An Investigation on the Pervasiveness of Light Pollution in Urban Areas within the Rocky Mountain West Region

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Abstract

Recent studies indicate light pollution can create adverse medical and ecological effects when combined with growth within urban environments. Growth is delineated as the change in land use composition and increases in city boundaries over time, meaning that development is an indicator of growth. The adverse medical and ecological effects of nighttime artificial lighting combined with the pervasiveness of light pollution in urban environments provides suitable motivation for this study. The purpose of this research is to create an understanding of how growth, defined in terms of population growth and urban growth, changes the amount of light pollution present.

Three of the fastest growing cities in the Rocky Mountain West, Albuquerque, New Mexico, Phoenix, Arizona, and Colorado Springs, Colorado, were examined at multiple levels of assessment including a GIS analysis of NASA Visible Infrared Imaging Radiometer Suite (VIIRS) and collected field data at various points within the greater metropolitan area of the three cities. The on-the-ground collected data indicated that creating an analysis of light pollution solely based on VIIRS data is not a comprehensive indicator of the lightscape of an urban environment. Therefore, a combination of collected data with VIIRS data would create a more complete picture of the lightscape. A comparison between 2012 and 2023 VIIRS data, a land use change analysis between the 1960s and 2023, sound decibel readings, crime and census data, and local and expert interviews indicate that growth within an urban environment does increase the amount of light pollution present in a visible and personal way affecting the lives of individuals. However, there is a glaring lack in policy initiatives and action within local governments besides those of nonprofit groups like Dark Sky International (DSI). These results support the hypothesis that urban growth and development lead to increased light pollution. Our research identified Albuquerque as the darkest city and Phoenix as the most light-polluted city. Between 2012 and 2023, Colorado Springs has had the most growth, considering land use change over time, as well as seeing the largest increase in brightest ranges of light pixels and is where the brightest 'on-the-ground' measurement was recorded. Commercial industries are identified as the largest contributors to light pollution and residential areas typically have lower levels of light pollution. Finally, interviews express that light pollution is an extremely pressing issue and is closely affiliated with development and urban growth/expansion. It is also clear that it is a relatively easy issue to solve as long as there is a willingness to do so.

Introduction

Light pollution is an issue that is gaining momentum in ecology, but also in the realm of health and urban planning. It refers to the addition of anthropogenic lighting making an area brighter than it is supposed to be naturally, and it takes on multiple forms including glare, sky glow, light trespass, and clutter (Dark Skies International n.d). Additionally, just like "other pollutants do," light pollution propagates in the atmosphere limiting the visibility of the night sky (Cinzano & Falchi 2012, 3353).

Light pollution is a threat because "most organisms, including humans, have evolved molecular circadian clocks controlled by natural day-night cycles" that regulate metabolism, growth, and behavior (Hölker 2010, 681). The introduction of light at night causes the "absence of [an] external cue" which may cause the circadian rhythm to "drift out of phase with day and night" (Gaston 2013, 919). Building on the negative consequences of light pollution demonstrated by ecological research, the American Medical Association submitted a press release on a resolution that "designated LP as a public health hazard" due to its harms on human health that include "disruptions to sleep and mood, circadian rhythms and melatonin production,; activation of stress hormones and related impacts such as increased risk of certain cancers and cardiovascular disease" (Pothukuchi 2023, 6). Beyond health risks, "[l]ight at the wrong place and time wastes energy and money and exacerbates climate change" by emitting tons of greenhouse gases into the atmosphere (Pothukuchi 2021, 159).

The current regulations and ordinances in place to control light pollution are far from sufficient as only "19 states, the District of Columbia and Puerto Rico have laws in place to reduce light pollution" and the large majority of planning scholarship in the United States have been "relatively silent on these issues and on related policy making, regulation, and partnerships" (NCSL) (Pothukuchi 2021, 155). The current recommended approach to tackle this issue of light pollution is to "(i) prevent areas from being artificially lit, (ii) limit the duration of lighting, (iii) reduce the 'trespass' of lighting into areas that are not intended to be lit (including the night sky), (iv) change the intensity of lighting; and (v) change the spectral composition of lighting" (Gaston 2012, 1256).

In an attempt to better understand light pollution in urban environments, this study will focus on light pollution and its underregulation as cities continue their growth. It has been found that the main drivers of urban growth consist of transportation and housing supply, amenities, human capital and entrepreneurship, and technology and "shocks to specific cities or industries" (Duranton & Puga 2014, 845).

Policy studies suggest that urbanization is the root cause of the "sprawling explosion of outdoor light at night," and, despite this evidence, it is "largely ignored by planners" (Pothukuchi 2021, 155). Local policies are important and are at the forefront of regulating artificial lighting; however, even these municipal ordinances are "plagued by lack of definition, merely encouraging language, or arbitrary measures" (Pothukuchi 2023, 26).

The adverse medical and ecological effects of nighttime artificial lighting combined with the pervasiveness of light pollution in urban environments provides suitable motivation for this study. The research conducted in this paper will address the following question: How does development and light pollution interact in urban environments?

To answer this question, three of the largest cities in the Rocky Mountain West region, Albuquerque, New Mexico, Phoenix, Arizona, and Colorado Springs, Colorado will be examined at multiple levels of observation. This includes consideration of NASA Visible Infrared Imaging Radiometer Suite (VIIRS) data as well as collected on-the-ground data, a comparison between 2012 and 2023 VIIRS data, a land cover/use change analysis between the 1960s and 2023, sound decibel readings, crime and census data, and local and expert interviews.

We hypothesize that light pollution is strongly related to urban development and population growth, where the more development there is, the more light pollution there will be.

Study Area

2.1 Location Selection (Cities)

Three urban areas within the Rocky Mountain Region of the United States were selected for this study. These cities Albuquerque, New Mexico; Phoenix, Arizona; and Colorado Springs, Colorado were selected because of the significant expansion in aerial extent of the cities and population growth over the last decade. We collected light and sound data at fifteen locations in each study city, interviewed city council and community members.

2.1.1 Albuquerque, New Mexico

Albuquerque was selected as a research site for this project because of an historical growth in population over the last twenty years. From 2000 to 2020, the total population increased from 450, 971 to 564, 855. (Neilsberg Research). Between 1980 and 1990, the population increased over 50,000 people (Gregory 2008). The key factors leading development in Albuquerque's market is the development of solar energy systems and computer equipment (Britannica.com). This growth calls into question the environmental impacts from the addition of this many people and households (Gregory 2008). Currently, areas of environmental concern receiving increased attention include water availability, quality, and usage and air quality issues (Gregory 2008).

The city of Albuquerque has publicly accessible interactive zoning maps and annual progress reports spanning from 2004 to 2022. Within the 2022 progress report, goals 1, 3, 4, and 5 are of interest to this project as many of these sub-sects are labeled as “Needs Improvement” and there is no mention of light pollution within the document (City of Albuquerque, 2022).

2.1.2 Phoenix, Arizona

Phoenix is a site of interest because it is one of the largest cities in the nation and the population is still on the rise. Between 2021 and 2022 the Phoenix metro area surpassed a population of 5 million, with Maricopa County being one of the five counties with the largest numeric gains in housing units in the nation between July 1, 2021, and July 1, 2022 (United States Census Bureau). Fueling the city’s development is “the arrival of tech companies and middle-class families from California and other more expensive parts of the country seeking more affordable housing” (New York Times, 2021). As the city continues to grow it continues to sprawl into the surrounding deserts, and this growth has added to increased anxieties regarding water availability and drought preparedness (New York Times, 2021).

The Phoenix metropolitan area's city officials have historically focused on specific areas for development, such as the northeast and southeast, while also maintaining various goals that outline that the city should maintain a high quality of life and an economically healthy community (City of Phoenix, 2015). Examining light pollution within the area will provide a standard for large cities.

2.1.3 Colorado Springs, Colorado

Colorado Springs, located on the Rocky Mountain front range in south central Colorado, was selected as another site where population growth has reached historical levels; it is listed as one of the largest cities in the Mountain West region) (Telada & Brown 2021). During the COVID-19 pandemic, Colorado added around 38,000 new residents, and currently Colorado Springs is home to about 67% of El Paso County residents (Boise Public Radio; PlanCOS). New housing units, attractive markets for retail and food, military presence, and scenic views have paved the way for the increased populations and development of the area (Laden & Murdock, 2023). The city government acknowledges that Colorado Springs is growing and has identified vacant land for development as well as outlined a plan for outward growth (PlanCOS). Why permit the city to continue to expand and what kind of environmental effects will this growth continue to have? What are the city's priorities when faced with development and increased populations?

Methods

3.1 Location Selection (Sites)

Visible Infrared Imaging Radiometer Suite (VIIRS) data for January 2024 was downloaded from the Earth Observation Group at Colorado School of Mines and uploaded into ArcGIS Pro to create a change over time analysis and visualization. VIIRS data was selected because it measures irradiance of light in W/(cm^2 -sr) which can be used to inform light pollution studies. XY data was added to the visible layer to create data points at the center of each pixel to understand the irradiance at the central point as opposed to the dispersed emittance. The range of colors selected for the brightest locations are yellows, medium brightest are orange, and the darkest locations are red. Within this symbology, for Phoenix and Albuquerque, the brightest locations ranged from 294-893.61 (Red/Yellow), medium 41.634-97.73 (Green), and darkest 10.079-41.633 (Blue). For Colorado Springs, the brightest locations range from 144.839-351.75 (Red), medium 33.1075-144.838 (Yellow/Green), and darkest 9.65-33.106 (Blue). These differences in table values and ranges are due to regional differences of where the cities are situated and clipped data values. This is because different cities have different ranges of intensities of brightness, for example, a city like Phoenix which is one of the largest cities in the nation, will have brighter lights than a city like Albuquerque due to population density and city regulations. The data points were then limited to the appropriate county (El Paso, Bernalillo, and Maricopa) and then further limited to the greater metropolitan areas of each city. This study used the greater metropolitan areas due to the irregular spread of nighttime lighting. Light is not confined to its source, so to get the most accurate information for this study, the greater metro-areas were selected rather than city centers. For each city, the data points were ranked in descending order of "brightness of light" according to the gradient of VIIRS measurements and the handheld light meter measurements. A total of 15 measurement sites were identified (5 light, 5 medium, 5 dark locations). Based on the categorized value ranges, locations 1-5 are noted as light locations, 6-10 medium, and 11-15 dark. These median values were determined by finding the median of the attribute table rows found within the ranges of light/medium/dark values. Selecting the median value based on row number in the attribute table rather than data number, ensures standardization for all point selection regardless of measurement values in the table. After these sites were selected, GPS coordinates of each site were obtained via x and y coordinates on the attribute table. These coordinates were placed into a separate Google Maps list and labeled with the site number and VIIRS data measurement.

3.2 On-Site Measurements (Day)

Each location was visited during the day to document what each site looked like during the day to identify the types of buildings that were present as well as potential contributors to light pollution. This time was also used to appropriately refine the GPS coordinates that we would be using to collect data during the night. These changes were made to respect private property and ensure no trespassing. Standing in the same GPS located spot in each of the 15 sites, four photos were taken, 90 degrees apart following cardinal directions in order of north, east, south, west, using a compass.

3.3 On-Site Measurements (Night)

Night Time data was collected from 5/27/24 to 6/29/24 between 9:30 PM and 1:00 AM at the previously designated GPS coordinates. If adjustments were made between day and night, a note will be made. Standing in the same location, four new photos would be taken in the same way as the daytime photos. In addition to the photos, data would be collected using a Sky Quality Meter measuring sky brightness on mag/(arcsec)^2. Four measurements were collected 90 degrees apart and then averaged to generate one value per site. While photos and measurements were collected, a Roland Sound Recorder was used to record the sounds of the area for 10 minutes.

3.4 VIIRS Reclassification (Comparison between 2012 and 2024)

In addition to the 2024 VIIRS data used for the comparison between VIIRS data and collected data, 2012 VIIRS data was downloaded from the Earth Observation Group by Colorado School of Mines for reclassification analysis. Data was divided into 20 different categories based on VIIRS value. This was used to create a measurement of the abundance of certain levels of light pollution that were present in 2012 and to create a comparison with the 2024 data.

3.5 Sound Decibel Analysis

Ten minute sound recordings were collected using the Roland Sound Recorder at night at each of the study sites. The recordings were processed through the Audacity version 3.7.2 software to visualize sound waves and report decibels.

3.6 Aerial Imagery

The historical aerial imagery used across all cities range from 1958 to 1964. All of these aerial images were georeferenced by hand using ArcGIS Pro, with an exception of Albuquerque which were already geocoded.

For Albuquerque, New Mexico, aerial images from 1961 were provided by the City of Albuquerque Planning Department AGIS Division. For Phoenix, Arizona, aerial images from

1958 and 1964 were provided by Arizona State University's Map and Geospatial Hub. Colorado Springs, Colorado's aerial images from 1963 were provided by the University of Colorado at Boulder's Map Library Program and courtesy of the Colorado Aerial Photo Service.

3.7 Digitization of Land Cover

Land cover was analyzed by 1.5 miles by 1.5 miles. The same perimeter size was used to delineate each of the 15 study sites per city. To conduct this analysis, historical aerial images were georeferenced and land cover was categorized to include residential, commercial, industrial, water features, and open land. The amount of land cover per category, in hectares, was then compared to the amount of land cover per category in 2023. The 2023 land cover data was based on identifiable features on the 2023 ArcGIS Pro satellite imagery base map.

3.8 Census Layers

Census layers were added using 2023 data for the following categories:

- Household median income
- Detailed Race including Population of one race: White, Black or African American, Asian, and Hispanic or Latino Origin

These Census layers were added and analyzed to see if there is any correlation between population types or incomes and light pollution. This information aims to identify what demographic factors could contribute to light pollution.

3.9 Crime Data

Crime data ranging from January 1, 2023- June 30, 2024 was collected from the Colorado Springs and Albuquerque Police Departments. The Arizona Uniform Crime Reporting (UCR) Program stated that the state repository does not release geolocation. The data downloaded for Albuquerque and Colorado Springs were uploaded to ArcGIS and a dynamic heat map was created.

Crime data was considered with a similar purpose as the Census data, to determine if there is any correlation between light pollution and the amount of crime present in an area.

3.10 Interviews

Throughout the course of this research project interviews were conducted in order to gain insight into the local processes in action to counter light pollution and if light pollution is even considered an issue. Interviewees were also asked for their personal opinions on light pollution and the role that it plays in urban planning and development. Individuals were selected for interviews based on their occupation and relevance of insight. This includes relevant city council members, experts, and community members. Consent to be interviewed was obtained via a standard consent form to conduct the interviews and use quotes and information collected. Individuals were asked a series of questions pertaining to their specific experience and profession. The following is a list of individuals interviewed for this project:

- John Sanchez - Owner of United Storage ABQ
- Debra Stark - Vice Mayor of Phoenix
- Colby Foos - Vice Chair of the Colorado Springs Planning Commission and Director of Southern Colorado of Weifield Group Contracting
- Elizabeth Mays - National Center for Atmospheric Research Science Outreach and Education Department

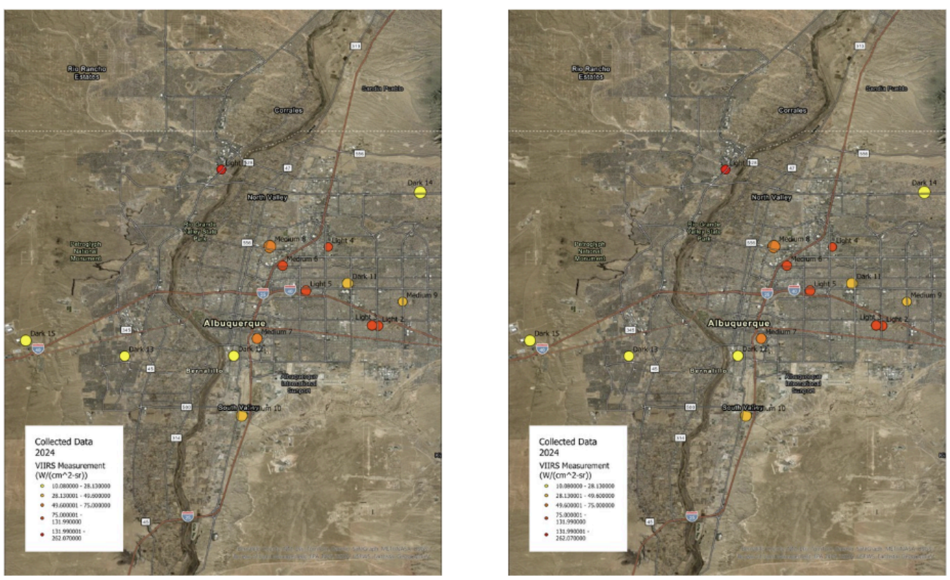
- Dr. Jeffery Hall - Executive Director of Lowell Observatory in Flagstaff and former Chair of the American Astronomical Society's Committee for the Protection of Astronomy and the Space Environment (COMPASSE)
- Dr. Christian Luginbuhl - Chair of the Flagstaff Dark Sky Coalition, founder of Dark Sky LLC, and former staff of the US Naval Observatory
- John Barentine - Executive Director and Principal Consultant at Dark Sky Consulting LLC and former Director of Public Policy for Dark Sky International
- Michael Rymer - Program Associate of Advocacy at Dark Sky International

Results

4.1 Albuquerque, NM

4.1.1 Collected data versus VIIRS data

Comparing the collected on-the-ground data with the VIIRS measurements, it becomes clear that there is some disagreement between the levels of light pollution present in the sky versus on the ground. This is why it is important to consider both variables together when making judgements of light pollution as light naturally disperses. The only two points where the collected and VIIRS data aligned were locations 6 and 11. Figure 1 shows a side by side comparison of the locations and their brightness using GIS.



Collected Measurements   VIIRS Measurements

Figure 1: Two panels of GIS imagery of the greater Albuquerque area. The dots indicate points where light measurements were collected. The coloration demonstrates the intensity of light measured at each location, with yellow being the brightest and dark red being the darkest. The left denotes the collected measurements from the ground and the right represents the VIIRS measurements collected aerially.

As well as the differences between the collected measurements and the VIIRS measurements, Figure 2, aGIS map, shows both the data collection sites and the broader VIIRs measurements across the city of Albuquerque. This map is to help better understand where as well as visualize the data collection sites and their measurements fall in terms of VIIRS data.

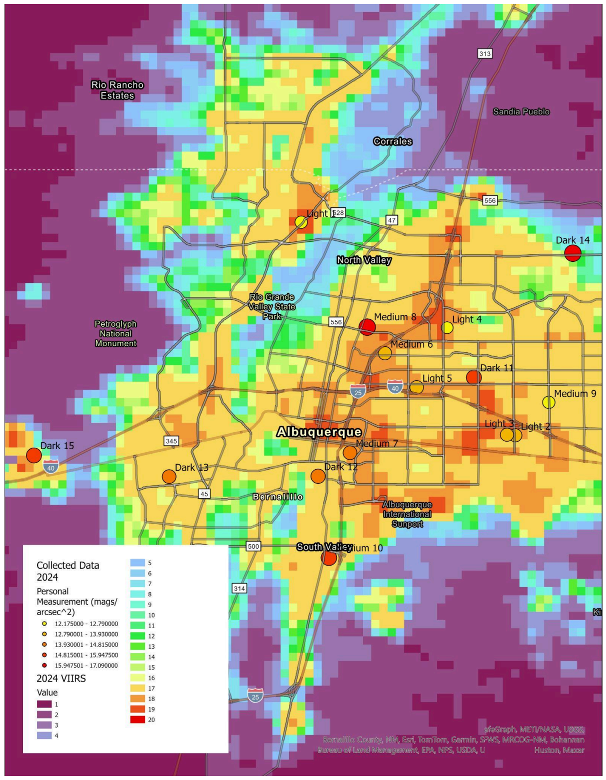


Figure 2: This GIS map situates the data collection sites in the broader imagery of VIIRS data in Albuquerque, New Mexico.

The VIIRS data indicates the Larry H. Miller Casa Chrysler Jeep site, labeled as 'light 1,' was the brightest location in greater Albuquerque with a measurement of 262.07 W/(cm^2-sr; Figures 2 and 3). However, when compared to our field measurements, light 4, the Goodwill off of San Mateo Blvd NE McLeod Rd NE, was the brightest location with a measurement of 12.175 mags/$arcsec^2$.

Figure 3: Light 1 Albuquerque, East facing during the day. Facing away from Larry H. Miller Casa Chrysler Jeep. Light 1 is the brightest location in Albuquerque, according to VIIRS.

Figure 4: Light 1 Albuquerque, East facing at night. The light from behind the camera is coming from Larry H. Miller Casa Chrysler Jeep. The VIIRS value of this location is 262.07 W/(cm2-sr). The collected measurement for this location is 12.79 mags/arcsec^2.

Figure 5: Light 4 Albuquerque, the Goodwill off of San Mateo Blvd NE McLeod Rd NE. South facing during the day.

Figure 6: Light 4 Albuquerque, the Goodwill off of San Mateo Blvd NE McLeod Rd NE. South facing at night. The VIIRS value of this location is 105.33 W/(cm2-sr). The collected measurement for this location is 12.175 mags/arcsec^2.

According to the VIIRS data, the darkest location, dark 15, was the intersection between Atrisco Vida Blvd and Tempur Pedic Pkwy with a measurement of 10.08 W/(cm^2-sr). The field data collected indicated the end of El Ensueño Rd NE, medium 8, as the darkest location in greater Albuquerque with 17.09 mags/arcsec^2.

Figure 7: Medium 8 Albuquerque, East facing during the day of El Ensueño Rd NE.

Figure 8: Medium 8 Albuquerque, east-facing of the end of El Ensueño Rd NE during the night. The VIIRS value of this location is 60.68 W/(cm2-sr). The collected measurement for this location is 17.09 mags/arcsec^2.

Figure 9: Dark 15 Albuquerque, east-facing of the intersection between Atrisco Vista Blvd and Tempur Pedic Pkwy during the day. Dark 15 is the darkest location in Albuquerque, according to VIIRS data.

Figure 10: Dark 15 Albuquerque, east-facing of the intersection between Atrisco Vista Blvd and Tempur Pedic Pkwy during the night. The VIIRS value of this location is 10.08 W/(cm2-sr). The collected measurement for this location is 15.54 mags/arcsec^2.

The table below shows the VIIRS and collected measurements for the locations pictured above as well as the land cover category of the surrounding area. The GPS coordinates where the collected measurements were taken are included.

Table 1: Locations and Data for Research Sites 1 , 4, 8, and 15 in Albuquerque, NM (See Table 1 in the Appendix)

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	262.07	12.79	(35.191288, -106.658328)	Commercial
Light 4	105.33	12.175	(35.1377563, -106.5844806)	Commercial
Medium 8	60.68	17.09	(35.1380614, -106.624889)	Commercial
Dark 15	10.08	15.54	(35.0730284, -106.7935549)	Commercial

4.1.2 VIIRS Change over time (2012 vs. 2024)

Between 2012 and 2024 Albuquerque saw, on average, a 73.90% increase in light pollution. Reclassification category 19, which includes the values between 114.43576 and 265.343506 W/(cm^2-sr), saw a 942.86% increase. In 2012, there were only 7 values that fell within the range and in 2024 there were 73. Meanwhile, reclassification category 15, ranging from 14.524425 to 15.565168 W/(cm^2-sr), saw a 17.29% decrease. In 2012 there were 113 values and in 2024 there were only 90.

