the light is flooding.
Source: James Madison University, John C Wells Planetarium

lighting – where there are multiple light sources and where surfaces with different reflective values are taken into consideration – as the kind of lighting that can reduce the "floodlit effect", the sharp drop-off of light beyond the path, and the potential for glare and contrast to blind and disorientate." *(Kalms, May 2019; The Conversation)*

The study's findings also show that sites with higher light levels, and color temperatures of 4000 Kelvin (K) and above, are more likely to be perceived by women as unsafe due to the "floodlit effect". This set of conditions was observed on the Tilikum Crossing bridge and surroundings during a nighttime walk led by Leni Schwendinger (Arup International) and Jeff Schnabel (Portland State University) in October of 2018. Some areas on the bridge approach registered as high as 25 footcandles. These exceedingly brightly lit areas next to areas of darkness create both real and perceived safety hazards as well as problems with wayfinding.

Concerns that brighter outdoor lighting increases safety related to crime are not supported by data. Studies show crime increases and decreases with more light, and as such, existing data does not show a clear or simple relationship between crime and lighting levels. The City of Chicago conducted a study to evaluate the effect of increased alley lighting on an eight-block area of the city's West Garfield Park neighborhood. The Illinois Criminal Justice Information Authority evaluated the results of the study and found that more brightly lit alleys actually led to an increase in reported crime. And, in a 2004 article in the British Journal of Criminology, researcher Paul Marchant found that studies on street lighting and crime shows that increased street lighting led to an increase in reported crime. *(Marchant, 2004; British Journal of Criminology)* Marchant's article was a review of a British Home Office study that inaccurately concluded that studies show that increased street lighting reduces crime.

- <u>Wildlife and ecosystem health and safety</u>

  Light emitted upwards at night is known to attract and disorient migratory birds, which are using stars to help them navigate. This results in birds colliding with buildings causing extensive mortality. "Light attracts birds and disorients them," explains Michael Mesure, executive director of the Toronto-based Fatal Light Awareness Program (FLAP). "It is a serious situation because many species that collide frequently are known to be in long-term decline and some are already designated officially as threatened." *(Chepesiuk, 2009; Environmental Health Perspectives)* The bulk of the fatalities happen during spring and fall, when artificial lights dramatically affect migratory birds. As described in the periodical Frontiers in Ecology and the Environment, "many species of migratory

birds have evolved the ability to migrate at night, and the recent and rapid expansion of artificial light at night has markedly altered the nighttime sky through which they travel. Migrating birds regularly pass through heavily illuminated landscapes, and bright lights affect avian orientation." *(Horton, et al, 2019; Frontiers in Ecology and the Environment)*

Migration begins just after sunset for many birds traveling between their wintering grounds as far south as South America and their breeding grounds as far north as the Arctic tundra. Night flight brings birds over ever-expanding urban areas across the landscape. The estimates as to the number of birds dying from window collisions across North America annually range from 98 million to close to a billion (includes both daytime and nighttime collisions). The U.S. Fish and Wildlife Service estimates 5–50 million birds die each year from collisions with communication towers. *(Chepesiuk, 2009; Environmental Health Perspectives)*

The Horton, et al, study mentioned above looked at over 20 years of satellite and radar data and rated the risk to birds from the exposure to urban light pollution in over the 125 of the largest US cities. Portland was among those cities recommended to take action, especially in spring, in order to reduce hazards posed by light pollution for nocturnally migrating birds. And data collected by Portland Audubon backs up the need for action. Between 2009 and 2011, Audubon volunteers conducted dawn community science surveys of 21 downtown buildings. The findings provide evidence that a variety of neotropical migrant songbirds (warblers, thrushes, tanagers and vireos), sparrows, woodpeckers, hummingbirds and shorebirds are colliding with buildings in downtown Portland. While the direct cause of mortality is glass, light pollution is a contributing factor. Data from these surveys, combined with Portland Audubon's Wildlife Care Center data during the same time period, documented 69 species of birds in window collisions, many of which are fatal.

Researchers have also identified harmful impacts on many other urban and non-urban species, including mammals, amphibians, bats, insects, plants, fish, turtles, marine invertebrates (including corals), and primates. According to a paper written by the IDA, "it is estimated that the majority of animal life on the planet is nocturnal; this preference for night activity may stem from predator avoidance, heat aversion, foraging advantages, or other factors. The alteration of the ambient light level at night can result in an otherwise suitable habitat being avoided or unusable. Artificial light in the environment may thus be considered a chronic impairment of habitat." *(International Dark-Sky Association, May 2010; Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting)* Studies show that nighttime lighting increases predation because the lighting makes it easier for predators to see and continue to hunt well into the night. Animals that forage at night are shown to decrease activity in order to avoid becoming prey.

Overly lit unused parking lot adjacent to Oaks Bottom Wildlife Refuge. Photo courtesy of Mary Coolidge, Portland Audubon.

The US Geological Service is studying the effect of light on salmon in the Puget Sound and has found that predation risk increases significantly as artificial light increases. "Virtually all salmon predators rely on vision to feed," said Dave Beauchamp of the U.S. Geological Survey. "Artificial light has increased to a degree that predators can be more effective feeding at night. Predation risks have

increased significantly, especially for juveniles." Beauchamp said many juvenile salmon migrate at night, and increased illumination gives their predators an extra advantage. Beauchamp estimates that reducing the illumination by 50 percent would decrease predation by 25 percent. *(Dungan, July 2018; Encyclopedia of Puget Sound)*

In the Portland region and on a global scale, native bird populations are declining due to many factors. Habitat impairment and building collisions are key factors in this decline. But artificial light at night is also a contributor to stresses on birds. As noted above, blue light (with shorter wavelengths) suppresses the production of melatonin in birds, which can weaken their immune response to diseases. *(Poon, January 2019; City Lab)* We can reduce this impact by selecting lamps with the lowest amount of blue light as possible that still meet energy efficiency goals. A 2018 shows that filtered yellow green and amber LEDs have lower melanopic impacts on wildlife than blue-rich white lighting. *(Longcore, et. al., 2018; Rapid Assessment of Lamp Spectrum to Quantify Ecological Effects of Light at Night)*

Sea turtles are also vulnerable to the negative effects of artificial light at night. Sea turtle hatchlings use moonlight reflecting off wave tops as a guide to the sea. Studies in Florida show that bright lights from urban development along the shoreline disorient the baby turtles causing them to wander into the road or onto properties with the result that they do not make it to the ocean. "There are tens of thousands of hatchling disorientations every year," says David Godfrey, executive director of the Gainesville-based Sea Turtle Conservancy. "Light pollution is one of the two highest sources of mortality for hatching sea turtles along our coastlines." *(Drake, 2019; National Geographic)*

Artificial light also has been shown to negatively affect insects and the pollination process. As reported in *The Guardian* newspaper, "light pollution is a significant but overlooked driver of the rapid decline of insect populations, according to the most comprehensive review of the scientific evidence to date. Artificial light at night can affect every aspect of insects' lives, the researchers said, from luring moths to their deaths around bulbs, to spotlighting insect prey for rats and toads, to obscuring the mating signals of fireflies." *(Carrington, Nov. 2019; The Guardian)* While we may not immediately grasp this, dramatic declines in insect populations has untold consequences for entire ecosystems.

Trees and plants are also affected by exposure to artificial light at night. According to Winslow Briggs's in a chapter on plant responses in the book *Ecological Consequences of Artificial Night Lighting*, prolonged exposure to artificial light prevents many trees from adjusting to seasonal variations. And, as reported on the website *Quartz*, "under a constant light source, trees and plants do not function as effectively; they may not know when to photosynthesize and what season it is as effectively as they would if they lived with periods of natural darkness...What's more, the bright lights affect the birds and insects that would normally live in a tree, which disturbs the tree's biome, or ecosystem." *(MacLellan, June 2017; Quartz)* These impacts on trees and plants will add to the anticipated stresses of climate change over time.

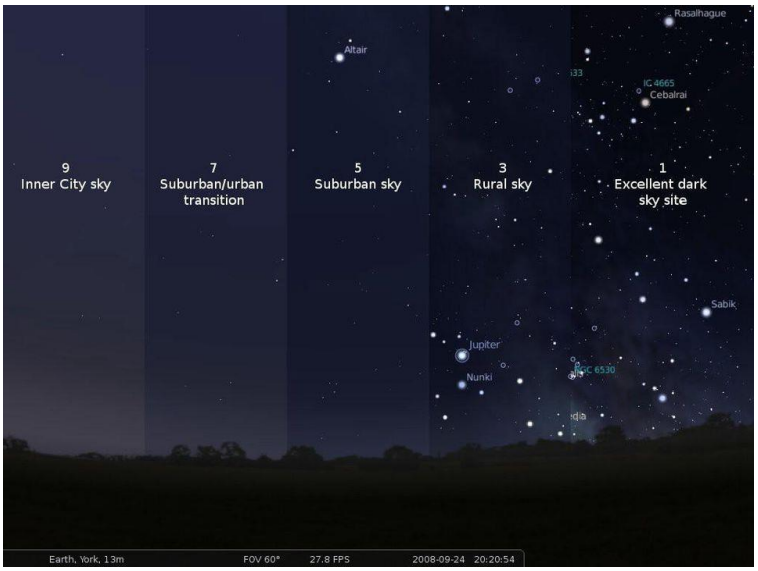
- Energy and Carbon

Over-illumination wastes energy and lack of shielding allows light to shine where it is not needed.
Photo courtesy of Mary Coolidge, Portland Audubon

Over illumination—lighting well beyond what is required for a specific activity—wastes money. The IDA estimates that 30 percent of all outdoor lighting in the U.S. alone is wasted including from too much lighting. That adds up $1.4 to $3.5 billion and the release of 6.7-16.9 million tons of carbon dioxide per year. The federally funded National Optical Astronomy Observatory (NOAO) reports that poorly aimed, unshielded outdoor lights waste $2 billion (17 billion kilowatt-hours) of energy in the U.S. each year. *(Scheer, Moss, August 2012; Scientific American)* NOAO has monitored outdoor lighting levels across the U.S. and beyond for the past six years through its GLOBE at Night program whereby community-scientists track nearby outdoor lighting levels over a two-week period beginning in late March and submit their observations to NOAO electronically.

