CONSIDERATIONS FOR SOLAR ENERGY DEVELOPMENT IN SOUTHEASTERN COLORADO

Produced by Colorado College Landscape Ecology students for Palmer Land Conservancy

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COLORADO COLLEGE

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LAND CONSERVANCY

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INTRODUCTION

The discussion between energy development and land conservation is one that is increasingly generating interesting discourse, innovative research and development, and creative, synergistic outcomes. Within Palmer Land Conservancy's service area of Southeastern Colorado, this topic of discussion has recently been amplified given the complex interaction between the demand for renewable energy, particularly solar energy, and the region's sensitive natural ecosystems, vulnerable range- and farmlands, and long-established agricultural communities.

Through a synthesis of available research on considerations related to solar energy development, in combination with pilot geospatial analyses that identify prospective areas for solar energy development areas based on numerous variables, the objective of this report is to provide a synthesis of information that provides regionally-specific context as discussions about solar energy development with stakeholders (*e.g.,* county commissioners, municipalities, energy developers, agricultural producers, conservation groups, hunting and fishing outfits, etc.) become increasingly prevalent. The data included herein encompass the spatial extent of Pueblo and Crowley Counties in southeastern Colorado. In this report, students from Colorado College's EV343: Landscape Ecology course, facilitated by Dr. Charlotte Gabrielsen, detail several considerations relevant for evaluating the suitability of solar energy in the region. Below are the topics – arranged as chapters – that were identified as high priority topics and are discussed herein:

- Chapter 1: Climate considerations to solar array placement
- Chapter 2: Current & historical land use
- Chapter 3: Soil characteristics & water availability
- Chapter 4: Wildlife & migratory corridors
- Chapter 5: Threatened & endangered species

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CHAPTER 1: CLIMATE CONSIDERATIONS

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Background

In this study, we set out to investigate the viability of photovoltaic (PV) solar development in Pueblo and Crowley counties of southeastern Colorado, with particular focus on properties managed by the Palmer Land Conservancy (PLC). This project is part of a broader effort to provide PLC with crucial insights into the potential for solar projects in the region, enabling them to better anticipate implications of future land uses in and around their easement properties. Climate is the first step of many in assessing the feasibility of solar and is important to be followed by evaluations of potential impacts on land cover, habitats, wildlife corridors, and various social and environmental factors.

Concerns over fossil fuel usage amid climate change paired with increased energy use and population growth has spurred further exploration of sustainable, green energy sources along the front range and across the world. It is of great importance to research the green energy potentials of surrounding areas as we continue to look for alternatives to hydrocarbon-based energy sources. Even if, ultimately, no additional projects are developed, important insight into local environmental features will have been gained. At first glance, Pueblo and Crowley counties appear to be prime candidates for solar energy development, given their vast rural landscapes, flat topography, and abundant sunshine. As part of this study, these assumptions are brought under scrutiny through a quantitative analysis of the direct normal irradiance, terrain slopes, and practicality of the existing infrastructure.

Our team drew on a range of relevant studies to inform the approach and provide additional insight. Adeh et al.'s work has guided our understanding of the optimal use of precious land resources and maximizing solar output, given the extensive land required for commercial solar energy generation. They highlight the importance of microclimates on the performance of photovoltaic panels and identify grasslands and croplands as the highest potential landcover types for development as well as the benefits of abundant insolation, light winds, moderate temperatures, and low humidity– features generally representative of the study area (Adeh et al. 2019). In addition to this background information, our team based some of the analyses off of those performed by Noorollahi et al. Their weighted criteria-based mapping approach informed our strategy for narrowing down potential areas for solar development using climate and infrastructure data.

In considering alternative energy sources in fragile ecosystems, it's crucial to explore innovative and sustainable approaches. Ravi et al. underline the possibility of agrovoltaic systems in land and water limited arid regions as a more financially and ecologically sound solution to the competition created over constrained resources (Ravi et al. 2016). Although our group did not delve into the viability of agrovoltaics in this region, it is suggested to take into further consideration of these more holistic and conservation-based strategies for PV installation in crop and grasslands. An additional benefit of implementing agrovoltaics is the anchorage provided for the soil. As noted on the visit to a PLC easement outside of Pueblo, much of the surface was sandy soils prone to erosion. Humood et al. point out that sand particles carried by strong winds, as may be found in the study area, can work to reduce the efficiency of PV solar energy transmittance (Humood et al. 2016). Research suggests that the disturbance of these landscapes could be mitigated by efforts to maintain soil stability through agrovoltaics.

Another environmental factor to be considered in this High Plains region, is the potential impact of snow on photovoltaic performance. As emphasized by Andenæs et al., the highly reflective nature of snow can significantly reduce solar panel efficiency, particularly during the short, sun-scarce winter days (Andenæs et al. 2018). While Pueblo and Crowley counties receive around 15 inches of snow annually, which is usually quick to melt, it could warrant further consideration.

Methods

When determining an area's viability for solar development, there are many factors that determine whether an area is suitable. When approaching our research question, the first step is to determine the factors we determine are the most important. In our research, this included proximity to roads, proximity to transmission lines, solar irradiance, slope, land ownership, and cover type. Our primary goal was to make this information easily analyzed and digested. To achieve this goal, we used ArcGIS Pro to create a series of maps that reflected how these climate factors impact solar development in Pueblo and Crowley.

We used many different shapefiles within ArcGIS Pro to create our maps. Firstly, we used solar irradiance data from National Renewable Energy Laboratory (NREL) to create a map of solar availability. This data is publicly accessible through NREL's website. The data from NREL has a spatial extent of the United States, so we used ArcGIS Pro's "clip" feature to focus the data on Pueblo and Crowley counties. We then added highways, Pueblo and Crowley county cities, and the Palmer Land Conservancy property outlines to give context as to where the greatest solar irradiance is in the two counties. This data was sourced from our original project folder.

We then used slope data to create our slope viability map. For this map, we manipulated the slope data to show viable slope areas in this region. According to the NREL Data Explorer, a 3% slope is ideal for CSV and a 5% slope is ideal for PV solar. We first created two maps, one with a 3% slope cutoff and one with a 5% slope cutoff, however, this discrepancy did not make much of a difference in the PV or CSV suitable areas, so we used a 3% cutoff to be more conservative. This map also includes highway data and PLC land data to give greater context to where suitable slope areas are in Pueblo and Crowley counties.

Using data from ArcGIS Hub (found at: ArcGIS Hub), we created a map of the existing infrastructure of Pueblo and Crowley, which includes: transmission lines, a transmission line buffer, roads, cities, and PLC land. The transmission line buffer represents the viable locations for solar development constrained by transmission line infrastructure, it is a 5km buffer (Legan, 2022).

These maps and data were then compiled, along with the cover type and ownership data (via Land Use chapter) to create an overlay map to represent suitable areas for solar development. This map uses the NREL solar irradiance data, ArcGIS Hub transmission lines data, and slope data along with the cover type and ownership data from the other group. To create this overlay map, we first looked at our solar irradiance data. NREL's website shows that, for a suitable solar development area, solar irradiance must be 6 kWh/m^2/day. Using this constraint, we cut any solar irradiance data that is lower than 6 kWh/m^2/day. This data was then converted to a polygon by using the raster to polygon function. This process was then repeated for the slope data with a 3% slope cutoff, any areas with a steeper than 3% slope were eliminated from the data, then the resulting data was converted to a polygon. The transmission line buffer was also converted to a polygon. Using these polygons, together with the polygons of ownership and cover type (via Land Use chapter) the overlay tool was used to create an overlaying map of viable locations for solar development.

Once the collection of maps was created, we then analyzed the suitable area versus the non-suitable areas to draw conclusions on whether Pueblo and Crowley are viable areas for solar development. This analysis and our recommendations are based only on the climate conditions (solar irradiance, infrastructure, and slope) of Pueblo and Crowley and are based on our maps.

Results and recommendations

Findings from our GIS analysis of Pueblo & Crowley counties display numerous locations that would support the development of solar infrastructure. The first measure of such availability is the presence of abundant solar energy in the region. Projection of 2018 data from the National Renewable Energy Lab (NREL) shows that Direct Solar Irradiance (DNI) is high for Pueblo & Crowley counties (Fig. 1.1). These values lie on a gradient stretching from 5.8 KWh/m^2/day, located primarily in the far western extent of Pueblo County, up to 7.1 KWh/m^2/day, which is most present in Crowley County and the eastern extent of Pueblo County (Fig. 1.1).

The EPA's EnviroAtlas states that the target DNI value for solar farm development is above 6 KWh/m^2/day. This would place a majority of Pueblo and Crowley Counties in the suitability zone, with several locations averaging much higher (Fig. 1.1). Among these locations is the region located on the border between the two counties. This section has a large amount of PLC easements, dividing up the land with protected parcels. This is a consideration for solar development in the region, as farms in the area would be limited in the scope of their expansion and would risk impacting valuable conservation objectives.

Another important consideration for construction of solar systems is the slope of the land. Photovoltaic (PV) panels require the land underneath them to be lower than 5 degrees in angle, while Concentrating Solar-thermal Power (CSP) installations require angles lower than 3 degrees (NREL). Terraforming to create such conditions is resource-intensive and impactful to the land, so priority was given to locations that would support both energy capture systems without such practices. A critical majority of Pueblo, (and especially), Crowley County falls within this <3 degree range, as is displayed in Figure 1.2.

Following similar trends to Solar Availability, regions with suitable slope angles were largely concentrated in Crowley County and eastern Pueblo County (Fig. 1.2). The region as a whole is very flat, with only small patches containing slopes above 3 degrees. These patches are predominantly on the western and southern edges of Pueblo County (Fig. 1.2). The overall flatness of the target region suggests that implementation of both PV and CSP systems has widespread viability.

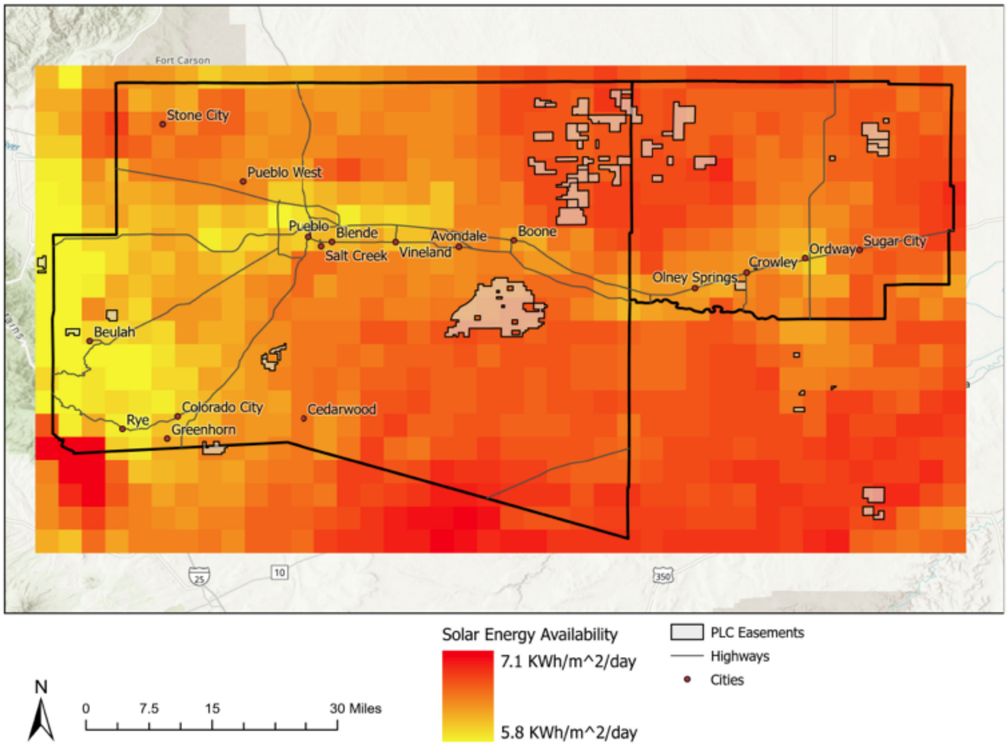

Figure 1.1. Map of average daily direct normal irradiance values for Pueblo and Crowley Counties. Irradiance is measured in KWh/m2/day.

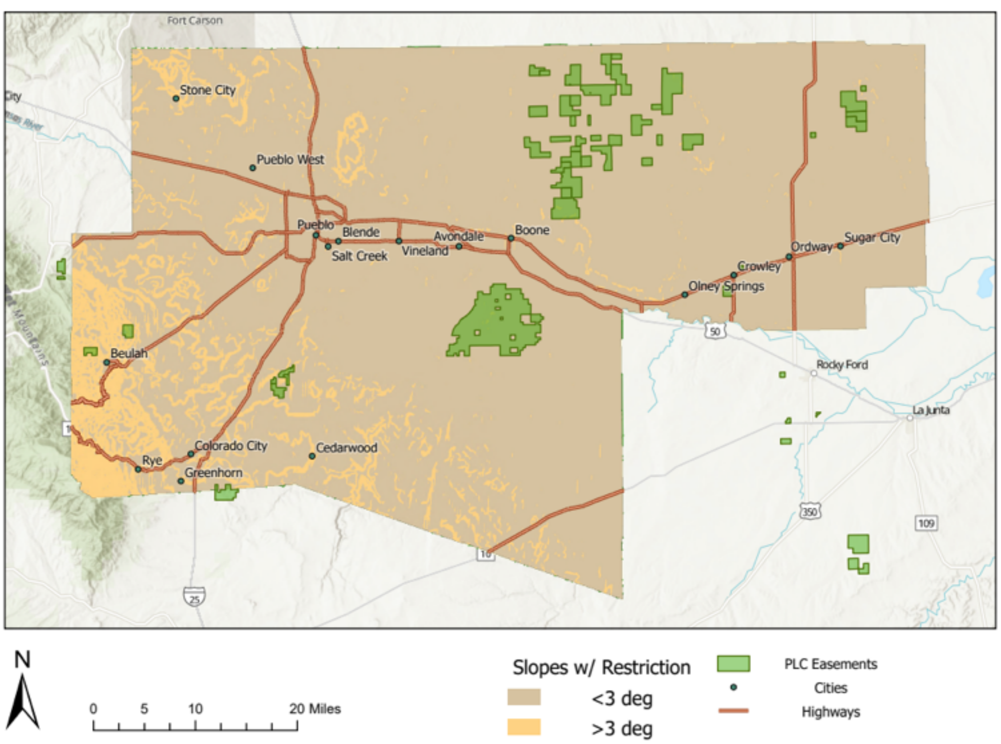

Figure 1.2. Classification of slope angles from a Digital Elevation Model (DEM) into patches greater than and less than three degrees.

The final consideration for solar development studied in this project is the access to existing infrastructure. Infrastructure can be created for such projects, but with an added cost that could eat into incentives for development. Based on the March 2023 transmission line data, a GIS map with a 5 km buffer around each line, (depicted in blue), was created (Fig. 1.3). A 5 km buffer was also constructed around existing roads, but extensive road networks in the region led to nearly no areas outside of the buffer.

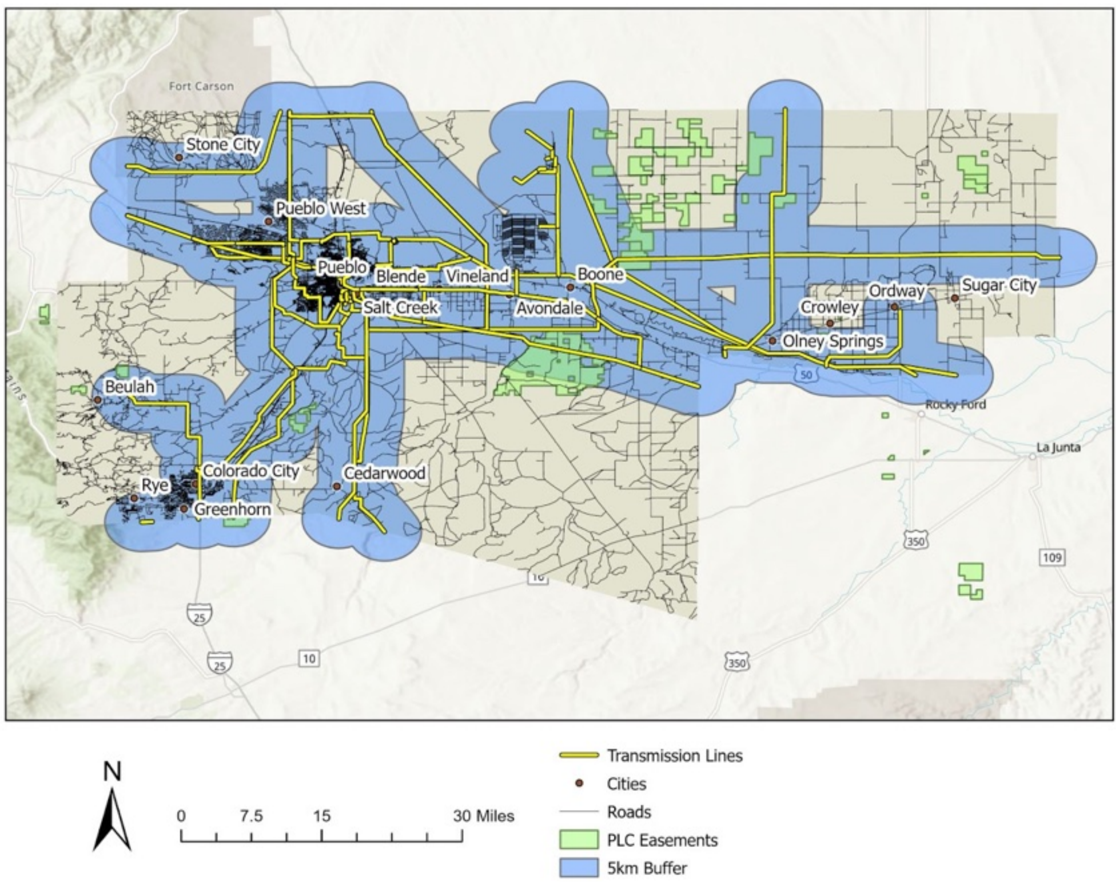

Figure 1.3. Map of existing infrastructure, including roads and energy transmission lines (with 5-km buffer) as of March 2023.

The findings from this figure detail several regions that are currently unconnected to the larger grid. Among these are the areas observed as having both the highest irradiance values and flattest land profile, such as southeastern Pueblo Country and northeastern Crowley County (Fig. 1.1 & 1.3). These areas exhibited sufficient road networks, but transmission line access was limited, often by 10 or more miles (Fig. 1.3). This poses a considerable and expensive challenge for solar development in the region, as transmission line construction would require the use of numerous adjacent and potentially protected land parcels.

The summation of these solar development considerations is an overlay map, where restrictions of irradiance, slope, and transmission line proximity are combined to create a singular classification of suitable areas (Fig. 1.4).