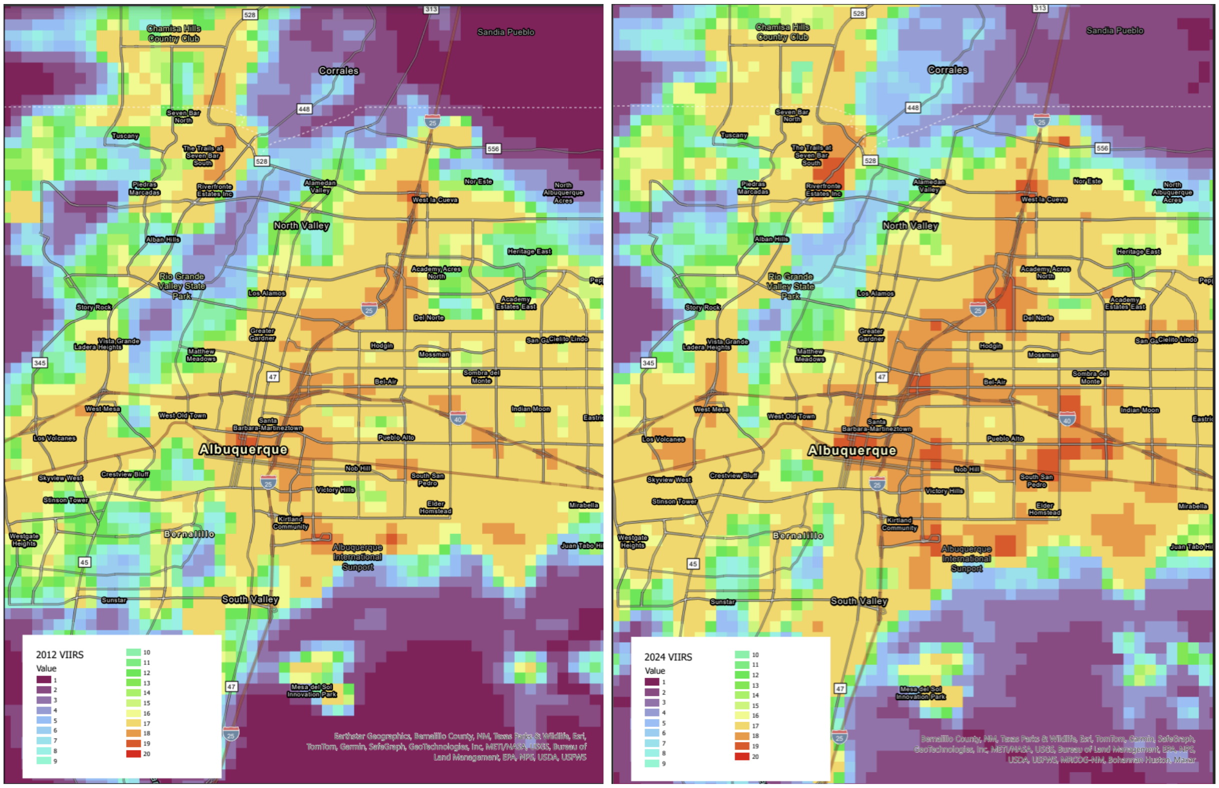


Figure 11: The images above demonstrate the reclassified VIIRS data to demonstrate the difference in abundances of higher values found between 2012 and 2024. The darker purple denotes the darker areas and the bright red and oranges represent the brightest areas according to VIIRS. The data was reclassified to make it comparable across time. It can be seen that the image on the right, the 2024 VIIRS data, has more values that belong to the brightest/most intense range.

Table 2: VIIRS Light Pollution Change Over Time using Reclassified Values for classifications 15 and 19 in Albuquerque, NM (See Appendix Table 3)

Reclassification Index	2012	2024	Percent Change %
15	113	90	-17.29
19	7	73	942.86

4.1.3 Sound data

Ten-minute sound recordings were collected at each data collection site at night using a Roland Sound Recorder. The recordings were processed through the Audacity version 3.7.2 software to visualize sound waves and report decibels. The purpose of collecting these audio recordings and visualizing the audio was to create an understanding if there is a correlation between the decibel readings and the amount of light present at a location.

Dark 15, a curb alongside a road off of I-40 to Gallup, has the highest decibel readings with -12.1355 dB. This location had very static loud background noise as there was a semi-truck idling with the driver asleep inside. Some trucks pass the location and besides the idle of the truck, it is relatively quiet.

Dark 13, a neighborhood, has the lowest decibel readings with -38.7602 dB. This location had a lot of intermittent noise. At 34 and 49 seconds there are a few dogs barking. At 2 minutes, 2:25, 2:33, 4:38, and 7:23 a motion sensored light and alarm system turn on.

Figure 12: Sound Waves of Dark 15 Albuquerque measuring at -12.1335dB.

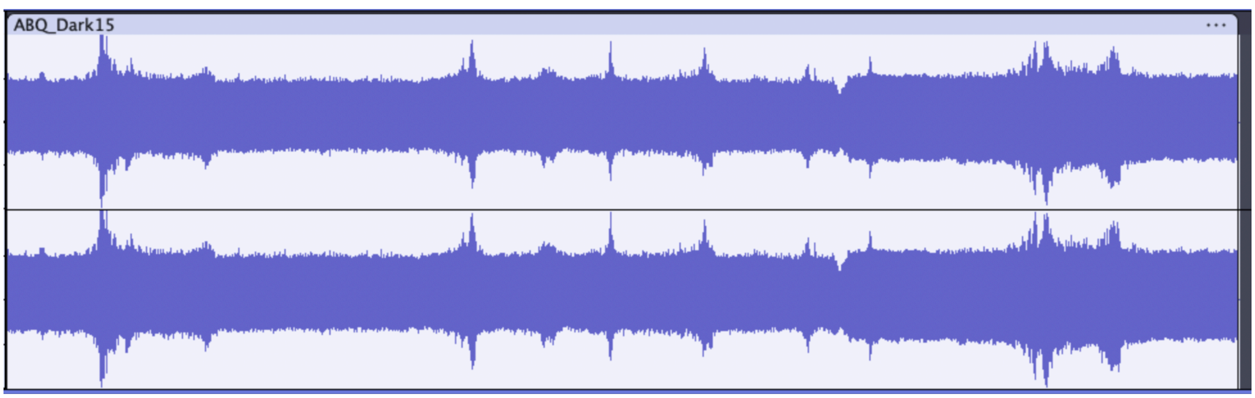


Figure 13: Sound Waves of Dark 13 Albuquerque measuring at -38.7602 dB.

4.1.4 Land use change over time (1961 vs. 2023)

On average Albuquerque saw 178.25% change in land use between 1961 and 2023. The largest increase was commercial land use with 552.42% while open land had the largest decrease, down 76.98%. Figure 14 shows a bar graph of the overall land use change within Albuquerque.

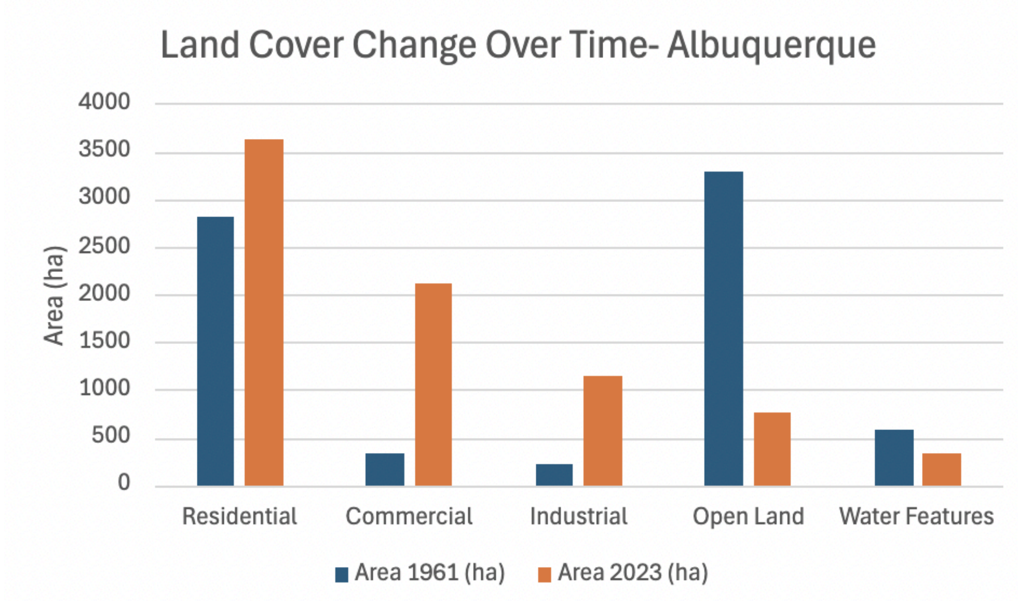


Figure 14: Land cover changes in hectares (ha) over time in Albuquerque.

In 2023, land for commercial use was 2104 ha while in 1961 only 322 ha was used. For open land, in 1961 3,297 ha was open land and in 2023 only 759 hectares.

Figure 15 shows an example of land use changing from open land to commercial in the location medium 7 site in Albuquerque. Site Medium 7 is Vance Emory Lane outside of Milne Stadium.

Figure 15: Land use types at medium 7 Albuquerque, Vance Emory Lane next to Milne Stadium. The left panel shows the digitized land use of the area using georeferenced aerial imagery from 1961, and the right panel shows the digitized land use of the area in 2023 using the GIS base

layer. Green denotes open land, blue is water, purple is residential land, pink is industrial, and orange is commercial land.

It is also important to note that industrial use of land increased significantly between 1961 and 2023 by 428.57%.

Table 3: Land Use Change over Time in Hectares (ha) in Albuquerque, NM (See Appendix Table 4)

Land Type	Area 1961 (ha)	Area 2023 (ha)	Percent Change (%)
Commercial	322	2104	553.42
Open Land	3297	759	-76.98

4.1.5 Crime and Census data

Across all locations, on average, the predominant races are white and hispanic with the exception of locations 4, 6, and 10 which are predominantly hispanic. The most common income range surrounding the locations are between $17,107 and $66,842.

For crime, the location with the highest number, 18.797, is light 2. The area with the lowest amount of crime is dark 15 with 43 crimes reported.

For greater Albuquerque, it looks as if there is no correlation between light pollution and race or with light pollution and income. There also appears to be no correlation between crime and income. There appears to be some slight alignment between decreasing amounts of light and decreasing crimes, but there is not a clear enough trend to call the pattern significant.

Table 4: Crime and Census Data for Each Location in Albuquerque, NM (See Appendix Table 5)

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Light 2	18.797	17,107 - 66,842	White and Hispanic
Light 4	11,291	17,107 - 66,842	Hispanic
Medium 6	10,344	17,107 - 66,842	Hispanic
Medium 10	218	45,146 - 66,842	Hispanic
Dark 15	43	17,107 - 94,867	White and Hispanic

4.1.6 Interviews

Three interviews were lined up from the city of Albuquerque; however, the two representatives from the City of Albuquerque declined to comment. The third interviewee, John

Sanchez, offered to provide an interview when he noticed the data collection outside of his property.

John Sanchez is the owner of United Storage ABQ on Escapardo Ave. and Indio Dr. He states that the city of Albuquerque does have a city ordinance of Dark Skies, for which he thought his business would be required to follow, but it was not. Sanchez states that the objective of lighting around his business is to promote that his storage facility is safe and secure; however, he decided to “be sensitive” to how much light was being emitted by his facilities. Since United Storage ABQ is one of the farther south locations, it falls under the jurisdiction of the city of Albuquerque and Bernalillo County. Sanchez stated that he has no city contacts regarding corporate light emittance, but works closely with electrical contractors.

Sanchez thinks that light pollution is an important issue as a resident of the county. When considering his own gated community, he thinks it is important to find the balance between security and the encroachment of light. He is concerned because he views it as a “quality of life issue,” but does not support “onerous policies” and “ludicrous requirements.” Sanchez emphasized that when dark sky ordinances are past cost and safety needs to be considered.

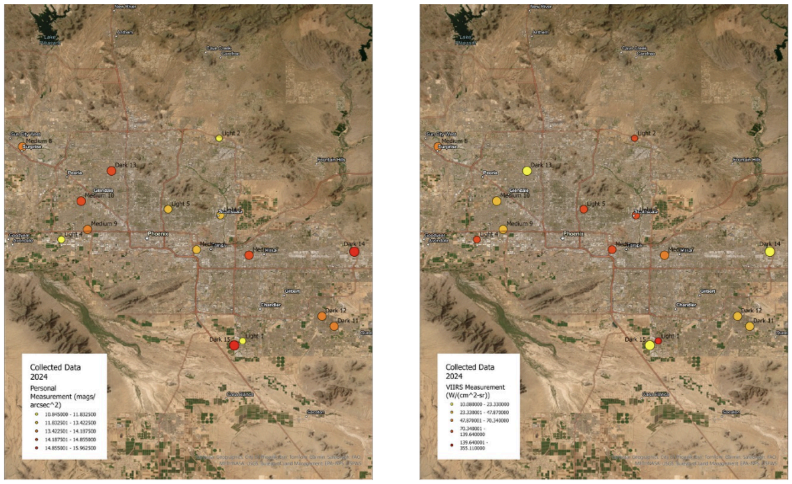
When asked about the change he has seen in the greater Albuquerque area, he said that Bernalillo’s regulations are starting to “look like the East coast’s” where there are higher standards in place becoming too hands-on for developers. As a native of Albuquerque, he expressed some sadness in the reputation that the city has. Sanchez stated that Albuquerque has historically been business centered, but the growth has slowed down due to a “regulatory environment” and additionally stated that it is “terrible to be known as a high crime environment.”

Sanchez concluded the interview by comparing Albuquerque with Phoenix. He said that in 1960 the two cities were the same size; however, said that the “common sense pro-business approach towards the private sector” in Phoenix was the defining difference that led to the split in growth.

4.2 Phoenix, AZ

4.2.1 Collected data versus VIIRS data

The greater Phoenix area demonstrates a greater agreement between the collected measurements and the VIIRS data with locations 5, 6, 13, 14, and 15 matching. Figure 15 shows a side by side comparison between the collected data points and VIIRS data points brightest and darkest areas.



Collected Measurements VIIRS Measurements

Figure 16: Two panels of GIS imagery of the greater Phoenix area. The dots indicate points where light measurements were collected. The coloration demonstrates the intensity of light measured at each location, with yellow being the brightest and dark red being the darkest. The left denotes the collected measurements from the ground and the right represents the VIIRS measurements collected aerially.

As well as the differences between the collected measurements and the VIIRS measurements, Figure 17 is a GIS map that shows both the data collection sites and the broader VIIRs measurements across the city of Albuquerque. This map is to help better understand where as well as visualize the data collection sites and their measurements fall in terms of VIIRS data.

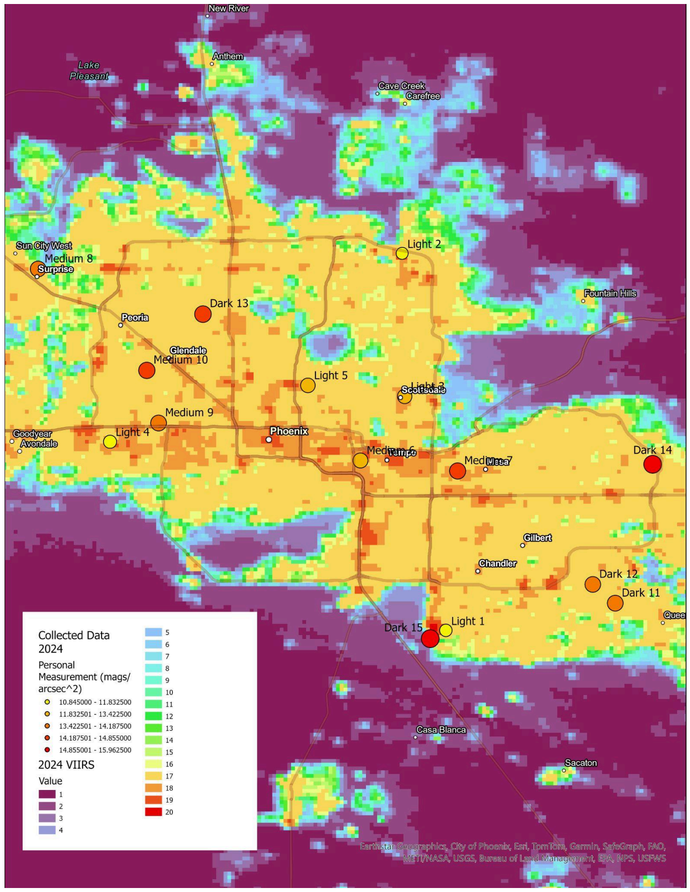


Figure 17: This GIS map situates the data collection sites in the broader imagery of VIIRS data in Phoenix, Arizona.

According to the VIIRS data, the Intel Ocotillo Campus is the greatest contributor of light pollution in the greater Phoenix area with a VIIRS measurement of 355.11 W/(cm^2-sr). However, according to the collected measurements light 2, Bell Lexus North Scottsdale is the largest contributor of light pollution with a measurement of 10.845 mags/$arcsec^2$.

Figure 18: Light 1 Phoenix, South facing during the day. Showing the intersection of S Dobson Rd and W Chaparral Way. Light 1 is the brightest location in Phoenix, according to VIIRS data.

Figure 19: Light 1 Phoenix, South facing during the night. Showing the intersection of S Dobson Rd and W Chaparral Way. The VIIRS value of this location is 355.11 W/(cm2-sr). The collected measurement for this location is 11.1825 mags/arcsec^2.

Figure 20: Light 2 Phoenix, South facing during the day. Showing Bell Lexus North Scottsdale.

Figure 21: Light 2 Phoenix, South facing during night. Showing Bell Lexus North Scottsdale. The VIIRS value of this location is 139.64 W/(cm2-sr). The collected measurement for this location is 10.845 mags/arcsec^2.

According to the VIIRS data, the darkest location, dark 15, is between Riggs North Farm and Sun Lakes RV Storage measuring 10.08 W/(cm^2-sr). For the collected data Riggs North Farm and Sun Lakes RV Storage is the darkest location in Phoenix, 15.9625.

Figure 22: Dark 15 Phoenix, West facing during the day. Facing Riggs North Farm and behind is Sun Lakes RV Storage. According to VIIRS, dark 15 is the darkest location in Phoenix.

Figure 23: Dark 15 Phoenix, West facing at night. Facing Riggs North Farm and behind is Sun Lakes RV Storage. The VIIRS value of this location is 10.08 W/(cm2-sr). The collected measurement for this location is 15.9625 mags/arcsec^2.

The table below shows the VIIRS and collected measurements for the locations pictured above as well as the land cover category of the surrounding area. The GPS coordinates where the collected measurements were taken are included.

Table 5: Locations and Data for Research Sites 1 , 2, and 15 in Phoenix, AZ (See Table 1 in the Appendix)

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	355.11	11.1825	(33.236425, -111.8758382)	Industrial/Residential
Light 2	139.64	10.845	(33.6549919, -111.9243708)	Commercial
Dark 15	10.08	15.9625	(33.2272175, -111.8931797)	Commercial/Agriculture

4.2.2 VIIRS Change over time (2012 vs. 2024)

Between 2012 and 2024, there was on average, a 25.00% increase in light pollution. Reclassification category 19, which includes the values between 114.43576 and 265.343506 W/(cm^2-sr), experiencing a 120.00% increase. In 2012, there were 125 values that fell within the range and in 2024 there were 275. Meanwhile, reclassification category 1, ranging from -0.045979 to 0.994765 W/(cm^2-sr), saw a 6.21% decrease. In 2012 there were 159950 values and in 2024 there were 150025.

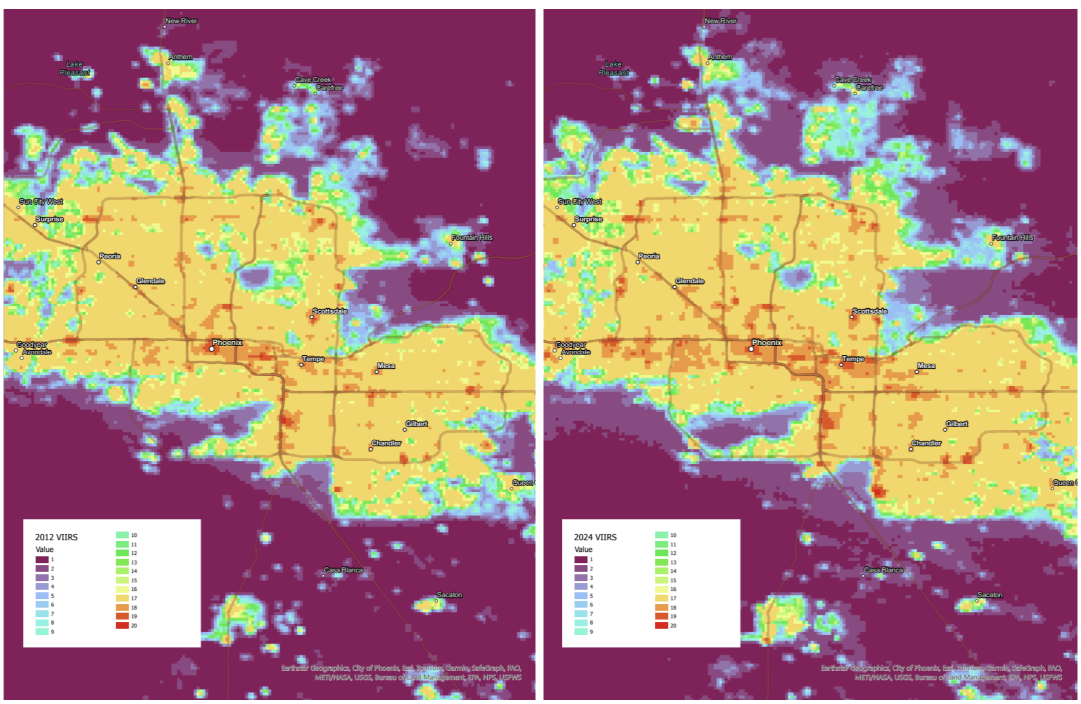


Figure 24: The images above demonstrate the reclassified VIIRS data to demonstrate the difference in abundances of higher values found between 2012 and 2024. The darker purple denotes the darker areas and the bright red and oranges represent the brightest areas according to VIIRS. The data was reclassified to make it comparable across time. It can be seen that the

image on the right, the 2024 VIIRS data, has more values that belong to the brightest/most intense range.

Table 6: VIIRS Light Pollution Change Over Time using Reclassified Values for classifications 1 and 19 in Phoenix, AZ (See Appendix Table 3)

Reclassification Index	2012	2024	Percent Change %
1	159950	150025	-6.21
19	125	275	120.00

4.2.3 Sound data

The highest decibel location measured in Phoenix was light 1 alongside Intel's Ocotillo Campus with a reading of -24.2329 dB. Most of the noise is attributed to passing cars along the main road and the humming of a nearby electrical generator. 5:48 into the recording there is a very loud truck that passes by that causes the spike in the sound waves about halfway through the recording.

The lowest decibel reading was from dark 12, a neighborhood measuring at -41.6523 dB. At the beginning of the recording dogs are barking very faintly in the background and there are a couple of loud cars on the main street nearby. No insects or animals can be heard beyond the first minute of the recording.

