Dark Sky Simulator

Light Pollution Mitigation Modeling for Alachua County Environmental Protection

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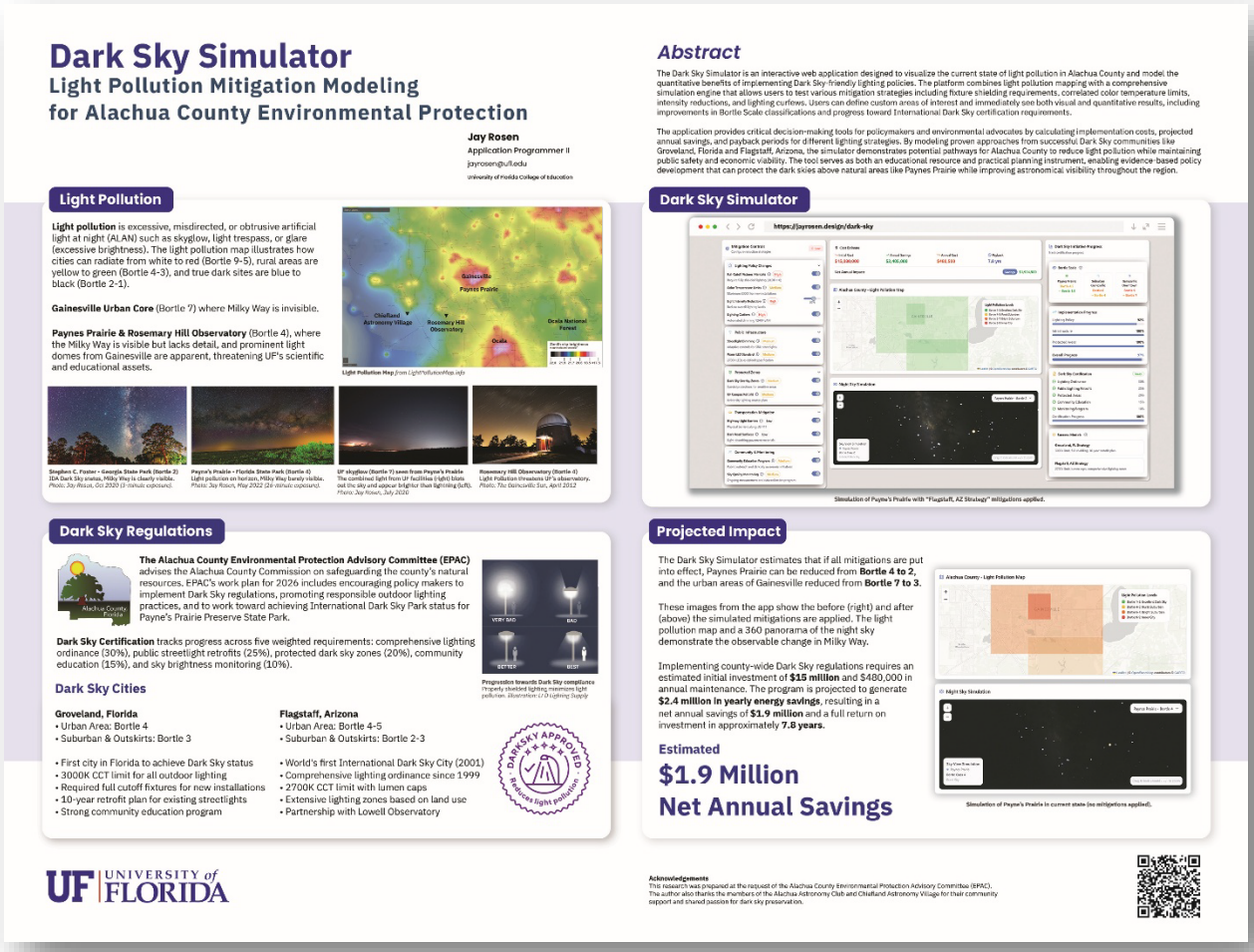

Acknowledgements

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Abstract

The Dark Sky Simulator is an interactive web application designed to visualize the current state of light pollution in Alachua County and model the quantitative benefits of implementing Dark Sky-friendly lighting policies. The platform combines real-time light pollution mapping with a comprehensive simulation engine that allows users to test various mitigation strategies including fixture shielding requirements, correlated color temperature limits, intensity reductions, and lighting curfews. Users can define custom areas of interest and immediately see both visual and quantitative results, including improvements in Bortle Scale classifications and progress toward International Dark Sky certification requirements.