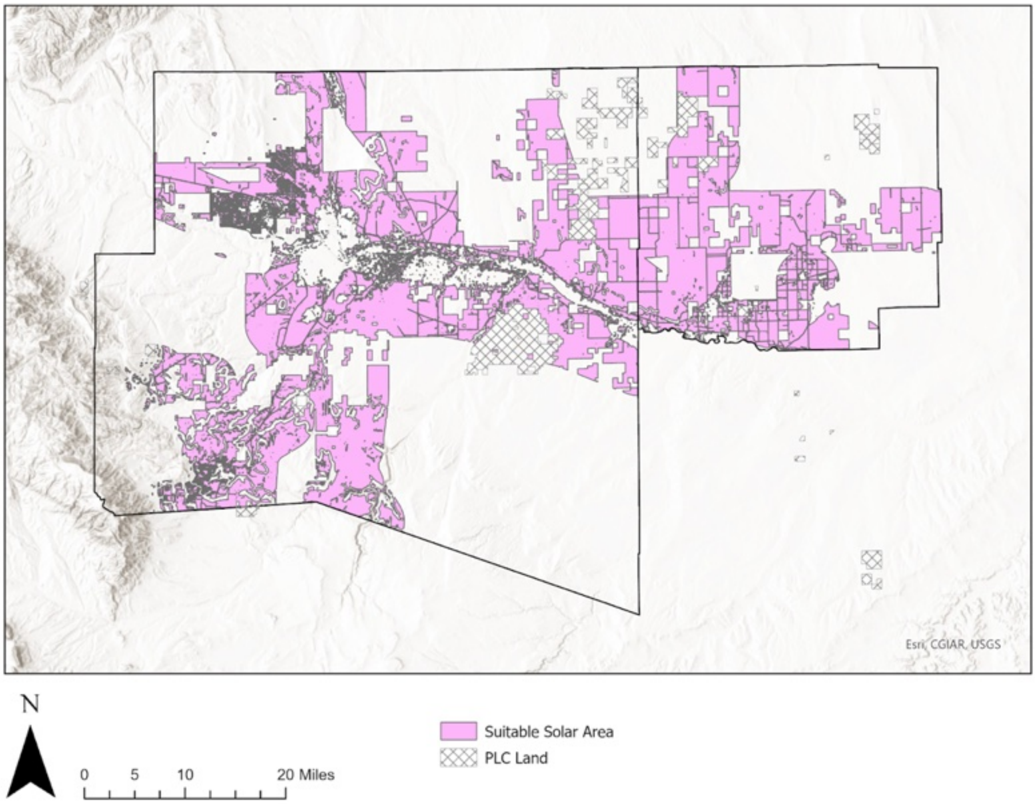

Figure 1.4. Combined overlay of irradiance, slope, and transmission line access restrictions in Pueblo and Crowley Counties.

According to this overlay, most of west and south Crowley County is currently suitable for the development of solar energy, along with central and south Pueblo County (Fig. 1.4). Such suitability suggests that the region is a viable consideration for solar development in the short term. New development projects should focus on the regions highlighted in pink on Figure 1.4, as their properties are favorable for solar energy production. With that, it must be noted that significant potential for solar development lies within regions not currently denoted in pink, namely southeast Pueblo and northeast Crowley Counties (Fig. 1.1 & 1.2). While these areas are restricted in Figure 1.4, this restriction is posed solely by the distance from existing transmission lines, which may be developed further in the coming years (Fig. 1.3).

Significance

First and foremost, this climate investigation is closely tied to the mission of the Palmer Land Conservancy, which seeks to safeguard and manage critical conservation easement properties. By determining the solar viability of these specific counties and providing data that can be manipulated for future use, this study contributes vital information to their decision-making process. This, in turn, allows the organization to prioritize sustainable land use practices that minimize large-scale landscape impacts and are economically viable. In other words, these findings can help rule out regions where solar energy development may not be a sustainable or profitable option, and conversely highlight areas that are most conducive to supporting such initiatives.

More broadly, the project can serve as a microcosm of a larger and increasingly urgent conversation about renewable energy transition. As the world grapples with the challenges of climate change and the shift away from fossil fuels, understanding the economic and ecological viability of solar energy in regions like Pueblo and Crowley becomes a vital part of the larger puzzle. This research begins to address the question of whether the substantial ecological, cultural, and financial costs associated with large-scale solar projects are justified in the context of regional sustainability and the global need for cleaner energy sources.

Furthermore, the above conclusions and recommendations for Pueblo and Crowley are not just pertinent to these counties but may also offer valuable insights for similar regions on a global scale. As a whole, the project can serve as a model for unpacking intricate challenges within green energy projects in regions with analogous environmental and logistical attributes.

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Additional Resources

- Legan, Seth. (2022). An Assessment and Accountability Tool for Renewable Energy Transitions at the Municipal Scale using a Web-Based GIS Application: a Case Study of Pueblo, Colorado, University of Denver. Retrieved from https://pueblo-renewable-energy-transitionpuebloco.hub.arcgis.com/documents/095206ad4e1f470eb27c3563658a02f7/explore
- Average Annual Daily Potential Solar Energy (2022) *EnviroAtlas*: Led by the U.S. Environmental Protection Agency, Fact Sheet. Retrieved from https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/Averageannualdailypotentialsolarenergy.pdf
- Annual Days of Sunshine in Colorado - Current Results
- RE Data Explorer (re-explorer.org)
- The National Map - Advanced Viewer

CHAPTER 2: LANDSCAPE LEGACIES & CURRENT LAND USE

Greta Cahill, Aidan Santos, Tyler Yung

Background

Solar development in the U.S. is becoming increasingly more frequent as calls for the transition to renewable energy sources from fossil fuels have received widespread support in the U.S. (Gaur 2023). However, even though solar energy can provide large-scale environmental benefits in terms of greenhouse gas reduction (in comparison to fossil fuel use), local impacts of solar development projects are much more complex. The installation of large solar arrays often necessitates the use of large plots of land, where soil health, ecosystem services, and biodiversity in chosen areas can be negatively altered by development (Hernandez 2015). Moreover, solar development in the U.S. in non-built environments has often taken the form of development in either shrubland or agricultural and pasture landscapes (Biggs 2022; Hernandez 2015). These areas are frequently chosen because they are often the cheapest areas for development that maximizes solar potential (Gaur 2023). However, studies have revealed that local opposition to solar development projects are often motivated by protecting lands that hold cultural significance in terms of the identity-based connections that many people have to targeted lands (Gaur 2023). Therefore, considering that agricultural and pasture landscapes are becoming increasingly viewed as effective sites for the installation of solar arrays, both Pueblo and Crowley counties can be defined as desirable areas due to the abundance of these landscape types within their borders. However, in order to accurately classify these counties' suitability for solar development, it is imperative that a more enhanced understanding of land-use in both Pueblo and Crowley counties is developed, along with a greater understanding of how solar development will impact the various legacies that historical uses carry.

This chapter is centered around current and historical land-use in both Pueblo and Crowley counties. We will provide an in-depth analysis of how historical land-use legacies shape current land-uses and therefore suitability for solar development. In particular, we hope to identify important environmental and non-environmental factors that solar companies must consider when developing land within this region. To do this, we have developed two objectives that drove our research for this chapter:

1) Identify different stakeholders/landowners and how the cultural legacies they have in relation to the land their occupy influence the suitability of land for solar development
2) Use census and NLCD data to document the varying land ownerships and cover types in Eastern Pueblo and Western Crowley County over time and identify areas best suited for solar technology.

In order to conduct research on both historical and current land use/ownership, we used firsthand accounts via historical census data and county council meeting minutes as well as generated data from online sources to compare in ArcGIS. Using these methods, we were able to produce findings that can help indicate suitable solar field places in terms of both the developability of the land and proximity to transmission lines and roads. Throughout this report a multitude of different resources will be used to demonstrate the complexities associated with renewable energy transitions and hopefully shed light on the importance of landowners and landscape cover in Pueblo and Crowley when considering solar development.

Methods

Historical Land Use

To understand historical land use, we wanted to outline both landownership in the area as well as how legacies impact peoples' perspective about solar infrastructure. In order to include an in-depth view as to how land in both counties was used, we took first and second hand accounts of landowners. We found the majority of the research through Colorado College's Tutt Library special collections archive. Working with the archivists in Special Collections, documents were found that outlined census data written by the Bureau of Business Research, which helped to understand what land was used for during the late 1950's and early 1960's. This also helped us to understand how much money was being made through agriculture and farming in the county. Information about acreage for farmland also helped show what landscape legacies might impact the current land for solar suitability.

Another key component to understanding historical land ownership/use was the book, "A History of Otero and Crowley Counties Colorado" written by Frances Bollacker Keck. This resource outlined the history of Crowley county in terms of U.S. land ownership politics, ranching and farming. It was used to get an understanding of a timeline from the 1800's and 1900's and what the rise of ranching and farming looked like in the area. The findings in this book helped us draw conclusions about the history of human managed land, water rights and what incentives homesteaders and ranchers had to continually manipulate the landscape to make it more productive.

The "Winds in the Cornfields of Early Pueblo County" written by Arla Aschermann for the Pueblo County Historical Society provided us with specific family accounts of what was happening during the shift of landownership in the area in the 1800's. This book covered everything from ranch lands, school buildings and small-town politics. With all sources presented in the Colorado College Special Collections, we intertextually connected experiences, census data and history timelines to get a full understanding of how existing landscape legacies might impact where there are suitable locations for solar development.

Current Land Use

In regard to collecting data on current land uses in Pueblo and Crowley Counties, we originally wanted to document the personal experiences and connections that ranchers and landowners have with the land by conducting interviews. However, conducting interviews would have required approval by the Institutional Board Review (IRB), and with the short time-frame available for our project, we were unable to carry out this aspect. Therefore, to collect data on current land uses in Pueblo and Crowley County, we scoured the available records from the Pueblo and Crowley County Board of County Commissioners (BOCC) meeting minutes. This data is publicly available online, but it ranges in temporal availability. For Pueblo County, meeting minutes were available from any desired time frame, however, we chose to limit our range of "current" use to the years 2000-2023. BOCC meeting minutes for Crowley County were less accessible, as available meeting minute dates ranged only from 2019-2023.

Geospatial Analysis

To create maps that depict suitable areas for solar development in Pueblo and Crowley counties, we first had to identify what data should be used, in terms of land cover and land-use, to accurately select those areas. The general framework that we used was based off of the white paper of a capstone project done by Seth Legan, a master's student at the University of Denver. He used protected areas data, transmission line data, land cover data and slope data, among other things, to create an overlay that outlined potential areas for development based on those factors. We decided to stick with just those four pieces of data and, using different thresholds for slope and transmission line buffers, created our own overlay. For protected areas, any land that was not protected was deemed viable for development. For land cover data, any land that fell into the categories of barren land, shrub/scrub land or herbaceous land was deemed viable for development. This selection was borrowed from Legan. For transmission lines, we used a buffer of 5km, as suggested by a study conducted in Tanzania by Aly et al., as the maximum distance from a line that a solar field could be developed. Finally, for the slope data, any land with a slope of less than 3 degrees was considered viable, based on data collected by the climate conditions group (see Chapter 1).

All of these layers were converted into polygons, with the area in each polygon being representative of the viable land for that particular layer. The layers were then run through the intersect tool in ArcGIS Pro, without being given a ranking, and the resultant output was a single layer that represented the overlap of all the polygons.

Findings and Recommendations

Historical Land Use in Pueblo County

Since its establishment in 1861, Pueblo County has been an economic focal point in the Southern Colorado Region ("Pueblo County," 2015). Prior to its American creation, the land on what is now known as the city of Pueblo was occupied by a number of Indigenous nations. In the 1500s, the Nuche peoples were the main inhabitants of the region, as they would often settle in warmer areas of the Front Range during the winter months ("Pueblo County," 2015). The Nuches continued to dominate the region through the mid-17th century. Additionally, the Jicarilla Apache nation occupied the land east of the Niche along the Arkansas, where they farmed various vegetables like corn, beans and squash ("Pueblo County," 2015). The Comanche soon moved into the Arkansas River Valley in the mid-18th century, but did not remain for long as the Arapaho established themselves in the valley early in the 19th century ("Pueblo County," 2015). Control of the region was then transferred to Mexico, whose occupation ended in 1848, when the United States received large swaths of land in the region that included Pueblo County. ("Pueblo County," 2015).

Americans were not very present in the region until the late 1850s and the early 1860s, when a combination of the Colorado Gold Rush and the establishment of the Homestead Act allowed for many Americans to settle the area, resulting in the establishment of Pueblo County in 1861 ("Pueblo County," 2015). Ranching and agriculture soon followed, dominating land-use early on through the late 1800s ("Pueblo County," 2015). The city now known as Pueblo was established between the years of 1872 and 1894, eventually setting up major changes to land-use and the character of Pueblo County as a whole (City of Pueblo, n.d.; "Pueblo County," 2015). The establishment of Colorado Fuel and Iron in 1892 saw the utilization of nearby coal fields, construction of numerous steel mills, and the frequent smelting of gold, silver, and carbonate ores ("Pueblo County," 2015). Additionally, railroads were constructed throughout the county, increasing continental connection at the cost of fragmenting the prairie (Visit Pueblo, n.d.; "Pueblo County," 2015). Even though these major changes to land-use and landscape compositions brought on new economic potential in the county, agriculture still remained quite prominent ("Pueblo County," 2015). Between the years of 1910 and 1920, agriculture in the county saw a large increase in both crop acreage (630,114 acres to 993,226 acres) and livestock value ($1.5 million to over $4.5 million) ("Pueblo County," 2015). Farming remained one of the most profitable industries in Pueblo County until about 1950, where ranching and pasture value exceeded farming value ("Pueblo County," 2015).

Historical Land Use in Crowley County

There has been evidence of human and animal life in Crowley and surrounding areas for thousands of years. Arrowhead and bison remains that have been found in northern New Mexico date back 10,300-10,800 years (Keck, 1999). As more and more European settlers moved to Crowley in the early 1800's, more description of the initial land was noted. This was specifically noted by Ulibarri, an early settler who described the Arkansas as, "... The largest river on the most fertile land that has been discovered in New Spain" (Keck, 1999). Descriptions like this would be used for many years to come as a marketing tool for Crowley County.

As more settlers came to Crowley and the surrounding areas, there were interactions between different nations in the form of trading. One of the larger trading posts, Bent's Fort, was located close to Pueblo and Crowley Counties. People from all over the place would come to trade different goods and shipments from Mexico would stop through on their way to the eastern side of the United States (Keck, 1999). This meant that there was much more human movement throughout the southwest and the landscape began to shift. This shift was influenced by a number of factors, including an increase of popularity in the land and the dwindling populations of certain species because of fur trapping and habitat destruction (Keck, 1999).

There are several accounts of families moving towards the Arkansas River to make their homes. Some of the main stories are outlined in the "Winds of Cornfields of Early Pueblo County" written by Arla Aschermann of the Pueblo County Historical Society, which describe motivations, plans, and stories of families. Specifically, in the chapter called "Mormon Town", authors state, "Upon arrival they immediately cleared a piece of land in the river bottom and planted turnips, corn, melon and pumpkins, and prepared ground for summer wheat." (Achermann 1982). Families moving to the counties was only the beginning of what was to come in terms of the land use complexities.

Settlers coming from the eastern United States began to notice quickly that farming and ranching was a challenging task in the southwest. With the east coast being humid, farmers realized that instead of the 15 to 16 acres it took to harvest a crop, it would take around 3000 acres to accomplish the same thing (Keck, 1999). The lawmakers of Crowley decided that instead of learning to work with the land, it was time to incentivize landscape alterations. This was done in the form of the Timber Act of 1873, which incentivized landowners to plant 10 acres of eastern United States trees on their property; if done successfully, land owners would receive another 160 acres of land in their name (Keck, 1999). This was meant to make the West feel and function more like the humid farmlands of the Eastern US. Interestingly, the United States congress went as far as to set aside money to do more research on how to increase moisture in the air (Keck, 1999). This was important given the amount of money coming into Crowley County due to ranching and agriculture (Fig. 2.1), which shows that even in the earlier 1950's, the economy was driven by agriculture and ranching production.

TABLE 3

AGRICULTURAL CENSUS DATA
CROWLEY COUNTY

	1950	1954	1959
NUMBER OF FARMS	490	442	348
LAND IN FARMS (ACRES)	420,673	403,692	424,904
VALUE OF LAND AND BUILDINGS AVERAGE PER FARM	$ 21,009	$ 27,216	$ 38,595
AVERAGE SIZE OF FARM (ACRES)	858.5	913.3	1221.0
NUMBER OF CASH GRAIN FARMS	66	18	70
NUMBER OF OTHER FIELD CROP FARMS	15	17	6
NUMBER OF VEGETABLE FARMS	11	0	0
NUMBER OF FRUIT AND NUT FARMS	0	0	0
NUMBER OF DAIRY FARMS	10	15	20
NUMBER OF POULTRY FARMS	5	20	15
NUMBER OF LIVESTOCK FARMS	128	175	147
NUMBER OF GENERAL FARMS	204	157	41
NUMBER OF MISCELLANEOUS AND UNCLASSIFIED FARMS	51	40	61
VALUE OF ALL PRODUCTS SOLD	$4,115,425/A	$2,362,067	$4,430,647
VALUE OF ALL CROPS SOLD	$2,031,165/A	$ 809,820	$1,779,746
VALUE OF LIVESTOCK AND LIVE-STOCK PRODUCTS SOLD	$2,084,260/A	$1,552,247	$2,650,901
VALUE OF FOREST PRODUCTS SOLD	$ 0/A	$ 0	$ 3,500/C
FARMS WITH ELECTRICITY	374	426	NA
FARMS WITH RUNNING WATER	NA	225	NA
FARMS WITH TELEPHONE	260	293	242
NUMBER OF FAMILY AND/OR HIRED WORKERS /B	873	1,020	541
NUMBER OF HIRED WORKERS	178	284	143
EXPENDITURES FOR HIRED LABOR	$ 385,453/A	$ 230,637	$ 281,756

NOTE: /A FIGURE IS FOR YEAR 1949.
/B THE CLASSIFICATION FOR 1959 IS FAMILY WORKERS, INCLUDING OPERATORS.
/C 1959, INCLUDES HORTICULTURAL SPECIALTY PRODUCTS.

SOURCE: U. S. BUREAU OF THE CENSUS, CENSUS OF AGRICULTURE: 1950, 1954, 1959.

Figure 2.1. "Local Area Statistics Crowley" Bureau of Business Research, University of Colorado Boulder. This table shows the agricultural statistics for Crowley county for years 1950, 1954, 1959.