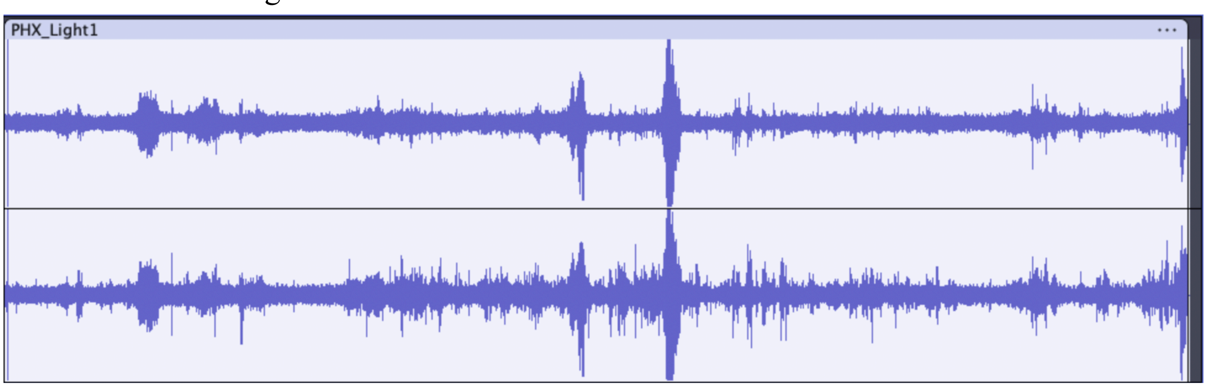


Figure 25: Sound waves for light 1 Phoenix measuring at -24.2329 dB.

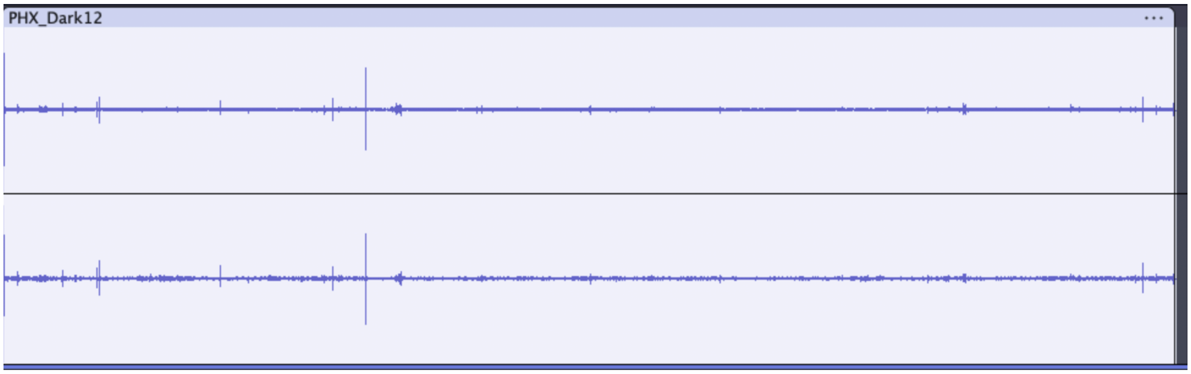


Figure 26: Sound waves for dark 12 Phoenix measuring at -41.6523 dB.

4.2.4 Land use change over time (1964 vs. 2023)

On average Phoenix saw 125.79% change in land use between 1964 and 2023. Similar to Albuquerque, commercial land use had the largest increase with 282.53% while open land had the largest decrease, down 86.41%. Figure 27 shows a bar graph of the overall land use change within Phoenix.

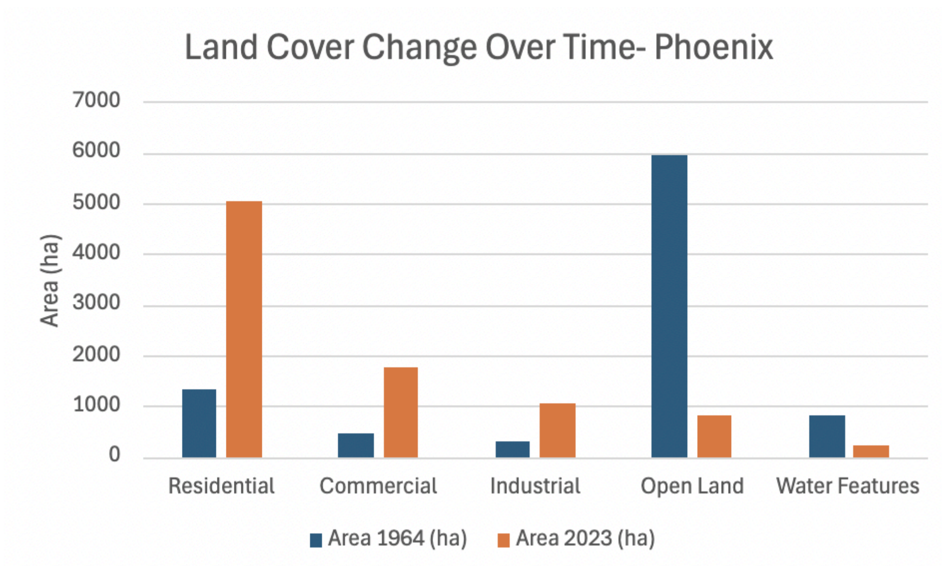
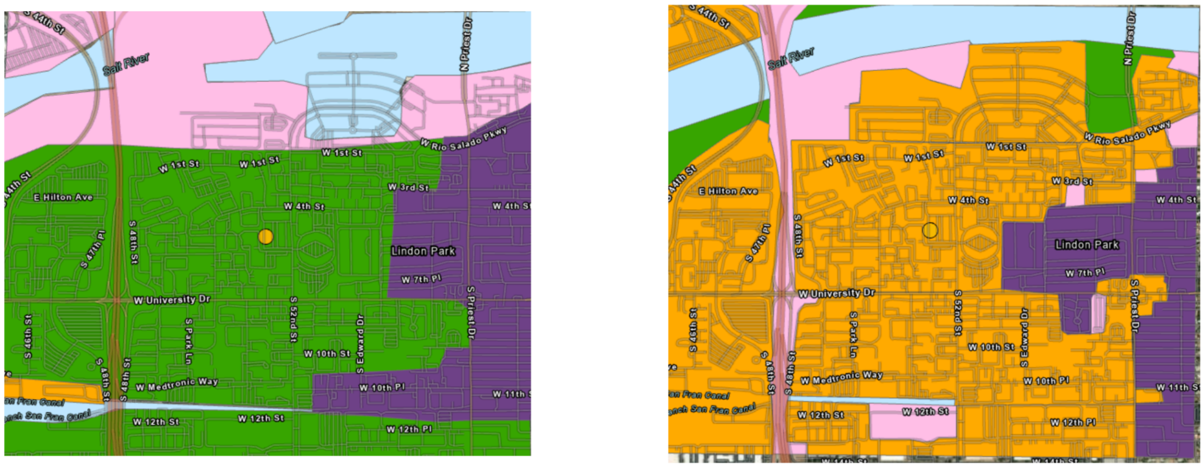


Figure 27: Land cover changes over time in Phoenix.

In 2023, land for commercial use was 1752 ha while in 1961 only 458 ha was used. For open land, in 1961 5,939 ha was open land and in 2023 only 807 ha.

Figure 28 shows an example of land use changing from open land to commercial in the location medium 6 in Phoenix. Medium 6 is outside of Arizona Tool Steel in Tempe.



1964 2023

Figure 28: Land use types at medium 6 Phoenix, Arizona Tool Steel in Tempe. The left panel shows the digitized land use of the area using georeferenced aerial imagery from 1964, and the right panel shows the digitized land use of the area in 2023 using the GIS base layer. Green denotes open land, blue is water, purple is residential land, pink is industrial, and orange is commercial land.

It is also important to note that residential areas also significantly increased between 1964 and 2023 by 274.87%.

Table 7: Land Use Change over Time in Hectares (ha) in Phoenix, AZ (See Appendix Table 4)

Land Type	Area 1964 (ha)	Area 2023 (ha)	Percent Change (%)
Commercial	458	1752	282.53
Open Land	5939	807	-86.41

4.2.5 Crime and Census data

The predominant races are more variable than in Albuquerque. The predominant races are white and hispanic in most locations with the exception of locations 3, 4, 6, 8, 9, 10, and 15. Location 3 is the only location that is predominantly white. Locations 4, 8, 9, and 10 are predominantly hispanic, and locations 6 and 15 have no discernable majority between races.

The most common income range surrounding the locations are between $14,746 and $82,958. For crime, there was no data reported so no analysis could be made.

For greater Phoenix, our data indicates there is no correlation between light pollution and race or with light pollution and income.

Table 8: Crime and Census Data for Each Location in Phoenix, AZ (See Appendix Table 5)

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Light 3	N/A	14,746 - 111,667	White
Light 4	N/A	14,746 - 57,656	Hispanic
Medium 6	N/A	14,746 - 82,958	No discernible majority
Medium 8	N/A	14,746 - 57,656	Hispanic
Medium 9	N/A	14,746 - 57,656	Hispanic
Medium 10	N/A	14,746 - 82,958	Hispanic
Dark 15	N/A	14,746 - 82,958	No discernible majority

4.2.6 Interviews

A total of four interviews were conducted for Phoenix and Flagstaff. In this section the interview with Phoenix Vice Mayor, Debra Stark, will be the focus. The three additional interviews with Dr. Jeffery Hall, Dr. Christian Luginbuhl, and John Barentine will be considered in the discussion section.

Vice Mayor Debra Stark has a background in urban planning and discussed some of the most pressing issues for the city of Phoenix, water and heat. Living in a desert makes heat and water critical issues, and to confront this, the city works in collaboration with Arizona State University to develop infrastructure, waste water, and water treatment strategies. Stark states that Phoenix is a "forward-thinking city" and having a population of almost 5 million people means that "you have to look at the big picture."

Light pollution is a low priority. The vice mayor states that the residents understand that it is an issue, but it is not a high priority compared to the other issues faced by the city. However, Phoenix's established Dark Sky Ordinance shows that there is some value placed on restricting light pollution. Stark emphasized the importance of the scientific community several times throughout her interview stating that it is a "critical industry here in Arizona."

One of the regulations that the city enforces is that all digital billboards must be shut off from 11pm until dawn. The regulation of digital billboards was actually founded upon complaints from scientific communities. Beyond digital billboards, most street lights use LEDs lighting as well as most parks. The lights are also directed towards the ground and not projecting towards the sky. Vice Mayor Stark stated that Phoenix is currently working on a "text amendment" for commercial lighting; however staffing issues have put a pause on this proposal.

Furthermore, the efforts to conserve the night sky is founded out of awareness of the animals and CAM4 cacti in the area. One of Stark and Phoenix's biggest goals is to protect the scientific industry, “anything we can do to protect the observatories” will have broader impacts for humans and animals.

To conclude the interview, the vice mayor acknowledges the efforts of the city of Flagstaff to promote the importance of protecting dark skies. “Flagstaff is the epicenter of protecting our dark skies,” and they have “embraced stargazing and the science of it.” Flagstaff has placed a lot of pressure on the rest of the state to address the issue of light pollution.

4.3 Colorado Springs, CO

4.3.1 Collected data versus VIIRS data

Similar to greater Albuquerque, the VIIRS and collected measurements do not exactly align. The collected data for light 1 and medium 10 are the only two that match the VIIRS rankings. Figure 27 shows a side by side comparison between the collected data points and VIIRS data points brightest and darkest areas.

Collected Measurements | VIIRS Measurements

Figure 29: Two panels of GIS imagery of the greater Colorado Springs area. The dots indicate points where light measurements were collected. The coloration demonstrates the intensity of light measured at each location, with yellow being the brightest and dark red being the darkest. The left denotes the collected measurements from the ground and the right represents the VIIRS measurements collected aerially.

As well as the differences between the collected measurements and the VIIRS measurements, Figure 30 is a GIS map that shows both the data collection sites and the broader VIIRs measurements across the city of Albuquerque. This map is to help better understand where as well as visualize the data collection sites and their measurements fall in terms of VIIRS data.

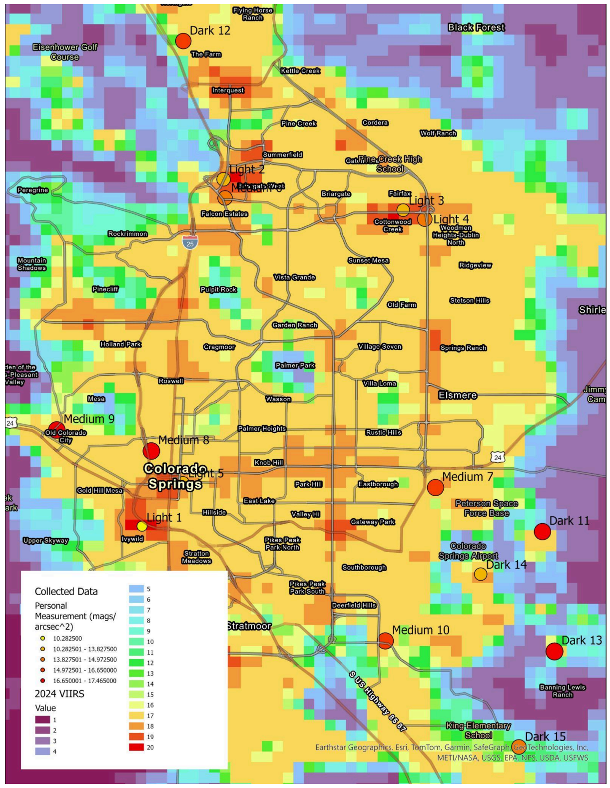


Figure 30: This GIS map situates the data collection sites in the broader imagery of VIIRS data in Colorado Springs, Colorado.

According to the VIIRS data the Motor City car lots are the greatest contributors of light pollution in greater Colorado Springs with a measurement of 351.75 W/(cm^2-sr). The collected measurements also indicate the Motor City area as the brightest in Colorado Springs.

Figure 31: Light 1 Colorado Springs, Motor City. East facing during the day. According to VIIRS, light 1 is the brightest location in Colorado Springs.

Figure 32: Light 1 Colorado Springs, Motor City. East facing at night. The VIIRS value of this location is 351.75 W/(cm2-sr). The collected measurement for this location is 10.2825 mags/arcsec^2.

According to the VIIRS data, the darkest location, dark 15, is alongside Colorado State Highway 21, S Powers Blvd, and Woody Creek Dr with a measurement of 9.66 W/(cm^2-sr). However, the collected data suggests that dark 13, The MiLL - National Training Center on Foreign Trade Zone Blvd, is the darkest in Colorado Springs at 17.465 mags/arcsec^2.

Figure 33: Dark 15 Colorado Springs, west-facing at Woody Creek Dr during the day. According to VIIRS, dark 15 is the darkest location in Colorado Springs.

Figure 34: Dark 15 Colorado Springs, north-facing at night. This photo is taken farther up the road than the daytime photo, at the intersection between Woody Creek Dr and Grand Valley Dr, due to residential activities. The VIIRS value of this location is 9.66 W/(cm2-sr). The collected measurement for this location is 14.9725 mags/arcsec^2.

Figure 36: Dark 13 Colorado Springs, South facing during the day. The MiLL - National Training Center not pictured.

Figure 35: Dark 13 Colorado Springs, South facing during the night. The MiLL - National Training Center not pictured. The VIIRS value of this location is 19.43 W/(cm2-sr). The collected measurement for this location is 17.465 mags/arcsec^2.

The table below shows the VIIRS and collected measurements for the locations pictured above as well as the land cover category of the surrounding area. The GPS coordinates where the collected measurements were taken are included.

Table 9: Locations and Data for Research Sites 1 , 13, and 15 in Colorado Springs, CO (See Table 1 in the Appendix)

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	351.75	10.2825	(38.8161573, -104.8328596)	Commercial
Dark 13	19.43	17.465	(38.7666391, -104.669449)	Commercial/Open Land
Dark 15	9.66	14.9725	(38.7288966, -104.6835555)	Residential/Commercial

4.3.2 VIIRS Change over time (2012 vs. 2024)

Between 2012 and 2024 Colorado Springs there was an average 257.61% increase in light pollution. Reclassification category 18, which includes the values between 65.520835 to 114.43576 W/(cm^2-sr), saw a 3475.00% increase. In 2012, there were 8 values that fell within the range and in 2024 there were 286. Meanwhile, reclassification category 10, ranging from 9.320709 to 10.361452 W/(cm^2-sr), experienced a 32.42% decrease. In 2012 there were 219 values and in 2024 there were 148.

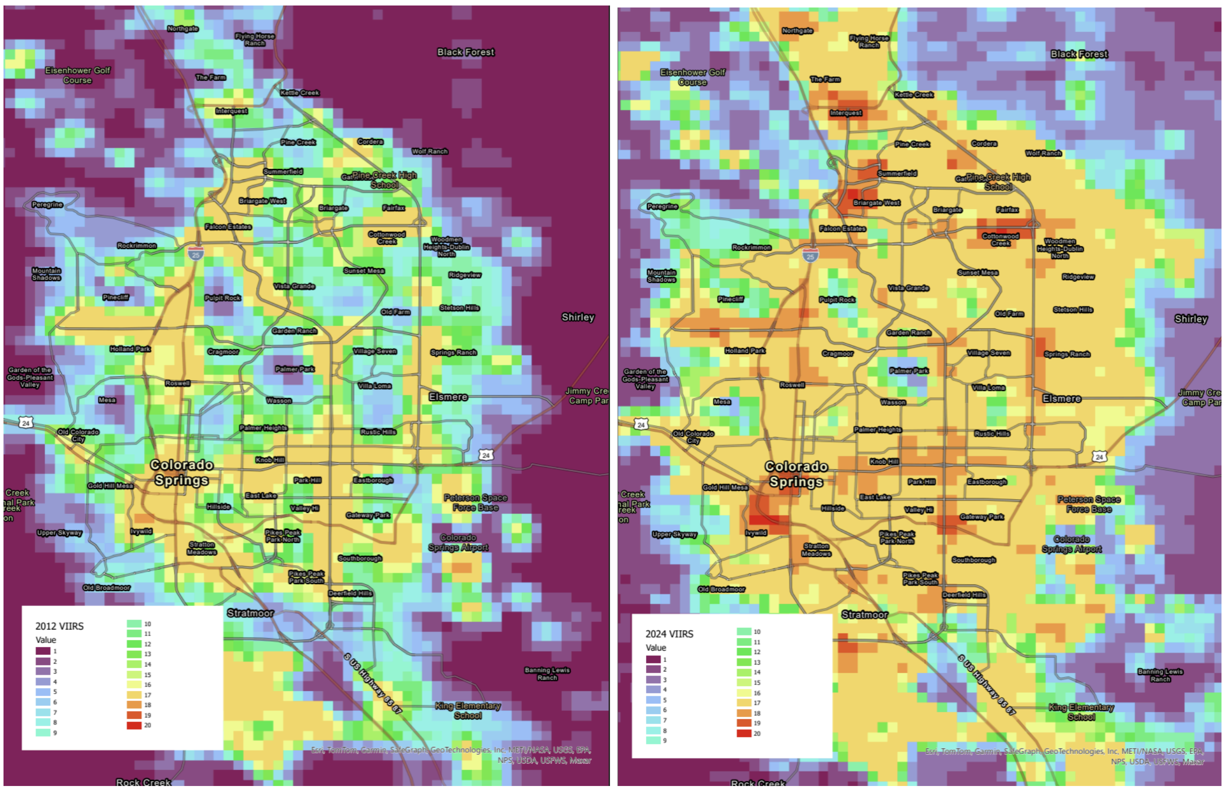


Figure 37: The images above demonstrate the reclassified VIIRS data to demonstrate the difference in abundances of higher values found between 2012 and 2024. The darker purple denotes the darker areas and the bright red and oranges represent the brightest areas according to VIIRS. The data was reclassified to make it comparable across time. It can be seen that the image on the right, the 2024 VIIRS data, has more values that belong to the brightest/most intense range.

Table 10: VIIRS Light Pollution Change Over Time using Reclassified Values for classifications 10 and 18 in Colorado Springs, CO (See Appendix Table 3)

Reclassification Index	2012	2024	Percent Change %
10	219	148	-32.42

18	8	286	3475.00

4.3.3 Sound data

The highest decibel reading in Colorado Springs was at light 2 at the Studio 6 parking lot along Voyager Parkway at -11.6902 dB. There is a lot of background noise from cars passing by on the main road along with some wind. At 6:30 a car pulls into the parking lot and sits with the engine on.

The lowest decibel reading comes from medium 7, the entrance of FedEx Freight at Airport Rd near Peterson Space Force Base and Colorado Springs Airport. Most of the noise in the recording comes from crickets and some cars in the background.

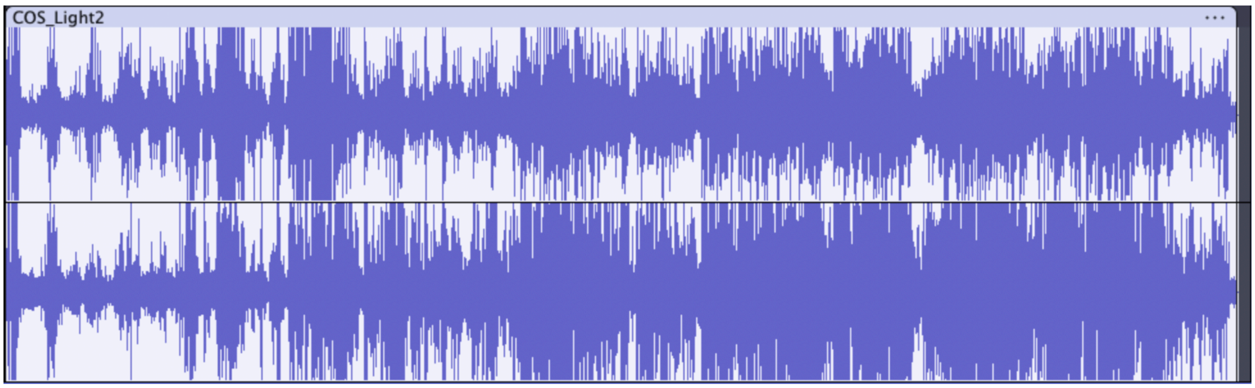


Figure 38: Sound waves for light 2 Colorado Springs measuring at -11.6902 dB.

Figure 39: Sound waves for medium 7 Colorado Springs measuring at -35.6389 dB.

4.3.4 Land use change over time (1963 vs. 2023)

On average there was a 70.49% change in land use between 1963 and 2023, in Colorado Springs. Similar to Albuquerque and Phoenix, commercial land use had the largest increase with 201.35%. However, water features had the largest decrease, down 64.29%. Figure 40 shows a bar graph of the overall land use change within Colorado Springs.

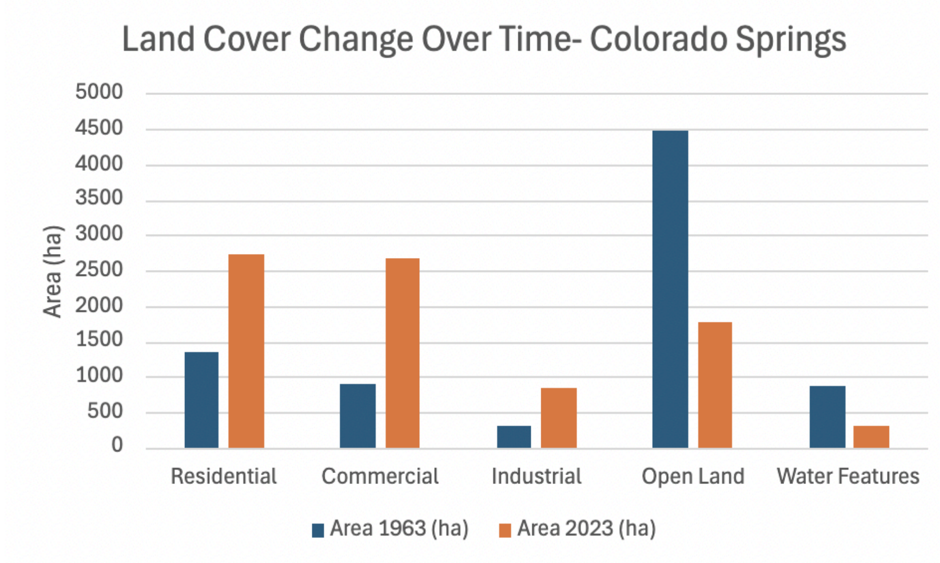


Figure 40: Land cover changes over time in Colorado Springs.