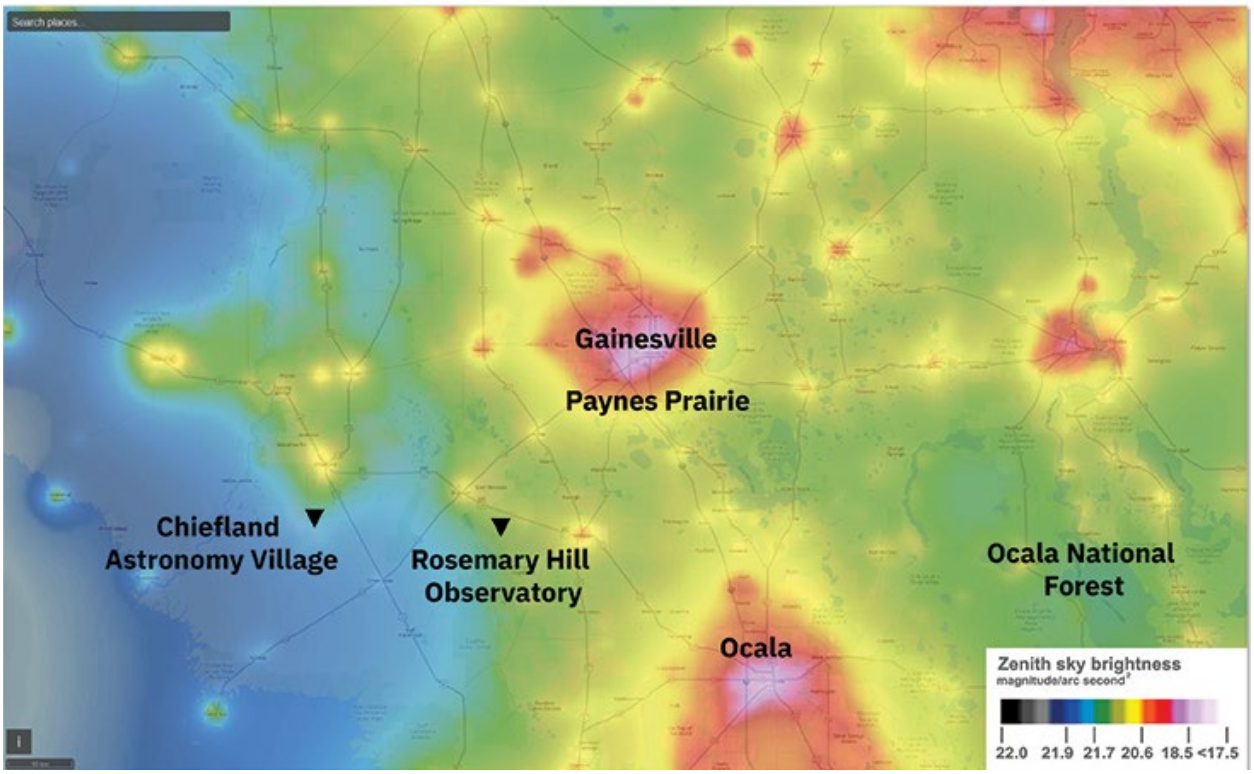
The application provides critical decision-making tools for policymakers and environmental advocates by calculating implementation costs, projected annual savings, and payback periods for different lighting strategies. By modeling proven approaches from successful Dark Sky communities like Groveland, Florida and Flagstaff, Arizona, the simulator demonstrates potential pathways for Alachua County to reduce light pollution while maintaining public safety and economic viability. The tool serves as both an educational resource and practical planning instrument, enabling evidence-based policy development that can protect the dark skies above natural areas like Paynes Prairie while improving astronomical visibility throughout the region.

Light Pollution

Light pollution is excessive, misdirected, or obtrusive artificial light at night (ALAN) such as skyglow, light trespass, or glare (excessive brightness). The light pollution map illustrates how cities can radiate from white to red (Bortle 9-5), rural areas are yellow to green (Bortle 4-3), and true dark sites are blue to black (Bortle 2-1).

Gainesville Urban Core (Bortle 7) where Milky Way is invisible.

Paynes Prairie & Rosemary Hill Observatory (Bortle 4), where the Milky Way is visible but lacks detail, and prominent light domes from Gainesville are apparent, threatening UF's scientific and educational assets.