By shielding lights and lowering bulb wattage to a reasonable level, the consequences of light pollution could be easily avoided, and we would save money.

- Night sky viewing



Portland currently ranks at about a 7 on the Bortle Scale—a tool used by amateur astronomers to compare the relative darkness of astronomical observation sites.

Despite an overall reduction in energy use worldwide due to the transition to and widespread use of more efficient LED lighting, according to a 2017 study, earth's artificially lit outdoor area grew by an average of 2.2% per year between 2012 and 2016, and continuously lit-up areas, such as cities, became 2.2% brighter each year, although the amount of upward light measurable in the United States has remained stable. *(Kyba, et al, 2017; Science Advances)* However, an important consideration reported by the authors is that the satellite sensors used for the study lack sensitivity to light in the range of 400 to 500 nano meters and therefore, the results may underestimate the amount of light pollution contributed by lighting systems that emit blue-rich white light in that range, including those which have been installed on Portland's city streets. The estimated growth in light pollution is due in part to what researchers call the "rebound effect", which is the increased use of lighting in response to the overall reduction in cost of lighting. In addition, LED lighting has a shorter wavelength than traditional High Pressure Sodium lights (the type of light that was frequently used before the transition to LED lights). Shorter wavelength light scatters more readily in the atmosphere, so increasing the short wavelength content of exterior lighting sources increases the potential for sky glow, which contributes to light pollution.

Astronomers at observatories can see the effects of sky glow from cities hundreds of miles away. Sky glow from the City of Portland is clearly visible from Goldendale Observatory in Goldendale, Washington, 117 miles to the east.

Best Practices: What the experts recommend

The **International Dark-Sky Association** (IDA) is a leading organization combating light pollution worldwide and their primary goals is to promote socially and environmentally responsible outdoor lighting. IDA was founded in 1988 and works with the public, city planners, legislators, lighting manufacturers, parks, and protected areas to provide and implement smart lighting choices. The **Illuminating Engineering Society** (IES) is the recognized technical and educational authority on illumination with a mission to improve the lighted environment by bringing together those with lighting knowledge and translating that knowledge into actions that benefit the public. Established in 1906, the IES membership includes: engineers, architects, designers, educators, students, contractors, distributors, utility personnel, manufacturers, and scientists in 64 countries.

IDA and IES recognize that modern society requires outdoor lighting for a variety of needs, including safety and commerce. To minimize the harmful effects of light pollution, IDA and IES together support the following principles for responsible outdoor lighting:

The American Medical Association (AMA) is also concerned about the negative human and environmental health effects of light pollution. In June 2009, the AMA adopted resolutions that support reducing light pollution and glare and advocate for use of fully shielded outdoor lighting. And, in June 2016, the AMA adopted guidance for communities on selecting among LED lighting options. The AMA encourages:

- That all LED lighting be properly shielded to minimize glare;
- The use of warmer color LED lights (3000 Kelvin or lower lighting temperature) for outdoor lighting, including on roadways; and
- That consideration be given to utilizing the ability for LED lighting to be dimmed during off-peak time periods.

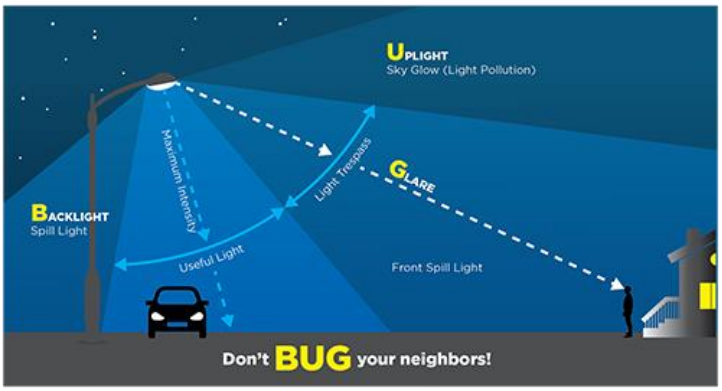
In addition to the IDA, IES and AMA, scientists, including from the National Park Service, the Earth Observation Group, the Light Pollution Science and Technology Institute in Thiene, Italy, and the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin, Germany, agree that "the main prescriptions to lower light pollution are as follows: full shielding of lights (that is, do not allow luminaires to directly send any light at and above the horizon or outside the area to be lit), using the minimum light for the task, shutting off light or lowering its levels substantially when the area is not in use, decreasing the total installed flux *(i.e. total amount of light emitted)...,* and strongly limiting the "blue" light that interferes with circadian rhythms and scotopic vision". *(Falchi, et. al., June 2016; Science Advances)*

And, according to the McDonald Observatory's Dark Skies Initiative (DSI), the solution to light pollution is 90 percent education and 10 percent technology. "We can reclaim vast amounts of energy currently wasted inadvertently into the night sky...by using light fixtures that are shielded to reflect light down where it is needed, as well as using the smallest number of lights and lowest wattage bulbs necessary to effectively light an area," says DSI. Leading by example through the installation of downward-pointing outdoor light fixtures is a great place for home and building owners to start. *(Scientific American, August 18, 2012)*

Local and national approaches: What other communities have done to reduce light pollution

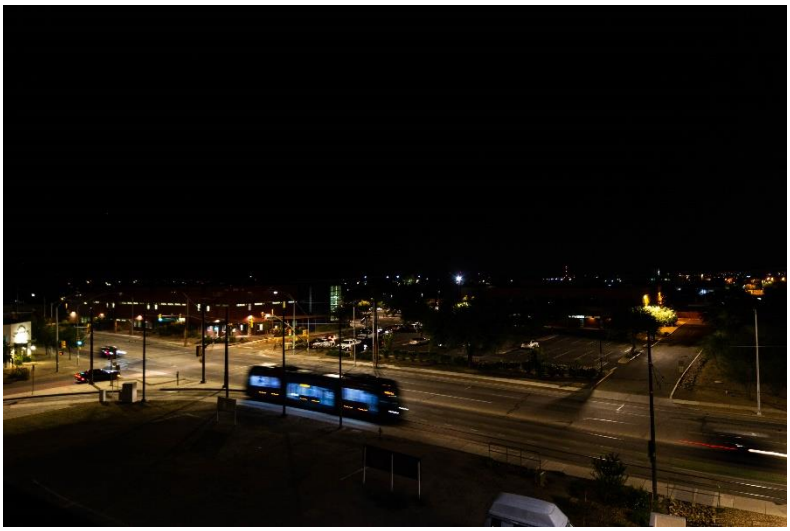
In 2010, USA Today estimated that 300 U.S. counties, cities and towns had adopted dark sky legislation, with popularity for such solutions gaining support from a wide range of stakeholders including conservationists, builders, planners and the military. Below are a few examples of different approaches and tools that jurisdictions and organizations have implemented to reduce light pollution. Appendix A contains a matrix that compares the regulatory approaches of 5 of the communities discussed below plus an additional 5 communities:

- IDA and IES worked together to create a model lighting ordinance that implements best practice principles. The model ordinance is a tool that jurisdictions can use to create zoning or building codes that reduce impacts from excessive lighting. The model ordinance includes the use of lighting zones to classify land use with appropriate lighting levels for each. And, the model ordinance makes use of the "BUG" (Backlight, Uplight and Glare) classification for outdoor lighting fixtures to ensure that only well-shielded fixtures are used. IDA and IES are currently working to update the model ordinance to bring it in line with the *Five Lighting Principles for Responsible Outdoor Lighting* described above, incorporate technological changes, and to make it accessible to more jurisdictions. Model Lighting Ordinance



- State of Oregon requires that all public buildings have shielded light fixtures.
- Multnomah County adopted dark sky lighting requirements in 2016. They require that all new exterior lighting and all exterior lighting on buildings that are being expanded by more than 400 square feet use fully shielded fixtures and contain the light entirely to the site. Fully shielded means no light is emitted above the horizontal plane located at the lowest point of the fixture's shielding. Multnomah County also prohibits upward lighting on signs and billboards. Multnomah County Dark Sky Regulations
- Wilsonville, Oregon applies dark sky regulations to all new outdoor lighting on public facilities, commercial, industrial, and multi-family housing with 3 or more dwelling units, and to major additions (defined as a 50% or more increase in dwelling units, floor area, seating, or parking; and replacing 50% or more of the existing exterior lights). The Wilsonville dark sky regulations include a prescriptive and a performance track. The prescriptive track includes standards that address lamp wattage and shielding requirements (based on wattage and light zone), overall light level limits (watts/sf per light zone), fixture height limits and setback requirements. The performance track includes a review of the lighting design plan and a photometric analysis. In all cases, all exterior lighting must be controlled by automatic devices that turn the lights off during certain hours. Wilsonville Outdoor Lighting Code

- Tucson, Arizona's outdoor lighting code applies to all new lighting installed on a site and requires lighting to be retrofitted when an addition or alteration to the site increases floor area, dwelling units, or parking spaces by 25% or more. Outdoor lighting is limited by use and lighting area and full cutoff shielding is required based on fixture type and proximity to residential zones and lot lines. If unshielded fixtures are used, they must not exceed 3,000 lumens and must be turned off between 11 pm and sunrise using automatic controls to extinguish the lights. The color temperature of all outdoor lighting must not exceed a 3,500 K. On-site signs must meet these standards as well. Lights on recreational facilities must be fully shielded and must have automatic controls to turn off the lights when not in use.

