Eastern Slope and Plains Wildlife Prioritization Study

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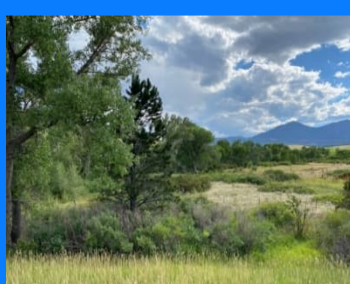

Prepared For

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Department of Natural Resources

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Disclaimer

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Eastern Slope and Plains Wildlife Prioritization

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16. Abstract

The Eastern Slope and Plains Wildlife Prioritization Study was launched following the completion of the Western Slope Wildlife Prioritization Study to provide Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) with a statewide perspective on priority wildlife-highway conflict areas and mitigation needs, and to ensure the most effective use of mitigation funds. The objective of this research was to identify wildlife-highway conflict areas under both current conditions and future land use and traffic scenarios where targeted mitigation could have the greatest impact on reducing wildlife-vehicle collisions and providing safer roads for wildlife and people. Specifically, this study was designed to identify regional priorities in each of the Eastern Slope and Plains CDOT regions building on the methods and framework originally developed for the Western Slope study. To meet this objective, the research team, in conjunction with the study panel, defined two discrete analysis areas and associated target species. Prioritization criteria were developed to comprehensively represent wildlife movement needs in each analysis area and highlight areas with high rates of wildlife-vehicle collisions. The prioritization results and mitigation recommendations for the top 5 percent priority segments in each region were then integrated into a decision-support framework. In addition to the prioritized highway segments, the decision-support framework includes high-level mitigation recommendations for each top 5 percent priority segment, a benefit-cost analysis tool, an implementation considerations matrix, and guidance for integrating mitigation for priority segments into CDOT transportation planning and project development. This study's results will inform the siting, design, and construction of effective wildlife-highway mitigation projects across the Eastern Slope and Plains.

Implementation Statement

This report includes a decision-support framework and tools to guide mitigation implementation in the highest-priority highway segments. In addition, several recommendations are provided as next steps for CDOT and CPW to advance the outcomes of this research.

17. Keywords Wildlife crossings, decision-support, transportation planning, wildlife mitigation, wildlife prioritization, wildlife-vehicle collision, traffic safety		**18. Distribution Statement**	
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Executive Summary

Overview

Across Colorado, nearly 4,000 vehicle crashes involving wildlife are reported to law enforcement each year (CDOT 2021b). These reported crashes result in injuries and fatalities to humans as well as wildlife mortalities. The societal costs of these crashes are estimated at $80 million annually, including the value of the wildlife killed in these collisions. To address the issue of wildlife-vehicle collisions (WVCs), in late 2016, the Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) launched the Western Slope Wildlife Prioritization Study (WSWPS; Kintsch et al. 2019) to create a regional-scale approach to wildlife-highway mitigation. Recognizing that WVCs and the impacts to wildlife and people are a statewide problem, CDOT and CPW sought to expand the WSWPS to the Eastern Slope and Plains to provide Colorado decision makers with a statewide perspective on priority wildlife-highway conflict areas and mitigation needs to ensure the most effective use of mitigation funds.

The Eastern Slope and Plains Wildlife Prioritization Study (ESPWPS) is based on the framework and lessons learned from the WSWPS, including the prioritization process and overall decision-support framework. Yet, there were several notable distinctions from the WSWPS because of the wide range of elevation zones and ecosystem types and their accompanying species represented in the eastern half of the state. These regional variations had to be addressed in adapting the prioritization process to new, diverse landscapes. For the purpose of this study, the Eastern Slope and Plains was defined as CDOT Regions 1, 2, and 4, which roughly corresponds to CPW's Northeast and Southeast Regions.

Prioritization Study Methods

The objective of this research was to identify wildlife-highway conflict areas under both current conditions and future land use and traffic scenarios and identify where targeted mitigation could have the greatest impact on reducing WVCs and providing safer roads for people and safer wildlife passage. Specifically, this study was designed to identify regional priorities for the Eastern Slope and Plains landscapes for select target species representative of the Eastern Slope and Plains ecoregions, building on the methods and framework originally developed for the WSWPS. To meet this objective, the research team, in conjunction with the study panel, defined two discrete analysis areas and associated target species. Prioritization criteria were developed to comprehensively represent wildlife movement needs in each analysis area. Combined, the prioritization criteria define the need for wildlife-highway mitigation for each 0.5-mile segment based on the safety hazard WVCs present to drivers and the wildlife need for cross-roadway movement during migration, or within seasonal summer and winter range home ranges. These criteria included the following:

- WVC risk models that estimate the probability of WVCs during migration and winter seasons under current and future land use and traffic volume scenarios
- The magnitude of movement during spring and fall migrations or within winter ranges
- WVC mortality as a proportion of the population
- Bighorn sheep habitat and WVC mortality hotspots
- Proximity to drainages, specifically for deer in the plains
- A habitat quality and movement index to capture factors influencing wildlife movements in the plains
- CDOT’s wild animal crash pattern recognition by road type

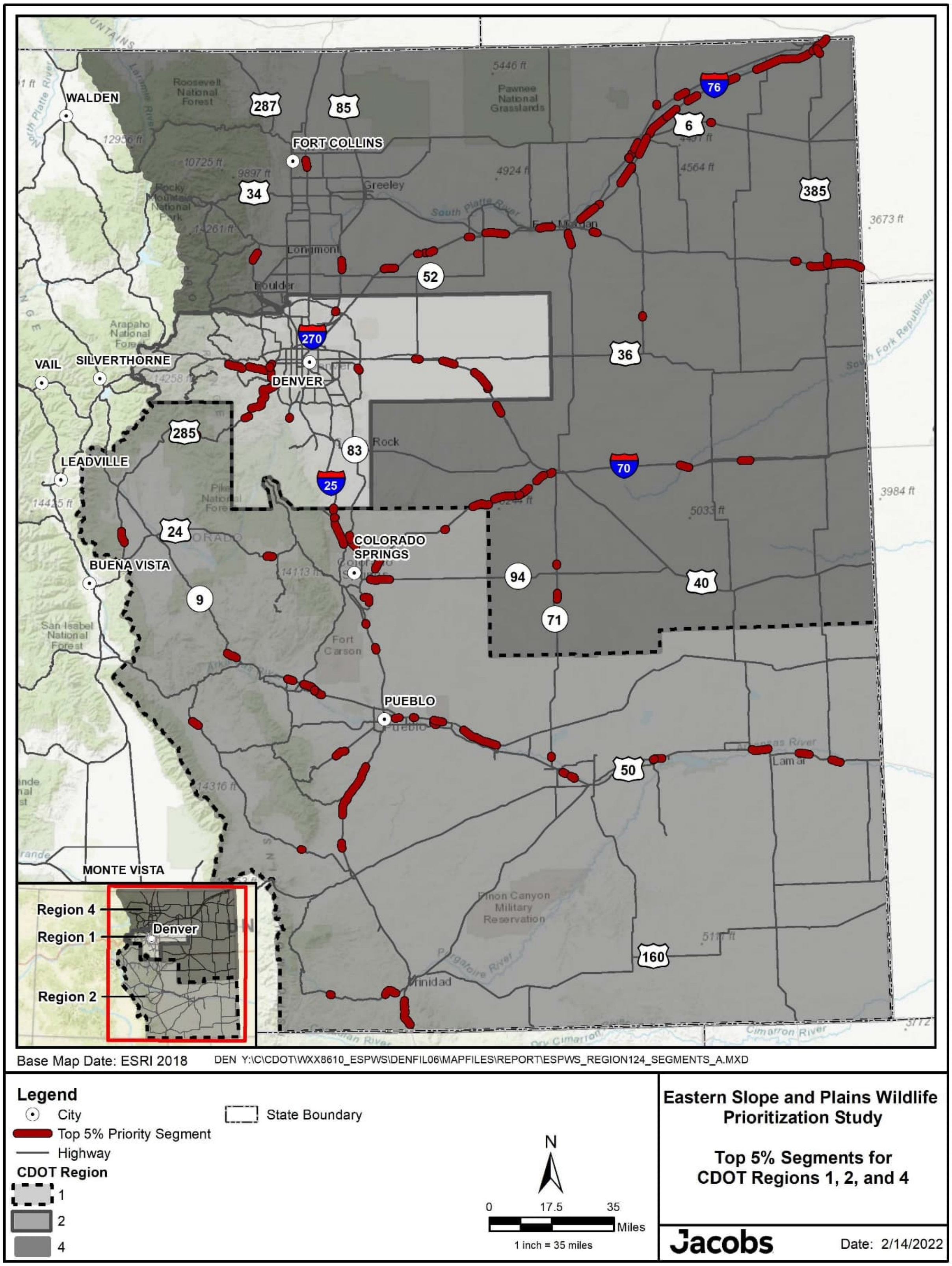
Values for each criterion were scaled between 0 and 1 and attributed to each 0.5-mile segment of CDOT-maintained highways across the study area. In addition, each criterion had an assigned priority score calculated using interagency committee–defined weights for each criterion. Combined, these prioritization criteria were used to identify areas of greatest need for wildlife-highway mitigation for each 0.5-mile segment of CDOT-administered highways in the Eastern Slope and Plains.

Prioritization Results

The resulting prioritization maps show the distribution of high-priority segments, defined as the 95th percentile (top 5 percent). The results from the Eastern Slope analysis area and the Plains analysis area were merged across the entire study area based on percentile rank. Because transportation projects are administered and prioritized by region, the results were then separated for each CDOT region (Figure ES-1). Overall, these results demonstrate the intent of the study panel to create a prioritization that is largely influenced by WVC safety needs but that also considers wildlife movement needs, particularly during winter and migration periods.

Field reviews were conducted of the top 5 percent priority segments in CDOT Regions 1, 2, and 4; this equated to roughly 289 miles of roadway. The field review identified opportunities for potential wildlife crossing structures and other mitigation needs within the highest-priority segments. Preliminary wildlife crossing mitigation recommendations for the top 5 percent highway segments in each region were developed based on the findings of the field surveys and the latest research on the effectiveness of different mitigation strategies. These mitigation recommendations provide a starting point for future mitigation project planning and budgeting.

Figure ES-1. Highest-priority Highway Segments (Top 5 Percent) in CDOT Regions 1, 2, and 4

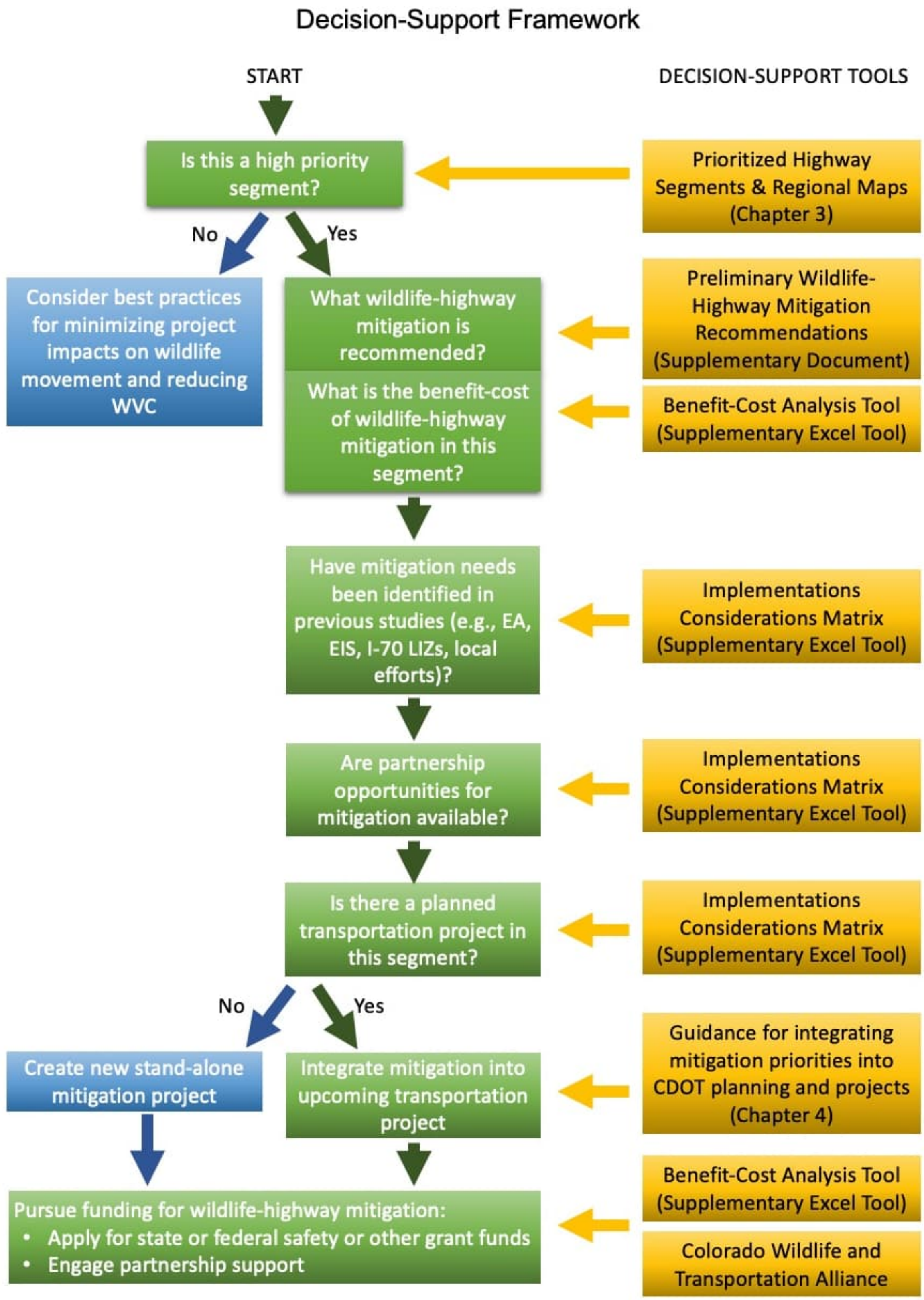


Decision-support Framework

The prioritization results and mitigation recommendations for the top 5 percent priority segments in each region were integrated into a decision-support framework. The purpose of the framework is to provide the necessary information and mechanisms to help CDOT and CPW integrate wildlife-highway mitigation actions into upcoming transportation plans and projects or to create new, stand-alone projects based on these priorities. Figure ES-2 depicts how these tools may be used to determine where to focus wildlife-highway mitigation and how to implement mitigation projects. Specifically, this decision-framework includes the following complementary tools:

- *Top 5 Percent Priority Segments for CDOT Regions 1, 2, and 4:* The primary outcome of this study is a prioritized list and accompanying maps and geographic information system file of the highway segments in each region where investments in wildlife-highway mitigation will have the greatest benefits for wildlife and motorists.
- *Wildlife-Highway Mitigation Recommendations:* Preliminary wildlife crossing mitigation recommendations for the top 5 percent highway segments in CDOT Regions 1, 2, and 4 were developed based on the findings of the field surveys and the latest research on the effectiveness of different mitigation strategies. These preliminary recommendations may be used to inform initial project planning and budgeting, although recommendations may be revised upon further project analysis. This compilation of high-level yet site-specific recommendations is provided as a separate deliverable accompanying the final report.
- *Updated Wildlife Valuations and Benefit-Cost Analysis Tool:* The Benefit-Cost Analysis (BCA) Worksheet first developed for the WSWPS and updated for the current study provides an automated tool for determining the benefits and costs of wildlife crossing mitigation (Section 2.8). The output of the tool is a BCA ratio, which is calculated in three ways: (1) using current CDOT Traffic and Safety Engineering's methods and valuations; (2) using current U.S. Department of Transportation methods and valuations; and (3) using the Wildlife Prioritization Study hybrid benefit-cost methods and valuations. This tool may be used for refining near-term project priorities and early project planning to help inform where wildlife-highway mitigation is most cost effective or to evaluate the benefits and costs of different mitigation strategies for a given priority segment.
- *Implementation Considerations Matrix:* This matrix is a compilation of additional considerations that may influence the likelihood of mitigation in a given highway segments, including factors that affect the opportunity, urgency, and feasibility of mitigation. These additional considerations were not scored as a part of the prioritization process but should be considered when further refining near-term project priorities and early planning, enabling CDOT to pursue mitigation projects in a more strategic manner that would be possible by ticking off projects from a ranked list based on priority scores alone.

Figure ES-2. Flowchart of the Wildlife Prioritization Study Decision-support Framework



- *Guidance for Integrating Priorities into CDOT Planning and Project Development:* The research team identified specific actions for integrating the ESPWPS into transportation planning, including sharing the prioritization results with each of the Transportation Planning Regions to support their integration into Regional Transportation Plans; adding priority segments to CDOT's online interactive mapping platform CPlan website; determining opportunities for integrating wildlife-highway mitigation into other transportation projects, or identifying where a stand-alone mitigation project may be warranted; referencing the Mitigation Recommendations document to inform early project planning and budgeting; and conducting BCAs using the worksheet tool to evaluate potential mitigation strategies and funding eligibility.

Together, the components of the decision-support framework will help users in developing appropriate mitigation strategies and identifying potential funding sources.

Conclusions and Next Steps

The ESPWPS and the WSWPS position CDOT and CPW to proactively pursue strategic wildlife-highway mitigation to improve connectivity for wildlife and reduce incidence of WVCs across the state. By focusing on data-driven priority areas, CDOT can develop well-designed mitigation to stretch limited funding resources to achieve the greatest benefits. Rather than addressing WVC problems on a site-by-site basis as transportation projects arise, these wildlife prioritizations studies provide CDOT and its partners with data and proactive tools for pursuing strategic wildlife-highway mitigation where it is needed most at a regional scale.

The results of this study help guide users in determining where to focus wildlife-highway mitigation. Specifically, the outcomes of this research provide CDOT and CPW with a prioritized list of highway segments in CDOT Regions 1, 2, and 4 and a decision-support framework to help integrate wildlife-highway mitigation actions into upcoming transportation plans and projects or to create new, stand-alone projects based on these priorities. In addition, specific findings and mitigation recommendations for the area around Rocky Flats National Wildlife Refuge are provided in an addendum to the report to support targeted efforts by CDOT, CPW, and the U.S. Fish and Wildlife Service in this area. The results of this research will lend greater confidence and credibility when wildlife-highway mitigation measures are incorporated into transportation projects.

In addition, this research outlines specific actions that are recommended for CDOT and CPW to advance this research. These next steps include, integrating mitigation priorities into Regional Transportation Plans, the development program, and asset management; periodically integrating new data and information to update the prioritization and decision-support tools; and conducting regional trainings to support CDOT and CPW staff in using the prioritization results and decision-support framework.

Over the course of these wildlife prioritization studies, the interagency collaboration between CDOT and CPW has deepened and will continue to be vital in the funding, design, and construction of effective wildlife-highway mitigation projects in Colorado.

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Accompanying Deliverables

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Master Wild Animal Benefit Cost Analysis Excel Worksheet V2 w/PDF of Wild Animal BCA Worksheet Instructions

GDB of ESPWPS Study Data including all Maps

Rocky Flats NWR Addendum

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
Alliance	Colorado Wildlife and Transportation Alliance
BCA	benefit-cost analysis
C-470	Colorado Highway 470
CDOT	Colorado Department of Transportation
CPW	Colorado Parks and Wildlife
DAU	data analysis unit
DTD	Division of Transportation Development
EA	environmental assessment
EIS	environmental impact statement
ESPWPS	Eastern Slope and Plains Wildlife Prioritization Study
FASTER	Funding Advancements for Surface Transportation and Economic Recovery Act
FASTLANE	Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies
GIS	geographic information system
GMU	Game Management Unit
GPS	global positioning system
HSIP	Highway Safety Improvement Program
I-25	Interstate 25
I-70	Interstate 70
Jacobs Team	Jacobs and ECO-resolutions
KMZ	keyhole markup language zipped
MP	milepost
NEPA	National Environmental Policy Act
PDO	property damage only
RTP	Regional Transportation Plan
SH 105	State Highway 105
STIP	Statewide Transportation Improvement Program
SWP	Statewide Transportation Plan
TIGER	Transportation Investment Generating Economic Recovery
TPR	Transportation Planning Region
USDOT	U.S. Department of Transportation
VZS	Vision Zero Suite
WSWPS	Western Slope Wildlife Prioritization Study
WTP	willingness to pay
WVC	wildlife-vehicle collision

1. Introduction

1.1 Framing the Issue

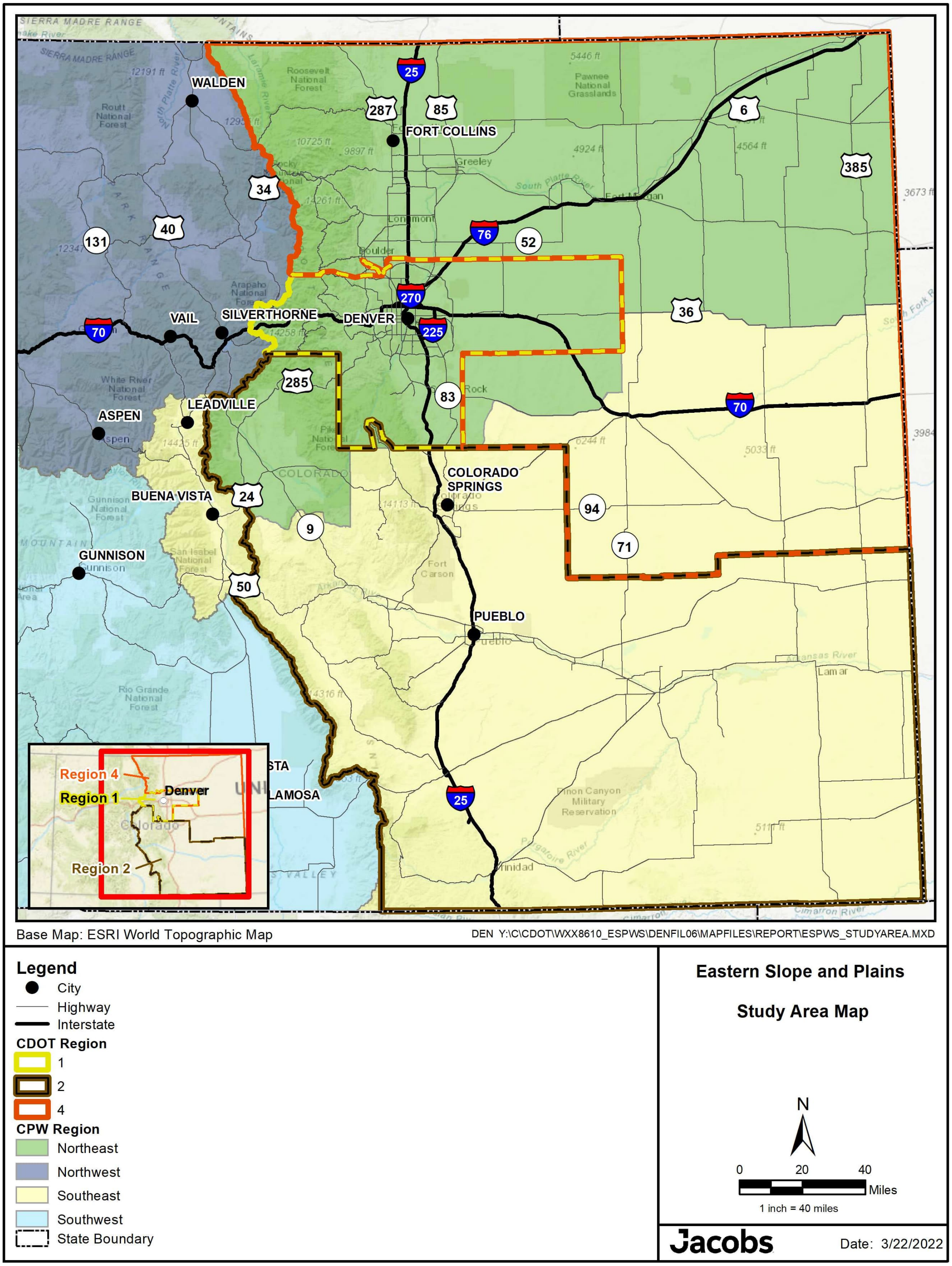
In North America, wildlife-vehicle collisions (WVCs) are a serious safety concern for state departments of transportation and the traveling public. Between 1 and 2 million collisions with large wildlife are estimated to occur in the United States each year (Conover et al. 1995; IIHS 2018; State Farm 2021), resulting in wildlife mortalities and human fatalities and injuries, as well as associated costs of more than 10 billion U.S. dollars annually (Huijser et al. 2007; adjusted for inflation to 2021 dollars). According to State Farm (2021), between July 2020 and June 2021, 1 out of every 179 Colorado drivers submitted a claim from hitting an animal—a 7 percent increase from 2018.

Across Colorado, nearly 4,000 vehicle crashes involving wildlife are reported to law enforcement each year (CDOT 2021b). These reported crashes result in injuries and fatalities to humans as well as wildlife mortalities. The societal costs of these crashes are estimated at $80 million annually, including the value of the wildlife killed in these collisions. Reported crashes represent a fraction of the actual number of WVCs with under-reporting rates of up to 60 percent or more (e.g., Kintsch et al. 2021; Olson 2013), and the actual costs and impacts to society are much greater.

To address the issue of WVCs, in late 2016, the Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) launched the Western Slope Wildlife Prioritization Study (WSWPS; Kintsch et al. 2019) to create a regional-scale approach to wildlife-highway mitigation to help inform CDOT decision makers where best to focus limited transportation dollars across the Western Slope. The WSWPS was initiated in CDOT's Western Slope regions (Regions 3 and 5) and CPW's Northwest and Southwest Regions because of the high WVC rates recorded in this portion of the state; the project-specific mitigation work already underway in each of these regions; and alignment with CPW's Colorado West Slope Mule Deer Strategy (CPW 2014), which directed the agency to work toward reversing the trend of declining mule deer populations across the Western Slope.

Yet, despite this Western Slope focus, WVCs and the impacts to wildlife and people are a statewide problem—nearly 50 percent of reported WVCs occur in CDOT Regions 1, 2, and 4, which roughly correspond with CPW's Northeast and Southeast Regions. Recognizing the statewide scope of the issue, CDOT and CPW sought to expand the WSWPS to the Eastern Slope and Plains (Figure 1-1) to provide Colorado decision makers with a statewide perspective on priority wildlife-highway conflict areas and mitigation needs to ensure the most effective use of mitigation funds.

Figure 1-1. Eastern Slope and Plains Study Area Map



Completed in 2019, the WSWPS established a framework and lessons learned for expanding the study to the Eastern Slope and Plains. Both the prioritization process and the decision-support framework created for the WSWPS were directly applicable to the Eastern Slope and Plains. Yet, there were several notable distinctions, one being the varied geography of the eastern half of the state. The eastern regions of CDOT and CPW capture a wide range of elevation zones and ecosystem types and their accompanying species – from the high alpine peaks along the Continental Divide to the Front Range foothills and the vast expanse of the plains. Mule deer and elk, which are common across much of the state, may engage in different behaviors in different areas depending on the landscape and the availability of resources. Other large mammals, such as bighorn sheep, pronghorn, and white-tailed deer are also important in these landscapes. These regional variations had to be addressed in adapting the prioritization process to new, diverse landscapes.

1.2 Research Need

Prior to the WSWPS, safety concerns due to WVC were addressed primarily on a project-by-project basis as transportation projects were developed in areas observed to have high WVC rates. Mitigation decisions were largely based on WVC data reported to law enforcement and CDOT maintenance carcass data, which were known to be inconsistently reported across maintenance patrols and subject to spatial inaccuracies depending on how the data were recorded (but with recent advancements, data quality is improving). WVC data alone do not account for the impacts of traffic volume on different wildlife species and may mask the road barrier effect on wildlife movement (Jacobson et al. 2016). Further, a project-focused approach to wildlife-highway mitigation does not consider how migratory ungulates, and other wildlife that must cross roads, move across the broader landscape to access seasonal resources or disperse to new territories. As a result, wildlife mitigation efforts focused on project limits may not align with where such mitigation could have the greatest impact on reducing WVCs, increasing driver safety, and improving roadway permeability for wildlife.

With the completion of the WSWPS, CDOT and CPW became equipped to address mitigation needs more proactively in the highest-priority areas in CDOT Regions 3 and 5. In conducting a similar study for the Eastern Slope and Plains, Colorado is now equipped with a complete statewide prioritization to guide mitigation funding and project development, making it one of the few states in the nation to have conducted a statewide analysis of wildlife-highway mitigation priorities based on both WVC concerns and wildlife movement needs. These research studies were designed to allow CPW wildlife managers and CDOT safety engineers, project planners, and environmental scientists to better identify wildlife conflict zones and create targeted mitigations to reduce WVCs in a fiscally responsible and ecologically effective manner. Fewer WVCs not only translate to fewer human injuries and fatalities, and reductions in property damage, but also provide cost savings for CDOT, individual motorists, insurance companies, and society at large and, finally, fewer wildlife mortalities and more resilient wildlife populations.

With the Department of the Interior Secretarial Order 3362 (“Improving Habitat Quality in Western Big Game Winter Range and Migration Corridors”), the State of Colorado Governor’s Executive Order D 2019 011 (“Conserving Colorado’s Big Game Winter Range and Migration Corridors”), and the recent passage of the 2021 Infrastructure Investment and Jobs Act and its provisions for wildlife mitigation funding alongside growing partnership efforts as exemplified by the Colorado Wildlife and Transportation Alliance and the Colorado Connectivity, Wildlife Corridors and Crossings Working Group, the state is well positioned to pursue and implement wildlife mitigation efforts.

1.3 Research Objectives

The purpose of these regional wildlife prioritization studies was to prioritize individual highway segments and provide a decision-support framework to guide strategic and cost-effective wildlife mitigation across Colorado. Together, the WSWPS and Eastern Slope and Plains Wildlife Prioritization Study (ESPWPS) support CDOT and CPW objectives of improving motorist safety, reducing conflicts with wildlife, and supporting habitat connectivity for resilient wildlife populations across Colorado.

The ESPWPS was launched in 2020 as a collaborative effort between CDOT and CPW and was conducted by Jacobs and ECO-resolutions (Jacobs Team). The objective of this research was to identify wildlife-highway conflict areas under both current conditions and future land use and traffic scenarios and identify where targeted mitigation could have the greatest impact on reducing WVCs and providing safer roads for wildlife and people. Specifically, this study was designed to identify regional priorities for the Eastern Slope and Plains landscapes for select target species representative of the Eastern Slope and Plains ecoregions building on the methods and framework originally developed for the WSWPS. The ESPWPS included the following deliverables:

- Prioritized list and maps of highway segments with wildlife-highway conflicts across the Eastern Slope and Plains (CDOT Regions 1, 2, and 4) and a replicable methodology for updating the prioritization as new data become available
- Decision-support toolbox, including the following:
  - Milepost-specific mitigation recommendations for potential wildlife crossing structures and benefit-cost analysis for the highest-priority highway segments in the Eastern Slope and Plains
  - Secondary considerations matrix of additional factors influencing the implementation of mitigation projects within the top 5 percent of highway segments

- Wildlife valuations and updates to the benefit-cost analysis tool originally developed for the WSWPS
- Guidelines for integrating prioritized wildlife-highway segments into transportation planning and project development or, in select cases, identifying potential stand-alone mitigation projects

1.4 How to Use This Report

This report documents the research objectives, methods, and results of the ESPWPS. Detailed methods are provided via the appendices. However, the primary utility of this study lies outside the report itself. Multiple tools are provided to assist users in advancing wildlife-highway mitigation projects:

- Geographic information system (GIS) shapefiles and keyhole markup language zipped (KMZ) files of the prioritization results and top 5 percent priority segments, which can be overlaid with other data layers to inform project planning.
- Implementation Considerations Matrix, a sortable Excel workbook that highlights opportunity, feasibility, and other considerations for each top 5 percent priority highway segment.
- Wildlife-Highway Mitigation Recommendations for top 5% Priority Segments, a large document that outlines specific opportunities for wildlife crossings and other types of mitigation for each priority segment with an accompanying segment map. A hyperlinked Table of Contents is provided to allow users to easily access the segment of interest.
- Benefit-Cost Analysis Tool Excel workbook.
- Complete prioritization results, provided in an Excel workbook, allowing users to view prioritization results for every highway segment in the study area
- Rocky Flats National Wildlife Refuge prioritization study findings – provided as an addendum to the report, focusing on the prioritization and mitigation needs for CDOT roadways adjacent to the Refuge.
- Supplementary GIS files including Brownian Bridge Movement Models, Getis-Ord WVC Hotspot Analysis, and wildlife crossing recommendations for top 5 percent segments, including new wildlife crossings and recommendations for enhancing existing structures.
- Eastern Slope and Plains Literature Review (completed in 2018).
- Final presentation to the Study Panel.

2. Prioritization Study Methods

The ESPWPS was conducted by the Jacobs Team and overseen by a study panel composed of CDOT and CPW staff representing all three CDOT regions (1, 2, and 4) and both the Northeast and Southeast Regions of CPW. The study panel was responsible for providing guidance to the Jacobs Team through the duration of the study. In addition, two committees were established to work with the Jacobs Team on specific study components. The Prioritization Committee developed and refined prioritization criteria and determined prioritization weights. The Wildlife Valuation Committee informed the process for updating wildlife values for deer and elk and calculating valuations for new target species. The work of these committees and the methods employed by the Jacobs Team to conduct the prioritization and develop decision-support tools are presented in the following sections.

2.1 Study Area

The ESPWPS study area is defined by CDOT Regions 1, 2, and 4, which roughly correspond to CPW's Northeast and Southeast Regions (Figure 1-1). Geographically, the Eastern Slope and Plains extend across the central and eastern two-thirds of the state and is home to 90 percent of the state's human population. The CDOT and CPW regions are administrative divisions to help in the management of their respective programs. The CDOT highway system consists of interstate highways, United States (U.S.) highways, and Colorado state highways. In total, CDOT Regions 1, 2, and 4 manage 5,595 route miles. CDOT Region 1 is responsible for managing 970 route miles (3,688 lane miles); CDOT Region 2 is responsible for 2,077 route miles (4,987 lane miles); and CDOT Region 4 is responsible for 2,548 route miles (6,322 lane miles).

Within this study area, the Prioritization Committee defined two distinct analysis areas to differentiate major differences in geography, ecosystems, target species, and movement patterns between the Eastern Slope portion of the study area and the Plains portion (Figure 2-1). The analysis areas were defined as follows:

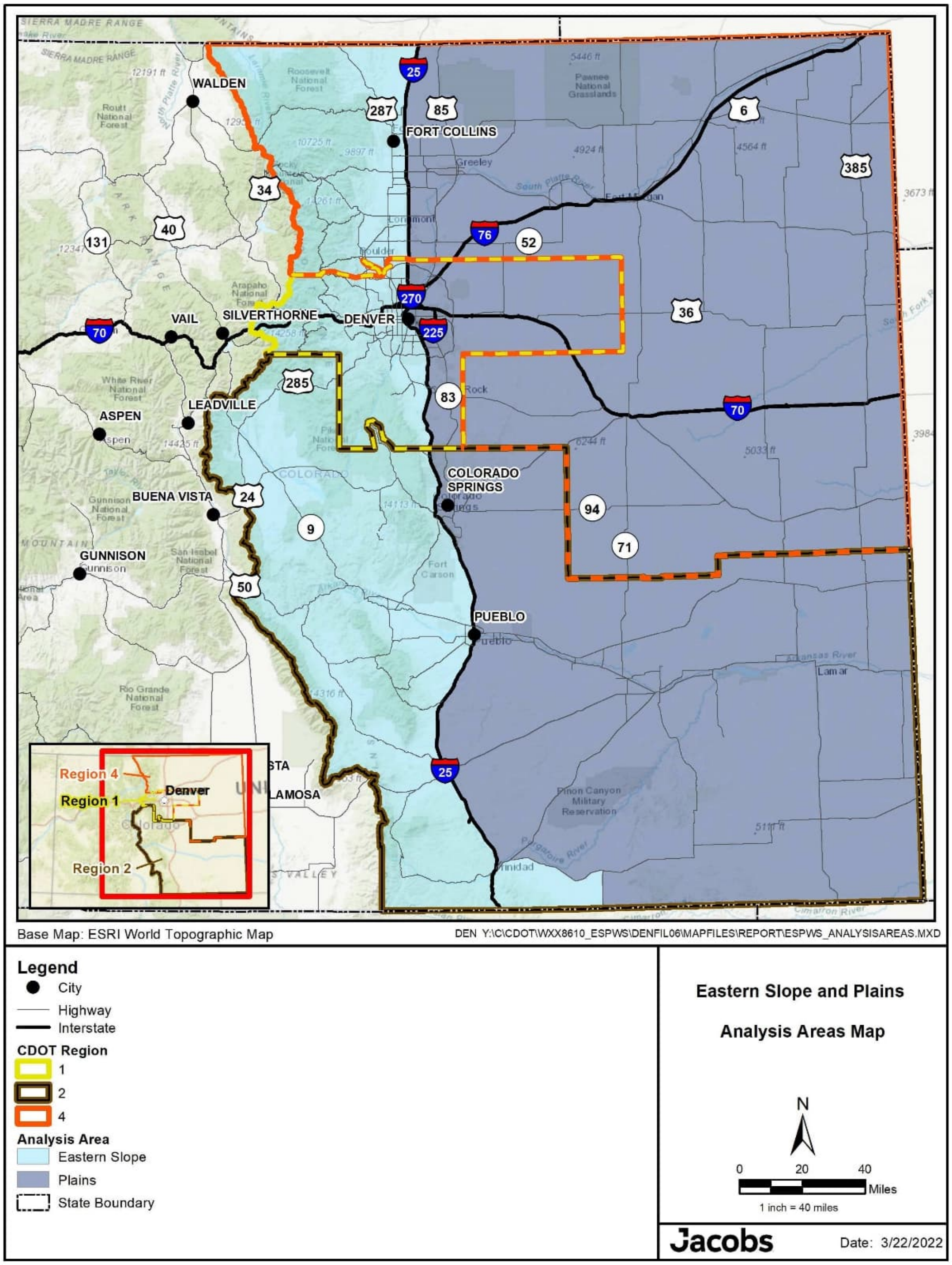
2.1.1.1 Eastern Slope Analysis Area

The portions of CDOT Regions 1, 2, and 4 west of and including Interstate 25 (I-25), plus CPW's Game Management Unit (GMU) 140. This GMU lies near the City of Trinidad, east of I-25 along the New Mexico border and includes the Fishers Peak area, which is more geographically and ecologically similar to the Eastern Slope than the Plains.