Light Pollution Map *from LightPollutionMap.info*

Stephen C. Foster - Georgia State Park (Bortle 2) IDA Dark Sky status, Milky Way is clearly visible. P*hoto: Jay Rosen, Oct 2020 (3-minute exposure).*

Payne's Prairie - Florida State Park (Bortle 4) Light pollution on horizon, Milky Way barely visible. *Photo: Jay Rosen, May 2022 (26-minute exposure).*

UF skyglow (Bortle 7) seen from Payne's Prairie
The combined light from UF facilities (right) blot out the sky and appear brighter than lightning (left). *Photo: Jay Rosen, July 2020*

Rosemary Hill Observatory (Bortle 4) Light Pollution threatens UF's observatory.
Photo: The Gainesville Sun, April 2012

Dark Sky Regulations

The Alachua County Environmental Protection Advisory Committee (EPAC) advises the Alachua County Commission on safeguarding the county's natural resources. EPAC's work plan for 2026 includes encouraging policy makers to implement Dark Sky regulations, promoting responsible outdoor lighting practices, and to work toward achieving International Dark Sky Park status for Payne's Prairie Preserve State Park.

DarkSky International (formerly the International Dark-Sky Association) recognizes communities, parks, and reserves that demonstrate exceptional commitment to preserving dark skies through responsible lighting policies and practices. Certification provides a framework for achieving measurable improvements in lighting quality while building community pride and economic benefits.

Dark Sky Certification tracks progress across five weighted requirements: comprehensive lighting ordinance (30%), public streetlight retrofits (25%), protected dark sky zones (20%), community education (15%), and sky brightness monitoring (10%).

Economic Benefits

- **Tourism revenue:** Astro-tourism can bring millions in economic impact
- **Energy savings:** Better lighting design reduces electricity costs
- **Property values:** Dark sky designation can increase property values
- **Business attraction:** Certification attracts environmentally conscious businesses
- **Grant opportunities:** Access to environmental and tourism grants

Environmental & Social Benefits

- **Wildlife protection:** Reduced impact on nocturnal animals
- **Human health:** Better sleep and reduced light pollution exposure
- **Cultural heritage:** Preservation of night sky viewing
- **Community pride:** Recognition as an environmental leader
- **Education opportunities:** Science and environmental education programs

Types of Dark Sky Places

International Dark Sky Communities (Most Relevant)

Towns, cities, or regions that adopt comprehensive lighting ordinances and demonstrate measurable improvements in light pollution reduction. These communities balance growth and development with environmental stewardship.

Examples: Flagstaff (AZ), Sedona (AZ), Bon Accord (Canada), Moffat (Scotland)

International Dark Sky Parks (Protected Areas)

Public or private parks with exceptional quality of starry nights and commitment to protecting dark sky resources for present and future generations.

Examples: Death Valley, Big Bend, Natural Bridges, Brecon Beacons

International Dark Sky Reserves (Large Areas)

Large areas consisting of a dark "core" zone surrounded by a populated "buffer" zone where communities work together to reduce light pollution. Examples: Central Idaho, Mont-Mégantic (Canada), Rhön (Germany), Aoraki Mackenzie (New Zealand)

Community Certification Process

1. **Initial Assessment & Commitment**
   Evaluate current lighting conditions, build community support, and secure government commitment to pursue certification. Form a working group of stakeholders. (Timeline: 3-6 months)

2. **Develop Lighting Ordinance**
   Create or strengthen existing lighting ordinances to meet DarkSky International standards. Must address fixture shielding, color temperature, timing controls, and light levels.
   Timeline: 6-12 months

3. **Implementation & Compliance**
   Implement ordinance requirements, conduct lighting audits, and achieve substantial compliance with new standards. Document improvements through photography and measurements. (Timeline: 1-3 years)

4. **Application & Review**
   Submit comprehensive application including ordinance documentation, compliance evidence, and community commitment letters. Undergo site visit and review by DarkSky International. (Timeline: 6-12 months)

5. **Certification & Ongoing Commitment**

   Receive designation and commit to ongoing compliance monitoring, community education, and continuous improvement. Participating in 5-year recertification process. (Timeline: Ongoing)

Progression towards Dark Sky compliance
Properly shielded lighting minimizes light pollution.
Illustration: LED Lighting Supply