  By installing new well-shielded and controllable 3000K streetlights, the City of Tucson has reduced light pollution and saved on energy costs. Photo: Bettymaya Foott, IDA.

  Tucson has also converted its streetlights from High Pressure Sodium to 3000 K white LED light fixtures. A study conducted by John Barrentine, Director of Conservation at IDA, found a 7 percent reduction in sky glow over Tucson after the conversion. Tucson Lighting Ordinance

- Fort Collins, Colorado and surrounding jurisdictions have formed an energy efficiency collaboration called Efficiency Works. Each jurisdictions utility designates funding to help support the Efficiency Works program and goals. The Fort Collins Building Code addresses outdoor lighting for both commercial and residential use by requiring Dark Sky Certified lighting fixtures. As an incentive for compliance with the code, Efficiency Works offers a $25 rebate on night sky compliance fixtures. To qualify the fixture must be fully-shielded, have a fully-integrated LED and be 3000 K or less. Efficiency Works Rebate

- Toronto, Canada requires that residential buildings with 5 or more dwelling units, and commercial, industrial and institutional buildings use Dark Sky compliant exterior lighting fixtures and that all exterior lighting minimize glare and light trespass. Dark Sky compliant means the fixture must be full-cutoff and with a color temperature rating of 3000 K or less. Unless the building is a City-owned building, Toronto incentivizes through fee waivers, but does not require, that architectural lighting be directed downward and turned off between 11 pm and 6 am, and that tall, non-residential buildings install automatic lighting controls that reduce internal, non-security lighting between the hours of 11 pm and 6 am. All of these conditions are required for City-owned buildings. Toronto Best Practices for Effective Lighting

- Phoenix, Arizona recently finished replacing 100,000 existing streetlight fixtures with 2,700 K LED light fixtures. The city estimates it will save approximately $3.5 million in annual energy costs. The city spent years testing and planning for the conversion and in 2016 revised the initial recommendation from installing 4000 K fixtures to 2700 K. The revision was based on extensive community input, potential environmental issues, technical lighting standards, and projected energy savings. Phoenix Street Light Conversion

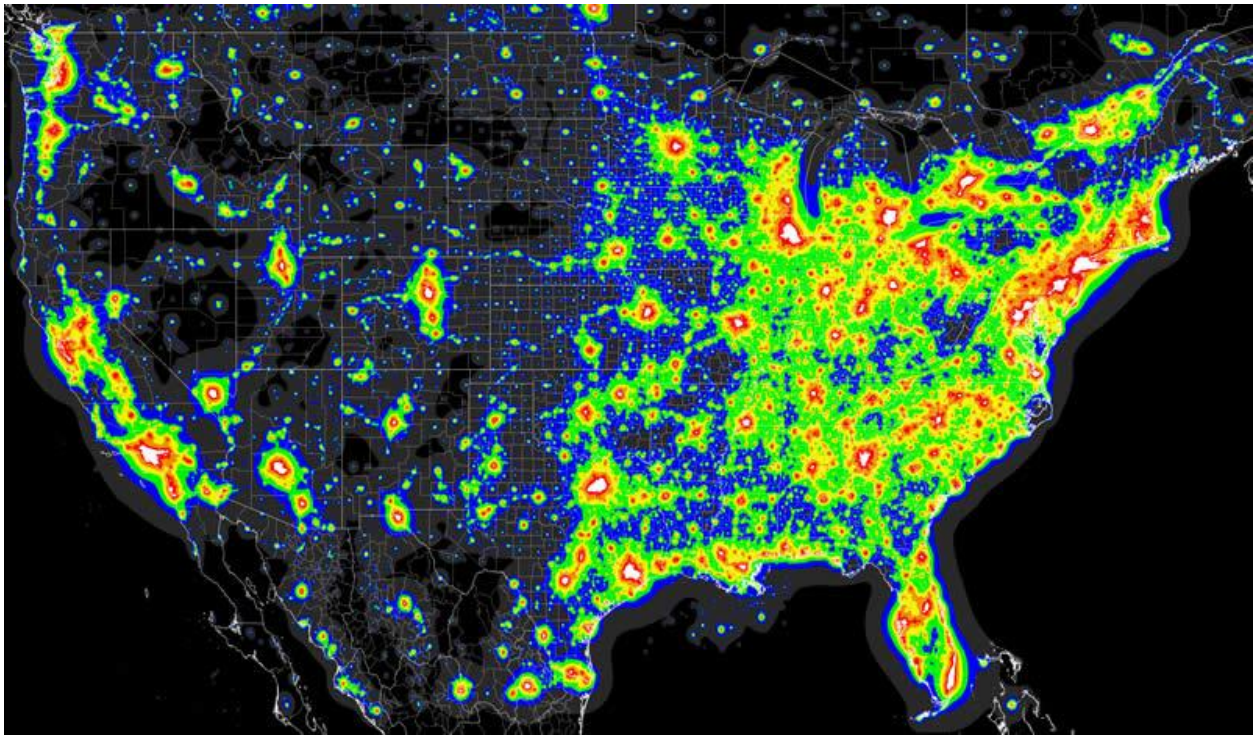
An example of good exterior lighting on a residential structure.
Photo courtesy of Mary Coolidge, Portland Audubon

- Davis, California converted its 2,600 streetlights to efficient LED lights in 2014. But, just months after Davis installed the 4,000K LED streetlights, a high volume of complaints about glare and intensity prompted the city to study and eventually replace 650 of those new lights with 2,700 K LED. Davis Street Light Retrofit
- Cambridge, Massachusetts replaced 7,000 High Pressure Sodium (HPS) street and park lighting fixtures with 4000 K LED fixtures. Cambridge also installed a wireless control system for the streetlights which allows the new LED streetlights to be dimmed after dark. After dimming (at 8 p.m. or 10 p.m. in most areas), the stimulatory effects of the lights are estimated to fall below that of the old HPS light by about 40%, reducing the risk of light disruption of sleep and circadian rhythms. The new streetlights can also be shielded to control unwanted light when further restriction is needed. Cambridge Massachusetts Street Light FAQ
- New York, New York and Chicago, Illinois both have robust Lights Out programs. Fatal Light Awareness Program (FLAP), a Toronto-based conservation society, spearheaded the lights-out movement in 1993 to bring awareness to and reduce instances of fatal bird collisions with buildings at night. New York began their Lights Out New York program in 2005. Over the years the number of buildings participating in the program has grown and now includes iconic buildings such as the Chrysler Building, Rockefeller Center, 501 Lexington Avenue (formerly known as Citigroup Center), Silverstein Properties, The Time Warner Center and the Worldwide Plaza. All of the participating buildings turn off their lights from midnight to dawn during peak migration season from September 1 to November 1. In downtown Chicago, about 100 buildings go dark after 11 pm for six months during spring and fall migrations. That is “virtually all of the buildings downtown over 40 stories,” according to Annette Prince, director of Chicago Audubon Society's Chicago Bird Collision Monitors. NYC Lights Out Program
- Other jurisdictions that have lighting codes or policies in place:
  - Alameda, CA Alameda California Bird Safe Regulations
  - Boulder, CO Boulder Colorado Outdoor Lighting Ordinance
  - Hillsboro, OR: Hillsboro Oregon Exterior Lighting Code