2.1.1.2 Plains Analysis Area

The portions of CDOT Regions 1, 2, and 4 east of I-25, minus GMU 140.

Figure 2-1. Analysis Areas for the Eastern Slope and Plains Wildlife Prioritization Study Overlaid with CDOT Regions 1, 2, and 4



2.1.2 Ecoregions and Flora

The study area is composed of three EPA Level 3 ecoregions: Southern Rockies, High Plains, and Southwestern Tablelands (USEPA 1997). The Eastern Slope analysis area is primarily composed of the Southern Rockies Ecoregion, with portions of the High Plains and Southwestern Tablelands Ecoregions in the easternmost portions of the analysis area. The Plains analysis area is composed of the High Plains and Southwestern Tablelands Ecoregions.

The Southern Rockies Ecoregion is a high-elevation mountainous ecoregion that covers much of central Colorado and parts of southern Wyoming and northern New Mexico (Omernik 1987; USEPA 1997). Across the ecoregion a steep elevation gradient runs from low foothills to high peaks, ranging from approximately 6,000 feet to more than 14,000 feet (Drummond 2012). Much of the annual precipitation in the ecoregion is received as snowfall, creating a high-elevation snowpack that is an important water source, feeding major river systems including the South Platte and Arkansas rivers.

Figure 2-2. A Landscape Characteristic of the Southern Rockies Ecoregion

This ecoregion is dominated by forest cover interspersed with grassy meadows or shrublands (Figure 2-2). Vegetation patterns correspond with the steep elevation gradients. In general, grassland and shrubland are found in the lower-elevation valleys and intermontane basins. Sagebrush (*Artemisia* spp.), oak (*Quercus* spp.), pinyon-juniper woodland (*Pinus edulis* and *Juniperus* spp.), and blue grama grass (*Bouteloua gracilis*) are common in the lower elevations of the ecoregion (Chapman et al. 2006). Ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), aspen (*Populus tremuloides*), and oak are common at middle elevations. The higher-elevation subalpine forests are often dense, consisting of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). High-elevation alpine zones above the tree line support a variety of low shrubs, wildflowers, krummholz (stunted trees), and other vegetation interspersed with exposed rocks and permanent snowfields (Drummond 2012).

The High Plains Ecoregion encompasses the northern Front Range, the entire northeast corner, and the easternmost portions of the state along the Kansas border. Higher and drier than the Central Great Plains to the east, and in contrast to the irregular, mostly grassland or grazing land of the Northwestern Great Plains to the north, much of the High Plains comprises smooth to slightly irregular plains having a high percentage of cropland (Figure 2-3). Much of the annual precipitation in this ecoregion arrives during mid-to-late summer monsoons with snowfall in the winter and early spring. Grama-buffalo grass is the natural vegetation in this region compared with mostly wheatgrass (*Agropyron* and *Pascopyron* spp.) and needlegrass (*Stipa* spp.) to the north, Trans-Pecos shrub savanna to the south, and taller grasses to the east. The northern boundary of this ecological region is also the approximate northern limit of winter wheat and sorghum and the southern limit of spring wheat. In Colorado, oil and gas fields are scattered throughout this region, with the greatest concentration found in the Denver-Julesburg Basin area. Along the Front Range portion of the ecoregion, land use is changing from mostly cropland and rangeland to more extensive urban development. Development has led to an increase in artificial lakes and gravel pits dotting the region (Chapman et al. 2006). Streams tend to be cooler than in other High Plains subregions and contain many Front Range aquatic species.

Figure 2-3. High Plains Ecoregion Landscape

The Southwestern Tablelands comprise most of south-central Colorado, south of Denver and east of the Front Range foothills. The Southwestern Tablelands are flanked by the Southern Rockies ecoregion to the west and the High Plains to the north. The ecoregion is characterized by red-hued canyons, mesas, badlands, and plains dissected by river breaks (Figure 2-4). Similar to the High Plains, much of the annual precipitation in this ecoregion arrives during mid-to-late summer monsoons with snowfall in the winter and early spring. Unlike most adjacent Great Plains ecological regions, little of the Southwestern Tablelands is in cropland. Much of this region is in subhumid grassland and semiarid rangeland. The boundary to the east in Colorado represents a transition from the more extensive cropland within the High Plains to the generally more rugged and less arable land within the Southwestern Tablelands ecoregion. The natural vegetation in the Colorado portion of this region is mostly grama-buffalo grass

Figure 2-4. Ephemeral Stream Channel in the Southwestern Tablelands Ecoregion

(*Bouteloua* spp.), with some juniper–scrub oak–grass savanna on escarpment bluffs (Chapman et al. 2006).

2.1.3 Fauna

Colorado's Eastern Slope analysis area is home to several large herds of elk, mule deer, Rocky Mountain bighorn sheep, white-tailed deer, and smaller herds of migratory pronghorn. For purposes of the ESPWPS, mule deer and white-tailed deer were lumped together because most crash and maintenance records do not distinguish between the two species. Current population estimates for elk in the Eastern Slope region are 43,840 animals, mule deer are estimated at 69,500, pronghorn are estimated at 5,600, and bighorn sheep are estimated at 2,315.

Colorado's Plains analysis area is home to a few smaller but still important herds of elk, mule deer, larger herds of pronghorn, white-tailed deer, and isolated herds of bighorn sheep. Current population estimates for elk in the Plains region are 3,040 animals, deer are estimated at 41,700, pronghorn are estimated at 49,870, and bighorn sheep are estimated at 620.

2.2 Study Design

In 2018, the Jacobs Team prepared and presented a white paper to CDOT and CPW, which reviewed the feasibility of expanding the WSWPS to the Eastern Slope and Plains (Jacobs 2018). The white paper expanded upon the literature review conducted for the WSWPS to include additional target species specific to the Eastern Slope and Plains landscapes. Our team met with CDOT and CPW personnel representing the eastern regions to determine which data were available and how the WSWPS could be adapted to the Eastern Slope and Plains. The white paper concluded that the methods used to prioritize wildlife-highway conflict on the Western Slope could be adapted to the Eastern Slope and Plains, specifically, for the following reasons:

- The WVC risk model developed as part of the WSWPS is readily adaptable to the Eastern Slope and Plains study because all data inputs are available statewide.
- The prioritization criteria (including the risk model) were developed for the WSWPS and may also be applied to the Eastern Slope and Plains, providing a consistent and comprehensive method for prioritizing wildlife mitigation needs statewide.

Based on these findings, our team's first task was to explore adapting the WSWPS methods and prioritization criteria to the Eastern Slope and Plains wildlife and landscapes. Over the course of 8 months from November 2020 through June 2021, the Jacobs Team held 4 meetings with the Prioritization Committee, 5 meetings with a smaller working group, and numerous email communications. The objectives for the committee and working group were to define the analysis areas; identify target species for each analysis area; and adapt and develop prioritization criteria. Four major steps were identified for developing quantifiable prioritization criteria and calculating priority scores for all CDOT-administered highways in the Eastern Slope and Plains:

Step 1 Model WVC risk for the entire study area.

Step 2 Develop complementary biological/wildlife criteria for each analysis area.

Step 3 Define weights for prioritization inputs for each analysis area.

Step 4 For each analysis area, sum the weighted scores of the prioritization criteria to calculate prioritization scores for each 0.5-mile highway segment.

In addition, the Jacobs Team conducted telephone and in-person interviews with study panel members as well as additional staff from CDOT, CPW, and The Nature Conservancy who are familiar with the Eastern Slope and Plains landscapes. The purpose of these interviews was to accomplish the following:

- Determine what wildlife data sets were available from CPW and other sources and their applicability and availability for this research study.
- Receive input on potential target species for the Eastern Slope and Plains analysis areas.
- Receive input on the factors influencing wildlife movements in the Plains and considerations for developing prioritization criteria.

Based on these investigations, the Jacobs Team refined the study approach and began compiling the appropriate data needed to conduct the study as described in the following sections.

2.2.1 Target Species

Based on available data sets, regional representation, findings in the literature review, and expert interviews, the Jacobs Team and the Prioritization Committee identified target species specific to each analysis area (Table 2-1).

Table 2-1. Analysis Areas for the Eastern Slope and Plains Wildlife Prioritization Study Overlaid with CDOT Regions 1, 2, and 4

Eastern Slope Analysis Area	Plains Analysis Area
Deer (combined mule deer and white-tailed deer; *Odocoileus hemionus* and *Odocoileus virginianus*)	Deer (combined mule deer and white-tailed deer; *Odocoileus hemionus* and *Odocoileus virginianus*)
Canada Lynx (*Lynx canadensis*)	Pronghorn (*Antilocapra americana*)
Elk (*Cervus elaphus*)	
Pronghorn (*Antilocapra americana*)	

Eastern Slope Analysis Area	Plains Analysis Area
Bighorn Sheep (*Ovis canadensis*)	

Black bear and mountain lion were also evaluated as potential target species for the Eastern Slope analysis area. Analyses of WVC locations and habitat data determined that these species movements and WVC risk were sufficiently captured by the deer and elk data sets. The Prioritization Committee also considered elk as a target species for the Plains analysis area, but given that elk are present only in a small portion of southeast Colorado and are not represented across the Plains landscape, this species was rejected. Other species, including small fauna migrations such as box turtles and tarantulas, were determined to be inappropriate for inclusion in a regional-scale analysis, but should be incorporated into local projects where relevant.

2.3 Data Synthesis and Analysis

As a result of the interviews and coordination with the ESPWPS research study panel, we compiled the following list of all potential data needs and sources. Because of a cyberattack on CDOT systems, a portion of the WVC carcass data from 2018 were lost. The study therefore drew its 10-year WVC crash and carcass data sets from the years 2009 to 2019 and excluded data from 2018 to ensure the completeness of the annual data sets for a 10-year period. The data needs and sources are as follows:

- CDOT highways, mileposts, speed limits, and current and future traffic volumes
- WVC-reported crash data from 2009 through 2019 (excluding 2018) compiled by CDOT Traffic and Safety Engineering Branch
- WVC carcass data from 2009 through 2019 (excluding 2018) recorded by CDOT maintenance personnel
- CPW mule deer and elk global positioning system collar data
- CPW species activity mapping data

A complete list of data and sources is available in Appendix B.

As with the WSWPS, all CDOT-administered roadways were split into roughly 0.5-mile segments for analysis purposes. To derive 0.5-mile segments from the CDOT roads layer, we used CDOT's highways data layer, which covers road segments within all CDOT regions. This data set was clipped to include only highways within Regions 1, 2, and 4. The length of each highway route was calculated, divided by 0.5 mile to determine the number of segments as an integer, and then split by the segment number. Actual segment lengths ranged from 0.1 to 0.64 mile depending on intersections, with smaller segments representing short spurs; overall average length was 0.435 mile.

The source data set contained traffic volume counts and other attributes, such as speed limit, which would potentially be used in the risk modeling process (Section 2.4.1). Accordingly, several preliminary analyses were conducted using the CDOT roadway data, WVC collision data, CDOT maintenance carcass data, and CPW mule deer and elk collar data (refer to Appendix C for detailed pre-analysis methods). Attributes were then attached to each carcass and WVC point event.

Absence data was also generated every 0.1 mile, but not within 0.25 mile of any carcass or WVC point event. All attributes generated for event points were also generated for the absence data to be used in the logistic regression analysis. This data set was then sampled during the analysis.

In addition, several complementary analyses were conducted and are provided as geographic information system shapefiles accompanying this study:

- Association of reported WVCs and CDOT carcass data to 0.5-mile road segments
- Analysis of seasonal distributions of CDOT maintenance carcass data over a 10-year period
- Hotspot analysis of 10 years of reported WVC data set using spatial autocorrelation test and statistical analysis (Moran’s I and Getis-Ord Gi* z-score)
- Brownian Bridge Movement Models derived from CPW deer, elk, and pronghorn collar data

2.4 Prioritizing Wildlife-Highway Conflict Areas

Multiple criteria were used to score and prioritize highway segments for wildlife-highway mitigation. The prioritization criteria used for the WSWPS served as the basis for establishing criteria specific to the Eastern Slope and Plains. Criteria for the Eastern Slope analysis area were the same as for the Western Slope; however, additional criteria were added for pronghorn and bighorn sheep (Table 2-2). For the Plains analysis area, the team determined that new criteria would be needed to capture the factors influencing wildlife movements in this landscape. Specifically, the team developed a proximity to drainage criterion for deer, a habitat quality and movement index for both deer and pronghorn, and a habitat and mortality criterion for bighorn sheep. All criteria are discussed in detail in the following sections.

Table 2-2. Prioritization Criteria Used to Score Highway Segments in the Eastern Slope and Plains Analysis Areas

Target	Prioritization Inputs	Eastern Slope Analysis Area	Plains Analysis Area
Deer	WVC risk modeling under current and future scenarios: winter range and migration models for Eastern Slope; winter range model only for Plains	X	X

Target	Prioritization Inputs	Eastern Slope Analysis Area	Plains Analysis Area
	Magnitude of migration movement	X	
	Magnitude of winter range use	X	
	WVC impacts on population	X	X
	Proximity to drainage		X
	Habitat quality and movement index		X
Elk	WVC risk modeling under current and future scenarios: winter range and migration models	X	
	Magnitude of migration movement	X	
	Magnitude of winter range use	X	
	WVC impacts on population	X	
Pronghorn	Magnitude of winter range use	X	
	WVC impacts on population	X	X
	Habitat quality and movement index	X	X
Bighorn Sheep	Habitat and WVC mortality hotspots	X	
Canada Lynx	Probability of lynx highway crossing (Baigas et al. 2017)	X	
Driver Safety	CDOT WVC pattern recognition analysis (2013)	X	X

2.4.1 Prioritization Criteria Descriptions

The Prioritization Committee identified prioritization criteria to comprehensively represent wildlife movement needs in each analysis area. Combined, the prioritization criteria define the need for wildlife-highway mitigation for each 0.5-mile segment based on the safety hazard WVCs present to drivers and the need for wildlife to cross roads during migration, or within seasonal summer or winter home ranges.

The Prioritization Committee identified and defined the following criteria:

- *WVC Risk for Elk and Deer (Current and Future)*—Modeled relative probability of WVC is based on the relationship between WVCs (combined crashes and random walk locations) and attributes of roads and the surrounding landscape. Separate risk models were produced for each species and each season of interest: migration periods and winter range use.
- *Magnitude of Winter Range Use for Elk, Deer, and Pronghorn*—Density of winter herds in winter concentration areas and other portions of winter range was calculated by attributing data analysis unit (DAU) herd size estimates so that density in concentration areas is twice that of other winter range areas within each DAU.

- *Magnitude of Migration Movement for Elk and Deer*—The distance between the point of highest elevation within each DAU and the centroid of winter concentration areas in the DAU was multiplied by the DAU herd size estimate.
- *WVC Mortality as a Proportion of Population for Elk, Deer, and Pronghorn*—The 5-year average annual WVC count in each DAU was divided by the DAU herd size estimate.
- *Proximity to Drainage for Deer*—Adjacency to a drainage was calculated as a 0.5-mile buffer around a major river (i.e., the Arkansas or South Platte rivers) and a 0.25-mile buffer around other perennial, intermittent, and ephemeral drainages to capture the influence of these geographic features on deer concentrations. This was calculated for the Plains analysis area only.
- *Habitat Quality and Movement Index for Deer and Pronghorn*—A moving window value based on the average deer home range size (3 square miles) or pronghorn average daily movement (4.5 square miles) was calculated based on reclassified land cover types relative to their value for deer/pronghorn habitat and movement (refer to Appendix C for reclassification of land cover and cropland habitat rating relative to target species).
- *Bighorn Sheep Habitat and WVC Mortality Hotspots*—Overlap between CDOT-administered highways and a 50-meter buffer around CPW species activity mapping data was determined for bighorn sheep winter and summer ranges. These segments were then reviewed by CPW biologists and augmented based on expert knowledge of WVC mortality hotspots.
- *Connectivity Value for Other Modeled Species (for example, Canada lynx)*—Added value was based on modeled crossing probability or modeled risk for other species for a given highway segment. This criterion may include up to four species total. This iteration of the prioritization includes only the probability of highway crossing for Canada lynx (based on Baigas et al. 2017), because this is the sole species for which such data are currently available for the WSWPS and ESPWPS areas.
- *CDOT Wild Animal Crash Pattern Recognition by Road Type*—The WVC hotspot value was calculated by CDOT Traffic and Safety Engineering. The most recent pattern recognition analysis available was from 2013, based on crash data from 2008 through 2012. WVC pattern recognition examines the percentage of crashes that are identified as WVCs with diagnostic normative baseline percentages of WVCs for comparable roadways. These WVC patterns were identified at a 95 percent cumulative binomial probability level.

The Jacobs Team and study panel noted that the WVC pattern recognition analysis has not been updated since 2013. However, CDOT Traffic and Safety Engineering staff stated that, in general, crash patterns do not dramatically change from one analysis period to the next except where a mitigation project has been undertaken to address a specific safety issue (A. Vu, pers. comm. 2021). Accordingly, the 2013 WVC analysis was deemed to still be relevant and appropriate for inclusion in the ESPWPS.

Maps of each of the scored prioritization input criteria contributing to the final prioritization results are provided in Appendix F.

2.4.2 WVC Risk Modeling

WVC risk modeling for the ESPWPS followed the same methods used to estimate risk for the WSWPS. The modeling process used for the WSWPS underwent several revisions because of the high degree of variability in habitat selection and movement patterns observed among collared elk and mule deer, resulting in moderate model fit. As a result of these complications, the Jacobs Team developed risk models based on the work of Kolowski and Nielsen (2008), comparing road and road adjacent attributes of known reported WVC and carcass locations to those of random locations distributed throughout the road network to estimate the relationship between each of these attributes and relative WVC risk.

We fit separate risk models for deer and elk, and estimated WVC risk specific to winter range use and, for the Eastern Slope analysis area, migration periods (spring and fall combined). WVC risk models were not created for bighorn sheep in the Eastern Slope analysis area because of the small sample of WVC data. Similarly, the team created and evaluated WVC risk models for deer and pronghorn in the Eastern Slope and Plains analysis areas but determined that pronghorn risk was captured by deer risk; thus, pronghorn models were removed from further consideration. Risk models were fit using a combination of crash data from CDOT Traffic and Safety Engineering and carcass reports from CDOT maintenance personnel, and derived data layers capturing the relevant attributes of roads, traffic, and the adjacent landscape. The potential drivers of risk evaluated for each analysis area are listed in Table 2-3.

Table 2-3. Explanatory Variables Evaluated as Potential Drivers of WVC Risk for Target Species in Each Analysis Area.

Variable	Deer and Elk Eastern Slope	Deer Plains
Traffic volume	X	X
Traffic speed	X	X
Road corridor width	X	X
Highway curve class	X	X
Absolute highway grade	X	X
Distance from speed transition	X	X
Percent impervious surface	X	X

Variable	Deer and Elk Eastern Slope	Deer Plains
Distance from suburban housing density	X	X
Slope adjacent to road surface	X	X
Slope aspect adjacent to road surface	X	X
Distance from drainage	X	X
Waterways, lakes, reservoirs, and wetlands		X
Topographic position (multiscale)	X	X
Local topographic position	X	X
Terrain ruggedness	X	X
Small-scale swales and draws (10-meter DEM)		X
Herd density by DAU	X	
Winter range herd density	X	
Percent aspen	X	
Percent conifer	X	X
Percent piñon	X	X
Percent oak brush	X	X
Distance to shortgrass prairie		
Distance to dryland crops		X
Distance to irrigated crops		X
Distance to pasture		X
Distance to native range		X
Wildfire severity	X	
NDVI (greenness index)	X	X
Right-of-way fence type		X
State wildlife areas and conservation easements		X

Notes:

DEM = digital elevation model
NDVI = normalized difference vegetation index

Regression-based risk models generated with this approach identify specific drivers of risk, as well as potential future risk associated with changes in traffic or landscape characteristics. Understanding the underlying factors that influence WVC risk can provide insights into potentially effective mitigation measures and may also help to identify road segments that are high-risk based on traffic and landscape characteristics, but where WVCs have been underreported. Complete methods, analysis, results, and discussion are presented in Appendix D.

2.4.3 Criteria Scoring and Weighting

The Jacobs Team's next step was to create a prioritization matrix to provide a standardized method for scoring individual highway segments. Values for each criterion presented in the previous subsections were scaled between 0 and 1 and attributed to each 0.5-mile segment of CDOT-maintained highways across the Eastern Slope and Plains. The interagency Prioritization Committee then assigned a weight to each criterion. The priority score was calculated as a weighted sum using the formula:

$$\text{Priority} = (\text{Weight } 1 \times \text{Criterion } 1) + (\text{Weight } 2 \times \text{Criterion } 2)$$

Table 2-4 depicts the weights assigned by the subcommittee to each prioritization criterion. In general, the criteria weights are the same for the Eastern Slope analysis area as those used for the WSWPS, and new criteria developed for the Plains analysis area were assigned corresponding weights. For the WSWPS, the maximum possible score a highway segment could receive was 41. Because of additional target species for the Eastern Slope analysis, and fewer target species with new prioritization criteria for the Plains analysis, the maximum possible scores for the Eastern Slope and Plains analysis areas were 53 and 24, respectively.

Because of these differences in the total maximum scores among the three analysis areas, the Prioritization Committee determined that the proportions of the total score represented by the sole safety criterion and by the combined wildlife connectivity criteria should remain equivalent across all three analysis areas. That is, in the WSWPS, the safety criterion, with a weight of 10, represented 24 percent of the maximum possible prioritization score; therefore, for both the Eastern Slope and Plains, the safety criterion was calculated to be 24 percent of the maximum possible score, or 13 and 6, respectively. This ensured that wildlife connectivity and safety were weighted similarly in each analysis area despite the differences in maximum possible scores.

Table 2-4. Prioritization Criteria Weights for the Eastern Slope and Plains Analysis Areas.

Primary Prioritization Criteria	Eastern Slope Criteria Weights	Plains Criteria Weights
WVC Risk Model Output		
Current Mule Deer Migration WVC Risk	2	
Current Mule Deer Winter Range WVC Risk	2	2
Current Elk Migration WVC Risk	2	
Current Elk Winter Range WVC Risk	2	
Future Mule Deer Migration WVC Risk	1	
Future Mule Deer Winter Range WVC Risk	1	1
Future Elk Migration WVC Risk	1	

Primary Prioritization Criteria	Eastern Slope Criteria Weights	Plains Criteria Weights
Future Elk Winter Range WVC Risk	1	
WVC Risk Models Maximum Score	**12**	**3**
Other Wildlife and Connectivity Criteria		
Magnitude of Winter Range Use		
Deer	3	
Elk	3	
Pronghorn	3	
Magnitude of Migration Movement		
Deer	3	
Elk	3	
WVC Mortality as a Proportion of Population		
Deer	3	3
Elk	3	
Pronghorn	3	3
Proximity to Drainage—Deer		3
Habitat Quality and Movement Index		
Deer		3
Pronghorn		3
Connectivity Value for Canada Lynx	1	
Bighorn Sheep WVC Mortality Areas	3	
Other Wildlife Criteria Maximum Score	**28**	**15**
Safety Criterion		
CDOT WVC Pattern Recognition (Rounded)	13	6
Safety Total Score	13	6
Maximum Possible Prioritization Score	**53**	**24**

Note:
Gray shading = criteria that were not used for that analysis area.

As in the WSWPS, the high individual weight assigned to the CDOT WVC pattern recognition analysis reflected the value placed on safety concerns when identifying and funding wildlife-highway mitigation projects. Risk model output criteria were individually given lower weights but had a combined weight of up to 12 in the Eastern Slope analysis and 3 in the Plains analysis. Within the risk model, current conditions were prioritized higher than future conditions because of the uncertainty of the latter.

The results from the two analysis areas were then merged across the entire study area based on percentile rank. Percentile ranks were used instead of prioritization scores because the different maximum possible scores resulted in a different range of prioritization scores for each of the analysis areas. Because transportation projects are administered and prioritized by region, we then separated and ranked priority segments by CDOT region.

2.4.4 Combining 0.5-mile Analysis Units to Define Priority Highway Segments

For various reasons, wildlife crossing mitigation projects are typically 1 mile long or more. (A single wildlife crossing structure will include a wildlife-exclusion fence that extends at least 0.5 mile in either direction.) To help in mitigation project planning and the field review, the Jacobs Team combined the 0.5-mile analysis units used for this research study to create longer high-priority segments. The following rules were established to combine segments:

- Combine adjacent 0.5-mile segments ranking in the 95th percentile within a CDOT region.
- Combine 0.5-mile segments ranking in the 95th percentile within a CDOT region that are separated by less than 1 mile if the intervening segments are within the 75th percentile for that region.

For each aggregated high-priority segment, criteria scores were averaged to produce an overall segment score for each criterion. In addition, the individual criteria scores for a high-priority segment were reviewed to highlight individual 0.5-mile segments with high maximum values for a given criterion within a larger combined segment.

2.4.5 Housing/Road Density Filter

Through further review of the 95th percentile segments in each region, the Jacobs Team identified a concern unique to the Eastern Slope and Plains landscape at the interface between urban/suburban areas and wildlife conflict. Unlike the Western Slope, Colorado’s Front Range is defined by large urban centers and expansive residential development. These developed areas overlap with historical wildlife ranges. While in some places wildlife has been displaced, in others, wildlife has habituated to human development and activity. These areas often see human-wildlife conflict, including WVCs. Yet, despite high concentrations of WVCs, these areas do not hold high connectivity values for wildlife (for example, Colorado 470 [C-470] between Ken Caryl Avenue and Wadsworth Boulevard, which has protected open space along the western side of the highway and high-density residential development along the eastern side of the highway). Because of the high weight placed on WVC conflict in this prioritization, in several cases, this resulted in highway segments adjacent to urban/suburban areas or in a high road density area scoring high in the prioritization. The Jacobs Team and the Prioritization Committee recognized this and therefore explored several methods for filtering out highway segments from the prioritization results with high WVC conflict but low connectivity value because of development. Neither municipal boundaries nor population/census data sufficiently captured the highway segments of concern. The team therefore developed a two-step process based on housing and road densities:

Step 1 Within a 0.25-mile buffer of each segment, calculate the percent of area that is classified as urban, suburban, or commercial/industrial using the Integrated Climate and Land-Use Scenarios housing density data layer. Buffered segments with 80 percent or more of these high-density categories were omitted from further consideration as high-priority segments in this analysis.

Step 2 Conduct a visual review of road density (approximately 1 mile per square mile) around each of the 95th percentile segments. This review resulted in two 95th percentile segments being removed from further consideration as high-priority segments in this analysis (C-470, mileposts [MPs] 0 to 0.4 at the cloverleaf interchange with Interstate 70 [I-70] and State Highway 105 [SH 105], MPs 4.7 to 5.1 in Monument at the cloverleaf interchange with I-25).

The team recommends that future iterations of this study apply these housing and road density filters to all highway segments in the study area and apply them earlier in the analysis process.

2.5 Field Review of Highest-Priority Segments

During summer 2021, the Jacobs Team conducted a field review of the top 5 percent priority segments in each region; this equated to approximately 280 miles of roadway. The purpose of the field review was to identify opportunities for potential wildlife crossing structures and other mitigation needs within the highest-priority segments. Existing bridges and culverts were also evaluated for functionality as wildlife crossings for the target species with recommendations given to improve an existing structure for wildlife passage or replace it with a new wildlife crossing structure. An abbreviated field survey was conducted in high-priority segments where wildlife crossing mitigation has already been constructed (for example, I-25 Monument Hill in El Paso County) or is currently in design (for example, I-70 at Genesee and Floyd Hill), except where additional mitigation was recommended to complement the existing crossing structures (such as the need for wildlife-exclusion fencing to tie into the Richmond Hill wildlife underpass on U.S. Highway 285). In addition, E-470, the tolled beltway around the eastern portions of the Denver metropolitan area is administered by the E-470 Public Highway Authority rather than CDOT and was also omitted from the field review and subsequent mitigation recommendations development. Some segments of E-470 have been mitigated with wildlife-exclusion fencing to reduce WVC. The complete findings of the field review and high-level mitigation recommendations are provided as a separate deliverable accompanying this report.

2.6 Benefit-Cost Formula for Evaluating Wildlife Crossing Projects

Deciding how best to spend limited transportation funds involves considering many factors and approaches. Benefit-cost analysis (BCA) is a commonly used approach to evaluate projects for potential funding. BCA provides a ratio of the expected or planned benefit in dollars versus the cost in dollars spent (Servheen et al. 2007). The Jacobs Team worked with a CDOT Division of Transportation Development (DTD) economist and traffic safety engineers to identify existing BCA methods currently used within CDOT. CDOT performs two different types of BCA depending on the project funding source.

CDOT's Traffic Safety and Engineering uses DiExSys: Vision Zero Suite (VZS) software to identify locations with a potential for crash reduction, then uses an expense-based approach to calculate benefit-cost consistent with the American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual*. The VZS software accounts for both economic (property damage, medical costs, crash cleanup, lost productivity and wages) and quality of life costs (except for fatalities, which only incorporate the economic cost to keep the value comparable to less severe crashes)(Harmon et al., 2018). CDOT Traffic and Safety Engineering annually updates crash cost values for fatalities, injuries, and property damage only (PDO) based on the national consumer price and employer cost indices. No national standard for valuing crash costs exists, and every state calculates these costs differently.

CDOT DTD uses a different benefit-cost approach when applying for federal funding grants or using federal bond funding. The U.S. Department of Transportation (USDOT) provides explicit requirements for calculating benefit-cost ratios and values that must be used when applying for federal grant funding (USDOT 2021). This CDOT DTD method uses the accepted economic theory of willingness to pay, whereby values for fatalities, injuries, and PDO crashes are not based on actual costs, but societies' willingness to pay to avoid such crashes in the first place.

CDOT's Traffic Safety and Engineering and CDOT DTD also use different discount rates and infrastructure life spans, as well as different methods for calculating discount rate over the life of the infrastructure. USDOT and CDOT DTD recognize that many transportation assets are designed for long-term use, such as major structures (for example, tunnels or bridges) and, thus, have an expected life that would exceed any reasonable analysis period (USDOT 2021). In addition, CDOT DTD incorporates additional factors in its BCAs, such as residual value of assets with life spans that exceed the BCA period, mobility, and emissions.

Beginning in 2017 with the WSWPS, CDOT and CPW sought a more comprehensive approach to assist in evaluating potential wildlife-highway mitigation projects. At that time in Colorado, wildlife values were not included in a BCA for wildlife mitigation projects. In addition, CDOT and CPW identified a need to include the residual value of wildlife mitigation beyond the typical BCA service life because wildlife crossing structures typically have a design life (75 years or more) that exceeds the analysis period used in benefit-cost equations (20 to 30 years). The USDOT recommends assessing the residual value of the remaining asset life when project assets have useful lifetimes that continue beyond the end of the analysis period (USDOT 2021). The USDOT further recommends, when calculating residual values, avoiding any analysis periods extending beyond 30 years of full operations and establishing a reasonable horizon year (that is, design life of bridges or large culverts) for such assets. For the WSWPS, the Jacobs Team held multiple meetings with CPW, CDOT Traffic and Safety Engineering, CDOT DTD, and regional staff over the course of a year to determine how best to integrate these items into a comprehensive benefit-cost equation. The result was a sophisticated and practical automated Excel tool for calculating benefit-cost using three different methods: CDOT Traffic and Safety Engineering methods, which would be used for federal Highway Safety Improvement Program or state Traffic and Safety Engineering grant applications; CDOT DTD methods, which would use the USDOT benefit-cost methods and valuations for federal grant applications; and a hybrid approach for comparing different mitigation scenarios within a high-priority highway segment or comparing across wildlife mitigation projects (Sections 2.8.1 and 2.8.2).

2.6.1 Integrating Wildlife Value into Benefit-Cost Analysis

Wildlife values for deer and elk in Colorado were originally calculated for the WSWPS. The purpose of these wildlife valuations was to provide a more robust estimate of the economic value of mule deer and elk in relation to their benefits to Colorado’s economy than is provided by statutory values assigned by the state legislature for wildlife that are unlawfully taken. Fishing, hunting, and wildlife-watching produce more than $5 billion of economic output annually, which supports nearly 50,000 jobs in Colorado (CPW 2014). Big game hunting alone contributes more than $609 million annually, while supporting more than 6,800 jobs (CPW 2014). To address the limitations of previous wildlife valuations, the Jacobs Team worked with CPW and CDOT to develop an alternative approach based on an accepted economic theory of contingent valuation, which is used to assign dollar values to nonmarket resources, such as wildlife or other environmental values. The contingent valuation method uses statistically valid public surveys to calculate net willingness to pay (WTP), or consumer surplus. Accordingly, this technique was used to identify the maximum amount that a hunter would pay for the opportunity to hunt mule deer or elk, beyond hunting fees or trip expenses.

For the ESPWPS, the Jacobs Team, in coordination with the Wildlife Valuation Committee, updated the previously calculated values for deer and elk with CPW's most recently available data (2018 to 2020) on deer and elk hunting licenses sold in Colorado and license fees for 2021, and updated WTP values and average nonresident hunting expenditures to 2021 dollars, resulting in the following:

Mule Deer Value = $2,178
Elk Value = $2,537

With the inclusion of new target species for the Eastern Slope and Plains, wildlife values for pronghorn and bighorn sheep were also needed. Because the USFWS (2011) report does not provide WTP values for species such as pronghorn and bighorn sheep, an alternate approach was needed to determine WTP for these species. Our team determined that the WTP valuations used for deer should also be used for pronghorn because license fees for both species were identical from 2018 through 2021, resulting in the following valuation:

Pronghorn = $2,106

Determining WTP valuations for bighorn sheep proved more challenging. CPW does not have recent formal hunter surveys or valuations other than license fees to determine a WTP value. However, Watson (1990) determined the economic value of Dall sheep hunting in Alaska and referenced a report published by Kay (1988), *Nevada Survey of the Economic Value of Trophy Big Game and Deer Harvest 1984 through 1986*. In this report, using contingent valuation methods, Kay was able to quantify WTP to hunt Rocky Mountain bighorn sheep in Nevada and calculated a WTP of $2,584.00 in 1986 dollars, including $97.00 for license fees. This WTP calculation for the same species in a nearby state is highly relevant to Colorado. However, for our purposes, the $97.00 license fee from the Nevada sum was subtracted to avoid double counting license fees, which we account for in the weighted average fee value, resulting in a WTP value of $2,487.33. Using the U.S. Bureau of Labor Statistics Consumer Price Index Inflation Calculator, we converted the1986 valuation to 2021 dollars, resulting in a WTP value of $5,937 for bighorn sheep. Accordingly, the following value was calculated for bighorn sheep:

Bighorn Sheep = $7,533

A detailed description of the contingent valuation methods used to calculate wildlife values for these species is provided in Appendix E. While still conservative, these wildlife values offer a more comprehensive estimate of the value of wildlife to society for integration into the benefit-cost equation. The inputs resulting in these new and updated valuations for deer, elk, pronghorn, and bighorn sheep are summarized in Table 2-5.