Dark Sky Cities

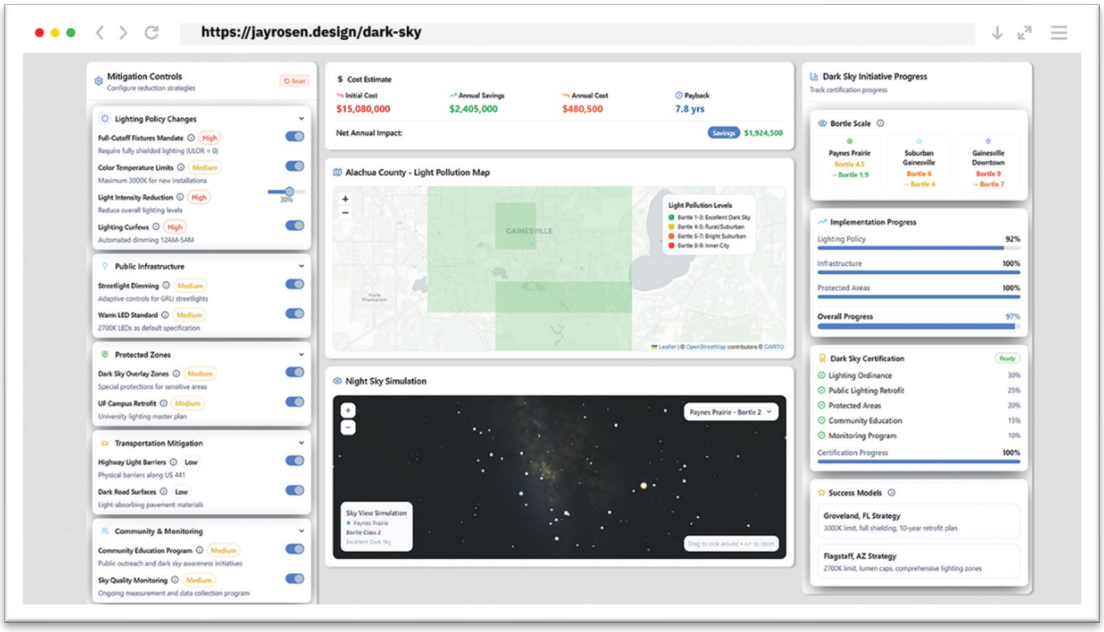
Groveland, Florida
- Urban Area: Bortle 4
- Suburban & Outskirts: Bortle 3

- First city in Florida to achieve Dark Sky status
- 3000K CCT limit for all outdoor lighting
- Required full cutoff fixtures for new installations
- 10-year retrofit plan for existing streetlights
- Strong community education program

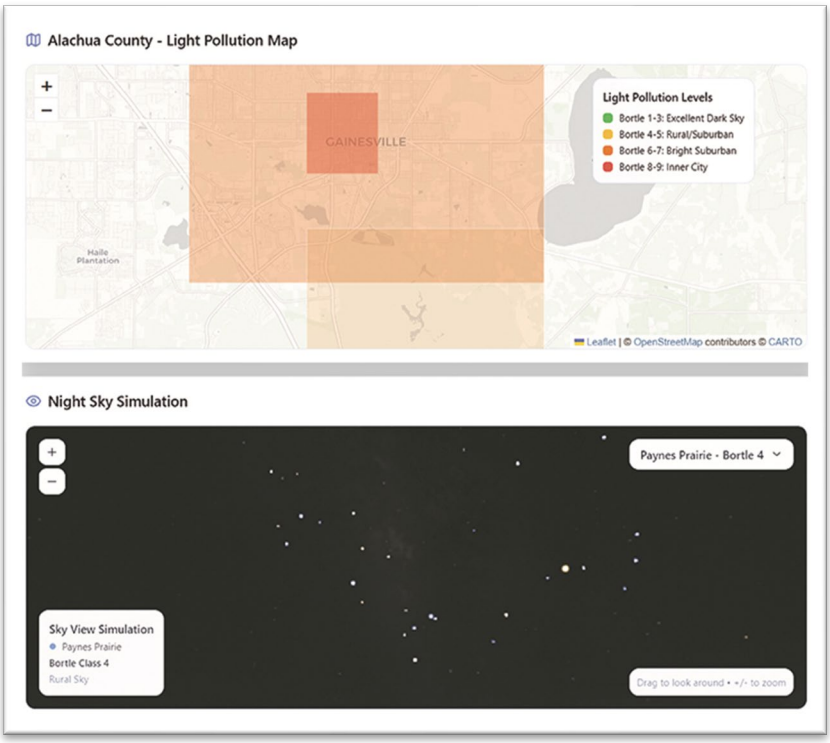
Flagstaff, Arizona
- Urban Area: Bortle 4-5
- Suburban & Outskirts: Bortle 2-3

- World's first International Dark Sky City (2001)
- Comprehensive lighting ordinance since 1999
- 2700K CCT limit with lumen caps
- Extensive lighting zones based on land use
- Partnership with Lowell Observatory

Dark Sky Simulator - https://jayrosen.design/dark-sky



Simulation of Payne's Prairie with "Flagstaff, AZ Strategy" mitigations applied.



Simulation of Payne's Prairie in current state (no mitigations applied).