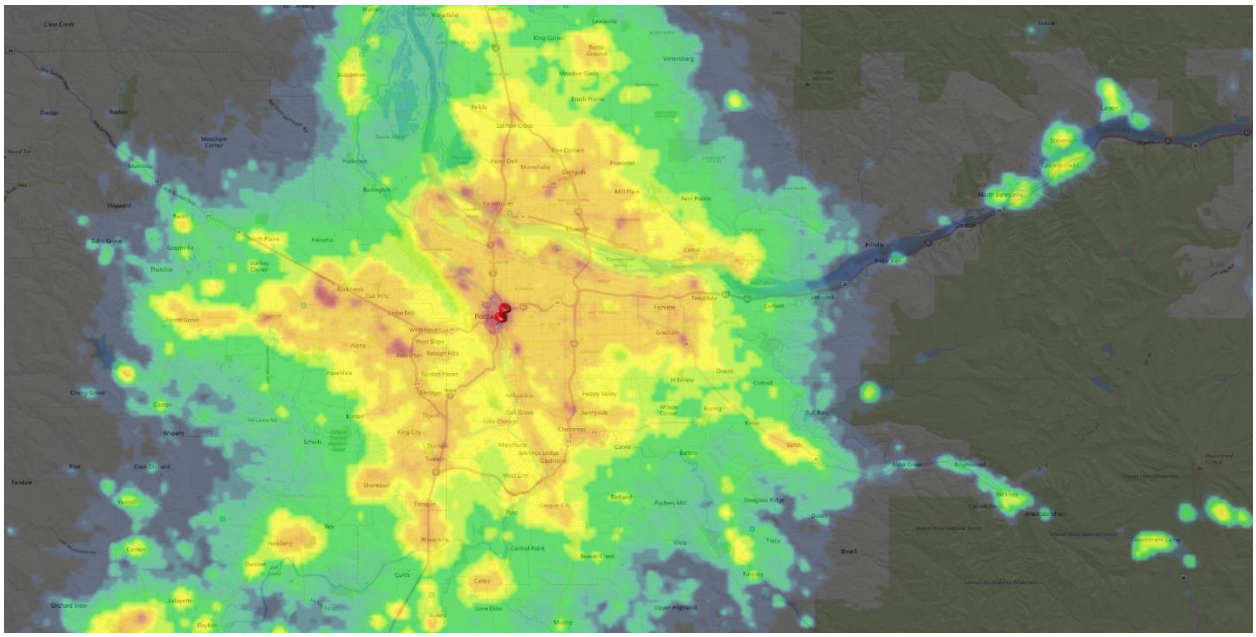
- Malibu, CA: Malibu California Dark Sky Ordinance
- Oakland, CA: Oakland California Outdoor Lighting Standard
- Flagstaff, AZ: Flagstaff Arizona Dark Sky Ordinance

Existing Conditions

Today Portland has a moderate light pollution problem relative to other North American cities. Below is a light pollution map of the United States followed by a light pollution map of Portland.



Light pollution map—United States. David Lornez; Light Pollution Map 2006 website



Light pollution map—Portland, Oregon. www.lightpollutionmap.info

But Portland is a growing city in a growing metropolitan area. According to Metro's 2016 population growth forecast, the seven-county Portland-Vancouver-Hillsboro Metropolitan Statistical Area will reach 3.5 million people by 2060, up from an estimated 2.4 million in 2015. Portland's commitment to compact urban form, resource efficiency, and limiting our carbon footprint has manifested in higher density development and efficient multi-model use of City rights-of-way. And, these trends are expected to continue as Portland strives to offer flexible, affordable housing choices that allow more people to live and work within the city. With this growth comes more lighting, and in the absence of thoughtful planning, more light pollution.

Within our metro area there are cities that have lighting plans—some are 3 pages long (Hillsboro), while others are 40 pages (Wilsonville). While Portland has adopted policies related to reducing light pollution, Portland lacks a strategic plan for outdoor lighting. Portland should be a leader in this arena as we are in so many others. Portland is a City that is widely considered on the leading edge of being "green", and much of our planning does in fact demonstrate the high value we place on our wildlife populations and our environmental and sustainability values. We are part of an international Biophilic Cities network as well as being an official U.S. Fish and Wildlife Service (USFWS) Urban Bird Treaty City. Being an Urban Bird Treaty City spurred the development of the Bird Agenda, which recommends programs to reduce window collisions and the development of a robust Lights Out campaign. While Portland is widely known for innovation in urban planning and design, to date, relatively little attention has been paid to lighting design that minimizes light pollution and the associated impacts on human and ecological health and safety.

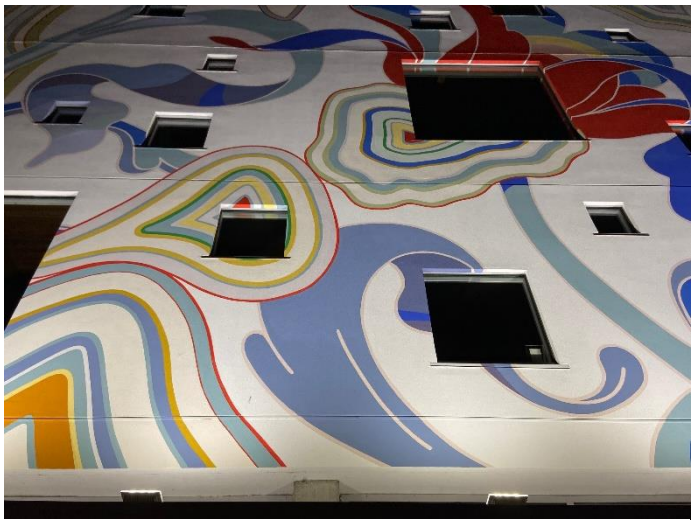
Portland currently ranks at about a 7 on the Bortle Scale (a tool used by amateur astronomers to compare the relative darkness of astronomical observation sites). Though we have considerable skyglow, there is still some night sky left to protect for the benefit of our ecosystems and our region's residents.

Outdoor artificial light at night is increasingly understood as a pollutant, but it is far more easily reversed than other forms of pollution. In order to reverse it, however, we have to improve the way that we design and install lighting systems; it is easier to preserve what you have than to restore what's been lost.

Existing City Policies, Codes, Guidelines and Practices: What Portland has done to reduce light pollution

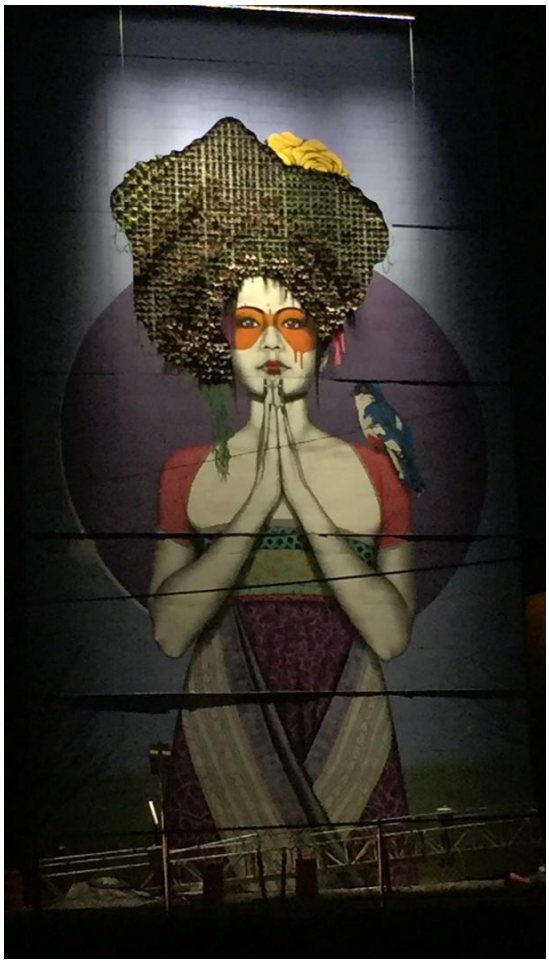
As mentioned above, Portland has recognized light pollution as an important issue to be addressed since in 2003 when the City of Portland was selected by the USFWS to become a pilot city for the Urban Conservation Treaty for Migratory Birds Program and work on the Portland Bird Agenda began. Today, several important City of Portland policy documents, including the Climate Action Plan, the Portland 2035 Comprehensive Plan and the Central City 2035 Plan, acknowledge that light pollution is a growing

problem and call for the City to take action to reduce the negative effects of light pollution. In fact, the City has already taken some steps to implement rules, regulations (Portland Zoning Code) and practices (Green Building Policy) aimed at reducing light pollution. But more needs to be done to achieve the goals envisions by the policies and plans described below:



Architectural lighting from below shining up into the sky.
Photo courtesy of Mary Coolidge, Portland Audubon

- The Portland Bird Agenda (2011)
  The Portland Bird Agenda was adopted by City Council in June 2011 as part of the adoption of the Terrestrial Ecology Enhancement Strategy (TEES). The purpose of the TEES is to have a common body of information and agreed-upon priorities for conservation and restoration of terrestrial plant and animal species and habitats in Portland. The TEES is designed to help achieve the watershed health goals and objectives in the *Portland Watershed Management Plan*, which was adopted in 2006. The Bird Agenda summarizes the Urban Conservation Treaty for Migratory Birds Program and the City's accomplishments to date, identifies key issues facing migratory birds in Portland, and outlines high priority actions and "next steps" for the City of Portland to take going forward. The agenda identifies structural hazards, including bird strikes, as a major issue facing migratory birds in Portland. To help alleviate the issue, the agenda identifies that following actions:
  - Explore opportunities to participate in a pilot Lights Out project (e.g., Portland Building, 1900 Building);
  - Review Lights Out program messages and explore opportunities to provide information to building owners and managers and the public;
  - Coordinate with the Mayor and City Council members in support of a proclamation to launch a Portland Lights Out Program;
  - Explore options for addressing bird-friendly building and illumination policies in the Portland Plan or Comprehensive Plan update and through voluntary efforts.



Best practice is to light buildings from above instead of from below, as shown in this example.
Photo courtesy of Mary Coolidge, Portland Audubon

- Portland's Resource Guide for Bird-friendly Building Design (2012)
  In partnership with Audubon of Portland, the USFWS and the American Bird Conservancy, the City sponsored the

development of a *Resource Guide for Bird-Friendly Building Design* for Portland. The Resource Guide includes extensive recommendations to reduce the risk of bird mortality from collisions with buildings and fatal light attraction.