Table 2-5. Inputs and Economic Valuations for Deer, Elk, Pronghorn, and Bighorn Sheep

Species	WTP	Weighted Average License Fee	Average Nonresident Expenditures	Economic Value	Year
Deer	$1,001	$119	$1,058	$2,178	2021
Elk	$1,218	$261	$1,058	$2,537	2021
Pronghorn	$1,001	$47	$1,058	$2,106	2021
Bighorn Sheep	$5,937	$538	$1,058	$7,533	2021

2.6.2 Calculating Benefit-Cost for Colorado's Wildlife Prioritization Studies

To evaluate wildlife-highway mitigation projects, the Jacobs Team and CDOT developed a hybrid technique, drawing from both the CDOT Traffic and Safety Engineering and DTD methodologies to allow potential wildlife-highway mitigation projects across the Western Slope to be compared. This hybrid approach, shown in Table 2-6, is designed to provide a more comprehensive evaluation than is currently possible with the formula used by CDOT Traffic Safety and Engineering; however, this approach is not as comprehensive as the CDOT DTD/USDOT approach, which also considers several variables not considered here, such as value of time savings and emission reductions, but that may be relevant for a larger improvement project. Such a detailed BCA is relevant only in the context of a larger roadway improvement project and is not needed to evaluate where wildlife-highway mitigation will have the greatest benefit for the investment. Most wildlife-highway mitigation projects are more likely to be funded by state grants than by highly competitive national grants. Therefore, the team applied the CDOT DTD/USDOT formula, including wildlife valuations and residual values, but used the CDOT Traffic Safety and Engineering crash costs and discount rate in its hybrid approach. Complete benefit-cost inputs and calculations can be viewed in the Benefit-Cost Analysis Worksheet and accompanying instructions document.

Table 2-6. Comparison of how Benefit-Cost Elements Are Evaluated

Benefit-Cost Equation Element	Evaluation Approach		
	CDOT Traffic and Safety Engineering Evaluation	CDOT DTD	WSWPS Hybrid Approach
Crash Costs	Derive from AASHTO	Derive from USDOT	Use traffic and safety costs
WVC Time Frame	10-year average	10-year average	10-year average
Discount Rate	5 percent	7 percent	5 percent
Infrastructure Life Span	20 years	30 years	30 years
Residual Value	Not considered	CDOT DTD/USDOT methodology	CDOT DTD/USDOT methodology

Benefit-Cost Equation Element	Evaluation Approach		
	CDOT Traffic and Safety Engineering Evaluation	CDOT DTD	WSWPS Hybrid Approach
Wildlife Value	Not considered	Nonmonetized benefit	▪ Deer value = $2,178 ▪ Elk value = $2,537 ▪ Pronghorn value = $2,106 ▪ Bighorn sheep value = $7,533

The hybrid WSWPS benefit-cost equation is represented as follows:

WSWPS Benefit-Cost Ratio = Total Discounted Benefits/Total Discounted Costs

Where:

Total Discounted Benefits = sum of:
Discounted Crash Reduction Benefit
Discounted Value of Mule Deer and Elk
Discounted Residual Value

Total Discounted Costs = sum of:
Discounted Construction Cost
Discounted Maintenance Cost

For this equation, predicted fatal crash counts, predicted injury crash counts, predicted PDO crash counts, predicted deer deaths, and predicted elk deaths derived from the crash history data are used to calculate discounted and undiscounted benefits. Discounted values pertain to the service life used in the benefit-cost formula; for the WSWPS, this equals 30 years. Residual value should be estimated using the total value of the asset and remaining service life at the end of the analysis period. The residual value of the project would, thus, be as follows:

$$RV = \left(\frac{U - Y}{U}\right) x\ Project\ Cost$$

Where:

RV = Residual Value
U = Useful Service Life (or Design Life) of Project
Y = Years of Analysis Period Project Operation

Notably, residual value benefits would occur during the final year of the analysis and should be discounted the same as other project benefits and costs in the BCA (USDOT 2021).

2.6.3 Updated Benefit-Cost Analysis Worksheet Tool

Updates to the WSWPS BCA tool were made in coordination with Anthony Vu (CDOT Traffic and Safety Engineering), the original programmer of the automated BCA Excel workbook. The purpose of these revisions was to include updated USDOT guidance, updated USDOT and CDOT crash costs, and new species valuations, and to incorporate revisions to enhance the tool's user-friendliness. The Jacobs Team reviewed the unit costs for mitigation items from the WSWPS BCA tool relative to recent mitigation project costs in Colorado from 2019 and 2020 and found that the unit costs calculated for the original tool were still appropriate for the purpose of estimating high-level project costs. Specific updates to the BCA tool are summarized in Table 2-7.

Table 2-7. 2021 Updates to the Wild Animal Benefit-to-Cost Worksheet Tool

Item	Update Description and Justification
Option for manual overrides	Manual overrides allow users to insert their own values instead of the default values provided. Manual override options are provided for mitigation item costs, crash reduction factor (i.e., mitigation effectiveness), crash costs, and wildlife values.
New species and option to add additional species values	The original WSWPS worksheet included only wildlife values for deer and elk. The ESPWPS includes updated 2021 values for deer and elk as well as new values for pronghorn and bighorn sheep. Users may also add additional species and values.
Updated crash costs	Default crash costs from CDOT Traffic and Safety Engineering were updated to the most recent cost values (effective July 1, 2021).
Updated crash reduction factor	The Jacobs Team conducted a review of the most recent available published literature and agency reports from across western states to calculate an updated crash reduction factor, which estimates the average effectiveness of wildlife crossings and fencing mitigation in reducing WVCs.
Updated instructions for calculating benefit-cost	Since the completion of the WSWPS, the USDOT has updated its guidance for conducting BCA (USDOT 2021). The updated BCA worksheet reflects this more recent guidance.

3. Prioritization Results

This chapter presents the results of the prioritization process that resulted in the identification of the highest-priority segments for wildlife-highway mitigation within each CDOT region.

3.1 Risk Modeling Results

Predicting the precise level of risk for any given road segment is difficult because of high variability where mule deer and elk are struck by vehicles while attempting to cross roads. For this reason, the WVC risk models are useful for highlighting the factors that influence risk when considering where to mitigate risk for the greatest cost-effectiveness. In addition, the WVC risk models can be used to identify highway segments that may have increased risk in the future based on predicted traffic volumes and development patterns.

The WVC risk models for mule deer and elk migration and winter periods performed far better than random chance, as estimated by comparison with null models and explained moderate levels of relative variance in WVC patterns across the Eastern Slope analysis area (57 to 63 percent) and moderate levels in the Plains analysis area (52 to 53 percent). Several general trends in WVC risk were observed across models while other risk factors varied across species and seasons. Traffic volume and speed, and distance to speed transitions were the strongest drivers of risk in most areas across the study area. Specifically, WVC risk was characterized as follows:

- Increasing with traffic volume
- Generally increasing with traffic speed
- Decreasing with increase in percent of impervious surfaces
- Decreasing with distance from points at which speed limits change

3.2 Prioritization Results

Figure 3-1 shows results of the prioritization process for the entire study area. Overall, 289 miles of highway ranked in the 95th percentile. As with the WSWPS, the WVC pattern recognition data input heavily influenced which segments were designated high priority because of the binary nature of the input data (score 0 or 1) and the high weight for this criterion (24 percent of the total score). Yet, while all of the top 5 percent segments in the Eastern Slope analysis area were identified as WVC hotspots, in the Plains analysis area, there were a number of top 5 percent segments that were not identified as WVC hotspots and received a high priority score based on the wildlife criteria alone. Overall, these results reflect the intent of the study panel to create a prioritization that is largely influenced by WVC safety needs but that also considers wildlife movement needs. The risk models and other wildlife criteria serve this purpose by discerning highway segments relative to their value for different seasonal wildlife movements and the impacts of road mortality on wildlife populations, thus lending a refined level of detail to the binary WVC patterns.

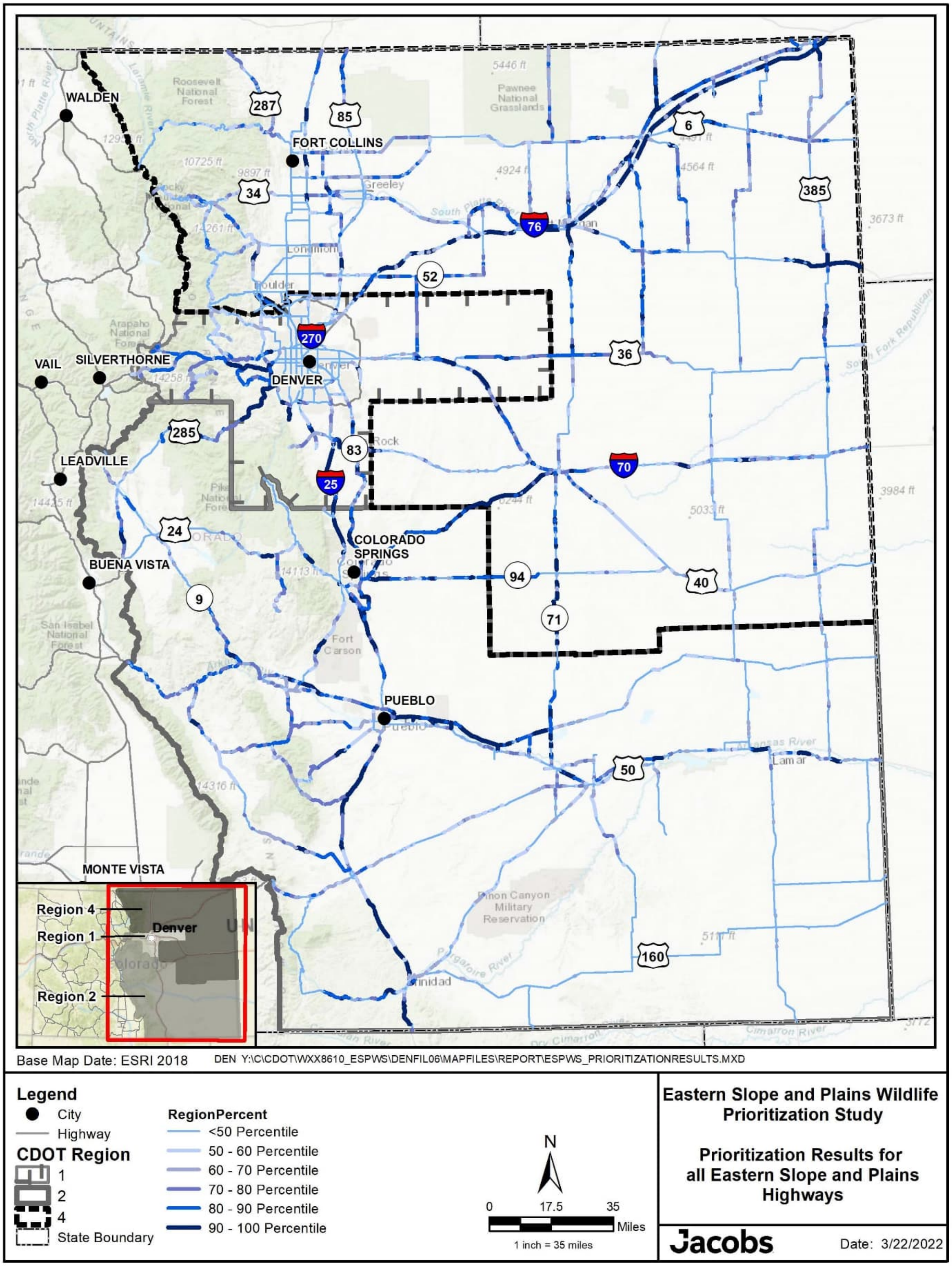
Across the study area, 92 roadway miles were in the top 5 percent in the Eastern Slope analysis area and 197 miles in the Plains. This is largely due to the fact that the Plains area (east of I-25) is larger and has more miles of roadway than the Eastern Slope area. The average segment length was the same in both analysis areas (3 miles). Compared with the WSWPS, there were more short segments (0.5 to 1 mile long) in the ESPWPS, indicating that the WVC hotspots and wildlife connectivity areas are generally broader on the Western Slope and shorter and more discrete on the Eastern Slope and in the Plains. However, both the Plains and Eastern Slope analysis areas also included longer top 5 percent segments, up to 15.8 and 15.7 miles, respectively. Although both CDOT Regions 1 and 2 had a relatively equal distribution of top 5 percent segments in both analysis areas, CDOT Region 4 priority segments were primarily in the Plains. Across regions, top 5 percent segments in the Plains were influenced by proximity to major riparian corridors (South Platte and Arkansas rivers) as well as other perennial and ephemeral drainages that provide natural habitat and cover.

As seen in the WSWPS, the input “probability of lynx highway crossing” derived from Baigas et al. (2017) had limited influence on the prioritization of highway segments in the Eastern Slope analysis area. In general, prime lynx habitat and lynx highway crossing areas occur in higher elevations with limited overlap with deer and elk migration and winter range areas. Within the top 5% highway segments, he highest-ranking segments for lynx were on US 285 on the east side of Kenosha Pass and on the I-70 Mountain Corridor through Genesee and Floyd Hill, which lies at the periphery of suitable lynx habitat and is a known high WVC hotspot for deer and elk.

Bighorn sheep also had limited influence on prioritization scores in the Eastern Slope analysis area. Like Canada lynx, there was only one input criterion for this species, and few of the identified bighorn sheep habitat and WVC mortality areas overlapped with deer and elk connectivity areas and WVC hotspots.

Segments with high wildlife criteria scores often appeared as clusters. In the Eastern Slope analysis area, several wildlife criteria were calculated at the coarse spatial resolution of DAUs or winter ranges, causing all segments within the same DAU or winter range unit to receive the same criterion score. High scores for winter range and migration movement magnitude were clustered in the DAUs west of Denver and farther south in the Colorado Springs and Trinidad areas. Distance to drainages was not based on management units, and high scores for this criterion were widely distributed across the Plains analysis area. Per capita elk mortalities from WVCs were highest closer to the Front Range (WVC mortalities represented a maximum of 0.58 percent of the DAU herd size estimate), but per capita deer mortalities from WVCs were highest in DAUs distributed across CDOT Regions 2 and 4 (WVC mortalities represented a maximum of 3.67 percent of the DAU herd size estimate).

Figure 3-1. Map of Prioritization Results across the Entire Eastern Slope and Plains Study Area



The prioritization of highway segments was conducted separately for the Eastern Slope and Plains analysis areas to individually address differences in target species and movement patterns across these two landscapes. The results from the two analysis areas were then merged across the entire study area based on percentile rank. However, because transportation projects are administered and prioritized at the regional scale, the Jacobs Team then separated and ranked priority segments by region. Given the varying sizes of the CDOT regions and the miles of road administered by each region, there were a total of 42 miles of roadway in the top 5 percent in CDOT Region 1; 110 miles in CDOT Region 2; and 138 miles in CDOT Region 4. The mileage breakdown by analysis area is 92 miles for the Eastern Slope and 187 miles for the Plains, which is also a reflection of the sizes of the respective analysis areas. Several segments on E-470 fell within the 95th percentile; however, these segments were omitted from the results because E470 is not managed by CDOT and, instead, is overseen by a separate highway authority. Wildlife-exclusion fencing has been constructed along much of the E-470 segments.

Prioritization results were not ranked numerically. All highway segments in the 95th percentile are considered equally important for wildlife-highway mitigation because all of these segments scored high on both the wildlife and safety criteria. The order in which mitigation projects are pursued should not be restricted by such a ranking because project implementation is also heavily influenced by other secondary considerations, including the alignment of a mitigation project with other transportation projects, construction feasibility, partnership or funding opportunities, and other considerations (Section 4.3).

Prioritization criteria scores for the top 5 percent of highway segments (95th percentile) in CDOT Regions 1, 2, and 4 are presented in Figures 3-2 through 3-4 and listed in Tables 3-1, 3-2, and 3-3, respectively. For detailed data demonstrating how individual prioritization criteria influenced the scoring for each top 5 percent segment, refer to Appendix G.

Figure 3-2. Top 5 Percent Segments for CDOT Region 1

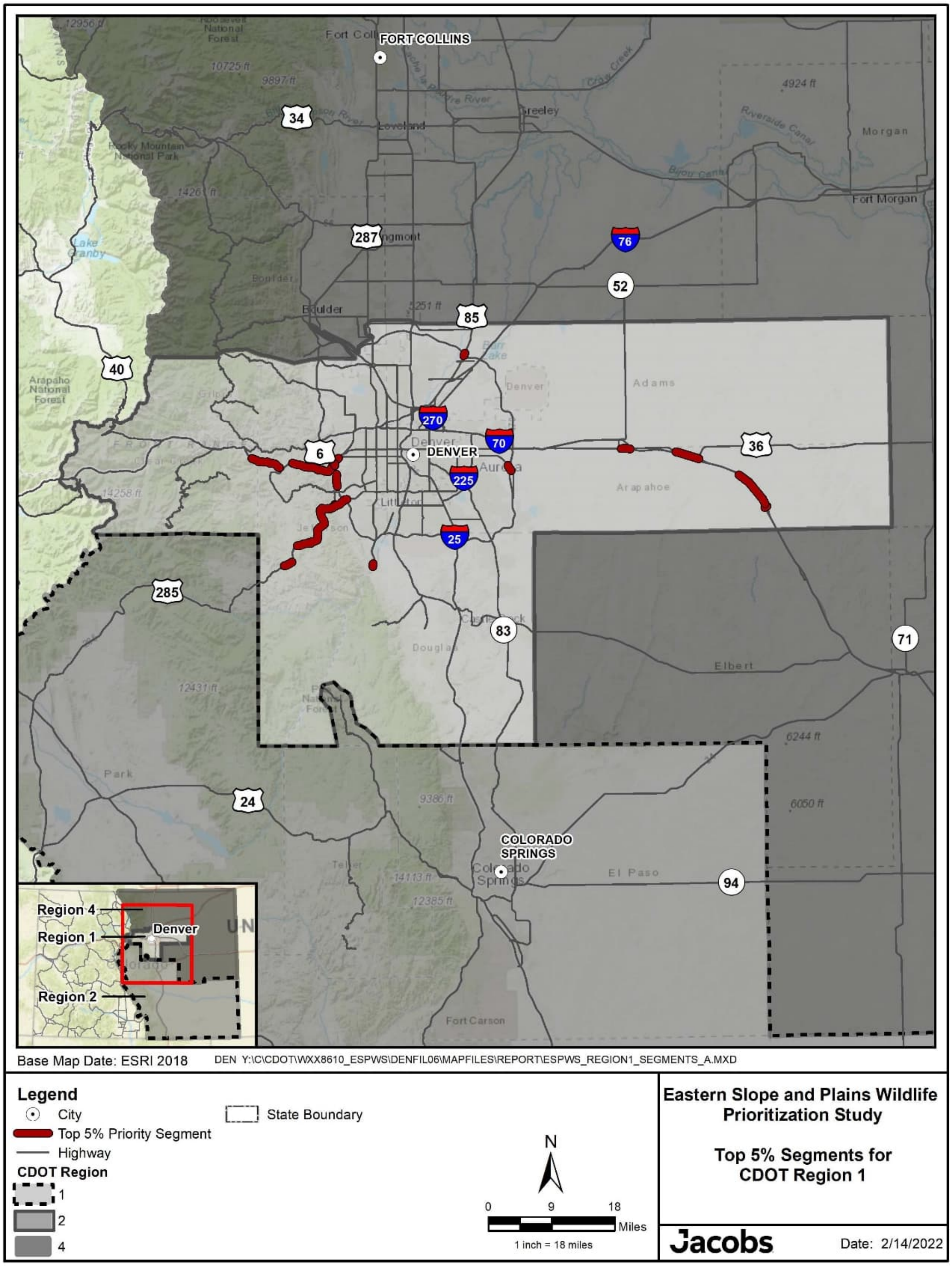


Table 3-1. Highest-priority Segments (Top 5 Percent) in CDOT Region 1

Route	Mileposts	Segment Length (miles)	Analysis Area (ES or P)	Analysis Target Species	Segment Name	County
I-70	246.3–250.7	4.3	ES	Deer, Elk	Floyd Hill to Bergen Park	Clear Creek and Jefferson
I-70	252.9–260.8	7.9	ES	Deer, Elk	Genesee	Jefferson
I-70	304.6–306	1.4	P	Deer	Bennett/Kiowa Creek	Adams and Arapahoe
I-70	312.5–316.1	3.6	P	Deer	Strasburg to Byers	Arapahoe
I-70	322.2–328.8	5.6	P	Deer	Peoria to Deer Trail	Arapahoe
C-470	1.7–3.4	1.8	ES	Deer, Elk	Green Mountain to Bear Creek	Jefferson
US 40	282.3–283.6	1.3	ES	Deer, Elk	Mother Cabrini	Jefferson
US 85	231.1–231.6	0.4	P	Deer	Henderson	Adams
US 285	233.7–235	1.3	ES	Deer, Elk	Richmond Hill	Jefferson
US 285	237.6–250.3	12.7	ES	Deer, Elk	Aspen Park to C-470	Jefferson
SH 30	15.5–16.4	0.9	P	Deer	C-470 Interchange	Arapahoe
SH 121	0.4–0.8	0.4	ES	Deer, Elk	Chatfield Reservoir	Douglas

Notes:

ES = Eastern Slope
P = Plains

Figure 3-3. Top 5 Percent Segments for CDOT Region 2

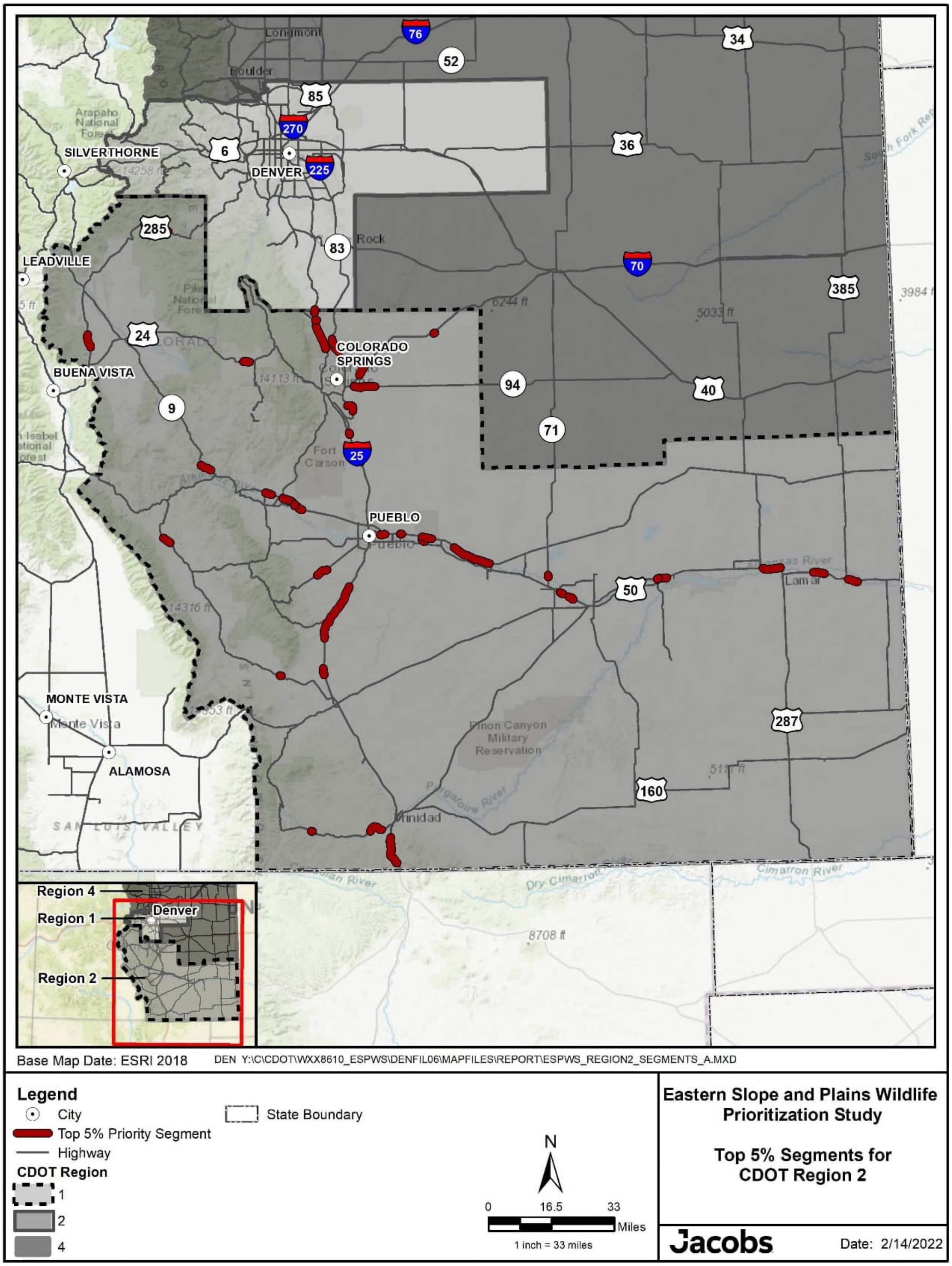


Table 3-2. Highest-priority Segments (Top 5 Percent) in CDOT Region 2

Route	Mileposts	Segment Length (miles)	Analysis Area (ES or P)	Analysis Target Species	Segment Name	County
I-25	2.2–10.1	7.9	ES	Deer, Elk	Raton Pass	Las Animas
I-25	58.5–60.2	1.7	ES	Deer, Elk	Huerfano River	Huerfano
I-25	67.9–83.7	15.8	ES	Deer, Elk	Colorado City	Huerfano and Pueblo
I-25	118.7–119.6	0.9	ES	Deer, Elk	Wigwam	El Paso and Pueblo
I-25	126.5–127	0.4	ES	Deer, Elk	Fountain Creek	El Paso
I-25	152.8–159.3	6.5	ES	Deer, Elk	Air Force Academy	El Paso
I-25	162.8–163.6	0.8	ES	Deer	Monument Hill	El Paso
US 24	274.8–276.7	1.8	ES	Deer, Elk	Florissant to Divide	Teller
US 24	315.9–320	4.1	P	Deer, Elk	Colorado Springs to Falcon	El Paso
US 24	340.5–340.9	0.4	P	Deer, Pronghorn	Calhan	El Paso
US 50	285.9–287.6	1.7	ES	Deer	Cañon City to Penrose	Fremont
US 50	290.7–296.8	6.1	ES	Deer, Elk	Penrose	Fremont
US 50	319–320.3	1.3	P	Deer	East Pueblo	Pueblo
US 50	330.3–331.2	0.9	P	Deer	Avondale/Arkansas River	Pueblo
US 50	370.4–371.3	0.9	P	Deer	Rocky Ford	Otero
US 50	373–374.4	1.4	P	Deer	Timpas Creek	Otero
US 50	400–402.7	2.7	P	Deer	Las Animas/Arkansas River	Bent
US 50	428.4–433.2	4.8	P	Deer	West of Lamar	Prowers
US 50	443.6–446.7	3.0	P	Deer	Carlton	Prowers
US 50	453.2–455.8	2.6	P	Deer	Granada	Prowers
US 285	166.6–270.1	3.5	ES	Deer, Elk, Pronghorn	North of Antero Junction	Park
US 285	208.9–209.3	0.4	ES	Deer, Elk	Webster to Grant	Park
US 285	210.6–211.1	0.4	ES	Bighorn Sheep, Deer, Elk	Grant	Park
US 285	214.9–215.8	0.9	ES	Deer, Elk	Santa Maria	Park
SH 9	2.2–5.2	3.0	ES	Deer	Twelvemile Park	Fremont
SH 12	45.5–45.9	0.4	ES	Deer, Elk	West of Weston	Las Animas
SH 12	62.9–66.9	4.0	ES	Deer, Elk	Trinidad Lake	Las Animas
SH 21	133.5–136.1	2.6	P	Deer, Pronghorn	Widefield	El Paso
SH 21	151.6–154.1	2.5	P	Deer	Kettle Creek	El Paso

Route	Mileposts	Segment Length (miles)	Analysis Area (ES or P)	Analysis Target Species	Segment Name	County
SH 69	17–17.4	0.4	ES	Deer, Elk	Badito Cone (East of Walsenburg)	Huerfano
SH 69	68.9–71	2.1	ES	Deer, Elk	Hillside	Custer
SH 71	18.9–19.2	0.4	P	Deer	Arkansas River	Otero
SH 78	19.7–22.7	3.0	ES	Deer, Elk	Southwest of Pueblo	Pueblo
SH 83	20.8–22.1	1.3	P	Deer	Black Squirrel Creek	El Paso
SH 94	1.4–7	5.6	P	Deer, Pronghorn	East of Colorado Springs	El Paso
SH 96	70.3–73	2.6	P	Deer	North Avondale	Pueblo
SH 96	79.2–89.7	10.5	P	Deer	Boone to Olney Springs	Crowley and Pueblo
SH 231	1.2–1.6	0.4	P	Deer	Devine/Arkansas River	Pueblo

Figure 3-4. Top 5 Percent Segments for CDOT Region 4

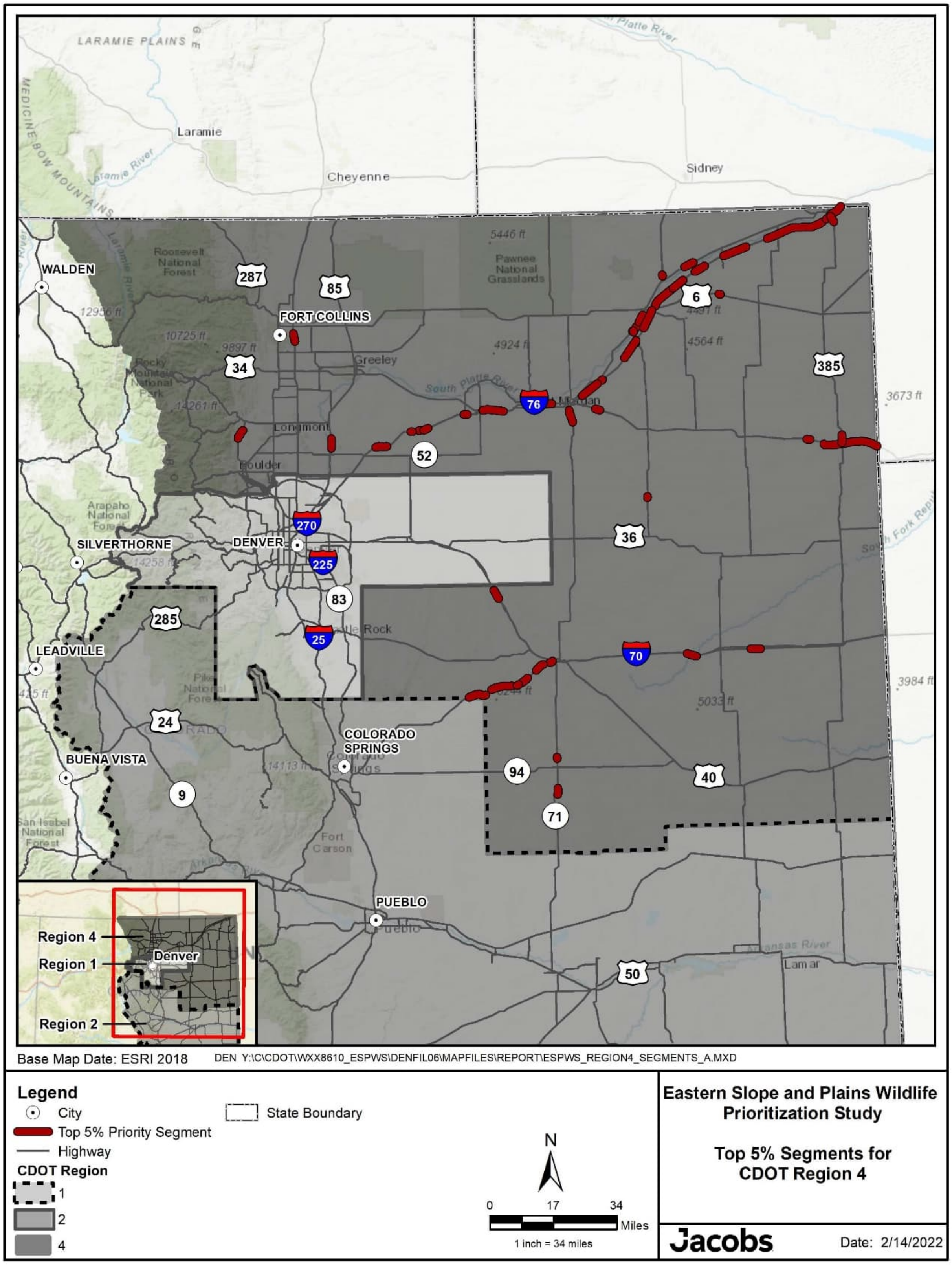


Table 3-3. Highest-priority Segments (Top 5 Percent) in CDOT Region 4

Route	Mileposts	Segment Length (miles)	Analysis Area (ES or P)	Analysis Target Species	Segment Name	County
I-25	265.3–267.5	2.2	ES	Deer	Timnath/South of Fort Collins	Larimer
I-70	333.6–336.2	2.6	P	Deer, Pronghorn	Deer Trail to Agate	Elbert
I-70	395.7–398.3	2.6	P	Deer, Pronghorn	South Fork Republican River	Kit Carson
I-70	412.3–415.8	2.6	P	Deer, Pronghorn	Vona	Kit Carson
I-76	35.4–38.5	3.1	P	Deer	Hudson to Keenesburg	Weld
I-76	46.3–46.8	0.4	P	Deer	West Roggen	Weld
I-76	48.5–48.9	0.4	P	Deer	Roggen	Weld
I-76	49.8–51.1	1.3	P	Deer	East of Roggen	Weld
I-76	61.6–62.4	0.9	P	Deer	West of Wiggins	Morgan
I-76	66.8–72.5	5.7	P	Deer	Bijou Creek	Morgan
I-76	82.6–86.1	3.5	P	Deer	East of Fort Morgan	Morgan
I-76	94.8–100	5.2	P	Deer, Pronghorn	Camden to Hillrose	Morgan
I-76	101.3–101.8	0.5	P	Deer, Pronghorn	East of Hillrose	Morgan
I-76	110–115.7	5.7	P	Deer, Pronghorn	Merino to Atwood	Morgan
I-76	119.6–124.8	5.2	P	Deer, Pronghorn	Atwood to Sterling	Logan
I-76	126.1–132.7	6.5	P	Deer, Pronghorn	Sterling to Iliff	Logan
I-76	133.1–136.6	3.5	P	Deer, Pronghorn	Iliff	Logan
I-76	140.5–143.6	3.1	P	Deer	East of Iliff	Logan
I-76	149.2–155.8	6.5	P	Deer, Pronghorn	Crook to West of Sedgwick	Logan
I-76	161.9–177.5	15.7	P	Deer, Pronghorn	East of Sedgwick to West of Julesburg	Sedgwick
I-76	178.8–184.1	5.3	P	Deer, Pronghorn	Julesburg to Nebraska State Line	Sedgwick
US 6	397.7–399.5	1.8	P	Deer	Atwood/South Platte River	Logan
US 6	400.8–403	2.2	P	Deer	Sterling	Logan
US 6	425.5–426	0.5	P	Deer	Fleming	Logan
US 24	350.9–355.8	4.9	P	Deer, Pronghorn	Ramah to Matheson	Elbert
US 24	357.9–363.6	5.7	P	Deer, Pronghorn	Matheson	Elbert

Route	Mileposts	Segment Length (miles)	Analysis Area (ES or P)	Analysis Target Species	Segment Name	County
US 24	364.9–365.3	0.4	P	Deer, Pronghorn	Matheson Hill	Elbert
US 24	366.2–368.4	2.2	P	Deer, Pronghorn	East of Matheson	Elbert
US 24	371.4–374.1	2.6	P	Deer, Pronghorn	West of Limon	Elbert
US 24	375.8–376.7	0.9	P	Deer	Limon/Big Sandy Creek	Elbert
US 34	180.6–182	1.4	P	Deer, Pronghorn	East of Brush	Washington
US 34	240–240.8	0.9	P	Deer	Eckley (West of Wray)	Yuma
US 34	244.8–249.6	4.8	P	Deer	West of Wray	Yuma
US 34	250.5–259.5	9.0	P	Deer	Wray to Nebraska State Line	Yuma
US 36	24.3–26.9	2.6	ES	Deer, Elk	St Vrain Rd to Nelson Rd	Boulder
US 85	243.4–246	2.6	P	Deer	Fort Lupton	Weld
US 385	243.6–245.7	2.2	P	Deer, Pronghorn	Holy Joe Creek (North of Wray)	Yuma
US 385	307.1–308.8	1.7	P	Deer, Pronghorn	South of Julesburg	Sedgwick
SH 71	65.4–67.1	1.7	P	Deer	South of SH 94	Crowley
SH 71	75–75.3	0.4	P	Deer, Pronghorn	South of Limon	Lincoln
SH 71	169.6–173	3.5	P	Deer, Pronghorn	South of Brush	Morgan
SH 113	1.4–1.8	0.4	P	Deer	West of Iliff	Logan
SH 138	16.1–18.8	2.6	P	Deer	East of Iliff	Logan

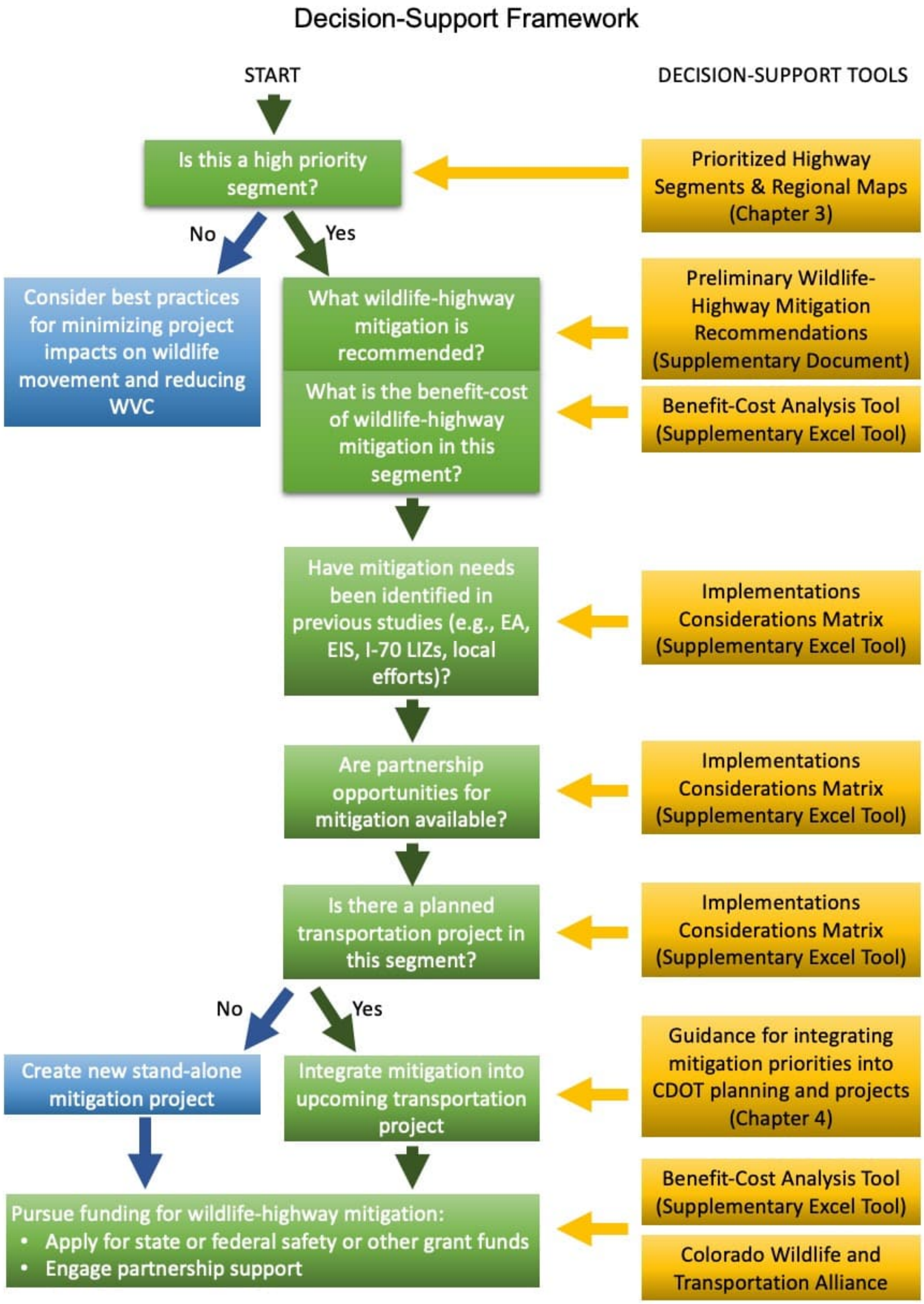
4. Decision-Support Framework

The decision-support framework described in this chapter is a crucial output of the ESPWPS and corresponding WSWPS, integrating the prioritized wildlife-highway segments with CDOT's transportation project development processes. The purpose of the framework is to provide the necessary information and mechanisms to help CDOT and CPW integrate wildlife-highway mitigation actions into upcoming transportation plans and projects or to create new, stand-alone projects based on these priorities. Figure 4-1 depicts how these tools may be used to determine where to focus wildlife-highway mitigation and how to implement mitigation projects. Specifically, this decision-support framework includes the following complementary tools:

- Prioritized list, maps, and GIS file of highway segments across the Eastern Slope and Plains demonstrating the greatest need for wildlife-highway mitigation (Chapter 3)
- Prioritization methodology to support future updates to the risk model and prioritization process (Chapter 2 and Appendix D)
- Potential mitigation recommendations for each of the highest-priority segments (top 5 percent) to support integrating wildlife-highway mitigation into project planning, budgeting, and design (supplementary deliverable)
- Updated wildlife valuations and BCA tool to help inform where wildlife-highway mitigation is most cost effective or to evaluate the benefits and costs of different mitigation measures for a given priority segment (this chapter and Excel spreadsheet tool)
- Implementation considerations matrix to flag factors that may influence opportunities to implement wildlife-highway mitigation (sortable Excel spreadsheet provided as supplementary deliverable)
- Guidance for integrating priority wildlife-highway segments into CDOT planning and project development (this chapter)

Together, the components of the decision-support framework will help users in developing appropriate mitigation strategies and identifying potential funding sources.