Mitigation Controls

Lighting Policy Changes

Full-Cutoff Fixtures Mandate (High) - Require fully shielded lighting (ULOR = 0)

Color Temperature Limits (Medium) - Maximum 3000K for new installations

Light Intensity Reduction (High) - Reduce overall lighting levels, scale from 0% - 50%

Lighting Curfews - Automated dimming 12AM-5AM (High)

Public Infrastructure

Streetlight Dimming (Medium) - Adaptive controls for GRU Streetlights

Warm LED Standard (Medium) - 2700K LEDs as default specification

Protected Zones

Dark Sky Overlay Zones (Medium) - Special protection for sensitive areas

UF Campus Retrofit (Medium) - University lighting master plan

Transportation Mitigation

Highway Light Barriers (Low) - Physical barriers along US 441

Dark Road Surfaces (Low) - Light-absorbing pavement materials

Community & Monitoring

Community Education Program (Medium) - Public outreach and dark sky awareness initiatives

Sky Quality Monitoring (Medium) - Ongoing measurement and data collection program

Projected Impact

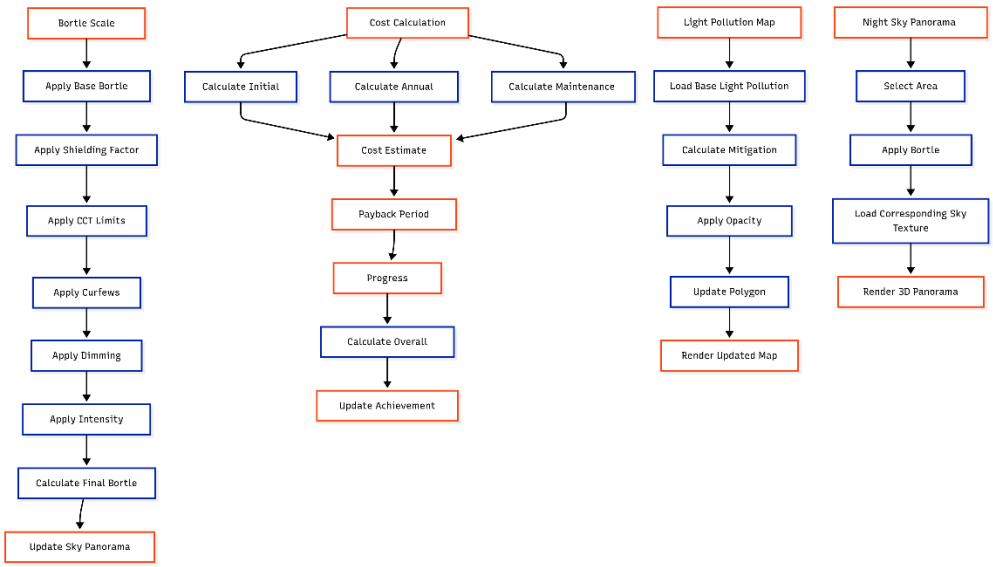
$1.9 Million Net Annual Savings

The Dark Sky Simulator estimates that if all mitigations are put into effect, Paynes Prairie can be reduced from Bortle 4 to 2, and the urban areas of Gainesville reduced from Bortle 7 to 3. These images from the app show the before (orange map) and after (green map) simulated mitigations are applied. The light pollution map and a 360 panorama of the night sky demonstrate the observable change in Milky Way.

Implementing county-wide Dark Sky regulations requires an estimated initial investment of $15 million and $480,000 in annual maintenance. The program is projected to generate $2.4 million in yearly energy savings, resulting in net annual savings of $1.9 million and a full return on investment in approximately 7.8 years.

System Architecture & Data Flow

This diagram illustrates how the Dark Sky Simulator processes user inputs to calculate mitigation costs, update Bortle classifications, and dynamically render both the light pollution map and night sky visualization.



Key Processing Components

Cost Calculation Engine

Processes each mitigation setting to calculate initial implementation costs, annual energy savings, maintenance expenses, and payback periods based on predefined cost data matrices.

Bortle Scale Calculator

Apply multiplicative reduction factors to base Bortle classifications, with each mitigation strategy contributing specific percentage improvements to overall light pollution levels.

Map Renderer

Dynamically updates polygon opacity and colors on the Leaflet map to visualize light pollution reduction in real-time as mitigation settings change.