- Bird-Friendly Building Design Resolution 37034 (2013)
  In October 2013 the City Council adopted Resolution 37034 directing City bureaus and offices to explore opportunities to integrate Bird-Friendly Building Design into City policies, plans, and programs, including updates to Portland's Comprehensive Plan, Central City Plan, and the City's Green Building Policy.

- Climate Action Plan (2015)
  The Portland/Multnomah County Climate Action Plan is a set of local strategies to reduce carbon emissions and address climate change. The Climate Action Plan identifies twenty objectives and more than one hundred actions to be completed or significantly underway in the next five years. Objective 19 is related to local government operations. The City and County own and operate hundreds of buildings, tens of thousands of streetlights and traffic signals, and large-scale industrial plants. The Plan includes strategies designed to influence how local governments operate, including the construction and maintenance of City and County buildings. Strategy 19E specifically calls for:
  - Implementing energy-efficient outdoor lighting, including light emitting diodes (LED) and dimming technologies when appropriate;
  - The complete conversion of all streetlights to LEDs; and
  - The use of Dark Skies best practices when possible to reduce light pollution and minimize bird strike hazards.

- Green Building Policy for City-owned Facilities (2015)
  The 2015 Green Building Policy is mandatory guidance for internal city operations. The policy requires all new and remodeled City-owned buildings and facilities to incorporate green building practices. The Policy is one way the City implements strategy 19E of the Climate Action Plan described above.

  Among the many green building practices that the Policy requires is a requirement for all new occupied and unoccupied City-owned buildings to incorporate measures to reduce bird strikes and fatal light attraction including:
  - Minimizing glare
  - No up-lighting or light beams
  - Installing full cut-off shielded or directional lighting
  - Installing time switch control devices, occupancy sensors or non-emergency interior lights that can be programmed to turn off during non-work or other designated hours.

- Portland's 2035 Comprehensive Plan (Adopted 2016, amended through March 2020)
  Portland's 2035 Comprehensive Plan guides how and where land is developed and infrastructure projects are built to prepare for and respond to population and job growth. The goals and policies in the Comprehensive Plan guide the City's land use planning program and is primarily implemented through the City's zoning code and infrastructure plans. The most recent version of the Comprehensive Plan was adopted in June 2016 and it contains several policies that call for reducing light pollution and mitigating the negative impacts of excessive light on wildlife and people:

- POLICY 4.38 Light Pollution: Encourage lighting design and practices that reduce the negative impacts of light pollution, including sky glow, glare, energy waste, impacts to public health and safety, disruption of ecosystems, and hazards to wildlife.
- POLICY 4.75 Low-impact Development and Best Practices: Encourage use of low-impact development, habitat friendly development, bird-friendly development and green infrastructure.
- POLICY 4.77 Hazards to Wildlife: Encourage building, lighting, site, and infrastructure design and practices that provide safe fish and wildlife passage, and reduce or mitigate hazards to birds, bats, and wildlife.
- POLICY 8.34 Resource Efficiency: Reduce the energy and resource use, waste, and carbon emissions from facilities necessary to serve designated land uses to meet adopted City goals and targets.

- Central City 2035 (2018)
  The Central City 2035 plan is an area-specific component of the City's 2035 Comprehensive Plan. It will guide development within the Central City for the next 20 years. The Central City 2035 plan contains goals and policies that are specific to the districts within downtown Portland. Among those goals and policies are several that pertain to reducing the negative effects of light pollution:
  - POLICY 6.6 Human health. Encourage the use of active modes of transportation by creating and enhancing a network of bike and pedestrian facilities that provide access to services and destinations including natural areas. Improve access for all people to locally grown and healthy foods. Encourage the use of building construction methods, materials, products and best practices in lighting design that do not have harmful effects on human health and the environment. Encourage social health by fostering community in a hospitable public realm.
  - POLICY 6.7 Light, Noise and Vibration Pollution. Encourage land use patterns, building design and landscape to limit and mitigate negative impacts of lighting, noise and vibration on public health and safety, disruption of ecosystems, and hazards to wildlife.
  - POLICY 6.13 Bird and wildlife-safe development. Encourage bird-friendly building and lighting design and management practices, to reduce hazards to resident and migrating birds, fish and other wildlife species.

  The Central City 2035 plan also contains implementation action items. Environmental action item EN13 directs the Bureau of Planning and Sustainability to, within 5 years, "initiate a Dark Skies project and implement best practices to reduce the impacts of nighttime lighting and sky glare on human health and well-being, wildlife and energy consumption." Funding for this project was allocated to the Bureau of Planning and Sustainability in July 2019 specifically to carry out at least the first phase of this action item.

- Washington Park Master Plan (2018)
  Portland Parks and Recreation (PP&R) updated its Washington Park Master Plan in January 2018. The updated master plan sets out guidance and recommendations for improving the park over the next 20 years. One of the main themes that the master plan focuses on is *Creating Identity*. The plan

calls for PP&R to identify areas to minimize noise and light pollution, meet best practices in exterior lighting design to address light pollution, reduce wasted energy, minimize impacts on wildlife and birds, minimize impacts to human health, and preserve night skies, and make Washington Park a Dark Sky Park. The first phase action identified to carry out this particular strategy states that PP&R will develop a lighting plan to meet the criteria established by the International Dark-Sky Association including criteria focused on proper light fixture shielding, direction and color temperature.

- Portland Zoning Code

  The City of Portland zoning code currently contains a few targeted and area-specific regulations related to outdoor lighting. Many of the existing regulations are in line with dark skies best practices and several of the regulations use different terminology to achieve the same outcome (e.g. light should not directly illuminate the sky vs. cutoff luminaires must be installed):
  - 33.219 Convenience Stores: Convenience stores are required to document that the lighting meets the 33.262, Off-site Impacts, glare standard.
  - 33.262 Off-Site Impacts: Certain non-residential uses are required to meet off-site impacts standards. One of the standards is related to glare and states that glare may not directly, or indirectly from reflection, cause illumination on other properties in excess of a measurement of 0.5 foot candles of light. The off-site impact standards are difficult to enforce, and many existing uses are exempt.
  - 33.420 Design Overlay Zone: Within the Design overlay zone, several design guidelines mention lighting, but only one mentions lightings effect on the night sky or skyline.
  - 33.430 Environmental Overlay Zones: Within the Environmental overlay zones, exterior lights must be placed 25 feet apart and lights exceeding 200 watts must not shine into resource areas.
  - 33.475 River Overlay Zones: Within the River overlay zone, exterior lights must not project up or to the side, the top and sides of all exterior lights must be fully shielded, and within 25 feet of the river setback, all lamps must fall below 3000 K or within an S/P ratio range of 1 to 1.2.
  - 33.508 Cascade Station/Portland International Center Plan District: Within Subdistrict A (roughly one-half of the plan district), all lights must direct light downward to not directly illuminate the sky.
  - 33.565 Portland International Airport Plan District: In the portion of this plan district where industrial development will continue, eco-industrial development is promoted. In the IG2 zone within this eco-industrial subdistrict, exterior lights must be shielded and placed so that they do not shine upward or into environmental overlay zones, or into the required vegetated setback area.
  - 33.570 Rocky Butte Plan District: Within the plan district, cut-off luminaires must be installed for any outdoor lighting fixtures on private property. On private property, glare may not directly, or indirectly from reflection, cause illumination on other properties in excess of a measurement of .5 foot candles of light. In the right-of-way, illumination may not exceed .5 average horizontal foot candles (Eh Ave) over an area 10 feet deep, adjacent to public rights-of-way. Lighting for the purpose of ensuring public safety is exempt from this standard.

- Seasonal Lights Out Program
  Portland Audubon, along with 21 other U.S. cities, sponsors a voluntary Lights Out program that encourages building and homeowners and managers to pledge to extinguish unnecessary overnight lighting during spring and fall migrations (late August through mid-November and mid-March through early June). Lights Out programs do not affect streetlights or safety lighting. Several City of Portland buildings and facilities are currently participating in the program including:
  - City Hall
  - The Portland Building
  - Community centers: Southwest, Montavilla, East, Dishman, Charles Jordan, Mt Scott, St Johns

Photo courtesy of Morgan Tracy, BPS

Portland's LED Street Lighting Conversion Project

Following the lead of cities throughout the region and the world, in 2014 the Portland Bureau of Transportation began replacing high pressure sodium (HPS) streetlights with modern LED light fixtures. The LED lights consume about 50 percent less energy when compared to their HPS predecessors. Roughly 90% of Portland's streetlights are cobra-head style fixtures. The remaining 10% are ornamental fixtures, such as the historic streetlights in downtown Portland. As a result of the conversion, the Pacific Northwest National Laboratory, using its Sky Glow Comparison Tool, estimates that Portland reduced the contribution of its street lighting system to sky glow over the city by about half. *(Kinzey, May 2020; PNNL-SA-153333)*

For the cobra-head conversions, PBOT converted to a Leotek E-Cobra fixture with a 4000 K correlated color temperature (CCT). For the ornamental streetlights, an acorn-style Amerlux fixture with a 3000 K CCT was specified. At the time, the fixtures and CCT chosen met the guidelines and specifications of the Illuminating Engineering Society (IES), the Municipal Solid State Lighting Consortium (MSSLC), and the US Department of Energy.