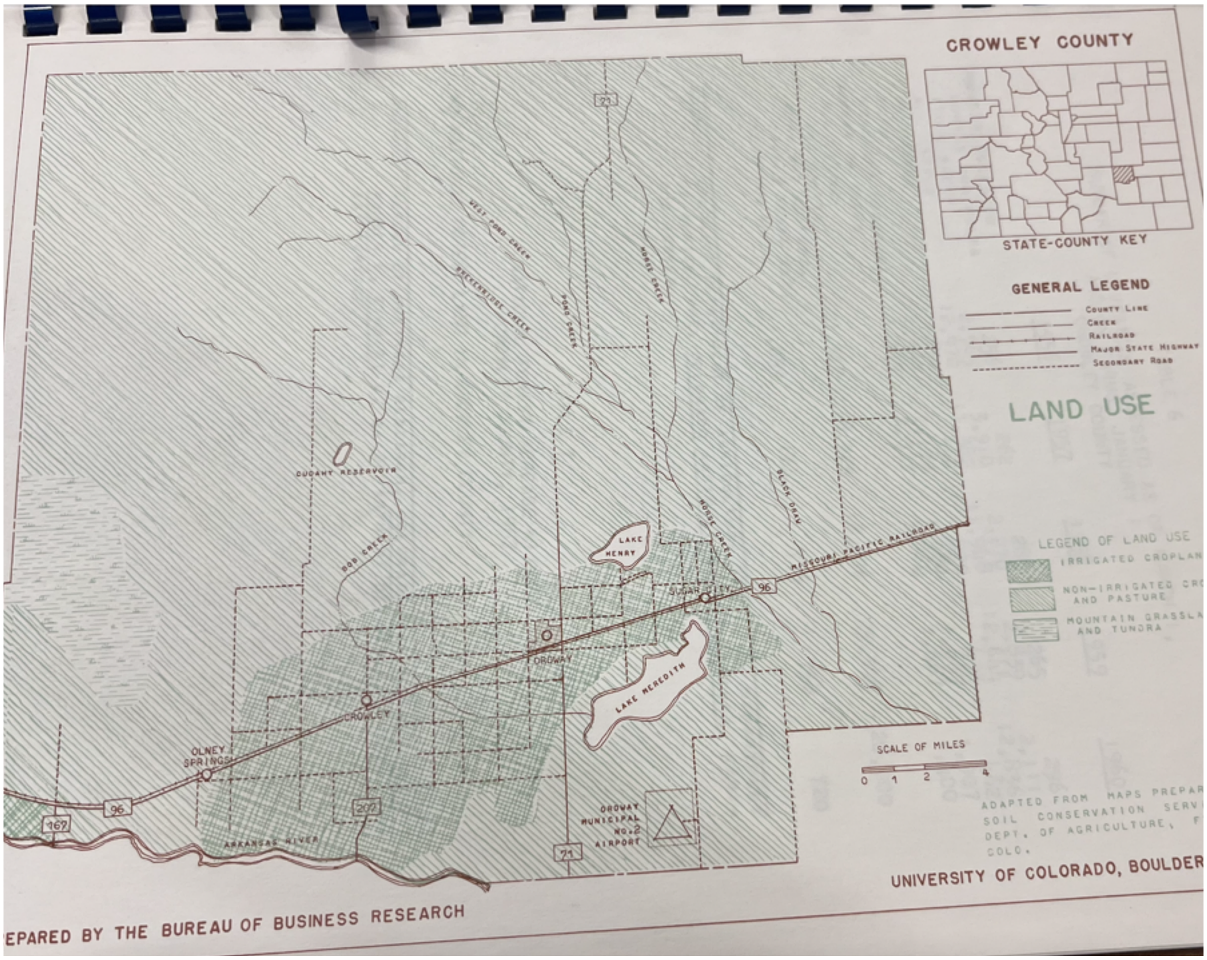

Figure 2.2. "Local Area Statistics Crowley" Bureau of Business Research, University of Colorado Boulder. This map explains irrigated and non-irrigated lands in Crowley Counties.

Historically, much of the land in Crowley County was used for non-irrigated farmland which also included pastures. According to the Bureau of Business Research for Crowley County, "Local Area Statistics", by 1959 Crowley had 424,904 acres of land in farms (1961). A lot of this non irrigated land is found in the more rural parts of the county (Fig. 2.2). The map shows that there is a lot of non-irrigated farmland/pasture on the outskirts of Crowley County and resembles the land cover found through our own geospatial analysis (Figs. 2.3 and 2.4). Both the historical and current maps showcase the fact that land cover type has not changed too much and therefore it is important to consider the ranching aspect of land ownership while thinking about solar implications.

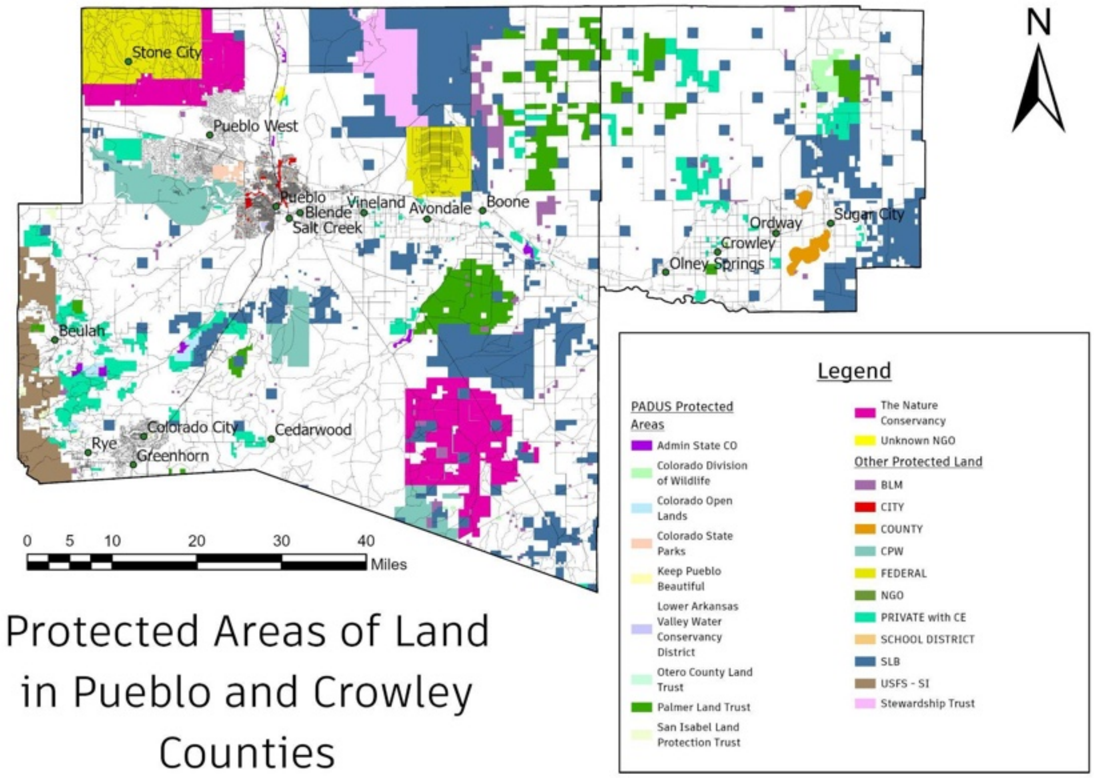

Figure 2.3. Protected lands in both Pueblo and Crowley Counties.

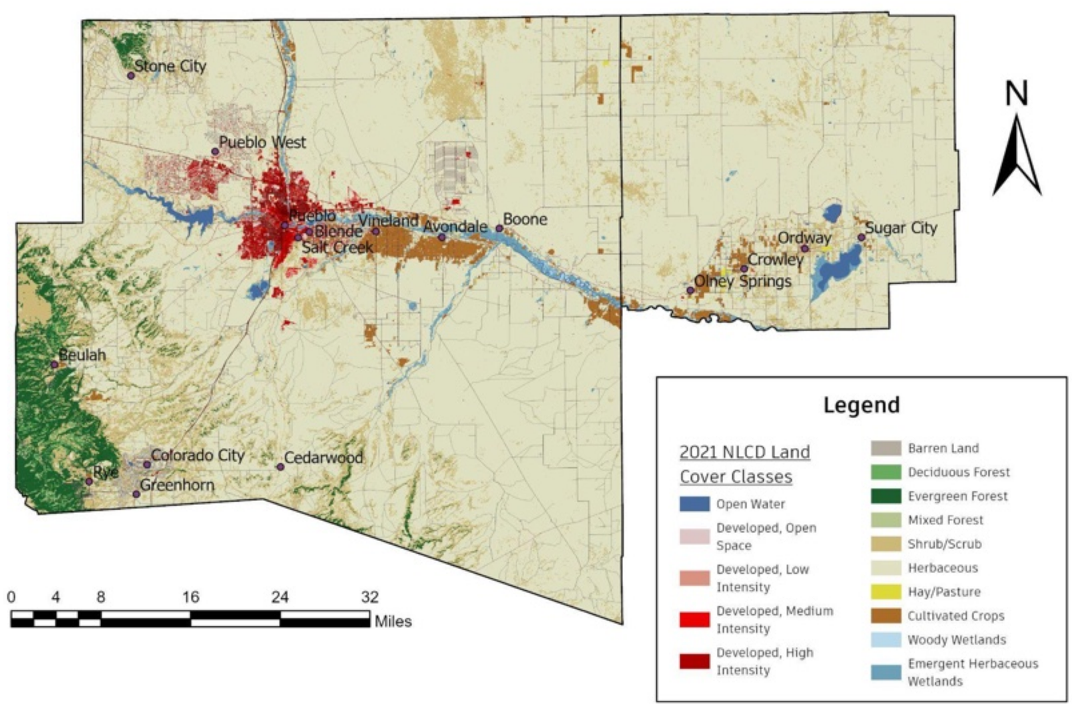

Figure 2.4. NLCD Land Cover, with all land covers shown in Pueblo and Crowley County for 2021.

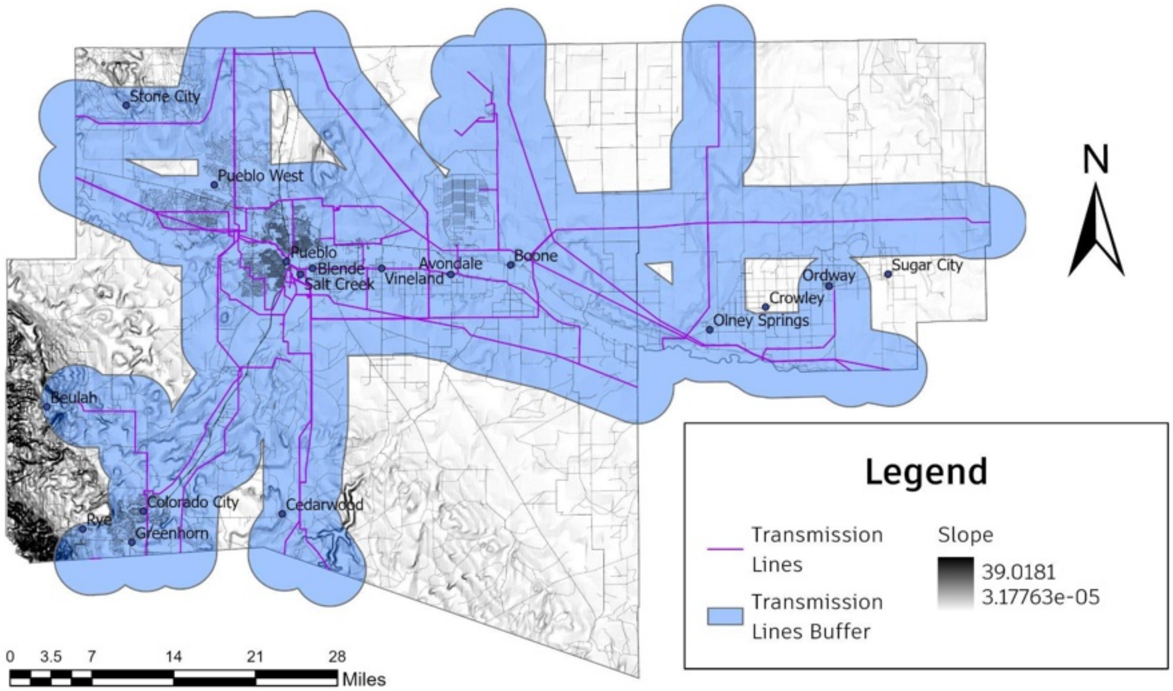

Figure 2.5. Slope and transmission line buffers for suitable solar in Pueblo and Crowley Counties.

Current Land Use in Pueblo County

In regard to the governing bodies that are responsible for county-wide decisions, the Pueblo Board of County Commissioners (BOCC) has ruled fairly consistently in favor of solar development. Records from BOCC meeting minutes show that the board established written support for the solar development in Pueblo County in 2008, stating that renewable solar energy production would "benefit the community in saving energy costs and protecting against rising utility rates" (Nunez & Ortiz, 2008). Additionally, the board stated renewable solar would greatly benefit the surrounding environment by mitigating the effects of climate change and reducing pollution, ultimately recommending that Colorado Public Utilities Commission (PUC) "look favorably on solar energy production projects in Pueblo County" (Nunez & Ortiz, 2008).

Since then, the BOCC has consistently approved various solar development projects in the county. In 2009, the BOCC approved the construction of a 1.2 Megawatt Photovoltaic (PV) Array located on the CSU-Pueblo campus as a part of the BP Solar project, stating that this was a "valuable project" for the county (Chostner & Ortiz, 2009). A year later, the BOCC again approved a solar development project, however, this time centered around installation in the built environment. This project entailed the implementation of solar PV panels on nine county buildings and parking lots that would greatly reduce energy costs (Chostner & Ortiz, 2010). Pueblo's favorable stance on solar development early on translated to the construction of solar panels within the built environment, thereby reducing environmental costs and complex-decision making associated with non-built environment installation. However, soon after, Pueblo County re-oriented their priority areas of solar installation.

In 2013, the BOCC issued a letter of support in regards to the construction of a 100 megawatt solar power facility in the San Luis Valley under the jurisdiction of Saguache County (Hart & Ortiz, 2013). Through this letter, the board, again, called for the PUC and the Governor of Colorado to approve the construction (Hart & Ortiz, 2013). From this point on, the BOCC seemed to turn their sights towards developing solar in grasslands and agricultural land. In 2014, the BOCC approved the construction of a 120 kW solar facility known as the "Community Solar Garden" in a parcel zoned as an A-1 Agricultural Zone District (Bruestle 2022). Parcels that are classified as A-1 Agricultural Zone Districts are areas of land that "are designed to retain and promote the appropriate use of dry range and irrigated lands and encourage open use of the land in keeping with its natural characteristics and agricultural functions." (Pueblo County Attorney, n.d.). Through this approval, the BOCC set a precedent that agricultural lands that were intended to remain in agricultural use were not protected from solar development. The BOCC continued to approve special-use permits for the construction of solar facilities in A-1 Agricultural Zoned Districts as, in 2019, they approved a special-use permit for the construction of an 84.34 acre 2-Megawatt DC Solar Facility that would primarily generate electricity (Lowe 2019). Additionally, as a part of this permit, the BOCC required that the developers "[incorporate] reasonable means to create an environment harmonious with that of the surrounding properties," including dust mitigation and noxious weed control (Lowe 2019). The BOCC approved the construction of another 11.8 acre 1.99 MW solar facility in 2021 that would adhere to the same standards of remediation and stewardship (Hatton 2021). However, this permit was met with some opposition from "staff," as they had concerns that the proposed project would not be "compatible with the intent, purpose, and spirit of" A-1 zoning requirements (Hatton 2021). The BOCC ultimately ruled that "no substantive evidence could be found to suggest that solar facilities [would be] detrimental to agricultural production on adjacent properties or to future agricultural use of the property" (Hatton 2021). However, the BOCC did recognize that there was "no guarantee that [the land] would be returned to agricultural production," even though the developers planned to "utilize native vegetation and pollinators as ground cover" (Hatton 2019).

Current Land Use in Crowley County

One of the largest considerations for current and future land ownerships is the use of ranch land in both counties. This is found consistently in both counties as well as through historical accounts as well.

In contrast to data collected for Pueblo County, meeting minutes for Crowley County spanned a much shorter time frame (2019-2023). However, despite this smaller sample size, Crowley County BOCC meeting minutes showed similar stances on solar development between both counties. In 2019, the BOCC approved several solar development projects and services, one of which included the amendment of a conservation easement granted in 2001 (Carter & Allumbaugh, 2019). This easement previously prohibited solar development and was amended to allow for the construction of a 100-acre solar farm (Carter & Allumbaugh, 2019). A year later, the BOCC approved another solar farm project (2 Megawatts) that served the purpose of producing electricity (Carter & Allumbaugh, 2020). However, after 2019 the BOCC did not make an open stance on solar farm development until 2022.

On September 26, 2022, the BOCC conducted a land-use review of a proposed 4020-acre solar farm project in Northern Crowley County by AES (Carter & Arbuthnot, 2022). In this review, BOCC members considered whether or not the proposed solar farm would have negative environmental impacts on both the property and surrounding adjacent properties (Carter & Arbuthnot, 2022). To do this, members shared experiences of visiting other solar farms. Members stated that they had recently visited the Comanche Solar Project located in Pueblo County, where they said that they were "impressed how the property was maintained" due to the fact that the "fences were clear of tumbleweeds, there was vegetation on the ground around the panels, and the property was very well kept" (Carter & Arbuthnot, 2022). Members also stated that they did not observe any issues related to increasing dirt blow (Carter & Arbuthnot, 2022). Additionally, another member stated that he had recently visited multiple solar farms in the San Luis Valley, where he did not witness any negative impacts from solar farms in the area (Carter & Arbuthnot, 2022). However, despite this support from the BOCC, members of the public in attendance expressed their concerns with the project that emphasized that community members want to ensure that neighboring property owners would be protected from adverse impacts, and that this project had too many unknowns to be approved (Carter & Arbuthnot, 2022). Eventually, the BOCC approved the AES solar project on February 21, 2023, on the condition that developers revegetate disturbed areas and develop a comprehensive plan for weed and pest control, among many other stipulations (Carter & Arbuthnot, 2/21/2023).

Besides the AES solar project, the BOCC conducted one more Use-by-Review in 2023. In February 2023, the BOCC executed a land-use review of the 1,415-2,830 Stellar Solar Farm Project (Carter & Arbuthnot, 2/28/2023). During the meeting, the Stellar representative stated that they had completed a hydrology study and a wetland delineation that addressed concerns related to increased erosion (Carter & Arbuthnot, 2/28/2023). Additionally, the BOCC asked questions of Stellar in relation to fencing, weed control, storage of lithium batteries, and liability concerning potential damages to neighboring properties and erosion (Carter & Arbuthnot, 2/28/2023). Two months later, this project was approved by the BOCC, on similar conditions to the approval of the AES Solar Farm: (1) requirement of a revegetation and reclamation plan that addresses disturbance management and erosion control and topsoil handling (2) a long-term monitoring plan for the success of this plan and (3) a management plant related to the control of noxious weeds and pests (Carter & Arbuthnot, 4/10/2023). Overall, the BOCC stated that the project is "an appropriate use of land, and [will] conserve and utilize Crowley County's resources" and "will be economically beneficial to the County of Crowley, Colorado" (Carter & Arbuthnot, 4/10/2023).

Geospatial Analysis

The overlay analysis that we conducted using the intersect tool in ArcGIS Pro showed that there is a large swath of land suitable for solar development in both Pueblo (Fig. 2.6.) and Crowley (Fig. 2.7.) Counties. That being said, several factors were not taken into account, primarily because our section of this project focused only on specific data. The most important data to include in order to procure a more accurate overlay analysis would be soil data, water availability and location of aquifers, proximity to residential areas and location of wildlife migration corridors. Another way that land use might be represented with further research is through maps depicting the projected dollar per acre yield of the land with solar and without. This would hopefully give a more accurate representation of how much potential monetary value the land has when being used in each of the two industries. Additionally, to incorporate the historical use of the land, if data is available on historical ownership and use, it might be informative to create a map detailing the change in usage over time. With all that being said, the GIS component of this project did identify that there is potentially a significant area of land suitable for development. Once the other data is incorporated into a more detailed analysis, there will most definitely be a smaller acreage that is deemed viable, but presumably still a significant portion of the land.

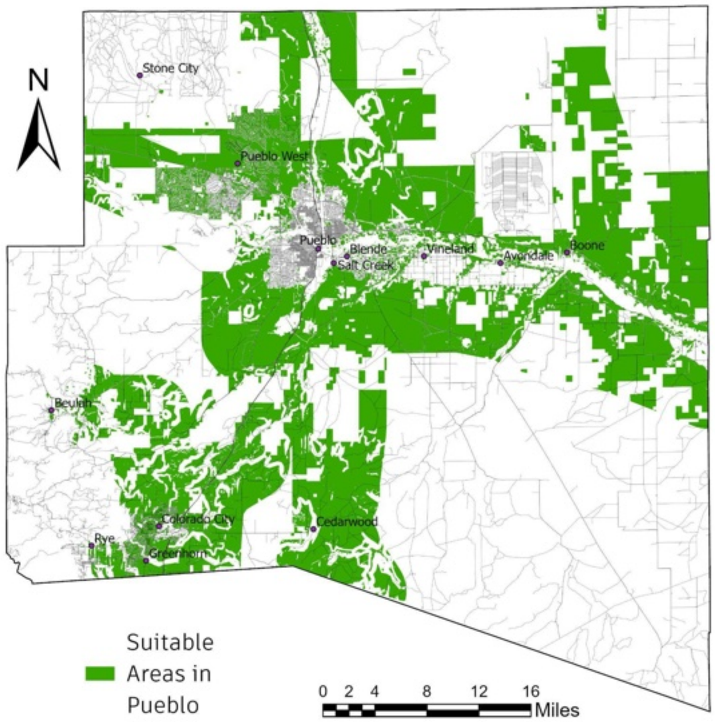

Figure 2.6. Solar suitability for Pueblo County in 2023.

