Applied Research and Innovation Branch

WESTERN SLOPE WILDLIFE PRIORITIZATION STUDY

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WESTERN SLOPE WILDLIFE PRIORITIZATION STUDY

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Prepared by

JACOBS

In association with

ECO-resolutions

and Conservation Science Partners, Inc.

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16. Abstract

The Western Slope Wildlife Prioritization Study (WSWPS) emerged from a commitment to increased collaboration between CDOT and Colorado Parks and Wildlife (CPW) to address wildlife conflicts on roads. The study's objective involved identifying wildlife-highway conflict areas where targeted mitigation could have the greatest impact on reducing WVCs. To meet this objective, the WSWPS identified, mapped and prioritized highway segments across the West Slope based on the risk of WVC and the need for mule deer and elk to make cross-highway movements, particularly during migration or within winter range. 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 and preliminary mitigation recommendations, the decision-support framework includes 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 Western Slope.

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.

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TABLE OF CONTENTS

Tables

Figures

APPENDICES

DIGITAL DELIVERABLES

Benefit-Cost Analysis Tool (Excel workbook)

Implementation Considerations Matrix (Excel workbook)

GIS Data Layers and Shapefiles

- WSWPS prioritization results
- Top 5% segments by region – raw scores
- Top 5% segments by region – aggregated segments
- BBMM – elk/mule deer migration/winter range
- Wildlife crossings point file
- Other data as outlined in Appendix C

ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
AASHTO	American Association of State Highway and Transportation Officials
Alliance	Colorado Wildlife and Transportation Alliance
BCA	Benefit-Cost Analysis
BLM	Bureau of Land Management
BUILD	Better Utilizing Investments to Leverage Development
CDOT	Colorado Department of Transportation
CPW	Colorado Parks and Wildlife
CSP	Conservation Science Partners
DAU	data analysis unit
DTD	Division of Transportation Development
EA	environmental assessment
EIS	environmental impact statement
FASTER	Funding Advancements for Surface Transportation and Economic Recovery Act
GPS	global positioning system
HSIP	Highway Safety Improvement Program
I-70	Interstate 70
IGA	intergovernmental agreement
Jacobs Team	Jacobs and ECO-resolutions and Conservation Science Partners
Jacobs	Jacobs Engineering Group Inc.
mph	miles per hour
MPs	mile posts
MODA	Multi-objective Decision Analysis
NEPA	National Environmental Policy Act
PDO	property damage only
ROW	right-of-way
RTP	Regional Transportation Plan
SH	State Highway
STIP	Statewide Transportation Improvement Program
SWP	Statewide Transportation Plan
TIGER	Transportation Investment Generating Economic Recovery
TPR	Transportation Planning Region
U.S.	U.S. Highway

USDOT	U.S. Department of Transportation
VZS	Vision Zero Suite
WSWPS	Western Slope Wildlife Prioritization Study
WVC	wildlife-vehicle collision

EXECUTIVE SUMMARY

Overview

Each year in Colorado nearly 4,000 vehicle crashes involving wildlife are reported to law enforcement, resulting in injuries and fatalities to humans. The cost to Colorado's economy of these collisions is estimated at $66.4 million, not including the value of the wildlife that is killed. Wildlife-vehicle collisions (WVC) especially are a problem in Colorado's Western Slope, which is home to several of the largest herds of migratory elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) in North America. Approximately 60 percent of reported WVC accidents occur in the Western Slope, defined as the area west of the Continental Divide, and represented by Regions 3 and 5 of the Colorado Department of Transportation (CDOT).

The Western Slope Wildlife Prioritization Study (WSWPS) emerged from a commitment to increased collaboration between CDOT and Colorado Parks and Wildlife (CPW) to address wildlife conflicts on roads with the objective of identifying wildlife-highway conflict areas where targeted mitigation could have the greatest impact on reducing WVCs and enabling wildlife movement. Fewer WVCs not only translate to fewer human injuries, fatalities and reductions in property damage but also a cost savings for CDOT, individual motorists, insurance companies, and society at large and, finally, fewer wildlife mortalities and healthier wildlife populations.

Prioritization Study Methods

To meet this objective, the research team identified, mapped and prioritized highway segments across the Western Slope. This prioritization was based on the risk of WVC and the need for mule deer and elk to make cross-highway movements, particularly during migration or within winter range. Specifically, WVC risk models were created to estimate the relationship between roadway and road-adjacent attributes (such as distance to tree cover, traffic volume and speed, and winter range herd density) and relative WVC risk based on known WVC accident and carcass locations. The regression-based risk models generated through this approach indicate several specific drivers of WVC risk, as well as potential future risk associated with changes in traffic or landscape characteristics.

The species-specific, seasonal WVC risk models were then integrated with other wildlife and safety considerations, such as:

- the magnitude of mule deer/elk spring and fall migration or movement within winter range use;
- WVC mortality as a proportion of the population;
- connectivity value for other modeled species, for example, Canada lynx (*Lynx canadensis*); and
- CDOT's wild animal accident 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 Western Slope. 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 Western Slope.

Prioritization Results

The resulting prioritization maps show high-priority segments along a stretch of highway. Because the analysis was conducted for the entire Western Slope, highest priority segments were initially identified by considering Regions 3 and 5 jointly. However, because transportation projects are prioritized and implemented by region, these results were separated, and priority segments ranked by region as shown in Figure ES1. Overall, these results demonstrate the intent of the WSWPS research study panel to create a prioritization that is largely influenced by WVC safety needs but that also considers wildlife movement needs during winter and migration periods.

Field reviews were conducted of the top 5-percent priority segments in Regions 3 and 5; this equated to roughly 185 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 both Regions 3 and 5 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 mitigation project planning and budgeting.

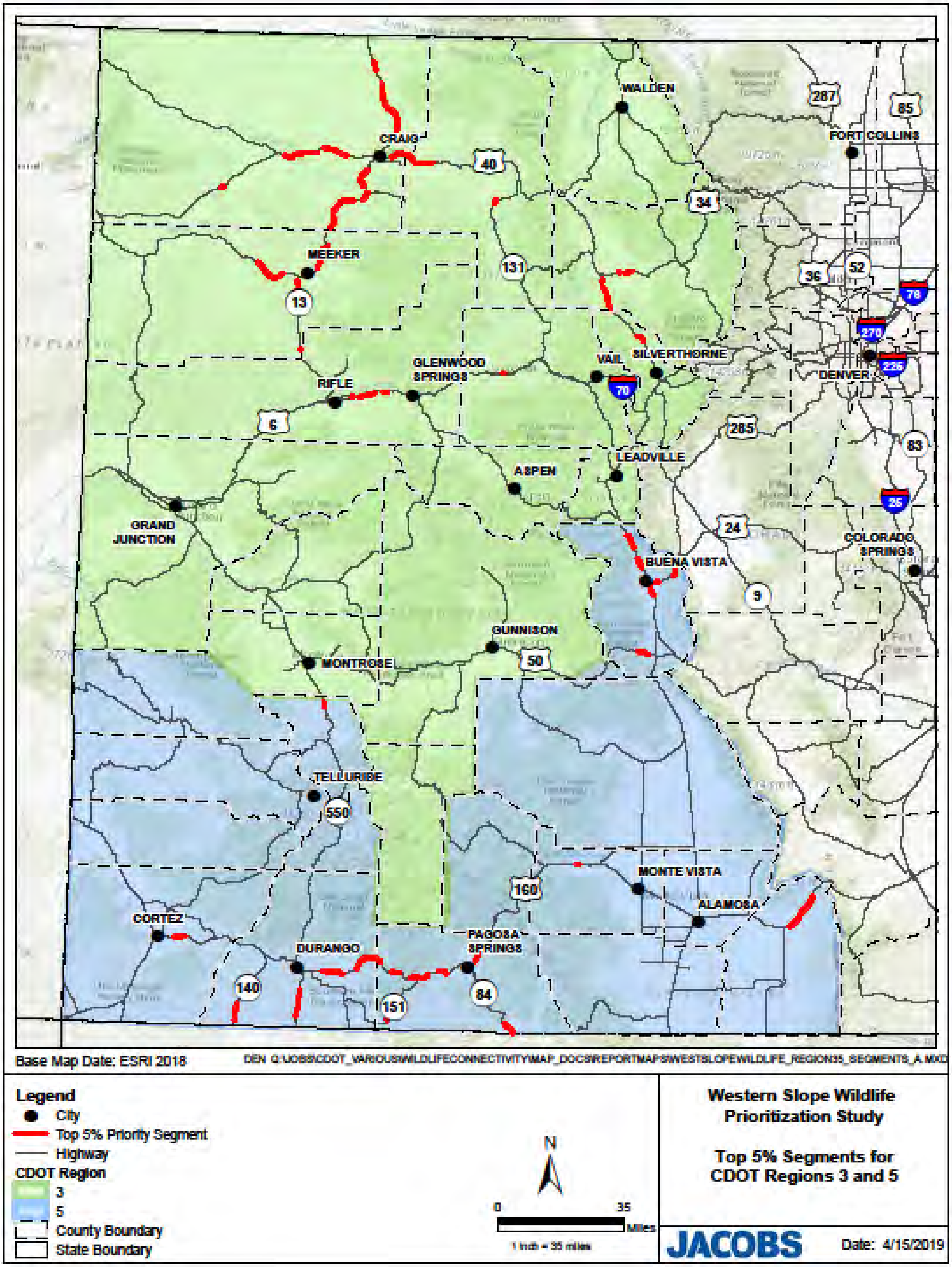

Figure ES1: Aggregated Highest Priority Highway Segments (Top 5 Percent) in CDOT Regions 3 and 5

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 to help CDOT and CPW integrate wildlife-highway mitigation actions into upcoming transportation plans and projects or create new, stand-alone projects based on these priorities. This framework may be used to inform regional and local-scale priority areas with the greatest need for wildlife mitigation. In addition to the prioritized highway segments and preliminary mitigation recommendations, the decision-support framework includes:

- a comprehensive benefit-cost analysis tool to help inform where wildlife-highway mitigation is cost effective;
- an implementation considerations matrix to flag factors that may influence opportunities to implement wildlife-highway mitigation; and
- guidance for integrating priority wildlife-highway segments into CDOT planning and project development.

The benefit-cost worksheet is an automated tool that provides a more comprehensive approach to assist in evaluating potential wildlife-highway mitigation projects. Unlike the existing methods used to calculate benefit-cost at CDOT, the approach developed for the WSWPS includes values for the wildlife that are killed in WVC, allowing a more thorough evaluation of the benefits and costs of wildlife-highway mitigation projects. The automated Excel tool allows users to calculate the benefit-cost of wildlife crossings in three ways:

1. using current CDOT Traffic and Safety's methods and valuations, for state safety grant applications,
2. using current U.S. Department of Transportation (USDOT) methods and valuations, for federal grant applications, and
3. using the WSWPS hybrid benefit-cost methods and valuations, for planning and prioritizing mitigation projects.

The Implementations Considerations Matrix is a sortable matrix, which summarizes select opportunity, feasibility and urgency considerations that do not affect the prioritization of highway segments but may influence the likelihood of mitigation in a given top 5-percent segment. These considerations include, existing commitments to wildlife crossings mitigation in the Statewide Transportation Improvement

Program (STIP), an Environmental Assessment (EA) or Environmental Impact Statement (EIS); overlap with planned or proposed transportation projects identified in the STIP, the statewide Development Plan, a regional transportation plan, or other planning documents or identified mitigation priority areas; the constructability of wildlife crossings mitigation based on the field reviews; security of adjacent lands; and overlap with key energy development corridors.

Implementation and Next Steps

The WSWPS positions CDOT and CPW to better address safety of the travelling public due to WVC and connectivity for wildlife across CDOT-maintained roads in western Colorado. 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, the WSWPS provides CDOT and its partners with data and proactive tools for pursuing strategic wildlife-highway mitigation where it is needed most at a regional scale.

This research developed implementation tools to 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 Regions 3 and 5 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. Figure ES2 depicts how the decision-support tools created for the WSWPS may be used to determine where to focus wildlife-highway mitigation and walks users through the major steps in the implementation process to provide cost effective, ecologically-effective wildlife-highway mitigation. 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' propose to expand the research outcomes for the Western Slope and statewide; integrate the WSWPS priority areas into local and regional planning efforts; and coordinate with efforts to increase partnerships and funding for wildlife-highway mitigation. Over the course of this study, the interagency collaboration between CDOT and CPW has deepened and will continue to be of vital importance in the funding, design, and construction of effective wildlife-highway mitigation projects across the Western Slope. Ultimately, this study is expected to support CDOT, CPW and their partners in implementing solutions to reduce incidence of WVC across the Western Slope.