In 2023, land for commercial use was 2685 ha while in 1961 only 891 ha was used. For water features, in 1961 868 ha was open land and in 2023 only 310 ha.

Figure 41 shows an example of land use changing from water features to commercial in the location medium 6 in Colorado Springs. Medium 6 is US Bank off N Academy Blvd and Briargate Blvd.

Figure 41: Land use types at medium 6 Colorado Springs, US Bank off N Academy Blvd and Briargate Blvd. The left panel shows the digitized land use of the area using georeferenced aerial imagery from 1963, and the right panel shows the digitized land use of the area in 2023 using the GIS base layer. Green denotes open land, blue is water, purple is residential land, pink is industrial, and orange is commercial land.

It is also important to note that industrial areas also significantly increased between 1963 and 2023 by 172.71%.

Table 11: Land Use Change over Time in Hectares (ha) in Colorado Springs, CO (See Appendix Table 4)

Land Type	Area 1963 (ha)	Area 2023 (ha)	Percent Change (%)
Commercial	891	2685	201.35
Water Features	868	310	-64.29

4.3.5 Crime and Census data

Across all locations in Colorado Springs, on average, the predominant races are white and hispanic with the exception of locations 7, 14, and 15 which are predominantly hispanic. The most common income range surrounding the locations are between $69,327 and $95,736.

For crime, the location with the highest number, 3,809, is light 1. The area with the lowest amount of crime is dark 15 with 3 crimes reported. Dark 11 also has one of the lowest amounts of crime, with 4 reports.

For greater Colorado Springs, it looks as if there is no correlation between light pollution and race or with light pollution and income. There also appears to be no correlation between crime and income. There appears to be some slight alignment between decreasing amounts of light and decreasing crimes, but there is not a clear enough trend to call the pattern significant.

Table 12: Crime and Census Data for Each Location in Colorado Springs, CO (See Appendix Table 5)

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Medium 7	263	69,327 - 95,736	Hispanic
Dark 14	93	95,736 - 132,750	Hispanic
Dark 15	3	95,736 - 132,750	Hispanic

4.3.6 Interviews

For Colorado, three interviews were conducted with UCAR Science Educator Elizabeth Mays, Dark Sky International Program Associate Michael Rymer, and Colby Foos, the Vice Chair of the Colorado Springs Planning Commission and Director of Southern Colorado for Weifield Group Contracting. For the purposes of this section, the interview with Colby Foos and

Elizabeth Mays will be discussed and the additional interview with Rymer will be presented in the discussion section.

Colby Foos is a Colorado Springs native as well as the Vice Chair of the Colorado Springs Planning Commission and Director of Southern Colorado for Weifield Group Contracting. This is his second year on the Planning Commision, a nine member committee of different backgrounds who “make judgements on land use issues” based on development codes put forward by the city. Foos sees the commission as his chance “to give back to the city that [he] love[s].”

Speaking on the growth and change within Colorado Springs, Foos states that “a city that’s not growing is dying.” The city has experienced steady growth over time. Fifty years ago, the farthest extent of the city was Citadel and Chapel Hill Mall, and now Security and Marksheffel are the newest areas. He attributes the Airforce expansion in the 90s as a factor contributing to the city’s growth.

Although Foos sees Colorado Springs’ growth as a positive, there are some people who see it as a negative. There is a ““constant push and pull” between anti-growth and pro-growth as the city looks at options like infill and land annexation to continue its growth and to remedy its housing crisis. However, his main goal as vice chair is to get “reliable information” and “trust the professionals.”

On the issue of light pollution, Foos said that during his last two years on the planning commission he “had it come up one time.” However, there is not much discussion on the issue because there is nothing in the commission's criteria to make a judgement in that area. The main focus is to contain lighting within a property. Foos believes that there is room for growth regarding light pollution as it wastes energy. He states that you cannot fully solve light pollution without making changes to nighttime lighting. Some of the ideas Foos has considered is pushing the city to place regulations about turning lights off in buildings not in use at night as well as upgrading old bulbs.

When reflecting on light pollution in Colorado Springs, Foos mentioned his own personal experience with light pollution. He used to have a ranch one hour Northeast of Colorado Springs and remembers the enjoyment associated with going outside and sitting on the porch at night. He reminisced about seeing the stars and how it was “mind blowing how beautiful it was.” However, Foos said if you looked North, you could see the sky glow from Denver. He says it is “troubling: that stars are gone in the city since “having beautiful skies is important.”

Elizabeth Mays is a science educator at the University Corporation for Atmospheric Research (UCAR) Center for Science Education based out of Boulder, CO. Mays said that light pollution “has not been a consideration recently,” but UCAR did conduct a citizen science project on it in 2008. The ‘Great World Wide Star Count’ was a grant funded mapping of light pollution by citizen scientists.

More recently, UCAR hosted an outreach program in Little Rock, Arkansas during the solar eclipse earlier in 2024. Light pollution was a major consideration for the event as organizers were concerned about how light pollution would impact the visibility of the eclipse.

The urban environment is “so bright [you] wouldn’t have had the full impact of the eclipse.” To address this challenge the organizers had the city’s parking lot, street, and pavilion lights shut off during the event.

Beyond her work, Mays shared that in Summit County the stars are more visible and helps “ground [her] in place.” She has a personal connection to the night sky as she used to lead stargazing programs in Chicago.

Discussion

6.1 Collected data versus VIIRS data

The Visible Infrared Imaging Radiometer Suite (VIIRS) is an application on the NASA/NOAA Suomi National Polar-orbiting Partnership satellite. VIIRS “collects visible and infrared imagery along with global observations of Earth's land, atmosphere, cryosphere, and ocean” (NASA). The infrared imaging provided by VIIRS can work in conjunction with the Moderate Resolution Imaging Spectroradiometer (MODIS) and NOAA's Advanced Very High Resolution Radiometer (AVHRR) for a variety of research purposes. VIIRS data is measured in watts per cubic cm minus steradian.

The collected data used a Sky Quality Meter (SQM) to produce measurements in magnitudes per square arcsecond to indicate sky brightness (NPS).

VIIRS data is collected in orbit while SQM data is collected on the Earth’s surface. One of the variables that must be considered with VIIRS is that it is difficult to pinpoint the exact source of radiance as VIIRS data is taken at such a broad scale, 375m-750m (USGS). Additionally, light spreads so certain locations may appear to emit more or less infrared wavelengths.

When comparing the brightness of the data collected on the ground using a SQM and VIIRS data, there appears to be some discrepancies with perhaps one or two sites matching in order of brightness. This demonstrates that while VIIRS is a reliable indicator of light pollution in the sky, there must be data collected ‘on-the-ground’ in order to validate the actual brightness of nighttime lighting at individual sites.

When looking at all three cities, Phoenix had the highest VIIRS reading at 355.11 W/(cm^2-sr), Colorado Springs was second with 351.75 W/(cm^2-sr), and Albuquerque was third with 262.07 W/(cm^2-sr). In terms of collected data, Colorado Springs had the brightest reading at 10.2825 mags/arcsec^2, Phoenix was a close second with 10.845 mags/arcsec^2, and Albuquerque had the least brightest highest value 12.175 mags/arcsec^2.

Looking in terms of the darkest points considered, Albuquerque and Phoenix had VIIRS values of 10.08 W/(cm^2-sr) and Colorado Springs 9.66 W/(cm^2-sr), making Colorado Springs home to the lowest infrared emittance of a considered location. In terms of collected data, Colorado Springs was also the darkest with a brightness of 17.465 mags/arcsec^2, Albuquerque was second with 17.009 mags/arcsec^2, and Phoenix had the brightest darkest location at 15.9625 mags/arcsec^2.

Combining all of the cities' results, Albuquerque is effectively the darkest city taken into account for this study. Meanwhile, Phoenix is the most light polluted or brightest city taken into account.

6.2 VIIRS Change over time (2012 vs. 2024)

VIIRS change over time can help judge how cities have grown during a certain time period. This section will look at the amount of light pollution increase in each city as well as changes in the highest available reclassification values present between 2012 and 2024.

Between 2012 and 2024, Albuquerque saw a 73.90% increase in light pollution. In 2012 the highest reclassification value was 19 (114.43576 to 265.343506 W/(cm^2-sr)) with 7 pixels showing this value, in 2024 reclassification value 19 was still the highest; however, there were 73 pixels containing these W/(cm^2-sr) values.

Phoenix experienced only a 25.00% increase in light pollution during this time. In 2012 reclassification value 20 (265.343506 to 893.61 W/(cm^2-sr)) was the highest with 4 pixels. In 2024, reclassification 20 was still the highest and still had 4 pixels.

Between 2012 and 2024, Colorado Springs experienced a 257.61% increase in light pollution. In 2012 the highest reclassification value was 18 (65.520835 to 114.43576 W/(cm^2-sr)) with 8 pixels belonging to it. However, in 2024 there is a jump in the highest observed value making the highest reclassification value 20 (265.343506 to 893.61 W/(cm^2-sr)). In 2024, reclassification value 18 had 286 pixels, value 19 had 57 pixels, and value 20 had 5 pixels.

Overall, it appears that Colorado Springs has had the most growth within the 11 year time period. When taking the results of section 6.1 into consideration, it appears that despite the amount of increase in overall light pollution, Colorado Springs has maintained a relatively neutral status among the three cities. However, it is critical to remember that Colorado Springs is home to the brightest 'on-the-ground' measurement.

6.3 Sound data

It appears that decibels and sound is not indicative of the amount of light pollution present within an area. For Albuquerque, the highest decibel reading was at dark 15 and the lowest was dark 13. For Phoenix, the highest was at light 1 and the lowest was at dark 12. Finally, for Colorado Springs, light 2 had the highest decibel reading and medium 7 had the lowest.

Taking these into consideration, Phoenix's decibel to VIIRS reading was the most accurate while Colorado Springs was somewhat accurate, and Albuquerque was far from close. Furthermore, based on this analysis, decibels may not tell the complete story of the level of noise and composition of the noise present at each specific study site. For example, heard within the audio recordings of several recordings were car engines revving, dogs barking, and security devices/alerts.

6.4 Land use change over time (1963 vs. 2023)

Just like VIIRS helped demonstrate a city's growth over time, land use change over time can also indicate how a city has changed between two time periods. The land use type with their associated percent changes were identified in the results and in this section they will be looked at more closely to determine how this connects with the amount of light present and city development.

For Albuquerque, the brightest locations were a mix of commercial and residential areas while the darkest locations were a mix of commercial, residential, and open land.

For Phoenix, the brightest locations were situated in industrial and commercial centers and the darkest sites were in residential areas.

For Colorado Springs, the brightest locations were surrounded by commercial land use and the darkest locations were surrounded by open land and residential areas.

This information helps identify that commercial industries are the biggest contributors to light pollution and that residential areas typically have lower levels of light pollution.

As for the scale of development within each city, the percent changes align with the amounts of light pollution found at each city and also correspond with the type of development. Almost every study site saw significant changes in the land use in the 1.5 by 1.5 mile area from 1960 to 2023.

6.5 Crime and Census data

There is not much significance in findings that pertain to crime and census data. For both Albuquerque and Phoenix there was no significance for income in relation to the VIIRS data. However, in Colorado Springs there is some increase in income the darker the location showing some potential relationship.

For crime, both Albuquerque and Colorado Springs demonstrated some downward trend with the amount of light and amount of crime. It appears that there is a slight relationship between lower VIIRS values and lower crime levels. However, neither of these are significant.

It may be beneficial to assess how crime relates to population density rather than the amount of light present at night.

6.6 Expert Interviews

6.6.1 Dr. Jeffery Hall

Dr. Jeffery Hall is the Executive Director Lowell Observatory in Flagstaff, Former Chair of the American Astronomical Society's Committee on the Protection of Astronomy and the Environment (COMPASSE). An astronomer by training, Dr. Hall became invested in understanding light pollution through his role at Lowell in 2012.

He explained that Flagstaff is the first dark sky designated area in the United States in 1958 and is home to two of the most prominent observatories in the U.S., Lowell and the US Naval Observatory. Nearly 70 years after its dark sky designation, dark skies are "part of the identity" of Flagstaff. In order to preserve its status, Flagstaff uses narrowband amber LEDs as well as has strict standards for outdoor lighting. Dr. Hall stated that the best resource on light pollution and LEDs in Flagstaff is the Flagstaff Dark Skies Coalition who discusses different lighting bands, temperature, and sky glow.

From 2017-2022 Dr. Hall served as the chair of COMPASSE and is still currently part of the committee in an advisory role. The committee's initial focus was the "big issue" of the conversion of outdoor lighting to "bright light glary LEDs" which have the potential to damage the night sky and contribute to sky glow. Currently, he is collaborating with Dark Sky Phoenix and the Arizona Department of Transportation (ADOT) on LED lighting in the city where there is a strong promotion of yellow LED lighting on residential streets versus white.

When discussing the issue of light pollution as a whole, he states that the concern about light pollution and preserving the night sky goes "well beyond astronomy." There are "well documented environmental impacts in losing light-dark cycles;" therefore, "increasing evidence in disrupting human health" through circadian rhythms, cancer, and diabetes. Furthermore, in Arizona and all around the country, indigenous peoples, like the Navajo and Hopi in Arizona, night skies mean culture and heritage. There is a risk of losing touch with that and "changing the character of the night sky."

To help mitigate light pollution, Dr. Hall shared that "there are some very simple things you can do to reduce light pollution on the ground," a philosophy that he calls the "three-legged stool." The three steps include, 1) shield lighting (cost effective and limits spread of unwanted light), 2) illumination limits (lumen per acre) prevent tremendous overlighting, and 3) spectrum measurement (ideally Amber LEDs) most cities do these.

For illumination at night there is a need to find the "Goldilocks level" where some light is better than no light and overlighting. Overlighting is concerning because it can cause glare and reduce safety.

At the end of his interview, Dr. Hall stated that there is a misconception with dark skies activism and when talking about light pollution there is a belief that promoting limitations on light pollution means promoting no lights at night. He says this understanding is incorrect and that "a dark sky policy is not a dark-ground policy."

6.6.2 Dr. Christian Luginbuhl

Dr. Christian Luginbuhl is a principal consultant at Dark Sky Partners LLC and a former staff at the US Naval Observatory in Flagstaff. He is an astronomer specializing in the quantification and modeling of the effects of outdoor artificial lighting on the night sky, and lighting codes and their effect on controlling sky glow.

Dr. Luginbuhl's introduction to light pollution began in the 1980s when his job at the US Naval Observatory began to encompass investigating the impacts that development in Flagstaff would have on the observatory. The observatory was mainly concerned about the growing population of Flagstaff and the associated light pollution that would impact the workings of the observatory as they had relocated in the 1950s to Flagstaff from Washington DC due to a similar issue.

Dr. Luginbuhl retired in 2014; however, he still works to protect the night sky and currently works closely with the Flagstaff Dark Skies Coalition as he views light pollution as something to “engage with and manage.” He conducts research to try to “understand the relationship of how lighting is used” and where our focus should be to effectively control it.

He believes that “dark skies matter for all kinds of people,” and there is a “diminishment of human spirit” if you can't see it. Dr. Luginbuhl also thinks that light pollution has not become a bigger issue due to “resistance in different areas,” and furthermore that it is an “unfortunate reflection of our general personal or cultural isolation from the environment which we live in.”

He said there are two obstacles to awareness of light pollution momentum, 1) indifference and 2) resistance. “You can’t care about things you don't know about.”

At the end of his interview he reaffirmed his belief that the pollution and lack of an effort to preserve it is a tragedy of the commons and that it is time to “stop treating Flagstaff as the exception, [and] treat it as an example.”

6.6.3 Dr. John Barentine

Dr. John Barentine has a PhD in astronomy, is the Executive Director and Principal Consultant of Dark Sky Consulting LLC, and the Former Director of Public Policy for Dark Sky International (DSI). He is originally from Phoenix and is currently involved in a lighting code project there. He also has experience working with the New Mexico Dark Sky Group.

At Dark Sky LLC he works in freelance consulting to provide measurements of light pollution for conservation purposes or city projects.

During his interview, Dr. Barentine emphasized the importance and value of science communication, especially when it comes to light pollution. “Light pollution is surprisingly easy to deal with as a problem” it is a “matter of convincing people to do something about it.” It is also “fortunate [that] the kind of pollution that we are trying to deal with does not dwell in our environment for a long time” unlike water and air pollution. There is a sense of “instant gratification.”

Dr. Barentine lived in New Mexico for 5 years where he staffed an astronomical observatory. This is where he was first introduced to the issue of light pollution. New Mexico is a leader in light pollution with its state law Night Sky Protection Act which was heavily influenced by interest groups such as Lincoln Labs military and defense and Kirkland Air Force Base.

When describing Phoenix, he states that the area produces so much light that you can see the glow from all corners of the state. This produces a challenge for very dark public lands because there is a light “footprint” that “grows together from adjacent metro areas.” This contributes to the loss of integrity of darkness from these “mega cities.”

Dr. Barentine believes that the root of the failings of public policy is that light pollution doesn’t respect boundaries, so it makes it difficult to regulate. A potential solution to this issue is to set regulation at a higher level than the municipality. He states that Colorado is a “great example” because of Governor Polis’ Dark Sky Month Proclamation.

To conclude his interview Dr. Barentine emphasized the need to tie the issue of light pollution to environmental quality in order to see success in public policy.

6.6.4 Michael Rymer

Michael Rymer is a Dark Sky International Program Associate and also works with programming for Dark Sky Certifications in the American Southwest (Colorado, New Mexico, Arizona, and Utah chapters)

Dark Sky International (DSI) is a non-profit whose headquarters are in Tucson, AZ. Founded in 1988 by astronomers to "lead in light pollution education" and advocacy, DSI has remote workers across the country as well as volunteers and advocates around the world. Currently the organization hosts workshops and collaborates with experts to discuss "best practices."

Rymer stated that "policy is our big goal right now" as DSI wishes to enhance their initiatives surrounding lighting ordinances through state and community governments. Another interest is to emphasize interstate collaboration and coalitions, for example an American Southwest coalition which includes Colorado, New Mexico, Arizona, and Utah.

He is proud of the Rocky Mountain area, specifically, because it is home to the "highest density of certified areas" in the world.

In general, Rymer stated that light pollution is a "big issue" that "covers a lot of things," not just about seeing the stars. There are "a lot of hazards" associated with it such as "wasted light is wasted energy, wasted energy is wasted dollars."

He also discusses the misconception that dissuades people from supporting the dark sky movement saying that they're "not trying to get rid of all the lights," but instead trying to use the lights present "responsibly."

6.7 Interviews

Interviews are crucial for this research because it demonstrates the human and social aspect of the work conducted. Light pollution is an important issue which touches almost everyone. The collected data demonstrates the quantitative differences between the past and present of Albuquerque, Phoenix, and Colorado Springs, but interviews allow for the sharing of lived experiences and the expression of qualitative shifts within these areas.

Beyond resident and city council members' opinions, expert opinion is critical to understand the relationship between development and light pollution and to understand the fundamentals as to why light pollution is an issue.

The overall sentiment expressed in the interviews (location specific and expert based) is that light pollution is an extremely pressing issue and is closely affiliated with development and urban growth/expansion.

It is also clear that it is a relatively easy issue to solve as long as there is a willingness to do so. Cities should enact stricter ordinances surrounding lumens, types of LEDs used, shading, and illumination.

Conclusion

Development and light pollution in urban environments profoundly affect both humans and the surrounding natural environment. The results of the six components of this study answer the guiding questions of 'how does development and light pollution interact in urban environments?' as well as for their pertinence to the level of light pollution in each city as well as how they are indicators of development. Our hypothesis that light pollution is strongly related to development, and the more development there is the more light pollution there will be is correct. The main indicators that prove the hypothesis are the VIIRS and collected data, VIIRS change over time from 2012 to 2024, land cover/use change analysis, and interviews. The sound decibel readings along with the crime and census data analysis did not provide any significant indicators or correlations when assessed for its relationship with light pollution.

The key takeaways from the research project is that VIIRS is a reliable indicator of light pollution in the sky; however, there must be data collected 'on-the-ground' in order to validate the actual brightness of nighttime lighting at individual sites. When using both metrics of illumination and brightness, Albuquerque is the darkest city taken into account for this study and Phoenix is the most light polluted city taken into account.

In terms of growth, between 2012 and 2024, Colorado Springs has had the most growth within the 11 year time period. Colorado Springs has seen the most increase in brightest level ranging pixels and is home to the brightest 'on-the-ground' measurement.

Tying this information together with the land use change during the last 60 years, commercial areas have seen significant increases while open land experiences losses. When using the 2023 land cover data in comparison to the amount of light present, this information helps identify that commercial industries are the largest contributors to light pollution and that residential areas typically have lower levels of light pollution.

Finally, interviews are critical to studies gauging the scientific and social impact of development on light pollution in urban environments. Residents, city council members, and expert opinions are needed to understand the fundamentals as to why light pollution is an issue. The overall sentiment expressed in the interviews is that light pollution is an extremely pressing issue and is closely affiliated with development and urban growth/expansion. It is also clear that it is a relatively easy issue to solve as long as there is a willingness to do so.

Avenues for future research include a comparison of light pollution's relationship with development in rural and urban areas, a study on health implications for animals and humans, an age of development study that looks at the age and its relationship to the amount of light pollution present, and, finally, exploring the potential policy directions needed to tackle this issue.