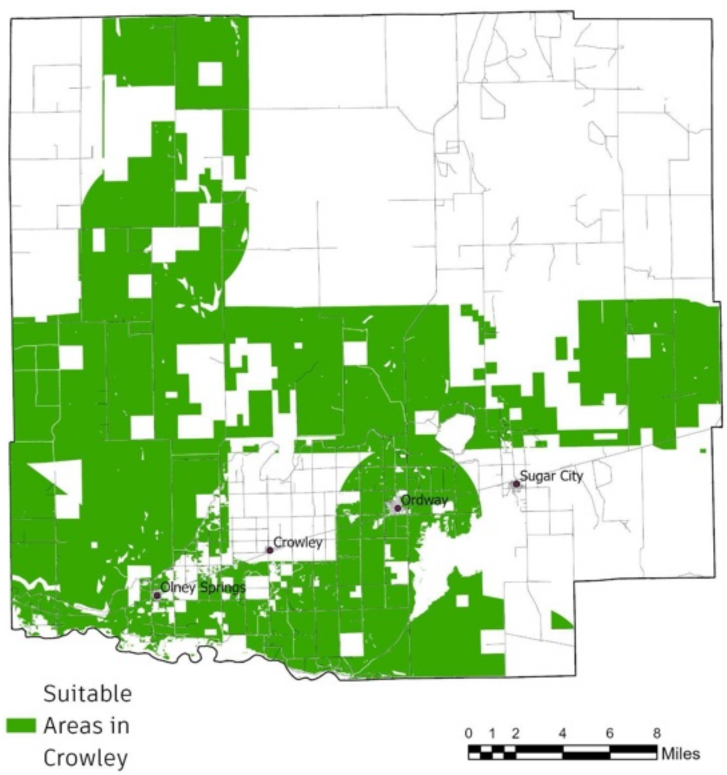

Figure 2.7. Solar suitability in Crowley County in 2023.

Significance

Land-use Legacies and Ranchlands

Historical land uses greatly influence the structure, composition, and configuration of any given landscape (Foster et al., 2003; Ziter et al., 2017). More specifically, historic anthropogenic land use has been documented to have lasting impacts on soil composition/soil nutrient content and the distribution and survival of both native and non-native plant species (Foster et al., 2003; Ziter et al., 2017). This, in turn, also affects the ability of ecosystems to provide essential ecosystem services that provide many practical benefits towards species occupying the landscapes (*e.g.* erosion/dust mitigation) (Ziter et al., 2017). However, these ecosystem services provided by landscapes are not just centered around the practical services, but also include the consideration of cultural connections to local ecosystems. Cultural landscapes can be thought of as anthropogenically altered landscapes that hold significant value for humans (Ziter et al., 2017).

One prominent example of a cultural landscape can be found in ranch landscapes. Ranch lands can be classified as a cultural landscape through the requirement of active management by human ranchers, as well as the significant value they hold for ranchers and landowners. More specifically, there exists a symbiotic relationship between ranchers and the land they occupy in which ranchers actively steward their pasture-land to ensure that both the land and their livestock herd can be sustained (Sheridan, 2007). Because of this relationship, ranchers have been known to establish deep connections with their land that are centered around integral local ecological knowledge of the land that has been passed down through generations (Sheridan, 2007). Additionally, ranchers strongly value family and community, which constitute the cultural legacies of ranch land that is inseparable from the land (Sheridan, 2007). In this way, the health of the ecosystems in which ranchers occupy is inherently tied to the survival of cultural legacies that are rooted in the land itself. Therefore, the health and survival of these cultural landscapes must be considered in terms of both protecting important ecosystems and preserving cultural identity, as current land uses have the ability to strongly impact the health of those ecosystems into the future (Ziter et al., 2017).

Pueblo and Crowley County's Solar Motivations

Through the data collected from meeting minutes from Pueblo County's Board of County Commissioners, the BOCC has clearly shown that they have taken a favorable stance on solar development within the region. Moreover, multiple recent instances occurred in which the BOCC approved special-use permits for the construction of solar projects zoned within A-1 Agricultural Zones despite the recognized unknown long-term impacts on the land. This further shows that the county is willing to disregard the agricultural importance and associated connections within certain parcels of land in favor of solar development that would potentially jeopardize the agricultural potential of the parcel. Therefore, considering the increasing development of solar in pasture and grasslands coupled with the stance of Pueblo's BOCC, it is extremely imperative that we work to protect our agricultural lands and the associated cultural legacies that are inherently tied to those lands.

Similar to the Pueblo County BOCC, the Crowley County BOCC has seemingly taken a favorable stance in regard to solar development in Pueblo County. This has translated into the BOCC ruling that, in some cases, solar development outweighs the benefits of current land-use (*i.e.* approving an amendment of a conservation easement to allow for solar development). Moreover, BOCC members all seem to be in agreement that solar farm projects in both Crowley County and the greater Southern Colorado region have minimal negative environmental impacts to the property and adjacent parcels to the solar farm. Requirements for revegetation and remediation plans, as well as noxious weed control, for Crowley County solar farms could possibly contribute to this opinion, however, the causality of these two notions remain unknown. Even though BOCC members believe that solar development will cause minimal impacts to the immediate and surrounding lands, the public (as expressed in 9/26/22 BOCC meeting) appears to have concerns regarding negative adjacent environmental impacts, with some even expressing that there are too many unknowns in order to approve solar farm projects. Therefore, despite strong BOCC support from both counties, it is necessary to consider not only the perspectives of those in power, but also the perspectives of those who live on the land, as the citizens of Pueblo and Crowley County will be the stakeholders who will bear the brunt of the potential negative impacts cause by solar development projects. Otherwise, developers who fail to consider these perspectives would intentionally cause harm to the livelihoods of people, as well as the cultural legacies that are inherently tied to the landscape.

General limitations

Because our study could only be conducted for a week and a half, there were certain limitations that prevailed, primarily in terms of the first objective of our study. As mentioned earlier in the report, we were originally planning on conducting interviews with landowners and solar companies to develop a more complete understanding of the cultural landscapes that exist in the region, as well as the motivations behind solar companies development practices. However, this did not come to fruition due to the fact that after our proposal was submitted, we were notified that in order to conduct interviews with "human subjects," we had to go through the Institutional Review Board (IRB) process through Colorado College. The Institutional Review Board ensures that research that uses humans or animal subjects is conducted in an ethical way (U.S. Food and Drug Administration, 2019). Though not extremely lengthy, the short time frame of one and a half weeks limited our ability to submit an application, receive approval, and then reach out to our interviewees and conduct the interviews. Additionally, there was an issue with time and distance, as traveling down to Crowley and Pueblo would have been logistically too difficult in the aforementioned short-time frame.

In terms of research, while we found great evidence of historical landscape use, it would have been beneficial to find more primary and secondary sources in a few realms. The first being more information on historical Pueblo county. Unfortunately, at Colorado College Tutt Library, which was our primary resource for historical context, there was not much information about Pueblo's history and an abundance for Crowley County. This made it a challenge to understand more about specific land ownership through the years but was compensated by generalizing much of the statewide land use policies throughout history.

Conclusion and Significance

Overall, our team is not able to make a confident recommendation on whether or not there is suitable land for solar infrastructure in Crowley and Pueblo Counties. On the one hand, our GIS data shows that there exist many suitable areas for solar development based on land cover, protection status and transmission line access. However, our maps do not paint the full picture of the story, as they do not consider the important cultural landscapes that exist in Pueblo and Crowley counties where ranchers, farmers, and other landowners have built their livelihoods in connection with the health of the land. Ethical stewardship and conservation practices require that the perspectives of those who live and rely on the land must be considered in a way that respects their histories and livelihoods.

Our maps also fail to include the perspectives of those people who stand to benefit from the more affordable prices promised by many solar companies. The residents of the city of Pueblo and the surrounding urban areas who would theoretically be receiving the majority of the electricity produced by the proposed solar arrays are an important stakeholder group that we were unable to gather much data on. To ensure that every person has a voice in the transition towards more renewable energy in counties that rely heavily on agriculture and ranching, it is first imperative to take a step back and understand the generational stories that exist on the land and in the communities that would be affected. Science and hard data only account for half of the picture. In conclusion, every stakeholder in this story of solar development has different opinions, perspectives, and motivations and, in order to truly work to find common ground, we must create a platform in which all voices can be heard and listened to with respect.

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CHAPTER 3: SOIL CHARACTERISTICS & WATER AVAILABILITY

Lila Galinkin, Oliver Kivett, Alexa Rennie



Background

Pueblo, Colorado, located at the base of the Rocky Mountains experiences a semi-arid climate characterized by limited water resources and periodic droughts. Pueblo is home to many solar and wind power developments across the region from the largest wind turbine production site to the BigHorn solar development project (EIS). Although these developments provide aid and resources to nearby residents, the construction of these solar arrays can harm local vegetation, water distribution, and soil composition. To illustrate the nature of soils in this region, water distribution, and the impacts of climatic conditions on the environment, this study asks: To what extent will suitable sites to develop solar arrays impact water supply, vegetation, and soil composition in Pueblo and Crowley counties? And how does land-use, either anthropogenic or environmental, change water availability and soil-nutrient cycling?

This scientific background provides an overview of factors influencing soil quality and water availability in Pueblo, focusing on key aspects such as soil composition, water supply, and the impacts of climate change. Pueblo and Crowley counties' soil is classified as an aridisol due to its hot and dry climate (Soil Survey Staff, 2023). Studies have investigated the soil types prevalent in the area, including sandy loam and clay loam. They emphasize the importance of understanding soil texture and its impact on water retention and nutrient availability for sustainable development and ecological success in climates similar to Pueblo (Naorem et al., 2023). Additionally, this paper will explore how water availability in Pueblo is primarily dependent on surface water and groundwater sources for agricultural, municipal, and ecological use, due to extreme scarcity exacerbated by allocation of water rights and rapid climate change effects. A study focusing on surface water availability, notably from the riparian river systems, emphasizes the significance of water management in semiarid regions to vegetation, soil-water retention rates, and sources for irrigation systems or municipal supply (Priyan, Pande & Moharir, 2021). Finally, as climate change increases its influence on the environment and the local community, understanding how temperature, precipitation, and land-use can influence and disrupt water and soil systems is vital. Pueblo and Crowley counties are susceptible to the impacts of climate change, leading to altered precipitation patterns, increased temperatures, and prolonged droughts throughout the region. These changes can directly affect soil moisture levels, crop productivity, and water availability, posing challenges for solar development and water management strategies. Additionally, rapid urbanization and land use changes in Pueblo has led to soil degradation, reduced permeability, and increased surface runoff, limiting natural water infiltration, groundwater recharge, and altering the hydrological cycle. Recent studies state that entire ecosystems will be changed and altered by climate change and exploitative land use. They illustrate that through these processes changes in precipitation regimes, vegetation recolonization, and nutrient-cycling will start to lag or be disrupted altogether (Grimm et al, 2013).

To address the impacts and influences that solar development will have on future ecosystem patterns and processes, future mitigation and solutions must be realized. Building upon research done to manage the challenges of soil quality and water availability in Pueblo, promoting water conservation and adopting effective land management strategies are essential to combat climate changes' impacts on local ecosystem functioning (Chartzoulakis & Bertaki, 2015). Additionally, promoting efficient irrigation methods and encouraging the use of aquifer and river basins can optimize water use in agriculture and municipal settings. Overall, incorporating findings from these studies is essential for comprehending the impacts of future solar developments on soil, water, and vegetation.

Methods

This study utilized open-source data for the creation and qualitative analysis of layered GIS maps. Maps were generated to address Crowley and Pueblo Counties, Colorado. All maps were created in ArcGISPro using shapefiles and data sourced from Dr. Charlotte Gabrielsen, WebSoilSurvey (SSURGO), ArcGIS online, and Colorado Decision Support System. Literature reviews were also conducted to obtain further information applicable to this study. All literature used in this study was deemed to be academic writing from experts in the field of study the paper discussed. Literature sources were obtained using the EbscoHost database using key words relating to soil, water, region and solar power. Using the information found in readings, maps were manipulated to best show main points. Layers such as soil type, for example, were aggregated into groups with parent materials deemed at risk for collapsibility. Final maps were analyzed in conjunction with literature on the subject matter.

Findings & Recommendations

Pueblo and Crowely counties are areas with complex soil composition and high water scarcity (Fig. 3.1). According to the National Oceanic and Atmospheric Administration (NOAA), the Pueblo and Crowley counties area have a 30-year annual average of 12.04 inches of precipitation, a high total precipitation of 23.09 inches in 1957 and a low of 3.94 inches in 2002. Colorado soil expert Jonathan White has reported that areas with less than 20 inches of annual precipitation are generally more vulnerable to collapse (2018). In addition, it was found that the area is composed of soil types with parent materials known to be susceptible to collapse (Fig. 3.2), including alluvium, colluvium and loess (White, 2018). Further risks posed to soil in the area come from erodibility and soil compaction. According to the Web Soil Survey, much of the soil in these counties is in the range of medium to high risk for soil compaction (Soil Survey Staff, 2023). The USGS soil survey shows Pueblo county to have 8.5% of its soil to be at high risk of compaction and 82.3% at medium risk, and 1.7% of Crowley county's soil to be at high risk of compaction with 85.9% at medium risk (Soil Survey Staff, 2023). To add to the fragility of the soil, the alluvial aquifers running through Pueblo and Crowley counties make the surrounding soils more vulnerable to water related collapse (Fig. 3.3).

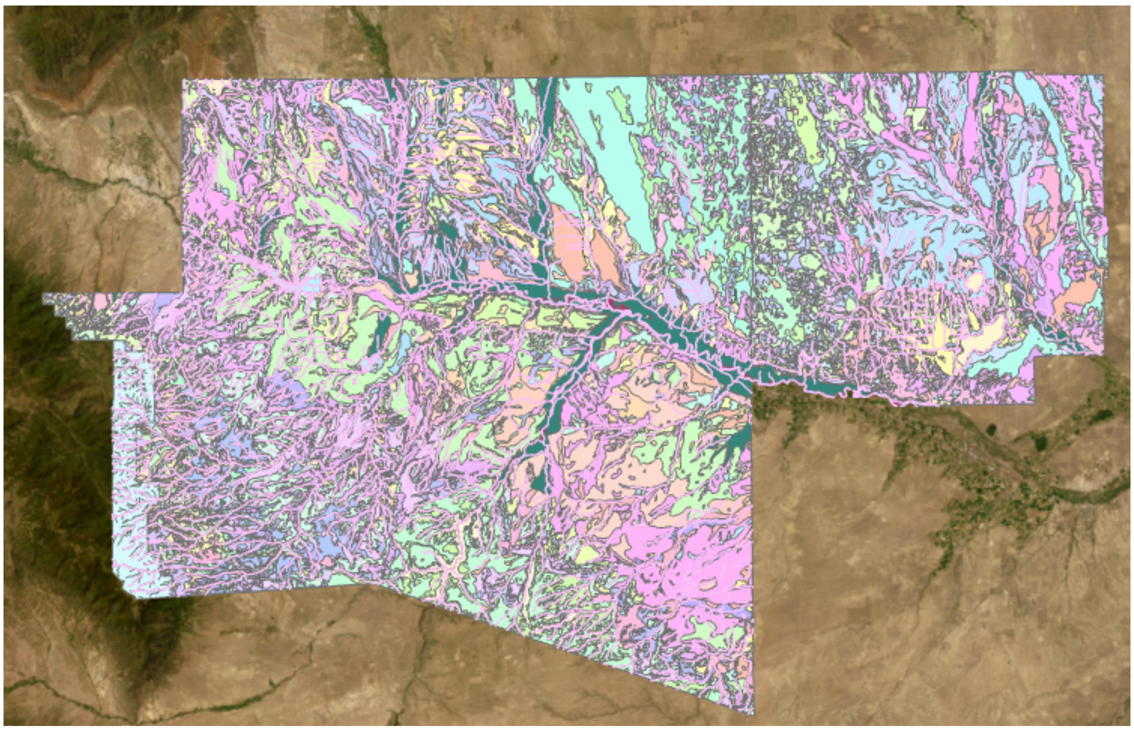

Figure 3.1. Soil type and water sources using USGS Web Soil Survey downloadable data, Colorado stream data and irrigation data from the Colorado Decision Support System.

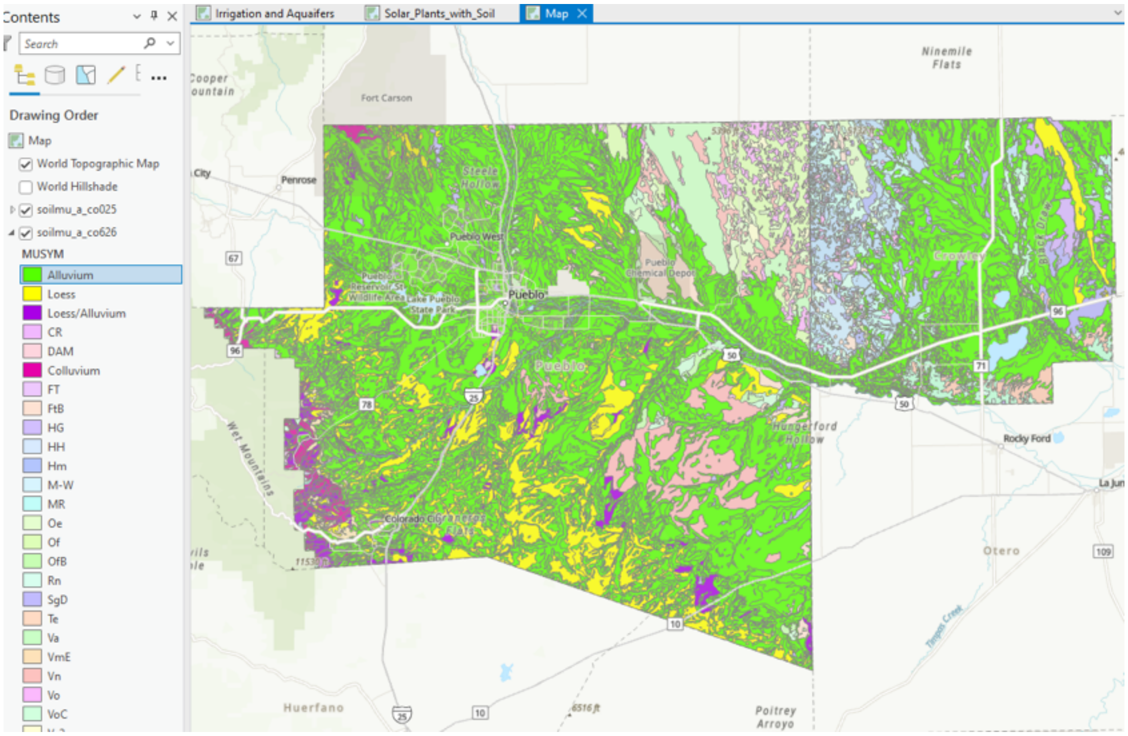

Figure 3.2. Soil collapsibility characterized by three parent soil types; Alluvium (green), Colluvium (pink), and Loess (yellow).