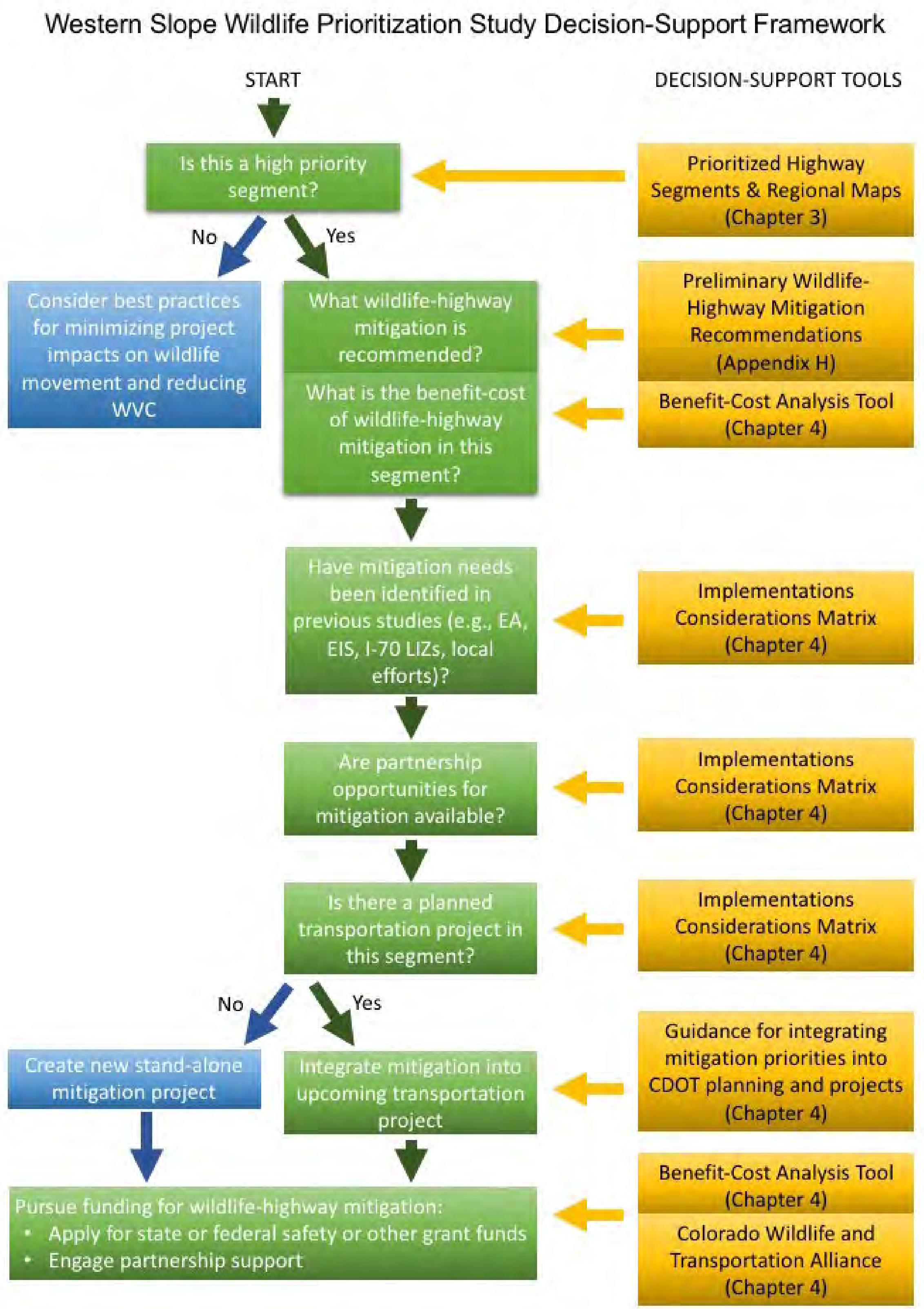

Figure ES2: Flowchart of the WSWPS Decision-Support Framework and Component Parts

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 travelling public. While overall highway safety has improved substantially over the last several decades (Huijser et al., 2018), WVCs have increased by about 50 percent between 1990 and 2004 (Huijser et al., 2007). This trend has since leveled off, although WVC rates vary from year to year. Still, according to State Farm (2018), 1 out of every 167 drivers will submit a claim from hitting a deer, elk, moose, or caribou during 2018. Between 1 to 2 million collisions with large wildlife are estimated to occur in the United States each year (Conover et al., 1995; IIHS, 2018; State Farm, 2018), resulting in wildlife mortalities and human fatalities and injuries, as well as associated costs of nearly 10 billion U.S. dollars annually (Huijser et al., 2007) (adjusted for inflation to 2018 dollars).

These trends are readily apparent in Colorado, where nearly 4,000 vehicle crashes involving wildlife are reported to law enforcement each year, resulting in injuries and fatalities to humans and costing an estimated $66.4 million annually, not including the value of the wildlife that is killed and the impacts to wildlife populations. Because reported accidents represent a fraction of the actual number of WVCs, with under-reporting rates of up to 80 percent or more (Kintsch et al., 2018a; Olson, 2013), the actual costs and impacts to society are much greater. WVCs especially are a problem in Colorado's Western Slope, which is home to several of the largest herds of migratory elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) in North America. Approximately 60 percent of reported WVC accidents occur in the Western Slope, represented by Regions 3 and 5 of the Colorado Department of Transportation (CDOT) (See Figure 2-1).

While WVC numbers tell a story of ongoing conflict between wildlife and motorists, a 2017 population status update for mule deer herds in Colorado indicates that population estimates are still far below the statewide population objective ranges, and many Western Slope herds still have not recovered from the severe winter of 2007-2008 (Mule Deer Working Group, 2018). In Colorado, 2 percent of mule deer does marked with telemetry devices are killed in vehicle collisions annually and Colorado Parks and Wildlife (CPW) estimates that across the Western Slope more mule deer does are killed each year in WVCs than from the annual hunter harvest (Holland, pers. comm., 2018). These estimates are supported by CDOT maintenance carcass data and Colorado State Patrol reported accident data across the western slope for the 10-year period 2006 – 2015.

Elk populations have also declined in many areas of Colorado, including the Western Slope. While many factors, such as managing herds to population objectives and declining calf ratios, contribute to this decline, the impacts of WVCs on herds that are already experiencing population declines can be pronounced (Holland, pers. comm., 2018).

In addition to its ecological values, Colorado's wildlife appeals to residents and visitors alike, drawing hunters, anglers, photographers, and wildlife watchers from across the globe. Each year Colorado sees more than 357,000 deer, elk, and pronghorn hunters. Hunting and other wildlife-related activities contribute at least $5 billion to the state's economy annually, and the declining size of many deer and elk populations is a matter concerning many organizations, agencies, and communities (CPW, 2014).

In December 2015, the CPW Commission adopted the *Colorado West Slope Mule Deer Strategy* (CPW, 2014), the focus of which was understanding and working towards reversing the trend of declining mule deer populations and restoring them to the state's objective of 410,000 to 450,000 for all of western Colorado. Currently, the mule deer population size falls more than 100,000 animals short of this goal.

While increases in the mule deer population would be of great value to state and local economies, it would also present an ever-greater concern to CDOT, which is already confronted with high rates of WVCs at current herd sizes. WVCs hinder CDOT's mission to provide safe, reliable, and efficient transportation. As CPW works towards its goal of increasing the deer population in western Colorado, with attendant increases in elk and other wildlife populations, enhanced collaboration and partnership between CDOT and CPW in research, implementation, and monitoring will be increasingly important to reduce WVCs and provide safer roads for wildlife and people alike.

1.2 Research Need

Currently, CDOT addresses WVC problem areas largely on a project-by-project basis, integrating mitigation as transportation projects arise in highway segments known to have high rates of WVCs. While CDOT biologists consider migratory ungulates and other wildlife movement across the broader landscape to access seasonal resources or disperse to new territories this project-focused approach is limited in getting wildlife mitigation implemented on the ground. Consequently, wildlife mitigation defined by transportation improvement project boundaries may not capture areas that lie beyond the project limits where mitigation could have the greatest impact on reducing WVCs and increasing driver safety.

Earlier studies of habitat connectivity and roads in Colorado can guide identifying likely wildlife-road crossing locations (Barnum, 2003) or flagged segments for further consideration (Crooks et al., 2008; Southern Rockies Ecosystem Project, 2005), but none produced outcomes that could directly inform mitigation priorities and project planning. Therefore, CDOT needed a regionwide prioritization to guide future wildlife mitigation projects across Regions 3 and 5. Specifically, CDOT desired a prioritized list of highway segments for wildlife mitigation that could be directly integrated into transportation project planning, budgeting, and design to provide greater confidence and credibility when wildlife-highway mitigation measures are incorporated into transportation projects.

To address their respective needs, CDOT and CPW created the Western Slope Wildlife Prioritization Study (WSWPS), which has served to deepen the collaborative partnership between the two agencies as they work to create safer roads for wildlife and people. This research study was 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, fatalities and reductions in property damage but also a cost savings for CDOT, individual motorists, insurance companies, and society at large and, finally, fewer wildlife mortalities and healthier wildlife populations.

1.3 Research Objectives

The WSWPS was launched during late 2016 as a collaborative effort between CDOT and CPW and was conducted by the Jacobs Engineering Group Inc. (Jacobs) and its partners, ECO-resolutions and Conservation Science Partners (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. The WSWPS included the following deliverables:

- Prioritized list and maps of highway segments with wildlife-highway conflicts across the Western Slope
- Milepost-specific mitigation recommendations for potential wildlife crossing structures and benefit-cost analysis for the highest priority highway segments
- Decision-support toolbox, including best practices for integrating prioritized wildlife-highway segments into transportation planning and project development or, in select cases, identifying potential stand-alone mitigation projects

- Replicable methodology for analyzing existing data to produce regional and local-scale priority areas with the greatest need for wildlife mitigation.

2 PRIORITIZATION STUDY METHODS

2.1 Study Area

The WSWPS study area is defined by CDOT Regions 3 and 5, which roughly correspond to CPW's Northwest and Southwest Regions (Figure 2-1). Geographically, the Western Slope extends across the western third of the state from the Continental Divide to the Utah border. Although it is home to 10 percent of Colorado's residents, the Western Slope contains 33 percent of the state's land, about 70 percent of its water, and some of the state's most popular tourist and recreation destinations (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 (SH). In total, CDOT Regions 3 and 5 manage 3,490 route miles. CDOT Region 3 is responsible for managing 2,055 route miles (5,030 lane miles). CDOT Region 5 is responsible for managing 1,435 route miles (3,090 lane miles).

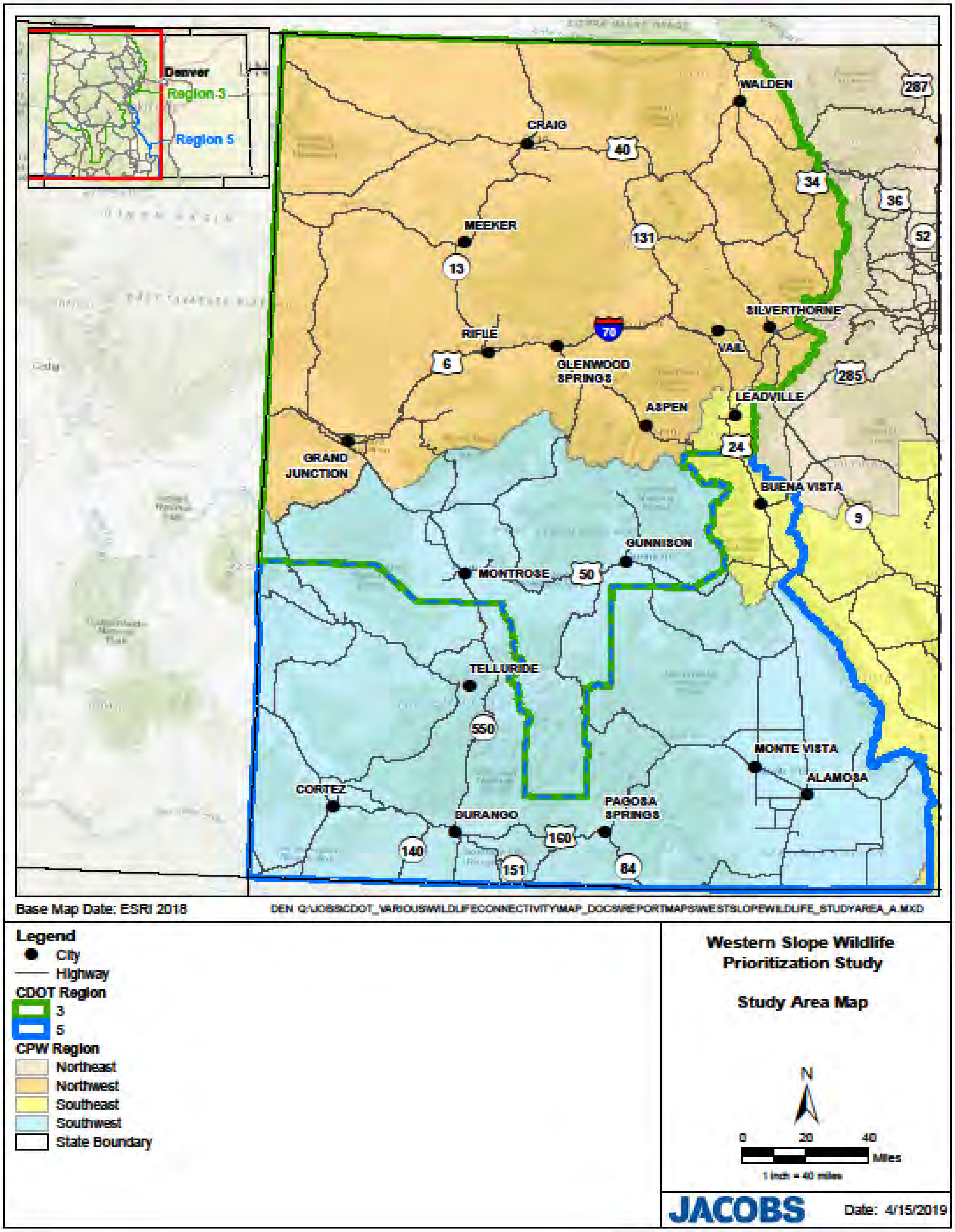

Figure 2-1: CDOT and CPW Regional Boundaries on the Western Slope

2.1.1 Western Slope Ecoregions and Flora

The Western Slope is primarily encompassed by two ecoregions—the Colorado Plateau and Southern Rocky Mountains. The Colorado Plateau Ecoregion includes much of southern and eastern Utah, as well as parts of western Colorado and northern Arizona (Omernik, 1987; U.S. Environmental Protection Agency, 1997). The terrain of this ecoregion is characterized by broad plateaus, ancient volcanoes, and deeply dissected canyons (Booth et al., 1999).

Climatically, the ecoregion is characterized as arid to semiarid and is commonly referred to as the high or cold desert.

Much of the ecoregion is covered by an extensive woodland zone (Figure 2-2), which is dominated by pinyon pine (*Pinus edulis*) and several species of juniper (*Juniperus* spp.), with sparse ground cover composed of a variety of grama and sage species. The mountainous portions of the ecoregion receive more precipitation and support a mixed forest of ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), quaking aspen (*Populus tremuloides*), and Engelmann spruce (*Picea engelmannii* (Hogan, 2015). Mixed grass-shrublands make up the predominant land cover type, accounting for approximately 63 percent of the ecoregion, while forest, agriculture, and barren lands make up much of the remaining landscape (Stier, 2012).

Figure 2-2: Landscape in the Colorado Plateau Ecoregion

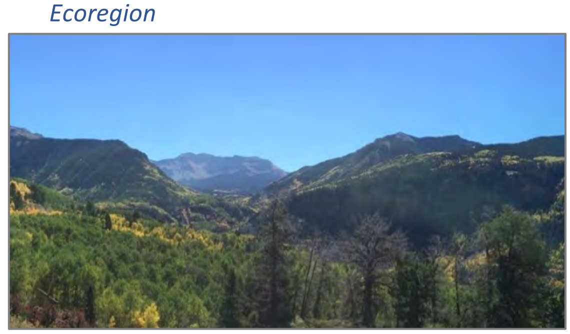

Figure 2-3: A Forested, Mountainous Landscape of the Southern Rockies Ecoregion

The Southern Rocky Mountains Ecoregion is a high-elevation mountainous ecoregion that covers much of central Colorado and parts of southern Wyoming and northern New Mexico (Omernik, 1987; U.S. Environmental Protection Agency, 1997). Across the ecoregion a steep elevation gradient runs from low foothills to high peaks, ranging from approximately 6,000 feet to over 14,000 feet (Drummond, 2012).