Figure 4-1. Eastern Slope and Plains Wildlife Prioritization Study Decision-Support Framework for Advancing Wildlife Mitigation Projects



4.1 Wildlife-Highway Mitigation Recommendations

Preliminary wildlife crossing mitigation recommendations for the top 5 percent highway segments in CDOT Regions 1, 2, and 4 were developed based on the findings of the field surveys and the latest research on the effectiveness of different mitigation strategies. The Mitigation Recommendations document accompanying this report presents mitigation recommendations by region for each priority highway segment. Milepost locations for potential wildlife crossing structures are provided as a starting point for mitigation project planning. These preliminary recommendations may be used to inform initial project planning and budgeting, although recommendations may be revised upon further project analysis. Ultimately, decisions regarding mitigation siting and design will take the following into consideration:

- Coordination of mitigation needs with the project limits (beginning and ending points) for other transportation projects
- Integration of mitigation with other aspects of a project
- Engineering feasibility
- Landowner support and land use compatibility
- Species-specific design considerations for deer and elk in addition to other species in the landscape with cross-roadway movement needs
- Spacing between crossing structures to provide sufficient passage opportunities
- Project cost

4.2 Benefit-Cost Analysis Worksheet

The BCA worksheet first developed for the WSWPS and updated for the current study provides an automated tool for determining the benefits and costs of wildlife crossing mitigation (Section 2.8). The output of the tool is a BCA ratio, which is calculated in three ways:

1. Using current CDOT Traffic and Safety Engineering's methods and valuations
2. Using current USDOT methods and valuations
3. Using the Wildlife Prioritization Study hybrid benefit-cost methods and valuations

The Wildlife Prioritization Study hybrid approach uses the USDOT formulas, which include an economic value for select wildlife species (deer, elk, pronghorn, and bighorn sheep) using the accepted economic contingency valuation method (Appendix E), and calculate the residual value for expensive bridge, overpass, or underpass structures that have a design life that exceeds the 30-year discount valuation period currently recommended by USDOT (USDOT 2021). However, the hybrid method derives valuations for fatalities, injury, and property damage crashes from CDOT Traffic and Safety Engineering and uses the CDOT Traffic and Safety Engineering discount rate of 5 percent. Accordingly, this tool automatically calculates benefit-cost using all three methods, allowing CDOT planning teams to compare potential wildlife-highway mitigation projects using the WSWPS hybrid approach and also evaluate a project's potential competitiveness for state and federal highway safety funding programs or federal grants. A BCA ratio greater than 1 is generally considered the threshold at which the benefits of a project exceed the costs of investment. However, grant requirements vary, and these ratios are provided for planning and identification of potential funding source purposes only.

4.2.1 Example Benefit-Cost Analyses using the WSWPS Hybrid Approach

Wildlife mitigation decisions for the highest-priority segments depend on many factors, such as how other aspects of a transportation improvement project interact with the needed spacing between crossing structures to provide sufficient passage opportunities. BCAs for each of the highest-priority segments (top 5 percent) are not provided as part of the ESPWPS because of the number of assumptions that would be required. Instead, examples are provided to demonstrate how the BCA worksheet tool may be used.

Benefit-cost was calculated for three hypothetical examples in each CDOT region. For the purposes of these examples, escape ramps are assumed to be 3:1 slope with perpendicular guide fence because this is the recommended slope for escape ramps in future mitigation projects. In addition, all deer guards are assumed to be 24-foot-wide round bar. These cost estimates are for wildlife mitigation components only and do not include roadway costs and other related items (e.g., right-of-way, utilities, and traffic control).

4.2.1.1 Example: Region 1, State Highway 121, Mileposts 0 to 3.5, Chatfield Reservoir

This example BCA is based on the recommendations developed for this segment as described in the Mitigation Recommendations supplementary document. Although the top 5 percent segment was just 0.5 mile long, mitigation is recommended for a longer segment from MPs 0 to 3.5, which is in the 93rd percentile for Region 1. Due to the limitations of the adjacent terrain, only one bridge underpass suitable for elk as well as deer is recommended for this segment, located at MP 0.4, in the 95th percentile portion of the project segment and where there was the highest concentration of WVCs. State Highway 121 is a four-lane road with wide shoulders and a narrow, open median. The following assumptions are made for this example: one 70-foot-wide by 185-foot-long bridge suitable for elk; 3.5 miles of wildlife-exclusion fencing; 14 escape ramps; 3 deer guards of varying widths; and 2 driveway swing gates. A service life of 75 years is assumed for wildlife crossing structures, and 20 years for fencing, escape ramps, and deer guards. The total cost of the mitigation including contingencies, construction engineering, and indirect charges was estimated at $5,778,712 with an additional $36,406 in ongoing maintenance costs. There were 81 WVCs in this segment over a 10-year period, including 7 injury crashes and 74 PDO crashes resulting in 57 mule deer and 24 elk mortalities. Table 4-1 summarizes these inputs and baseline calculations.

Table 4-1. Estimated Benefits and Costs of Mitigation on State Highway 121, Mileposts 0 to 3.5

Costs of WVCs (2010 – 2019)				Costs of Mitigation			
Cost Type	Units	Unit Cost	Total Cost	Mitigation Item	Units	Unit Cost	Total Cost
Crash fatalities (persons killed)	0	$1,820,600	$0	Bridge Underpass	1	$225/ linear foot	$2,913,750
Crash injuries (persons injured)	7	$101,800	$712,600	Wildlife-Exclusion Fence	3.5	$98,900/ lane mile	$346,150
Property damage only crash	74	$11,100	$821,400	Escape Ramps	14	$13,378	$187,292
Value of deer killed in reported crashes	57	$2,178	$124,146	Deer Guards	3	Var.	$191,000
Value of elk killed in reported crashes	24	$2,537	$60,888	Driveway Swing Gate	2	$1,200	$2,400
Total 10-Year Cost of WVCs			$1,719,034	Mitigation Subtotal			$3,640,592
Average Annual Cost of WVCs			$171,903	**Total Costs including Contingencies (30%), Construction Engineering, and Indirect Charges (22.10%)**			**$5,778,712**
Average Annual Benefit of Mitigation (87% Crash Reduction Factor)			**$149,556**				

% = percent

Based on these inputs, the benefits of mitigation are projected to exceed the cost of the mitigation investment within 34 years. These calculations are based on reported WVCs only and do not include the benefits of reductions in additional carcasses picked up by CDOT maintenance patrols. Other unquantifiable benefits include increased wildlife connectivity and population resilience. The resulting BCA ratios calculated for this segment were as follows:

- Using CDOT Traffic and Safety Engineering methods for federal Highway Safety Improvement Program (HSIP) and state Funding Advancement for Surface Transportation and Economic Recovery (FASTER) Safety Mitigation grants: 0.35
- Using the guidance for federal Transportation Investment Generating Economic Recovery (TIGER) and Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies (FASTLANE) grants: 1.12
- Using the hybrid approach developed for Colorado's wildlife prioritization studies: 1.73

4.2.1.2 Example: Region 2, Interstate 25, Mileposts 2.1 to 7.5, Raton Pass

I-25 over Raton Pass is a major barrier to wildlife movement, yet WVCs continue to occur as wildlife attempts crossing at-grade. This example BCA is based on the primary recommendation for the Mitigation Recommendations supplementary document, which suggests focusing mitigation efforts on the segment from MPs 2.1 to 7.5. The interstate through this segment is a divided, four-lane highway. In some portions of the segment, the northbound and southbound lanes are vertically offset. Mule deer, elk, and black bear are the primary target species for this segment. The following assumptions are made for this example: two 80-foot-wide by 150-foot-long bridge underpasses suitable for elk; two 42-foot-wide by 150-foot-long bridge or arch underpasses; 5.4 miles of wildlife-exclusion fencing; 22 escape ramps; and four 40-foot-wide deer guards. A service life of 75 years is assumed for wildlife crossing structures, and 20 years for fencing, escape ramps, and deer guards. The total cost of the mitigation including contingencies, construction engineering, and indirect charges was estimated at $14,856,138 with an additional $93,594 in ongoing maintenance costs. There were 96 WVCs in this segment over a 10-year period, including 12 injury crashes, and 84 PDO crashes resulting in 84 mule deer and black bear mortalities and 10 elk mortalities. Table 4-2 summarizes these inputs and baseline calculations.

Table 4-2. Estimated Benefits and Costs of Mitigation on Interstate 25, Mileposts 2.1 to 7.5

Costs of WVCs				Costs of Mitigation			
Cost Type	Units	Unit Cost	Total Cost	Mitigation Item	Units	Unit Cost	Total Cost
Crash fatalities (persons killed)	0	$1,820,600	$0	80-foot-wide Bridge Underpasses	2	$225/ linear foot	$5,400,000
Crash injuries (persons injured)	12	$101,800	$1,221,600	84-foot-wide Bridge or Arch Underpasses	2	$225/ linear foot	$2,835,000
Property damage only crash	84	$11,100	$932,400	Wildlife-Exclusion Fence	5.4	$98,900/ lane mile	$534,060
Value of deer killed in reported crashes	84	$2,178	$182,952	Escape Ramps	22	$13,378	$294,316
Value of elk killed in reported crashes	10	$2,537	$25,370	Deer Guards	4	$74,000	$296,000
Total 10-Year Cost of WVCs			$2,362,322	Mitigation Subtotal			$9,359,376
Average Annual Cost of WVCs			$236,232	**Total Costs including Contingencies (30%), Construction Engineering, and Indirect Charges (22.10%)**			**$14,856,138**
Average Annual Benefit of Mitigation (87% Crash Reduction Factor)			**$205,522**				

Based on these inputs, the benefits of mitigation are projected to exceed the cost of the mitigation investment within 72 years These calculations are based on reported WVCs only and do not include the benefits of reductions in additional carcasses picked up by CDOT maintenance patrols. Other unquantifiable benefits include increased wildlife connectivity and population resilience. The resulting BCA ratios calculated for this segment were as follows:

- Using CDOT Traffic and Safety Engineering methods for federal HSIP and state FASTER Safety Mitigation grants: 0.0
- Using the guidance for federal TIGER and FASTLANE grants: 0.57
- Using the hybrid approach developed for Colorado's wildlife prioritization studies: 1.33

4.2.1.3 Example: Region 4, Interstate 25, Mileposts 265.3 to 268.5, Timnath/ South of Fort Collins

This stretch of I-25 has a large bridge over the Cache la Poudre riparian corridor as well as a bridge over railroad tracks. The former, in particular, has excellent potential as a wildlife crossing structure, and the latter may also be used for wildlife passage. Mule deer and elk are the target species for this segment. The Mitigation Recommendations accompanying this report suggest installing fencing between two interchanges at either end of the segment and tying into these two structures. Specifically, the following assumptions are made for this example: 3.2 miles of wildlife-exclusion fencing; and 12 escape ramps. A service life of 75 years is assumed for wildlife crossing structures, and 20 years for fencing and escape ramps. The total cost of the mitigation including contingencies, construction engineering, and indirect charges was estimated at $741,469 with an additional $4,671 in ongoing maintenance costs. There were 44 WVCs in this segment over a 10-year period, including 3 injury crashes, and 41 PDO crashes resulting in 43 mule deer mortalities and 1 elk mortality. Table 4-3 summarizes these inputs and baseline calculations.

Table 4-3. Estimated Benefits and Costs of Mitigation on Interstate 25, Mileposts 265.3 to 268.5

Costs of WVCs (2010 – 2019)				Costs of Mitigation			
Cost Type	Units	Unit Cost	Total Cost	Mitigation Item	Units	Unit Cost	Total Cost
Crash fatalities (persons killed)	0	$1,820,600	$0	Wildlife-Exclusion Fence	3.1	$98,900/ lane mile	$306,590
Crash injuries (persons injured)	3	$101,800	$305,400	Escape Ramps	12	$13,378	$160,536
Property damage only crash	41	$11,100	$455,100	N/A	N/A	N/A	N/A
Value of deer killed in reported crashes	43	$2,178	$93,654	N/A	N/A	N/A	N/A
Value of elk killed in reported crashes	1	$2,537	$2,537	N/A	N/A	N/A	N/A

Costs of WVCs (2010 – 2019)		Costs of Mitigation	
Total 10-Year Cost of WVCs	$856,691	Mitigation Subtotal	$467,126
Average Annual Cost of WVCs	$85,669	**Total Costs including Contingencies (30%), Construction Engineering, and Indirect Charges (22.10%)**	**$741,469**
Average Annual Benefit of Mitigation (87% Crash Reduction Factor)	**$74,532**		

N/A = not applicable

Based on these inputs, the benefits of mitigation are projected to exceed the cost of the mitigation investment within 10 years. These calculations are based on reported WVCs only and do not include the benefits of reductions in additional carcasses picked up by CDOT maintenance patrols. Other unquantifiable benefits include increased wildlife connectivity and population resilience. The resulting BCA ratios calculated for this segment were as follows:

- Using CDOT Traffic and Safety Engineering methods for federal HSIP and state FASTER Safety Mitigation grants: 1.36
- Using the guidance for federal TIGER and FASTLANE grants: 1.69
- Using the hybrid approach developed for Colorado's wildlife prioritization studies: 1.50

4.2.2 Benefit-Cost Analyses for Grant Applications

The CDOT Traffic and Safety Engineering Services Branch administers funding through two primary programs: (1) the federal HSIP, and (2) the state program, FASTER Safety Mitigation, which is a component of the FASTER Act of 2009. Traditionally, grant funding eligibility for HSIP and FASTER Safety funding was contingent on meeting a minimum benefit-cost ratio based on potential benefits gained measured in predicted reduction of crashes as the result of a project. However, beginning in 2020, CDOT started evaluating projects using a risk-based, preventative approach, which, while continuing to use benefit-cost ratio to evaluate projects, does not require that a project meet a minimum ratio to be eligible for funding (D. Swenka, pers. comm., 2022).

CDOT DTD generates BCAs for project proposals seeking federal grant funding from programs such as the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Transportation Discretionary Grant Program (previously known as Better Utilizing Investments to Leverage Development [BUILD] and TIGER grants) and FASTLANE grants. USDOT requires that grant applicants use BCAs based on what people would be willing to pay for better safety to avoid an crash in the first place rather than an expense-based approach. Federal guidance for BCA must be done in a manner consistent with Executive Order 12893 ("Principles for Federal Infrastructure Investments," 59 *Federal Register* 4233) and Office of Management and Budget Circular A-94 (*Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*). In February 2021, USDOT published its current *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* (USDOT 2021). In addition, in November 2021, Congress passed the Infrastructure Investment and Jobs Act, which includes dedicated funding via the newly established Wildlife Crossings Pilot Program, as well as other potential funding opportunities for wildlife-highway mitigation through other provisions of the bill. Specific criteria for the pilot program had not yet been established at the time of this writing.

The BCA worksheet calculations do not guarantee approval for grant funding or safety funding. Funding requests must still be completed through the process governed by the CDOT Traffic Safety and Engineering Branch and DTD, respectively.

4.3 Implementation Considerations Matrix

In addition to the wildlife-highway mitigation prioritization process discussed in Chapter 2, the Prioritization Committee also considered urgency, opportunity, and feasibility considerations that may influence the likelihood of mitigation in a given highway segment. These additional considerations were not scored as a part of the prioritization process but should be considered during planning because they may influence implementation. These additional considerations were compiled in an Implementation Considerations Matrix, which is provided as a sortable Excel spreadsheet in the digital deliverables accompanying this report. The matrix includes the following considerations that may influence implementation decision-making or support grant applications:

- Environmental assessment (EA) or environmental impact statement (EIS) commitments to wildlife crossing mitigation, indicating that environmental review as required by the National Environmental Policy Act (NEPA) has already been completed and the project has an anticipated construction time frame in the next 10 to 20 years. EA or EIS commitments were derived from CDOT's list of studies and assessments (CDOT 2022a)
- Funded wildlife crossings mitigation listed as a planned project in the Statewide Transportation Improvement Program (STIP) (CDOT 2021)
- Other types of transportation projects in the STIP that overlap with a top 5 percent segment (CDOT 2021)
- Wildlife crossings mitigation identified for a highway corridor in a Regional Transportation Plan (CDOT 2022b) or in the Statewide Transportation Plan (CDOT 2020)
- A transportation project identified in the 10-Year Plan Project Pipeline that overlaps with a top 5 percent segment. Projects in the development plan may or may not have NEPA completed and may or may not include wildlife-highway mitigation (CDOT 2022c).
- Wildlife crossing mitigation identified in a Planning and Environmental Linkages Corridor document, I-70 Linkage Interference Zones, or comparable planning document
- A high-priority segment (top 5 percent) that overlaps with a priority herd as defined by Secretarial Order 3362 (USDOI 2018)

- Average WVC crashes per mile per year (based on 2009 to 2019 data, except 2018), to provide a standardized comparison across highway segments
- Opportunities to improve existing infrastructure, for example, by retrofitting existing bridges or culverts to function as passageways for deer or elk and adding wildlife-exclusion fencing to these existing structures
- Near-term mitigation opportunities that highlight potential lower-cost mitigation projects (e.g., adding wildlife-exclusion fencing to existing structures, or removing or replacing standard right-of-way fencing with more wildlife-friendly alternatives) that may be pursued as stand-alone projects
- Feasibility and constructability of wildlife crossing structures mitigation (including wildlife-exclusion fencing and associated features) as assessed by the research team during the field review of the top 5 percent of highway segments and the subsequent development of mitigation recommendations for that segment. This evaluation of feasibility and constructability is subjective and may be revised during project development as wildlife mitigation is integrated with other roadway improvements.
- Security of adjacent lands, specifically, the presence of lands managed by a public agency or private conservation lands or easements (based on the Protected Areas Database) within a 0.5- by 0.5-mile moving window. Presence scores for each segment were converted to Low, Medium, and High, where Low is less than or equal to 0.33; Medium is greater than 0.33 to less than or equal to 0.66; and High is greater than 0.66.
- Overlap with key energy development corridors as defined in CDOT's 2045 Statewide Transportation Plan (CDOT 2020)

The Implementation Matrix does not provide users with a definitive answer regarding how to proceed with wildlife-highway mitigation in a given highway segment. Instead, the matrix is designed to help highlight opportunities, partnerships or alignment with other efforts as well as bringing potential challenges to light. The matrix will require periodic updating to reflect changes in the STIP, 10-year strategic pipeline, regional plans, and other planning documents or partner initiatives.

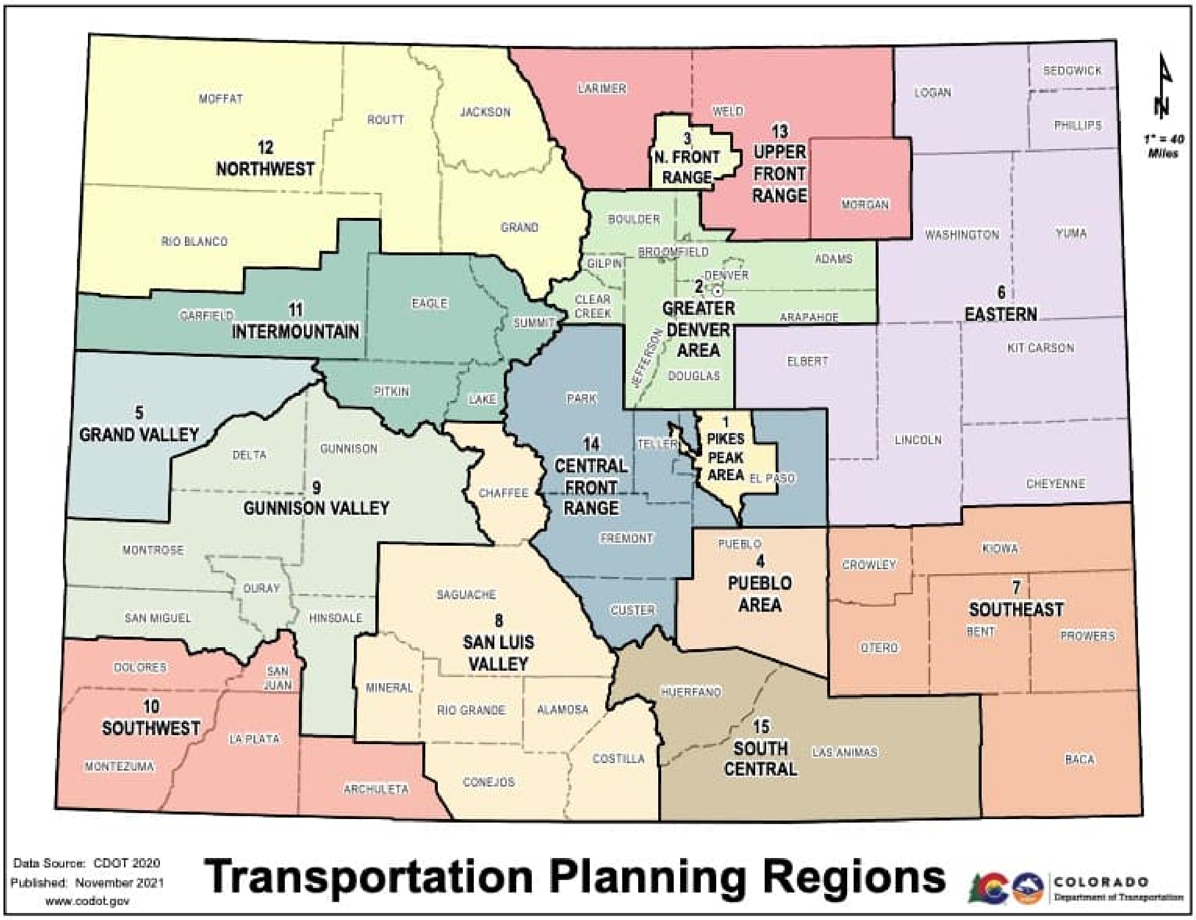
Other considerations are not appropriate for scoring priority segments at the scale of this study and must be assessed during project development and planning, such as accommodations for other species, local WVC hotspots within a high-priority segment (e.g., as highlighted by Getis-Ord analysis), and the estimated likelihood of success of wildlife-highway mitigation in reducing WVC and providing connectivity for wildlife across a roadway, based on terrain, land use, landowner acceptance, and other factors.

4.4 Integrating Wildlife Priorities into Transportation Planning

Transportation planning at CDOT is the process guiding transportation project development and the expenditure of funds to meet Colorado's transportation needs, as documented in the CDOT Planning Manual (CDOT 2017). CDOT, in collaboration with its partners and local agencies, must prioritize where project spending will bring the greatest benefit to ensure its mission—the safe and effective transport of goods, people, and information. Planning at CDOT occurs at multiple scales: locally, though Transportation Planning Regions (TPRs); at the statewide scale; and at the project scale. Although each regional and statewide plan covers a distinct time frame, planning is a continual process to support CDOT's mission.

Transportation priorities are set first at the local scale by each TPR. There are nine planning regions across the Eastern Slope and Plains (Figure 4-2). CDOT gathers input from each TPR to develop Regional Transportation Plans (RTPs). Regional plans look 25 years into the future but focus on actions and investments within the first 10 years. Stakeholders, including local governments and other entities, identify priority transportation corridors in need of near-term improvements and identify their unique needs, priorities, and strategies for the future.

Figure 4-2. Transportation Planning Regions in Colorado
The Eastern Slope and Plains comprise the nine central and eastern regions (Map Credit: CDOT).



The need for wildlife-highway mitigation has been identified as a priority by most Eastern Slope and Plains TPRs. For example, the Pueblo Area Council of Governments specifically identified “protecting critical wildlife migration corridors” as a goal and committed to reviewing projects from an ecosystem perspective (PACOG 2016). Using the prioritization results and BCA tool, CDOT and CPW regional staff can work with the TPRs to ensure that wildlife-highway mitigation needs are effectively captured in the resulting RTPs.

Each TPR’s priority transportation corridors and the goals and strategies for each corridor, including wildlife-highway mitigation, are then integrated into the Statewide Plan (CDOT 2020). The Statewide Plan is a long-range plan with a 25-year outlook that provides the blueprint for how CDOT intends to improve the state’s transportation systems. ESPWPS priorities that are integrated into RTPs ultimately feed into the Statewide Plan and the 10-year Strategic Pipeline Projects list, a prioritized list of potential projects that remain unfunded.

Ultimately, these regional and statewide planning processes direct state and federal project funding. Near-term implementation priorities are compiled into the STIP, which has a 4-year outlook. Federally funded programs and regionally significant projects for which funding has been identified are included in the STIP. Project priorities are selected using guidance from the RTPs and in close cooperation with local officials. Where wildlife-highway mitigation priorities are identified at the regional and statewide levels (including ESPWPS high-priority segments), these projects are better positioned to receive project funding and be included on the STIP.

The ESPWPS decision-support framework was developed to assist planning and environmental staff in determining which potential wildlife-highway projects to pursue within a TPR or priority transportation corridor. While all segments in the top 5 percent are recognized as having high WVC rates and high need for wildlife movement, some segments may be easier to implement where mitigation may be integrated into other transportation improvement projects or where the terrain lends itself to the construction of wildlife crossing structures, or for other reasons. The information about each top 5 percent segment compiled in the Implementation Matrix can be used to identify opportunities and challenges to wildlife-highway mitigation, and the mitigation recommendations for each segment (refer to Mitigation Recommendations supplementary document) can guide early discussions about project planning and budgeting. These decision-support tools enable CDOT to pursue mitigation projects in a more strategic manner than would be possible by ticking projects off from a ranked list based on priority scores alone.

Traditionally, wildlife-highway mitigation is integrated into other transportation projects, for example, when mitigation is needed to compensate for project impacts (e.g., I-25 South Gap Project or I-70 on West Vail Pass). In a few cases, the need for WVC reduction has spurred a more comprehensive highway improvement project (e.g., State Highway 9 in Grand County). Stand-alone mitigation projects are less common, but particularly important in areas where no improvements are anticipated in the foreseeable future or for less extensive enhancements to existing infrastructure, such as adding wildlife-exclusion fencing to an existing bridge or culvert (e.g., U.S. Highway 24/U.S. Highway 285 east of Johnson Village in Chaffee County). Stand-alone mitigation projects for both lower-cost retrofit projects and new wildlife crossing projects are an important part of a comprehensive statewide strategy for reducing WVCs and improving connectivity for wildlife at targeted locations.

Actions for integrating ESPWPS into Transportation Planning

- Regional CDOT staff share and present ESPWPS priorities to each of the TPRs and support their integration into RTPs.
- Add ESPWPS priority segments and other supporting GIS data to the C-Plan website, an open-access, interactive online mapping platform (e.g., add "Wildlife Mitigation Priorities" to the Environmental Gallery).
- Reference the Implementation Matrix to identify potential opportunities for advancing a mitigation project on a high-priority segment.
- Determine opportunities for integrating wildlife-highway mitigation into other transportation projects, or where a stand-alone mitigation project may be warranted.
- Reference the Mitigation Recommendations document accompanying this report and review and revise high-level mitigation strategies as a basis for early planning and budgeting.
- Conduct BCAs using the worksheet tool to evaluate potential mitigation strategies and funding eligibility.

5. Conclusions and Next Steps

The WSWPS and subsequent ESPWPS emerged from a commitment to increased collaboration between CDOT and CPW to address wildlife conflicts on roads. Over the course of these studies, this interagency collaboration has deepened and will continue to be vital in the funding, design, and construction of effective wildlife-highway mitigation projects across the state. Together, these studies position the agencies to proactively pursue strategic wildlife-highway mitigation to improve connectivity for wildlife and reduce incidence of WVCs in Colorado.

5.1 Lessons and Considerations for Future Prioritization Studies

The following insights are offered as guidance for future updates to the WSWPS and ESPWPS.

5.1.1 Re-evaluate Prioritization Criteria for capturing Wildlife Movements in the Plains

The ESPWPS is the first prioritization study of its kind conducted for wildlife in a plains landscape. Accordingly, the research team and study panel had the unique challenge of developing measurable criteria that capture the factors influencing wildlife movements in a landscape that is not defined by pronounced terrain and large elevation gradients. Instead, the prioritization criteria for the Plains were based on proximity to drainages and habitat quality (riparian corridors, native habitat, and agricultural cropland). Although data analyzed herein showed that pronghorn WVC risk was adequately captured by the deer WVC risk models in the Plains, as better data become available over time it may be appropriate to develop risk models specifically for pronghorn or other new criteria that capture factors influencing pronghorn movements, such as fences and other barriers. Likewise, an overlay of black bear and mountain lion WVCs and habitat in the Eastern Slope determined that these species were sufficiently captured by the WVC risk models and other prioritization criteria for deer and elk; however, over time, it may be appropriate to add additional WVC risk models or other criteria for one or both species.

Updates to the WSWPS and ESPWPS are recommended every at least every 10 years and should be conducted concurrently using updated data sets. Although the WVC pattern recognition analysis is applicable statewide, other prioritization inputs are best evaluated separately for each of the analysis areas (Western Slope, Eastern Slope, and Plains) to capture regional variations in the factors influencing wildlife movements and WVC conflicts across the state. For example, the WVC risk modeling process provides a consistent analysis framework for evaluating WVC risk across the state, but each analysis area had a different suite of target species, seasonal time frames, and explanatory variables that were included in these analyses. Other prioritization criteria are also specific to a given analysis area, such as the habitat and land cover indices, which were tailored for deer and pronghorn in the Plains.

5.1.2 WVC Risk Is an Important Consideration informing Mitigation Placement

WVC hotspot analyses of spatial patterns in WVCs (e.g., pattern recognition, Getis-Ord analysis) are useful for objectively identifying road segments with greater numbers of WVCs than expected by chance given the distribution of other WVCs in the data. However, WVC crash data sets are known to be incomplete because of the underreporting of WVCs by drivers. Mitigation project decisions that rely exclusively on these data are likely to miss some areas that are not reflected in the reported crash data, and these data sets do not allow for predicting potential future areas of concern.

WVC risk models use both maintenance carcass data and reported crash data and, unlike hotspot analyses, are useful in identifying the underlying drivers of patterns in WVCs as well as assessing potential future risk. Understanding the factors that influence WVC risk may help to identify road segments that are high risk based on traffic and landscape characteristics in locations where WVCs have been underreported. In addition, each of the individual risk models for deer and elk winter range and migration describe the type and seasonality of WVC risk. The resulting risk models used in conjunction with CDOT's WVC pattern recognition analysis, which analyzes crash patterns for roadways with similar structure (two lanes and four lanes), terrain (flat, rolling mountainous), traffic volumes, and speed limits, provide a deeper analysis of WVC problem areas than a hotspot analysis alone. Both the WVC risk models and the CDOT pattern recognition analysis were included in the WSWPS and ESPWPS prioritizations.

5.1.3 To Address Challenges with Large Urban and Suburban Areas, Incorporate Housing and Road Density Analyses Earlier in the Prioritization Process

Because the ESPWPS was based on the WSWPS, which studied a landscape lacking in large urban centers, the influence of extensive suburbanization and urbanization on the prioritization results was not revealed until later in the analysis process. Although WVC hotspots may occur in or adjacent to urban and dense suburban areas that lie within historical wildlife ranges, these developed areas are not priorities for wildlife connectivity. To address this issue, the research team added a step to the analysis process that was not part of the WSWPS, namely, a housing and road density filter that was applied only to segments in the 95th percentile (Section 2.6.5). Future iterations of the prioritization should incorporate this filter to the entire study area and earlier in the analysis process.

5.1.4 The ESPWPS May Not Fully Address WVC Impacts or Movement Needs for Other Species

The ESPWPS was specifically designed to address WVC conflict and roadway barriers to those animals most frequently involved in WVCs that result in fatalities, injuries, or property damage for the traveling public, primarily focusing on deer, elk, and pronghorn. Yet, the study panel and Jacobs Team recognized that other species are involved in WVCs or require safe passage across roads, and we sought to include considerations for other species in the prioritization process. Bighorn sheep was included as a target species for the Eastern Slope analysis area; however, because the specificity of habitat preferences and road crossing behavior for this species, only one prioritization criterion was included for this species. Consequently, this species had little impact on the overall prioritization scores.

Black bear and mountain lion were considered as potential targets species for the Eastern Slope analysis area. The research team reviewed WVC mortality patterns for bear and mountain lion and determined that WVC hotspots for these species generally align with WVC hotspots for deer and elk and, therefore, these species did not need to also be included as target species. Canada lynx was the only non-ungulate species included in the prioritization, and, as with the WSWPS, the results of this study demonstrated that highway segments that may be important for lynx movement and dispersal do not overlap with the highest-priority segments for deer and elk migration and winter range. Knowing this, separate considerations will be needed to address lynx mitigation in Colorado.