Calculation Methodology

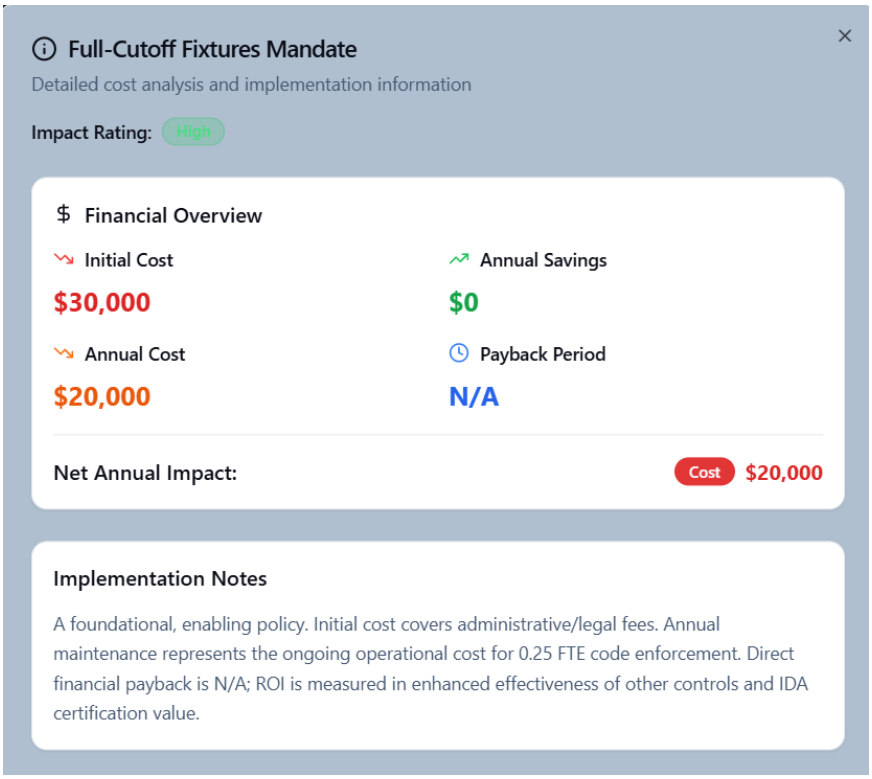
Mitigation Factors

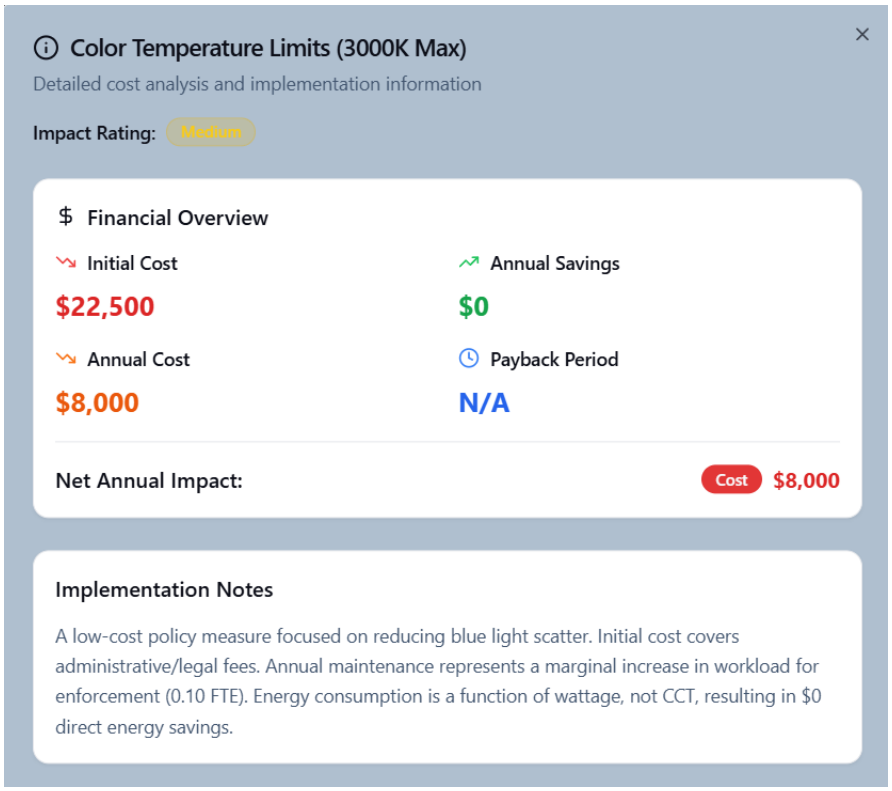
- **Full Shielding:** 25% reduction (0.75x factor)
- **CCT Limits:** 15% reduction (0.85x factor)
- **Curfews:** 30% reduction (0.70x factor)
- **Dimming:** 10% reduction (0.90x factor)
- I**ntensity:** Variable 0-50% reduction

Sky Texture Selection

Each calculated Bortle class (1-9) corresponds to a specific panoramic sky texture that accurately represents star visibility and atmospheric glow levels for that light pollution category.