Much of the annual precipitation in the ecoregions is received as snowfall, creating a high-elevation snowpack that is an important water source, feeding major river systems.

The ecoregion is dominated by forest cover interspersed with grassy meadows or shrublands (Figure 2-2 and Figure 2-3). 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 tree line support a variety of low shrubs, wildflowers, krummholz (stunted trees), and other vegetation interspersed with exposed rocks and permanent snowfields (Drummond, 2012).

2.1.2 Western Slope Fauna

Figure 2-4: Foraging Elk Herd Credit CPW

Colorado's Western Slope is home to several of the largest herds of migratory elk and mule deer in North America (Figure 2-4). The northwest region of Colorado is home to two of the largest migratory mule deer and elk herds in Colorado and perhaps the United States. Current population estimates for the Bear's Ears mule deer herd are 40,500 and White River mule deer herd are 32,500 animals. The combined elk herd units range from 65,000 to 70,000 animals. A significant proportion of these herds migrate 60 to 70 miles each spring and fall. Elk populations within

these two herds are very robust; however, mule deer herds in these two herd units, like many other deer herds across the West, have been steadily declining over the past several decades. The White River deer herd in particular has experienced significant declines over the past decade.

In the southwestern Colorado, the San Juan Basin also supports large populations, with the deer herd estimated at 27,000 and the elk herd at 19,000. These animals depend upon migratory routes that cross multiple jurisdictional boundaries, including National Forest, Bureau of Land Management (BLM), Southern Ute Tribe, and private lands, as well as interstate movements into New Mexico. Recent studies by CPW, the Southern Ute Tribe, and WEST, Inc. using global positioning system (GPS) collars have identified numerous discrete migration corridors, highway crossings, and stop-over areas for various segments of the San Juan deer (Sawyer, 2018) and elk herds. Other large deer and elk herds of importance in the Western Slope include the North and Middle Park Gunnison Basin and Uncompahgre Plateau herds. Smaller resident herds are also common in many areas of the Western Slope.

2.2 Study Design

The Jacobs Team's first task was to refine the proposed study design. The team first conducted a comprehensive literature review of published and gray literature sources to glean lessons learned from similar prioritization processes conducted in other locations and inform other aspects of this research (complete literature review is included in Appendix A). Specifically, the following topics were addressed:

- Prioritization processes
- Wildlife studies focusing on potential target species (elk, mule deer, and Canada lynx) movements and habitat use in Colorado and adjacent states
- Benefit cost analyses for wildlife-highway mitigation projects
- Wildlife-highway mitigation techniques and best management practices
- Decision support tools

In addition, the Jacobs Team conducted telephone and in-person interviews at the outset of the research study with CDOT and CPW personnel and representatives from other western state transportation and wildlife agencies. The purpose of these interviews was to accomplish the following:

- Determine what wildlife datasets were available from CPW and other sources and their applicability and availability for this research study
- Learn from previous wildlife connectivity prioritization processes conducted in other states such as Idaho, Montana, and Washington
- Determine how WVC accident and carcass datasets are compiled and used to identify statewide or regional WVC hotspots
- Determine how wildlife-highway mitigation projects are currently identified and prioritized at the statewide and regional levels

Interviews were also conducted with researchers at the University of Melbourne, Australia regarding a risk modeling approach they had developed that the Jacobs Team was considering adapting for the WSWPS (Appendix B includes a complete list of interviewees and their affiliations).

Based on the findings of the literature review and interviews, the Jacobs Team refined the study approach and began compiling the appropriate data needed to conduct the study as described in the following sections.

2.3 Data Synthesis and Analysis

As a result of the interviews and coordination with the WSWPS research study panel, the Jacobs Team compiled the following list of all potential data needs and sources:

- CDOT highways, mileposts, speed limits, and current and future traffic volumes
- WVC reported accident data from 2006 through 2015 compiled by CDOT Traffic and Safety Engineering Branch
- WVC carcass data from 2006 through 2015 recorded by CDOT Maintenance personnel
- CPW mule deer and elk GPS collar data
- CPW species activity mapping data

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

The Jacobs Team, in coordination with the study panel, determined that 0.5-mile road segments were the appropriate analysis unit for this study. To derive 0.5-mile segments from the CDOT roads layer, the Jacobs Team used CDOT's highways data layer, which covers road segments within all CDOT regions. This dataset was clipped to include only highways within Regions 3 and 5. The source dataset contains traffic volume counts and other attributes, such as speed limit, which would potentially be used in the risk modeling process (Section 2.4). Accordingly, several preliminary analyses were conducted using the CDOT roadway, WVC collision data, CDOT maintenance carcass data, and CPW mule deer and elk collar data. The following geographic information system shapefiles are included among the deliverables for this research study (Appendix D includes detailed analysis methods and output):

- Association of reported WVC accidents and CDOT carcass data to 0.5-mile road segments
- Analysis of seasonal distributions of CDOT Maintenance carcass data over a 10-year period
- Cluster analysis of 10 years of reported WVC accident dataset using spatial autocorrelation test and statistical analysis (Moran's I and Getis-Ord Gi*z-score)

- Brownian Bridge Movement Models (BBMM) derived from CPW mule deer and elk collar data

2.4 Risk Modeling

For this WSWPS, Conservation Science Partners (CSP), as part of the Jacobs Team, was tasked with modeling WVC risk for mule deer and elk throughout the road network in CDOT Regions 3 and 5 using available spatial data to inform mitigation prioritization (based on projected land use and traffic volume). CSP led the exploration of three general approaches to estimating WVC risk using data from a range of models, including state-of-the-art, data-intensive models to a simpler model informed directly by recorded WVC. In each approach, the aim was to estimate WVC risk separately for mule deer and elk, as well as estimate risk specific to migration periods (spring and fall combined) and winter range use, yielding a total of four risk models under both current and future conditions.

2.4.1 Proposed Study Approach for Landscape-Scale WVC Risk Assessment

Initially, CSP pursued adapting an approach developed by Visintin et al. (2016), estimating *exposure* (presence of wildlife on roads) and *hazard* (presence of vehicles on roads) separately as two distinct risk components. Specifically, *exposure* was estimated as the probability of animals crossing a given road segment using a methodology adapted from McClure et al. (2017). CSP obtained GPS collar data from CPW biologists, Aran Johnson (Southern Ute Indian Tribe), and Dr. Hall Sawyer (WEST, Inc.), representing ten mule deer collaring efforts and five elk collaring efforts throughout the Western Slope. These data were cleaned and filtered to migration and winter periods. Brownian Bridge Movement Models (Horne et al., 2007) were fit to each individual movement period to estimate the probability of movement through each raster cell between observed GPS relocations, then these probabilities were summed across individuals in each herd to estimate population-level probability of movement (adapted from Sawyer et al., 2009).

The next step was to fit models of habitat suitability specific to migration periods and winter range use; this was accomplished using population-level probability of movement as the response variable and a variety of landscape attributes identified from published literature on mule deer and elk habitat selection and by prioritization subcommittee members as explanatory variables. The resulting habitat suitability maps were then used as resistance surfaces for circuit theory-based connectivity models (McClure et al., 2017; Littlefield et al., 2017) predicting likely migration paths between summer and winter range areas and likely movement paths within winter range areas.

Hazard was estimated as a product of the volume and speed of vehicle traffic on roads. CSP obtained estimates of average annual daily traffic (AADT) per road segment and spatial data on posted speed limits from CDOT. The intent was to test alternative hypotheses for the most appropriate means of combining traffic volume and speed to estimate hazard (that is, relative weights on each component) and combining *exposure* and *hazard* to estimate risk by evaluating each alternative risk estimate against observed patterns of WVC.

2.4.2 Revised Study Approach for WVC Risk Assessment

The second approach explored was based on an approach similar to the first, except rather than estimating wildlife movement probability continuously throughout the Western Slope in response to landscape attributes, the approach focused on probability of movement immediately adjacent to and across roads in response to road-adjacent landscape attributes. In other words, the analysis and inference were restricted to the road network, buffered by a distance sufficient to encompass attributes that may influence animals' selected path of approach to the road.

The first two approaches, which integrated GPS collar data collected during migration and winter range movements to estimate the exposure component of risk (that is probability of wildlife on roads), were not viable because of the naturally high variability (that is, random noise) in the study system. Despite the availability of a very high volume of data from multiple herds and many individuals with extensive geographic coverage, the preliminary exposure models failed to explain a meaningful proportion of variance in these data. Based upon the ecology of these species, their ubiquity across the Western Slope, the nature of the Western Slope landscape with very expansive amounts of diverse high-quality habitat, and the team's experiences working with these and other data, the CSP suggested that high levels of "noise," or random variability, are inherent to the occurrence of elk- and mule deer-vehicle collisions in the Western Slope, and the models' fair to moderate proportions of variance explained is simply a reflection of this reality. Stated simply, no selection of particular topographic, vegetative, or other landscape characteristics, either by individuals or as an emergent property of herd space use, could be discerned. Despite evidence in the literature for patterns of habitat selection by mule deer and elk in some landscapes at some spatial and temporal scales, these findings are consistent with many other previous studies (Ager et al., 2003; D'Eon and Serrouya, 2005; Lendrum et al., 2012) and re-emphasizes the generalist nature of both species and the almost ubiquitous habitat suitability of the Western Slope.

Further confounding the effort to create an exposure model for mule deer and elk migration and winter range movements across the Western Slope relates to the nature of the collar data. CPW's collaring studies have typically targeted herds that primarily use habitats away from highways and have been designed to collect demographic data. As a result, location points in these datasets were collected at a much coarser level (that is, 13 to 20 hours) than what would be required for a collaring study targeting more detailed movement patterns, which can then be more accurately attributed to landscape variables.

2.4.3 Final Risk Model Approach

Because of the challenges faced using the first two approaches, the Jacobs Team, in coordination with the study panel, settled on an approach that differed substantially from the first two. This involved modeling WVC risk directly based on observed WVC and CDOT maintenance carcass data rather than using GPS collar data on animal movements to model exposure as a distinct component of risk. Based on the work of Kolowski and Nielsen (2008), this approach compares road and road-adjacent attributes of known reported WVC accident 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. 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. CSP's complete methods, analysis, results, and discussion are presented in Appendix E.

2.5 Prioritizing Wildlife-Highway Conflict Areas

After producing the WVC risk models, the Jacobs Team worked to develop a comprehensive approach to prioritize highway segments for wildlife-highway mitigation, integrating the risk models with other wildlife and safety considerations. A subcommittee was formed involving CPW biologists, CDOT biologists, CDOT Traffic and Safety Engineering personnel, and the Jacobs Team. The subcommittee identified other prioritization criteria and created a prioritization matrix to provide a standardized method for scoring individual highway segments. The subcommittee held six in-person or conference-call meetings between December 2017 and July 2018; additional communications and reviews were conducted over email. Specifically, this subcommittee was tasked with the following:

- Identifying and defining prioritization criteria
- Determining how the criteria should be weighted relative to one another

- Determining how a given segment should be scored for each criterion

Combined, the prioritization criteria discussed in the following subsections define the need for wildlife-highway mitigation for each 0.5-mile segment based on the safety hazard WVC present to drivers and the wildlife need for cross-roadway movement during migration or in winter range.

2.5.1 Prioritization Criteria

The subcommittee identified and defined the following criteria:

- ***WVC Risk for Elk and Mule Deer (Current and Future)***—Modeled relative probability of WVC is based on the relationship between WVC (combined accidents and locations) with attributes of roads and 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 and Mule Deer***—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 Mule Deer***—Distance between the point of highest elevation within each DAU and the centroid of winter concentration areas in the DAU were multiplied by the DAU herd size estimate.
- ***WVC Mortality as a Proportion of Population***—A 5-year average annual WVC count in each DAU was divided by the DAU herd size estimate.
- ***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 4 species, total. This iteration of the prioritization only includes the probability of highway crossing for Canada lynx (Baigas et al., 2017), because this is the sole species for which such data are currently available for the WSWPS study area.
- ***CDOT Wild Animal Accident Pattern Recognition by Road Type***—WVC hotspot value was calculated by CDOT Traffic and Safety Engineering Branch. The most recent pattern recognition analysis available was from 2013, based on accident data from 2008 through 2012. WVC accident pattern recognition is a calculation of the percentage of WVC accidents per volume of traffic per road type as

compared with the relative norm. These WVC patterns were identified at a 95 percent confidence level.

2.5.2 Criteria Scoring and Weighting

Values for each criterion presented in the previous subsection were scaled between 0 and 1 and attributed to each 0.5-mile segment of CDOT-maintained highways across the Western Slope. In addition, each criterion had an assigned priority score calculated using interagency committee-defined weights for each criterion. The priority score was calculated as a weighted sum using the formula:

Priority = (Weight 1 x Criteria 1) + (Weight 2 x Criteria 2) +…

Table 2-1 depicts the weights assigned by the subcommittee to each prioritization criterion. While the highest single criterion weight was assigned to the CDOT pattern recognition (10 points), the combined weight of the wildlife criteria totaled 19 points out of the 41 maximum points in this prioritization. The high individual weight assigned to the CDOT pattern recognition reflected the value placed on safety concerns when identifying and funding wildlife-highway mitigation projects. Due to the fair to moderate explanatory power of the risk model, the model output criteria were individually given lower weights, but with a combined weight of up to 12. Within the risk model, current conditions were prioritized higher than future conditions due to uncertainty of the latter.

Table 2-1: Prioritization Criteria Weights

Prioritization Criteria	Weight
Risk Model	
Current Mule Deer Migration WVC Risk	2
Current Mule Deer Winter Range WVC Risk	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
Future Elk Migration WVC Risk	1
Future Elk Winter Range WVC Risk	1
Wildlife	
Magnitude of Migration Movement for Mule Deer	3
Magnitude of Migration Movement for Elk	3
Magnitude of Winter Range Use for Mule Deer	3
Magnitude of Winter Range Use for Elk	3
High Mule Deer WVC Mortality as a Proportion of the Population	3
High Elk WVC Mortality as a Proportion of the Population	3
Connectivity Value for Other Modeled Species (Canada Lynx)	1[a]
Safety	
CDOT Wild Animal Accident Pattern Recognition	10
Maximum Possible Prioritization Score for this Analysis	**41**

[a] This criterion has a maximum potential score of 4 for up to four additional species; however, for this analysis, the maximum score was 1 because the only other modeled species included was Canada lynx.