5.1.5 Wildlife Is Undervalued in the Benefit-Cost Analysis

The wildlife valuation originally conducted for the WSWPS and updated and expanded for the ESPWPS was developed as a more comprehensive approach for integrating wildlife values into BCA than other methods currently used by CDOT. Yet, these wildlife valuations are still a conservative estimate of deer, elk, pronghorn, and bighorn sheep values. They do not address all potentially quantifiable benefits of wildlife because comprehensive, discrete data do not currently exist, nor do these valuations capture the numerous unquantifiable benefits of wildlife (for example, passive values such as wildlife viewing, reproductive value of cows and does, and ecosystem value of connectivity). In addition, the amount of wildlife involved in WVCs is grossly underestimated because WVC reports, upon which the BCA is based, represent only a portion of the actual number of WVCs. Systematic, consistently collected, and spatially accurate carcass data combined with the WVC data (with double-counted records eliminated) would provide a better estimate of the number of deer and elk involved in WVCs for inclusion in BCA.

5.2 Data and Research Needs

As a result of this study, several data and research needs were identified that would improve future iterations of the prioritization and efforts to implement effective wildlife-highway mitigation. These recommendations are outlined as follows.

5.2.1 Incorporate Updated CDOT WVC Pattern Recognition Analysis Data

The most recent WVC pattern recognition analysis available from CDOT Traffic Safety and Engineering was conducted in 2013 and was based on crash data from 2008 to 2012. Crash patterns are generally consistent over time, barring major changes in land use or the roadway itself, such as the completion of a highway improvement project; however, an updated WVC pattern recognition analysis using the most recent WVC data sets would lend greater confidence to the accuracy of the prioritization results.

5.2.2 Incorporate Carcass Data deriving from the WVC Carcass Data Collection App

In 2021, CDOT and CPW rolled out new apps designed to facilitate the collection of more comprehensive and spatially accurate carcass data collection across the state. Each agency has developed its own app, whereupon the data may be combined. These apps ease reporting effort, expand roadkill reporting to CPW in addition to CDOT for more comprehensive coverage, and deliver a simple and powerful way to capture highly reliable and accurate data. Future iterations of the prioritization will benefit from these more comprehensive and accurate data.

5.2.3 Develop New Research Studies Focused on understanding Wildlife Movement Patterns Relative to Roadways

Future studies of ungulate habitat use and movement patterns, particularly those that focus on road impacts, would benefit from increased internal coordination among CPW researchers working in different regions. In addition, CPW and CDOT staff need to continue coordinating efforts to understand and meet data needs for research and monitoring related to road impacts on wildlife. The global positioning system collar data provided to the research team for the initial study approach were not collected for this purpose, and thus were accompanied by several caveats from CPW staff. Namely, the sampling effort across the Western Slope was known to be highly skewed toward particular herds. Also, avoidance of major highways in collaring efforts because of safety concerns likely biased the data sets toward individuals that occupy ranges further from highways. If regional-scale studies of road impacts on ungulate movements are of future interest, coordination of collaring efforts to ensure more frequent and even sampling, using consistent methods that include individuals who interact with roads, will be essential to proper inferences.

5.2.4 Contribute to the Crash Modification Factors Clearinghouse

The Federal Highway Administration maintains the comprehensive Crash Modification Factors Clearinghouse (http://cmfclearinghouse.org/), but this national database does not include crash modification factors for wildlife mitigation. Submitting relevant scientific research documenting wildlife mitigation crash reduction rates for inclusion in the clearinghouse would help establish nationally accepted crash modification factors for wildlife mitigation. This would aid state departments of transportation in conducting BCA for wildlife mitigation or pursuing mitigation funding.

5.2.5 Monitor Effectiveness in reducing WVCs for Every Wildlife-Highway Mitigation Project

Not all wildlife-highway mitigation projects necessitate a comprehensive research study to evaluate mitigation effectiveness in providing safe passage for wildlife and reducing WVCs. In-depth research is warranted for projects that employ novel mitigation strategies or designs and for species for which there is limited research regarding their use of crossing structures. For other projects using more standard mitigation strategies and designs, simply comparing 5-year pre- and post-construction WVC rates will sufficiently evaluate mitigation effectiveness. Postconstruction WVC rates that remain higher than the objective may need adaptive management.

5.2.6 Create a Centralized Data Repository for Wildlife Data Sets

A centralized data repository would assist in the compilation of wildlife data and ensure greater consistency in data collection, storage, processing, and, where appropriate, data sharing.

5.3 Next Steps

Since the completion of the WSWPS in 2019, several of the next steps identified in that report have since been addressed or are in progress, including the following:

- Expand the WSWPS to the Eastern Slope and Plains (this study).
- Link WSWPS priorities to the Colorado Wildlife and Transportation Alliance (Alliance).

Still other items require additional attention:

5.3.1 Integrate Wildlife-Highway Mitigation Priorities into Regional Transportation Plans, the Development Program, and Asset Management

Rural transportation project priorities at CDOT are generally determined at the local scale by the TPRs, as described in Section 4.4 of this report. Further integrating priority segments identified through the WSWPS and ESPWPS into RTPs will help in securing future funding for wildlife mitigation. As the RTPs are developed, regional CDOT planning and environmental staff, along with CPW biologists, must communicate the findings of these prioritization studies at TPR meetings and via other community outreach. The research team will further support this process through the regional trainings, which are a follow-up task at the completion of this study (Section 5.3.2).

In addition, as each CDOT region begins developing funding strategies for mitigation projects (for example, discretionary asset management and maintenance projects), regional environmental and planning staff can coordinate to determine where low-cost improvements in priority areas can be made and integrated into projects as funding and program flexibility allow. An example might be modifying right-of-way fence in critical areas by replacing woven wire fence with a more wildlife friendly alternative or adding wildlife-exclusion fence to existing bridges or culverts in discrete high-priority segments.

5.3.2 Periodically Integrate New Data and Information into the Decision-support Tools

The results of this research are anticipated to assist CDOT and CPW to strategically address wildlife-highway mitigation across the Eastern Slope and Plains for a minimum of 10 to 20 years. In general, identified regional priority areas are expected to remain consistent over this time frame, although some local shifts because of changes in land use or habitat conditions are likely. However, components of the decision-support tool should be updated more frequently. These include the following:

- *Benefit-Cost Analysis Tool*—Update crash costs annually as provided by CDOT Traffic and Safety Engineering; update mitigation costs and mitigation effectiveness every 2 to 5 years.
- *Implementation Considerations Matrix*—Coordinate with the Alliance to update matrix considerations relative to the Alliance's Project Priorities Status list every 1 to 3 years.
- *Prioritization of Highway Segments*—Every 10 years, update the prioritization of highway segments across each of the analysis areas in the state with updated data, including new collar data and wildlife habitat maps, traffic demand forecast models, and updated WVC data and pattern recognition analyses from CDOT Traffic and Safety Engineering. Updates to the prioritization of highway segments should address the limitations of the current study by reconsidering the prioritization criteria and incorporating other lessons learned (Section 5.1).

5.3.3 Regional Trainings using the Eastern Slope and Plains Wildlife Prioritization Study

Following the completion of this report, the research team will develop and host training modules to provide CDOT, CPW, and Rocky Flats National Wildlife Refuge staff (refer to Rocky Flats Addendum for the focused prioritization of highway segments around the Refuge) with a comprehensive understanding of the ESPWPS and decision-support framework. The modules will be designed to train participants in the use of the study's prioritization results and decision-support tools for integrating wildlife mitigation recommendations into projects or creating stand-alone projects and evaluating mitigation options during project development. The need for such trainings was also evident following the completion of the WSWPS, particularly for regional agency staff that may be involved in future project development but that were not directly involved in the prioritization process. Specifically, the training modules will provide an overview of the ESPWPS and train participants in the use of each of the components of the decision-support framework, including the prioritization results, mitigation recommendations, implementation matrix, and BCA tool, as well as the GIS files produced as a result of this study. The trainings will also prepare agency staff for working with individual TPRs to integrate wildlife-highway mitigation priorities into regional plans and priority lists, and demonstrate how the findings of this study may be used to advance individual mitigation projects for grant applications and partnership development.

5.3.4 Future Updates to Colorado's Wildlife Prioritization Studies

The research team recommends rerunning the prioritization analyses with updated data sets every 10 years. The WVC risk models may be rerun using an R-script that was developed for the project, and other analyses were conducted using ArcGIS spatial analyses as documented in the analysis methods (Appendix D). All these analyses may be repeated by CDOT or CPW staff.

In general, wildlife movement patterns and WVC problem areas remain consistent over the long run; however, major changes in land use resulting in habitat destruction or the implementation of wildlife-highway mitigation projects in current priority areas will result in adjustments to the prioritization of highway segments. Periodically rerunning these analyses will ensure that CDOT and CPW continue to invest in mitigation where it will bring the greatest benefits for wildlife and people alike.

6. References

Baigas, P.E., J.R. Squires, L.E. Olson, J.S. Ivan, and E.K. Roberts. 2017. “Using environmental features to model highway crossing behavior of Canada lynx in the Southern Rocky Mountains.” *Landscape and Urban Planning* Volume 157, pp. 200-213.

Chapman, S.S., G.E. Griffith, J.M. Omernik, A.B. Price, J. Freeouf, and D.L. Schrupp. 2006. Ecoregions of Colorado (color poster with map, descriptive text, summary tables, and photographs). U.S. Geological Survey, Reston, Virginia.

Colorado Department of Transportation (CDOT). 2013. *Wildlife-vehicle Collisions Pattern Recognition Analysis*. Traffic and Safety Engineering Branch, Colorado Department of Transportation, Denver, Colorado.

Colorado Department of Transportation (CDOT). 2017. *Transportation Planning in Colorado: CDOT Planning Manual*. Colorado Department of Transportation, Denver, Colorado. May.

Colorado Department of Transportation (CDOT). 2020. *Your Transportation Plan: 2045 Statewide Transportation Plan*. Colorado Department of Transportation, Denver, Colorado.

Colorado Department of Transportation (CDOT). 2021. *Colorado Statewide Transportation Improvement Program Fiscal Years 2022-2025*. Colorado Department of Transportation, Denver, Colorado.

Colorado Department of Transportation (CDOT). 2022a. Studies & Assessments. https://www.codot.gov/projects/studies-assessments.

Colorado Department of Transportation (CDOT). 2022b. 2040 Regional Transportation Plans. https://www.codot.gov/programs/planning/transportation-plans-and-studies/2040-regional-transportation-plans.

Colorado Department of Transportation (CDOT). 2022c. *Project Pipeline*. Adopted May 2020, updated January 2022. Colorado Department of Transportation, Denver, Colorado.

Colorado Parks and Wildlife (CPW). 2014. *Colorado West Slope Mule Deer Strategy*. Colorado Parks and Wildlife, Denver, Colorado. November.

Conover, M.R., W.C. Pitt, K.K. Kessler, T.J. DuBow, and W.A. Sanborn. 1995. “Review of Human Injuries, Illnesses, and Economic Losses Caused by Wildlife in the United States.” *Wildlife Society Bulletin* Volume 23, Number 3, pp. 407-414.

Drummond, M.A. 2012. “Southern Rockies Ecoregion.” In B.M. Sleeter, T.S. Wilson, and W. Acevedo, editors. *Status and Trends of Land Change in the Western United States – 1973 to 2000*. Professional Paper 1794–A. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.

Felsburg Holt & Ullevig and BBC Research & Consulting (FHU and BBC). 2015. *Oil and Gas Impacts on Transportation.* Report Number CDOT-2015-09. Applied Research and Innovation Branch, Colorado Department of Transportation, Denver, Colorado. November.

Harmon, Tim, G. Bahar and F. Gross. 2018. "Crash Costs for Highway Safety Analysis". U.S. Department of Transportation, Federal Highway Administration, Washington D.C. Report No. FHWA-SA-17-071.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, and R. Ament. 2007. *Wildlife-Vehicle Collision Reduction Study: Report to Congress*. U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

Insurance Institute for Highway Safety (IIHS). 2018. Facts + Statistics: Deer vehicle collisions. https://www.iii.org/fact-statistic/facts-statistics-deer-vehicle-collisions.

Jacobs. 2018. *Considerations for the East Slope and Plains wildlife prioritization study*. White Paper to the Colorado Department of Transportation, Denver, Colorado.

Jacobson, S.L., L.L. Bliss-Ketchum, C.E. de Rivera, and W.P. Smith. 2016. "A behavior-based framework for assessing barrier effects to wildlife from vehicle traffic volume." *Ecosphere* Volume 7, Number 4, e01345.

Kay, F.R. 1988. *Nevada survey of the economic value of trophy big game and deer harvest 1984 through 1986*. Nevada Department of Wildlife, Biological Bulletin Number 9.

Kintsch, J., P. Cramer, P. Singer, and M. Cowardin. 2021. *State Highway 9 Wildlife Crossings Mitigation Monitoring*. Report No. CDOT-2021-01. Colorado Department of Transportation, Denver, Colorado. March.

Kintsch, J., P. Basting, M. McClure, J. O. Clarke. 2019. *Western Slope Wildlife Prioritization Study*. Report No. CDOT-2019-01. Colorado Department of Transportation, Denver, Colorado.

Kolowski, J.M. and C.K. Nielsen. 2008. "Using Penrose distance to identify potential risk of wildlife–vehicle collisions." *Biological Conservation* Volume 141, Issue 4, pp. 1119-1128.

Olson, D.D. 2013. *Assessing Vehicle-Related Mortality of Mule Deer in Utah*. PhD Dissertation, Paper 1994. Utah State University, Logan, Utah.

Omernik, J.M. 1987. "Ecoregions of the Conterminous United States." *Annals of the Association of American Geographers* Volume 77, Issue 1, pp. 118-125.

Pueblo Area Council of Governments (PACOG). 2016. *2040 Long Range Transportation Plan*. Pueblo Area Council of Governments, Pueblo, Colorado.

Servheen, C., R. Shoemaker, and P. Basting. 2007. "Measuring the success of wildlife linkage efforts." In C.L. Irwin, D. Nelson, and K.P. McDermott, editors. *Proceedings of the 2007 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.

State Farm. 2021. How likely are you to have an animal collision? https://www.statefarm.com/simple-insights/auto-and-vehicles/how-likely-are-you-to-have-an-animal-collision .

Watson, S.M. 1990. *Economic Value of Dall Sheep Hunting in Alaska*. Master of Science Thesis. University of Alaska, Fairbanks, Alaska. May.

U.S. Department of the Interior (DOI). 2018. *Improving Habitat Quality in Western Big-Game Winter Range and Migration Corridors*. Secretarial Order No. 3362. U.S. Department of the Interior, Washington, D.C.

U.S. Department of Transportation (USDOT). 2021. *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. U.S. Department of Transportation, Office of the Secretary, Washington, D.C. February.

U.S. Environmental Protection Agency (USEPA). 1997. Level III and IV Ecoregions of the Continental United States. U.S. Environmental Protection Agency database. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states.

U.S. Fish and Wildlife Service (USFWS). 2011. *Net Economic Values for Wildlife-Related Recreation in 2011: Addendum to the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. Report No. 2011-8. U.S. Fish and Wildlife Service, Washington, D.C.

Appendix A
Interviewees

Appendix A. ESPWPS Interviewee List

- Angelique Curtis, Wildlife Biologist, Colorado Parks and Wildlife, Northeast Region
- Marty Stratman, Wildlife Biologist, Colorado Parks and Wildlife, Northeast Region
- Galen Guerrero-Murphy, The Nature Conservancy
- Chris Pague, The Nature Conservancy
- Julie Stiver, Senior Terrestrial Biologist, Colorado Parks and Wildlife, Southeast Region
- Travis Black, Northwest Regional Manager, Colorado Parks and Wildlife; Former Deputy Southeast Regional Manager
- Shannon Schaller, Northeast Deputy Regional Manager, Colorado Parks and Wildlife; Former Senior Terrestrial Biologist Northeast Region
- Jeff Peterson, Statewide Wildlife Biologist, Colorado Department of Transportation
- Gabriel Cosyleon, Region 2 Planning and Environmental Manager, Colorado Department of Transportation
- Chuck Attardo, I-25 South Corridor Environmental Manager, Colorado Department of Transportation
- Jim Eussen, Region 4 Planning and Environmental Manager, Colorado Department of Transportation
- Anthony Vu, Engineer in Training III, Traffic and Safety Engineering Services, Colorado Department of Transportation
- Eastern Slope and Plains Study Panel Members

Appendix B
Data Synthesis and Sources

Appendix B. Data Synthesis and Sources

Wildlife Movement/Space Use Data (CSP)					
Species	*Data Type/Extent*	*Resolution*	*Data Source*	*Contact*	*Expected Uses/Status Notes*
Deer	GPS locations - home range		CPW		Parameterize RSFs, verify/validate landscape permeability models
Deer	GPS locations - migratory		CPW		Parameterize RSFs, verify/validate seasonal migration corridor models
Deer	GPS locations - home range		Sawyer et al.	Hall Sawyer	Parameterize RSFs, verify/validate landscape permeability models
Deer	GPS locations - migratory		Sawyer et al.	Hall Sawyer	Parameterize RSFs, verify/validate seasonal migration corridor models
Deer	Summer/winter range polygons		CPW		Nodes for modeling seasonal migration corridors
Deer	DAU boundaries & herd size estimates (2016)		CPW	Andy	Estimation and mapping of wildlife criteria
Elk	GPS locations - home range		CPW		Parameterize RSFs, verify/validate landscape permeability models
Elk	GPS locations - migratory		CPW		Parameterize RSFs, verify/validate seasonal migration corridor models
Elk	Summer/winter range polygons		CPW		Nodes for modeling seasonal migration corridors
Elk	DAU boundaries & herd size estimates (2016)		CPW	Andy	Estimation and mapping of wildlife criteria
Pronghorn Antelope	GPS locations - home range		CPW		Estimation and mapping of wildlife criteria
Pronghorn Antelope	GPS locations - migratory		CPW		Estimation and mapping of wildlife criteria
Pronghorn Antelope	Summer/winter range polygons		CPW		Estimation and mapping of wildlife criteria
Pronghorn Antelope	DAU boundaries & herd size estimates (2016)		CPW		Estimation and mapping of wildlife criteria
Bighorn Sheep	GPS locations		CPW		Estimation and mapping of wildlife criteria
Mtn Lion			CPW		Estimation and mapping of wildlife criteria
Lynx	Prioritized lynx hwy segments		Baigas et al. 2016	John Squires	ID lynx priorities or verify/validate landscape permeability models (if other data available to
Wildlife Habitat Data (CSP)					
Attribute	*Data Type Extent*	*Resolutio*	*Data Source*	*Contact*	*Expected Uses Status Notes*
SAM habitat layers	Existing species habitat layers		CPW		
Land cover	Gridded vegetation type	25m	Colorado Vegetation Classification Project		Colorado Vegetation Classificaiton Project from NLCD 2016
Land cover	Gridded land cover type	30m	NLCD (USGS)		RSF model variables (percent cover type, forest edge distance, etc.)
Land cover	Gridded existing vegetation type	30m	LandFire EVT		LF EVT data created 2011
NDVI	Gridded data derived from satellite imagery	250m	MODIS		
Roads	Road network polylines		CDOT		RSF model variable (density/distance to roads/segmentation)
Topography	Digital elevation model	30m	LandFire Topographic		RSF model variables (elevation, slope, aspect, ruggedness, TPI)
Topography	Compiled bare earth elevation data	1m	USGS National Elevation Dataset		
Water sources	Point sources, stream lines, and water body		NHD+		RSF model variables (distance to water)
Wildfire Data					
Collision Risk Data (Jacobs GIS)					
Attribute	*Data Type Extent*	*Resolutio*	*Data Source*	*Contact*	*Expected Uses Status Notes*
Animal-vehicle collisions Animal-vehicle collisions	Collision point locations		CDOT CPW	Jeff Peterson	Identify collision risk hotspots, cost-benefit analysis, validate connectivity models Identify
Animal carcass data	Wildlife carcass point locations		CPW	Jeff Peterson	Identify collision risk hotspots, cost-benefit analysis, validate connectivity models
WVC Pattern Recognition	Shapefile with elevated WVC		CDOT Traffic and Safety Engineering	David	Identify collision risk hotspots, cost-benefit analysis, validate connectivity models

Current/Projected Human Infrastructure Data (CSP)					
Attribute	*Data Type Extent*	*Resolutio*	*Data Source*	*Contact*	*Expected Uses Status Notes*
Bridge Enterprise Projects	Locations/descriptions of planned CDOT		CDOT		
Crossing structures	Point locations of bridges, underpasses,		CDOT		
Highway Absolute Grade			CDOT		
Highway Curve Class			CDOT		
Highway fencing	Fenced road section line polylines		CDOT		
Land use, current	Land use type (general)		NLCD		
Land use, current	Land use type (detail)		NAIP imagery		
Land use, current	Parcel polygons		Counties		
Land use, future	Existing land use projections (2040)		ICLUS/SERGoM		
Land use, future	Parcel-level build-out analysis (2040)		CSP		
Lakes, Streams, Rail Lines	Lake polygons, stream lines and rail lines		CDOT OTIS		Mapping Priority Segments showing natural and built features
Long Range Plan Priorities	Locations/descriptions of planned CDOT		CDOT		
MPO and TPR Boundaries	Planning unit boundary polygons		CDOT		
Ownership/Protected Status	Protected land ownership polygons		COMaP		
Ownership/Protected Status	Protected land ownership polygons		PADUS		
Projected human population	Population projections (2040)		State demographer/Census Bureau		
Protected areas	Protected area polygons status/ownership		PADUS		Criterion for status of road-adjacent lands
Roads	Road network polylines		CDOT		
Road characteristics: Width, number of lanes, surface type, speed, etc.	Attribute data for road network		CDOT		
Roads Mileposts, Number of lanes, surface type, Current annual traffic, Future annual traffic, Highway fencing, Crossing structures,	Milepost point locations/identifiers		CDOT		Reference/alignment, Reference/alignment, Circuitscape resistance surface, Circuitscape resistance surface, Circuitscape resistance surface, Circuitscape resistance surface and/or contextual, Circuitscape resistance surface and/or contextual, Circuitscape resistance surface (projected)
STIP and long-range plan	Locations/descriptions of planned CDOT projects		CDOT		
Traffic volume: Current annual/monthly traffic	Traffic volume road attribute		CDOT		
Traffic volume: Future annual/monthly traffic	Projected traffic volume (2040)		CDOT		

Appendix C
Pre-Analysis Methods

Appendix C. Data Processing Overview

Baseline modeling data were derived from the Highway_Traffic feature class provided by the Colorado Department of Transportation (CDOT) Division of Transportation Development Information Management branch. This data set covers road segments within all CDOT regions and was reduced to include only roadways within Regions 1, 2, and 4. The original feature class contains traffic volume counts and other attributes identified as being important in the wildlife-vehicle collision (WVC) modeling process.

C.1 Linear Referencing System

CDOT's Route layer was used to create a linear referencing system (LRS) representing the centerline of state highways. It contains LRS measures, suitable for dynamic segmentation in the geographic information system (GIS). The LRS was used to move the data between the GIS and Excel spreadsheets, enabling the data to maintain a spatial reference.

All highway reference features were then added into the GIS by their route and milepost reference: mileposts, WVC events, and carcass events. This ensured proper placement of all features within the GIS without any offsets.

C.2 Attribution of WVC and Carcass Events

WVC and wildlife carcass data sets were provided by CDOT for use in the modeling process and were contained in multiple spreadsheets. The data used in the process span the 10 years between 2009 and 2019, excluding 2018, and focus on deer, elk, and antelope. The WVC data were cleaned up by removing records without valid spatial coordinates, species not analyzed in our study, and any records pertaining to 2018, resulting in 14,867 WVC events for analysis. The GIS data points provided were imported into the LRS using the route and milepost of each event.

The carcass data were cleaned up and imported in a similar manner with the additional process of checking for records that may be duplicates of WVC events. It is assumed that many of the carcasses located and picked up by the maintenance department are the same animals that are in the WVC data records. To identify and remove maintenance carcasses that are duplicates of the WVC reports, the two data sets were joined by segment, date, and animal type. If the same type of animal carcass is recorded by maintenance and the WVC reports on the same segment of road, and no more than 2 days after the WVC, then the carcass is assumed to be the same animal as the one reported in the WVC data. After cleanup, the resulting carcass data set contained 9,146 records (Table C-1).

The WVC and carcass data were maintained as points throughout the attribution process. This differed from the Western Slope Wildlife Prioritization Study, which segmented the highways first and then assigned the event to the highway before processing. The change in process was made to maintain the spatial location of each event so that accurate parameters could be determined. Many of the early segmentation issues were avoided by maintaining points for attribution:

- Highway segments cannot be segmented by 0.5 mile cleanly while maintaining attributes for speed, volume, and width. The correct attributes can be assigned to each point.
- Points are a more accurate feature type for extracting raster data for attributes such as land cover and distance to features.
- R processes individual records, allowing for the data points with each set of unique attributes to be considered individually.
- The LRS made it easy to go back and forth between GIS and Excel forms of data by reinserting the points by route and milepost.

All spatial analysis and attribution were performed at this level.

C.3 Road Segment Determination

FME, by Safe Software, was used to create the road segments. Each route length was calculated, the number was divided by 0.5 mile, and the result was rounded to the closest interval. A total of 12,271 road segments were created. This ensured a more consistent length division. After the point events were processed and calculated, the attributes for the points along each segment were averaged and given to that segment. Road segmentation was the last step and was used to provide CDOT a clearer result that aligned with project management.

Table C-1. Summary of Animal Counts by Species

Wildlife-Vehicle Collisions And Carcass Counts By Species

Species	WVC		Carcass		Other WVC Animal Count	
	Animal Count	% of Total	Animal Count	% of Total		
Antelope	121	0.9%	193	2.1%	Bear	227
Deer	11,777	87.7%	8,334	91.1%	Lion	44
Elk	1,532	11.4%	619	6.8%	Sheep	30
Total Animal Count (select animals)	13,430		9,146			301
Other	301					
Total Reports	**13,731**		**9,146**			

Note:

The CDOT crash data contained numerous other species that were filtered out prior to importing into Jacobs' software for analysis.

% = percent

C.4 Cluster Analysis of the Collision and Carcass Data

WVC and maintenance carcass data were run through two different cluster analyses: hotspot analysis and Anselin Local Moran's I. The Hot Spot Analysis tool was run on the WVC data in ArcGIS Pro 2.8 (Figure C-1). According to the description by Esri (n.d.),

> *The Hot Spot Analysis tool calculates the Getis-Ord Gi statistic… for each feature in a dataset. The resultant z-scores and p-values tell you where features with either high or low values cluster spatially. This tool works by looking at each feature within the context of neighboring features. A feature with a high value is interesting but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature will have a high value and be surrounded by other features with high values as well. The local sum for a feature and its neighbors is compared proportionally to the sum of all features; when the local sum is very different from the expected local sum, and when that difference is too large to be the result of random chance, a statistically significant z-score results.*

For weighing the neighborhood events, the spatial conceptualization method used was Zone of Indifference. This method is a combination of Inverse Distance and Fixed Distance Band. Anything up to a critical distance affects analysis. Once that critical distance is exceeded, the level of impact quickly drops off. The distance used to hold all events equal was 1,086 meters, approximately two-thirds mile. This distance smoothed out small isolated pockets by bringing them equal to the general area without combining too large an area into large combined events—a best-fit compromise.

The carcass data were run through the Cluster and Outlier Analysis (Anselin Local Moran's I) tool in ArcGIS Pro 2.8 (Figure C-2). This cluster analysis tool identifies where high or low values cluster spatially. Features with values that are very different from surrounding feature values are identified as outliers. The method chosen for the carcass clustering was Inverse Distance Squared (IDS) using Euclidean distances and row standardization. The default neighborhood search threshold was 1,086 meters. Under this method, nearby neighboring features have a larger influence on the computations for a target feature than features that are far away. Using IDS the slope is sharper than in normal Inverse Distance, so influence drops off more quickly, and only a target feature's closest neighbors will exert substantial influence on computations for that feature.

Figure C-1. Getis-Ord Gi Hotspot Zones for WVC

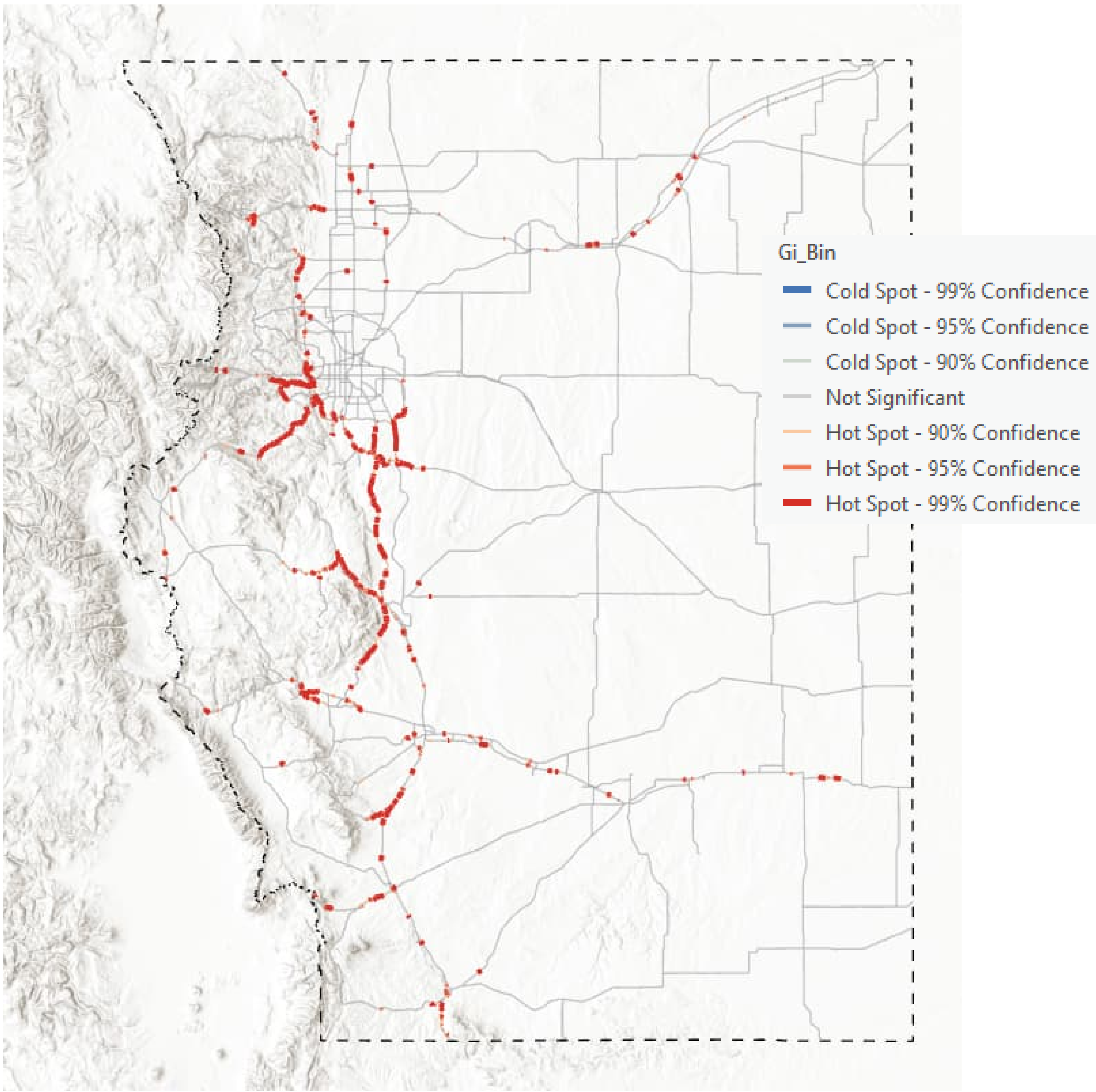
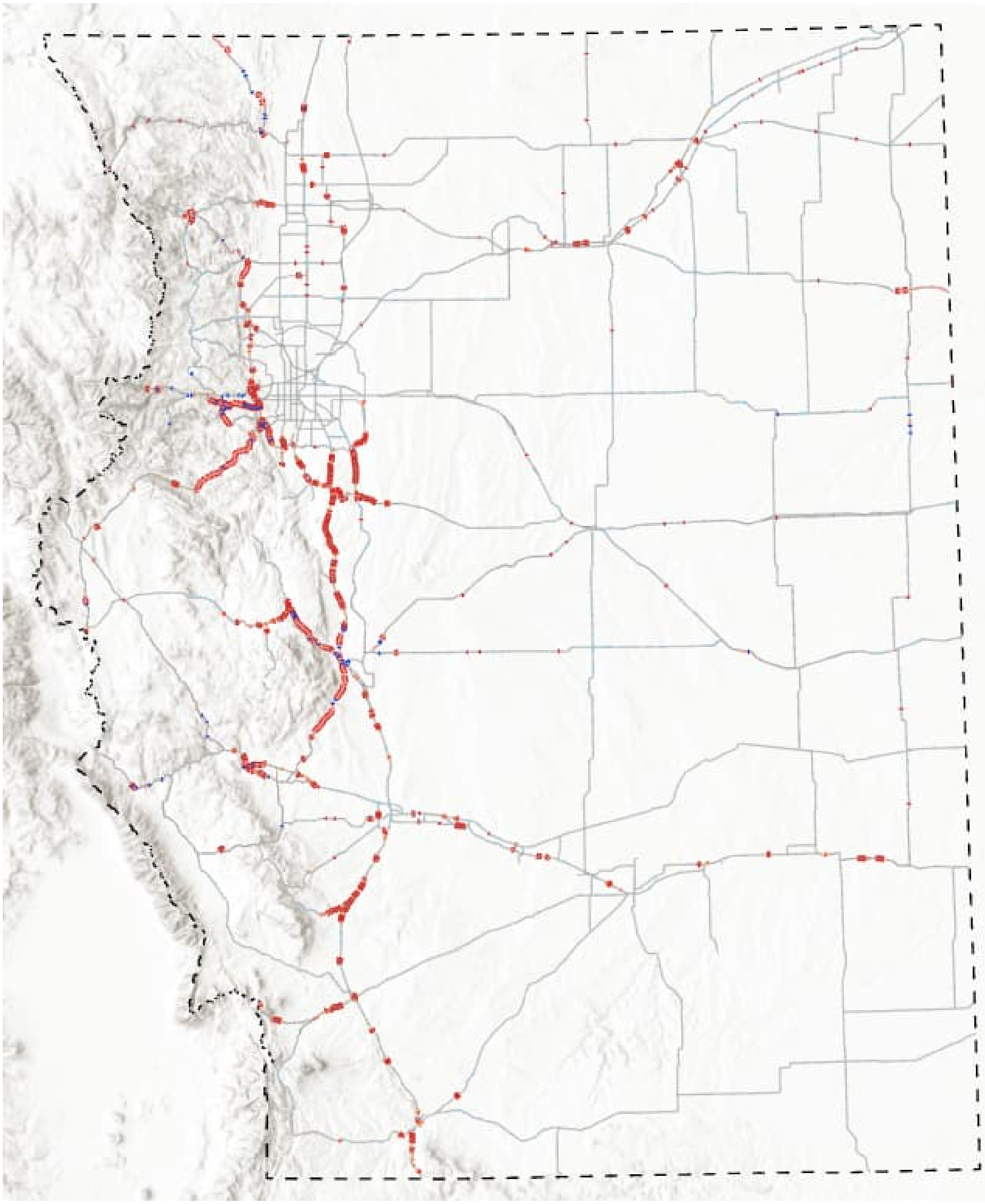


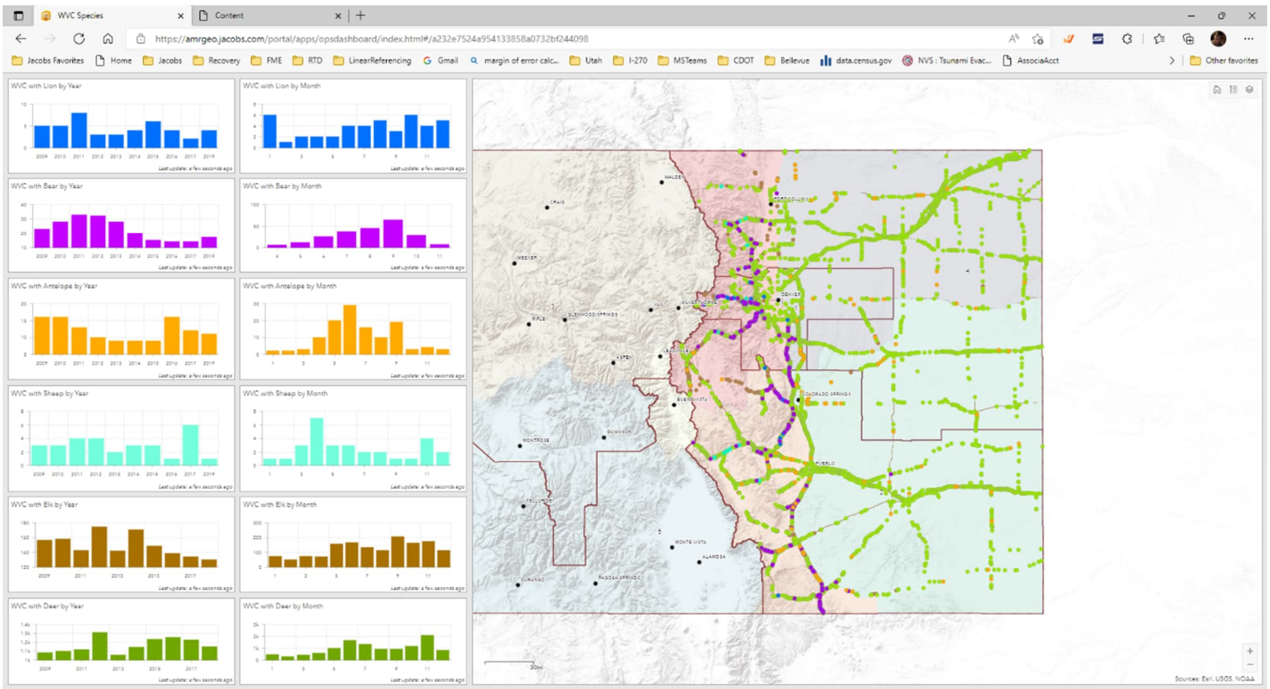
Figure C-2. Cluster and Outlier Analysis for Carcass Data



C.5 Seasonal and Annual Patterns

The WVC point data was filtered to show seasonal and annual trends as a supplement. The intent of showing the adjusted raw data sets in this way is to help identify whether changes might be occurring during the 10-year data collection period because of construction of mitigation structures or other sudden events (annual filter). It is also to help identify whether the WVC events occur during particular movement periods or impact herds within seasonal ranges (monthly filter). This data does not stand alone, but is used only as a supplement to the other models.