Appendix

Table 1: Locations and Data for Research Sites (Albuquerque, Phoenix, and Colorado Springs)
Albuquerque, New Mexico

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	262.07	12.79	(35.191288, -106.658328)	Commercial
Light 2	131.99	13.42	(35.0832181, -106.5499578)	Commercial
Light 3	113.40	13.525	(35.0835246, -106.5542407)	Residential
Light 4	105.33	12.175	(35.1377563, -106.5844806)	Commercial
Light 5	98.00	13.93	(35.1075334, -106.599861)	Commercial/Residential
Medium 6	97.71	13.745	(35.1248217, -106.6159305)	Commercial
Medium 7	75.00	14.2275	(35.07438, -106.6336203)	Commercial
Medium 8	60.68	17.09	(35.1380614, -106.624889)	Commercial
Medium 9	49.60	12.78	(35.0999295, -106.5330512)	Commercial

Medium 10	41.64	15.9475	(35.0210958, -106.6442968)	Industrial
Dark 11	41.62	15.4425	(35.1124851, -106.5709341)	Residential
Dark 12	28.13	14.815	(35.0624204, -106.6497571)	Residential
Dark 13	20.01	14.125	(35.0622497, -106.7251661)	Residential
Dark 14	14.49	17.015	(35.1755647, -106.5208716)	Residential
Dark 15	10.08	15.54	(35.0730284, -106.7935549)	Commercial

Phoenix, Arizona

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	355.11	11.1825	(33.236425, -111.8758382)	Industrial/Residential
Light 2	139.64	10.845	(33.6549919, -111.9243708)	Commercial
Light 3	117.03	12.975	(33.496103, -111.9216007)	Commercial/Residential
Light 4	105.32	11.8325	(33.4458268, -111.24919)	Industrial

Light 5	97.74	13.065	(33.508333, -112.029166)	Commercial
Medium 6	97.66	13.4225	(33.425, -111.970833)	Commercial
Medium 7	70.34	14.52	(33.4133121, -111.862746)	Commercial
Medium 8	56.53	14.0225	(33.6375, -112.329166)	Commercial
Medium 9	47.87	14.1875	(33.4666659, -112.1952343)	Residential
Medium 10	41.64	14.6675	(33.525, -112.208333)	Residential
Dark 11	41.63	14.1525	(33.266666, -111.687499)	Commercial
Dark 12	30.52	14.09	(33.2875, -111.712499)	Residential
Dark 13	23.33	14.855	(33.5875, -112.145833)	Residential
Dark 14	16.78	15.9425	(33.420833, -111.645833)	Residential
Dark 15	10.08	15.9625	(33.2272175, -111.8931797)	Commercial/Agriculture

Colorado Springs, Colorado

Location Name (according to VIIRS)	VIIRS Measurement (W/(cm^2-sr))	Field Collected Data (mags/arcsec^2)	GPS Coordinate	Category of Area
Light 1	351.75	10.2825	(38.8161573, -104.8328596)	Commercial

Light 2	257.32	13.8275	(38.9532584, -104.8005812)	Commercial/Open Land
Light 3	184.57	12.97	(38.9410607, -104.7293957)	Commercial
Light 4	160.58	14.8475	(38.9375, -104.720833)	Commercial/Residential
Light 5	145.06	12.675	(38.833333, -104.816666)	Commercial
Medium 6	142.61	14.8625	(38.945833, -104.799999)	Commercial
Medium 7	66.27	16.65	(38.8314105, -104.7166046)	Industrial
Medium 8	50.07	17.0475	(38.8458331, -104.8291659)	Open Land/Park
Medium 9	39.86	17.105	(38.8541659, -104.866662)	Residential
Medium 10	33.12	16.625	(38.7707942, -104.7364787)	Residential/Open Land
Dark 11	33.09	16.825	(38.8140053, -104.6742113)	Commercial
Dark 12	25.46	15.895	(39.0078714, -104.8165172)	Open Land/Commercial
Dark 13	19.43	17.465	(38.7666391, -104.669449)	Commercial/Open Land

Dark 14	14.01	12.855	(38.7971584, -104.6987227)	Commercial
Dark 15	9.66	14.9725	(38.7288966, -104.6835555)	Residential/Commercial

Table 2: Key for Reclassified Values

VIIRS Measurement Range (W/(cm^2-sr))	Reclassified Value
-0.045979 to 0.994765	1
0.994765 to 2.035508	2
2.035508 to 3.076251	3
3.076251 to 4.116994	4
4.116994 to 5.157737	5
5.157737 to 6.19848	6
6.19848 to 7.239223	7
7.239223 to 8.279966	8
8.279966 to 9.320709	9
9.320709 to 10.361452	10
10.361452 to 11.402195	11
11.402195 to 12.442938	12
12.442938 to 13.483681	13
13.483681 to 14.524425	14
14.524425 to 15.565168	15
15.565168 to 18.687397	16
18.687397 to 65.520835	17

65.520835 to 114.43576	18
114.43576 to 265.343506	19
265.343506 to 893.61	20

Table 3: VIIRS Light Pollution Change Over Time using Reclassified Values (Number of values within range)
Albuquerque, NM
Average Change: 73.90%

Reclassification Index	2012	2024	Percent Change %
1	27291	23190	-15.03
2	1236	4050	227.67
3	585	1000	70.94
4	352	543	54.26
5	276	345	25.00
6	209	248	18.66
7	201	210	4.48
8	158	194	22.78
9	139	139	0.00
10	161	153	-4.97
11	129	151	17.05
12	145	125	-13.79
13	125	105	-16.00
14	133	123	-7.52
15	113	90	-17.29
16	287	311	8.36

17	1270	1548	21.89
18	159	378	137.74
19	7	73	942.86
20	0	0	0.00

Phoenix, AZ
Average Change: 25.00%

Reclassification Index	2012	2024	Percent Change %
1	159950	150025	-6.21
2	6569	12030	83.13
3	2836	3534	24.61
4	1775	2005	12.96
5	1291	1430	10.77
6	1018	1133	11.30
7	776	939	21.01
8	719	794	10.43
9	635	713	12.28
10	587	715	21.81
11	560	629	12.32

12	541	622	14.97
13	511	585	14.48
14	537	586	9.12
15	466	561	20.39
16	1407	1572	11.73
17	10861	12250	12.79
18	932	1698	82.19
19	125	275	120.00
20	4	4	0.00

Colorado Springs, CO
Average Change: 257.61%

Reclassification Index	2012	2024	Percent Change %
1	31417	24255	-22.80
2	962	4900	409.36
3	472	1508	219.49
4	316	701	121.84
5	295	443	50.17
6	247	310	25.51

7	203	209	2.96
8	230	172	-25.22
9	196	157	-19.90
10	219	148	-32.42
11	172	137	-20.35
12	154	130	-15.58
13	130	96	-26.15
14	101	124	22.77
15	94	100	6.38
16	231	293	26.84
17	368	1984	439.13
18	8	286	3475.00
19	0	57	undefined
20	0	5	undefined

Table 4: Land Use Change over Time in Hectares (ha)

Albuquerque, NM

Average Change: 178.25%

Land Type	Area 1961 (ha)	Area 2023 (ha)	Percent Change (%)
Residential	2819	3619	28.38
Commercial	322	2104	553.42
Industrial	217	1147	428.57
Open Land	3297	759	-76.98
Water Features	586	339	-42.15

Phoenix, AZ

Average Change: 125.79%

Land Type	Area 1964 (ha)	Area 2023 (ha)	Percent Change (%)
Residential	1349	5057	274.87
Commercial	458	1752	282.53
Industrial	316	1046	231.01
Open Land	5939	807	-86.41
Water Features	802	216	-73.07

Colorado Springs, CO

Average Change: 70.49%

Land Type	Area 1963 (ha)	Area 2023 (ha)	Percent Change (%)

Residential	1341	2725	103.21
Commercial	891	2685	201.35
Industrial	309	841	172.71
Open Land	4471	1765	-60.52
Water Features	868	310	-64.29

Table 5: Crime and Census Data for Each Location
Albuquerque, NM

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Light 1	5,843	45,146 - 94,867	White and Hispanic
Light 2	18,797	17,107 - 66,842	White and Hispanic
Light 3	17,396	17,107 - 66,842	White and Hispanic
Light 4	11,291	17,107 - 66,842	Hispanic
Light 5	10,492	17,107 - 94,867	White and Hispanic
Medium 6	10,344	17,107 - 66,842	Hispanic
Medium 7	15,233	17,107 - 45,146	White and Hispanic
Medium 8	3,408	45,146 - 66,842	White and Hispanic
Medium 9	6,957	17,107 - 94,867	White and Hispanic
Medium 10	218	45,146 - 66,842	Hispanic
Dark 11	8,443	45,146 - 66,842	White and Hispanic
Dark 12	5,716	17,107 - 66,842	White and Hispanic
Dark 13	6,145	17,107 - 94,867	White and Hispanic
Dark 14	141	94,867 - 250,001	White and Hispanic
Dark 15	43	17,107 - 94,867	White and Hispanic

Phoenix, AZ

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Light 1	N/A	57,656 - 243,542	White and Hispanic
Light 2	N/A	82,958 - 111,667	White and Hispanic
Light 3	N/A	14,746 - 111,667	White
Light 4	N/A	14,746 - 57,656	Hispanic
Light 5	N/A	57,656 - 111,667	White and Hispanic
Medium 6	N/A	14,746 - 82,958	No discernible majority
Medium 7	N/A	14,746 - 57,656	White and Hispanic
Medium 8	N/A	14,746 - 57,656	Hispanic
Medium 9	N/A	14,746 - 57,656	Hispanic
Medium 10	N/A	14,746 - 82,958	Hispanic
Dark 11	N/A	111,667 - 243,542	White and Hispanic
Dark 12	N/A	150,000 - 243,542	White and Hispanic
Dark 13	N/A	14,746 - 82,958	White and Hispanic
Dark 14	N/A	14,746 - 82,958	White and Hispanic
Dark 15	N/A	14,746 - 82,958	No discernible majority

Colorado Springs, CO

Location	Crimes (Reported)	Income ($)	Race (Predominantly)
Light 1	3,809	20,747 - 69,327	White and Hispanic
Light 2	853	69,327 - 95,736	White and Hispanic
Light 3	599	132,750 - 228,750	White and Hispanic
Light 4	680	69,327 - 132,750	White and Hispanic
Light 5	3,927	20,747 - 69,327	White and Hispanic
Medium 6	986	95,736 - 132,750	White and Hispanic
Medium 7	263	69,327 - 95,736	Hispanic
Medium 8	1,288	20,747 - 69,327	White and Hispanic
Medium 9	1,282	69,327 - 95,736	White and Hispanic
Medium 10	16	47,952 - 95,736	White and Hispanic
Dark 11	4	69,327 - 95,736	White and Hispanic
Dark 12	123	132,750 - 228,750	White and Hispanic
Dark 13	12	95,736 - 132,750	White and Hispanic
Dark 14	93	95,736 - 132,750	Hispanic
Dark 15	3	95,736 - 132,750	Hispanic

Table 6: Sound Data Analysis
Albuquerque, NM

Location	Decibel Reading (dB)
Light 1	-26.6062
Light 2	-28.7626
Light 3	-24.9485
Light 4	-33.8727
Light 5	-35.8689
Medium 6	-30.9492
Medium 7	-26.5381
Medium 8	-35.6065
Medium 9	-18.5439
Medium 10	-30.2225
Dark 11	-38.1657
Dark 12	-28.081
Dark 13	-38.7602
Dark 14	-34.0132
Dark 15	-12.1355

Figures 42 - 56: Audiographs of data collection sites in Albuquerque, New Mexico.

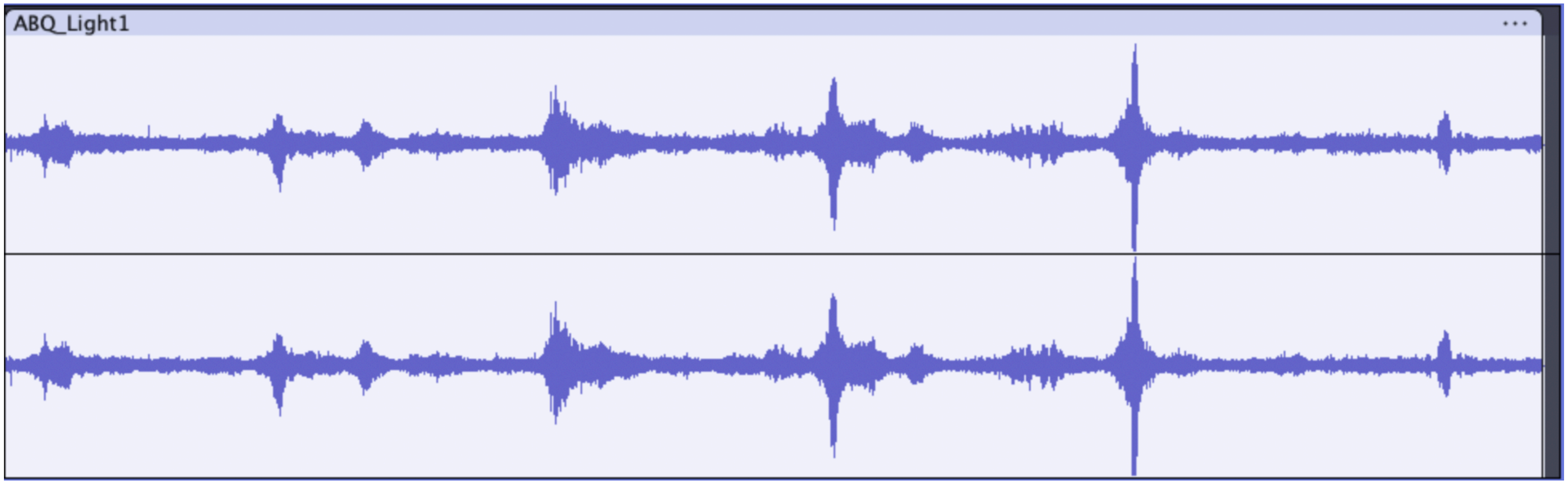


Figure 42: Light 1 Albuquerque. -26.6062 dB.

Figure 43: Light 2 Albuquerque. -28.7626 dB.

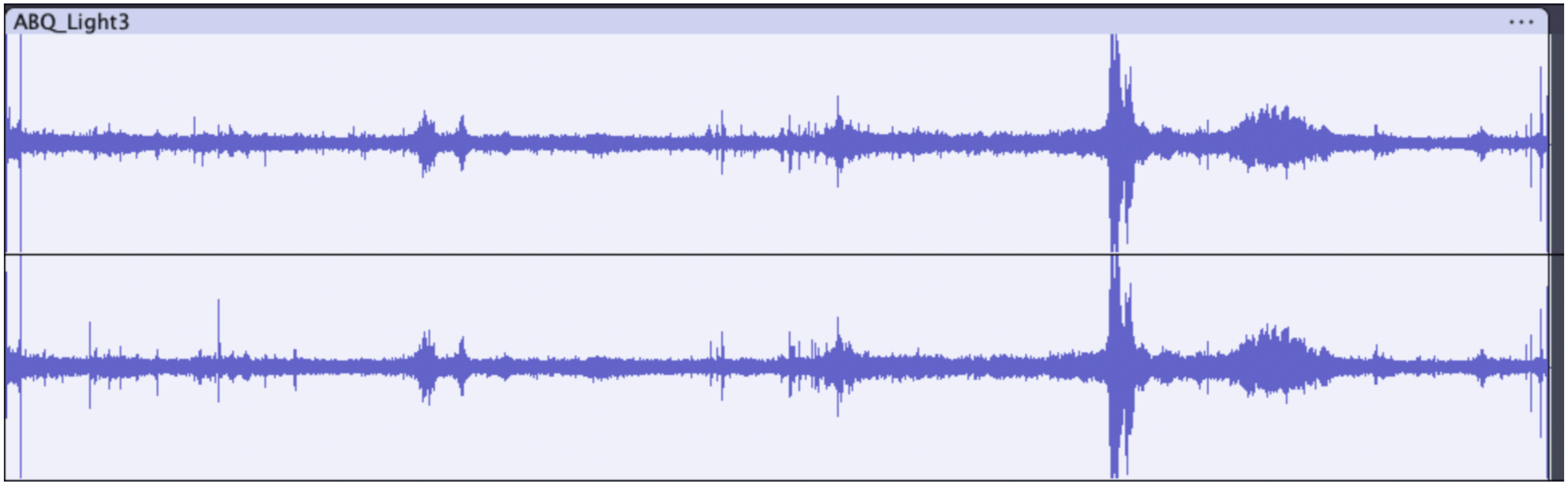


Figure 44: Light 3 Albuquerque. -24.9485 dB.

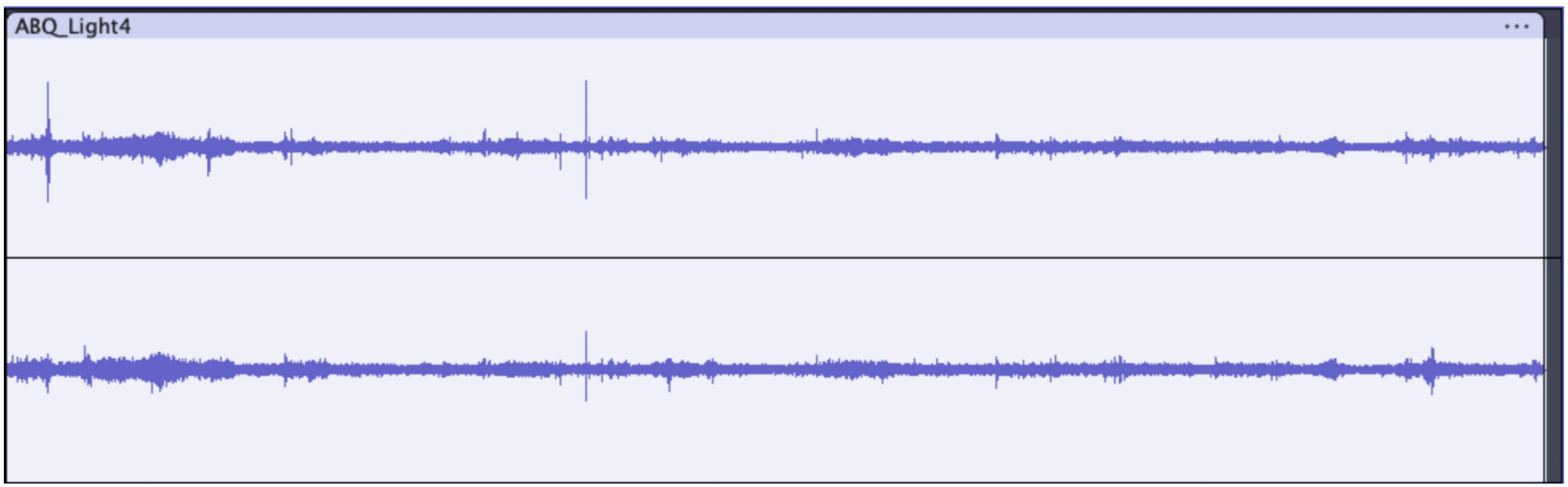


Figure 45: Light 4 Albuquerque. -33.8727 dB.

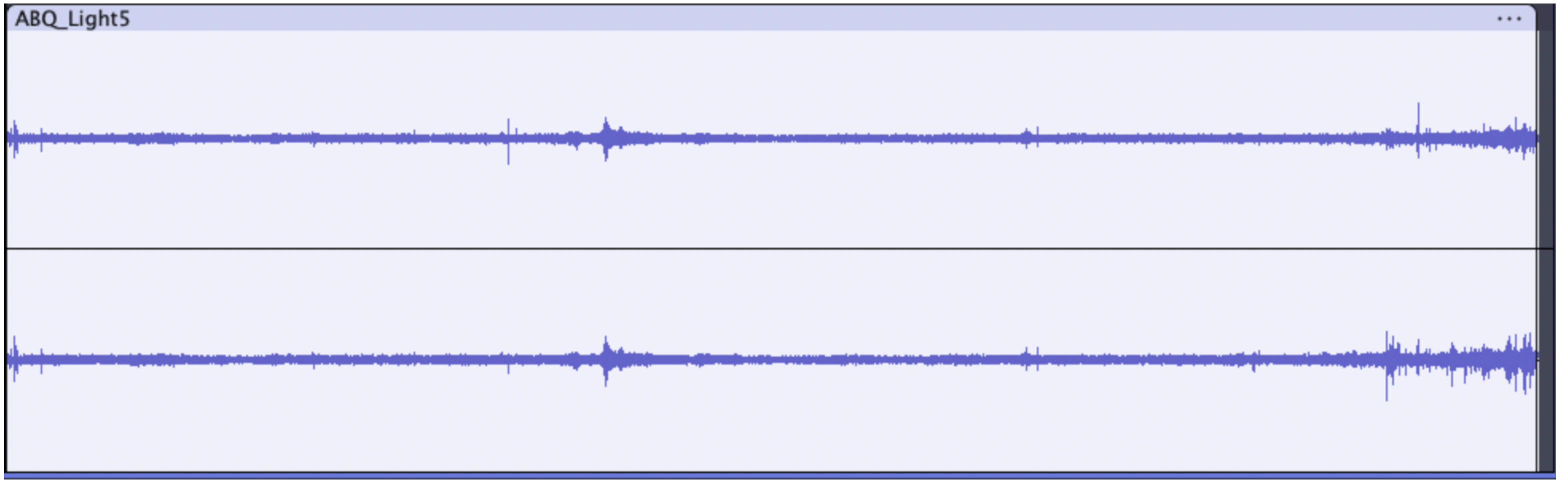


Figure 46: Light 5 Albuquerque. -35.8689 dB.

Figure 47: Medium 6 Albuquerque. -30.9492 dB.

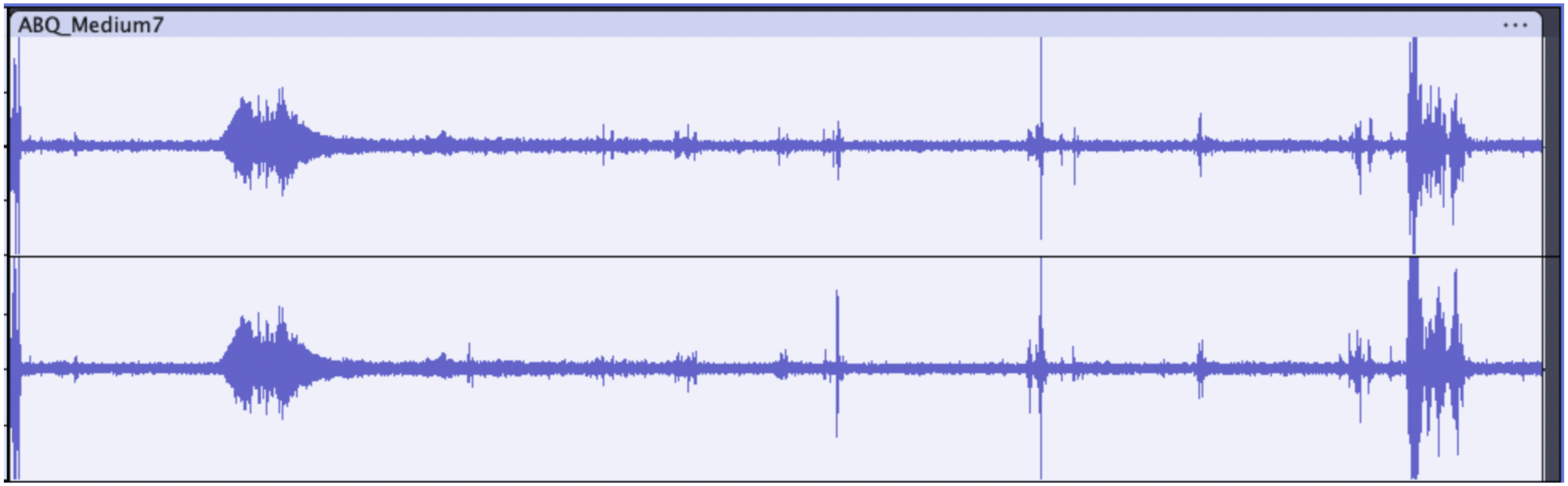


Figure 48: Medium 7 Albuquerque. -26.5381 dB.

Figure 49: Medium 8 Albuquerque. -35.6065 dB.

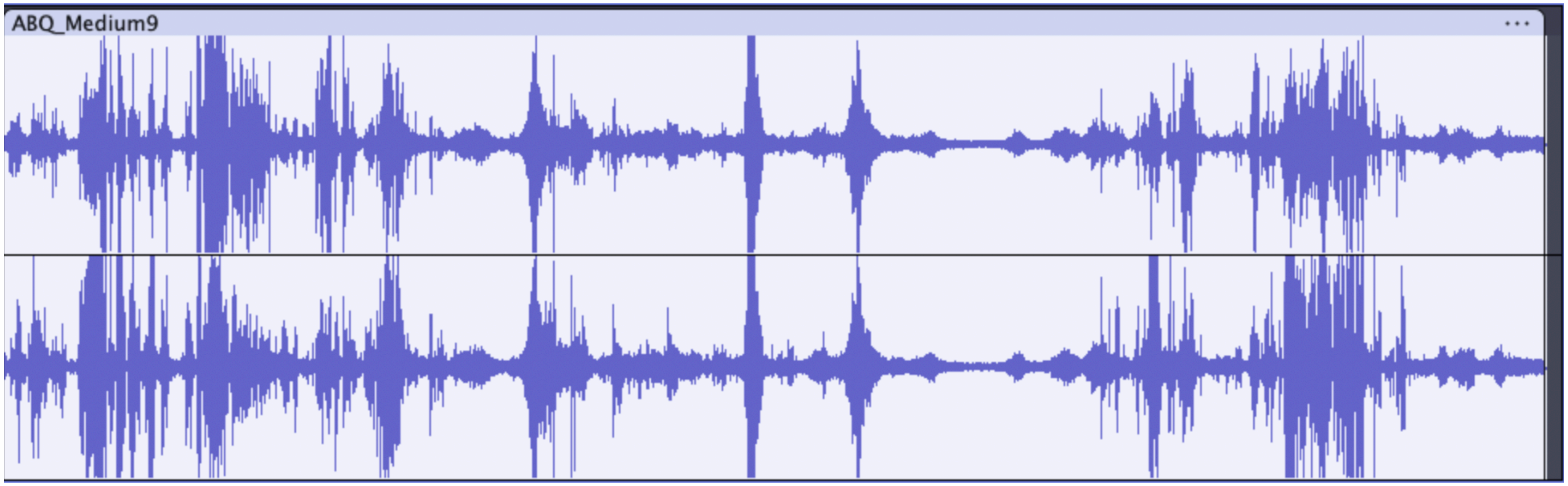


Figure 50: Medium 9 Albuquerque. -18.5439 dB.