The converted street lighting has recessed diodes rather than drop lenses, and are considered full cut-off, which is an improvement over the older HPS fixtures. The cobra-head fixtures have an up-light rating of zero, which means the fixtures are pointed downward and do not omit light into the sky. However, 4000 K color temperature of the originally installed cobra-head fixtures is not currently Dark Sky compliant because this type of lamp emits more blue-rich white light than the older HPS fixtures. Blue-rich white light has a shorter wavelength that scatters more readily into the atmosphere than longer wavelength lighting. At the time, a lower CCT cobra-head fixture was not specified because that type of fixture did not perform adequately based on 2014 technology.

Today, the American Medical Association recommends that the CCT not exceed 3000 Kelvin, and IDA and IES jointly recommend that warmer color temperatures be used where possible. Over time Portland's cobra-head fixtures will become more Dark Sky compliant because, based on public feedback and evolving standards and technology, PBOT is using 3000 K LED lighting fixtures for new installations and, as existing fixtures wear out, is the replacing the 4000 K lighting with 3000 K fixtures. As technology continues to advance, the City will continue to evaluate cobra-head fixtures that meet City lighting

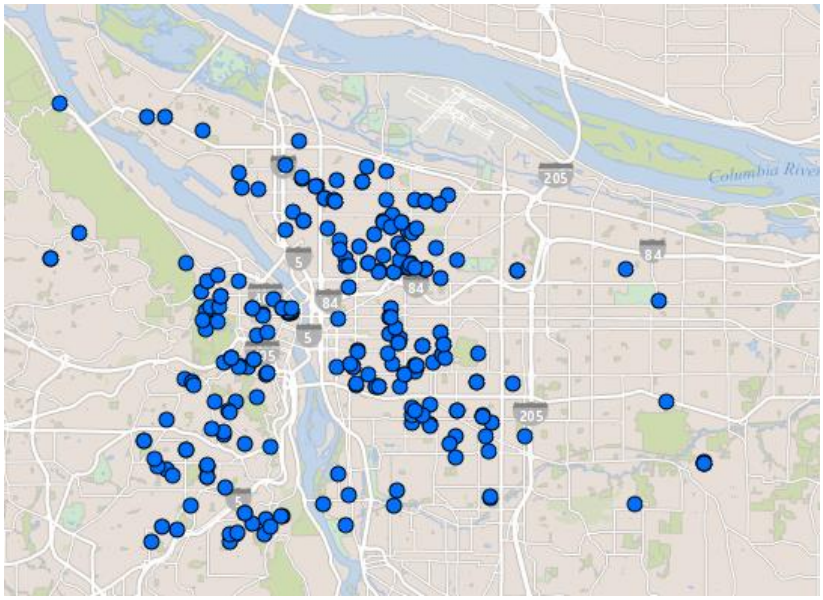
objectives while remaining cognizant of Dark Sky recommended practices. Shields to reduce backlighting from the new cobra-head fixtures were not provided with the initial installations in 2014, but shields have been installed on a requested basis at several locations throughout Portland to reduce light trespass onto private property.

Streetlight shining on to property located behind the light.
Photo courtesy of Dawn Nilson

The ornamental streetlights are a top-down style of fixture that greatly reduces, but does not eliminate, light trespass. Light continues to reflect upward off the vertical components of the ornamental streetlights, but the percentage of uplight is dramatically reduced compared to the original ornamental luminaire. PBOT is working toward replacing the ornamental light fixtures in non-historic lighting districts with fixtures that emit less light upward toward the sky, however the alternate styles currently available are not recommended because they produce too much glare and are unsafe for drivers. PBOT will continue to research and test fixtures to retrofit non-acorn ornamental lights with comparable fixtures as they become available.

PBOT's primary goal in lighting design can be summed up as providing adequate and efficient lighting for each individual application. Guidelines for carrying out this goal are summarized in the City of Portland *Recommended Light Levels and Guidelines for Roadway Lighting* dated May 2019. The Guideline document specifies the steps to adjust minimum recommended average horizontal light levels on roadways based on user needs and roadway conditions. The guidelines do not specify fixture shielding parameters or CCT limits, both of which will be important elements in ensuring that we are adequately addressing this source of light pollution in our City.

As mentioned above, streetlight shields may be installed on a case-by-case basis when a streetlight shines directly into a home. Requests are evaluated by the Signal and Street Lighting team at PBOT. It is a complaint driven system and installation is not guaranteed. In addition, the shield installation work has no public outreach and has no funding. There are also equity concerns about access to this program as can be seen by the distribution of requests made over the past 3 years— the bulk of the requests that are received come from inner SE and SW Portland. East Portland and areas that are more diverse or where vulnerable communities are located are underrepresented in shield requests. But the needs and concerns are just as valid in these communities.



Distribution of shield requests since 2017.
Data courtesy of Portland Bureau of Transportation, Signals and Street Lighting

Section III: Equity Considerations

The 2035 Comprehensive Plan provides a framework to ensure Portlanders more equitably share in the benefits and burdens of growth and development. This includes recognizing and taking past inequities into account when making decisions. Using this framework as guidance as we researched the implications and impacts of artificial light pollution, staff have identified several issues that need exploration. The following are equity considerations that will be discussed during the public review phase of this project with the goal of evaluating and addressing community impacts, promoting community benefits and mitigating unintended outcomes:

- Who benefits from and who is burdened outdoor light at night?
- How can we ensure positive equity benefits from regulations that reduce the impacts of artificial light at night?
- Some studies are indicating an association between artificial light at night and lower sleep quality and quantity, and the association is larger in neighborhoods with higher levels of poverty. We also know that there are light poor areas in Portland that need to be better lit. There could be disproportionate impacts of increased lighting in vulnerable communities. How can we ensure that both ends of this spectrum—too much and too little light—are addressed?
- What is the intersection between neighborhoods with less tree canopy and the amount of light that shines into residential buildings at night? Could the lack of tree canopy in historically marginalized neighborhoods be a factor in terms of light pollution having a greater effect on people in these areas?
- Under certain circumstances the City will add a shield to a streetlight if the streetlight is shining into a home at night. The way that the shield process works is that shields are installed in communities that complain more. Most of the requests for shielding come from inner east and SW Portland. Outer east Portland and areas that are more diverse or where vulnerable communities are located are underrepresented in shielding requests. But the needs and concerns are just as valid in these communities. How do we make the shield program more equitable?

Section IV: Recommendations

Strategies for reducing light pollution in Portland

As shown above, the groundwork is in place, but the City needs to translate these high level policies into comprehensive regulatory and non-regulatory actions to implement the vision on the ground. Without such actions light pollution is likely to continue to proliferate. The following are recommended strategies and actions for reducing light pollution in Portland.

Strategy 1: Addressing light pollution associated with new and existing development on private and publicly owned property				
Action		**Lead Organization**	**Recommended Timeline**	**Priority**
1.1	Establish in the Portland City Code, a comprehensive set of regulations for outdoor lighting associated with new construction and remodeling projects. Either amend Title 33, Planning and Zoning, to consolidate and expand existing exterior lighting regulations, OR create a new City Code title specific to exterior lighting. Use the IDA/IES Model Lighting Ordinance and other municipal ordinances as references to inform development of regulations for Portland, but at a minimum add regulations for new construction and alterations to existing development that: • Limit total light output; • Require exterior lighting to be directed only where needed and not shine horizontally, upward, or onto adjacent properties; • Limit the color temperature of exterior lighting so that it does not exceed 3000 Kelvin, with a lower temperature specified for environmentally sensitive areas; • Encourage or require lighting control devices that allow dimming of exterior lights when full output is not needed; • Require that rooftop and other exterior architectural lighting be directed downward; • Prohibit spotlights that direct lighting into the sky. *(see Appendix A for a comparison of outdoor lighting ordinances and Appendix B for an example zoning code chapter)*	BPS	Fiscal year 2021/2022	High

1.2	Update Title 33 Design Review guidelines and Historic Resources Review guidelines to address: • The design of exterior, architectural and sign lighting to reduce the impacts of nighttime lighting and sky glare. • Reducing the effects of light spill from buildings (e.g. encourage shades that drop automatically; or a curfew for dimming or turning off internal lights in tall buildings)	BPS	within 2 years	High
1.3	Amend Title 33 Conditional Use Review approval criteria for Radio Frequency Transmission Facilities to ensure that issues related to lighting at night and fatal light attraction are evaluated and addressed during review.	BPS	Fiscal Year 2021/2022	High
1.4	Ensure that the City's code compliance staff have the equipment and training necessary to enforce existing and new exterior lighting regulations.	BDS	Fiscal year 2021/2022	High

Strategy 2: Addressing light pollution associated with signs				
Action		**Lead Organization**	**Recommended Timeline**	**Priority**
2.1	Amend Title 32, the Sign Code, to ensure that all lighting associated with outdoor signage, including billboards and electronic signage, is directed downward or otherwise adhering to Dark Sky best practices.	BDS	within 5 years	Medium

Strategy 3: Addressing light pollution associated with City-owned buildings and facilities including streetlights				
Action		**Lead Organization**	**Recommended Timeline**	**Priority**
3.1	Update the Green Building Policy (GBP) to specifically call for • All new occupied and unoccupied city-owned buildings and facilities and additions or expansions to existing city-owned buildings to adhere to Dark Sky best practices; and	BPS	Fiscal year 2020/2021	High