Figure C-3. WVC Seasonal and Annual Trends 2009 – 2017 & 2019



C.6 Brownian Bridge Movement Models

Data provided by CPW was fit to a Brownian bridge movement model (BBMM), estimating the probability of an individual passing through any given raster cell between observed GPS collar locations. The BBMM analysis was performed using University of Wyoming's Migration Mapper (Mapper), "a free application for researchers, biologist, and managers" based on the statistical language R. (Migration Mapper | Wyoming Migration Initiative). The GPS collar datasets provided by CPW included:

- Bighorn sheep RBS 9 west of Canon City. Due to problems processing the ram data, only the ewes were processed.
- Bighorn sheep near Pike's Peak was not processed due to some formatting issues. The data will need further formatting to process within the Mapper program.
- Elk, mule deer, and bighorn sheep in the Northeast region.
- Pronghorn on the Plains. This data was processed by CPW and was included with no further processing.
- Elk in South Park.

Some of the data contained formatting issues that required additional processing to reformat dates and time, remove records that had more than 25 hour gaps, and remove location changes under 100 feet (not all datasets). The default parameters were accepted for most processing with the exception of Maximum fix interval of 8 hours. Much of the collar data was recorded at 12+ hour intervals for the maximum, therefore, the maximum interval was reset in Mapper.

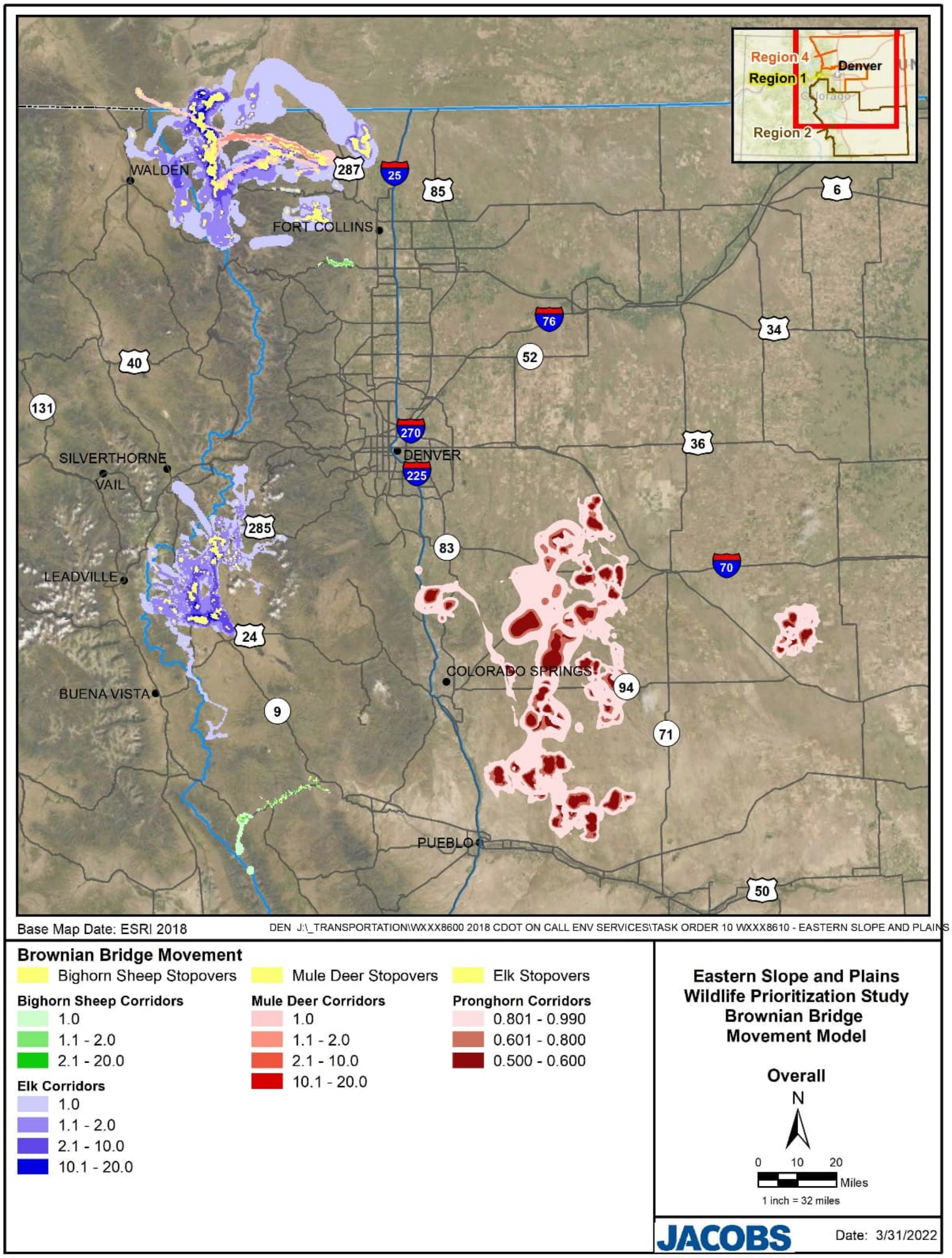
Table C-2. BBMM Data Resets and Adjustments

Dataset	Species	Location	Max interval (hrs)	Other adjustments
RBS9 ewes	Bighorn ewes	Canon City	13	Δxy < 100 remove
S6-S46	Bighorn	Pike's Peak	not processed	
NE_Elk	Elk	Northeast	18	no additional processing
MDGPS CDOT	Mule deer	Northeast	25	Δxy < 100 remove
NE_S57	Bighorn	Northeast	25	Δxy < 100 remove
Plains	Pronghorn	Plains	CPW processed	
SP_Elk	Elk	South Park	20	Δxy < 100 remove

Mapper provides a user interface that gives visual graphs of maps showing individual animal movement distances and locations. The user then selects any apparent migration dates based on Spring or Winter migration. For those records that showed migration, Spring was loosely between February and June, and Winter was August through November depending on the dataset.

In working through some of the difficulties in processing the data, I corresponded with the support team at the University of Wyoming Mapper team. I found the support responsive and helpful. One important point that the support person made was that by deleting records of movement less than 100 feet and more than 25 hours, that a bias for corridors over stopovers may be introduced. Note: the BBMM data, as processed, may underrepresent stopovers.

Figure C-4. ESPWPS Study Area Overview of BBMM Data



C.7 References

Esri. n.d. How Hot Spot Analysis (Getis-Ord Gi*) works. https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm.

Appendix D
Risk Modeling Methods

Appendix D. Pre-Analysis Methods

D.1 Background and Purpose

The Eastern Slope and Plains Wildlife Prioritization Study (ESPWPS) is a collaborative effort between Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW), conducted by Jacobs and its partner, ECO-resolutions. The goal of the project is to analyze wildlife populations, wildlife movement patterns, roadway infrastructure, and travel demand overlap under current and projected future scenarios to highlight regional mitigation priorities. Additionally, this project aims to improve interagency communication; identify landscape-level priorities for mitigation in important, high-risk wildlife movement areas; improve driver safety; provide benefit-cost analysis of wildlife mitigation options; and improve transportation planning and funding of wildlife mitigation on the Eastern Slope and Plains. Ultimately, the methodology developed here could be adopted and applied statewide.

As part of the ESPWPS, Jacobs was tasked with modeling wildlife-vehicle collision (WVC) risk for mule deer, elk, and pronghorn throughout the road network in CDOT Regions 1, 2, and 4 (i.e. Eastern Slope and Plains) using available spatial data to inform mitigation prioritization, under both current and future conditions (i.e., projected land use and traffic volume). In this report, we summarize our methodology and findings, and discuss challenges and implications for future work.

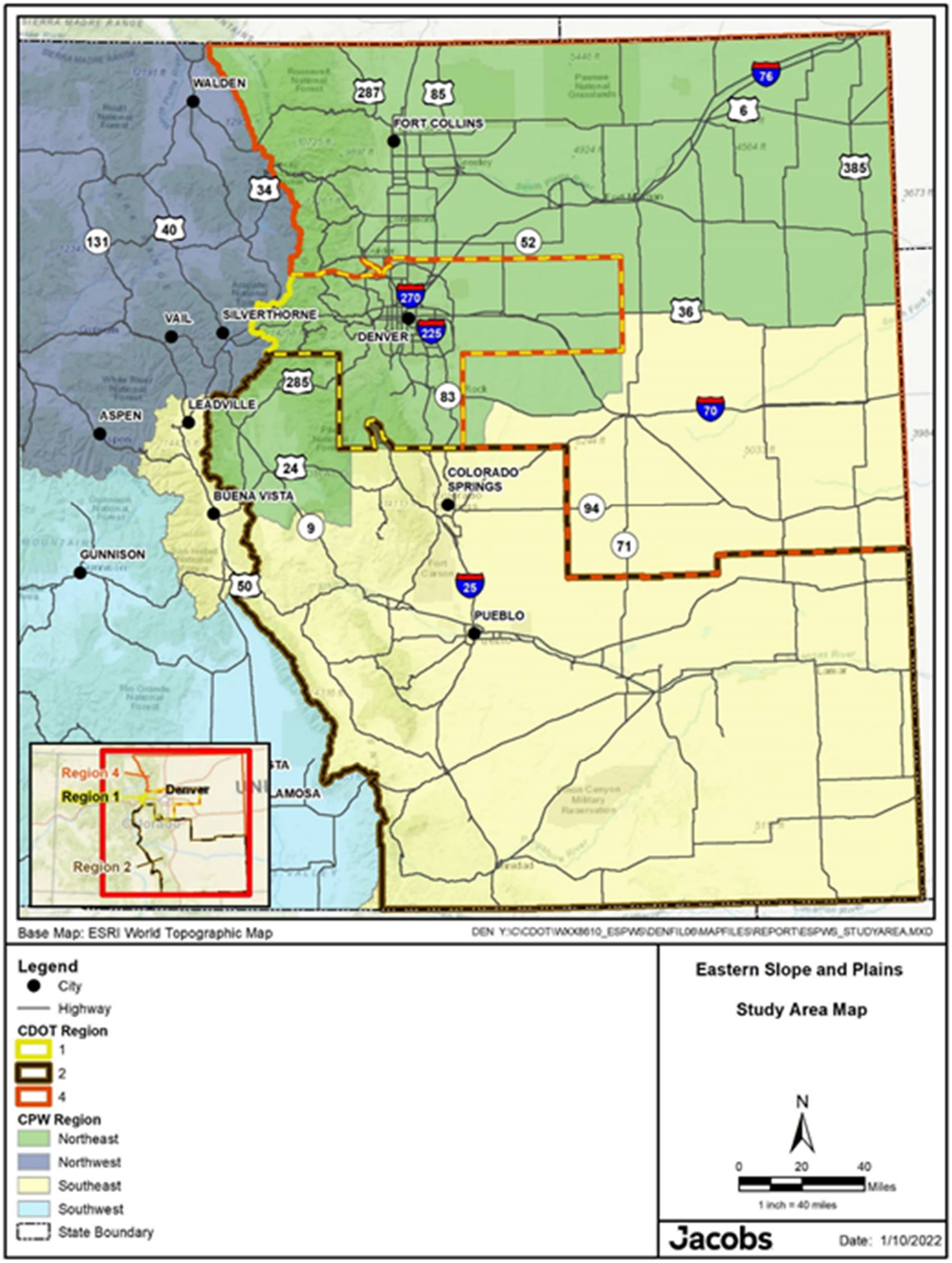
D.2 Methods

D.2.1 Study Area

The ESPWPS study area is defined by CDOT Regions 1, 2, and 4, which roughly correspond to CPW's Northeast and Southeast Regions (Figure D-1). Geographically, the Eastern Slope and Plains extends across the central and eastern two-thirds of the state from the Continental Divide to the Nebraska and Kansas borders. It is home to 90 percent of Colorado's residents, and the Eastern Slope and Plains contains 67 percent of the state's land, but only about 30 percent of its water (Vandenbusche 2018).

The CDOT and CPW regions are administrative divisions to help in the management of their respective programs. The CDOT highway system consists of interstates, U.S. highways, and Colorado state highways. In total, CDOT Regions 1, 2, and 4 manage 5,595 route miles. CDOT Region 1 is responsible for managing 970 route miles (3,688 lane miles); CDOT Region 2 is responsible for 2,077 route miles (4,987 lane miles); and CDOT Region 4 is responsible for 2,548 route miles (6,322 lane miles).

Figure D-1. Eastern Slope and Plains Study Area Map



Within this study area, the Prioritization Committee defined two distinct analysis areas to differentiate major differences in geography, ecosystems, target species, and movement patterns between the Eastern Slope portion of the study area and the Plains portion.

The analysis areas were defined as follows:

- Eastern Slope Analysis Area: The portions of CDOT Regions 1, 2, and 4 west of and including Interstate 25, plus CPW's Game Management Unit (GMU) 140. This GMU lies east of Trinidad along the New Mexico border and includes the Fishers Peak area, which is more geographically and ecologically similar to the Eastern Slope than the Plains.
- Plains Analysis Area: The portions of CDOT Regions 1, 2, and 4 east of Interstate 25, minus GMU 140.

Our focus was on the CDOT-maintained road network.

D.2.2 Risk Modeling Approach Overview

For consistency, we used the same methods as used for the Western Slope Wildlife Prioritization Study (WSWPS) to estimate WVC risk informed directly by recorded WVCs (reported crashes and CDOT maintenance carcass data).

In our approach, we aimed to estimate WVC risk separately by species, analysis area, and movement period, yielding a total of seven models:

- Deer, three models
  - Eastern Slope—migration periods (spring and fall)
  - Eastern Slope—winter range use
  - Plains—winter range use
- Elk, two models
  - Eastern Slope—migration periods (spring and fall) and winter range use
  - Plains—not modeled
- Pronghorn, two models
  - Eastern Slope—all records (year round)
  - Plains—all records (year round)

We modeled WVC risk directly based on observed WVC data rather than using Global Positioning System (GPS) collar data on animal movements to model exposure as a distinct component of risk. We compared road and road-adjacent attributes of known WVC locations with those of random locations distributed throughout the road network to estimate the relationship between each of these attributes and relative WVC risk. The following paragraphs describe the approach in detail.

D.2.3 Data

We used a combination of reported crash data on WVCs and animal carcass data as the response variable in our risk models. We obtained 10 years of WVC data for the years 2009 to 2019, throwing out 2018 data because of an incomplete data set. These data are collected from crash reports, and are geolocated to the nearest estimated 0.1 mile on the highway routing map. In addition, wildlife carcass data for the same period are collected by the CDOT maintenance crew and are also typically georeferenced to the nearest mile (or sometimes 0.1-mile) marker.

To associate all records in the proper geographic location, linear referencing was used. All CDOT highway segments were used to create a statewide network and then calibrated to the CDOT milepost shapefile. This allowed all future work to be referenced to the same baseline. CDOT provided carcass and WVC data for each region in shapefile and Microsoft Excel format, with each record having an attribute for its location by route number and milepost. The data sets were provided as clean and free of duplicates, although some records were removed that were for years not within the study period. All records were imported by the route-milepost attributes, resulting in a final data set consisting of 9,211 carcass records and 11,680 WVC records over the 5,595 route miles.

The treatment of the relationships between the carcass and WVC records and the highway segments deviated from the WSWPS process. Instead of splitting the highway into 0.5-mile segments and attaching all related wildlife attributes to those segments, the wildlife records were maintained as individual points throughout the compilation process. By maintaining the wildlife data as unique points, conditions were not diluted:

- Highway attributes for speed, width, and traffic volume were not averaged into 0.5-mile segments, allowing each wildlife point to acquire the precise highway attributes for that location.
- Environmental analysis was performed for each unique location instead of a surrounding area for a 0.5-mile segment that encompassed potentially several different wildlife points. This allowed a more localized determination of such conditions as grade, drainage proximity, and land cover analysis.

After a complete analysis and model determination was made, the wildlife points scores were then averaged for each adjoining 0.5-mile highway segment to allow for better field review and organizational decision-making.

In Table D-1, we summarize all explanatory variables by analysis area considered as potential drivers of WVC risk. These variables were selected based on the WSWPS analysis of WVC risk (Kintsch et al. 2019) as well as further input from the study team and prioritization subcommittee.

Table D-1. Names, Source Data, and Descriptions of All Explanatory Variables Considered as Drivers of WVC Risk

Name	Description	Resolution	Source	Analysis Area
DAU herd density	DAU population size estimate divided by DAU area	DAU	CPW 2017	
Winter range herd density	DAU population size estimate distributed such that density in winter concentration areas is twice that in other portions of winter range within DAU	Winter range polygons	CPW 2017	
Traffic volume	Annual average daily traffic (number of vehicles per day)	30 m	CDOT 2019	
Traffic speed	Posted speed limit	30 m	CDOT 2019	
Road corridor width	Total width of road corridor, lanes only	30 m	CDOT 2019	
Highway curve class	Highway curvature class as determined by CDOT (six classes)	30 m	CDOT 2019	
Absolute highway grade	Absolute value of grade recorded by CDOT for primary right-of-way	30 m	CDOT 2019	
Distance from speed transition	Road-miles from nearest point of change in speed limit	30 m	CDOT 2019	
Slope adjacent to road surface	Slope of 30-m pixel intersected by road polyline	30 m	USGS NED 2017	
Slope aspect adjacent to road surface	Aspect of 30-m pixel at event location	30 m	USGS NED 2017	
Distance from stream	Geographic distance to nearest stream	30 m	NHD 2021	
Distance to waterbody			NHD 2021	
Percent impervious surface	Percent impervious surface cover within 1-km grid cell	1 km	EPA 2013	
Adjoining fence type	Fence type adjoining event location (type 0 = no fence within 50 meters; 1 = five-strand barbed wire, non-barbed wire, living snow fence, picket snow fence, bridge safety fence, other; 2 = chain link, chain link with barb, game fence, wildlife fence, wood fence, snow fence)	50 m	CDOT 2020	
Distance to SWA lands	Distance to nearest state wildlife area		COMaP 2019	
Distance from suburban housing density	Distance from nearest area classified as suburban or greater housing density	100 m	EPA 2013	

Name	Description	Resolution	Source	Analysis Area
Distance to high-intensity wildfire area			MTBS 2009 to 2019	
Distance to low-intensity wildfire area			MTBS 2009 to 2019	
Distance to dryland crops	Distance from nearest area classified as dryland crop		NLCD 2016	
Distance to grasslands			NLCD 2016	
Distance to irrigated lands			NLCD 2016	
Distance to pasture lands			NLCD 2016	
NDVI score		30 m	NDVI 2020	
Percent aspen	Percent aspen cover within 270- by 270-m moving window	30 m	USGS 2011	
Percent conifer	Percent conifer cover within 270- by 270-m moving window	30 m	USGS 2011	
Percent pinyon	Percent pinyon juniper cover within 270- by 270-m moving window	30 m	USGS 2011	
Percent oak brush	Percent oak brush cover within 270- by 270-m moving window	30 m	USGS 2011	
Terrain ruggedness	Standard deviation of elevation values within 270- by 270-m moving window	30 m	USGS NED 2017	
Topo position (multiscale)	Relative topographic position (canyon = low, ridge = high) averaged across five spatial scales	30 m	USGS NED 2017	
Topo position (local)	Relative topographic position within 90 m	30 m	USGS NED 2017	

Notes:

DAU = data analysis unit
km = kilometer(s)
m = meter(s)
NDVI = normalized difference vegetation index
SWA = state wildlife area

D.2.4 Model

We used logistic regression and multimodel inference in an information theoretic framework to estimate the relative risk of WVCs (Akaike 1973; Burnham and Anderson 2002). Formally, our model can be described as a logistic discrimination function (Keating and Cherry 2004), which discriminates between locations where WVCs are known to have occurred and random locations based on the distributions of explanatory variables associated with each. This approach avoids problematic assumptions of other model structures that use WVC counts as the response variable (i.e., Poisson regression models) or that treat locations where no WVCs were recorded as being free of WVCs (presence-absence logistic regression models). These modeling approaches rely on assumptions that are known to be violated by inconsistency and bias in reporting of WVCs and carcasses. For example, relative carcass counts among highway segments may be strongly influenced by less consistent reporting in some areas compared with others. Similarly, we cannot assume that locations in which no carcasses are recorded are in fact free of WVCs because of underreporting or spatially inaccurate reporting. We therefore judged the assumptions of a logistic discrimination function by comparing what we consider to be a sample of WVC locations to a sample of random locations to be the most appropriate means of estimating risk.

We fit separate risk models for mule deer, elk, and pronghorn, as well as separate risk models for migration and winter periods, resulting in seven risk models. We defined migration periods as September to November and April to June; winter was defined as December to March, based on the distribution of migration start and end dates observed across GPS collar data sets provided by CPW biologists (Appendix A). We used all available elk, deer, and pronghorn WVC data to fit risk models for migration and winter periods within both analysis areas:

- Deer, three models
  - Eastern Slope, migration periods: n = 4,485
  - Eastern Slope, winter range use: n = 7,068
  - Plains, winter range use: n = 4,612
- Elk, two models
  - Eastern Slope, migration periods: n = 947
  - Eastern Slope, winter range use: n = 254
- Pronghorn, two models
  - Eastern Slope, all records: n = 39
  - Plains, all records: n = 82

Absence data were generated by creating points along the highways every 0.1 mile. The same attributes as the WVC and carcass points were generated by the same methods as depicted in Table D-1. The absence data was then filtered for species and analysis area, then randomly sampled to the ratio of three absence points for every WVC point and combined into one file to run through the model selection.

Our global model included all explanatory variables described in Table D-1, an interaction term between traffic volume and speed, as well as quadratic terms for traffic volume and speed. We tested for univariate correlations between variables and multicollinearity among variables by calculating pairwise Pearson correlation coefficients and variance inflation factors, respectively; in the case of terms exceeding cutoff values of 0.7 or 4.0, respectively, we excluded the collinear term with the lowest univariate explanatory power (Booth et al. 1994; Belsley 1991). After fitting global models for each species and season, we dropped variables that did not meet the marginal significance criterion ($\leq$ 0.1) in order to achieve a workable number of variables for all-subsets multimodel inference.

We used the glmulti package for R to analyze the Level 1 main events. glmulti is used to fit all additive subsets of these reduced models and to compute model-averaged regression coefficients, unconditional standard errors (SEs), cumulative Akaike information criterion (AIC) weights of evidence as a measure of variable importance (Burnham and Anderson 2002), and 95 percent confidence intervals. Model averaging and multimodel inference allows for more robust inference than selection of a single “best” model, producing coefficient estimates and SEs that are not conditional on any one model, but that are instead informed by all possible models that include the explanatory variables of interest.

We evaluated the overall explanatory power and fit of each model based on Nagelkerke’s pseudo-R^2 (Nagelkerke 1991), a generalized coefficient of determination describing relative variance explained, calculated for each global model, and the difference in AIC (ΔAIC) value between the global model and a null model with consideration of how much it differed from the null model. We assessed the relative importance of each explanatory variable based on (1) effect size indicated by each regression coefficient; (2) 95 percent confidence intervals on each regression coefficient; and (3) AIC weights of evidence.

Finally, we assessed future WVC risk by applying the previously described risk models using data layers representing future traffic volume. We used annual average daily traffic projections for the year 2040 to best match CDOT’s planning horizon, the closest available time increment, under a “baseline case” (i.e., “business as usual” scenario; EPA 2013).

D.3 Results

The inferential risk models performed better than null models for each of the seven species–season combinations in each analysis area, as indicated by ΔAIC values ranging from 105 to 13839. The relative variance explained by each was moderate to good (Nagelkerke r^2: 0.525 to 0.754) (Table 2). However, the ΔAIC values were not considered as direct comparisons because of the wide range of null AIC values. For example, the pronghorn Plains null AIC was 371, performing much better than most of the other models; but the model AIC was only a 36 percent improvement from the null model with a score of 237 and the lowest r^2 at 0.525. To compare the various models, the improvement from the null combined with the r^2 value were considered together with the ΔAIC values.

Note that although this pseudo-r^2 statistic does not represent the absolute proportion of variance explained and should be interpreted with caution, its value is bounded by 0 and 1. Based on these results, the best-performing risk model was for pronghorn on the Eastern Slope, whereas the worst-performing risk model was for pronghorn on the Plains.

Table D-2. Summary of Model Fits

Species	Analysis Area	Season	Nagelkerke r^2	(Null) – (Fitted) ΔAIC	Model AIC
Mule deer	Eastern Slope	Migration	0.593	8144	10314
Mule deer	Eastern Slope	Winter	0.574	13839	17960
Mule deer	Plains	Winter	0.535	8230	12520
Elk	Eastern Slope	Migration	0.626	2045	2217
Elk	Eastern Slope	Winter	0.624	524	621
Pronghorn	Eastern Slope	All	0.754	105	72
Pronghorn	Plains	All	0.525	134	237

We observed several generalizable trends across models in drivers of WVC risk, while other risk factors varied across species and seasons. Distance to speed transitions, traffic volume and speed, and percentage of impervious surface were most often the strongest drivers of risk. WVC risk decreased (negative correlation) with distance from speed transition, and increasing impervious surface, but increased (positive correlation) with speed and volume increases. No leveling off of risk was observed related to speed limit.

D.4 References

Akaike, H. 1973. Information Theory as an Extension of the Maximum Likelihood Principle. *In:* Petrov, B.N. and F. Csaki, eds. *Second International Symposium on Information Theory*. Akademiai Kiado, Budapest. pp. 267-281.

Belsley, D.A. 1991. *Conditioning Diagnostics*. John Wiley & Sons, Inc.

Booth, G.D., M.J. Niccolucci, and E.G. Schuster. 1994. *Identifying Proxy Sets in Multiple Linear Regression: An Aid to Better Coefficient Interpretation*. Research Paper INT-470. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah. January.

Burnham, K.P. and D.R. Anderson. 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. Second Edition. Springer, New York.

Colorado Department of Transportation (CDOT). 2017. CDOT highways and highway attributes, reported WVCs, and roadkill. File geodatabase. Courtesy of Gary Aucott, CDOT. Accessed January 2019.

Colorado Department of Transportation. 2020. Fencing GIS shapefile.

Colorado Parks and Wildlife (CPW). 2010. Elk and mule deer winter range and winter concentration areas. Spatial dataset. CPW. Accessed September 2017. Available: https://databasin.org.

Colorado Parks and Wildlife (CPW). 2017. Post-hunt elk and mule deer DAU population estimates versus objectives and targets. Tabular dataset. Courtesy of Andy Holland, CPW. Accessed April 2018.

Colorado Ownership, Management and Protection database (COMaP). 2019. Colorado Natural Heritage Program, Colorado State University. https://cnhp.colostate.edu/projects/comap/.

Keating, K.A. and S. Cherry. 2004. "Use and interpretation of logistic regression in habitat selection studies." *Journal of Wildlife Management* Volume 68, pp. 774-789.

Kintsch, J., P. Basting, M. McClure, and J.O. Clarke. 2019. *Western Slope Wildlife Prioritization Study*. Applied Innovation and Research Branch, Colorado Department of Transportation, Denver, Colorado. Report No. CDOT-2019-01.

Monitoring Trends in Burn Severity (MTBS). 2009 to 2019. https://www.mtbs.gov.

Nagelkerke, N.J. 1991. A note on a general definition of the coefficient of determination. *Biometrika* Volume 78, Issue 3, pp. 691-692.

U.S. Environmental Protection Agency (EPA). 2013. ICLUS Tools and Datasets (Version 1.3.2). EPA/600/R-09/143F. U.S. Environmental Protection Agency, Washington, DC. https://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=257306.

U.S. Geological Survey (USGS). 2011. National gap analysis program land cover data, Version 2. https://www.usgs.gov/programs/gap-analysis-project/science/land-cover-data-overview.

U.S. Geological Survey (USGS). 2016. National gap analysis program land cover data, Version 2. https://www.usgs.gov/programs/gap-analysis-project/science/land-cover-data-overview.

U.S. Geological Survey (USGS). 2017. 30-meter resolution, 1-60th degree national elevation dataset (NED) for CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. https://www.usgs.gov/centers/eros/science/usgs-eros-archive-products-overview.

U.S. Geological Survey (USGS). 2020. Landsat Normalized Difference Vegetation Index. https://www.usgs.gov/landsat-missions/data.

U.S. Geological Survey (USGS). 2021. National Hydrograph Data Plus (NHDPlus) and National Hydrography Dataset (NHD). TNM Download v2.0. https://www.usgs.gov/national-hydrography/access-national-hydrography-products.

Vandenbusche, D. 2018. “Western Slope.” Colorado Encyclopedia. http://coloradoencyclopedia.org/article/western-slope.

Appendix E
Wildlife Valuation

Appendix E. Wildlife Valuation using Contingent Valuation Methods for the

Final 11/23/2021

Developed by: Travis Black (Colorado Parks and Wildlife [CPW]), Julie Stiver (CPW), Shannon Schaller (CPW), Jeff Peterson (Colorado Department of Transportation [CDOT]), Erik Schmude (CDOT), Katie Lanter (CPW), Kristen Koehler (CPW), Pat Basting (Jacobs), and Julia Kintsch (ECO--resolutions)

E.1 Background

Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) desire updated and augmented wildlife valuations, originally developed for the Western Slope Wildlife Prioritization Study (WSWPS) in 2019, for assigning a dollar value to wildlife. This report documents the process used to update the values previously developed for deer (mule deer and white-tailed deer) and elk, as well as develop new valuations for pronghorn and bighorn sheep. These wildlife valuations are important for comprehensive benefit-cost analyses evaluating potential wildlife-highway mitigation projects.

Originally, our team considered a variety of methods for deriving the value of wildlife to society, in particular, deer and elk that are killed in wildlife-vehicle collisions (WVCs; CDOT 2019). The most-used values are statutory values assigned by a state legislature for the purpose of providing a defined value for wildlife that are unlawfully taken (e.g., poaching). In Colorado, these values are $500 for deer and $700 for elk, as set in Statute 33-6-110, not including criminal penalties for illegal possession. Although there is little economic justification behind these numbers, and they are commonly understood to be underpriced, in most instances these are the only agreed-upon values that hold credence across disciplines and across administrative units. Accordingly, these values have been used previously to represent the value of wildlife killed in WVCs for other state wildlife prioritization studies and reports (e.g., Cramer et al. 2016; Wakeling et al. 2015).

The peer-reviewed literature offers a different approach. Huijser et al. (2009) calculated the costs per incident for the average deer-, elk-, and moose-vehicle collision for inclusion in a benefit-cost equation to assess mitigation measures to reduce vehicular collisions with large ungulates. These costs included vehicle repair costs, human injuries and fatalities, towing, crash attendance and investigation, the hunting value of the animal, and the cost of disposal of the animal carcass. The assigned values of $150 for each deer killed in a collision and $513 for elk (in 2021 dollars) are the hunting values expressed as the probability that an animal will be successfully harvested by a hunter, which are derived from the U.S. Fish and Wildlife Service's (USFWS's) *2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation*

(USFWS 2002). However, the value of wildlife to hunters alone does not capture the myriad benefits that wildlife brings to the state (e.g., wildlife viewing, hunting-related expenditures, and intrinsic values). In addition, when compared with the statutory values set by the Colorado legislature, this wildlife valuation approach further underestimates the benefits to society.

E.2 Methods

Our team thereby proposes an alternative approach based on accepted economic theory of contingent valuation. The contingent valuation method (CVM) is a survey-based economic technique that is used to assign dollar values to nonmarket resources, such as wildlife or other environmental values, including both use and nonuse values. Using this method, wildlife value is calculated as:

Wildlife Value = Willingness to Pay Value (deer/elk/pronghorn/bighorn sheep) + Weighted Average Fee Value (deer/elk/pronghorn/bighorn sheep) + Average Expenditure per Nonresident Hunter

Net willingness to pay (WTP), or consumer surplus, in this context is the maximum amount that a hunter would pay for the opportunity to hunt deer, elk, pronghorn or bighorn sheep, beyond hunting fees or trip expenses. WTP values are derived from the net economic values addendum to the USFWS's *2011 National Survey of Fishing, Hunting and Wildlife-Associated Recreation* (USFWS 2011), which uses contingent valuation questions to determine people's willingness to pay for these activities. We used the regional value for elk and the national aggregate values for deer because Colorado-specific values are currently not available from the USFWS survey. These WTP values were then converted to 2021 dollars using the U.S. Bureau of Labor Statistics Consumer Price Index Inflation Calculator (Table E-1).

Advantages of this approach are as follows:

- It is based on accepted economic theory and used in other published reports.
- Although still a conservative estimate of deer, elk, pronghorn, and bighorn sheep values, this approach provides a more comprehensive wildlife valuation than either of the alternative approaches reviewed.
- The input values may be updated when more refined data become available, for example, Colorado-specific WTP values for each species.
- Input values are derived from two primary data sources: the USFWS and CPW.

Disadvantages of this approach are as follows:

- This method still does not address all the potentially quantifiable benefits of wildlife, because comprehensive, discrete data do not currently exist.
- This method also does not address the numerous unquantifiable benefits of wildlife (e.g., passive values; reproductive value of cows/does; ecosystem value of connectivity), and these nonmonetary benefits can only be acknowledged separately.
- Future iterations of this valuation would be enhanced by a greater separation of the data (e.g., wildlife watching by species group, and state-specific WTP values) in the USFWS survey reports on wildlife-related recreation.

Because the USFWS (2011) report does not provide WTP values for species such as pronghorn and bighorn sheep, an alternate approach was needed to determine WTP for these species. Our team determined that the WTP valuations used for deer should also be used for pronghorn because license fees for both species were identical in 2021.

Determining WTP valuations for bighorn sheep proved more challenging. CPW does not have recent formal hunter surveys or valuations other than license fees to determine a WTP value. However, Watson (1990) determined the economic value of Dall sheep hunting in Alaska and referenced a report published by Kay (1988), *Nevada Survey of the Economic Value of Trophy Big Game and Deer Harvest 1984 through 1986*. In this report, using contingent valuation methods, Kay was able to quantify WTP to hunt Rocky Mountain bighorn sheep in Nevada and calculated a WTP of $2,584.00 in 1986 dollars, including $97.00 for license fees. This WTP calculation for the same species in a nearby state is highly relevant to Colorado. However, for our purposes, the $97.00 license fee from the Nevada sum was subtracted to avoid double counting license fees, which we account for in the weighted average fee value. Therefore, the WTP value from the 1986 Nevada study for our purposes is $2,487.33. Using the U.S. Bureau of Labor Statistics Consumer Price Index Inflation Calculator, the converted 1986 valuation to 2021 dollars is $5,936.50.

Table E-1. Willingness to Pay Mean Aggregate Values for Deer, Elk, Pronghorn, and Bighorn Sheep in 2011 and 2021 Dollars
USFWS 2011; Kay 1988

Species	WTP (2011)	WTP (2021)
Deer	$843	$1,001
Elk	$1,025	$1,218
Pronghorn	$843	$1,001
Bighorn Sheep	$2,487	$5,937

The weighted average fee value for deer, elk, pronghorn, and bighorn sheep is based on CPW's most recently available data (2018 to 2020) of deer and elk hunting licenses sold in Colorado and license fees for 2021. For elk, the nonresident license fee is the weighted average of antlerless and either-sex license fees.