Mitigation Controls Cost Estimate screens.





Light Intensity Reduction (Variable 0-50%)

Detailed cost analysis and implementation information

Impact Rating: High

Financial Overview

Initial Cost	Annual Savings
$7,750,000	$450,000
Annual Cost	**Payback Period**
$75,000	14.8 yrs

Net Annual Impact: Savings $525,000

Implementation Notes

A capital-intensive program assuming a 30% average reduction across GRU streetlights and commercial fixtures. Annual savings include $450k energy savings and $75k maintenance savings from extended LED lifespan.

Lighting Curfews (12AM-5AM Dimming)

Detailed cost analysis and implementation information

Impact Rating: High

Financial Overview

Initial Cost	Annual Savings
$1,250,000	$1,600,000
Annual Cost	**Payback Period**
$50,000	1 yrs

Net Annual Impact: Savings $1,550,000

Implementation Notes

Offers the most rapid financial return. Initial cost covers installation of simple timers for 5,000 businesses. Annual savings are substantial for the community business sector, leading to a payback period of less than one year for individual businesses.

Streetlight Dimming (Adaptive Controls)

Detailed cost analysis and implementation information

Impact Rating: Medium

Financial Overview

Initial Cost	Annual Savings
$6,060,000	$420,000
Annual Cost	**Payback Period**
$420,000	15 yrs

Net Annual Impact: Savings $0

Implementation Notes

A major capital project to upgrade 30,000 GRU fixtures. Annual energy savings are projected to be offset by annual Software-as-a-Service (SaaS) licensing fees and network management costs, resulting in a net annual impact near zero, extending the payback period.

Warm LED Standard (2700K Default)

Detailed cost analysis and implementation information

Impact Rating: Medium

Financial Overview

Initial Cost	Annual Savings
$5,000	$0
Annual Cost	**Payback Period**
$0	N/A

Net Annual Impact: Savings $0

Implementation Notes

A procurement policy change with minimal administrative cost (<$5,000). It is financially neutral but sets a gold standard for municipal leadership.

Warm LED Standard (2700K Default)

Detailed cost analysis and implementation information

Impact Rating: Medium

Financial Overview

Initial Cost	Annual Savings
$5,000	$0
Annual Cost	**Payback Period**
$0	N/A

Net Annual Impact: Savings $0

Implementation Notes

A procurement policy change with minimal administrative cost (<$5,000). It is financially neutral but sets a gold standard for municipal leadership.

Dark Sky Overlay Zones

Detailed cost analysis and implementation information

Impact Rating: Medium

Financial Overview

Initial Cost	Annual Savings
$115,000	$0
Annual Cost	**Payback Period**
$20,000	N/A

Net Annual Impact: Cost $20,000

Implementation Notes

Strategic planning initiative. Initial cost includes planning, legal fees, and a grant program seed fund. Annual cost is for enhanced enforcement. ROI is derived indirectly from astrotourism and enhanced property values, not direct savings.

UF Campus Retrofit

Detailed cost analysis and implementation information

Impact Rating: Medium

Financial Overview

Initial Cost	Annual Savings
$4,000,000	$250,000
Annual Cost	**Payback Period**
$100,000	11.4 yrs

Net Annual Impact: Savings $350,000

Implementation Notes

Keystone project, with costs borne by the University of Florida (UF). Savings accrue to UF ($350,000 net annual impact from energy and maintenance reductions).

Highway Light Barriers (US 441)

Detailed cost analysis and implementation information

Impact Rating: Low

Financial Overview

Initial Cost	Annual Savings
$500,000	$0
Annual Cost	**Payback Period**
$10,000	N/A

Net Annual Impact: Cost $10,000

Implementation Notes

Extremely high-cost protective measure, estimated at over $500,000 per mile. Provides no financial return and incurs ongoing maintenance liability. Justified only for high-value assets.

Dark Road Surfaces (Low-Albedo Materials)

Detailed cost analysis and implementation information

Impact Rating: Low

Financial Overview

Initial Cost	Annual Savings
$750,000	$0
Annual Cost	**Payback Period**
$5,000	N/A

Net Annual Impact: Cost $5,000

Implementation Notes

High-cost strategy whose implementation is viable only when integrated into existing resurfacing schedules as a material premium (estimated 15% premium). No direct financial return, and may lead to potentially higher maintenance costs.