	• Add a corollary appendix, checklist and specs (as appropriate) akin to the Ecoroof and Bird-Safe appendices currently in the GBP.			
3.2	As part of the next update of the Climate Action Plan include the following action under Objective 2: *Update the Portland Zoning Code or create a new Exterior Lighting Code to require new construction and remodeling projects to comply with Dark Sky best practices.*	BPS	Fiscal year 2020/2021	High
3.3	Update the Master Specifications for City Buildings document to require compliance with Dark Sky best practices, including fully shielded exterior light fixtures and lighting dimming devices, when existing city-owned building and facilities are being updated.	OMF	Currently underway	High
3.4	In support of existing PBOT street lighting best practices, amend Portland City Code and the City of Portland Standard Construction Specifications document to: • Ensure that streetlights to have zero uplight; • Limit color temperature to not more than 3000 K, with a lower temperature specified for environmentally sensitive areas.	PBOT	Fiscal Year 2022/2021 (to align with code work recommended in action 1.1)	High
3.5	Provide resources to PBOT's Signals and Street Lighting department to formally fund a streetlighting shield program that: • Respond to requests in a timely manner; and • Conducts a public outreach and awareness campaign to educate the public about the program and addresses the inequities in the geographic distribution of shield requests.	PBOT	within 2 years	High
3.6	In support of PedPDX strategies 6 and 12, fund a street lighting design demonstration project to research and test innovative ways, including the use of adaptive controls, to improve the safety of pedestrians through Dark Sky friendly street lighting.	PBOT	within 5 years	Medium
3.7	Identify funding for a Dark Sky compliant outdoor lighting demonstration project at Portland Parks and Recreation facilities and solicit public reaction and input on the lighting design. Location options include: retrofitting the outdoor lighting at Hoyt Arboretum to create an Urban Night Sky Place in	PP&R	within 2 years	Medium

	Washington Park or retrofitting outdoor lighting at another appropriate, high profile PP&R facility.			

Strategy 4: Addressing light pollution through public awareness, outreach and education				
Action		**Lead Organization**	**Timeline**	**Priority**
4.1	Design and fully fund a robust public education and outreach campaign, including rebate and recognition program, to encourage and incentivize private property owners to retrofit their existing exterior lighting to be Dark Sky compliant. Coordinate the outreach campaign with the Audubon-Columbia Land Trust Backyard Habitat Certification Program to promote Dark Sky compliance on residential private property.	BPS/ Audubon	within 5 years	High
4.2	Design and fully fund a robust Central City outreach campaign to encourage and incentivize downtown building owners and managers to participate in Portland Audubon's "Take the Pledge" Dark Skies Initiative and seasonal lights out program.	BPS	within 5 years	High
4.3	Support and promote Portland Audubon's "Take the Pledge" Dark Skies Initiative by continuing to enroll high profile city buildings in the program and developing and prominently displaying certification signage. (e.g. City Hall, Portland Building, Community Centers, etc.)	BPS, Audubon	within 1 year	High

Section V: Appendices

Appendix A: Outdoor Lighting Ordinances Comparison Chart (Produced by Fregonese Associates)

		Flagstaff, Arizona	Tucson/Pima, Arizona	Malibu, California	Multnomah County, Oregon	Sisters, Oregon	Troutdale, Oregon	Bainbridge Island, Washington	Black Diamond, Washington	Redmond, Washington
		Chapter 10-50.70 Outdoor Lighting Standards	2012 Outdoor Lighting Code Ordinance 10963	Chapter 17.41 Malibu Dark Skies	2016 Dark Sky Lighting Requirements	Dark Skies Ordinance 251	Ordinance 712	Municipal Code Outdoor Lighting 18.15.040	City Code, Chapter 18.70 Lighting/Dark Sky	Ordinance 2109
Purpose	*Public Health*	x		x	x			x	x	
	Safety	x	x	x	x	x	x	x	x	x
	Natural Environment	x	x	x	x	x		x	x	
	Energy Conservation		x	x	x				x	x
	Light Pollution	x	x	x	x			x	x	
	Economy	x		x				x		
	Enjoyment	x		x	x	x		x		
	Quality of life			x						
Standards/Regulations	*Shielded and directed downward*	x	x	x	x	x	x	x	x	
	Meet lighting standards in development application or separate plan				x		x		x	x
	Light trespass prohibited			x				x	x	x (minimize)
	IESNA illumination standards								x	
	Light curfew		x	x					x	
	No illumination of public bodies of water							x	x	
	Light level (eg. Foot-candle, lumens)		x				x		x	
	Vegetation standards							x		x
	Motion sensors, timers, dimmers		x	x						x
	Lamp wattage	x	x							
	Light temperature		x	x						
	Light fixture dimensions		x	x			x			
Exemptions	*Lighting installed before ordinance*		x		x	x		x (streetlights)		
	Temporary lighting (<90 days, eg. Decorations)	x	x		x	x		x	x	
	Construction lighting	x			x	x			x	
	Lighting required by state or federal agencies				x				x	
	Emergency lighting	x			x			x		
	Traffic control devices				x			x	x	

	Underwater lighting				x				
	Specialized lighting necessary for safety								x
	Sports field lighting								x
	Motion-activated home security lighting								x
	Infrared security lighting	x							
	Airport	x				x			
	Lighting n the United States flag		x			x			x
	Fossil fuel lighting		x			x			
	Individual light fixtures less than 40 watts					x			
	Navigation lights						x		
	Moving vehicle lights						x		
	Internally illuminated signs						x		

Appendix B: Example City Code Chapter (Produced by Fregonese Associates)

Outdoor Light

Purpose
The Outdoor Light chapter regulates the fixture, direction, and temperature of external, artificial light with the intent of mitigating light pollution. Light pollution negatively impacts human health and safety, wildlife and ecosystem health, energy conservation, and night sky viewing.

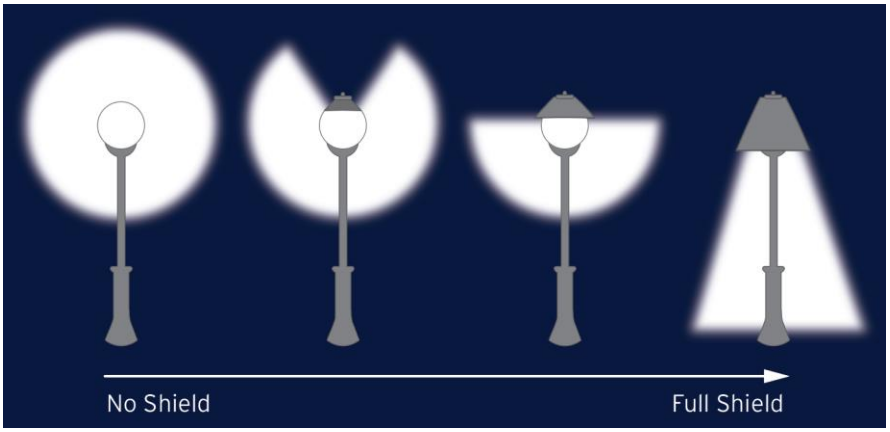
Where These Regulations Apply
The regulations of this chapter apply to new outdoor lighting and existing outdoor lighting for developments that trigger compliance for non-conforming use 33.258.070.D.2.b.

Exemptions

The following outdoor lighting is exempt from the outdoor lighting standards:
1) Outdoor lighting lawfully installed prior to the effective date of this chapter that do not trigger compliance for non-conforming use 33.258.070.D.2.b.
2) Outdoor lighting in support of work necessary to protect, repair, maintain, or replace existing structures, utility facilities, service connections, roadways, driveways, accessory uses and exterior improvements in response to emergencies, provided that after the emergency has passed, all lighting to remain is subject to the requirements of this Section.
3) Outdoor lighting used by a public agency in service of a temporary public need, when such lighting cannot both serve the public need and comply with the outdoor lighting standards in this chapter.
4) Outdoor lighting required by a federal, state, or county law or rule, when such lighting cannot comply with both the law or rule and the outdoor lighting standards in this chapter.
5) Lighting used in support of public agency search and rescue recovery operations.
6) Traffic control devices
7) Lighting necessary to meet federal, state or local historic preservation standards when such lighting cannot both meet historic preservation standards and comply with the outdoor lighting standards in this chapter.
8) Underwater lighting

Outdoor Lighting Standards
New development is required to meet the following outdoor lighting regulations:

Light Fixtures
All exterior lighting must be fully shielded fixtures and directed downwards. “Fully shielded” means no light is emitted above the horizontal plane located at the lowest point of the fixture’s shielding. Shielding must be permanently attached to the fixture.



Light Direction

- All exterior light must be contained within the boundaries of the lot.
- Rooftop and other exterior architectural lighting must be directed downward.
- Prohibit spot lighting.

Light Temperature

The color temperature of exterior lighting must not exceed 3,000 K.

Appendix C: Bibliography

The following sources were reviewed for the drafting of this report.

1. A Garcia-Saenz, A Sanchez de Miguel, A Espinosa, A Valentin, N Aragones, J Llorca, P Amiano, V Sanchez, M Guevara, R Capelo, A Tardon, R Peiro-Perez, J Jimenez-Moleon, B Perez-Gomez, T Dierssen-Sotos, T Fernandez-Villa, C Moreno-Iribas, V Moreno, J Garcia-Perez, G Castano-Vinyals, M Pollan, M Aube, M Kogevinas. (2018). Evaluating the association between artificial light-at-night exposure and breast and prostate cancer risk in Spain. Environmental Health Perspectives. 10.1289/EHP1837.