Figure 51: Medium 10 Albuquerque. -30.2225 dB.

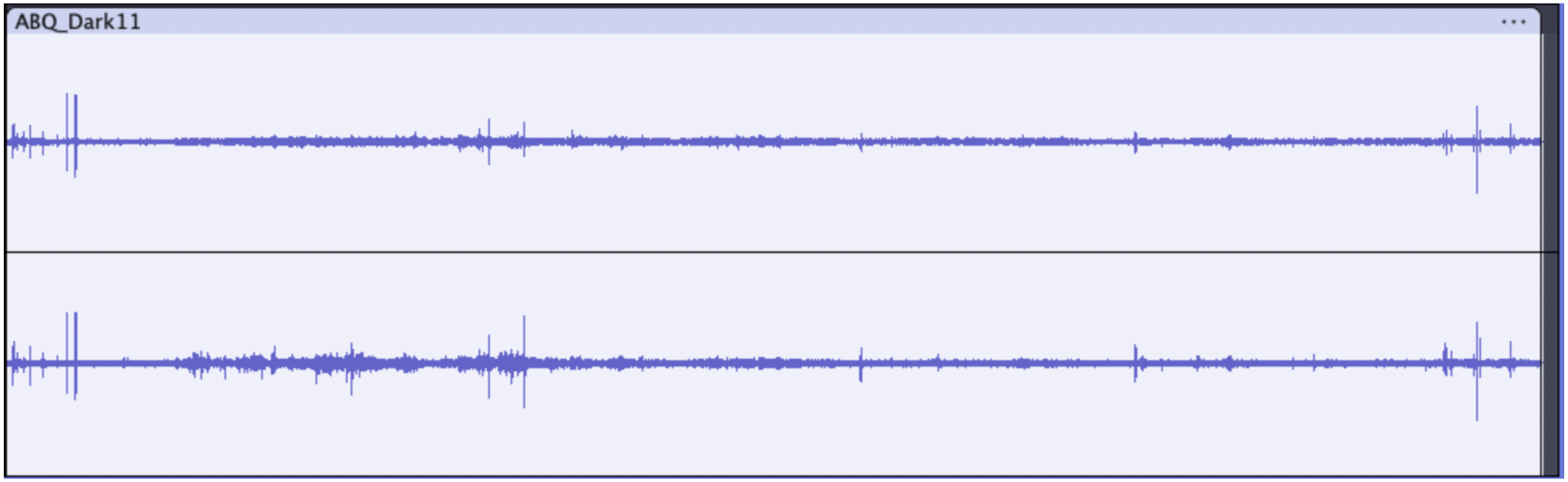


Figure 52: Dark 11 Albuquerque. -38.1657 dB.

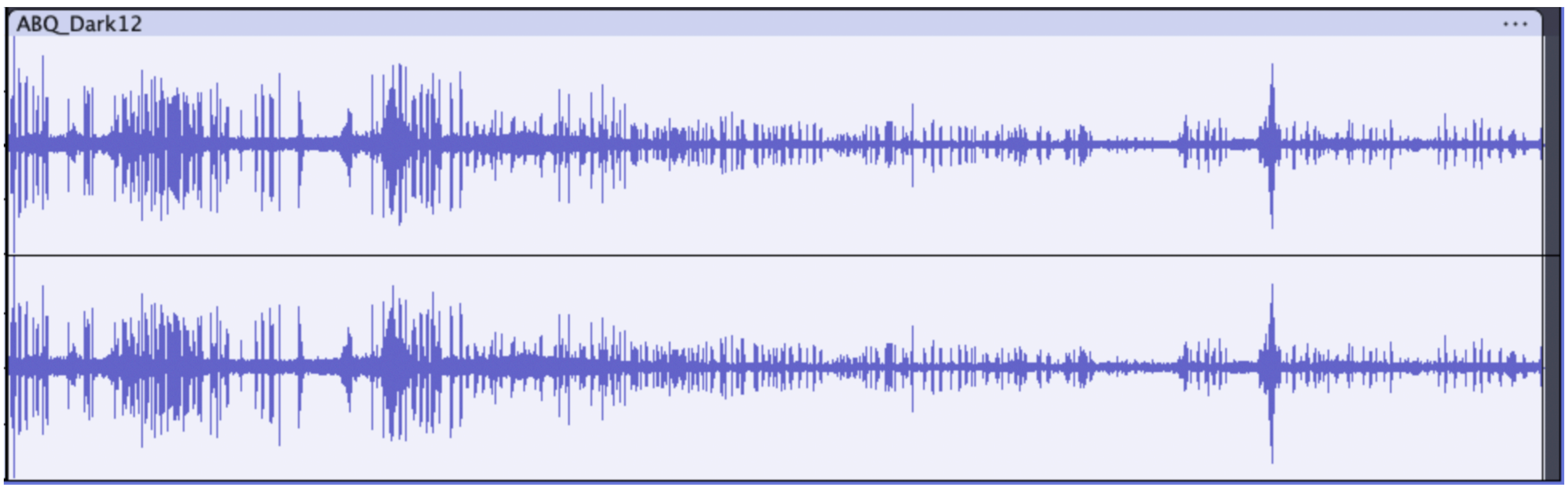


Figure 53: Dark 12 Albuquerque. -28.081 dB.

Figure 54: Dark 13 Albuquerque. -38.7602 dB.

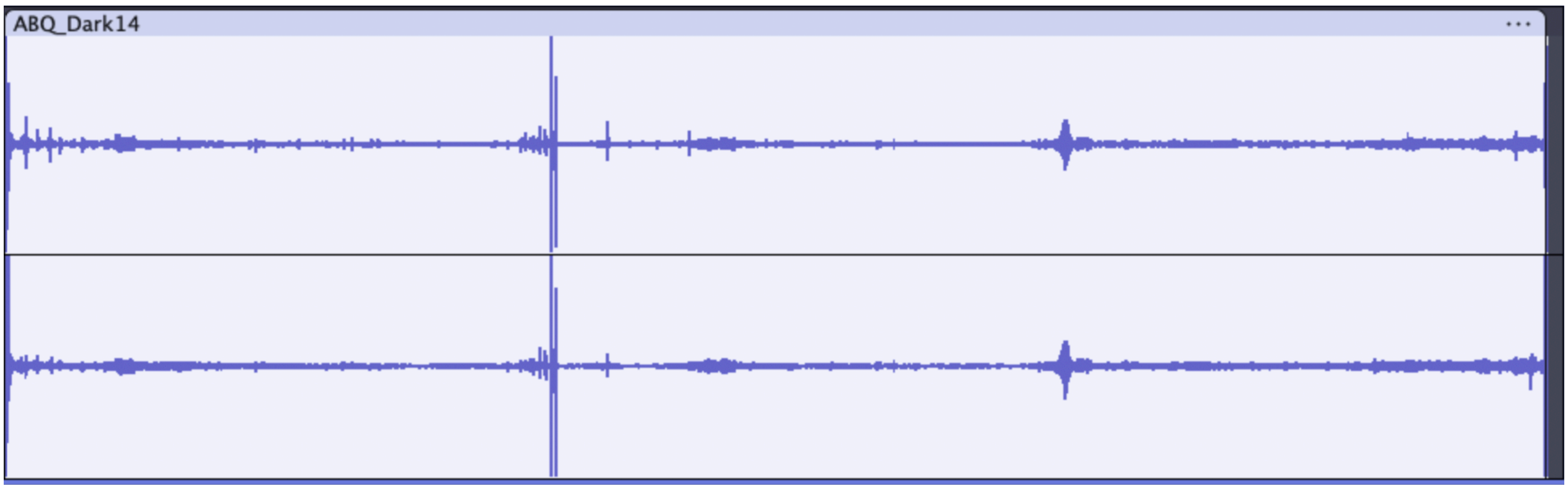


Figure 55: Dark 14 Albuquerque. -34.0132 dB.

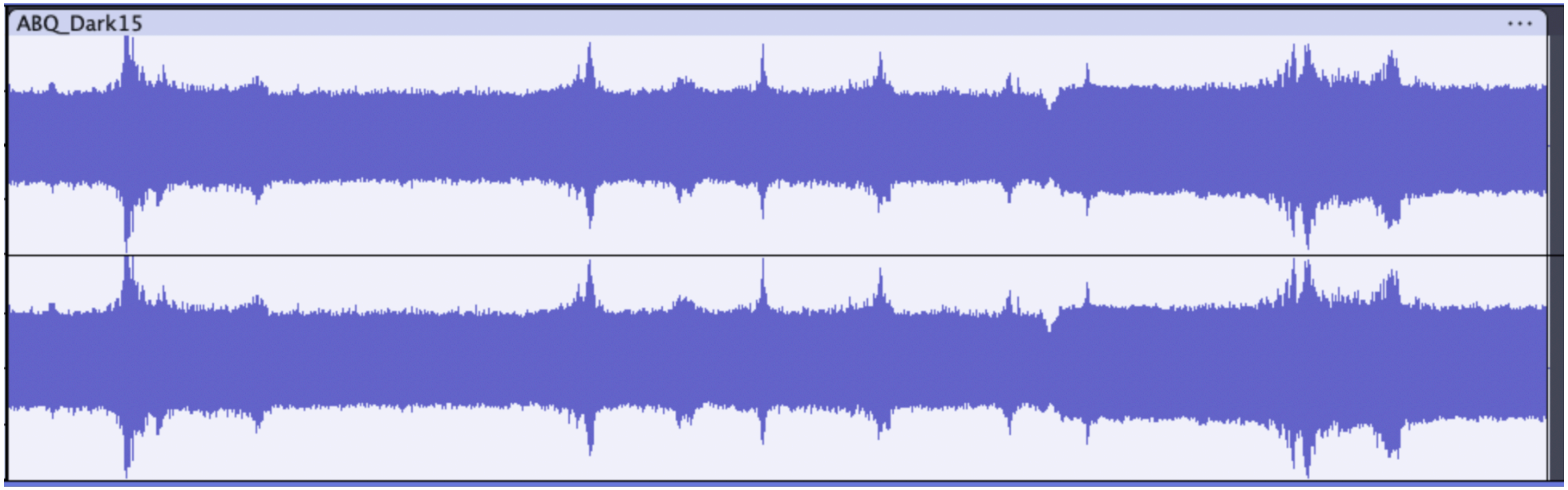


Figure 56: Dark 15 Albuquerque. -12.1355 dB.

Phoenix, AZ

Location	Decibel Reading (dB)
Light 1	-24.2329
Light 2	-25.7304
Light 3	-28.9376
Light 4	-21.6245
Light 5	-31.0834
Medium 6	-30.5312
Medium 7	-31.2892
Medium 8	-32.6002
Medium 9	-28.7036
Medium 10	-33.1036
Dark 11	-30.4602
Dark 12	-41.6523
Dark 13	-30.7783
Dark 14	-34.7536
Dark 15	-36.9482

Figures 57 - 71: Audiographs of data collection sites in Phoenix, Arizona.

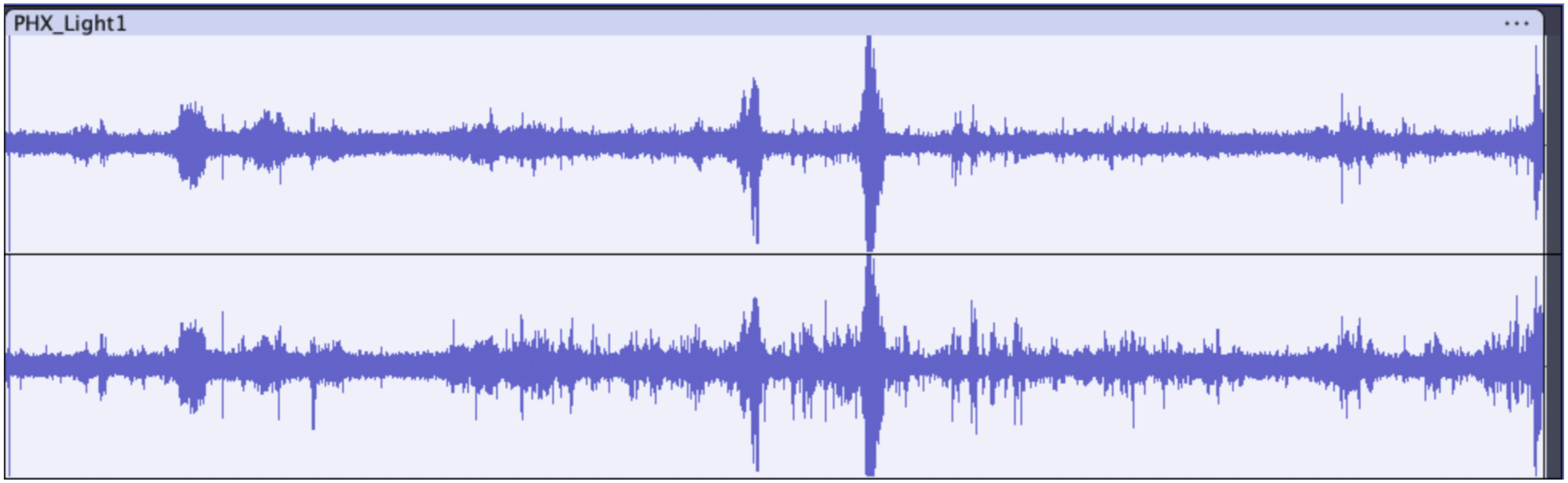


Figure 57: Light 1 Phoenix. -24.2329 dB.

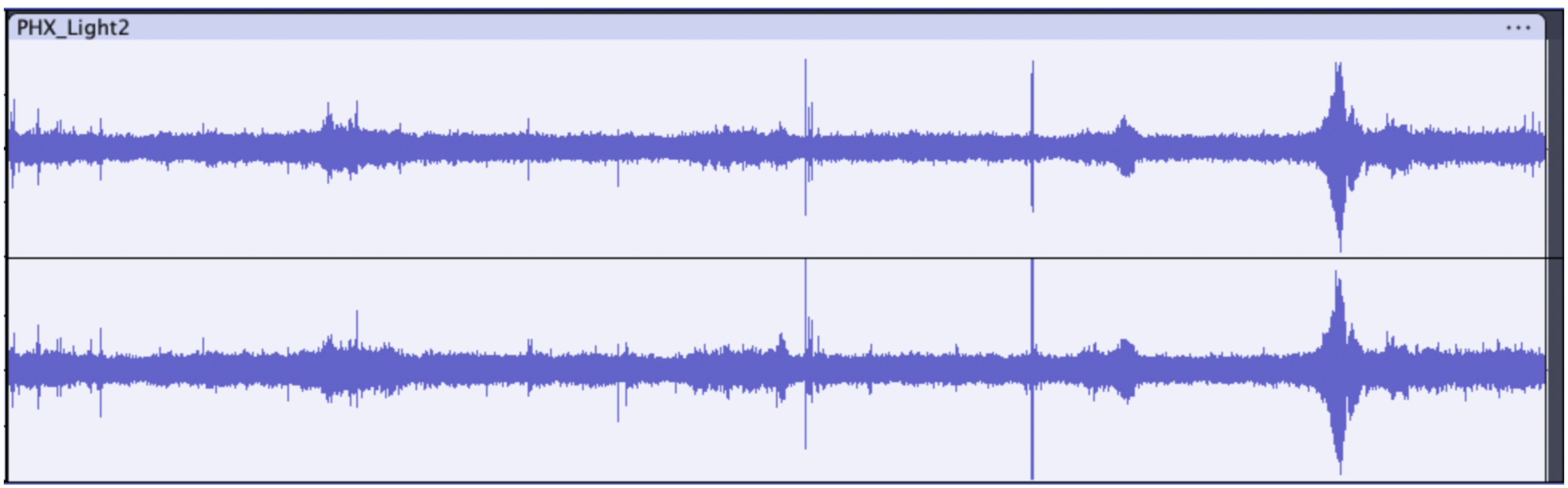


Figure 58: Light 2 Phoenix. -25.7304 dB.

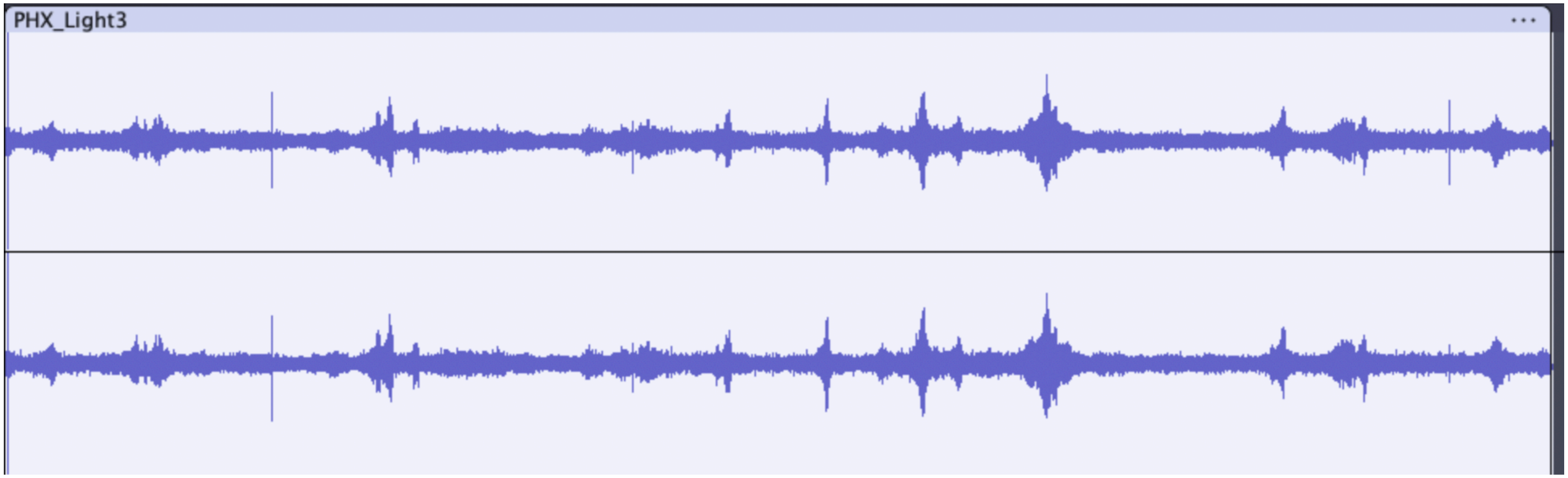


Figure 59: Light 3 Phoenix. -28.9376 dB.

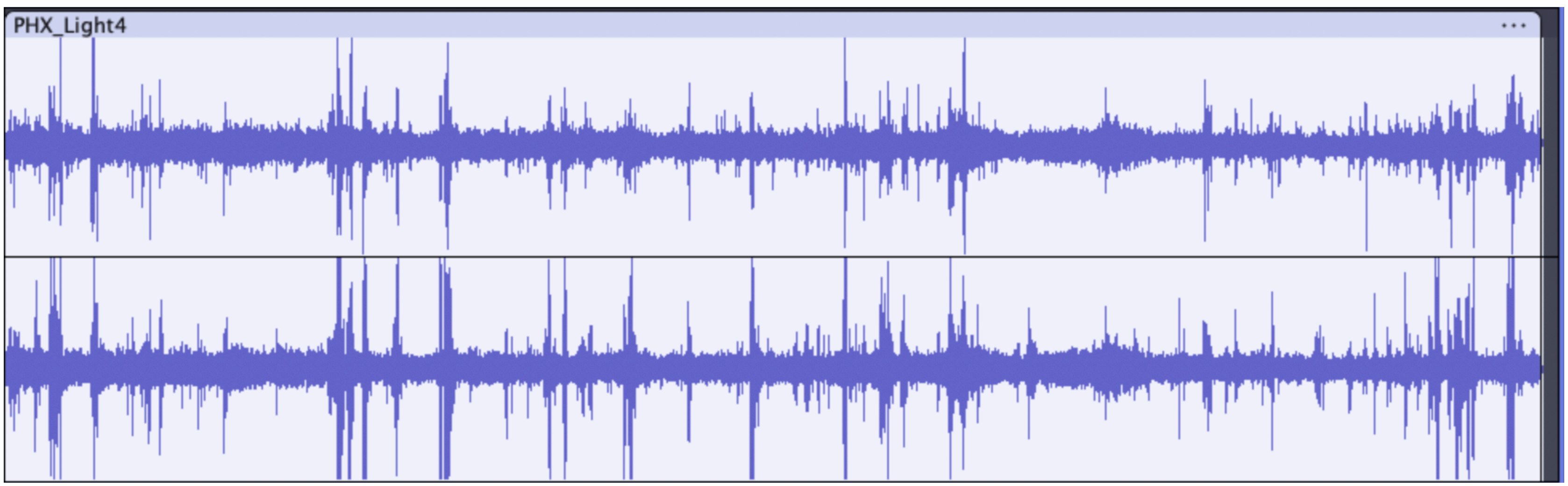


Figure 60: Light 4 Phoenix. -21.6245 dB.

Figure 61: Light 5 Phoenix. -31.0834 dB.

Figure 62: Medium 6 Phoenix. -30.5312 dB.

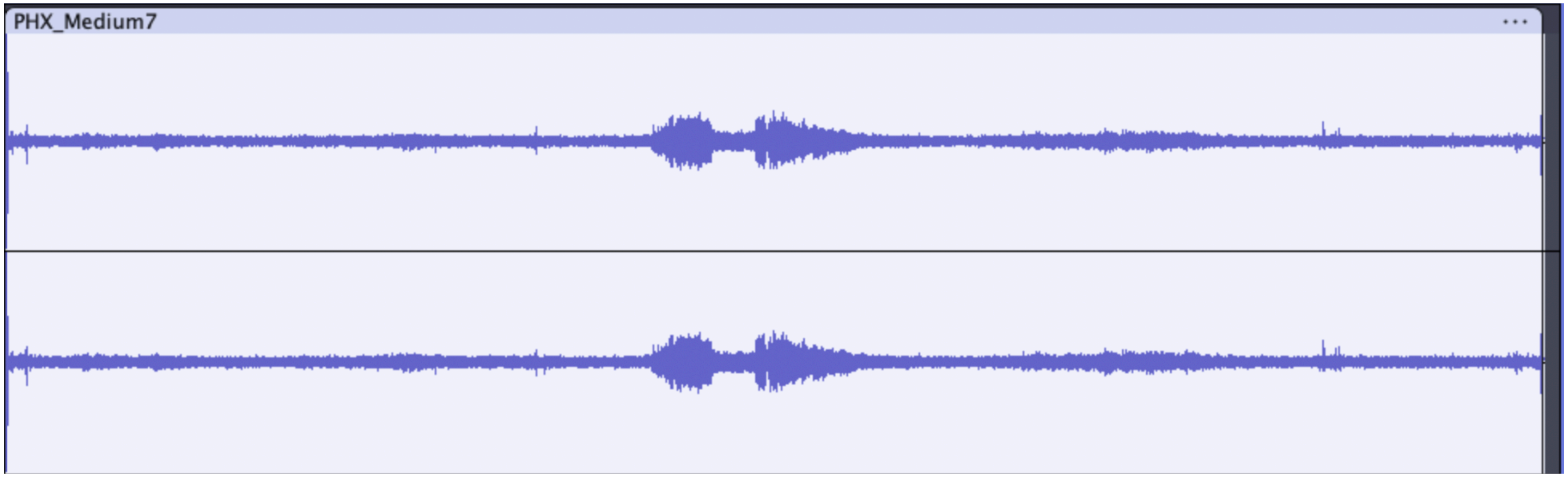


Figure 63: Medium 7 Phoenix. -31.2892 dB.