Weighted Average Fee Value (deer/elk) = [(3-Year Average Number of Resident Licenses Sold × Resident License Fee) + (3-Year Average Number of Nonresident Licenses Sold × Nonresident License Fee)]/3-Year Average Total Number Licenses Sold

Weighted Average Fee Value for Deer = [(75,418 × $39.53) + (20,569 × $410.86)]/ 95,987 = $119.10

Weighted Average Fee Value for Elk = [(142,500 × $55.13) + (74,000 × $656.59)]/ 216,500 = $260.71

Weighted Average Fee Value for Pronghorn = [(81,783 × $39.53) + (1,667 × $410.86)]/ 83,450 = $46.95

Weighted Average Fee Value for Bighorn Sheep = [(304 × $312.05) + (39 × $2,298.76)]/ 343 = $537.94

Average expenditures for nonresident hunters are derived from the same USFWS survey, as presented in the state-specific report for Colorado (USFWS 2014). For our purposes, we included only trip-related expenditures (gas, food, and lodging; equipment expenditures were excluded, and hunting fees were also excluded to avoid double counting). Only nonresident expenditures are included because they represent new money coming into the state, whereas it is assumed that residents would spend their money elsewhere in Colorado's economy if they were not spending it on hunting. These expenditures encompass all types of hunting because deer and elk hunting expenditures are not distinguished from other types of hunting. However, this remains a conservative estimate. Accordingly, average expenditures per hunting season are reported as $439 for food and lodging and $452 for transportation, resulting in an average expenditure of $891 in January 2011 dollars, which converts to $1,058.33 in January 2021 dollars.

Each of the values that comprise the wildlife value equation are presented in Table E-2.

Table E-2. Wildlife Value Equation Components for Deer, Elk, Pronghorn and Bighorn Sheep

Species	WTP Value	Weighted Average Fee Value	Average Expenditures
Deer	$1,001	$119	$1,058
Elk	$1,218	$261	$1,058
Pronghorn	$1,001	$47	$1,058
Bighorn Sheep	$5,937	$538	$1,058

E.2.1 Results

We calculated the following values for deer and elk in Colorado:

Deer Value = $1,001 + $119 + $1,058 = *$2,178*

Elk Value = $1,218 + $261 + $1,058 = *$2,537*

Pronghorn = $1,001 + $47 + $1,058 = *$2,106*

Bighorn Sheep = $5,937 + $538 + $1,058 = *$7,533*

E.3 References

Colorado Department of Transportation (CDOT). 2019. *Western Slope Wildlife Prioritization Study*. Report No. CDOT-2019-01. Website: https://www.codot.gov/programs/research/pdfs/2019/WSWPS.

Cramer, P.C., J. Kintsch, K. Gunson, and F. Shilling. 2016. *Reducing wildlife-vehicle collisions in South Dakota*. Report to the South Dakota Department of Transportation, Pierre, South Dakota.

Huijser, M.P., J.W. Duffield, A.P. Clevenger, R.J. Ament, and P.T. McGowen. 2009. "Cost–Benefit Analyses of Mitigation Measures Aimed at Reducing Collisions with Large Ungulates in the United States and Canada: a Decision Support Tool." *Ecology and Society.* Volume 14, Number 2.

Kay, F.R. 1988. *Nevada Survey of the Economic Value of Trophy Big Game and Deer Harvest 1984 through 1986*. Nevada Department of Wildlife, Biological Bulletin Number 9.

U.S. Fish and Wildlife Service (USFWS). 2002. *2001 National Survey of Fishing, Hunting and Wildlife-Associated Recreation*. Report No. FHW/01-NAT. October.

U.S. Fish and Wildlife Service (USFWS). 2011. *Net Economic Values for Wildlife-Related Recreation in 2011: Addendum to the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. Report No. 2011-8.

U.S. Fish and Wildlife Service (USFWS). 2014. *Colorado: 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation*. Report No. FHW/11-CO (RV). Revised February 2014.

Wakeling, B.F., J.W. Gagnon, D.D. Olson, D.W. Lutz, T.W. Keegan, J.M. Shannon, A. Holland, A.J. Lindbloom, and C. Schroeder. 2015. *Mule Deer and Movement Barriers*. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies.

Watson, S.M. 1990. *Economic Value of Dall Sheep Hunting in Alaska*. Master of Science Thesis. University of Alaska, Fairbanks. May.