2.5.3 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 wildlife exclusion fence that extends at least a 0.5-mile in either direction.) To help in mitigation project planning and the field review (this chapter, Section 2.6), 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 scanned to highlight individual 0.5-mile segments with high maximum values for a given criterion within a larger combined segment. Maximum criteria values that are notably greater than the values in the remainder of the segment may warrant attention during mitigation planning.

2.6 Field Review of Highest Priority Segments

During fall 2018, the Jacobs Team conducted a field review of the top 5 percent priority segments in each region; this equated to roughly 185 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 mule deer or elk, with recommendations given to improve an existing structure for wildlife passage or replace it with a new wildlife crossing structure. High-priority segments where wildlife crossings mitigation has already been constructed (for example, State Highway 9 in Grand County, U.S. Highway 285 (U.S. 285) in Chaffee County, and portions of U.S. 550 and U.S. 160 in La Plata County) were omitted from the field review, except where additional mitigation was recommended to complement the existing crossing structures. Field review results are detailed in Appendix H.

2.7 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 is a commonly used approach to evaluate projects for potential funding. Benefit-cost analysis 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 benefit-costs analysis methods currently used within CDOT. CDOT performs two different types of benefit-cost analysis depending upon the project funding source.

CDOT's Traffic and Safety Engineering Branch uses the Vision Zero Suite (VZS) software to identify crash locations above expected norms for a facility, then uses an expense-based approach to calculate benefit-cost derived from the American Association of State Highway and Transportation Officials (AASHTO) Highway Safety Manual. The VZS software accounts for direct (medical costs, crash cleanup) and indirect (lost productivity and wages, lost quality of life) costs. Traffic and Safety Engineering annually updates crash costs values for fatalities, injuries, and property damage only (PDO) based upon the national consumer price and employer cost indexes. CDOT Traffic and Safety Engineering slightly modifies AASHTO values to be more specific to Colorado and avoid over-valuing fatalities. No national standard for valuing crash costs exists, and every state calculates these costs differently.

DTD uses a different benefit-cost approach when applying for federal funding grants or using federal bond funding. The USDOT provides explicit requirements for calculating benefit-cost ratios and values that must be used when applying for federal grant funding (USDOT, 2018). This DTD method uses the accepted economic theory of willingness to pay, whereby values for fatalities, injuries, and PDO accidents are not based upon actual costs, but societies willingness to pay to avoid such accidents in the first place.

CDOT's Traffic and Safety Engineering and DTD Branches 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 DTD recognize that many transportation assets are designed for very 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, 2018). In addition, CDOT DTD incorporates additional factors in its benefit-cost analyses, such as residual value of assets with life spans that exceed benefit-cost analysis period, mobility, and emissions.

For this WSWPS, CDOT and CPW sought a more comprehensive approach to assist in evaluating potential wildlife-highway mitigation projects. Currently in Colorado, wildlife values are not included in a benefit-cost analysis for wildlife mitigation projects. In addition, CDOT and CPW identified a need to include the residual value of wildlife mitigation beyond the typical benefit-cost analysis 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, 2018). 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. The Jacobs Team held multiple meetings with CPW, CDOT Traffic and Safety Engineering, DTD, and regional staff over the course of a year to determine how best to integrate these items into a comprehensive benefit-cost equation.

2.7.1 Integrating Wildlife Value into Benefit-Cost Analysis

Current methods for integrating wildlife values into benefit-cost analysis include using statutory values assigned by a state legislature for wildlife that are unlawfully taken (Cramer et al., 2016; Wakeling et al., 2015) or using the hunting value of the animal expressed as the probability that an animal will be successfully harvested by a hunter (Huijser et al., 2009). However, study panel members believed that both approaches underestimate the economic value of mule deer and elk in relation to their benefits to Colorado's economy. Fishing, hunting, and wildlife-watching produce more than $5 billion dollars 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, 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 (see Appendix F). While still conservative, the following values were calculated for mule deer and elk in Colorado in 2018 dollars:

Mule Deer Value = $2,061

Elk Value = $2,392

These values were then integrated into the benefit-cost equation.

2.7.2 Estimating Wildlife Mitigation Costs and Effectiveness

The Jacobs Team synthesized actual costs of wildlife-highway mitigation from recent projects (2016 through 2018) across Colorado and developed costs for the various components of a mitigation project, such as wildlife underpasses and overpasses of varying dimensions, deer guards, fencing, and escape ramps. These cost estimates were then reviewed by CDOT estimators.

After reviewing maintenance costs on existing mitigation projects, the Jacobs Team determined to use a maintenance cost of 1 percent over the life of the structure in the WSWPS benefit-cost formula.

In addition, the team reviewed the literature to determine how best to estimate the effectiveness of various wildlife mitigation measures. For road-based improvements, estimating the change in the number of fatalities, injuries, and amount of PDO can be calculated using crash modification factors, which relate different types of safety improvements to crash outcomes (USDOT, 2018). The team calculated crash modification factors for different mitigation measures, which were included in the benefit-cost analysis.

2.7.3 Calculating Benefit-Cost for the Western Slope Wildlife Prioritization Study

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 2-2, is designed to provide a more comprehensive evaluation than is currently possible with the formula used by CDOT Traffic and Safety Engineering; however, this approach is not as comprehensive as the 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 benefit-cost analysis is only relevant 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 Traffic and Safety Engineering crash costs and discount rate in its hybrid approach. Complete benefit cost inputs and calculations can be viewed in the Benefit-cost worksheet.

Table 2-2: Comparison of How Benefit-cost Elements Are Evaluated

Benefit Cost Equation Element	Evaluation Approach		
	Traffic and Safety Engineering Evaluation	DTD	WSWPS Hybrid Approach
Crash Costs	Derive from ASHTO	Derive from USDOT	Use traffic and safety costs
WVC Timeframe	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
Wildlife Value	Not considered	Nonmonetized benefit	Deer value = $2,061 Elk value = $2,392

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:	Total Discounted Costs = sum of:
Discounted Crash Reduction Benefit	Discounted Construction Cost
Discounted Value of Mule Deer and Elk	Discounted Maintenance Cost
Discounted Residual Value	

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 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 benefit-cost analysis (USDOT, 2018).

2.7.4 Developing an Automated Benefit-Cost Analysis Tool

Using inputs discussed in this chapter, in partnership with the Jacobs team, a sophisticated and practical automated Excel tool for calculating benefit-cost was created by Anthony Vu (CDOT Traffic & Safety Engineering) with significant input from Oana Ford (CDOT DTD). In addition to the hybrid approach discussed above, this Excel worksheet tool, accompanying this report as a deliverable to CDOT, also calculates benefit-costs using the CDOT Traffic and Safety Engineering Office and DTD methods so that it may be used by CDOT staff for planning purposes. Specifically, the CDOT Traffic and Safety Engineering benefit-cost formula and valuations would be used for state Traffic and Safety Engineering grant applications. DTD would use the USDOT benefit-cost methods and valuations for federal grant applications.

3 PRIORITIZATION RESULTS

This chapter presents the results of the risk modeling (Section 1.1), which fed into the overall prioritization process (Section 2.1), and identification of high-priority segments for wildlife-highway mitigation.

3.1 Risk Modeling Results

Predicting the precise level of risk for any given road segment is difficult because of high variability as to where mule deer and elk attempt to cross roads and are struck by vehicles; 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, yet they explained only fair to moderate levels of relative variance (29 to 43 percent) in WVC patterns across the Western Slope. Several general trends in WVC risk were observed across models, while other risk factors varied across species and seasons. Distance to tree cover, traffic volume and speed, and herd density were the strongest drivers of risk in most areas across the Western Slope. Specifically, WVC risk can be characterized as follows:

- Decreased with greater distance from tree cover
- Increased with traffic volume but leveled off as volumes approached approximately 21,000 vehicles/day
- Generally increased with traffic speed, but risk for mule deer may peak at approximately 60 mph
- Increased with distance from points at which speed limits change
- Not predictable relative to distance to higher housing density, road corridor width, highway curve class, highway grade, or slope adjacent to the road, suggesting that these variables had little influence on WVC risk

3.2 Prioritization Results

Figure 3-1 shows results of the prioritization process. Most of the highest priority segments were found in Region 3. Many high-priority segments were found on highways leading into Craig in Region 3 and within the Southern Ute Reservation in Region 5. In many cases, high-priority segments were clustered so that long stretches of highway had high-priority rankings. Because of the weighting developed by the prioritization subcommittee, most of the high-priority segments and all of the top 5 percent were considered to have high WVC rates based on CDOT's pattern recognition analysis. However, some segments ranked high in priority because of high WVC risk and wildlife criteria scores. Each of the scored prioritization criteria contributing to the final prioritization results are mapped in Appendix G.

Areas with high wildlife criteria scores often showed clusters of high prioritization scores because wildlife criteria were calculated at the coarse spatial resolution of DAUs or winter ranges, causing all segments within a DAU or winter range unit to receive the same criterion score. High scores for winter range density were widely distributed across the Western Slope, whereas high scores for migration movement magnitude were clustered in the DAUs around Craig in Region 3 for both elk and mule deer. Per capita elk deaths 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 mule deer deaths from WVCs were highest in DAUs distributed across Region 5 (WVC mortalities represented a maximum of 3.67 percent of the DAU herd size estimate).

Because the analysis was conducted for the entire Western Slope, highest priority segments were identified by considering Regions 3 and 5 together. However, because transportation projects are administered and prioritized by region, the Jacobs Team also separated and ranked priority segments by region. In so doing, the 95th percentile rankings shift by region somewhat compared to the percentile ranks across the entire Western Slope (Figure 3-2 and Figure 3-3). The final prioritization scores and rank for the aggregated highest priority (top 5 percent) segments for each region are presented in Table 3-1

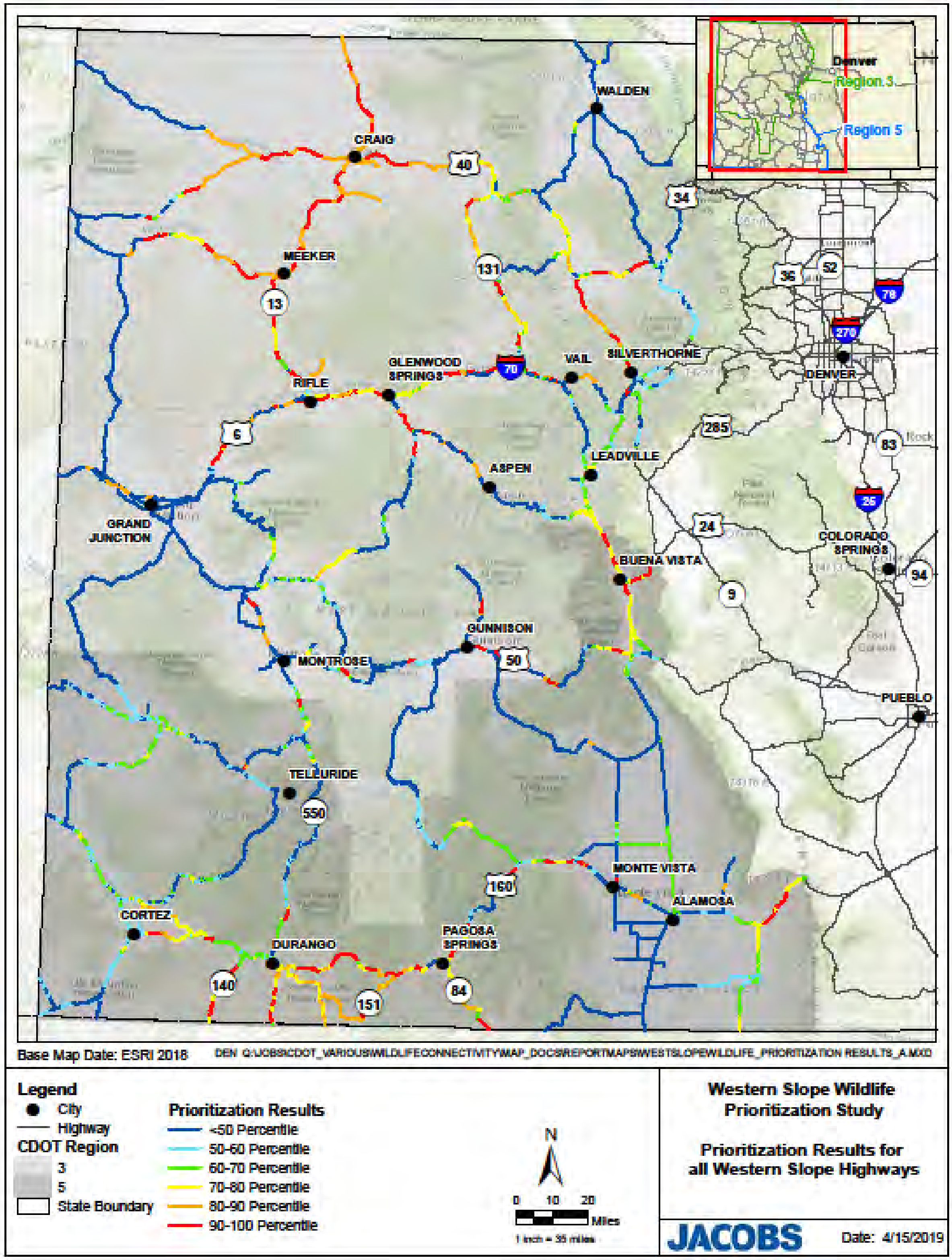

Figure 3-1: Map of Prioritization Results for the Western Slope

Figure 3-2: Aggregated Highest Priority Highway Segments (Top 5 Percent) in CDOT Region 3