Figure 64: Medium 8 Phoenix. -32.6002 dB.

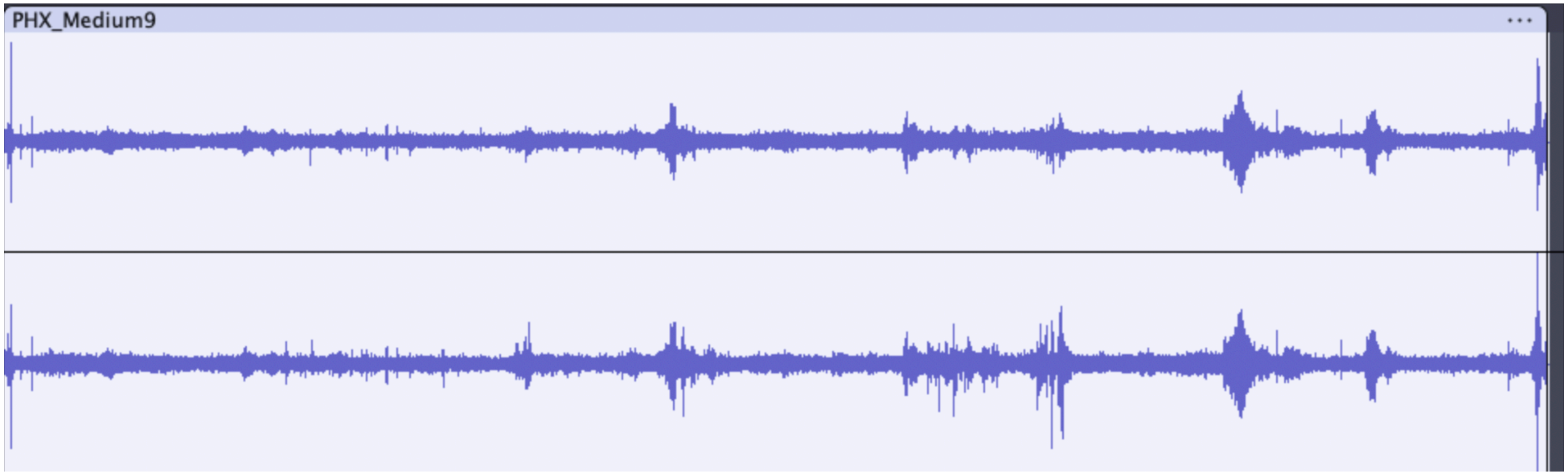


Figure 65: Medium 9 Phoenix. -28.7036 dB.

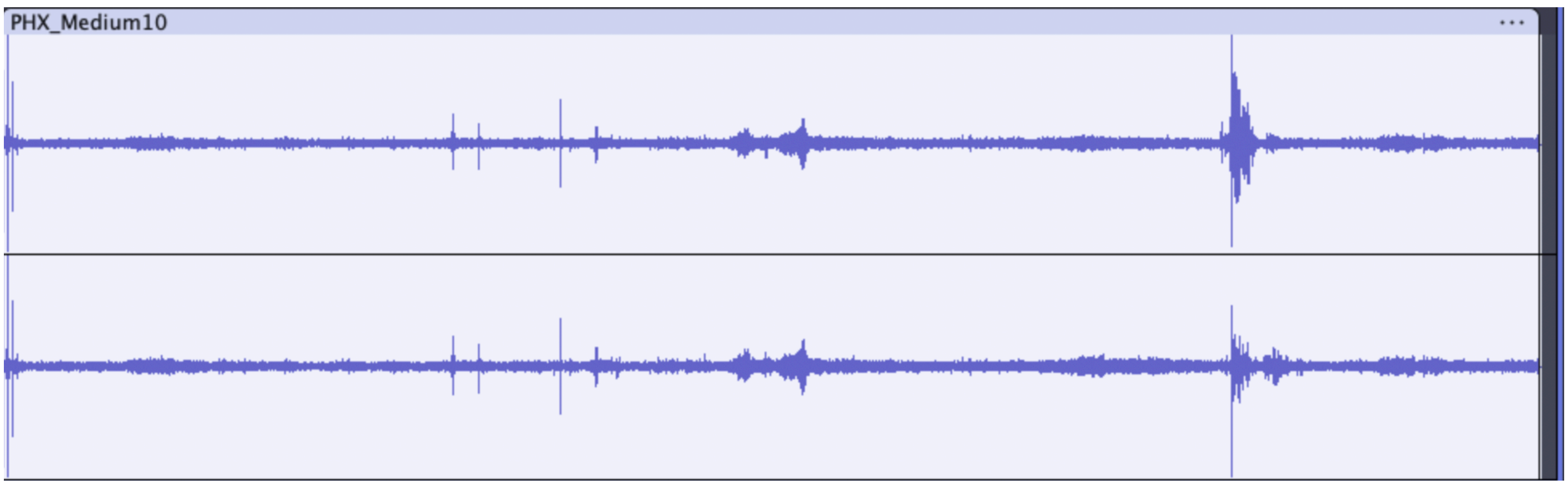


Figure 66: Medium 10 Phoenix. -33.1036 dB.

Figure 67: Dark 11 Phoenix. -30.4602 dB.

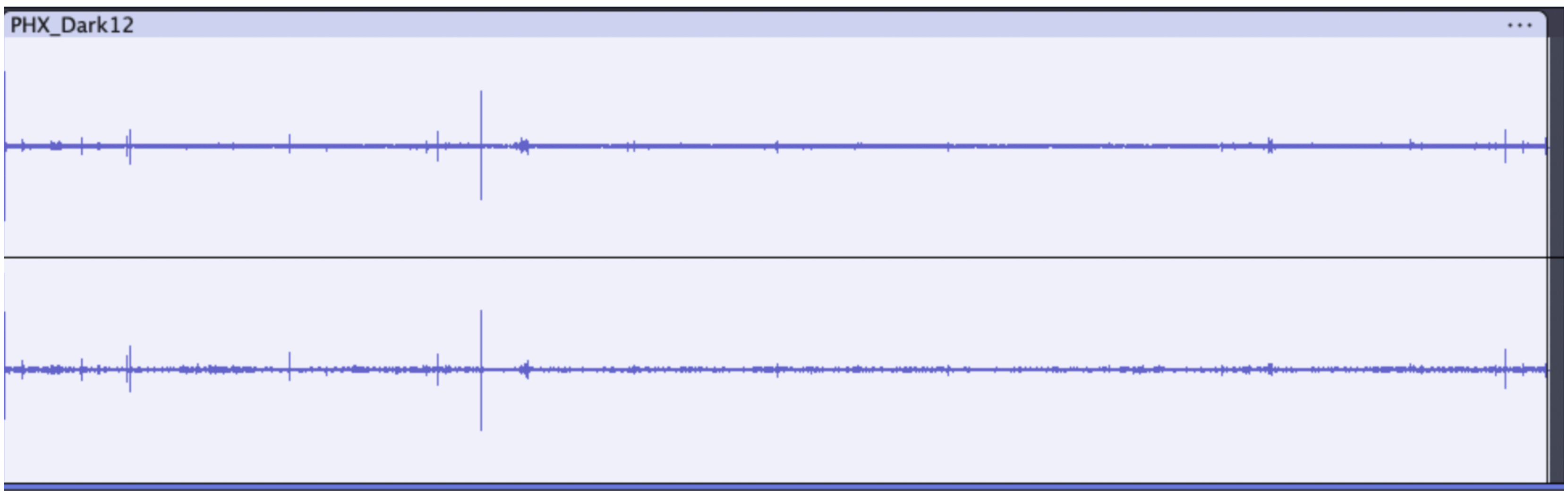


Figure 68: Dark 12 Phoenix. -41.6523 dB.

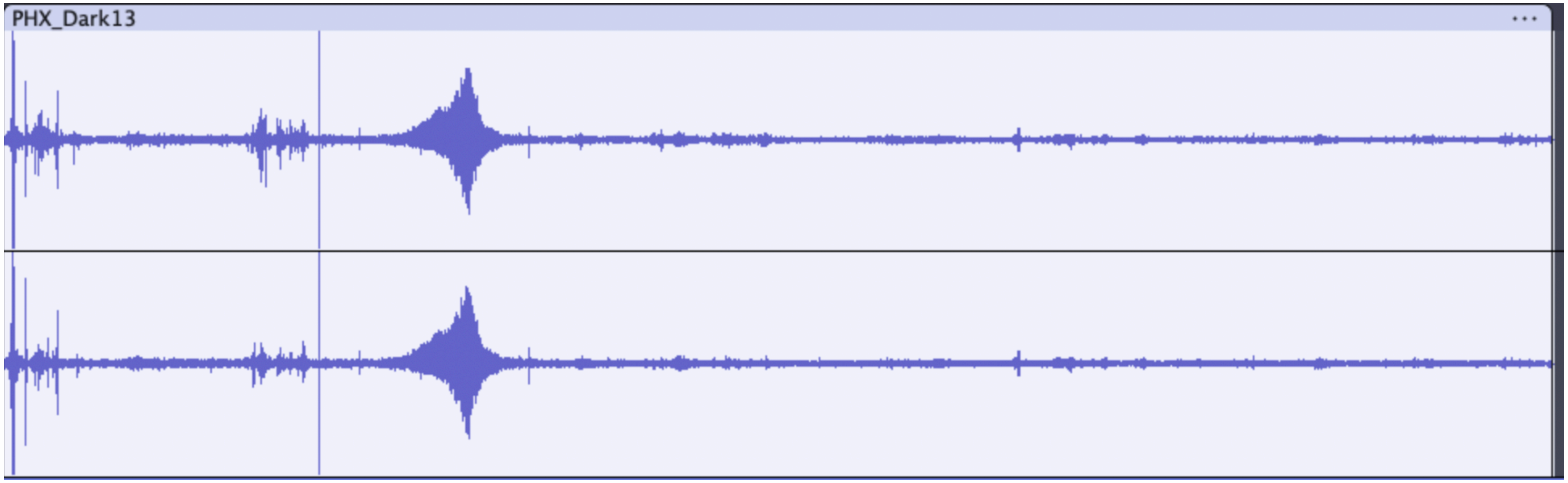


Figure 69: Dark 13 Phoenix. -30.7783 dB.

Figure 70: Dark 14 Phoenix. -34.7536 dB.

Figure 71: Dark 15 Phoenix. -36.9482 dB.

Colorado Springs, CO

Location	Decibel Reading (dB)
Light 1	-27.8556
Light 2	-11.6902
Light 3	-28.2849
Light 4	-30.8378
Light 5	-30.2274
Medium 6	-23.9176
Medium 7	-35.6389
Medium 8	-24.7717
Medium 9	-33.2016
Medium 10	-33.3765
Dark 11	-22.9959
Dark 12	-27.5815
Dark 13	-34.9585
Dark 14	-29.8518
Dark 15	-29.9829

Figures 72 - 86: Audiographs of data collection sites in Colorado Springs, Colorado.

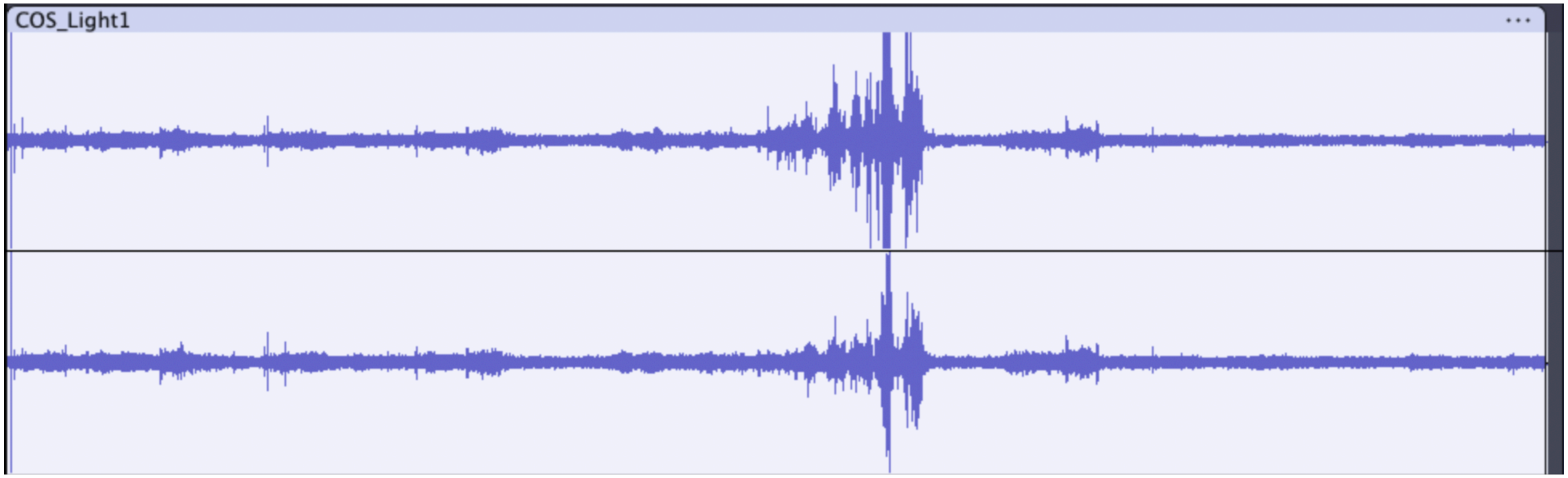


Figure 72: Light 1 Colorado Springs. -27.8556 dB.

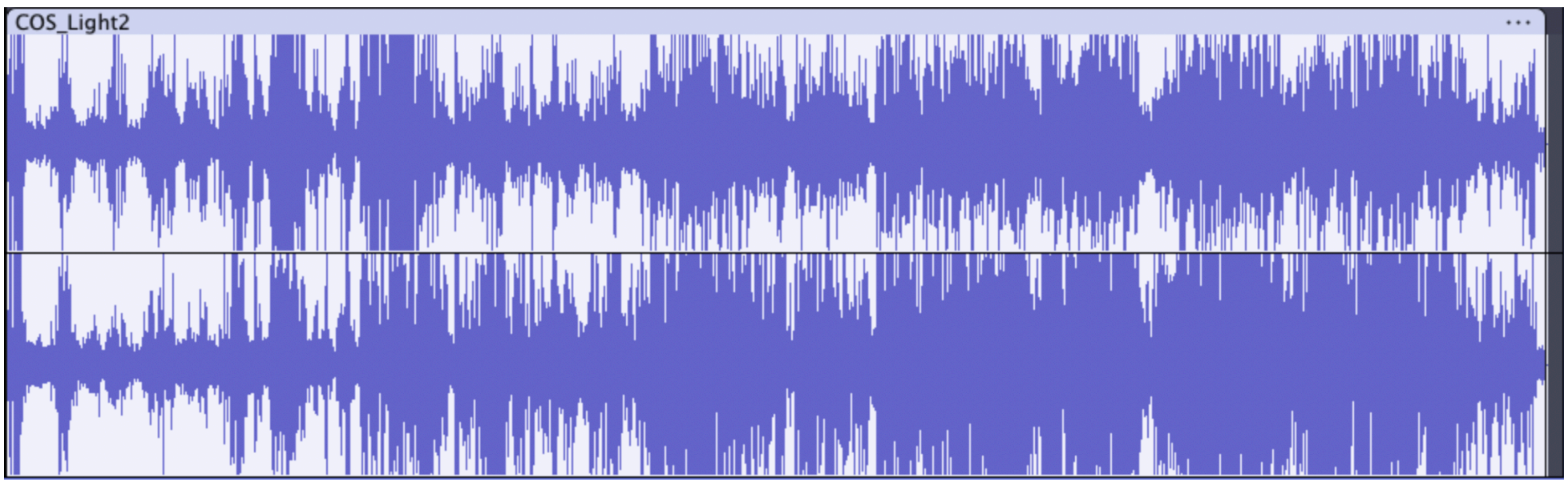


Figure 73: Light 2 Colorado Springs. -11.6902 dB.

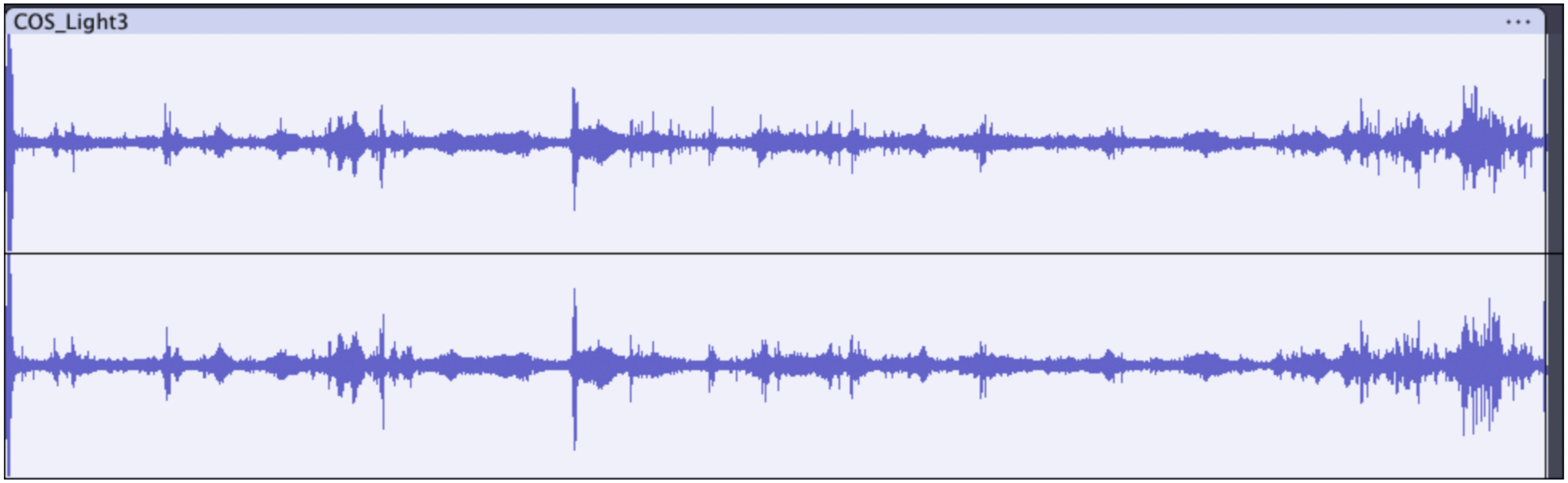


Figure 74: Light 3 Colorado Springs. -28.2849 dB.

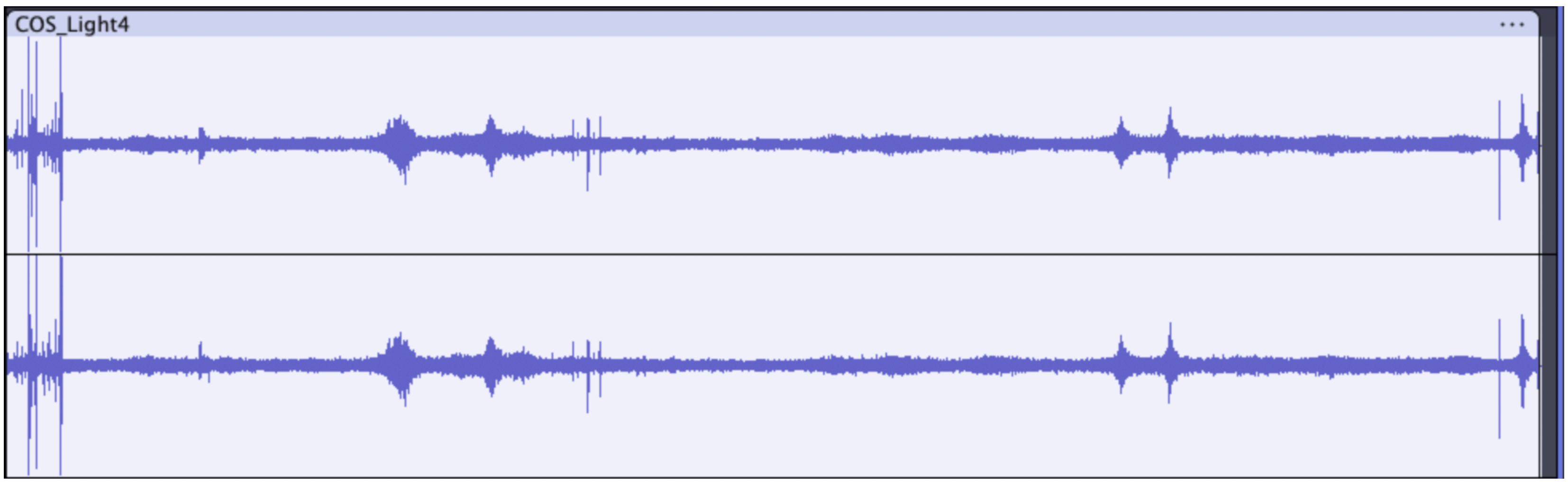


Figure 75: Light 4 Colorado Springs. -30.8378 dB.

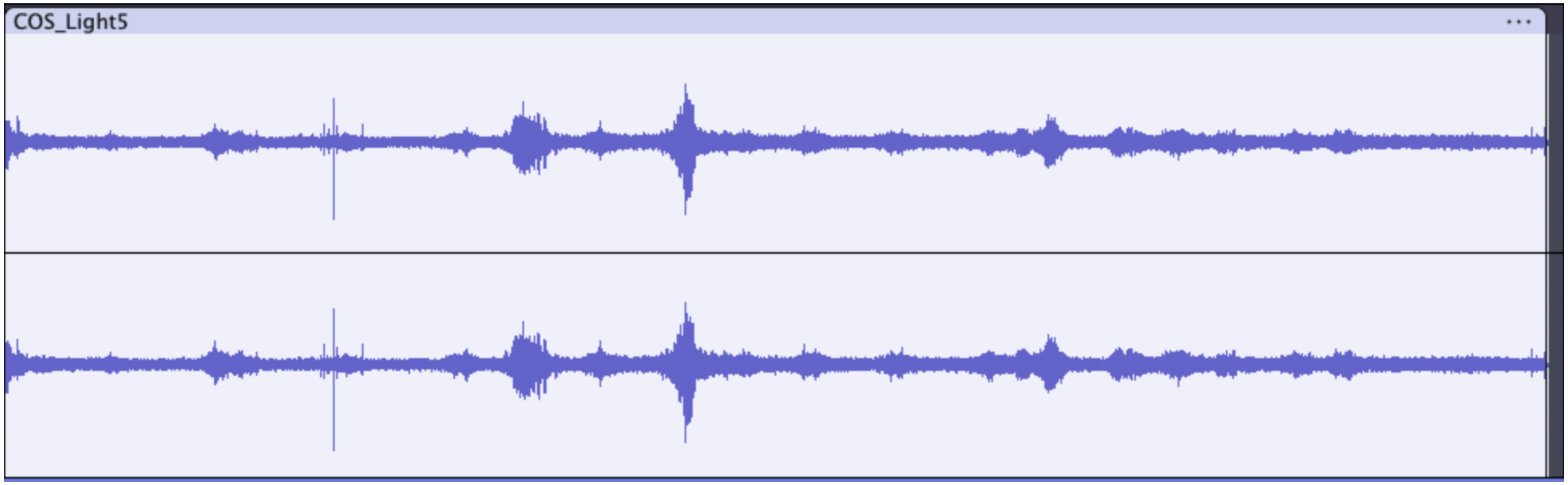


Figure 76: Light 5 Colorado Springs. -30.2274 dB.