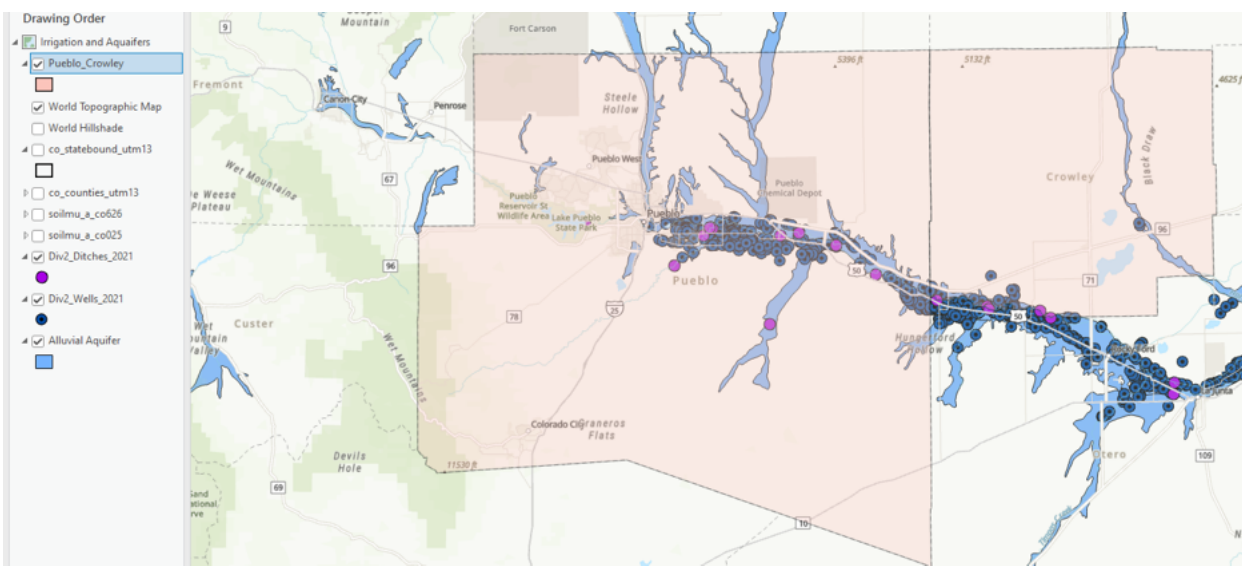

Figure 3.3. Irrigation ditches, alluvial aquifers, and water wells in Pueblo and Crowley Counties.

Studies surrounding solar panel power plants effects on soil in arid climates have historically been conducted in areas like Western China and the Western coast of the United States. While one can extrapolate that the soils in these areas differ to that of Colorado, several key findings from these studies should be brought into consideration for the purposes of examining Pueblo and Crowley counties for their solar energy potential (Fig. 3.4). Three studies conducted in

Western/Northwestern China by Liu, Z. et al. 2019, Liu, Y. et al. 2023 and Wang & Gao 2019 all pointed to similar results. The results of the 2019 Lui et al. study conclude that solar panels in the area had a net cooling effect that positively impacted vegetation and the soil microbiome on a short-term timescale. The 2023 Liu et al. study indicated similar results with the caveat that areas in which solar panels shaded the area but blocked precipitation posed a negative risk to soil health, but that it could be mitigated with water redistribution. Finally, Wang & Gao found that photovoltaic panels can benefit soil health when successfully placed on hillslopes (2019). These findings seem promising in the potential to improve soil health while combating desertification through revegetation, however, this is in application to areas with average annual precipitation of 7 inches (Liu, 2019). In a differing climate with approximately 5 inches more of precipitation yearly, Pueblo and Crowley counties may look to these studies as a useful tool in examining solar power production with future climate change bringing more similar conditions.

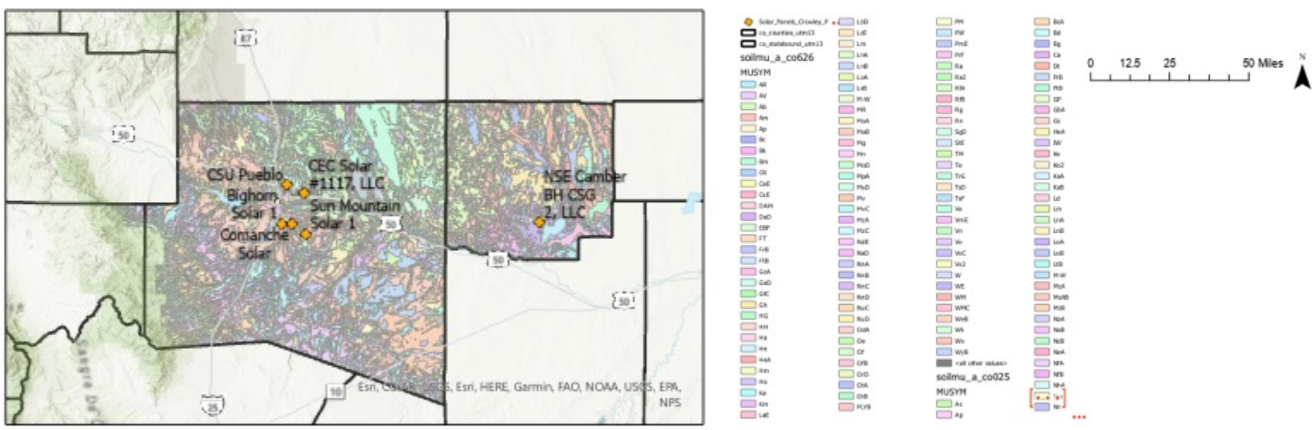

Figure 3.4. Solar power plant and solar development locations as of October 2023.

Further concerns of solar panels effects on local soil health are addressed by Leda et al. in their study reviewing solar park construction and PV panel lifecycles (2023). Leda et al. found that the construction of solar plants may lead to harmful chemicals leaching into soils that may be further exacerbated through the panel's lifespan if proper waste management and recycling techniques are not maintained (2023). This study looks at the impact of solar energy production on soil health, water and air quality on a broader scale in terms of waste generation from solar parks (Leda et al., 2023). This study was chosen to be included here to allow for further expansive thought on soil health and beyond.

Literature reviewed for the purpose of this study shares a common critique to solar power research in relation to soil; there is a lack of understanding of long-term effects of solar panel fields on soil health and water availability. Lambert et al. suggests in their 2021 study that short term studies of solar panels are helpful in their understanding of detriments of installation and early establishment, but long-term research is lacking. Tanner et al. conducted a seven-year study of solar panels in California's Mojave desert that further states the importance of long term studies on a much larger temporal scale than current research is looking at (2020).

Significance

The intersection of solar energy development, water supply, and soil composition hold immense significance in the context of sustainable resource management and climate change mitigation. Solar energy, as a renewable power source, is rapidly expanding worldwide, and is contributing significantly to reducing greenhouse gas emissions. However, the development of solar facilities in the area of study may impact local ecosystems, particularly due to the scarcity of water and weak soil structure in these counties. Understanding these effects is crucial for developing environmentally responsible energy strategies for future solar development. This study investigated the intricate relationships between solar developments, water supply management, and soil composition, shedding light on the environmental implications of renewable energy expansion.

Examining the impacts of solar developments on water supply is vital due to the growing competition for water resources in arid regions, like Pueblo and Crowley counties, where many solar installations are already situated. Water is essential for both maintenance and cleaning of solar panels, and the scarcity and increased demand can strain local water sources, affecting both human communities and natural landscapes. Additionally, utilizing responsible and sustainable water management strategies can help to redistribute water to all state needs. Currently, only 18% of water is used to supply local needs, so harnessing rainfall, groundwater, and surface water availability can increase supply overall (Pueblo Water). Additionally, solar facilities require vast and solid areas to be built upon. The soils of this region face soil degradation, loss of biodiversity, and altered nutrient cycles, due to the breakdown and collapse of parent materials in the landscape. Thus, understanding the soil and water-related implications is critical for maintaining safe and sustainable solar developments and is vital to preserving ecosystem structure and services.

Findings from this study and associated recommendations have not taken into account ethical concerns in acknowledgement of native lands, it is clarified here that this should be weighted in the decisions made. Additional ethical and ecological concerns outside the scope of soil and water availability are not discussed here but should certainly be factored in as well. With that clarifying statement it is concluded that these results have determined that limited solar power development can be established in areas at low risk for soil collapse and greater annual rainfall. Further research is needed to accommodate successful integration of solar power plants in the area including research into optimal angles of solar panels, hillslope placement and water allocation considerations.

Future Directions

Warming temperatures and changing weather conditions make combatting and mitigating the effects of climate change vital to restoring ecosystem prosperity. Addressing the challenges of water loss and soil degradation associated with solar development and climate change requires a holistic approach and innovative solutions. Researchers are actively exploring different ways to combat water scarcity and soil collapse in semi-arid regions across the globe. The case study in Jordan explores the implementation of floating solar photovoltaic (PV) systems to address water scarcity and energy needs. By deploying floating solar panels on water bodies, the technology reduces water evaporation, conserving precious water resources in the region's water-stressed areas. This innovative approach provides a sustainable solution that can potentially be applied in Pueblo, showcasing the potential of floating solar technology to address pressing environmental and energy challenges in water-scarce regions (Abdelal, 2023). Additionally, this approach not only conserves water but also allows for solar development on bodies of water, whereas weak land and collapsible soil structure may prove less reliable.

Moreover, the integration of soil conservation and the stabilization of collapsible soils through geotechnical infrastructure should pave the way for stability in solar development. Also, utilizing the Life Cycle Assessment Study will help to conduct assessments on solar energy systems, to better understand the environmental footprint that solar technologies have on the environment, including their impact on water and soil resources (Finnveden & Potting, 2014). Finally, thinking about opening discussion to policymakers and government officials would be important to raise awareness to the potential drawbacks and implications of solar development. Regulations and incentives to encourage the adoption of eco-friendly practices will be crucial moving forward to ensure that solar developments are sustainable. Educating the public, local property owners, and developers can foster a sense of responsibility and drive the adoption of these practices in solar energy projects. By embracing these future directions, the integration of solar energy into landscapes can be achieved harmoniously, ensuring the conservation of water resources and the preservation of soil integrity for generations to come.

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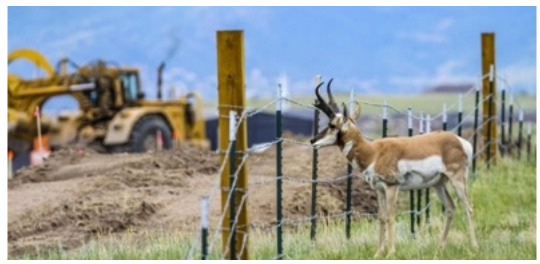
Chapter 4: Wildlife & Migratory Corridors

Maggie Henson, Lucie King, Jasmine Sone





Introduction

The expansion of renewable energy sources, such as solar power, is crucial for mitigating climate change and reducing reliance on fossil fuels. In the United States, the growth of renewable energy, particularly solar, wind, and geothermal has been substantial, with a predicted rise of approximately 68% in renewable electricity generation by 2040 (Agha, 2020; Pocewicz et al., 2011). However, as the transition to renewable energy accelerates, the development of utility-scale solar installations presents a complex challenge for wildlife conservation, especially in areas of high biodiversity. Solar development and other renewable energy infrastructure can cause loss of habitats, deplete vegetation and soil health, cause an increase in mortality from collisions for volatile species, and interrupt migratory corridors (Chock et al., 2020; Smallwood et al., 2022). This research aims to identify how solar development in Pueblo and Crowley counties will impact the wildlife present in the area.

Pueblo and Crowley counties exhibit a diverse array of habitats, most notably including the Shortgrass Prairie, Sandsage, and Playas, which each support numerous Species of Greatest Conservation Need (SGCN) as defined by Colorado Parks and Wildlife. These habitats are emblematic of the profound ecological value of Colorado plains, historically hosting species such as bison, pronghorn, prairie dogs, and other top predators such as the gray wolf and grizzly bear (CPW, 2015).

However, Colorado's Shortgrass Prairies are under increasing pressure from various threats, including habitat conversion for agriculture and urban development, invasive species, and energy development. The eastern prairie region, particularly the shortgrass prairies, is being rapidly developed for both renewable and non-renewable energy production, with solar energy development being one of the most prominent. The expansion of utility-scale solar energy highlights challenges in balancing the implementation of renewable energy and wildlife conservation. Alteration of land cover types, loss of connectivity of wildlife habitat, and direct mortality of wildlife are all concerns associated with solar development. Establishing solar energy facilities transforms the landscape, often resulting in fragmentation of vital habitats, impediment of free movement, formation of migratory bottlenecks, and reduction of effective winter range size. The operation and maintenance of solar arrays can result in direct wildlife mortalities such as bird collisions, burns, and vaporization (Agha, 2020). Operation and maintenance of energy facilities can also negatively impact wildlife behavior and lead to changes in habitat use, as seen in the avoidance and abandonment of core habitat areas by mule deer after oil and gas exploration and development altered the landscape (Lovich, 2011).

Furthermore, solar energy, when compared to other renewable energy sources, has relatively lower greenhouse gas emissions and higher land-use efficiency (Sawyer et al., 2022). Therefore, the amount of energy generated per area is greater than alternative energy sources. The trade-off, however, is that solar installations require expansive amounts of land to produce adequate energy. Furthermore, the conversion of land required for a solar array extends beyond the panels' area. Additionally, intensive development is required to ease facility management (such as the construction of stormwater retention ponds), and federal requirements for fencing around solar arrays typically result in the complete loss of habitat for big game species (Levin, 2023; CPW, 2020). The barbed fences act as a physical barrier, potentially blocking access for larger animals who may use that area as a migration corridor or daily movement of resident species (Merkle et al., 2023).

In arid landscapes such as Colorado, ecosystems tend to be more sensitive to disturbances (Sawyer et al., 2022). To understand how species will react to a disturbance such as a solar array, an assessment of the impacts of solar development on wildlife and migratory corridors in Pueblo and Crowley counties was conducted to generate recommendations regarding solar array placement, considering best practices for wildlife habitat management. The assessment categorized privately owned land within Pueblo and Crowley counties as potential areas for solar development. Using GIS modeling and linkage mapping, the potential threats to the migration and behavioral patterns of ungulates, specifically Pronghorn (*Antilocapra americana*) and Mule Deer (*Odocoileus hemionus*), in the area were investigated. Additionally, a literature review and ecological assessment were performed to compile and organize data to highlight trends in wildlife populations in the area and provide information to landowners in this area as the development of solar farms proceeds.

Methods

Study Area

The study area for this report is the Pueblo and Crowley counties in Colorado, as shown in Figure 4.1. Pueblo County, spanning approximately 2,398 square miles, is geographically located in the southern portion of Colorado (Panjabi et al., 2003). With an area of roughly 800 square miles, Crowley County is situated east of Pueblo ("Crowley County," 2017). These counties are predominantly distinguished by vast prairie grasslands, notably influencing regional biodiversity (Panjabi et al., 2003; "Crowley County," 2017). Furthermore, the Arkansas River, which traverses Pueblo County, is a significant water resource for the many wildlife populations inhabiting the area. Moreover, the research region provides crucial pathways for migratory species (Panjabi et al., 2003). This area is essential for learning about how solar farm development may impact wildlife and their critical migratory paths, owing to the expanding solar energy sectors within these counties ("2021 CEDS Strengths," 2021).

Data Collection

The data on species activity for this study was obtained from the Colorado Parks and Wildlife (CPW), and information on species status was acquired from the International Union for Conservation of Nature (IUCN). The land cover data used in this study were sourced from the

National Land Cover Database (NLCD). The spatial resolution of this raster layer is 30-meters. In addition, the Colorado's land ownership data were obtained from the Colorado Ownership, Management, and Protection (COMaP) database. Finally, a shapefile encompassing all counties in Colorado was acquired from The United States Census Bureau.

Pre-Processing Data

In order to ensure the compatibility and meaningful integration of varied datasets in the research, it was necessary to preprocess all of the downloaded data. The procedure was started by selecting Pueblo and Crowley counties from the Colorado Counties shapefile, producing a shapefile that functioned as the geographical border for the following investigations. Recognizing the importance of focusing on the study area, all other datasets were clipped to the borders of Pueblo and Crowley. This crucial procedure excluded extraneous information, optimizing the analysis to focus solely on the designated regions of interest.

Due to the lack of data on sites specifically leased for solar farm development, an assumption was made that all privately owned lands within the counties, excluding easement areas, possess the capacity for potential solar farm development. To support this premise, a shapefile that exclusively contained privately owned properties not subject to easements by filtering attributes where the values for "Owner" and "legend" had been defined as "private" was created. Furthermore, this evaluation required identifying core areas for Pronghorn and Mule Deer. "Concentration Areas" for the target species based on the data acquired from CPW were selected to achieve this objective. Subsequently, these areas were clipped to the boundaries of Pueblo and Crowley.

In addition, a resistance layer reflecting the Pronghorn and Mule Deer's ease or difficulty in traversing the terrain was created. Resistance values were allocated to various land cover types, drawing upon an academic paper by Drake et al. (Drake et al., 2017). Values were modified to reflect the specific objectives of this report accurately. (See Appendix) The same resistance layer was used for both species because Pronghorns and Mule Deer are ungulates. Assigning resistance values was conducted using the Reclassify tool in Geographic Information Systems (GIS). This involved replacing the original values with the resistance values. This process established the groundwork for developing least-cost corridors and paths.

A series of analyses were conducted in this study to assess the potential impacts of solar farm construction on wildlife and migratory corridors in Pueblo and Crowley. These analyses comprised an assessment of the species in the counties, a GIS overlay analysis, the use of the Linkage Mapper tool to evaluate habitat connectivity, and a case study.

Species Status

CPW data was used to identify species present in the study area to understand the species composition in Pueblo and Crowley. Additional data was collected from the IUCN, including factors such as the conservation status, concentration areas, overall ranges, and migratory paths of the present species, allowing identification of species' vulnerability. Overall, this research assisted in learning more about the local biodiversity and its ecological importance.

Overlay Analysis

An overlay analysis was conducted using GIS. The process entailed overlaying Mule Deer and Pronghorn activity data with the potential sites for solar farm development. The main inputs for this analysis were species activity and non-easement private land layers. This aids in the identification of potential conflicts between wildlife and solar energy development.

Linkage Mapper Analysis

In order to evaluate wildlife connectivity and potential migration routes, the Linkage Mapper tool was used. Specifically, least-cost paths and corridors were generated using the "Build Network and Map Linkages" tool. The inputs necessary for conducting this analysis included the Core Areas of the target species, the resistance layer derived from NLCD land cover data (resistance values in Table 4.1), and a truncated distance value, which is the maximum distance for creating corridors. Given the small study extent, the default value of 200,000 meters was used.

Table 4.1. Resistance values allocated to the various NLCD land cover types. Resistance values reflect the ease or difficulty of Pronghorn and Mule Deer traversing particular land types. These values were adapted and modified from Drake *et al.* 2017.