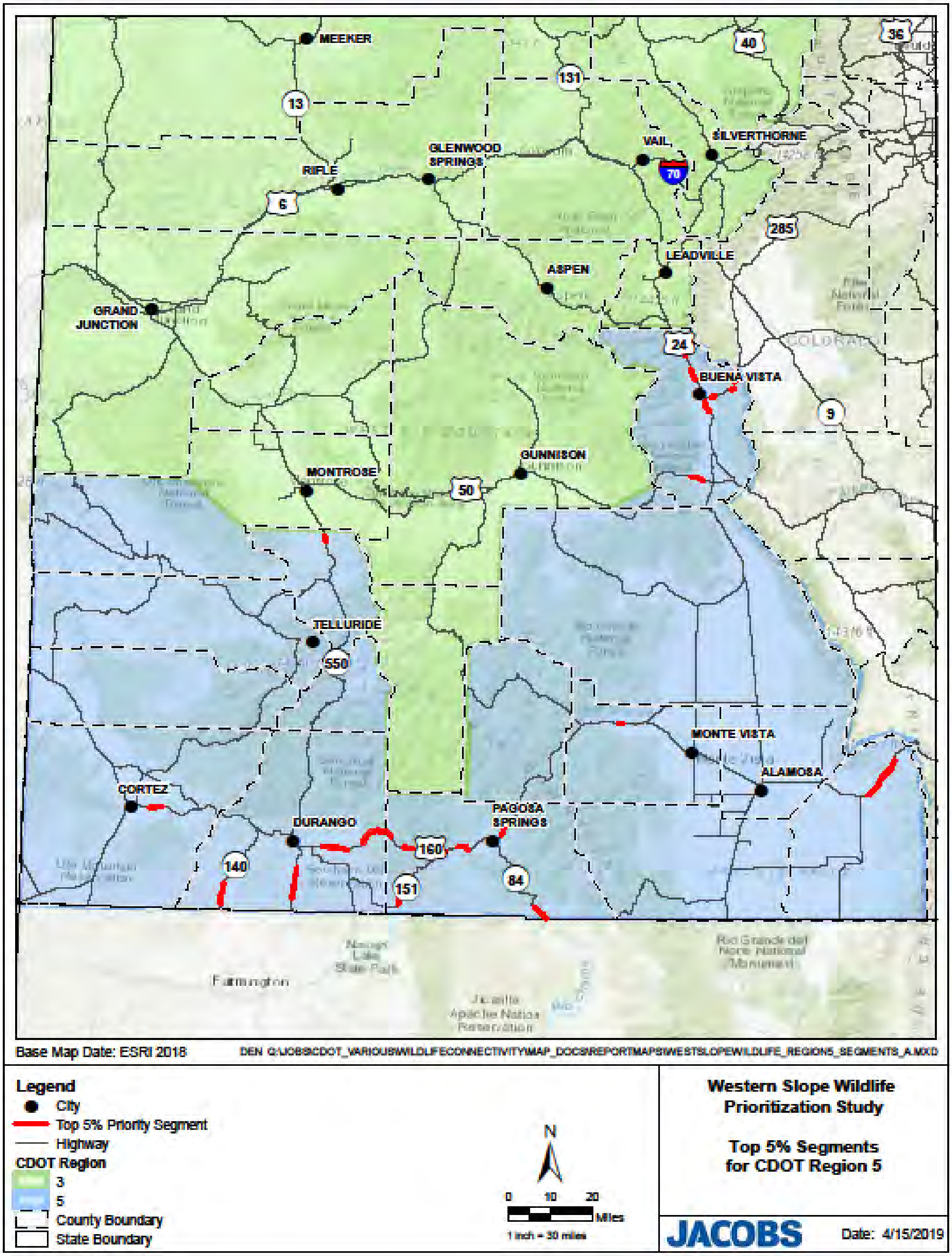

Figure 3-3: Aggregated Highest Priority Highway Segments (Top 5 Percent) in CDOT Region 5

Table 3-1: WSWPS Prioritization Scores for Highest Priority Segments (Top 5 Percent) within Regions 3 and 5

Route	Milepost	Prioritization score	Percentile rank
CDOT Region 3 (Northwest)			
State Highway 13	58.5 to 70.5	26.07	98.92
State Highway 13	99 to 114	23.64	98.58
State Highway 13	73 to 75.7	23.53	98.60
State Highway 13	78 to 84	22.59	97.83
U.S. 40	61.9 to 71.5	22.34	97.63
U.S. 40	74 to 81	21.80	97.14
State Highway 64	59 to 68.5	21.61	97.22
U.S. 40	40.5 to 41.5	21.22	96.50
State Highway 13	118 to 120.5	20.80	96.40
State Highway 13	45 to 52.5	20.70	96.27
U.S. 40	93.7 to 106.5	20.63	96.29
I- 70	98.5 to 103	20.27	95.78
State Highway 9	136 to 136.6	20.18	96.00
State Highway 13	18 to 18.3	19.55	95.00
U.S. 40	192 to 194	19.51	95.00
State Highway 9	114.2 to 116.5	19.46	95.33
I- 70	131 to 132.5	19.40	95.00
U.S. 40	190 to 190.5	19.37	95.00
State Highway 131	57 to 58	19.34	95.00
State Highway 13	30.5 to 37.5	19.29	95.08
State Highway 9	128 to 134	19.29	95.00
I- 70	105.5 to 107	19.18	95.00
I- 70	1431 to 43.5	19.06	95.00
I- 70	96.5 to 97	19.04	95.00
CDOT Region 5 (Southwest)			
U.S. 160	94 to 100.5	20.19	98.92
State Highway 151	17 to 19.5	19.79	98.80
U.S. 550	4.5 to 7.5	19.31	98.83
U.S. 160	124.5 to 129.9	19.21	98.18
U.S. 160	104.5 to 113.5	19.11	98.33
U.S. 160	43.5 to 46.5	18.63	97.67

Route	Milepost	Prioritization score	Percentile rank
U.S. 160	118 to 120.5	18.35	97.00
U.S. 550	8.5 to 11	18.08	97.00
U.S. 160	145.5 to 148	18.07	97.00
U.S. 160	133 to 136	18.04	96.83
U.S. 84	0 to 4	17.95	96.75
U.S. 550	114.5 to 116	17.77	96.50
U.S. 285	144.5 to 147.5	17.74	96.17
U.S. 160	265.5 to 271	17.74	96.09
U.S. 24	205 to 208	17.69	95.83
State Highway 140	1.5 to 6.5	17.64	96.00
U.S. 160	260 to 265	17.50	95.57
U.S. 550	3.5 to 4	17.47	95.00
U.S. 50	211.5 to 214.5	17.45	95.33
U.S. 24	214.5 to 215.5	17.37	95.00
U.S. 24	197.5 to 201.5	17.36	95.00
U.S. 160	195 to 196.1	17.36	95.00
U.S. 24	220 to 220.5	17.30	95.00
U.S. 24	222 to 223.5	17.28	95.00

Prioritization criteria scores for the top 5 percent of highway segments in Region 3 and 5 are presented in Table 3-2 and Table 3-3, respectively. The WVC pattern recognition data 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. Thus, based on that criterion alone, any segment recognized as a WVC pattern (roughly 13 percent of all 0.5-mile segments across the Western Slope) ranked in the 83rd percentile or higher in Region 3 and in the 91st percentile or higher in Region 5 in the WSWPS prioritization.

Overall, these results demonstrate the intent of the WSWPS research study panel to create a prioritization that is largely influenced by WVC safety needs but that also considers wildlife movement needs during winter and migration. 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.

These results also demonstrate limited overlap between highway segments that are priorities for deer and elk mitigation and those that may be priorities for lynx mitigation. The greatest overlap between these two types of priorities was observed on U.S. 40 around Rabbit Ears Pass. In this area, several segments ranked in the 74^{th} percentile within Region 3, largely because of high numbers of migrating deer and elk, and scored in the 87^{th} percentile for probability of lynx highway crossing in the study conducted by Baigas et al. (2017). Across the Western Slope, no 95^{th} percentile segments in the WSWPS prioritization ranked higher than the 12^{th} percentile for probability of lynx highway crossing.

Table 3-2: Prioritization Criteria Scores for the Top 5 Percent Aggregated Segments in Region 3

Highway and Milepost	Pattern Recognition	Elk Winter Density	Mule Deer Winter Density	Elk Migration Magnitude	Mule Deer Migration Magnitude	Elk WVC Proportion	Mule Deer WVC Proportion	Lynx Probability of Hwy Crossing	Risk Model: Elk Winter	Risk Model: Elk Migration	Risk Model: Mule Deer Winter	Risk Model: Mule Deer Migration	Future Risk: Elk Winter	Future Risk: Elk Migration	Future Risk: Mule Deer Winter	Future Risk: Mule Deer Migration	Primary Prioritization Score	Percentile (within Region)
***75th Percentile Threshold (within Region)**	**-**	**0.44**	**0.41**	**0.31**	**0.38**	**0.38**	**0.23**	**0.75**	**0.04**	**0.05**	**0.20**	**0.21**	**0.07**	**0.08**	**0.27**	**0.52**	**17.87 (95th percentile)**	
I-70																		
96.5 to 97	1	0.30	0.36	**1.00**	0.07	0.21	0.22	0.00	**0.24**	**0.16**	0.14	0.14	**0.27**	**0.16**	**0.27**	0.51	19.04	95.00
98.5 to 103	1	**0.50**	0.36	**1.00**	0.07	0.21	0.22	0.00	**0.51**	**0.17**	0.10	0.11	**0.51**	**0.16**	0.25	**0.52**	20.27	95.78
105.5 to 107	1	0.30	0.36	**1.00**	0.07	0.21	0.22	0.00	**0.30**	**0.17**	0.08	0.11	**0.42**	**0.20**	0.26	0.51	19.18	95.00
131 to 132.5	1	0.30	**0.56**	**1.00**	0.04	0.21	0.17	0.00	**0.20**	**0.14**	**0.20**	0.17	**0.21**	**0.13**	**0.29**	0.51	19.40	95.00
143 to 143.5	1	0.29	**0.82**	0.04	0.26	0.22	0.21	0.00	**0.07**	**0.16**	**0.50**	**0.47**	**0.09**	**0.12**	**0.41**	**0.54**	19.06	95.00
U.S. 40																		
40.5 to 41.5	1	**0.50**	0.21	**0.76**	**0.62**	0.22	0.16	0.00	**0.16**	**0.12**	**0.53**	**0.34**	**0.23**	**0.17**	**0.59**	0.50	21.22	96.50
61.9 to 71.5	1	**0.46**	0.40	**0.85**	**1.00**	**0.39**	0.11	0.00	**0.14**	**0.07**	**0.35**	**0.25**	**0.14**	**0.09**	**0.35**	0.51	22.34	97.63
74 to 81	1	**0.46**	0.40	**0.85**	**1.00**	**0.39**	0.11	0.00	**0.10**	**0.06**	**0.27**	0.16	**0.11**	0.07	**0.30**	0.51	21.80	97.14
93.7 to 106.5	1	**0.50**	0.06	**0.89**	**0.95**	**0.34**	0.10	0.00	**0.11**	**0.06**	0.12	**0.29**	**0.11**	**0.08**	0.23	0.51	20.63	96.29
190 to 190.5	1	**0.50**	**0.84**	0.09	**0.40**	0.11	**0.23**	0.01	**0.07**	0.04	**0.63**	0.17	**0.07**	0.05	**0.34**	**0.52**	19.37	95.00
192 to 194	1	**0.50**	**0.77**	0.09	**0.40**	0.11	**0.23**	0.01	**0.07**	**0.06**	**0.68**	**0.26**	**0.07**	0.06	**0.35**	0.51	19.51	95.00
State Highway 9																		
114.2 to 116.5	1	0.35	**0.49**	0.15	**0.40**	**0.59**	**0.23**	0.00	**0.06**	**0.06**	**0.43**	**0.25**	**0.09**	**0.08**	**0.42**	**0.60**	19.46	95.33
128 to 134	1	0.35	**0.49**	0.15	**0.40**	**0.59**	**0.23**	0.00	**0.06**	0.04	**0.43**	0.19	**0.10**	**0.08**	**0.50**	**0.52**	19.29	95.00
136 to 136.6	1	0.35	**0.63**	0.15	**0.40**	**0.59**	**0.23**	0.00	**0.04**	0.03	**0.63**	0.20	**0.08**	0.06	**0.63**	0.50	20.18	96.00
State Highway 13																		
18 to 18.3	1	0.30	0.00	**1.00**	**0.83**	0.21	0.09	0.01	**0.05**	**0.10**	0.07	**0.46**	**0.07**	**0.09**	0.21	0.51	19.55	95.00
30.5 to 37.5	1	0.22	0.27	**0.65**	**0.83**	0.27	0.09	0.04	0.02	**0.10**	0.19	**0.35**	0.06	**0.11**	**0.27**	0.51	19.29	95.08

Highway and Milepost	Pattern Recognition	Elk Winter Density	Mule Deer Winter Density	Elk Migration Magnitude	Mule Deer Migration Magnitude	Elk WVC Proportion	Mule Deer WVC Proportion	Lynx Probability of Hwy Crossing	Risk Model: Elk Winter	Risk Model: Elk Migration	Risk Model: Mule Deer Winter	Risk Model: Mule Deer Migration	Future Risk: Elk Winter	Future Risk: Elk Migration	Future Risk: Mule Deer Winter	Future Risk: Mule Deer Migration	Primary Prioritization Score	Percentile (within Region)
***75th Percentile Threshold (within Region)**	**-**	**0.44**	**0.41**	**0.31**	**0.38**	**0.38**	**0.23**	**0.75**	**0.04**	**0.05**	**0.20**	**0.21**	**0.07**	**0.08**	**0.27**	**0.52**	**17.87 (95th percentile)**	
45 to 52.5	1	0.30	0.19	**1.00**	**0.83**	0.21	0.09	0.01	**0.16**	**0.24**	0.14	**0.26**	**0.20**	**0.26**	**0.27**	**0.53**	20.70	96.27
58.5 to 70.5	1	**0.55**	0.25	**1.00**	**0.83**	0.21	0.09	0.01	**0.76**	**0.60**	**0.56**	**0.64**	**0.66**	**0.53**	**0.47**	0.49	26.07	98.92
73 to 75.5	1	**0.57**	0.27	**1.00**	**0.83**	0.21	0.09	0.00	**0.52**	**0.31**	**0.34**	**0.42**	**0.40**	**0.24**	**0.33**	0.48	23.53	98.60
78 to 84	1	**0.60**	0.27	**1.00**	**0.83**	0.21	0.09	0.00	**0.33**	**0.21**	**0.30**	**0.34**	**0.25**	**0.17**	**0.31**	**0.52**	22.59	97.83
99 to 114	1	**0.45**	0.40	**0.85**	**1.00**	**0.39**	0.11	0.00	**0.23**	**0.18**	**0.56**	**0.41**	**0.20**	**0.15**	**0.43**	**0.53**	23.64	98.58
118 to 120.5	1	0.25	0.32	**0.85**	**1.00**	**0.39**	0.11	0.00	**0.06**	**0.06**	**0.26**	0.19	**0.07**	0.06	0.26	0.50	20.80	96.40
State Highway 64																		
59 to 68.5	1	0.30	0.27	**1.00**	**0.83**	0.21	0.09	0.00	**0.13**	**0.20**	**0.31**	**0.41**	**0.20**	**0.27**	**0.44**	0.51	21.61	97.22
State Highway 131																		
57 to 58	1	**0.52**	0.00	**1.00**	**0.83**	0.21	0.09	0.00	0.03	**0.07**	0.01	0.17	0.06	0.07	0.19	0.51	19.34	95.00

Notes:

*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. Although criteria scores are scaled to range 0 to 1, differences in distributions of values among criteria result in different values associated with 75th percentile thresholds.