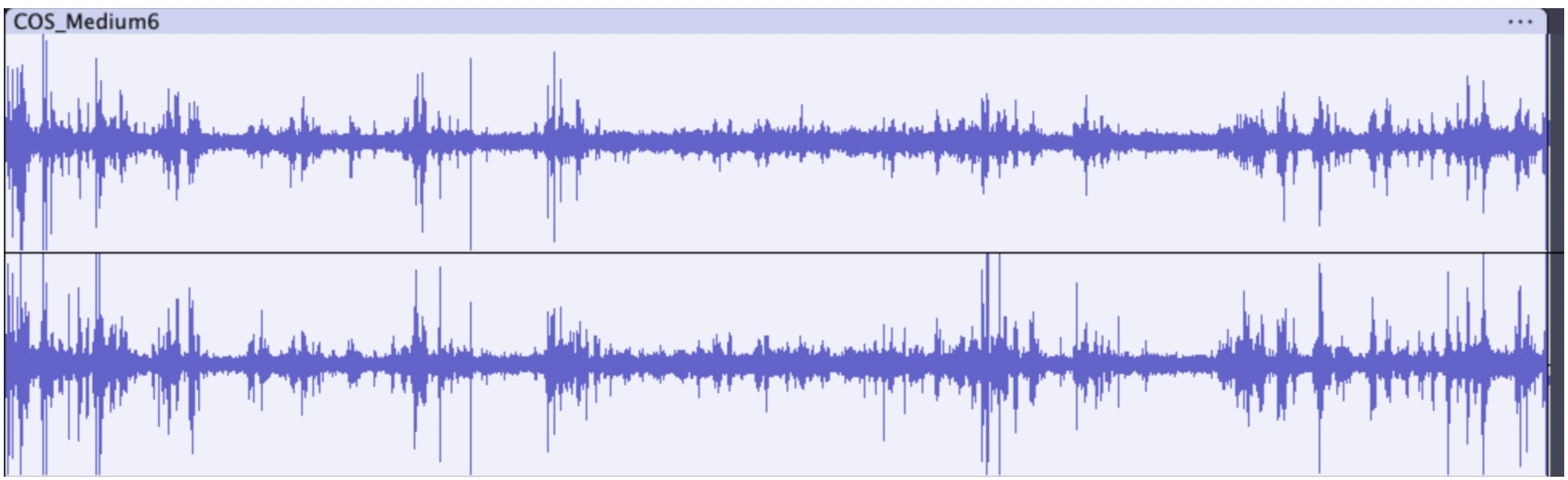


Figure 77: Medium 6 Colorado Springs. -23.9176 dB.

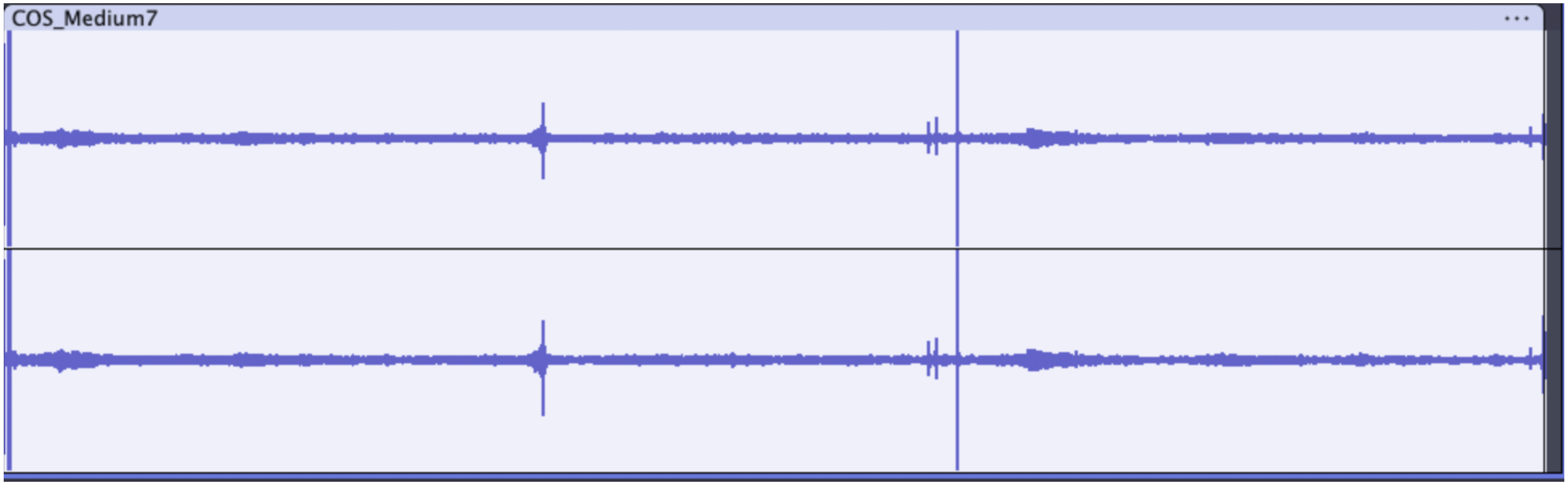


Figure 78: Medium 7 Colorado Springs. -35.6389 dB.

Figure 79: Medium 8 Colorado Springs. -24.7717 dB.

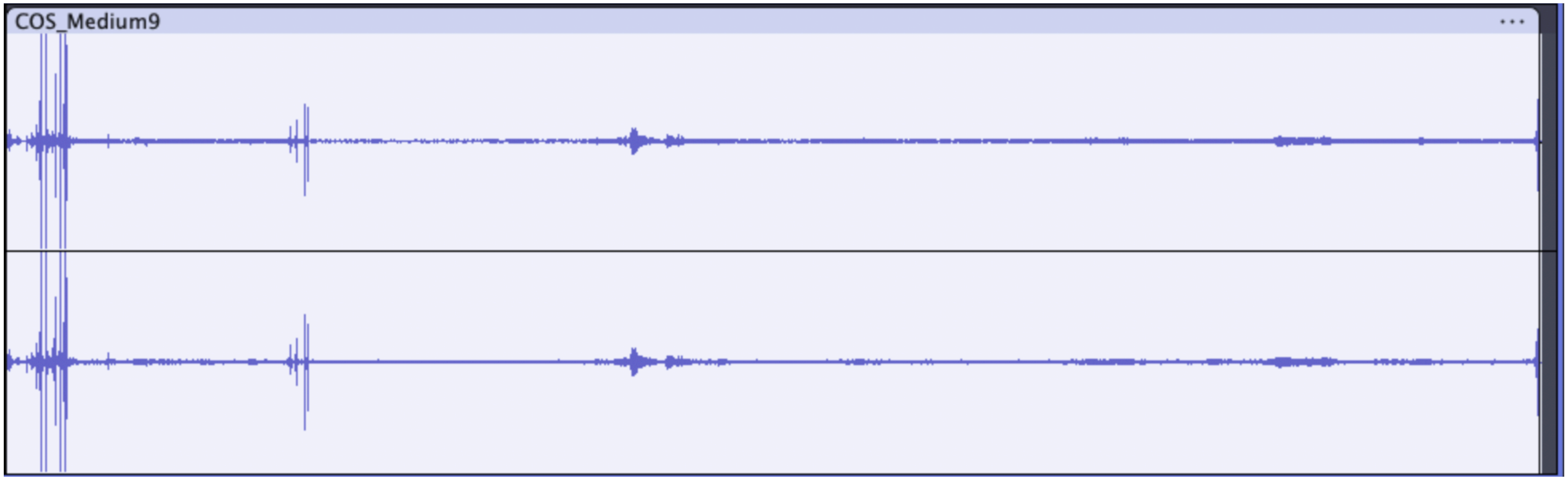


Figure 80: Medium 9 Colorado Springs. -33.2016 dB.

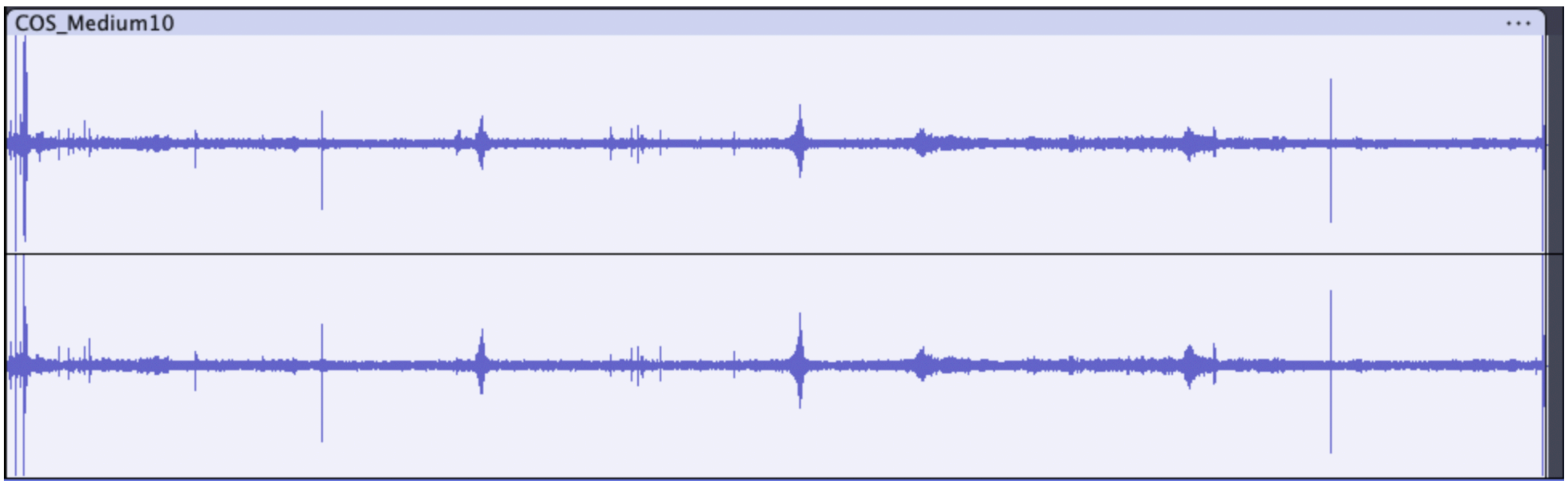


Figure 81: Medium 10 Colorado Springs. -33.3765 dB.

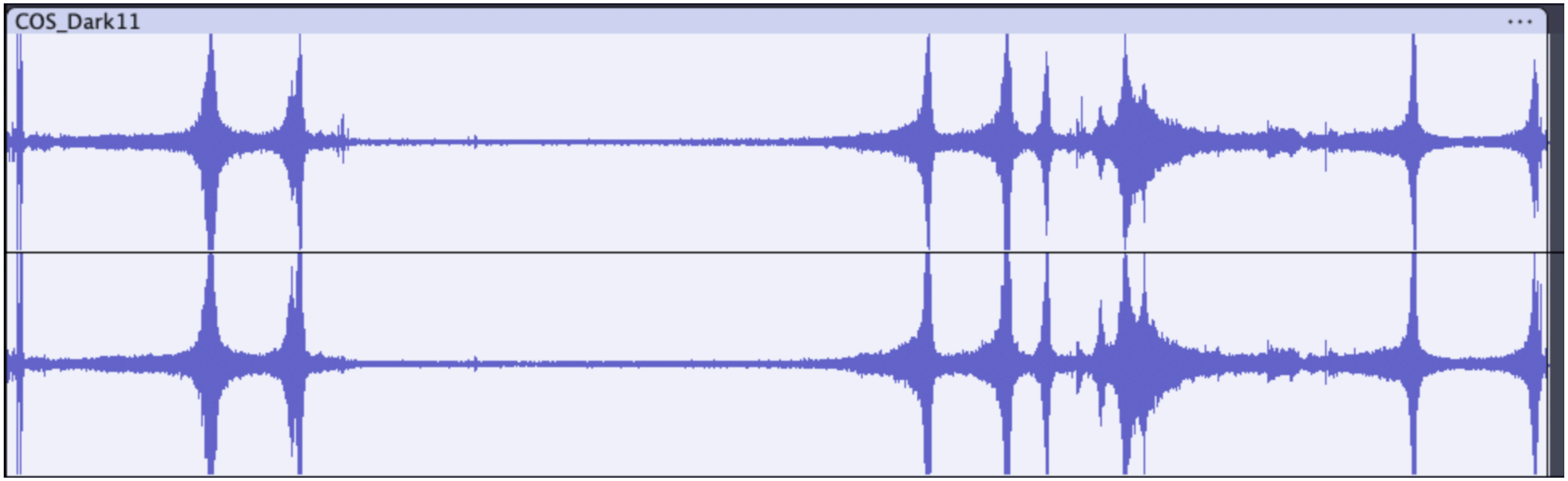


Figure 82: Dark 11 Colorado Springs. -22.9959 dB.

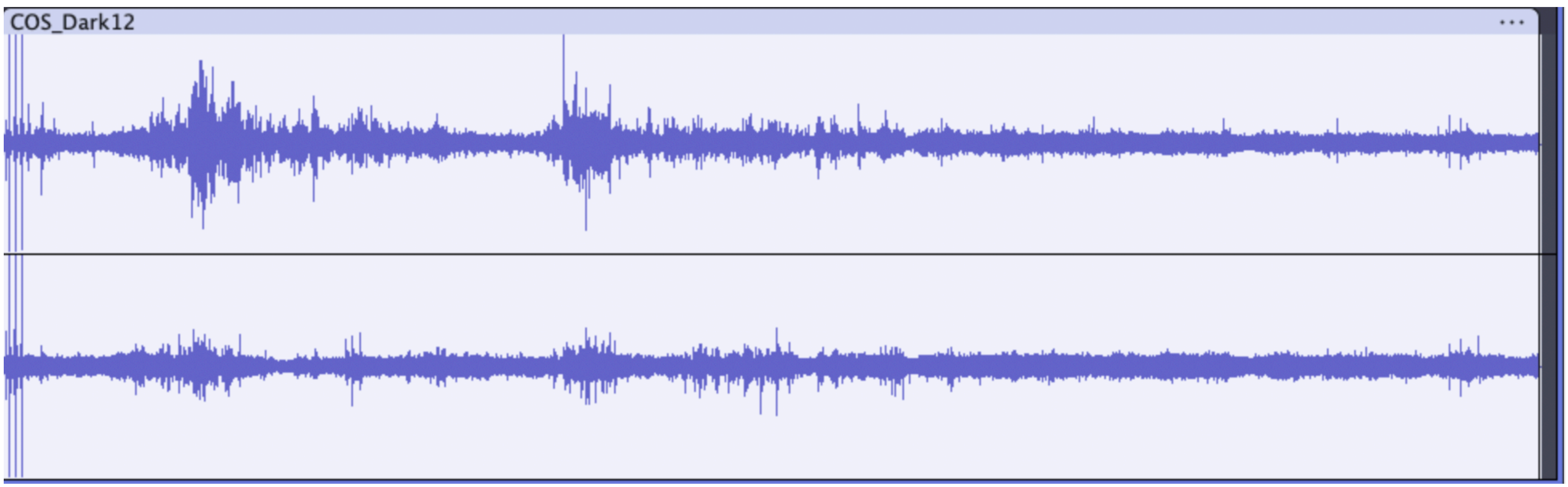


Figure 83: Dark 12 Colorado Springs. -27.5815 dB.

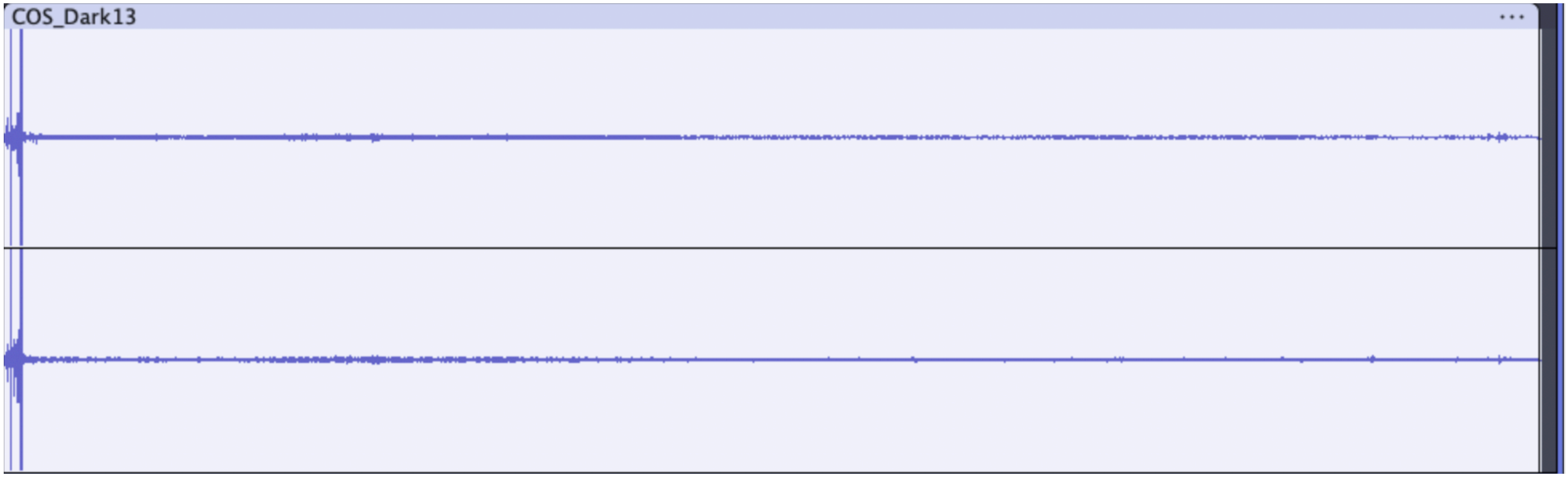


Figure 84: Dark 13 Colorado Springs. -34.9585 dB.

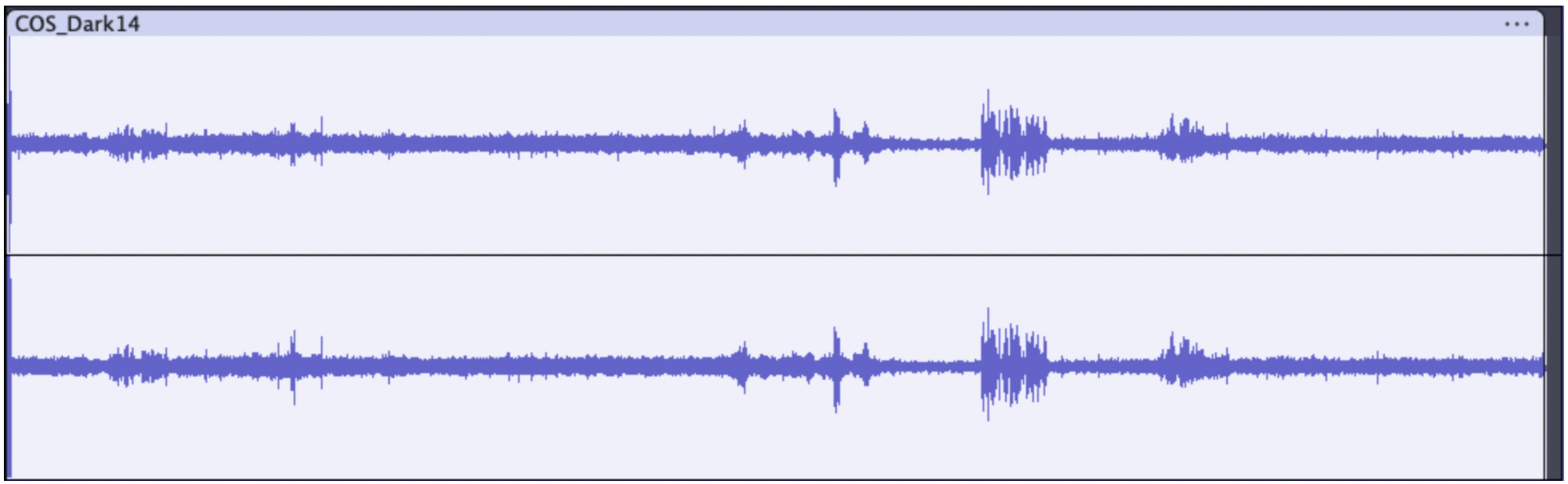


Figure 85: Dark 14 Colorado Springs. -29.8518 dB.

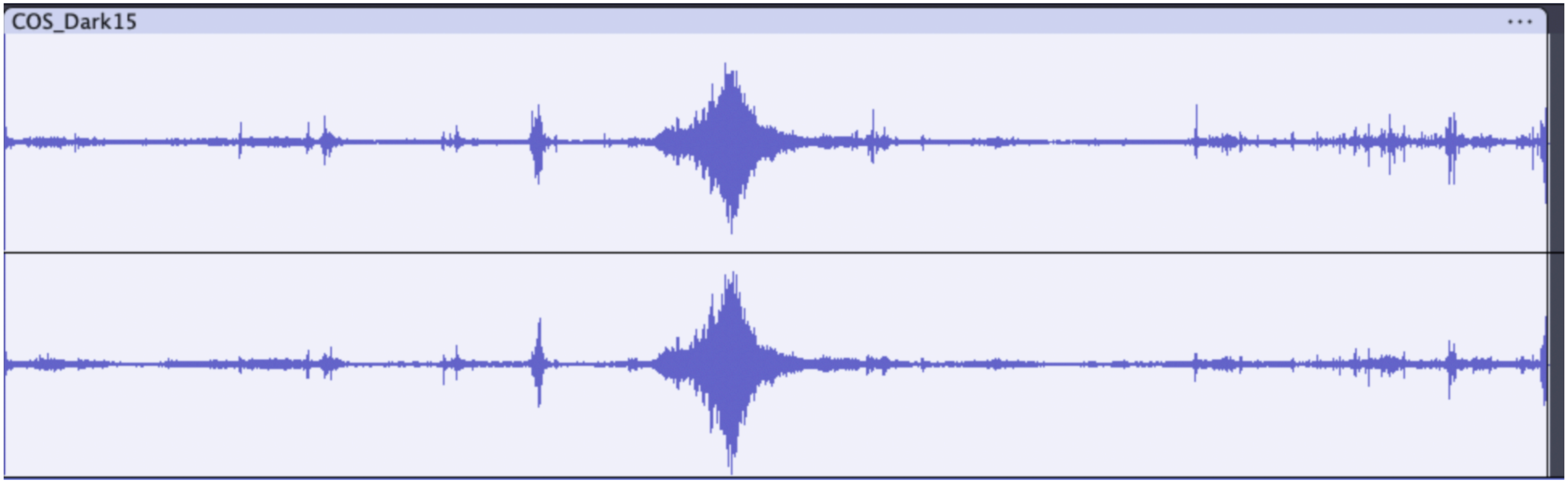


Figure 86: Dark 15 Colorado Springs. -29.9829 dB.

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