NLCD Land Cover	Resistance
Open Water	90
Developed, Open Space	70
Developed, Low Intensity	50
Developed, Medium Intensity	60
Developed, High Intensity	90
Barren Land	90
Deciduous Forest	30
Evergreen Forest	20
Mixed Forest	40
Shrub/Scrub	40
Herbaceous	30
Hay/Pasture	40
Cultivated Crops	50
Woody Wetlands	60
Emergent Herbaceous Wetlands	30

Case Study

Due to a lack of available species data for the study location. The paper examined was by Sawyer et al., which investigated the effects of utility-scale solar energy (USSE) on Pronghorns in Wyoming (Sawyer et al., 2022). The case study helped draw valuable insights and identify parallels to this research, owing to the shared characteristics in the environmental and ecological context. The paper proved to be highly beneficial in offering significant insights into the implications of USSE on wildlife and migratory paths, as well as potential sustainable USSE development methods.

Results

Species Table Results

Using data sourced from Colorado Parks and Wildlife (CPW) and the International Union for Conservation of Nature (IUCN), 117 species were identified as having an overall, breeding or seasonal range within Pueblo and/or Crowley Counties (Table 4.2.). These 117 species include one amphibian species, 40 bird species, 32 mammal species, 37 reptile species, and 7 fish species. All species population statuses were tracked using the IUCN Red List and CO state and U.S. Federal listings. On the IUCN Red List, seven species are considered near threatened, five species are listed as vulnerable, and three are endangered on a global scale. However, most species in the Red List were last updated in 2007, so population statuses could have changed due to increased habitat disruption. Six species were state-threatened, five species were federally threatened, six species were state-endangered, and two species were federally endangered.

Additionally, 15 species are considered by Colorado Parks and Wildlife to have significant ecological value either because they are a good indicator of the overall health of the habitat or they are a keystone species (play a significant role in defining the habitat in which they live) or an umbrella species (protecting these species indirectly protects the many other species that make up the ecological community used by the species). Over half of these 15 species exhibit global population decline, most largely due to land development.

In 2015, the state of Colorado published a Wildlife Action Plan, which includes a list of *Species of Greatest Conservation Need* to prioritize conservation of certain species, with a focus on native species. Species were categorized into two levels of concern, Tier 1 and Tier 2, with Tier 1 requiring more immediate attention. 19 of the species with ranges in Pueblo and/or Crowley counties were considered Tier 1, and 44 species were categorized as Tier 2 (Table 4.2.). Most Tier 1 and Tier 2 species have stable or declining global populations, warranting concern for their populations in the face of development and climate change. Many Tier 1 and Tier 2 species are experiencing population decline due to land development and human land use in their vital habitats, such as shortgrass prairies.

Overlay Analysis Results

Pronghorn populations are concentrated throughout Pueblo County and reside in many private land parcels. Additionally, Pronghorn winter ranges are present within the county, and their overall range spans throughout the entire area, making Pueblo County a high-use area (Fig. 4.1). Their ranges and concentration areas produce low-cost corridors for migration primarily in the northernmost region of Pueblo County (Fig. 4.2). These corridors pass through large parcels of private land, making conservation of these lands essential for Pronghorn migration.

Population concentrations for Mule Deer are scattered throughout both Pueblo and Crowley Counties. Mule Deer summer ranges fall along the western side of Pueblo County, and their winter ranges are present both North and South of the counties (Fig. 4.3). Evidently, private and public lands in both counties provide crucial corridors for migratory Mule Deer. Concentration patterns determine a wide range of least-cost migratory pathways in both counties that rely on conserving private land (Fig. 4.4).

Table 4.2. Species tracked by CPW with overall, breeding, or seasonal ranges in Pueblo or Crowley Counties. Includes common and scientific names for all species, global population trends, CPW status (State or Federal listing), Species of Greatest Conservation Need (SGCN) Priority Tier, IUCN Red List status, other agency lists of concern and general species importance, type of range, and different ways the species uses land.

Animal Classes	Population Trend	CPW Status	Species of Greatest Conservation Need Priority Tier	IUCN Status	Type of Range
Amphibians: 1	Decreasing: 36	State Special Concern: 16	Tier 1: 19	Least Concern: 102	Overall: 70
Birds: 40	Stable: 58	Federally Threatened: 5	Tier 2: 44	Near Threatened: 7	Breeding: 30
Mammals: 32	Increasing: 17	Federally Endangered: 2		Vulnerable: 5	Release Sites: 1
Reptiles: 37		State Endangered: 6		Endangered: 11	Historic Range: 1
Fish: 7		State Threatened: 6			Potential Habitat: 1
Total Species: 117					

Linkage Mapper Results

The model of least cost corridors and pathways for Pronghorn in Pueblo and Crowley reveals a limited number of least-cost corridors and pathways for Pronghorns (Fig. 4.2). Furthermore, numerous portions of private land intersect with these critical migration corridors. This finding suggests that Pronghorns in the region are already facing constraints in accessing migration routes and core habitats, even in the absence of solar farms.

The least cost corridors and pathways for Mule Deer are depicted in Figure 4.4. In contrast to the least cost corridors and pathways modeled for pronghorn, it can be observed that Mule Deer have a higher number of core areas, consequently leading to an increased presence of corridors and least-cost pathways. The map highlights the substantial role of the county in supporting the population of Mule Deer, as reflected in the abundance of corridors and core areas. Private lands are also integral to Mule Deer, as they serve as migratory routes for these animals.

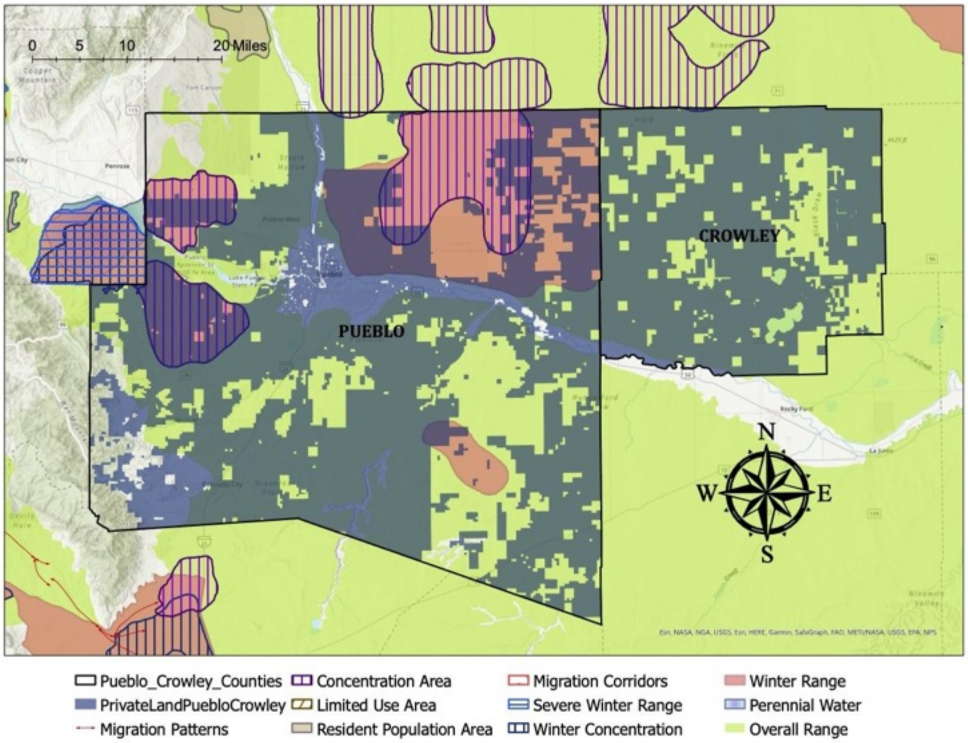


Figure 4.1. Pronghorn distribution in Pueblo and Crowley Counties in Colorado. Pronghorn concentration areas (dark purple lines) and winter ranges (pink) are shown along with privately owned land (dark blue). Concentration areas are found mainly in upper Pueblo County.

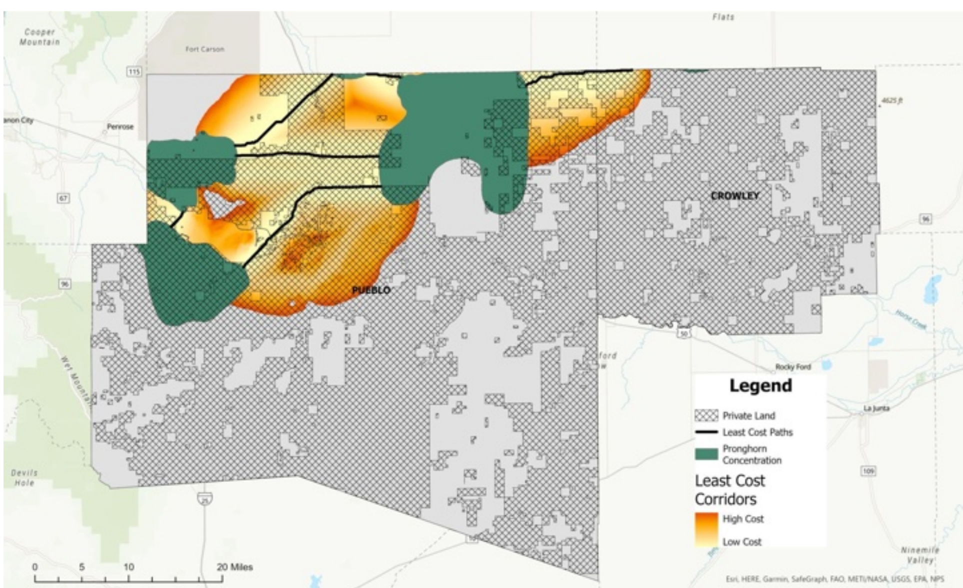


Figure 4.2. Least-Cost Corridors and Pathways for Pronghorn. Darker orange areas show greater resistance, while black lines suggest the least-cost pathways, essentially the most favorable migration routes. The green areas indicate Pronghorn's core areas, and the crossed black lines illustrate all non-easement private lands that could be potentially used for solar farm development.

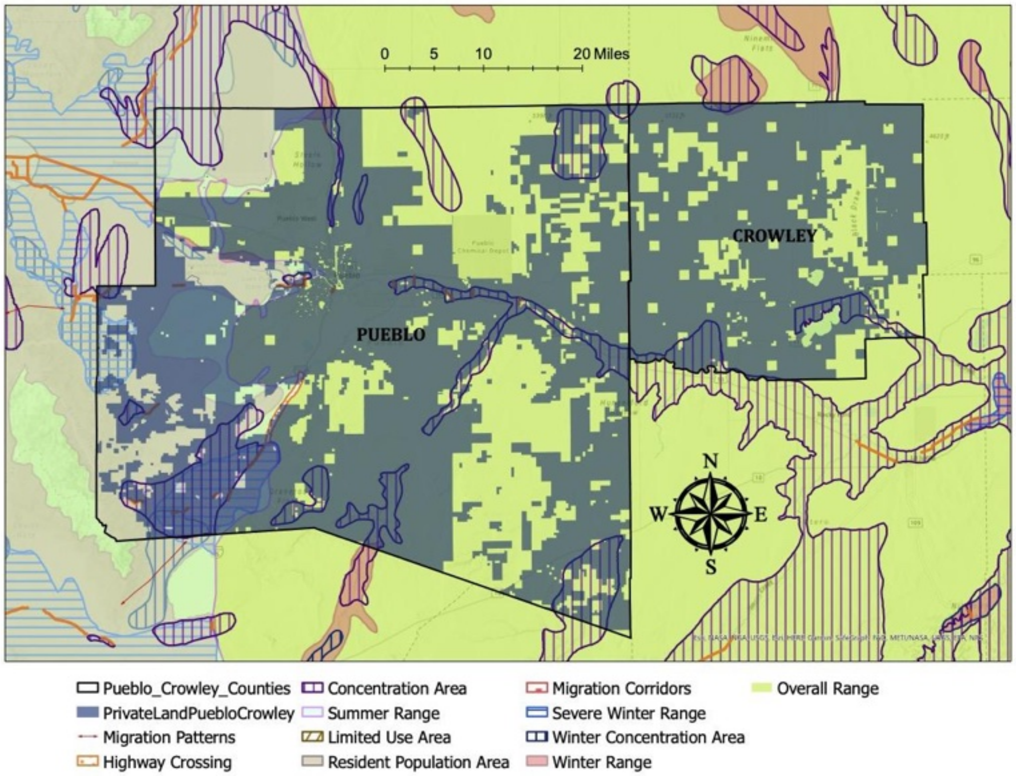


Figure 4.3. Mule Deer distribution in Pueblo and Crowley Counties, Colorado. Mule Deer concentrations (dark purple lines) are present throughout both counties, with summer ranges primarily to the west of Pueblo County. Private land is overlaid in dark blue.

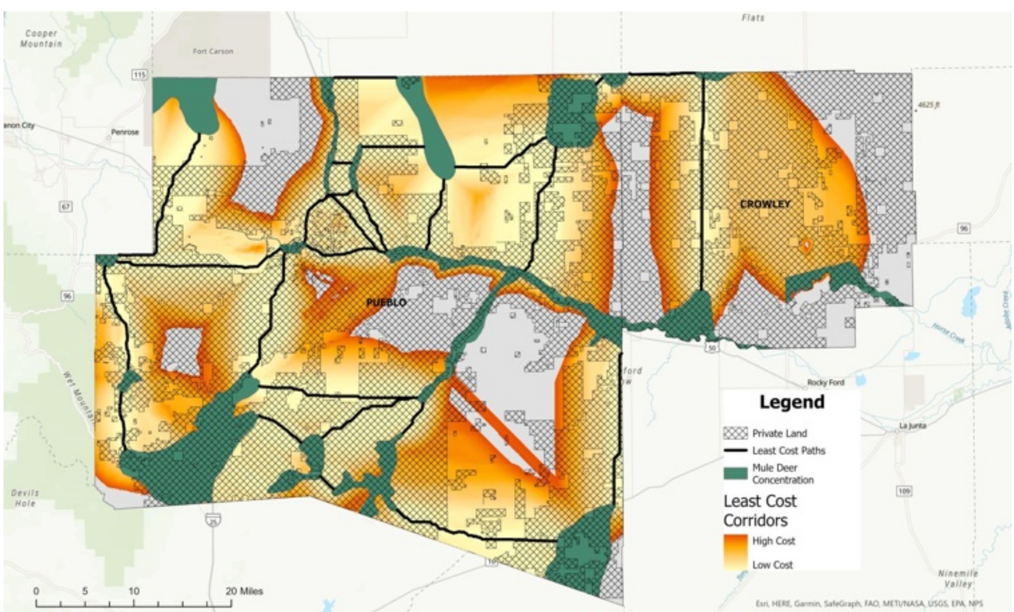


Figure 4.4. Least-Cost Corridors and Pathways for Mule Deer. The areas shaded in darker orange indicate higher resistance, the black lines denote the least-cost paths, the green areas mark the core Mule Deer habitats, and the crossed lines signify non-easement private property.

Case Study Results

Utility-Scale Solar Energy (USSE) development in the western U.S. is disruptive to habitats and has adverse responses to the wildlife present in the area. Solar development is most desirable in arid landscapes where solar energy potential is high, and land is flatter. Pronghorn are particularly vulnerable to USSE impacts because flat, arid landscapes are their preferred habitats, and they are more susceptible to barriers and fragmentation than other ungulates. However, USSE impacts on ungulates are largely undocumented. Identifying these impacts is necessary to determine the best location, layout design, and to understand the trade-offs against wildlife and ecosystem services.

This case study specifically looks into Pronghorn movement patterns in Southwestern Wyoming before and after the construction of the Sweetwater Solar Facility in 2018. This land is a high-use area for Pronghorn populations and a crucial winter range for migration. The researchers placed GPS tracking collars on 23 Pronghorn and collected their locations every two hours. They found that 30% of Pronghorn in the study area were migratory, and 70% were non-migratory. Additionally, they calculated the proportion of habitat loss from USSE construction using the Brownian Bridge movement model (models the probability of being in an area based on starting and ending locations, the elapsed time between those points, and the mobility or speed of movement). Pronghorn lost 2.3 km^2 of high-use areas, which is 10% and 12% of their winter and summer ranges, respectively. High-use areas were reduced by 40%, and 69% of residents were forced to alter their year-round movement. Additionally, 89% of Pronghorn lost their migratory pathway and had to find alternate routes. Overall, USSE construction blocked access to critical habitats, interrupted migratory pathways, and caused displacement of populations.

Prior to the construction of the facility, the developers had proposed a square layout design for the grid. The Wyoming Game and Fish Department addressed concerns regarding the proposed layout, as the grid shape would block Pronghorn migration and divert the animals onto a nearby highway. In response, the developers angled the corner of the grid to accommodate movement. This case study identifies the impacts of USSE on Pronghorn populations and migration patterns and addresses the importance of these assessments when considering solar development. Solar construction, along with any large infrastructure on open lands, has unavoidable effects on the ecosystem dynamics. However, thoughtful consideration of these effects can minimize the disruption and barrier impacts on wildlife as well as maintain connectivity in the landscape (Sawyer et al., 2022).

Conclusion

Recommendations

Based on report findings, the presence of solar farms on these lands has the potential to pose a substantial threat to the preservation of crucial migration corridors for Pronghorns and Mule Deer. This, in turn, may result in adverse outcomes for these species, including increased susceptibility to road mortality, loss of habitat, isolation of populations, genetic bottlenecks, and reduced movement between core habitats. Thus, this could potentially affect their overall viability and the well-being of their population (Lovich & Ennen, 2011). To best conserve these species, protection for migration corridors must be established. Studies suggest that mule deer and pronghorn require a functional migration corridor width of 400–600 meters. It is recommended that discussions about functional corridor widths are promoted to aid in habitat conservation within migration corridors and prioritize conservation efforts at different levels (Merkle et al., 2023). Additionally, an integrative research approach is required, drawing from various disciplines such as population dynamics, evolution, genetics, behavior, and physiology to fully understand and mitigate the impact of utility-scale solar facilities on migrations (Bolger et al., 2008).

In Pueblo and Crowley Counties, it is not recommended that solar be developed to conserve Pronghorn and Mule Deer migration corridors best. The best way to support populations is to protect and preserve their vital habitats. However, it is also important to acknowledge the need for solar energy and the ongoing transition from fossil fuels to renewable energy. Therefore, if landscape assessments determine that Pueblo and Crowley counties are ideal areas for solar development, it is recommended that utility-scale solar facilities be placed in the Eastern half of Crowley County least to interrupt ungulate migratory pathways and species core habitats. Further, more detailed research is suggested into specific parcels in Eastern Crowley County slated for solar development before land conversion begins to consider aspects such as the solar farm's angle and the facility's permeability (Sawyer et al., 2022).

The transition from fossil fuel energy to clean energy sources is a critical step toward mitigating climate change impacts. The development of renewable energy facilities presents numerous drawbacks for ecological systems, and understanding those drawbacks can help minimize adverse effects on wildlife dynamics. Because solar farms require expansive areas of open land, thorough land assessments must be performed before construction. Assessments should include reports of all wildlife species present in the area and their responses/sensitivity to disruptions, migratory corridors for species present, and a cost-weight analysis of alternate pathways. Performing assessments can allow developers to properly choose a site, and design the layout and size of solar farms to accommodate resident and migratory animals best (Pocewicz et al., 2011; Sawyer et al., 2022).

Significance

The extent of this study covered Pueblo and Crowley counties; however, much of the Eastern Colorado prairies face similar challenges in balancing renewable energy development and wildlife conservation. Results from this study could serve as background information for development considerations in other areas of eastern Colorado. Solar energy development can negatively impact habitat connectivity and result in habitat fragmentation, a growing concern in the field of landscape ecology. More research on ungulate migration patterns is needed in this area to conserve habitat connectivity. Additionally, while this research primarily focused on ungulate species, there is also evidence that bird and bat fatalities increase in the presence of utility-scale solar installations (Smallwood, 2022). However, the research could not be conducted research on these species because of a lack of available data. Therefore, it is important to prioritize data collection on species beyond migratory ungulates, especially native, keystone, and threatened or endangered species. Additional data is also needed on the potential benefits of USSE to wildlife. There is a consideration that certain taxa or life histories could be more compatible with USSE and potentially promote the movement of species (Hernandez et al., 2014). Further investigation could be conducted to determine the most suitable infrastructure layout within the United States Space Exploration (USSE) framework for facilitating species migration and their genetic material. (Hernandez et al., 2014; Sawyer et al., 2022).