2. A Irwin. (2018). The dark side of light: how artificial lighting is harming the natural world. Nature. 553. 268-270. 10.1038/d41586-018-00665-7.

3. A Keshet-Sitton, K Or-Chen, E Huber, A Haim. (2017). Illuminating a Risk for Breast Cancer: A Preliminary ecological study on the association between streetlight and breast cancer. 10.1177/1534735416678983.

4. A Lewy, T Wehr, F Goodwin, D Newsome, S Markey. (1981). Light suppresses melatonin secretion in humans. Science (New York, N.Y.). 210. 1267-9. 10.1126/science.7434030.

5. American Medical Association. (2016). AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights. https://www.ama-assn.org/ama-adopts-guidance-reduce-harm-high-intensity-street-lights.

6. American Medical Association. (2016). Human and environmental effects of light emitting diode (LED) community lighting. AMA Council on Science and Public Health.

7. B Kinzey. (2020). Estimated Reductions in Sky Glow from Portland, OR's Streetlight Conversion. PNNL-SA-153333.

8. B Kinzey, T Perrin, N Miller, M Kocifaj, M Aube, H Lamphar. (2017). An Investigation of LED Street Lightings Impact on Sky Glow. U.S. Department of Energy.

9. C Cizeisler. (2013). Perspective: Casting light on sleep deficiency. Nature. 997, S13(2013).

10. C Dungan. (2018). New studies on emerging threats to salmon. Encyclopedia of Puget Sound.

11. C Ingraham. (2017). What actually happens to crime 'when the lights are on,' as Rick Perry suggests. The Washington Post.

12. C Ingraham. (2019). Where the last pristine skies in America are. The Washington Post.

13. C Kyba, et. al. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. Science Advances. 10.1126/sciadv.1701528.

14. City of Portland Oregon, Portland Bureau of Transportation. Lighting Portland for Safety. Last modified March 29, 2018. https://www.portlandoregon.gov/transportation/article/675952.

15. City of Phoenix, Street Transportation Department. “LED Street Light Conversion Q&A.” Last modified November 2017. https://www.phoenix.gov/streetssite/Documents/LED%20Full%20Conversion%20QandA%20FINAL%20-%20Nov.%202017.pdf.

16. C Rich, T Longcore. (2005). Ecological consequences of artificial night lighting. Island Press.

17. C Zimmer. (2019). Birds are vanishing from north america. The New York Times.

18. D Carrington. (2019). Light pollution is key ‘bringer of insect apocalypse’. The Guardian.

19. D Blask, G Brainard, R Gibbons, S Lockley, R Stevens, M Motta. (2012). Light pollution: Adverse health effects of nighttime lighting. AMA Council on Science and Public Health.

20. E Morrow, S Hutton. (2000). The Chicago Alley Lighting Project: Final Evaluation Report. Illinois Criminal Justice Information Authority.

21. F. Falchi, P Cinzano, C Elvidge, D Keith, A Haim. (2011). Limiting the impact of light pollution on human health, environment and stellar visibility. Journal of Environmental Management. 10.1016/j.jenvman.2011.06.029.

22. F Falchi, P Cinzano, D Duriscoe, C Kyba, C Elvidge, K Baugh, B Portnov, N Rybnikova, R Furgoni. (2016). The new world atlas of artificial night sky brightness. Science Advances. 10.1126/sciadv.1600377.

23. F. Falchi, R. Furgoni, T.A. Gallaway, N.A. Rybnikova, B.A. Portnov, K. Baugh, P. Cinzano, C.D. Elvidge. (2019). Light pollution in USA and Europe: The good, the bad and the ugly. Journal of Environmental Management. 10.1016.

24. Harvard Health Letter. (2012). Blue light has a dark side. Harvard Health Publishing.

25. H Yang. (2019). Making Cities Safer for Girls and Women. ARUP Research.

26. I Ashdown. (2015). Color Temperature and Outdoor Lighting. Wordpress blog.

27. International Dark-Sky Association. (2010). Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting.

28. J Barrentine. (2020). State of the science briefing: Artificial light at night (ALAN). International Dark-Sky Association.

29. J Hecht. (2016). LED streetlights are giving neighborhoods the blues. IEEE Spectrum.

30. J Learn. (2019). Bright lights, big cities, big problems for migrating birds. The Wildlife Society.

31. J Uttley. (2017) Vanishing act. Why pedestrians and cyclists disappear when it starts getting dark. The Conversation.

32. K Gaston, T Davies, J Bennie, J Hopkins. (2012). Reducing the ecological consequences of night-time light pollution: options and developments. British Ecological Society. 10.1111/j.1365-2664.2012.02212.x.

33. K Horton, C Nilsson, B Van Doren, F La Sorte, A Dokter, AFarnsworth. (2019). Bright lights in the big cities: migratory birds' exposure to artificial light. (2019). Frontiers in Ecology and the Environment. 10.1002/fee.2029.

34. K Mandel. (2019). Light Pollution Is Taking Away Our Night Skies. Here's Why That Matters. Huffington Post.

35. KNKX. (2018). Light Pollution Identified As a Potential Issue for Threatened Puget Sound Chinook Salmon. Last modified February 27, 2018. https://www.knkx.org/post/light-pollution-identified-potential-issue-threatened-puget-sound-chinook-salmon?utm_source=Sightline%20Institute&utm_medium=web-email&utm_campaign=Sightline%20News%20Selections.

36. K Sweater-Hickcox, N Narendran, J Bullough, J Freyssinier. (2013). Effect of different coloured luminous surrounds on LED discomfort glare perception. Lighting Research & Technology. 45. 10.1177/1477153512474450.

37. Lam Partners. (2016). Is LED street lighting bad for your health?

38. L MacLellan. (2017). Urban trees are stressed out because they can't get enough sleep. Quartz.

39. L Poon. (2018). More lights, more diseases? CityLab.

40. M Kernback, D Newhouse, J Miller, R Hall, J Gibbons, J Oberstaller, D Selechnik, R Jiang, T Unmasch, C Balakrishnan, L Martin. (2019). Light pollution increases West Nile virus competence of a ubiquitous passerine reservoir species. Proceedings of the Royal Society B. 10.1098/rspb.2019.1051.

41. M Ohayon, C Milesi. (2016). Artificial outdoor nighttime lights associate with altered sleep behavior in the american general population. Sleep. 10.5665/sleep.5860.

42. M Rea, M Figueiro. (2016). Response to the 2016 AMA report on LED lighting. Lighting Research Center at Rensselaer Polytechnic Institute.

43. N Drake. (2019). Our nights are getting brighter, and Earth is paying the price. National Geographic.

44. N Kalms, T Hunt, H Yang. (2019). More lighting alone does not create safer cities. Look at what research with young women tells us. The Conversation.

45. N Miller, B Kinzey. (2016). Home nighttime light exposures: How much are we really getting? International Association of Lighting Designers.

46. P Boyce, N Eklund, B Hamilton, L Bruno. (2000). Perceptions of safety at night in different lighting conditions. Lighting Research & Technology.

47. Pacific Northwest National Laboratory. (2017). Street Lighting and Blue Light Frequently Asked Questions. Solid-State Lighting Program, U.S. Department of Energy.

48. P Marchant. (2004). A Demonstration That the Claim That Brighter Lighting Reduces Crime Is Unfounded. British Journal of Criminology. 44. 10.1093/bjc/azh009.

49. P Marchant. (2017). Why lighting claims might well be wrong. International Journal of Sustainable Lighting. 10.26607/ijsl.v19i1.71.

50. Q Xiao, G Gee, R Jones, P Jia, P James, L Hale. (2020). Cross-sectional association between outdoor artificial light at night and sleep duration in middle-to-older aged adults: The NIH-AARP diet and health study. Environmental Research. 10.1016/jenvres.2019.108823.

51. R Chepesiuk. (2009). Missing the dark: Health effects of light pollution. Environmental Health Perspectives. 10.1289/ehp.117-a20.

52. R Scheer, D Moss. (2012). Glare-raising: How much energy Does Excessive nighttime lighting waste? Scientific American.

53. R Skibba. (2017). Astronomers Encourage Cities to Shield Outdoor Lighting. Inside Science.

54. R Stevens, G Brainard, D Blask, S Lockley, M Motta. (2015). Breast cancer and circadian disruption from electric light in the modern world. CA: A Cancer Journal for Clinicians. 10.3322/caac.21218.

55. S Knight. (2019). Holland Aims to Bring Back Its Starry Nights. CityLab.

56. S Lawal. (2020). Fireflies have a mating problem: The lights are always on. The New York Times.

57. S Lewis, C Wong, A Owens, C Fallon, S Jepsen, A Thancharoen, C Wu, R De Cock, M Novak, T Lopez-Palafox, V Khoo, J Reed. (2020). A global perspective on firefly extinction threats. BioScience. 70. 440. 10.1093/biosci/biaa026.

58. T Longcore, A Rodríguez, B Witherington, J Penniman, L Herf, M Herf. (2018). Rapid assessment of lamp spectrum to quantify ecological effects of light at night. Journal of Experimental Zoology Part A: Ecological and Integrative Physiology. 329. 10.1002/jez.2184.

59. Y Koo, J Song, E Joo, H Lee, E Lee, S Lee. (2016). Outdoor artificial light at night, obesity, and sleep habits: Cross-sectional analysis in the KoGES study. The Journal of Biological and Medical Rhythm Research. 10.3109/07420528.1143480.