Community Education Program

Detailed cost analysis and implementation information

Impact Rating: Medium

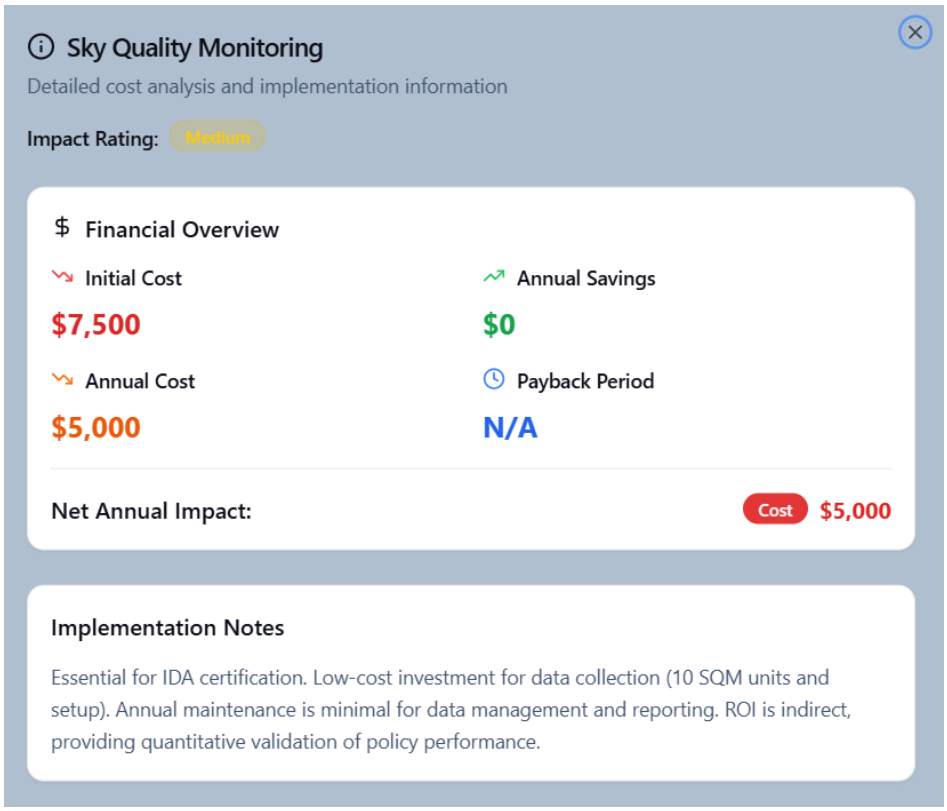
Financial Overview

Initial Cost	Annual Savings
$15,000	$0
Annual Cost	**Payback Period**
$65,000	N/A

Net Annual Impact: Cost $65,000

Implementation Notes

Essential for IDA certification. Initial cost covers materials development; annual maintenance represents the ongoing operational budget for staffing and events. ROI is indirect, realized through increased voluntary compliance and sustained political support.



Policies & Solutions

Well-designed lighting ordinances can dramatically reduce light pollution while maintaining safety and security. The most effective policies combine fixture standards, timing controls, and lighting levels appropriate for different zones. These regulations protect both human health and wildlife while often reducing energy costs.

Essential Policy Components

Fixture Shielding Requirements — Critical

Require fully shielded fixtures that direct light downward where needed, eliminating upward light emission.

Full Cutoff	Cutoff	Semi-Cutoff
0% upward light	≤2.5% upward light	≤5% upward light

Color Temperature Limits — Important

Restrict lighting to warmer colors that scatter less in the atmosphere and have lower biological impact.

≤2200K	3000K	4100K	5000K+
Amber/LPS	Warm White	Neutral	Cool White

Timing and Controls — Effective

Implement curfews and adaptive controls to reduce unnecessary lighting during low-activity periods.

Curfew Ordinances	Adaptive Controls
Turn off decorative/advertising lights after 11 PM	Motion sensors, dimming, smart controls

Lighting Zones — Flexible

Establish different lighting standards for different areas based on usage and environmental sensitivity.

E0-E1	E2	E3	E4
Dark/Rural	Residential	Commercial	High Activity

Model Ordinance Framework

Core Requirements

- All new fixtures must be fully shielded
- Maximum 3000K color temperature
- Lighting curfews for non-essential lighting
- Illumination level limits by zone
- Glare control requirements

Implementation Support

- Technical assistance for compliance
- Approved fixture lists and guides
- Reasonable replacement schedules
- Enforcement procedures and penalties
- Regular ordinance review and updates

Success Tip

Start with a simple, clear ordinance focused on the most impactful changes. Build on early successes and community support to strengthen and expand protections over time.