The limited amount of existing research in this specific field of study, coupled with the growing prevalence of solar energy companies, highlights the crucial importance of examining the potential consequences associated with the establishment of solar farms. Pronghorn, Mule Deer, and other wildlife species encounter distinct obstacles, mainly when private lands that could be developed into solar farms overlap with their crucial migration routes and core habitats. Within this particular setting, it is imperative to underscore the need to make well-informed decisions that are both sustainable and considerate of wildlife. This analysis serves as a valuable resource and a call to action for stakeholders and policymakers within the expanding landscape of renewable energy projects. By considering the ecological ramifications, individuals may make informed choices that effectively balance the production of clean energy with the protection of vital wildlife habitats and migration corridors, thus ensuring the well-being of the natural environment and nearby communities.

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Chapter 5: Threatened & Endangered Species

Sam Thanassi, Dee Knox, Devon Ortman

Background

There are 74 threatened and endangered species in Colorado. The study's main goal was to determine whether implementing solar panels in Pueblo and Crowley counties would negatively affect the threatened and endangered species in those two counties. To answer this central question, the following sub-questions first had to be answered: Out of the 74 threatened and endangered species that are present in Pueblo and Crowley, what are the species' ideal habitats, and what does the current population size of the species look like in the two counties.

In regional dynamics and broad-scale trends, whether solar panels would negatively or positively affect endangered animals in Pueblo and Crowley Counties in Colorado is a complex and multifaceted issue. To answer this question effectively, the researchers need to consider the existing management, permitted uses, funding structures for the parcels, current initiatives, and other relevant factors in the region. This analysis will focus on ten endangered species in Pueblo and Crowley counties in Colorado.

Pueblo and Crowley Counties in Colorado typically comprise a mix of ownership and management structures. Some land parcels may be under private ownership, while others are under state or federal management. Public lands in the area may be governed by agencies like the Bureau of Land Management (BLM), the U.S. Forest Service, or the Colorado Division of Parks and Wildlife. Understanding who manages the land is crucial as it can influence land use and conservation efforts. A combination of federal, state, and local regulations determines the permitted land uses in these counties. In rural areas like these, land uses often include agriculture, ranching, recreation, and energy development. Solar panel installations would require compliance with zoning and permitting regulations, which could vary across the region.

Understanding ongoing initiatives and conservation programs in the region is vital. Pueblo and Crowley Counties may have efforts to protect endangered animals and their habitats, such as the Preble's Meadow Jumping Mouse or the Arkansas Darter. These initiatives could involve habitat restoration, land acquisition, or conservation easements. Before installing solar panels on the land, an understanding of the conservation laws should be known.

Methods

The first method for the analysis, collecting population maps and using extensive maps from GIS, did not work out. This was due to a lack of available relevant information caused by the particular target area. This ruled out a vast majority of the available data. However, this was solved by gathering an extensive report about the threatened and endangered species in Pueblo and Crowley counties through CODEX and iNaturalist. CODEX provided an overlay of where each species is present in Colorado. This allowed the study to hone in on the species within the defined spatial extent. From looking at CODEX, a list of 11 endangered and threatened species in the area of interest was accumulated. While CODEX is a trustworthy database, the list was also cross-checked with a secondary source, iNaturalist, to ensure the information was accurate and consistent. The main concern with gathering information from iNaturalist was that the information published on iNaturalist can be from anybody, meaning that some posts would be from people who are not experts in identifying species. This would have allowed room for error in this study's species counts. To avoid the issue of misidentified species in the system, only information from verified experts who work with and for the website was counted in this study. One at a time, the species names were entered into the website to identify whether the threatened or endangered species had been spotted in the area, and were then cross-searched with Pueblo and Crowley County in the search bar. After doing this for each species, a list of endangered and threatened species in the target area was finally accumulated, and was verified by experts. From this list, the study only chose the species that CODEX and iNaturalist agreed were present in Pueblo and Crowley ounties, which concluded as ten species on the Colorado Parks and Wildlife threatened and endangered list.

Awareness of the species present is vital to mitigate any harm; similarly, knowledge of estimated population size is also important. After extensive research, Pueblo and Crowley Counties are not well represented in any studies. iNaturalist had to be utilized once again. The analysis pieced together approximate population sizes by looking at the timeline of when people posted about sightings, as well as the number of sightings recorded within this timeline. The weakness of this method is that the information is not the most accurate due to the wide spectrum of published dates.

The final list had ten threatened or endangered species and recorded an estimated population size for each species. The preferred habitats of the ten species were also researched. This data on best-suited habitats would allow for a more in-depth analysis of how solar panels would affect the species in Pueblo and Crowley Counties. While there was no direct research regarding Pueblo and Crowley, a literature review was done to gain an understanding of how solar, in general, would affect habitats.

Findings and Recommendations

Throughout the extensive research, roughly forty graphs and images were generated that help represent not only what species are present, but also species population size and an estimated location of the species.

The Plains Leopard Frog was the first species identified as a state special concern was the Plains Leopard Frog (Appendix B). The Plains Leopard Frog preferred the northwestern portion of Pueblo County, and it did not reside in Crowley County at all, according to iNaturalist (Appendix A). Compared to CODEX, which states the frogs preferred the southernmost portion of Pueblo and the northernmost portion of Crowley, this information showed that the species had a wide range in which they could reside (Appendix A). After some digging on the Colorado Parks and Wildlife page, the research showed a close relationship between frogs and wet environments, particularly riparian areas with dense and extensive vegetation, which could help explain the location in Pueblo and Crowley. iNaturalist was a great resource for information regarding the time frame for sightings. The times allowed the study to have approximate population sizes within a given period. The oldest post occurred in August 2016 for the Plains Leopard Frog and the newest one in September 2023 . From the 22 sightings, nine occurred in 2023, which is a hopeful observation that these species are doing well in their current habitat.

The next species in the study was the bald eagle, considered a state special concern but also resides in Pueblo and Crowley (Appendix B). From iNaturalist, the analysis determined that the Bald Eagle prefers the lower northmost area of Pueblo and the southernmost portion of Crowley (Appendix A). When cross-examining with CODEX, a similar trend appeared. Due to Bald Eagles preferring wetlands with tall trees, the pattern the researchers saw in Pueblo and Crowley was due to migration patterns, and most likely, the birds never stayed too long within the two counties (Appendix A). The unfortunate portion was looking at the dates of sightings, and there was no post before March 2022 and the oldest post was five years ago. From this observation, the researchers were nervous that the climate of Pueblo and Crowley had already become intolerable for the Bald Eagles.

The next bird species, the Burrowing Owl, was listed as state-threatened (Appendix B). Neither iNaturalist nor CODEX had any information to determine a range in which these species like to live, but due to research on Colorado Parks and Wildlife, it was identified grasslands, prairies, and pastures that have fine or medium textured soils were the best place for Burrowing Owls to reside. From iNaturalist, the researchers could understand population size based on the recency of sightings, with the earliest coming from five months ago and the oldest being from 13 years ago and with only ten observations in this area (Appendix A). Unfortunately, the population size of Burrowing Owls might be diminishing due to many factors that could affect their burrowing abilities.

The next bird species examined was the Ferruginous Hawk, listed as a state special concern residing in Pueblo and Crowley (Appendix B). Based on observations from iNaturalist, it was identified that the Ferruginous Hawk prefers the central most part of Pueblo and Crowley (Appendix A). From CODEX, the hawk is not only the centermost but also the easternmost part of Pueblo and the entirety of Crowley (Appendix A). Based on this information, the location of the hawk could be due to its preference for flat, rolling terrain such as prairies or canyons. Still, it also avoids areas of intense agriculture and intense human disturbance. With this in mind, it was surprising when the most recent sighting of the hawk had been recorded 24 days ago, with the oldest occurring 18 years ago. While there were only 13 sightings, the number of sightings proves there might not be a large population of Ferruginous Hawk, but they still come to Pueblo and Crowley.

The Long-Billed Curlew was the next bird species the researchers checked out due to its listing as a state special concern (Appendix B). Based on a limited number of observations from iNaturalist, it appeared that the curlew preferred the northernmost portion of Pueblo and avoided Crowley altogether (Appendix A). Still, when cross-examining with CODEX, the curlew seemed to do the opposite. CODEX placed the curlew in the easternmost portion of Crowley and non-existent in Pueblo (Appendix A). These observations could be due to the bird's preference for near-water grasslands. The unfortunate portion is the number of sightings in iNaturalist: only four observations, with the youngest occurring three years ago and the oldest occurring seven years ago. Due to the low sightings, the Long-Billed Curlew is not thriving in Pueblo or Crowley and should be prioritized as the highest protection.

The researchers moved on to focus on the Mountain Plover, a state special concern (Appendix B). Based on limited information from iNaturalist, this bird prefers the northeast portion of Pueblo (Appendix A). Still, when cross-referenced with CODEX, this bird should prefer almost all of

Pueblo and Crowley minus a small sliver of the westernmost portion of Pueblo (Appendix A). These observations could make sense due to the Plover's avoidance of wet sites and an affirmation for areas with buffalo grass, blue grama, and prickly pear. While it may seem the Mountain Plover would thrive in Pueblo and Crowley, there have only been three recorded sightings of the bird, the earliest occurring two years ago and the oldest occurring no more than five years ago. The Mountain Plover may have the highest likelihood of survival in the future of Pueblo and Crowley. Still, the Mountain Plovers may not exist in these two counties due to the low number of sightings and many years since a sighting.

Moving on from bird species, the Black-Tailed Prairie Dog and the Black-Footed Ferret prefer the same habitats of dry, flat, sparsely vegetated grasslands where they can burrow . Unfortunately, the Black-Footed Ferret is considered both federally endangered and state endangered, while the Black-Tailed Prairie Dog is considered of state special concern (Appendix B). While the Black-Tailed Prairie Dog faces plagues from year to year, they have a relatively high sighting rate, according to iNaturalist, with the earliest sighting occurring just two months ago and the oldest occurring about eight years ago. While the researchers wished the story was the same for the Black-Footed Ferret, unfortunately, there was only one sighting of this species in November of 2021. CODEX agrees with the analysis iNaturalist provided for the two different species. While the dominance of the Black-Tailed Prairie Dog is a hopeful sight, saving the population of the Black-Footed Ferret could no longer be a viable option.

The second to last species the researchers examined was the Swift Fox, which is considered to be of state special concern (Appendix B). This species prefers a habitat filled with native short to mid-length grass but can thrive in a sagebrush-dominated landscape. The 11 sightings of the Swift Fox have occurred in northeastern Pueblo and central Crowley, according to iNaturalist, whereas CODEX places the fox over a wide diversity of the two counties (Appendix A). A more hopeful observation was the newest sighting of a Swift Fox occurred in June of 2021, but along with that, the oldest sighting occurred about 13 years ago. While there is good news from recent sightings, there is still more work to ensure these key species do not continue to decline in population size.

The final species the researchers looked at was the Triploid Checkered Whiptail, which is considered a state special concern even though iNaturalist has 207 sightings of the species (Appendix B). CODEX and iNaturalist agree that these species predominantly occupy the northwesternmost portion of Pueblo and stay away from Crowley mainly due to their preference for woodland, arid and shrubby areas, which is the main terrain of that portion of Pueblo (Appendix A). The Whiptail has the most hopeful outcome because the most recent sighting was 21 days ago, and the oldest was roughly eight years ago. These species are key to a stable environment, and maintaining their health is vital to the Pueblo and Crowley areas.

While many species wander throughout the Pueblo and Crowley counties, the ten listed above are crucial to the health of the two counties, and their status as threatened or endangered species means that preserving these animals and their habitats should be a primary goal for anyone looking to develop the area.

Significance

The question of how solar panels might affect endangered species in Pueblo and Crowley counties is essential in the broader context of regional conservation and planning efforts. Here's how these findings and recommendations fit into a larger ecological and real-world context:

- Pueblo and Crowley counties are part of a region with diverse ecosystems and wildlife, some of which are listed as endangered or threatened species. The findings help us understand the potential trade-offs between renewable energy development and species conservation, a critical issue in many regions worldwide. This case is representative of the ongoing challenge of balancing human expansion with protecting vulnerable species.
- The habitat disruption and fragmentation caused by solar projects underscores the importance of considering landscape ecology principles in regional planning. Creating wildlife corridors and habitat connectivity benefits local species and contributes to broader conservation efforts in the region. It aligns with the principles of ecological connectivity, which aim to maintain or restore the movement of species across landscapes.
- The recognition that solar energy can contribute to climate change mitigation highlights its relevance to broader conversations in conservation. Climate change poses a significant threat to ecosystems and species worldwide. Increasing renewable energy decreases greenhouse gas emissions, which is a crucial strategy for protecting habitats and species locally and globally. However, it is vital to understand the consequences that can come from solar energy installation if done too hastily. Meticulous planning should be a priority before installing solar panels to minimize the negative impact on the ecosystem.
- As indicated in the findings, the need for ongoing research and monitoring reflects the importance of adaptive management in conservation planning. This approach involves continuously assessing the impact of human activities on the environment and adjusting practices as needed. Adaptive management is a fundamental concept in conservation, and the lessons learned in this region can inform practices in similar landscapes.
- Engaging with local communities, conservation organizations, and regulatory agencies is essential for success. This emphasis on collaboration is a core principle of contemporary conservation efforts. The findings and recommendations highlight the necessity of using local knowledge and values in planning and decision-making processes.
- The findings underscore the importance of responsible renewable energy development. This is not a localized issue but a global challenge. Many regions aim to balance renewable energy production and wildlife protection sustainably. It requires innovative solutions such as dual-use land concepts and wildlife-friendly construction practices.

In summation, the question of how solar panels impact endangered species in Pueblo and Crowley counties is a microcosm of the complex choices and trade-offs faced in regional conservation and planning. The findings and recommendations highlight the need for science-based, adaptive, collaborative approaches considering local context while contributing to broader conversations in conservation planning and landscape ecology. The lessons learned in this region can inform and inspire conservation efforts in other areas, promoting the coexistence of renewable energy and the protection of vulnerable species.

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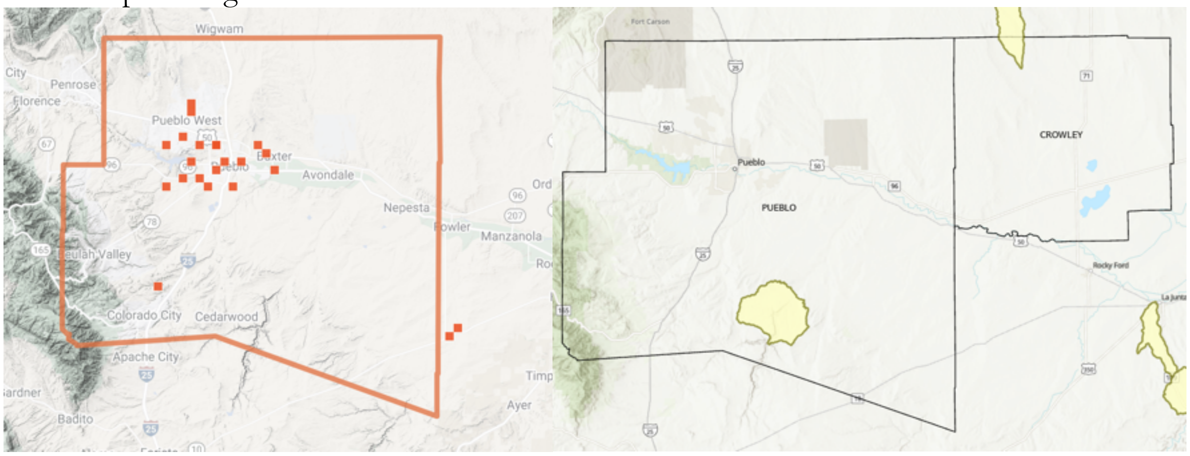
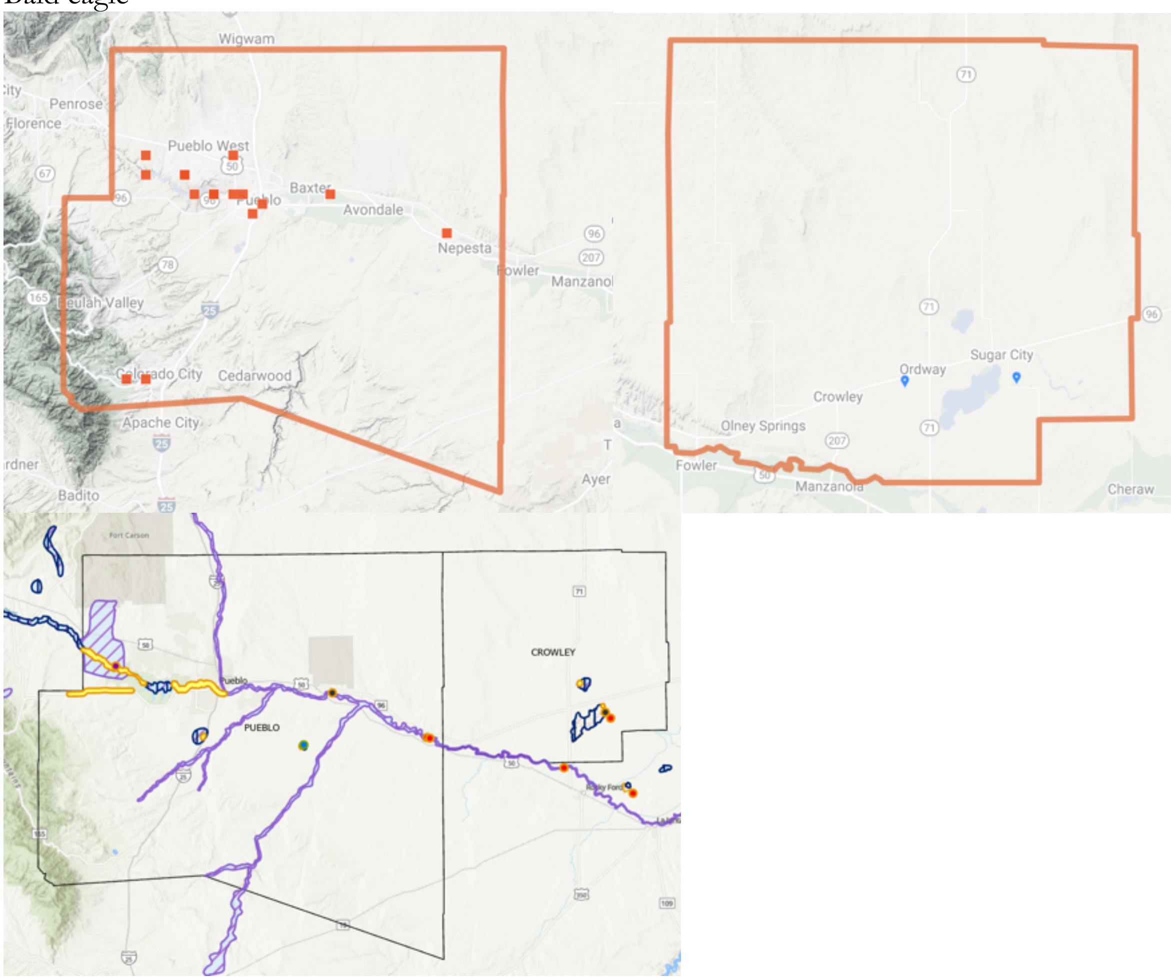
Appendix A. Species observations from iNaturalist (locations indicated by orange squares) and species distribution estimates from CODEX (yellow polygons).