Table 3-3: Prioritization Criteria Scores for the Top 5 Percent Aggregated Segments in Region 5

Highway and Milepost	Pattern Recognition	Elk Winter Density	Mule Deer Winter Density	Elk Migration Magnitude	Mule Deer Migration Magnitude	Elk WVC Proportion	Mule Deer WVC Proportion	Lynx Probability of Hwy Crossing	Risk Model: Elk Winter	Risk Model: Elk Migration	Risk Model: Mule Deer Winter	Risk Model: Mule Deer Migration	Future Risk: Elk Winter	Future Risk: Elk Migration	Future Risk: Mule Deer Winter	Future Risk: Mule Deer Migration	Primary Prioritization Score	Percentile (within Region)
***75th Percentile Threshold (within Region)**	**-**	**0.42**	**0.22**	**0.35**	**0.26**	**0.47**	**0.71**	**0.75**	**0.03**	**0.04**	**0.19**	**0.23**	**0.06**	**0.06**	**0.26**	**0.51**	**17.87 (95th percentile)**	
U.S. 24																		
197.5 to 201.5	1	0.18	0.21	0.06	0.06	**0.47**	**0.82**	0.10	**0.05**	**0.08**	0.15	0.22	**0.06**	**0.07**	0.23	**0.51**	17.36	95.00
205 to 208	1	0.18	0.21	0.06	0.06	**0.47**	**0.82**	0.00	**0.03**	**0.05**	**0.27**	**0.28**	**0.07**	**0.08**	**0.34**	**0.52**	17.69	95.83
214.5 to 215.5	1	0.10	0.09	0.10	**0.28**	**1.00**	0.21	0.01	0.01	0.02	0.16	**0.36**	0.05	0.05	**0.26**	**0.52**	17.37	95.00
220 to 220.5	1	0.10	0.09	0.10	**0.28**	**1.00**	0.21	0.01	**0.03**	**0.04**	0.16	**0.27**	**0.06**	**0.07**	**0.26**	**0.51**	17.30	95.00
222 to 223.5	1	0.10	0.09	0.10	**0.28**	**1.00**	0.21	0.01	**0.04**	**0.07**	0.12	**0.26**	**0.07**	**0.09**	0.25	**0.51**	17.28	95.00
U.S. 50																		
211.5 to 214.5	1	0.18	0.21	0.06	0.06	**0.47**	**0.82**	0.01	**0.03**	**0.06**	**0.23**	**0.26**	0.05	**0.06**	0.25	**0.51**	17.45	95.33
U.S. 84																		
0 to 4	1	**0.55**	0.19	**0.41**	**0.41**	0.12	0.36	0.01	**0.07**	**0.05**	0.13	**0.26**	0.05	0.04	0.20	**0.52**	17.95	96.75
U.S. 160																		
43.5 to 46.5	1	0.00	**0.39**	**0.38**	0.06	0.08	**0.93**	0.00	0.01	0.03	**0.72**	**0.28**	0.04	0.05	**0.40**	**0.51**	18.63	97.67
94 to 100.5	1	**0.56**	**0.38**	**0.41**	**0.41**	0.12	0.36	0.01	**0.04**	0.02	**0.59**	**0.47**	**0.08**	**0.06**	**0.57**	**0.52**	20.19	98.92
104.5 to 113.5	1	**0.56**	**0.29**	**0.41**	**0.41**	0.12	0.36	0.02	**0.06**	**0.04**	**0.34**	**0.41**	**0.07**	**0.06**	**0.30**	**0.51**	19.11	98.33
118 to 120.5	1	**0.46**	**0.31**	**0.41**	**0.41**	0.12	0.36	0.00	**0.07**	**0.07**	**0.19**	**0.25**	**0.09**	**0.09**	**0.27**	**0.51**	18.35	97.00
124.5 to 129.9	1	**0.57**	**0.38**	**0.41**	**0.41**	0.12	0.36	0.01	**0.05**	0.03	**0.35**	**0.30**	**0.08**	**0.06**	**0.35**	**0.51**	19.21	98.18
133 to 136	1	**0.57**	0.19	**0.41**	**0.41**	0.12	0.36	0.12	**0.05**	**0.04**	0.08	**0.24**	**0.08**	**0.08**	0.23	**0.53**	18.04	96.83
145.5 to 148	1	**0.57**	0.19	**0.41**	**0.41**	0.12	0.36	0.00	**0.05**	0.03	0.15	**0.27**	**0.07**	**0.06**	0.25	**0.51**	18.07	97.00
195 to 196.1	1	**0.42**	0.09	0.05	0.01	0.17	**0.96**	0.00	0.10	**0.06**	**0.25**	**0.24**	**0.09**	**0.07**	**0.27**	**0.51**	17.36	95.00

Highway and Milepost	Pattern Recognition	Elk Winter Density	Mule Deer Winter Density	Elk Migration Magnitude	Mule Deer Migration Magnitude	Elk WVC Proportion	Mule Deer WVC Proportion	Lynx Probability of Hwy Crossing	Risk Model: Elk Winter	Risk Model: Elk Migration	Risk Model: Mule Deer Winter	Risk Model: Mule Deer Migration	Future Risk: Elk Winter	Future Risk: Elk Migration	Future Risk: Mule Deer Winter	Future Risk: Mule Deer Migration	Primary Prioritization Score	Percentile (within Region)
***75th Percentile Threshold (within Region)**	**-**	**0.42**	**0.22**	**0.35**	**0.26**	**0.47**	**0.71**	**0.75**	**0.03**	**0.04**	**0.19**	**0.23**	**0.06**	**0.06**	**0.26**	**0.51**	**17.87 (95th percentile)**	
260 to 265	1	0.20	0.11	0.32	0.00	0.26	**1.00**	0.00	**0.03**	0.03	**0.22**	0.16	**0.07**	**0.06**	**0.31**	**0.52**	17.50	95.57
265.5 to 271	1	0.27	0.07	0.32	0.00	0.26	**1.00**	0.00	**0.06**	**0.11**	0.14	0.19	**0.09**	**0.12**	**0.26**	**0.52**	17.74	96.09
U.S. 285																		
144.5 to 147.5	1	0.18	0.21	0.06	0.06	**0.47**	**0.82**	0.04	0.02	**0.04**	**0.30**	**0.29**	**0.06**	**0.07**	**0.35**	**0.52**	17.74	96.17
U.S. 550																		
3.5 to 4	1	0.26	**0.25**	0.25	**0.26**	0.35	0.42	0.00	0.02	0.03	**0.26**	**0.25**	**0.06**	**0.06**	**0.34**	0.50	17.47	95.00
4.5 to 7.5	1	0.28	**0.38**	**0.41**	**0.41**	0.12	0.36	0.00	0.02	0.02	**0.66**	**0.47**	0.05	0.05	**0.46**	**0.54**	19.31	98.83
8.5 to 11	1	0.28	**0.38**	**0.41**	**0.41**	0.12	0.36	0.00	0.02	0.01	**0.40**	0.18	0.05	0.04	**0.35**	**0.52**	18.08	97.00
114.5 to 116	1	**0.56**	**0.37**	0.12	0.22	0.07	0.10	0.00	**0.11**	**0.07**	**0.57**	**0.49**	**0.09**	**0.07**	**0.34**	**0.51**	17.77	96.50
State Highway 140																		
1.5 to 6.5	1	0.24	**0.22**	0.09	0.12	**0.59**	0.49	0.00	0.02	**0.04**	**0.34**	**0.35**	0.05	**0.06**	**0.34**	0.49	17.64	96.00
State Highway 151																		
17 to 19.5	1	**0.57**	**0.38**	**0.41**	**0.41**	0.12	0.36	0.00	**0.05**	0.02	**0.39**	**0.45**	**0.10**	**0.06**	**0.49**	**0.55**	19.79	98.80

Notes:

*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. Although criteria scores are scaled to range 0 to 1, differences in distributions of values among criteria result in different values associated with 75th percentile thresholds

4 DECISION-SUPPORT FRAMEWORK

The decision-support framework described in this chapter is a crucial output of the WSWPS. 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-framework includes the following complementary tools:

- Prioritized list of highway segments across the Western Slope demonstrating the greatest need for wildlife-highway mitigation (Section 3)
- Prioritization methodology to support future updates to the risk model and prioritization process (Section 2 and Appendix E)
- Potential mitigation recommendations for the highest priority segments (top 5 percent) to help integrate wildlife-highway mitigation into project planning, budgeting, and design (Appendix H)
- Comprehensive benefit-cost analysis tool to help inform where wildlife-highway mitigation is most cost effective, (this chapter)
- Implementation considerations matrix to flag factors that may influence opportunities to implement wildlife-highway mitigation (this chapter)
- Guidance for integrating priority wildlife-highway segments into CDOT planning and project development (this chapter)

4.1 Wildlife-Highway Mitigation Recommendations

Preliminary wildlife crossing mitigation recommendations for the top 5 percent highway segments in both Regions 3 and 5 were developed based on the findings of the field surveys and the latest research on the effectiveness of different mitigation strategies. Appendix H 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. Ultimately, decisions regarding mitigation siting and design will depend on where CDOT sets project limits (beginning and ending points), and will take the following into consideration:

- How mitigation may be integrated with other aspects of a project
- Engineering feasibility
- Land owner 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

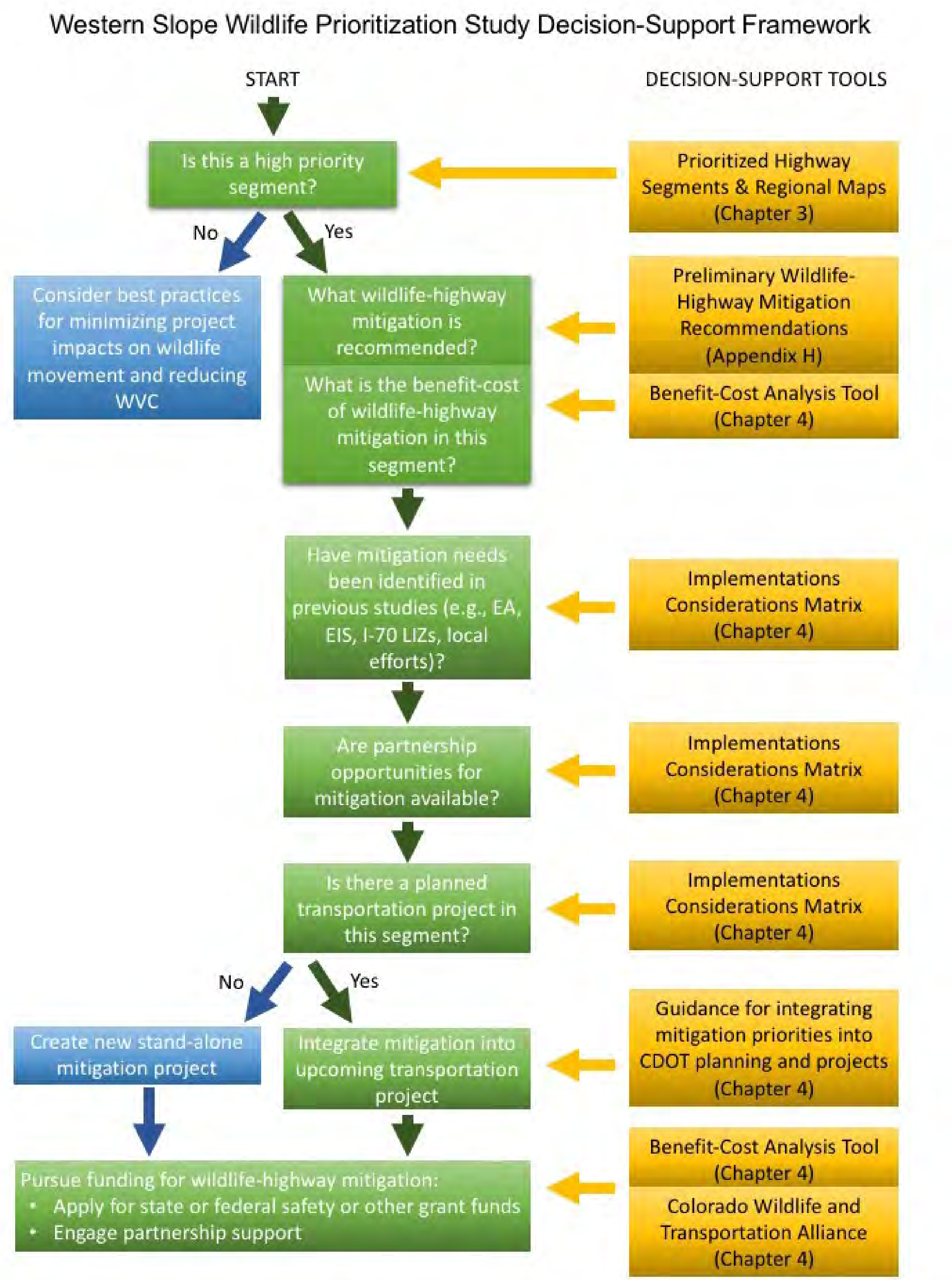

Figure 4-1: Flowchart of the WSWPS Decision-Support Framework and Component Parts

4.2 Benefit-Cost Analysis Worksheet

Recognizing the limitations of the benefit-cost analyses (BCA) currently conducted by CDOT Traffic and Safety and by DTD with regard to wildlife-highway mitigation projects, the research team developed a more comprehensive approach to evaluating the benefits and costs for these types of projects (Section 2.7). The resulting BCA Worksheet provides an automated tool for calculating the benefit-cost of wildlife crossing mitigation in three ways:

1) using current CDOT Traffic and Safety's methods and valuations,

2) using current USDOT methods and valuations,

3) using the WSWPS hybrid benefit-cost methods and valuations.

The WSWPS hybrid approach includes an economic value for deer and elk using the accepted economic contingency valuation method (Appendix F). The hybrid method also calculates 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 (Section 2) (USDOT, 2018). By providing a tool that automatically calculates benefit-cost using all three methods, CDOT planning teams can compare potential wildlife-highway mitigation projects using the WSWPS hybrid approach and also evaluate a project's potential competitiveness for state highway safety funding programs or federal grants.