Appendix F
Prioritization Criteria Output Maps

Appendix F. Prioritization Criteria Output Maps

Figure F-1. Canada Lynx Probability of Highway Crossing

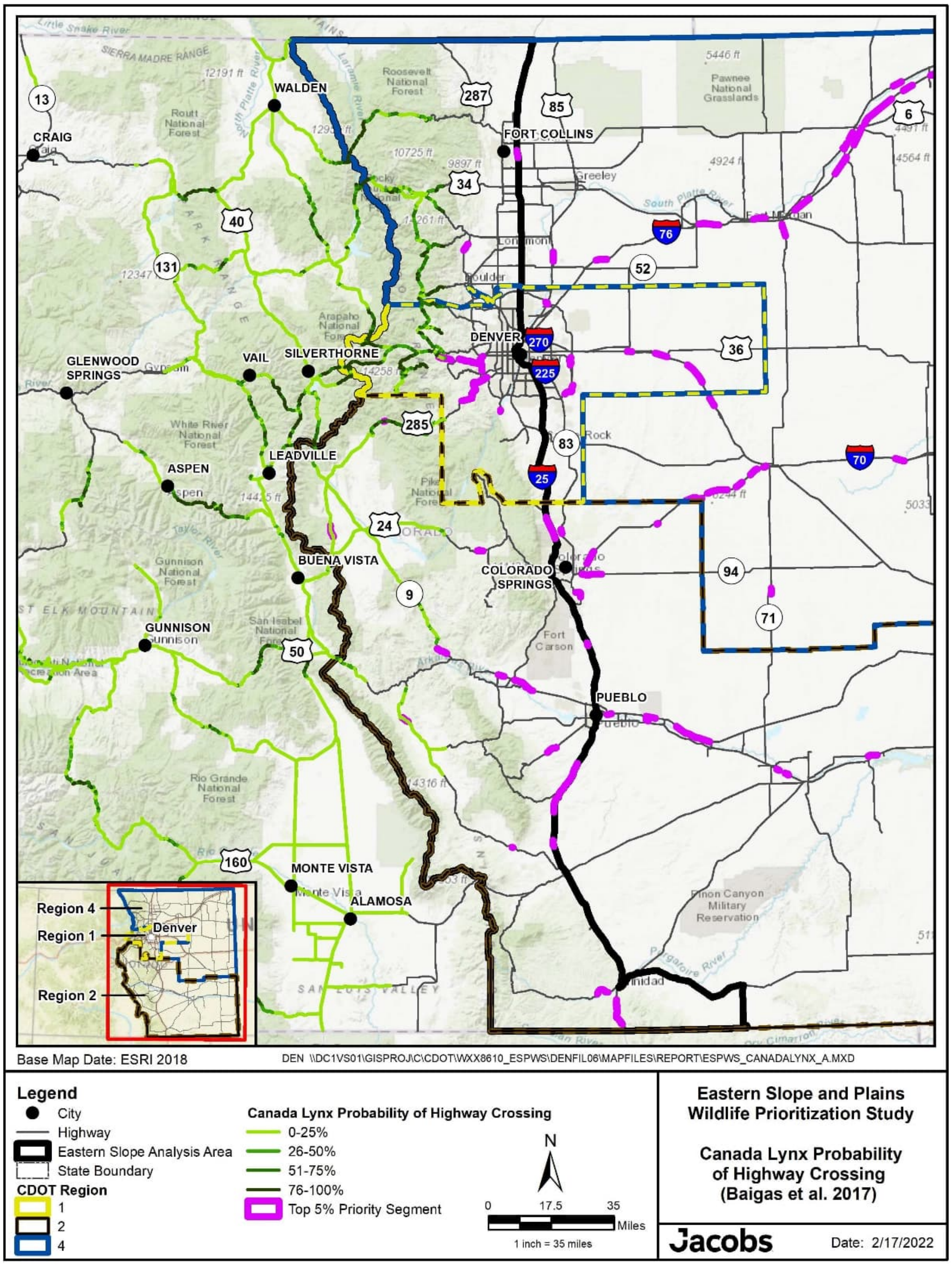


Figure F-2. CDOT Wild Animal Accident Pattern Recognition by Road Type

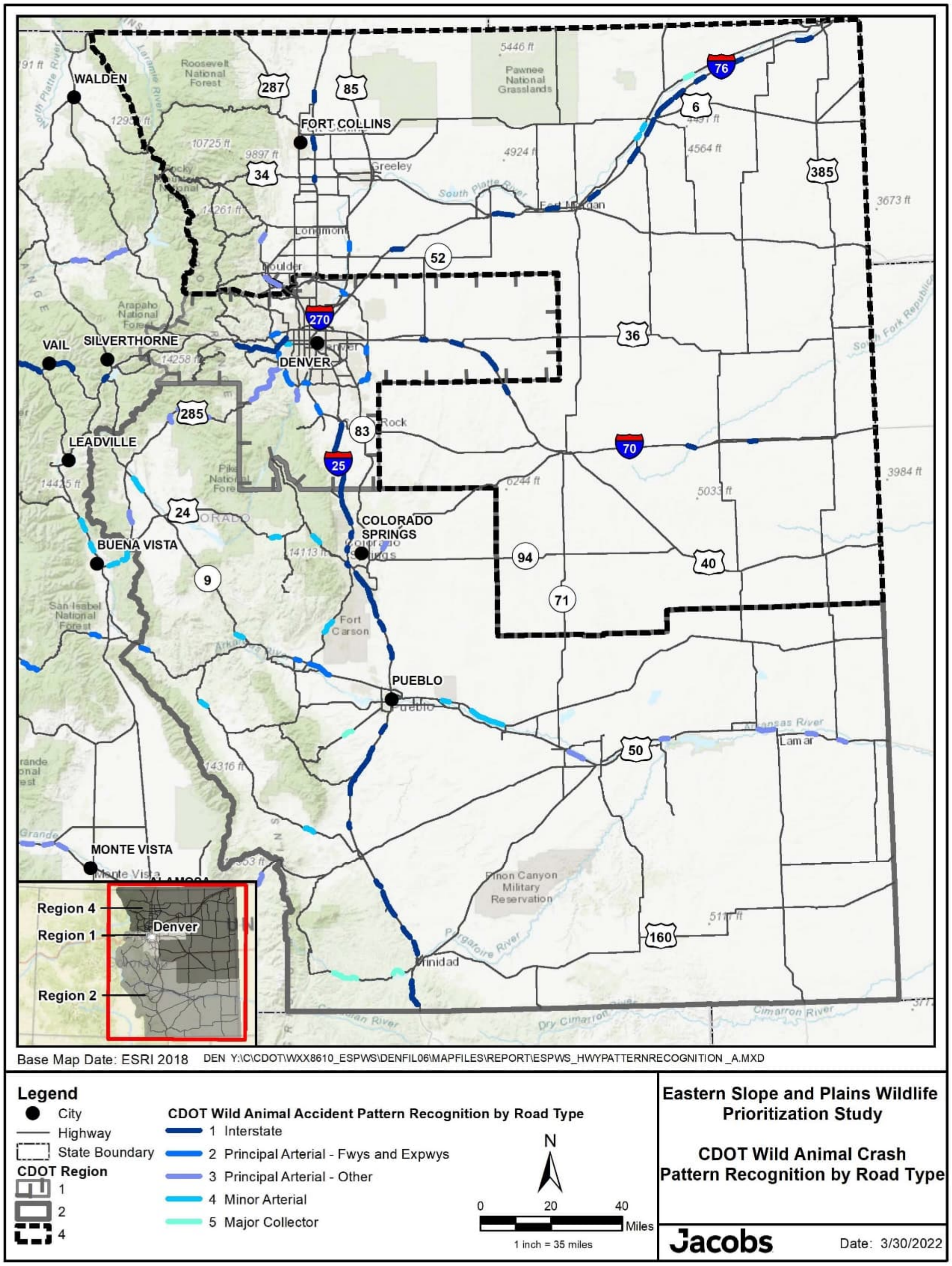


Figure F-3. Bighorn Sheep Areas of Concern

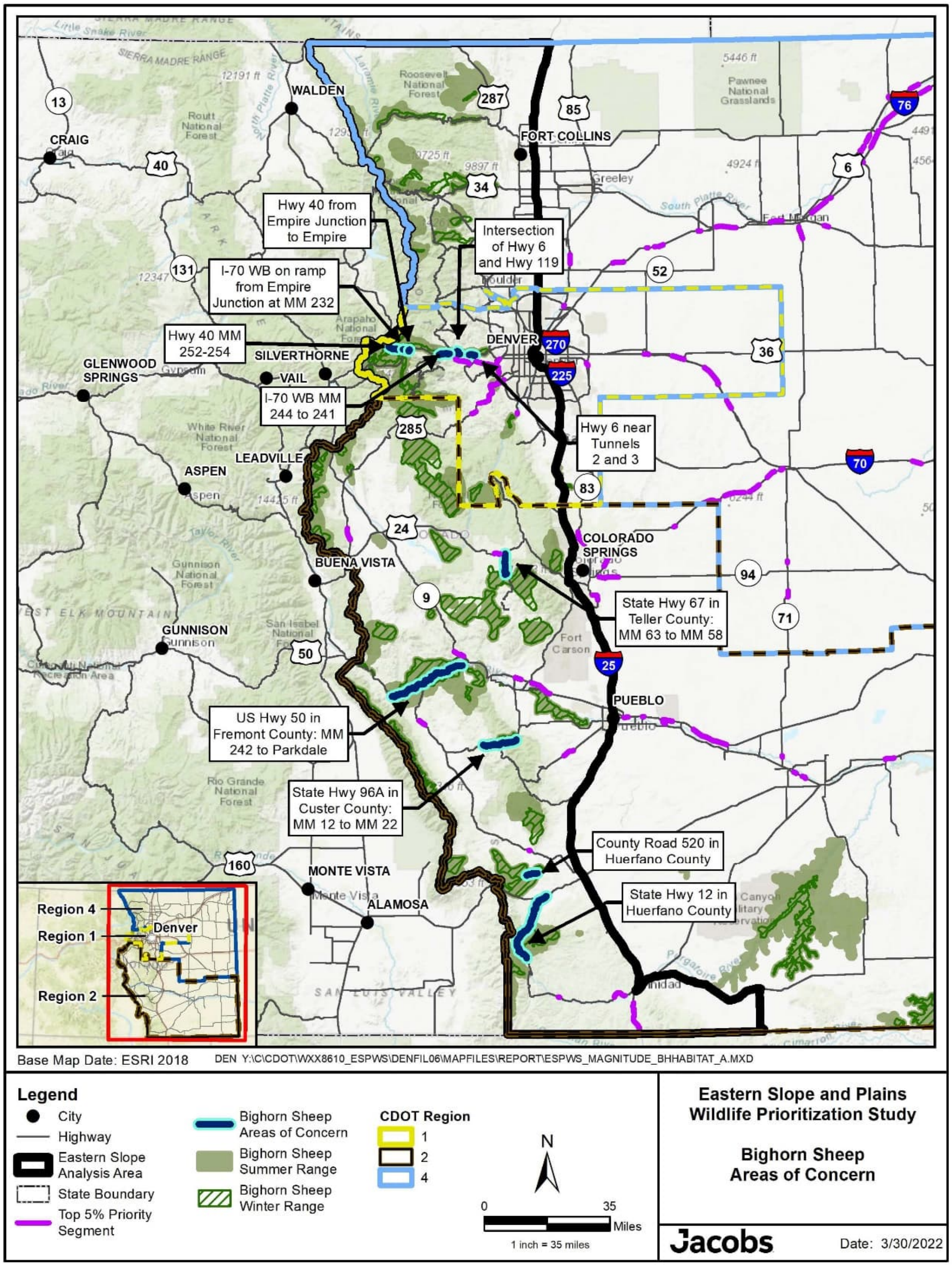


Figure F-4. Elk Migration Magnitude

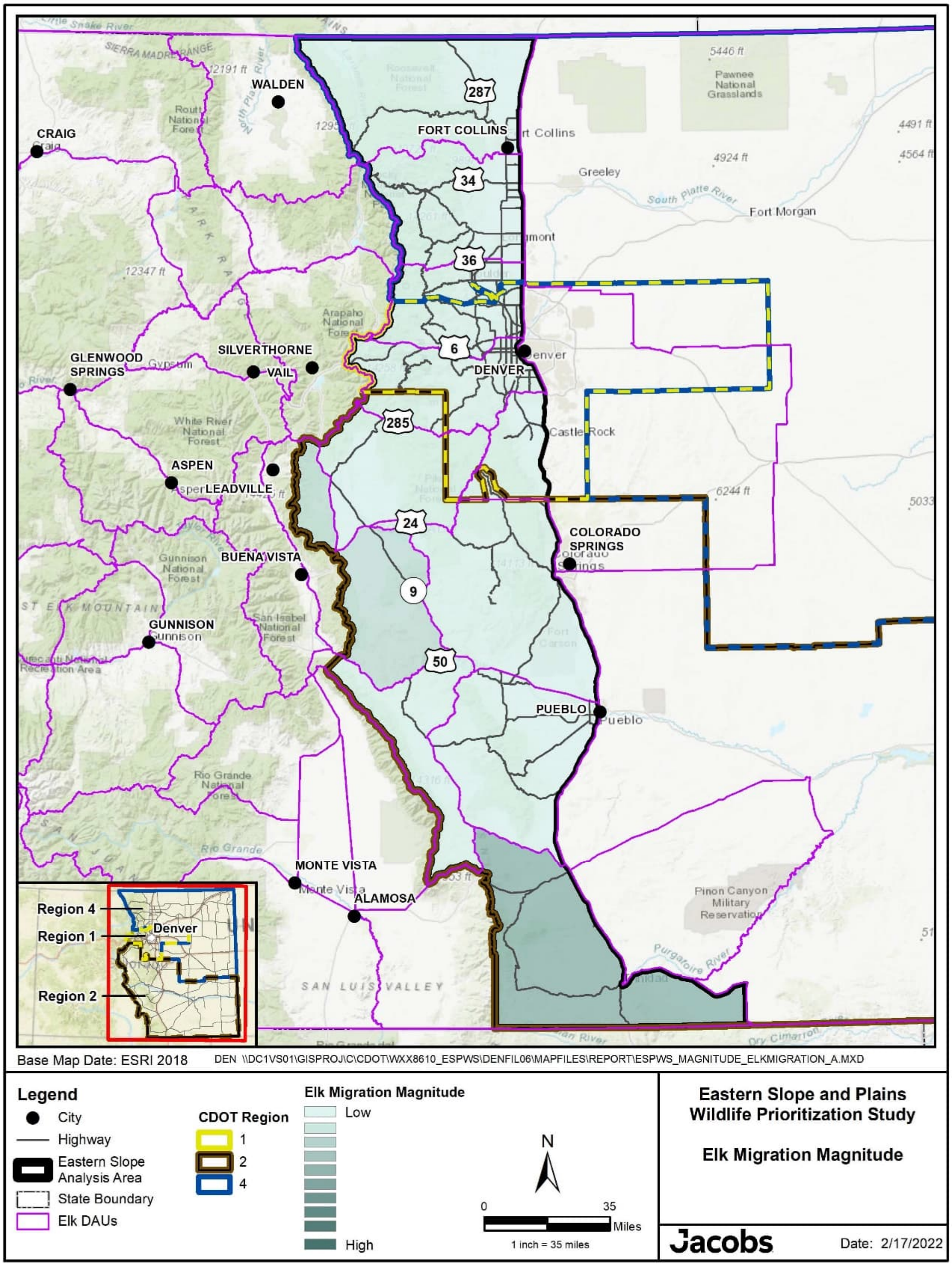


Figure F-5. Elk Magnitude of Winter Range Use

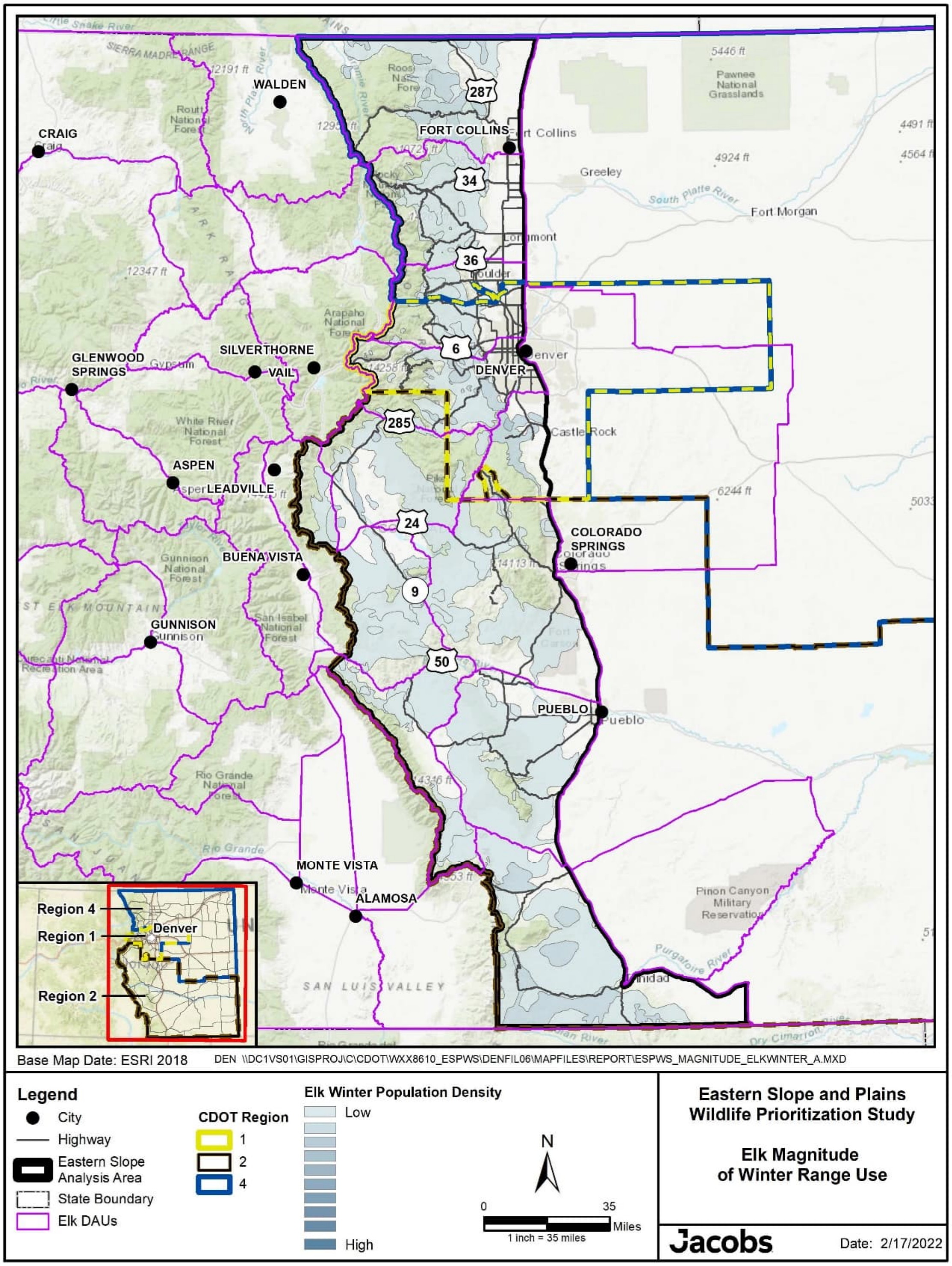


Figure F-6. Elk WVC Mortality as a Proportion of the Population

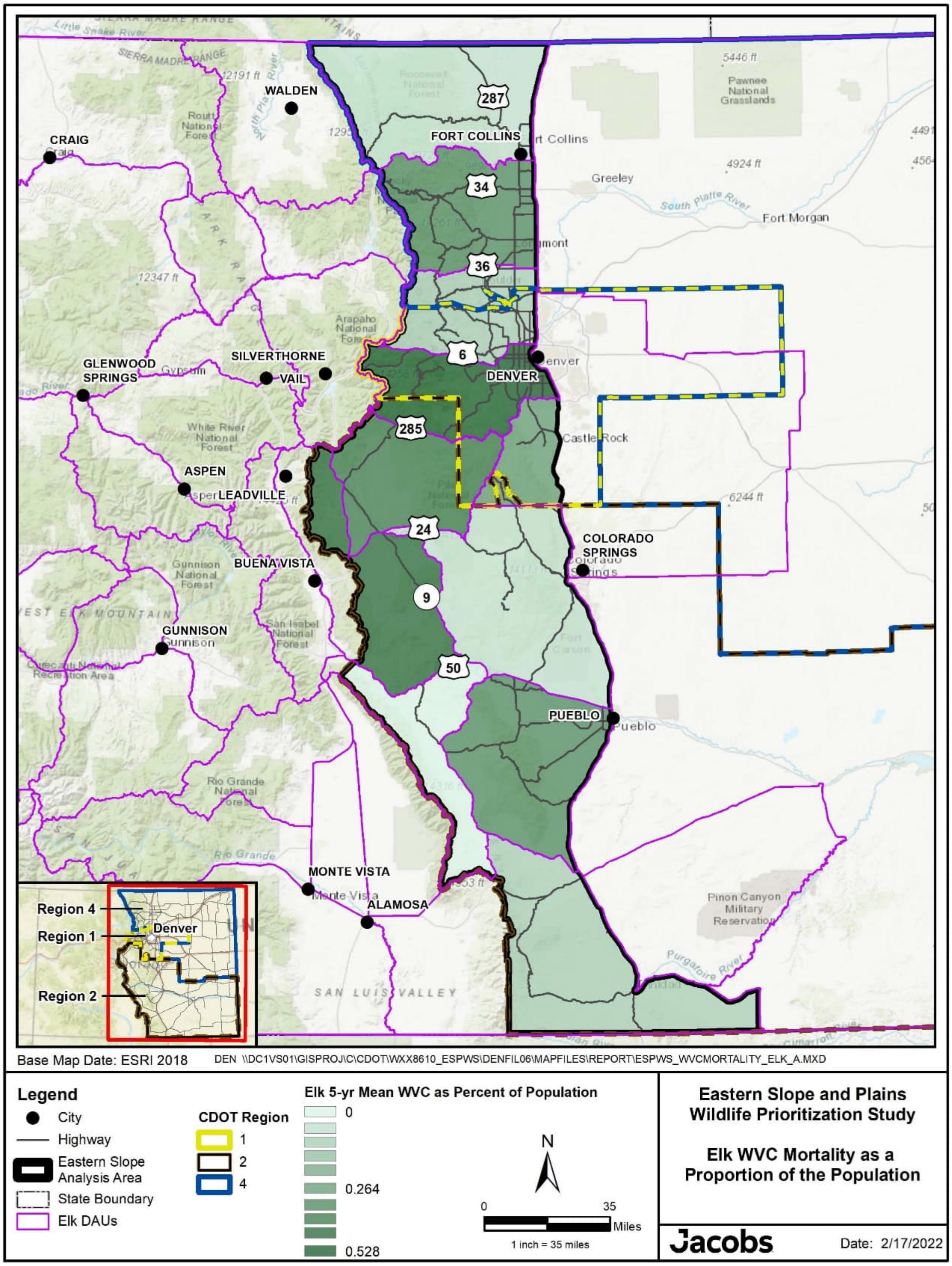


Figure F-7. Deer Migration Magnitude

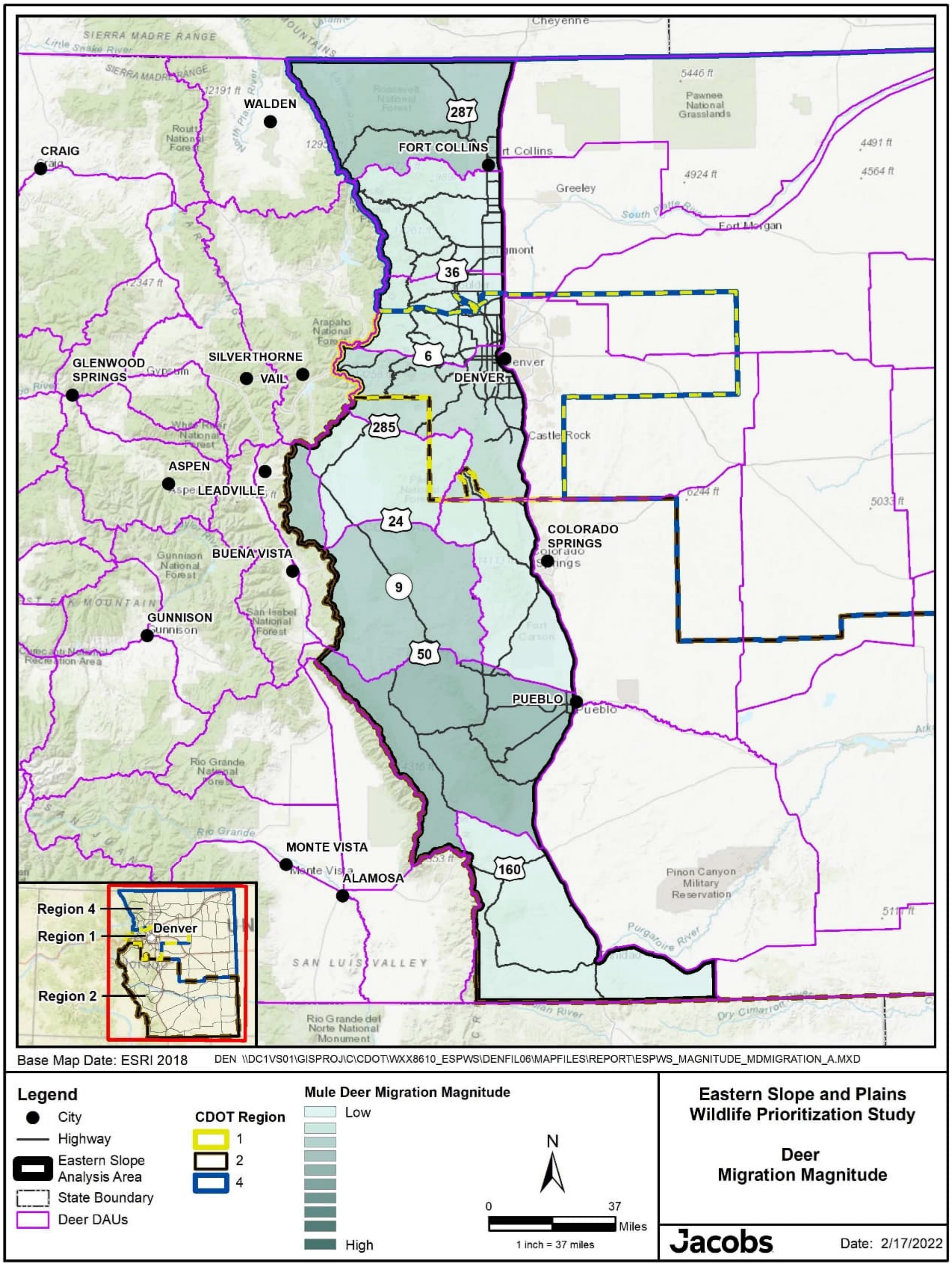


Figure F-8. Deer Magnitude of Winter Range Use

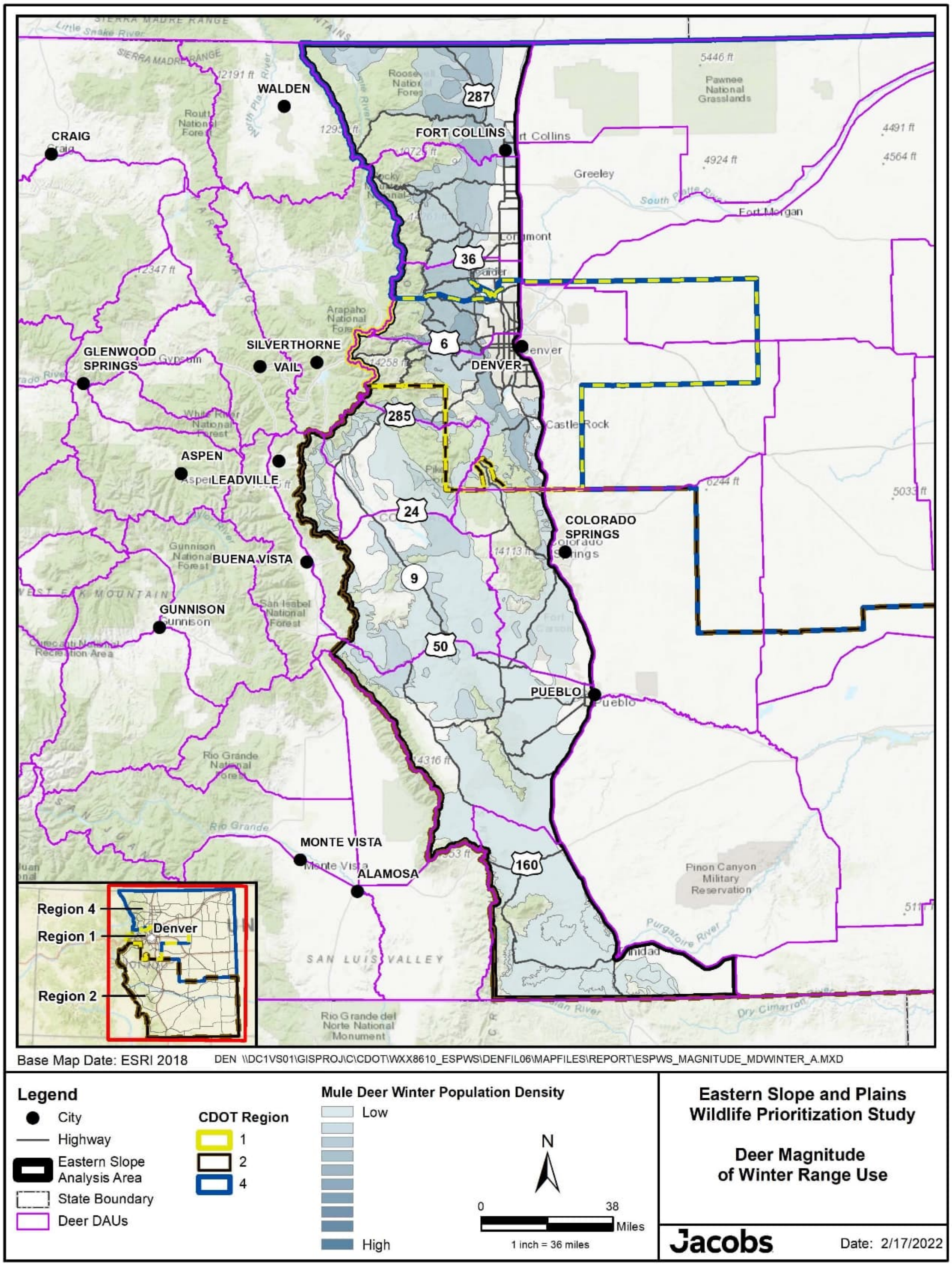


Figure F-9. Deer WVC Mortality as a Proportion of the Population

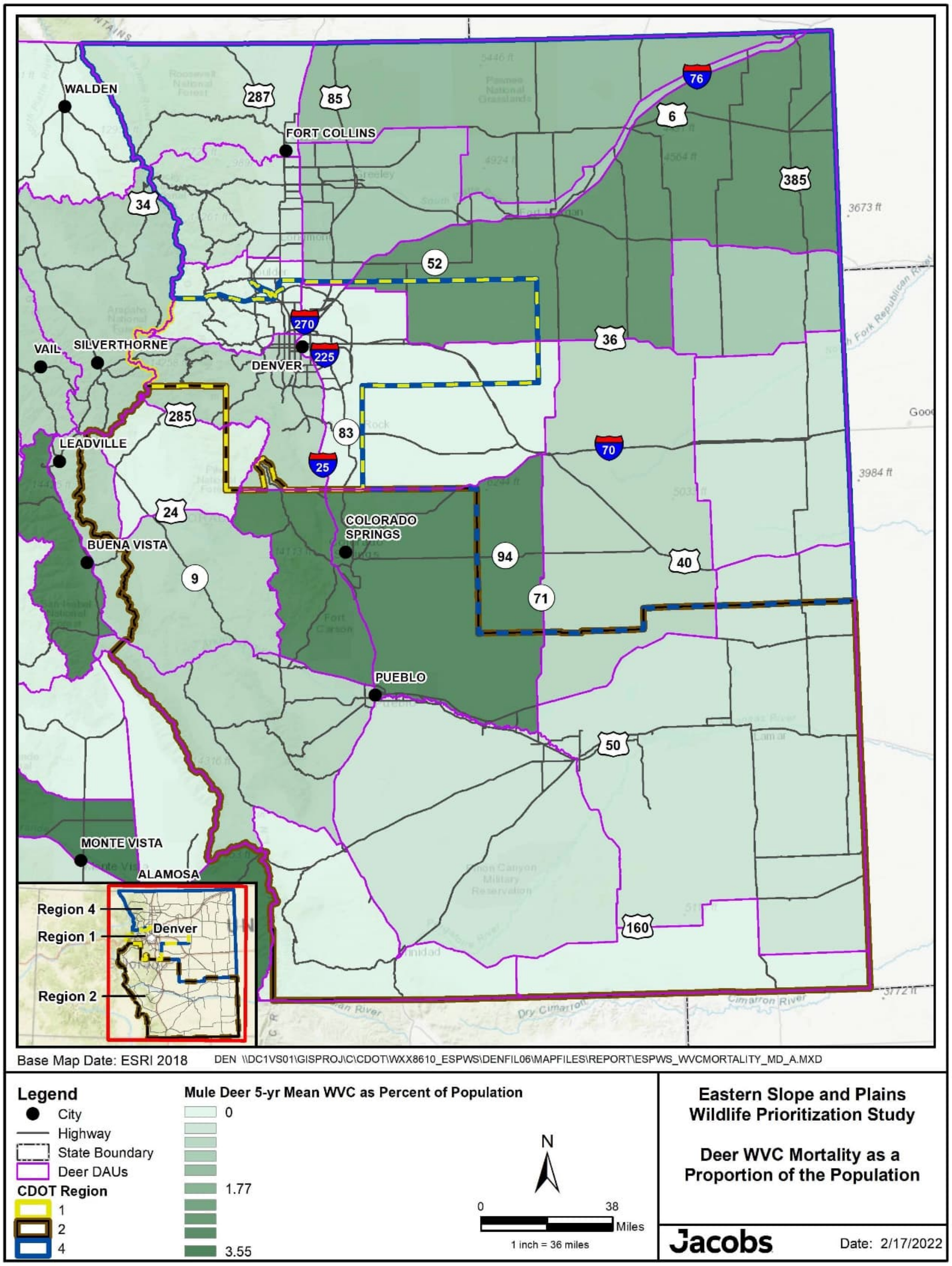


Figure F-10. Stream Proximity

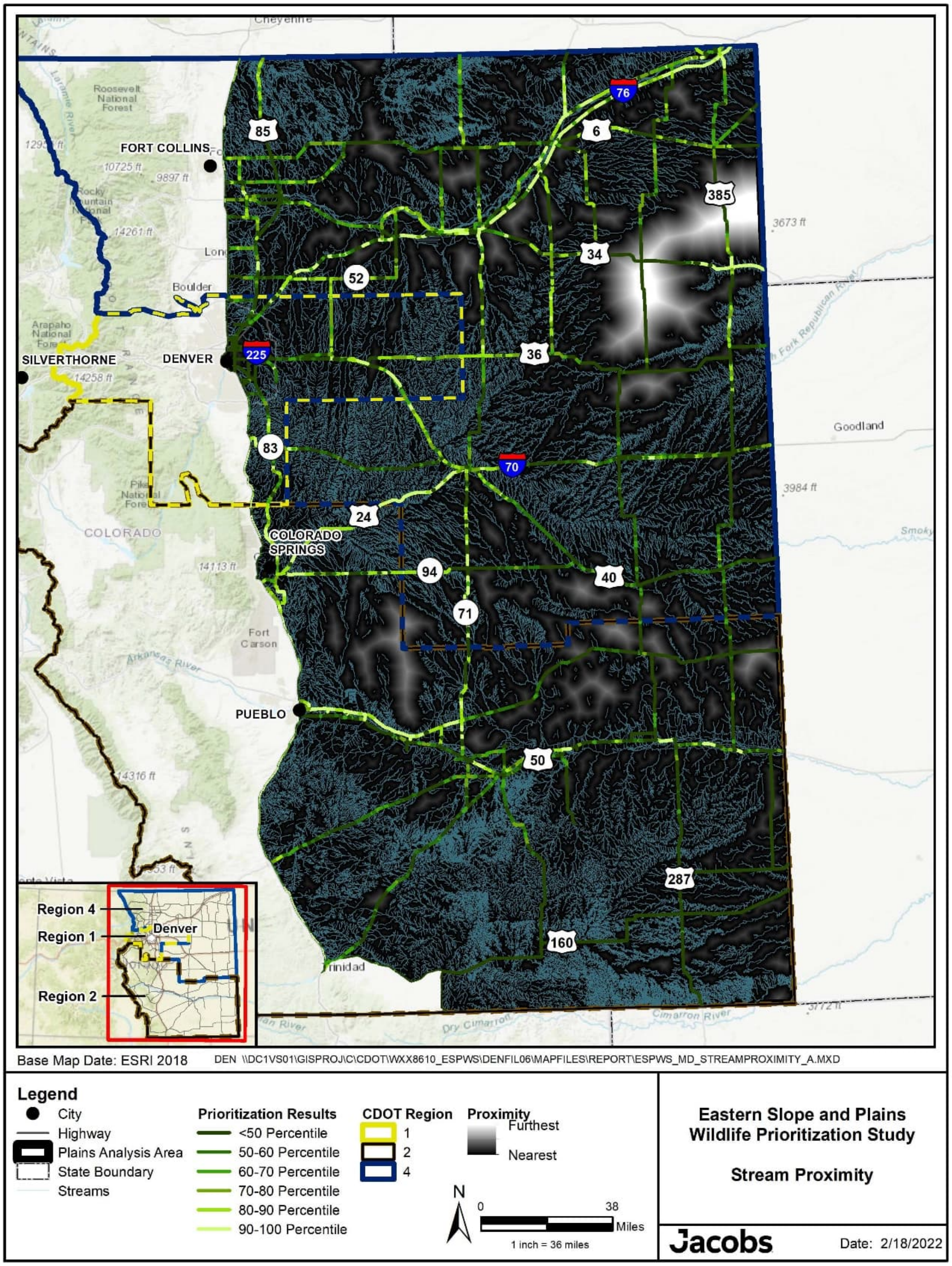


Figure F-11. Pronghorn Magnitude of Winter Range Use

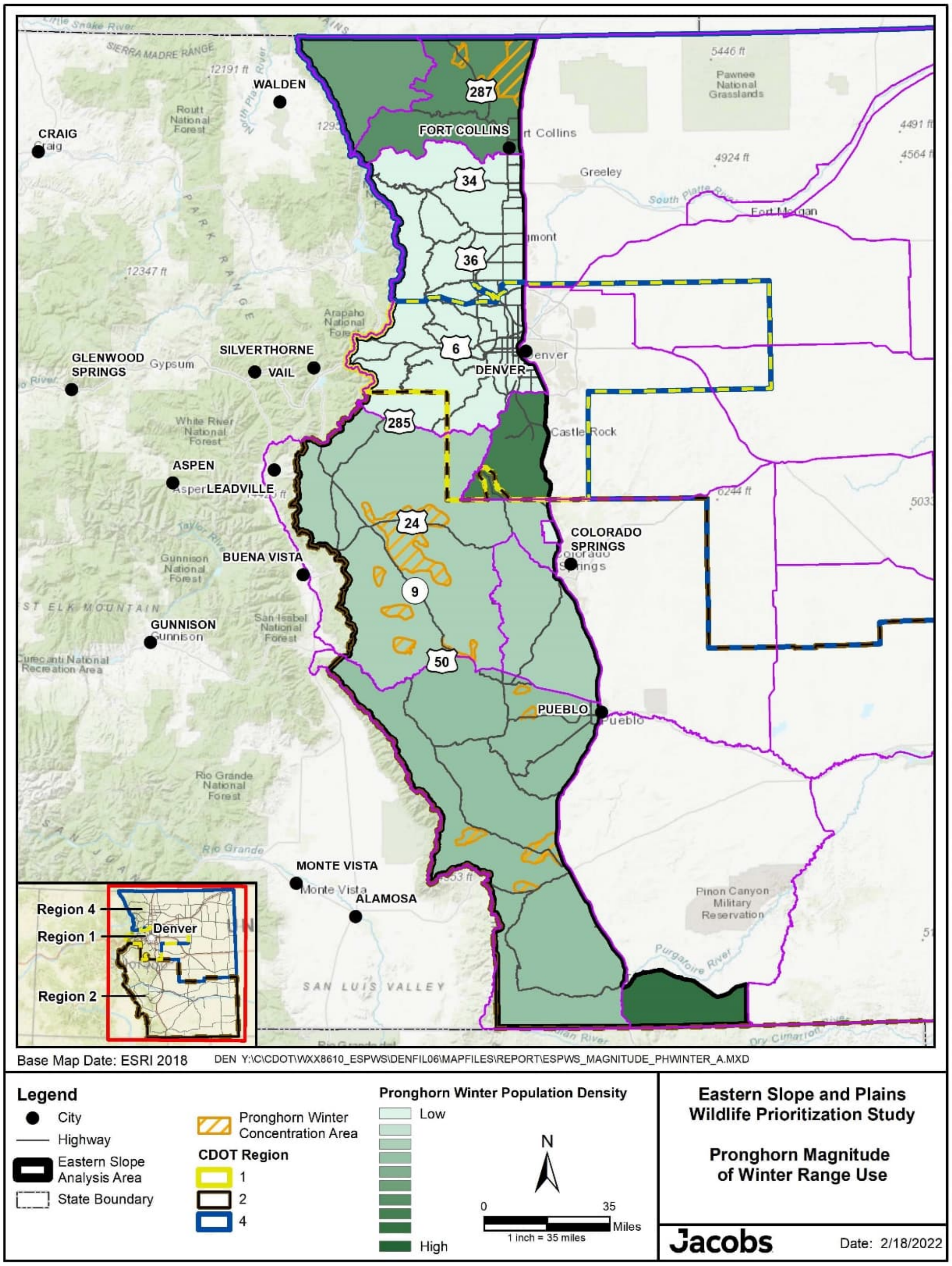
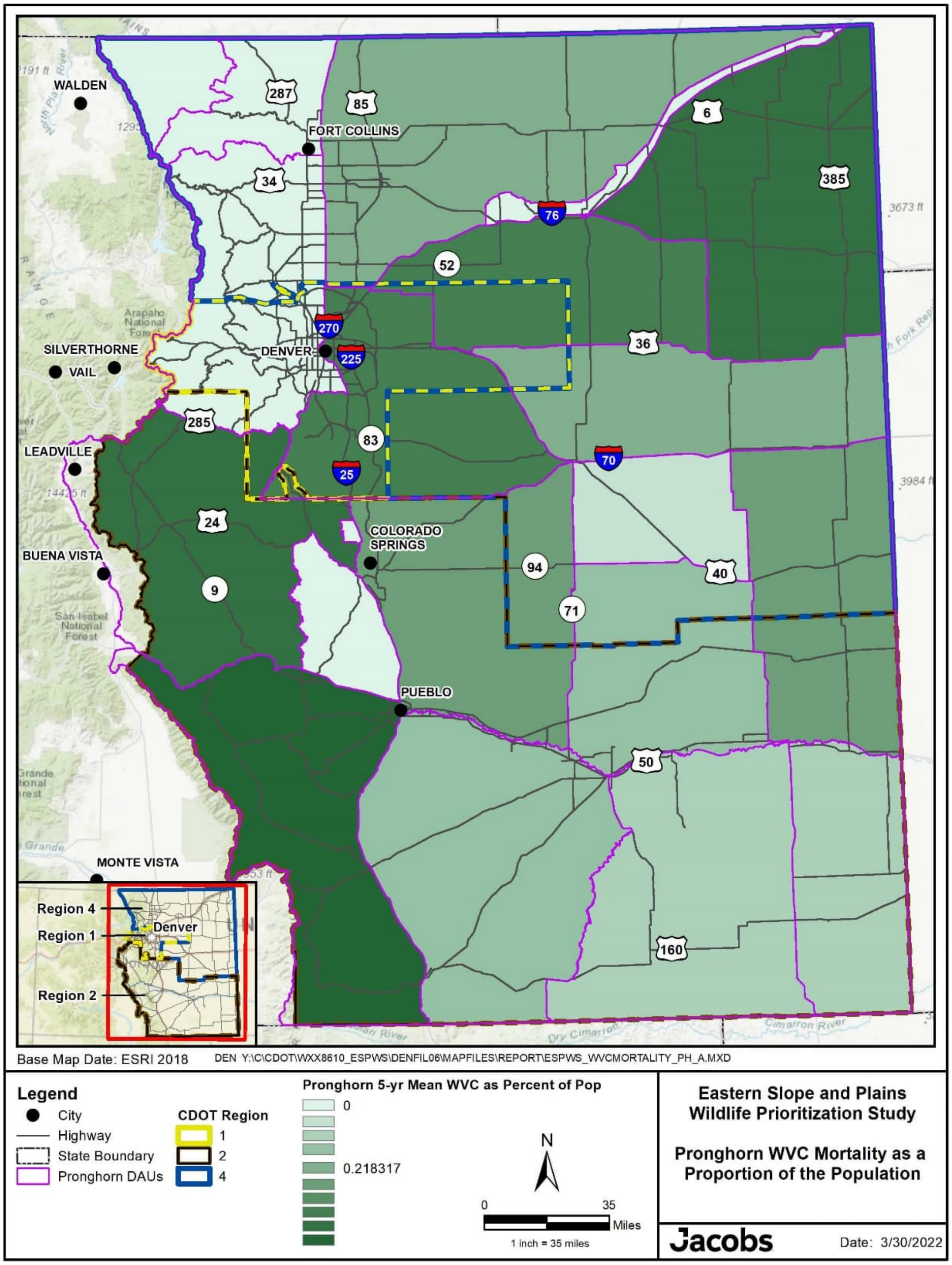


Figure F-12. Pronghorn WVC Mortality as a Proportion of the Population



Appendix G
Prioritization Output Drivers

Appendix G. Prioritization Criteria Scores for Top 5%

Table G-1. Prioritization Criteria Scores for the Top 5 Percent Aggregated Segments in Region 1

Highway and Milepost	Pattern Recognition	Deer Winter Density	Elk Winter Density	Pronghorn Winter Density	Deer Migration Magnitude	Elk Migration Magnitude	Deer WVC Proportion	Elk WVC Proportion	Pronghorn WVC Proportion	Bighorn WVC Mortality Hotspot	Lynx Probability of Highway Crossing	Deer Drainage Proximity	Deer Habitat Index	Pronghorn Habitat Index	WVC Risk Model: Deer Winter	Future WVC Risk: Deer Winter	WVC Risk Model Elk Winter	Future WVC Risk: Elk Winter	WVC Risk Model: Deer Migration	Future WVC Risk: Deer Migration	WVC Risk Model: Elk Migration	Future WVC Risk: Elk Migration	Prioritization Score
Eastern Slope Analysis Area																							
75th Percentile Threshold[a] (within Region)	9.75	1.1	1.1	0	1.2	0.3	1.9	2.3	0.4	2.3	0.75	-	-	-	3	0.75	0.9	0.5	1.1	0.5	1	0.5	
Interstate 70																							
246.3 to 250.7	**13**	0.7	0.7	0	**1.5**	0.1	0.8	**3**	0	0	0	-	-	-	1	0.5	**1**	**0.5**	0.9	**0.5**	1	**0.5**	25.5
252.8 to 260.8	**13**	**1.1**	0.6	0	1.2	0.1	0.8	**3**	0	0	0	-	-	-	1	0.5	**1**	**0.5**	0.9	**0.5**	0.8	0.4	25.5
Colorado 470																							
1.7 to 3.4	**13**	1	0	0	**1.5**	**0.4**	0.8	**3**	0	0	0	-	-	-	1	0.5	**0.9**	**0.5**	**1.2**	**0.6**	0.9	**0.5**	25.9
U.S. Highway 40																							
282.3 to 283.6	**13**	**1.4**	**1.3**	0	0.9	0.1	0.8	**3**	0	0	0	-	-	-	1	0.5	**1**	**0.5**	1	**0.5**	0.9	0.4	26.4
U.S. Highway 285																							
233.7 to 235	**13**	0	0.7	0	**1.5**	**0.4**	0.8	**3**	0	0	0	-	-	-	0.9	0.5	**1**	**0.5**	0.5	0.3	**1**	**0.5**	24.7
237.6 to 250.3	**13**	0.5	1	0	**1.5**	**0.4**	0.8	**3**	0	0.5	0	-	-	-	0.9	0.5	**1**	**0.5**	0.6	0.3	**1**	**0.5**	25.9
State Highway 121																							
0.4 to 0.8	**13**	0	**1.4**	0	**1.5**	**0.4**	0.8	**3**	0	0	0	-	-	-	0.7	0.3	**1**	**0.5**	0.5	0.3	**1**	**0.5**	24.8
Plains Analysis Area																							
75th Percentile Threshold[a] (within Region)	4.5	-	-	-	-	-	1.9	-	0.4	-	-	2.3	1.3	1.3	3	0.75	-	-	-	-	-	-	
Interstate 70																							
304.6 to 306	**6**	-	-	-	-	-	0.1	-	0	-	-	**3**	**1.3**	1.2	0.8	0.2	-	-	-	-	-	-	12.6
312.5 to 316.1	**6**	-	-	-	-	-	2.5	-	0	-	-	**2.6**	1.1	**1.4**	0.9	0.2	-	-	-	-	-	-	14.8
322.2 to 328.8	**6**	-	-	-	-	-	0.1	-	0	-	-	**2.6**	**1.4**	**1.6**	0.9	0.2	-	-	-	-	-	-	12.8
U.S. Highway 85																							
231.1 to 231.6	**6**	-	-	-	-	-	0.1	-	0	-	-	**3**	0.7	0.8	1.3	0.3	-	-	-	-	-	-	12.4
State Highway 30																							
15.5 to 16.4	**6**	-	-	-	-	-	0.1	-	0	-	-	**3**	**1.3**	0.9	0.8	0.2	-	-	-	-	-	-	12.4

[a] For a given criterion, scores in the 75th percentile (selected as an arbitrary but reasonable and useful threshold) are bolded to denote those criteria most responsible for driving high prioritization scores. Criteria scores are scaled to range 0 to 1 and weighted; differences in distributions of values among criteria as well as the weights assigned to each criterion result in different values associated with 75th percentile thresholds.

Notes:

Bold = Score is greater than or equal to the 75th percentile threshold for that criterion.
WVC = wildlife-vehicle collision

Table G-2. Prioritization Criteria Scores for the Top 5 Percent Aggregated Segments in Region 2

Highway and Milepost	Pattern Recognition	Deer Winter Density	Elk Winter Density	Pronghorn Winter Density	Deer Migration Magnitude	Elk Migration Magnitude	Deer WVC Proportion	Elk WVC Proportion	Pronghorn WVC Proportion	Bighorn WVC Mortality Hotspot	Lynx Probability of Highway Crossing	Deer Drainage Proximity	Deer Habitat Index	Pronghorn Habitat Index	WVC Risk Model: Deer Winter	Future WVC Risk: Deer Winter	WVC Risk Model Elk Winter	Future WVC Risk: Elk Winter	WVC Risk Model: Deer Migration	Future WVC Risk: Deer Migration	WVC Risk Model: Elk Migration	Future WVC Risk: Elk Migration	Prioritization Score
Eastern Slope Analysis Area																							
75th Percentile Threshold[a] (within Region)	9.75	2.3	2.3	0.5	2.3	2.3	2.3	2.3	2.3	2.3	0.75	-	-	-	2.1	0.5	1.3	0.7	1.5	0.7	1.3	0.7	
Interstate 25																							
2.2 to 10.1	**13**	0.1	1.1	0	0.7	**3**	0.2	0.6	0	0	0	-	-	-	1	**0.5**	1.1	0.5	0.9	0.5	1.1	0.6	25.0
58.5 to 60.2	**13**	**3**	0	0	**3**	0.2	0.7	1.8	0.9	0	0	-	-	-	1.2	**0.6**	1	0.5	1.1	0.6	0.7	0.4	28.6
67.9 to 83.7	**13**	**2.5**	0	0	**3**	0.2	**3**	1.8	0	0	0	-	-	-	1.1	**0.6**	0.9	0.5	1.2	0.6	0.8	0.4	29.6
118.7 to 119.6	**13**	0.7	1.1	0	0	0.6	**3**	0.5	0	0	0	-	-	-	0.9	**0.5**	0.9	0.5	0.9	0.4	0.9	0.5	24.3
126.5 to 127	**13**	0.7	0.6	0	0	0.6	**3**	0.5	0	0	0	-	-	-	1	**0.5**	1	0.5	1	0.5	1	0.5	24.2
152.8 to 159.3	**13**	0.7	0	0	0	0.4	**3**	1.5	0	0	0	-	-	-	1	**0.5**	1	0.5	1.1	0.6	1	0.5	24.7
162.8 to 163.6	**13**	0	0	0	1.5	0.6	**3**	1.5	0	0	0	-	-	-	0.9	**0.5**	1	0.5	0.2	0.1	0.9	0.4	24.1
U.S. Highway 24																							
274.8 to 276.7	**13**	0	0.6	0	**2.7**	0.6	**3**	0.5	0	0	0	-	-	-	0.9	0.4	0.9	0.4	0.6	0.3	0.8	0.4	25.1
U.S. Highway 50																							
285.9 to 287.6	**13**	0.3	0	0	**3**	0.6	**3**	1.8	0	0	0	-	-	-	0.7	0.4	0.8	0.4	0.4	0.2	0.8	0.4	25.7
290.7 to 296.8	**13**	0.3	0.2	0	**3**	0.6	**3**	1.8	0.2	0	0	-	-	-	0.6	0.3	0.7	0.4	0.3	0.1	0.7	0.4	25.6
U.S. Highway 285																							
166.6 to 170.1	**13**	0	1.3	0	**2.7**	0.2	0.7	**2.4**	0.2	0	0	-	-	-	0.9	**0.5**	1.1	0.5	**1.9**	0.5	1.3	0.6	26.9
208.9 to 209.3	**13**	1	0.7	0	1.5	0.2	0.8	**3**	0	0	0	-	-	-	1	**0.5**	1	0.5	0.2	0.1	0.8	0.4	24.6
210.6 to 211.1	**13**	1	0	0	0.2	0.2	0.8	**3**	0	**3**	**0.7**	-	-	-	0.8	0.4	0.7	0.4	0	0	0.8	0.4	25.3
214.9 to 215.8	**13**	1	0.4	0	1.5	0.2	0.8	**3**	0	0	0	-	-	-	0.7	0.4	1	0.5	0.1	0.1	1	0.5	24.1
State Highway 9																							
2.2 to 5.2	**13**	0.3	0	0	**2.7**	0.6	0.7	**2.4**	0	0	0	-	-	-	0.8	0.4	0.8	0.4	0.8	0.4	0.8	0.4	24.6
State Highway 12																							
45.5 to 45.9	**13**	0.1	1.1	0	0.7	**3**	0.2	0.6	0	0	0	-	-	-	1	**0.5**	1	0.5	0.5	0.3	1	0.5	24.0
62.9 to 66.9	**13**	0.1	2	0	0.7	**3**	0.2	0.6	0	1.3	0	-	-	-	1.1	**0.6**	1.1	0.5	1.2	0.6	1.1	0.6	27.8
State Highway 69																							
17 to 17.4	**13**	0.3	1.1	0	**3**	**3**	0.7	1.8	0	0	0	-	-	-	0.6	0.3	1	0.5	0.6	0.3	0.8	0.4	27.4
68.9 to 71	**13**	0.3	1.1	0	**3**	0.4	0.7	0.2	0	0	0	-	-	-	1.2	**0.6**	0.9	0.5	1.3	**0.7**	1	0.5	25.5
State Highway 78																							
19.7 to 22.7	13	0.3	0.3	0	3	0.2	0.7	1.8	0.4	0	0	-	-	-	0.9	0.4	0.8	0.4	0.9	0.4	0.7	0.3	24.6

Highway and Milepost	Pattern Recognition	Deer Winter Density	Elk Winter Density	Pronghorn Winter Density	Deer Migration Magnitude	Elk Migration Magnitude	Deer WVC Proportion	Elk WVC Proportion	Pronghorn WVC Proportion	Bighorn WVC Mortality Hotspot	Lynx Probability of Highway Crossing	Deer Drainage Proximity	Deer Habitat Index	Pronghorn Habitat Index	WVC Risk Model: Deer Winter	Future WVC Risk: Deer Winter	WVC Risk Model Elk Winter	Future WVC Risk: Elk Winter	WVC Risk Model: Deer Migration	Future WVC Risk: Deer Migration	WVC Risk Model: Elk Migration	Future WVC Risk: Elk Migration	Prioritization Score
Plains Analysis Area																							
75th Percentile Threshold[a] (within Region)	4.5	-	-	-	-	-	2.3	-	2.3	-	-	2.3	1.3	1.4	2.1	0.5	-	-	-	-	-	-	
U.S. Highway 24																							
315.9 to 320	4.0	-	-	-	-	-	**2.9**	-	0.1	-	-	2	**1.5**	**1.4**	1	0.3	-	-	-	-	-	-	13.3
340.5 to 340.9	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.5**	**1.6**	**2.2**	**0.5**	-	-	-	-	-	-	11.7
U.S. Highway 50																							
319 to 320.3	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.3**	**1.4**	2.1	**0.5**	-	-	-	-	-	-	11.2
330.3 to 331.2	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.4**	**1.6**	1.8	**0.5**	-	-	-	-	-	-	11.2
370.4 to 371.3	**6**	-	-	-	-	-	0.4	-	0	-	-	**3**	1.1	1.3	1.3	0.3	-	-	-	-	-	-	13.4
373 -374.4	**6**	-	-	-	-	-	0.4	-	0	-	-	**3**	1.2	1.3	0.9	0.2	-	-	-	-	-	-	13.0
400 to 402.7	**6**	-	-	-	-	-	0.5	-	0	-	-	**2.6**	1.2	**1.4**	1.3	0.3	-	-	-	-	-	-	12.8
428.4 to 433.2	**6**	-	-	-	-	-	0.5	-	0	-	-	**3**	**1.3**	1.3	1.2	0.3	-	-	-	-	-	-	13.5
443.6 to 446.7	**6**	-	-	-	-	-	0.5	-	0	-	-	**3**	1.2	**1.4**	1.1	0.3	-		-	-	-	-	13.5
453.2 to 455.8	**6**	-	-	-	-	-	0.5	-	0	-	-	**3**	1	1.3	0.6	0.2	-	-	-	-	-	-	12.7
State Highway 21																							
133.5 to 136.1	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	**1.4**	**1.5**	1.9	**0.5**	-	-	-	-	-	-	11.2
151.6 to 154.1	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	**1.3**	1	1.6	0.4	-	-	-	-	-	-	10.4
State Highway 71																							
18.9 to 19.2	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.4**	**1.6**	1.7	0.4	-	-	-	-	-	-	11.1
State Highway 83																							
20.8 to 22.1	0	-	-	-	-	-	**2.9**	-	0.1	-	-	1.3	**1.3**	1.3	**2.7**	**0.7**	-	-	-	-	-	-	12.0
State Highway 94																							
1.4 to 7	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	**1.4**	**1.5**	**2.2**	**0.6**	-	-	-	-	-	-	11.7
State Highway 96																							
70.3 to 73	**6**	-	-	-	-	-	**2.9**	-	0	-	-	**2.5**	**1.4**	**1.6**	1	0.3	-	-	-	-	-	-	15.7
79.2 to 89.7	**6**	-	-	-	-	-	**2.9**	-	0	-	-	**2.8**	**1.5**	**1.7**	0.7	0.2	-	-	-	-	-	-	15.7
State Highway 231																							
1.2 to 1.6	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.3**	**1.6**	1.7	0.4	-	-	-	-	-	-	11.0

[a] For a given criterion, scores in the 75th percentile (selected as an arbitrary but reasonable and useful threshold) are bolded to denote those criteria most responsible for driving high prioritization scores. Criteria scores are scaled to range 0 to 1 and weighted; differences in distributions of values among criteria as well as the weights assigned to each criterion result in different values associated with 75th percentile thresholds.

Note:

Bold = Score is greater than or equal to the 75th percentile threshold for that criterion.

Table G-3. Prioritization Criteria Scores for the Top 5 Percent Aggregated Segments in Region 4

Highway and Milepost	Pattern Recognition	Deer Winter Density	Elk Winter Density	Pronghorn Winter Density	Deer Migration Magnitude	Elk Migration Magnitude	Deer WVC Proportion	Elk WVC Proportion	Pronghorn WVC Proportion	Bighorn WVC Mortality Hotspot	Lynx Probability of Highway Crossing	Deer Drainage Proximity	Deer Habitat Index	Pronghorn Habitat Index	WVC Risk Model: Deer Winter	Future WVC Risk: Deer Winter	WVC Risk Model Elk Winter	Future WVC Risk: Elk Winter	WVC Risk Model: Deer Migration	Future WVC Risk: Deer Migration	WVC Risk Model: Elk Migration	Future WVC Risk: Elk Migration	Prioritization Score
Eastern Slope Analysis Area																							
75th Percentile Threshold[a] (within Region)	9.75	1.1	1.1	0.5	1.9	0.5	2.2	1.4	0.5	2.3	0.75	-	-	-	2.4	0.6	0.8	0.4	1	0.5	0.9	0.5	
Interstate 25																							
265.3 to 267.5	13	0.5	0	0	2.5	0.6	1.2	0.7	0	0	0	-	-	-	0.9	0.5	1	0.5	0.6	0.3	0.9	0.5	23.8
U.S. Highway 36																							
24.3 to 26.9	13	0.4	0.9	0	0.7	0.2	0.5	1.9	0	0	0	-	-	-	1	0.5	1.1	0.5	0.9	0.5	1.2	0.6	24.0
Plains Analysis Area																							
75th Percentile Threshold[a] (within Region)	4.5	-	-	-	-	-	2.2	-	0.5	-	-	2.3	1.4	1.4	2.4	0.6	-	-	-	-	-	-	
Interstate 70																							
333.6 to 336.2	6	-	-	-	-	-	0.1	-	0	-	-	3	1.5	1.7	1.4	0.4	-	-	-	-	-	-	14.0
395.7 to 398.3	6	-	-	-	-		0.9	-	0	-	-	3	1.5	1.7	1.4	0.4	-	-	-	-	-	-	14.7
413.2 to 415.8	6	-	-	-	-	-	0.6	-	0	-	-	2.5	1.1	1.4	0.9	0.2	-	-	-	-	-	-	12.7
Interstate 76																							
35.4 to 38.5	6	-	-	-	-	-	2.5	-	0	-	-	3	0.8	1.1	1.6	0.4	-	-	-	-	-	-	15.4
46.3 to 46. 8	0	-	-	-	-	-	2.5	-	0	-	-	3	1.4	1.7	1.3	0.3	-	-	-	-	-	-	10.4
48.5 to 48.9	0	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.7	1.3	0.3	-	-	-	-	-	-	1.4
49.8 to 51.1	0	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.7	1.5	0.4	-	-	-	-	-	-	10.6
61.6 to 62.4	0	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.6	1.5	0.4	-	-	-	-	-	-	10.5
66.8 to 72.5	5.5	-	-	-	-	-	2.5	-	0	-	-	1.8	1.4	1.6	1.1	0.3	-	-	-	-	-	-	14.3
82.6 to 86.1	6	-	-	-	-	-	2.5	-	0	-	-	3	1.6	1.3	1.4	0.4	-	-	-	-	-	-	16.2
94.8 to 100	4	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.7	1	0.3	-	-	-	-	-	-	14.0
101.3 to 101.8	0	-	-	-	-	-	2.5	-	0	-	-	3	1.4	1.8	1.5	0.4	-	-	-	-	-	-	10.6
110 to 115.7	5.1	-	-	-	-	-	2.5	-	0	-	-	1.5	1.5	1.8	1	0.3	-	-	-	-	-	-	13.8
119.6 to 124.8	6	-	-	-	-	-	2.5	-	0	-	-	1.5	1.5	1.6	1	0.2	-	-	-	-	-	-	14.4
126.1 to 132.7	6	-	-	-	-	-	2.5	-	0	-	-	1.8	1.5	1.8	1	0.2	-	-	-	-	-	-	14.9
133.1 to 136.6	6	-	-	-	-	-	2.5	-	0	-	-	0.8	1.5	1.8	0.6	0.1	-	-	-	-	-	-	13.4
140.5 to 143.6	6	-	-	-	-	-	2.5	-	0	-	-	0	1.6	1.8	1.4	0.4	-	-	-	-	-	-	13.7
149.2 to 155.8	6	-	-	-	-	-	2.5	-	0	-	-	0.2	1.5	1.7	1.1	0.3	-	-	-	-	-	-	13.4
161.9 to 177.5	0.8	-	-	-	-	-	2.5	-	0	-	-	2.8	1.5	1.7	1.7	0.4	-	-	-	-	-	-	11.5
178.8 to 184.1	0	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.7	1.9	0.5	-	-	-	-	-	-	11.1
U.S. Highway 6																							
397.7 to 399.5	6	-	-	-	-	-	1.5	-	0	-	-	3	1.6	1.4	1.1	0.3	-	-	-	-	-	-	14.9
400.8 to 403	6	-	-	-	-	-	1.5	-	0	-	-	1.8	1.2	1.4	0.8	0.2	-	-	-	-	-	-	12.8
425.5 to 426	0	-	-	-	-	-	2.5	-	0	-	-	3	1.5	1.5	1.5	0.4	-	-	-	-	-	-	10.4

Highway and Milepost	Pattern Recognition	Deer Winter Density	Elk Winter Density	Pronghorn Winter Density	Deer Migration Magnitude	Elk Migration Magnitude	Deer WVC Proportion	Elk WVC Proportion	Pronghorn WVC Proportion	Bighorn WVC Mortality Hotspot	Lynx Probability of Highway Crossing	Deer Drainage Proximity	Deer Habitat Index	Pronghorn Habitat Index	WVC Risk Model: Deer Winter	Future WVC Risk: Deer Winter	WVC Risk Model Elk Winter	Future WVC Risk: Elk Winter	WVC Risk Model: Deer Migration	Future WVC Risk: Deer Migration	WVC Risk Model: Elk Migration	Future WVC Risk: Elk Migration	Prioritization Score
U.S. Highway 24																							
350.9 to 355.8	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	**1.5**	**1.7**	2.1	0.5	-	-	-	-	-	-	11.8
357.9 to 363.6	0	-	-	-	-	-	**2.9**	-	0.2	-	-	**2.8**	**1.5**	**1.7**	1.7	0.4	-	-	-	-	-	-	11.2
364.9 to 365.3	0	-	-	-	-	-	**2.9**	-	**0.5**	-	-	**3**	**1.5**	**1.7**	0.8	0.2	-	-	-	-	-	-	10.6
366.2 to 368.4	0	-	-	-	-	-	**2.9**	-	0.3	-	-	**3**	**1.5**	**1.7**	0.9	0.2	-	-	-	-	-	-	10.5
371.4 to 374.1	0	-	-	-	-	-	**2.9**	-	0.2	-	-	**3**	**1.4**	0.7	1.2	0.3	-	-	-	-	-	-	10.8
375.8 to 376.7	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	1.3	**1.7**	1.5	0.4	-	-	-	-	-	-	11.0
U.S. Highway 34																							
180.6 to 182	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.5**	**1.7**	1.5	0.4	-	-	-	-	-	-	10.6
240 to 240.8	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.5**	**1.7**	1.4	0.3	-	-	-	-	-	-	10.4
244.8 to 249.6	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.5**	**1.7**	2.5	**0.6**	-	-	-	-	-	-	11.9
250.5 to 259.5	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.4**	**1.6**	**2.7**	**0.7**	-	-	-	-	-	-	11.9
U.S. Highway 85																							
243.4 to 246	**6**	-	-	-	-	-	1.2	-	0	-	-	**3**	1.1	1.0	0.9	0.2	-	-	-	-	-	-	13.5
State Highway 71																							
65.4 to 67.1	0	-	-	-	-	-	**2.9**	-	0.1	-	-	**3**	**1.4**	**1.7**	1.2	0.3	-	-	-	-	-	-	10.7
75 to 75.3	0	-	-	-	-	-	**2.9**	-	0	-	-	**3**	**1.5**	**1.7**	1.1	0.3	-	-	-	-	-	-	10.4
169.6 to 173	0		-	-	-	-	**2.5**	-	0	-	-	**3**	**1.5**	**1.7**	1.7	0.4	-	-	-	-	-	-	10.8
State Highway 113																							
1.4 to 1.8	0	-	-	-	-	-	1.5	-	0	-	-	**3**	**1.5**	**1.6**	2.3	**0.6**	-	-	-	-	-	-	10.5
State Highway 138																							
16.1 to 18.8	**6**	-	-	-	-	-	1.5	-	0	-	-	**3**	**1.7**	**1.6**	1.2	0.3	-	-	-	-	-	-	15.3
State Highway 385																							
243.6 to 245.7	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.4**	**1.7**	1.7	0.4	-	-	-	-	-	-	10.7
307.1 to 308.8	0	-	-	-	-	-	**2.5**	-	0	-	-	**3**	**1.5**	**1.7**	1.5	0.4	-	-	-	-	-	-	10.6

[a] For a given criterion, scores in the 75th percentile (selected as an arbitrary but reasonable and useful threshold) are bolded to denote those criteria most responsible for driving high prioritization scores. Criteria scores are scaled to range 0 to 1 and weighted; differences in distributions of values among criteria as well as the weights assigned to each criterion result in different values associated with 75th percentile thresholds.

Note:

Bold = Score is greater than or equal to the 75^{th} percentile threshold for that criterion.