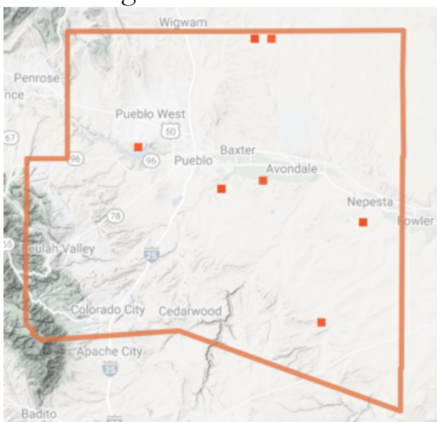
Plains leopard frog

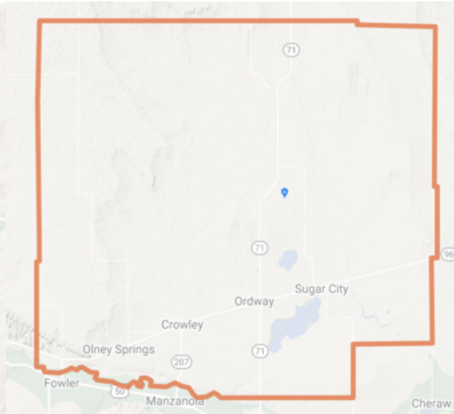


Bald eagle

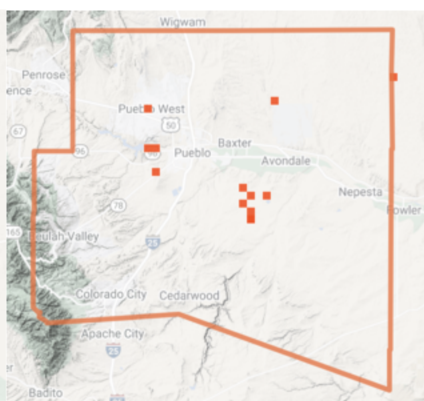


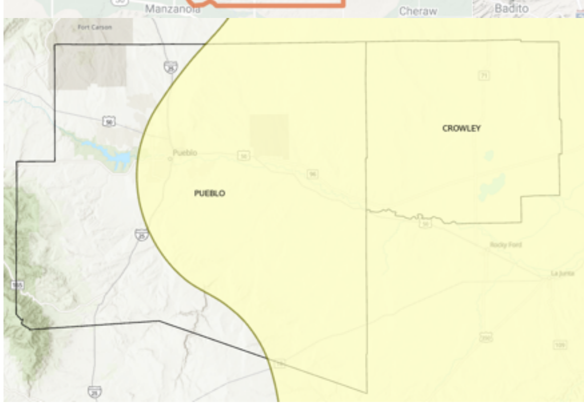
Burrowing owl



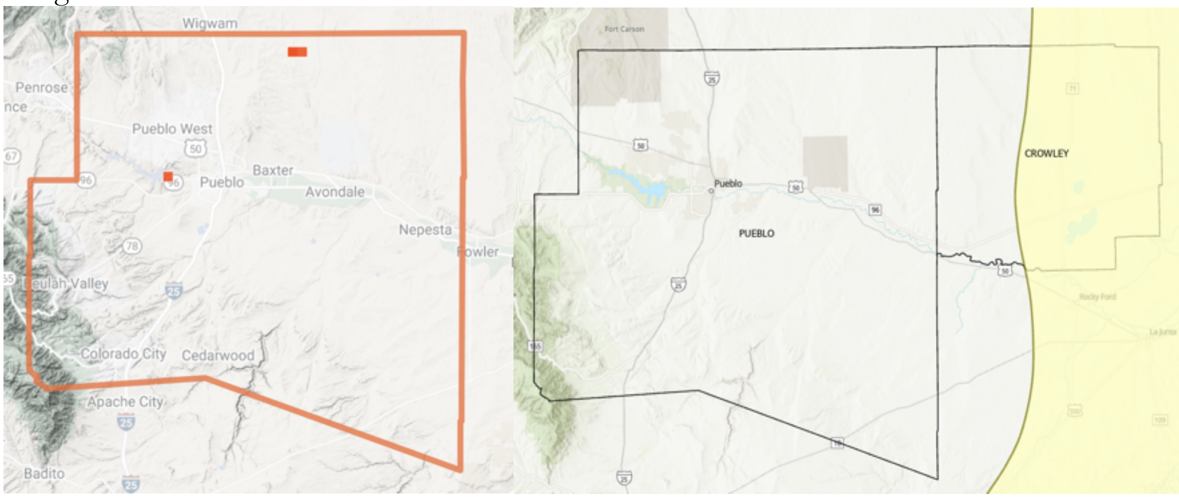


Ferruginous hawk

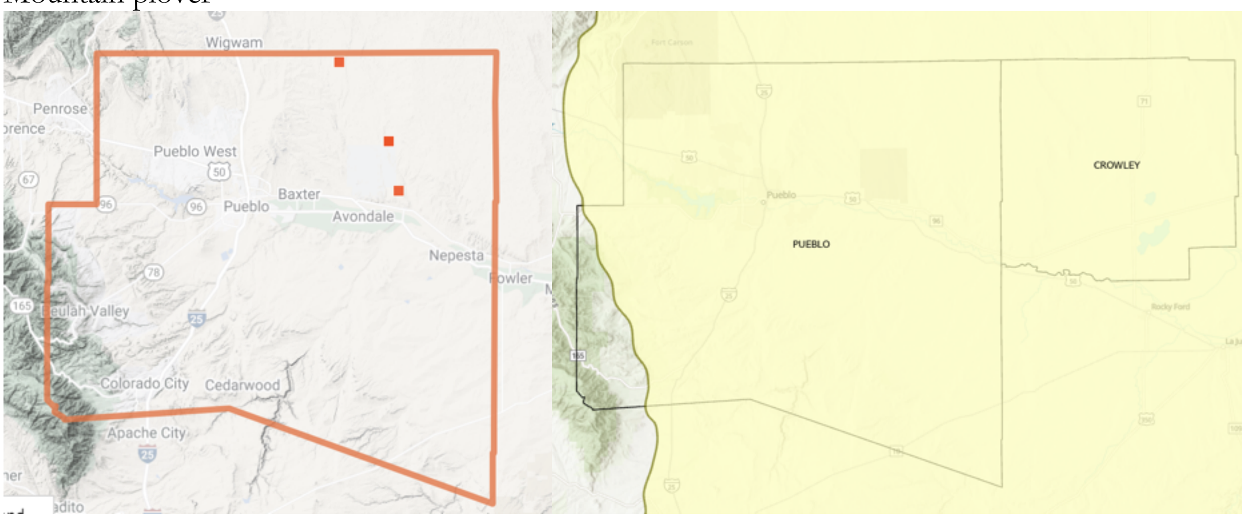




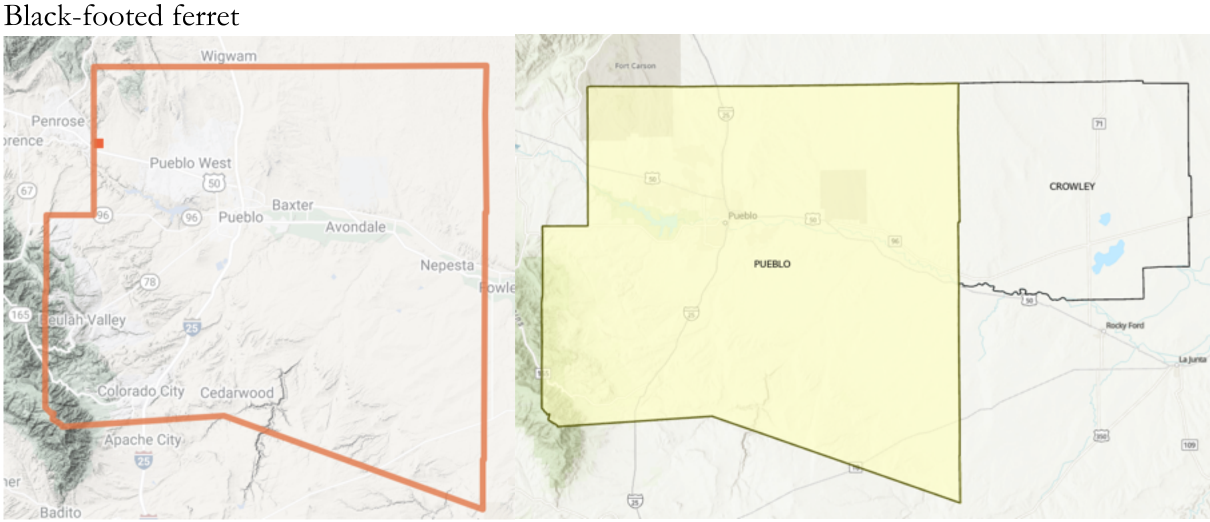
Long-billed curlew



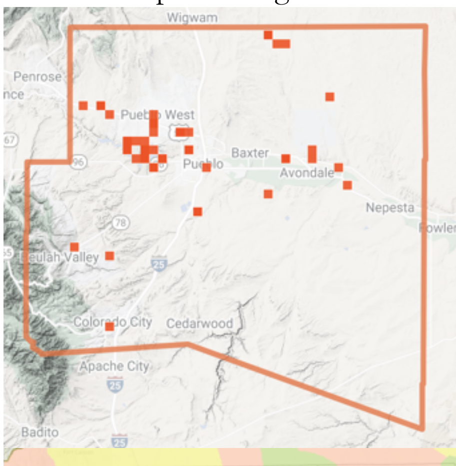
Mountain plover

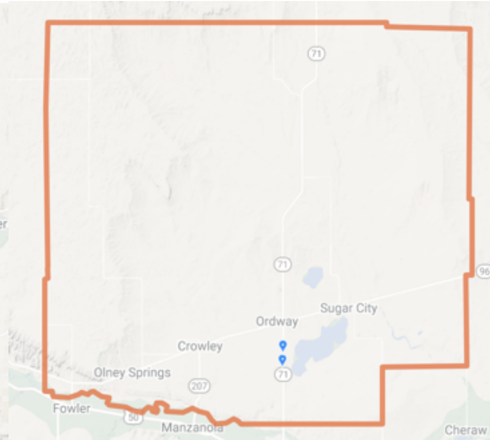


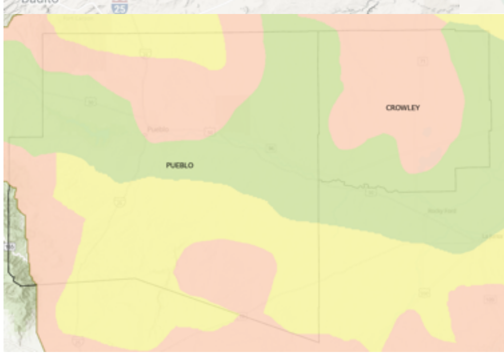
Black-footed ferret



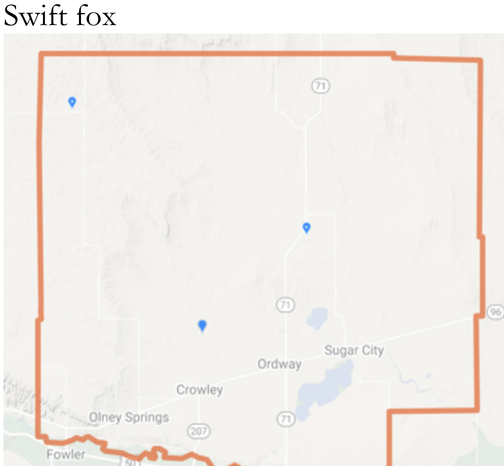
Black-tailed prairie dog

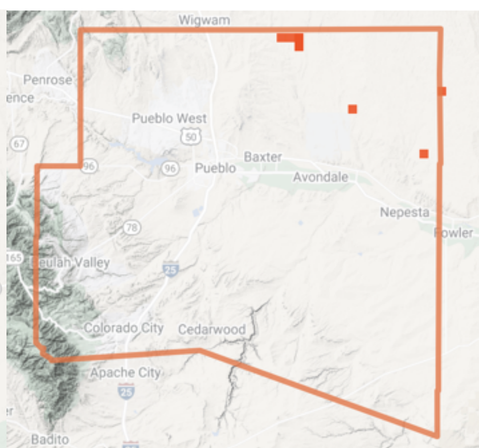


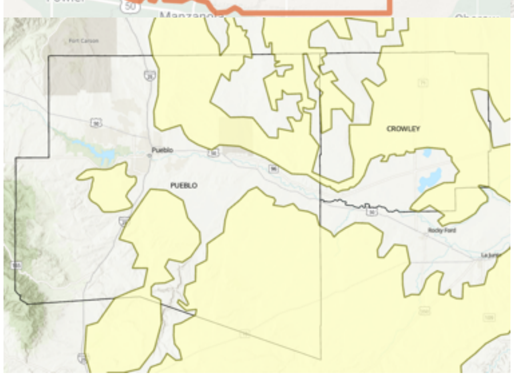




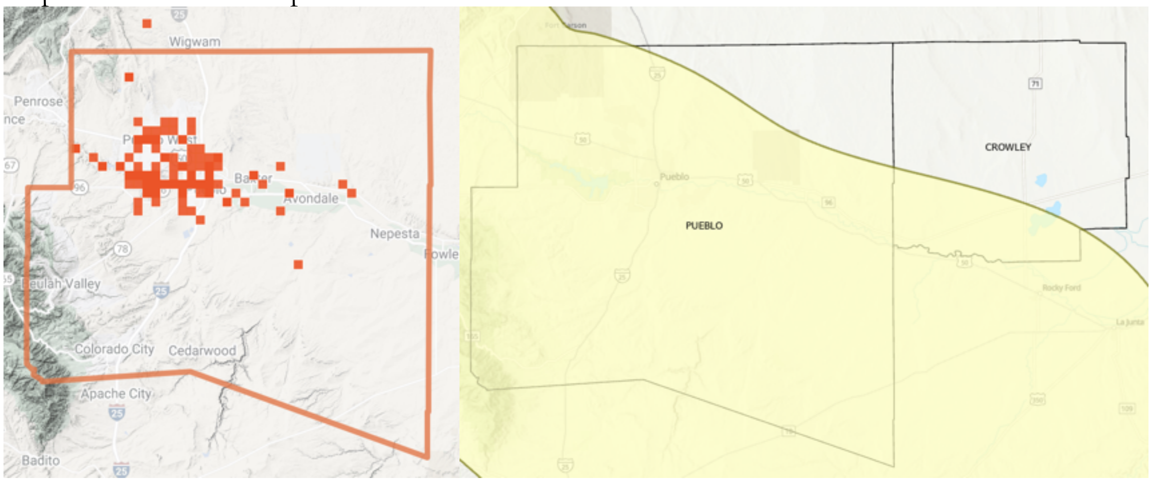
Swift fox







Triploid checkered whiptail



Appendix B. Chart of Endangered and Threatened Species in Colorado as well as Pueblo and Crowley Counties.

Common Name	Scientific Name	Status	Present according to CODEX	Present according to iNaturalist
AMPHIBIANS				
Boreal Toad	*Bufo boreas boreas*	SE	No	no
Couch's Spadefoot	*Scaphiopus couchii*	SC	n/a	**YES**
Great Plains Narrowmouth Toad	*Gastrophryne olivacea*	SC	No	no
Northern Cricket Frog	*Acris crepitans*	SC	No	no
Northern Leopard Frog	*Rana pipiens*	SC	No	**YES**
Plains Leopard frog	*Rana blairi*	SC	**YES**	**YES**
Wood Frog	*Rana sylvatica*	SC	No	no
BIRDS				
American Peregrine Falcon	*Falco peregrinus anatum*	SC	n/a	no
Bald Eagle	*Haliaeetus leucocephalus*	SC	**YES**	**YES**
Burrowing Owl	*Athene cunicularia*	ST	**YES**	**YES**
Columbian Sharp-Tailed Grouse	*Tympanuchus phasianellus columbianus*	SC	n/a	no
Ferruginous Hawk	*Buteo regalis*	SC	**YES**	**YES**
Greater Sage Grouse	*Centrocercus urophasianus*	SC	n/a	no
Greater Sandhill Crane	*Grus canadensis tabida*	SC	No	no
Gunnison Sage-Grouse	*Centrocercus minimus*	FT, SC	No	no
Least Tern	*Sterna antillarum*	SE	Possible	possible
Lesser Prairie-Chicken	*Tympanuchus pallidicinctus*	FT, ST	No	no
Long-Billed Curlew	*Numenius americanus*	SC	**YES**	**YES**
Mexican Spotted Owl	*Strix occidentalis lucida*	FT, ST	n/a	no
Mountain Plover	*Charadrius montanus*	SC	**YES**	**YES**
Plains Sharp-Tailed Grouse	*Tympanuchus phasianellus jamesii*	SE	n/a	
Piping Plover	*Charadrius melodus circumcinctus*	FT, ST	No	no
Southwestern Willow Flycatcher	*Empidonax traillii extimus*	FE, SE	n/a	no
Western Snowy Plover	*Charadrius alexandrinus*	SC	Possible	no

Western Yellow-Billed Cuckoo	*Coccyzus americanus*	SC, FT	n/a	**YES**
Whooping Crane	*Grus americana*	FE, SE	n/a	no
MAMMALS				
Black-Footed Ferret	*Mustela nigripes*	FE, SE	**Possible**	**YES**
Black-Tailed Prairie Dog	*Cynomys ludovicianus*	SC	**YES**	**YES**
Botta's Pocket Gopher	*Thomomy bottae rubidus*	SC	Possible	no
Gray Wolf	*Canis lupus*	SE, FE	n/a	no
Grizzly Bear	*Ursus arctos*	FT, SE	n/a	no
Kit Fox	*Vulpes macrotis*	SE	No	no
Lynx	*Lynx canadensis*	FT, SE	No	no
Northern Pocket Gopher	*Thomomys talpoides macrotis*	SC	n/a	**YES**
Preble's Meadow Jumping Mouse	*Zapus hudsonius preblei*	FT, ST	No	no
River Otter	*Lontra canadensis*	ST	No	no
Swift Fox	*Vulpes velox*	SC	**YES**	**YES**
Townsend's Big-Eared Bat	*Corynorhinus townsendii pallescens*	SC	n/a	no
Wolverine	*Gulo gulo*	SE	n/a	no
REPTILES				
Triploid Checkered Whiptail	*Cnemidophorus neotesselatus*	SC	**Possible**	**YES**
Midget Faded Rattlesnake	*Crotalus viridis concolor*	SC	n/a	No
Longnose Leopard Lizard	*Gambelia wislizenii*	SC	No	No
Yellow Mud Turtle	*Kinosternon flavescens*	SC	No	No
Common King Snake	*Lampropeltis getula*	SC	Possible	No
Texas Blind Snake	*Leptotyphlops dulcis*	SC	No	No
Texas Horned Lizard	*Phrynosoma cornutum*	SC	No	No
Roundtail Horned Lizard	*Phrynosoma modestum*	SC	No	No
Massasauga	*Sistrurus catenatus*	SC	**possible**	**YES**
Common Garter Snake	*Thamnophis sirtalis*	SC	No	No
MOLLUSKS				
Rocky Mountain Capshell	*Acroloxus coloradensis*	SC	n/a	no
Cylindrical Papershell	*Anodontoides ferussacianus*	SC	n/a	no