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. BCA for each of the highest priority segments (top 5 percent) are not provided as part the WSWPS given the number of assumptions that would be required. Instead, several examples are provided to demonstrate how the BCA worksheet tool may be used.

Benefit-cost was calculated for two recently completed CDOT projects and two additional hypothetical examples – one for a 9-mile-long segment and, the other, a much shorter 1.5-mile segment. 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 feet wide round bar. These cost estimates are for wildlife mitigation components only and do not include roadway costs and other related items (e.g., ROW, utilities, traffic control).

Example: State Highway 9, Grand County Wildlife and Safety Improvement Project

Wildlife mitigation on SH 9 from Mile Posts(MPs) 126 to 137 was completed in 2016 and included two wildlife overpasses, five wildlife underpasses, 10.4 miles of wildlife-exclusion fencing, 61 escape ramps, and 29 deer guards. Table 4-1 presents the inputs into the BCA Worksheet for this project. One-hundred and nineteen (119) WVC accidents in this segment occurred from January 1, 2006 to December 31, 2015 resulting in 6 injuries and 113 PDO accidents. As a result of these WVC accidents, 114 mule deer and 5 elk were killed. Using these inputs resulted in a WSWPS benefit-cost analysis ratio for this segment of State Highway 9 of **1.2.** A benefit-cost ratio greater than '1' indicates that the benefits of wildlife-highway mitigation are greater than the costs of mitigation.

Table 4-1: Estimated Cost of Mitigation for State Highway 9 from MP 126 to 137

Mitigation Features and Specifications	Number	Unit Cost	Service Life	Estimated Effectiveness in Reducing WVC	Total Cost
Wildlife Overpass 100 feet wide x 66 feet long	2	$225 per linear foot	75 years	83%	$2,970,000
Wildlife Underpass 14 feet high x 42 feet wide x 66 feet long	5	$225 per linear foot	75 years	83%	$3,118,500
Wildlife Exclusion Fencing	10.4 miles	$98.900 per lane mile	20 years	83%	$1,028,560
Escape Ramps 3:1 slope	61	$13,378 each	20 years	Not applicable	$816,058
Deer Guards 24 feet wide	29	$51,000 each	20 years	Not applicable	$1,479,000
Mitigation Subtotal					$9,412,118
Total Costs including contingencies (30%), construction engineering and indirect charges (22.10%)					$14,939,858
Additional Maintenance Costs (1% of the mitigation cost)					$94,121

As construction has been completed for this project, these estimates may be compared to the actual costs and benefits. Wildlife-highway mitigation was included in a larger highway widening and safety project. The cost of the mitigation components was $15,755,144 in 2016 dollars. Since the project was completed, WVC have decreased by 89 percent (Kintsch et al., 2019).

Example: U.S. 285, Chaffee County Wildlife Mitigation and Roadway Widening Project

Wildlife mitigation on U.S. 285 between MPs 145.5 and 147.5 was completed in 2018 and included 1 wildlife underpass, 2 miles of wildlife-exclusion fencing, 12 escape ramps, and 14 deer guards. In addition to the new wildlife crossing arch, the fencing tied into three existing 8- to 10-foot-high x 8- to 10-foot-wide box culverts, which provide additional crossing opportunities for deer and other wildlife. Table 4-2 presents the inputs into the BCA Worksheet for this project. There were 103 WVC accidents in this segment from January 1, 2006 to December 31, 2015, resulting in 2 injury accidents and 101 PDO accidents and in the death of 90 mule deer and 13 elk. The resulting WSWPS benefit-cost ratio for this segment of highway is **1.43**.

The total cost for this project was $3.5 million, including chipseal resurfacing, intersection improvements, signing, striping, and guardrail. The estimated cost for the wildlife mitigation components was $1.5 million in 2018 dollars (Lawler, pers. comm., 2019).

Table 4-2: Estimated Cost of Mitigation for U.S. 285 from MPs 145.5 to 147.5

Mitigation Feature and Specifications	Number	Unit Cost	Service Life	Estimated Effectiveness in Reducing WVC	Total Cost
Wildlife Underpass 13 feet high x 25 feet wide x 69 feet long	1	$225 per linear foot	75 years	83%	$388,125
Wildlife Exclusion Fencing	2 miles	$98.900 per lane mile	20 years	83%	$197,800
Escape Ramps 3:1 slope	12	$13,378 each	20 years	Not applicable	$160,536
Deer Guards 24 feet wide	14	$51,000 each	20 years	Not applicable	$714,000
Mitigation Subtotal					$1,460,61
Total Costs including contingencies (30%), construction engineering and indirect charges (22.10%)					$2,318,190
Additional Maintenance Costs (1% of the mitigation cost)					$14,605

Example: U.S. Highway 160, MPs 104.5 to 113.5

This hypothetical example based on the recommendations developed for this segment as described in Chapter 4 demonstrates how the benefit-cost tool may be used to help evaluate potential mitigation projects. U.S. 160 is a two-lane road and target species for this segment are elk and deer. The following assumptions are made for this example: 2 wildlife underpasses suitable for elk; 4 wildlife underpasses suitable for deer; 9 miles of wildlife exclusion fencing; 36 escape ramps; and 4 deer guards. Inputs for the BCA Worksheet are listed in Table 4-3. There were 129 WVC accidents in this segment from January 1, 2006 to December 31, 2015, including 1 human fatality, 13 injury accidents, and 115 PDO accidents resulting in 119 mule deer and 10 elk mortalities. The resulting WSWPS BCA Ratio for this segment of highway is **1.3**.

Table 4-3: Estimated Cost of Mitigation for U.S. 160 from MPs 104.5 to 113.5

Mitigation Feature and Specifications	Number	Unit Cost	Service Life	Estimated Effectiveness in Reducing WVC	Total Cost
Wildlife Underpass 14 feet high x 36 feet wide x 66 feet long	2	$225 per linear foot	75 years	83%	$1,069,200
Wildlife Underpass 12 feet high x 20 feet wide x 66 feet long	4	$225 per linear foot	75 years	83%	$1,188,000
Wildlife Exclusion Fencing	9	$98,900 per lane mile	20 years	83%	$890,100
Escape Ramps 3:1 slope	36	$13,378 each	20 years	Not applicable	$481,608
Deer Guards 24 feet wide	52	$51,000 each	20 years	Not applicable	$2,652,000
Mitigation Subtotal					$6,280,908
Total Costs including contingencies (30%), construction engineering and indirect charges (22.10%)					$9,969,685
Additional Maintenance Costs (1% of the mitigation cost)					$62,809

Example: U.S. 40, MPs 40 to 41.5 (West of Craig)

This hypothetical example based on the recommendations developed for this segment as described in Chapter 4 demonstrates how the benefit-cost tool may be used to help evaluate potential mitigation projects. U.S. 40 is a two-lane road and target species for this segment are elk and deer. The following assumptions are made for this example: one wildlife underpass; 1.5 miles of wildlife exclusion fencing; six escape ramps; and four deer guards. Inputs for the BCA Worksheet are listed in Table 4-4. There were eight WVC accidents in this segment from January 1, 2006 to December 31, 2015. This resulted in 8 PDO accidents involving 5 deer and 3 elk. In this example, the effectiveness of the wildlife exclusion fencing is reduced to 52.7 percent because of the short fence length (Huijser et al., 2016). The resulting WSWPS BCA ratio for this segment of highway is **0.96**.

Table 4-4: Estimated Cost of Mitigation for U.S. 40 from MPs 40 to 41.5

Mitigation Feature and Specifications	Number	Unit Cost	Service Life	Estimated Effectiveness in Reducing WVC	Total Cost
Wildlife Underpass 14 feet high x 36 feet wide x 66 feet long	1	$225 per linear foot	75 years	83%	$534,600
Wildlife Exclusion Fencing	1.5	$98,900 per lane mile	20 years	52.7%	$148,350
Escape Ramps 3:1 slope	6	$13,378 each	20 years	Not applicable	$80,268
Deer Guards 24 feet wide	4	$51,000 each	20 years	Not applicable	$204,000
Mitigation Subtotal					$967,218
Total Costs including contingencies (30%), construction engineering and indirect charges (22.10%)					$1,535,265
Additional Maintenance Costs (1% of the mitigation cost)					$9,672

4.2.2 Benefit-cost Analyses for Grant Applications

The CDOT Traffic and Safety Engineering Branch administers funding through two primary programs: 1) the federal Highway Safety Improvement Program (HSIP), and 2) the state program, Faster Safety Mitigation, which is a component of the Funding Advancements for Surface Transportation and Economic Recovery Act (FASTER) of 2009. As such, Traffic and Safety has developed a benefit-cost formula for the specific purpose of guiding which projects qualify for each of these safety mitigation funding sources.

The benefit-cost analysis in the HSIP process has multiple functions. Its primary use is to prioritize projects competing for a limited annual budget allocation when there are more applications than the HSIP budget allows for. A comparison of benefit-cost ratios is most frequently enacted to evaluate applications submitted for the more competitive local agency allocation, which represents approximately 50 percent of the state's allocation from the Federal Highway Administration. The remainder of HSIP funding is allocated to the CDOT regions, which do not compete with each other for this funding. The CDOT portion of HSIP funding is distributed according to the percentage of crashes occurring within respective regions. The regions then select which projects get prioritized. The second application of the benefit-cost ratio is to establish minimum requirements that projects must meet to qualify for funding. To help maintain consistency and meet performance measures, the minimum benefit-cost ratio of 1.0 is set for HSIP projects (the minimum is 0.25 for FASTER Safety Mitigation). There are some exceptions to this rule (for example, systemic safety improvement applications), but generally this minimum threshold is applied to qualifying projects for funding approval (Swenka, pers. comm., 2018).

CDOT DTD generates benefit-cost analyses for project proposals seeking federal grant funding from programs such as Better Utilizing Investments to Leverage Development (BUILD, previously known as Transportation Investment Generating Economic Recovery, or TIGER grants), as well as Fostering Advancements in Shipping and Transportation for the Long-Term Achievement of National Efficiencies or FASTLANE grants. USDOT requires that grant applicants use benefit-cost analyses based upon what people would be willing to pay for better safety to avoid an accident in the first place rather than an expense-based approach. Federal guidance for benefit-cost analysis 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 December of 2018, USDOT published its current *Benefit-Cost Analysis Guidance for Discretionary Grant Programs* (USDOT, 2018).

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

4.3 Implementation Considerations Matrix

In addition to the wildlife-highway mitigation prioritization process discussed in Chapter 2.5, the Prioritization Subcommittee 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 as they may influence implementation. These additional considerations were compiled in an Implementation Considerations Matrix. The matrix includes the following considerations that may influence implementation:

- EA or 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 timeframe in the next 10 to 20 years. EA or EIS commitments were derived from CDOT's list of studies and assessments (CDOT, 2018a).

- Funded wildlife crossings mitigation listed as a planned project in the Statewide Transportation Improvement Program (STIP) (CDOT, 2018b).
- Other types of transportation projects in the STIP that overlap with a top 5 percent segment (CDOT, 2018b).
- Wildlife crossings mitigation identified for a highway corridor in a Regional Transportation Plan (RTP)(CDOT, 2018c) or in the Statewide Transportation Plan (SWP)(CDOT, 2007)
- A transportation project identified in the Development Plan overlaps with 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 2018d).
- Wildlife crossing mitigation identified in a Planning and Environmental Linkages Corridor document, I-70 Linkage Interference Zones, a county-level connectivity plan such as Eagle County Safe Passages for Wildlife (Kintsch and Singer, 2018) or Summit County Safe Passages for Wildlife (Kintsch et al., 2017) or comparable planning document.
- A high-priority segment (top 5 percent) overlaps with a priority herd as defined by Secretarial Order 3362 (CPW, 2018).
- 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 criterion includes the potential to retrofit existing bridges or culverts to function as passageways for deer or elk. 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- x 0.5-mile moving window. Presence scores for each segment were converted to Low, Medium and High, where Low is ≤ 0.33; Medium is > 0.33 to ≤ 0.66; and High is > 0.66.
- Overlap with key energy development corridors as defined in CDOT's 2035 Statewide Transportation Plan (CDOT, 2007).

A sortable version of the Implementations Considerations Matrix is included as one of the deliverables to CDOT and CPW for the WSWPS. The matrix is also summarized in Appendix I. The matrix will require periodic updating to reflect changes in the STIP, regional plans, and other planning documents, as well as the forthcoming 2045

Statewide Plan and updates to key energy development corridors informed by the oil and gas impacts on transportation report (FHU and BBC, 2015).

Other considerations are not appropriate at the scale of this study and must be assessed during project development and planning, such as wildlife crossing considerations for other species, local WVC accident hotspots within a high-priority segment (Getis-Ord analysis); and the estimated likelihood of success of wildlife-highway mitigation in reducing WVC and providing connectivity for wildlife across a roadway.

4.3.1 Example Using the Implementations Considerations Matrix

To evaluate a high priority segment relative to these urgency, opportunity and feasibility considerations, users should reference the sortable Implementations Considerations Matrix, which is provided as a digital deliverable accompanying this report. Table 4-5 demonstrates how the Implementations Considerations Matrix applies to the four highway segments that were also considered in Section 4.2.1 above. Notably, two of these example segments already have wildlife crossings mitigation that has been constructed – SH 9 from MP 126-137, and U.S. 285 from MP 144.5-147.5, although in the latter example, some additional mitigation is recommended in a portion of this segment. The other two segments were identified in the 95th percentile but no wildlife-highway mitigation projects have been constructed or planned in these segments.

Table 4-5: Implementation Considerations for Four Example Highway Segments

Implementation Consideration	SH 9 MPs 126 – 137	U.S. 285 MPs 144.5 – 147.5	U.S. 160 MPs 104.5 -113.5	U.S. 40 MPs 40 – 41.5
EA or EIS Commitments to Wildlife Crossings Mitigation (NEPA complete)	n/a	No	No	No
Funded Wildlife Crossings Mitigation in STIP	n/a	No	No	No
Other Types of Transportation Projects in STIP	No	No	No	No
Wildlife crossings mitigation identified in an RTP or SWP	Yes	Yes	Yes	Yes
Transportation Project in Development Plan	Yes	No	Yes	No

Implementation Consideration	SH 9 MPs 126 – 137	U.S. 285 MPs 144.5 – 147.5	U.S. 160 MPs 104.5 -113.5	U.S. 40 MPs 40 – 41.5
Wildlife Crossing Mitigation Identified in PEL, I-70 LIZs, or comparable	n/a	No	No	No
Secretarial Order 3362 Priority Herd	No	No	Yes	Yes
Feasibility and constructability of wildlife crossings mitigation	n/a	High	High	High
Land Security	Medium	Low	Low	Low
Energy Development Corridor	No	No	Yes	Yes

This exercise does not provide the user with a definitive answer regarding how to proceed with wildlife-highway mitigation in a given highway segment; however, it may highlight new opportunities or partnerships or, conversely, bring certain challenges to light.

4.4 Integrating WSWPS 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 2017b). 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. While each regional and statewide plan covers a distinct timeframe, planning is a continual process to support CDOT's mission.

Transportation priorities are set first at the local scale, within each TPR. There are six rural TPRs across the Western Slope. CDOT gathers input from each of these TPRs 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.

The need for wildlife-highway mitigation has been identified as a priority by most Western Slope TPRs. For example, the Southwest TRP has identified "adding WVC reduction measures such as wildlife fencing, underpasses, overpasses, elevated highways or equally effective methods" to reduce WVCs in wildlife corridors (URS Corporation, 2008). Using the prioritization results and BCA tool of the WSWPS, 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 SWP (CDOT, 2017a). The SWP 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. In 2019, CDOT will begin working on development of the next iteration of the SWP, looking out to the year 2045. The results of the WSWPS are well-timed for integration into RTPs, which will ultimately feed into the SWP and the 10-year Development Plan, a wish list of potential projects with unidentified funding.

Ultimately, these regional and statewide planning processes direct CDOT 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 WSWPS high-priority segments), these projects are better positioned to receive project funding and be included on the STIP.

The WSWPS decision-support framework was developed to assist planners in prioritizing among wildlife-highway projects within a TPR or priority transportation corridor. For example, 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. Projects with a favorable benefit-cost ratio demonstrating that wildlife crossing mitigation could have a large effect on reducing the costs associate with WVC may also be more readily advanced. By prioritizing mitigation projects in segments where WVC mortality has a large impact on a herd (e.g., U.S. 160 near Cortez or U.S. 24 near Buena Vista), wildlife-highway mitigation may bring greater benefits to the health of these herds.

5 CONCLUSIONS AND NEXT STEPS

The WSWPS positions CDOT and CPW to better address the problems of driver safety due to WVC and connectivity for wildlife across CDOT-maintained roads in western Colorado. 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, the WSWPS provides CDOT and its partners with a proactive framework for pursuing strategic wildlife-highway mitigation where it is needed most. Ultimately, this study is expected to lead to reduced incidence of WVC in the Western Slope.

The WSWPS emerged from a commitment to increased collaboration between CDOT and CPW to address wildlife conflicts on roads. Over the course of this study, this interagency collaboration has deepened and will continue to be of vital importance in the funding, design, and construction of effective wildlife-highway mitigation projects across the Western Slope.

5.1 Lessons and Considerations for Future Prioritization Studies

The following insights are offered as guidance for future prioritization studies and iterations of the WSWPS.

Deriving landscape movement models from CPW collar data collected for other objectives was not adequate.

The Jacobs Team was unable to model WVC risk as a function of hazard (traffic volume and speed) and exposure (wildlife on roads) as originally proposed for the following reasons:

- the nature of the available mule deer and elk collar data sets,
- the ecology of the species,
- the species' ubiquity across the Western Slope, and
- the overlap in summer and winter ranges.

As a result, the study approach was revised. Instead of using movement models to evaluate the risk of a WVC, the study team conducted an analysis of the roadway and landscape features that influence the risk of WVC (see section 2.4.3). This risk analysis, along with other layers of information, was used to identify and prioritize highway segments for mitigation.

Models are useful but imperfect.

Models are useful for extrapolating information to a broader area—in this case, the entire Western Slope. The WSWPS WVC risk models performed far better than null models, and several generalized trends emerged, lending greater insight into underlying factors influencing where WVC are likely to occur. Still, the models explained only fair to moderate levels of variance in observed WVCs because of the high levels of noise in the data. Both elk and mule deer are generalist species, capable of and willing to use a wide variety of habitats, resulting in likely use of many different paths when approaching and crossing highways. In addition, the Western Slope offers extensive high-quality habitat for both species, further reducing the odds that animals will be restricted to particular routes when approaching and crossing roads. Variability in driver behavior (e.g., attentiveness, adherence to posted speed limits, response to animals on or approaching a road) may also be significant and cannot be reasonably represented in the risk models. The fair to moderate variance explained by the model results reflects these realities.

WVC risk is an important consideration informing mitigation placement.

WVC hotspot analyses of spatial patterns in WVC (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, the WVC data sets are known to be incomplete because of the underreporting of WVC accidents by drivers. Mitigation project decisions that rely exclusively on these data are likely to miss some areas that are not reflected in the reported accident data, nor do these data sets allow for predicting potential future areas of concern.

WVC risk models use both maintenance carcass data and reported accident data and, unlike hotspot analyses, are useful in identifying the underlying drivers of patterns in WVCs as well as potential future risk. Understanding the factors that influence risk may help to identify road segments that are high-risk based on traffic and landscape characteristics and 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 the WVC pattern recognition analysis 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 prioritization.

The WSWPS may not fully address WVC impacts or movement needs for other species.

The WSWPS was specifically designed to address WVC conflict and roadway barriers to deer and elk movement. Yet, the study panel and Jacobs Team recognized that other species are involved in WVC or require safe passage across roads, so the Jacobs Team sought to include considerations for other species in the prioritization process. Because of the lack of modeled data for most other species across the Western Slope study area, the only additional species included in the prioritization was lynx. However, the results of this study demonstrate that highway segments that may be important for lynx movement and dispersal do not overlap with the highest priority segments for deer and elk. Knowing this, considerations are needed to address lynx mitigation on the Western Slope separately. Considerations for other species (for example, bighorn sheep, pronghorn) whose movements do overlap with the highest priority segments must be addressed at the project level to ensure that wildlife crossing designs meet the needs of these species.

Wildlife are undervalued in the benefit-cost analysis.

The wildlife valuation conducted for the WSWPS was developed as a more comprehensive approach for integrating wildlife values into BCA than other methods currently used by CDOT. Yet, the WSWPS wildlife valuation is still a conservative estimate of deer and elk values. It does not address all potentially quantifiable benefits of wildlife because comprehensive, discrete data do not currently exist, nor does it address the numerous unquantifiable benefits of wildlife (for example, passive values, reproductive value of cows and does, ecosystem value of connectivity). In addition, the number of wildlife involved in WVCs is grossly underestimated because WVC accident 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 accident data (with double counted records eliminated) would provide a better estimate of the number of deer and elk involved in WVC 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 WSWPS prioritization and coordination between CDOT and CPW. These recommendations are outlined below.

Promote and support consistent carcass data collection methodology by maintenance personnel statewide through tools such as a GPS-enabled tablet to improve the reporting rates and spatial accuracy of WVC carcass data.

Improved carcass data collection will have many benefits to future research.

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 GPS 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 did not occupy ranges near highways or interact with 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 that interact with roads, will be essential to proper inferences.

Maintain comprehensive, up-to-date data on wildlife crossing structures and highway barriers, including wildlife fencing.

These data are needed to support statistical analysis of the impacts of barriers on movement and WVCs. Data produced by such efforts may help team members better understand the selection of highway crossing sites and associated WVC risk, as well as where highways are and are not barriers to movement. Because of incomplete data on placement and attributes of fencing, as well as changes in highway infrastructure over the course of the WVC data set analyzed, the effect of barriers on WVC rates could not be accurately assessed with the modeling approaches presented here. Moreover, it was beyond the scope of this study to assess changes in temporal trends in WVCs following installation of fencing or other barriers. Such an analysis may help to distinguish the effects of traffic volume itself from those of highway infrastructure associated with high-volume highways on WVCs in the future. It is critical that CDOT compile and regularly update information on highway barriers, including wildlife fencing, in order to understand their effects on wildlife movement and WVCs.

Contribute to Crash Modification Factors database.

The FHWA maintains a 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 benefit-cost analysis for wildlife mitigation or pursuing mitigation funding.

Monitor effectiveness in reducing WVC 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 WVC. 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 provide sufficient evaluation of mitigation effectiveness. Post-construction WVC rates that are below objective may need adaptive management.

Create a centralized data repository for wildlife datasets.

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

Several next steps were identified to advance the goals and objectives of the WSWPS. These next steps are described in this section.

Expand upon the WSWPS Field Reviews and Mitigation Recommendations.

Informed by the results of the WSWPS prioritization, the Jacobs Team will conduct field reviews for high-priority segments beyond those presented in this report (the top 5 percent). The expanded assessment will go further to provide CDOT, CPW, and their partners with preliminary wildlife-highway mitigation recommendations for more Western Slope highways. The assessment will focus on high-ranked segments adjacent to those already reviewed in the top 5 percent, resulting in greater continuity of high-priority areas for integration into future transportation projects. The results of the expanded assessment will be delivered to the study panel as an addendum to the final report by the end of the 2019 fiscal year (June 30).

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 Chapter 4. Further integrating priority segments identified through the WSWPS 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 WSWPS findings and priorities at TPR meetings and via other community outreach. The Colorado Wildlife and Transportation Alliance (see below) may also assist with these activities (for example, by developing materials for presentations to TPRs).

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 (ROW) fence in critical areas by replacing woven wire sheep fence with a more wildlife-friendly alternative or closing gaps in existing segments of wildlife exclusion fencing at interchanges along I-70 to increase effectiveness in preventing animals from accessing the interstate.

Create an Overarching Intergovernmental Agreement between CDOT and CPW.

In 2018, the CPW Commission allocated $1 million toward wildlife-highway mitigation projects. These funds were distributed to three projects in three separate CDOT regions, necessitating three separate intergovernmental agreements (IGAs) to oversee the transfer of funds from CPW to CDOT. This marked the first time CPW provided project construction funding to CDOT for these types of projects. In anticipation of continued funding from CPW, a single, overarching IGA between the two agencies would streamline funding agreements and allow CPW to assist in project selection at the committee level. This could also serve as a template for other potential IGAs with other federal agencies such as the U.S. Forest Service, BLM, or the U.S. Fish and Wildlife Service.

Integrate Wildlife Priorities into CDOT's Multi-objective Decision Analysis Tool.

To further integrate the wildlife-highway mitigation priorities defined by the WSPWS, the Jacobs Team has been tasked with incorporating these priorities using the Jacobs proprietary Multi-objective Decision Analysis (MODA) software tool that CDOT is adopting to assist in project prioritization and decision making during the transportation planning process. The MODA framework is used by many agencies to provide a structured, logical approach for developing a ranked list of projects in a manner that reflects agency values, providing context and justification for investments in capital improvement projects. Figure 5-1 provides an overview of this framework.

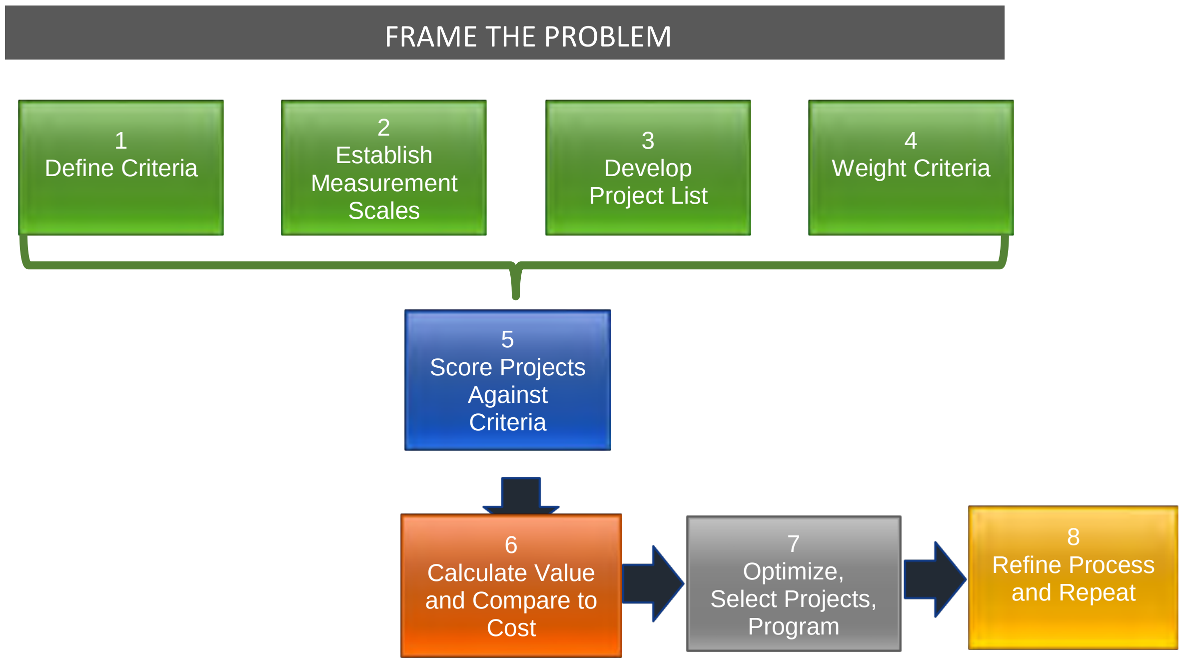

Figure 5-1: Overview of the MODA Approach

CDOT has taken a practical approach using MODA for project selection that includes adopting a set of common criteria that can be used as a starting point for any situation where decisions must be made about which projects to fund when there are more needs than available funds. The WSWPS prioritization followed a similar approach, defining and weighting criteria that reflect CDOT and CPW values and objectives. However, the results of the WSWPS remain separate from the MODA. By incorporating the WSWPS output and decision tools into the MODA, CDOT will be better equipped to evaluate where wildlife-highway mitigation may be integrated with other transportation needs, such as adding shoulders, surface treatments or bridge or culvert replacements. In addition to prioritizing among wildlife-highway mitigation projects, integrating the WSWPS into the MODA will allow CDOT to prioritize wildlife-highway mitigation projects relative to other transportation projects. Proposed projects with a wildlife mitigation component may influence project scoring in three of the five MODA criteria: safety, economic vitality, and other considerations. For example, the crash reduction benefits can be scored in the safety criterion and wildlife benefits can be scored as an "other consideration." Both may influence the economic vitality criterion.

Use of the WSWPS prioritization, benefit-cost tool, and other decision support tools in conjunction with the MODA approach is expected to help CDOT and the Western Slope TPRs develop strategic, data-driven priorities for integration into RTPs, with the ultimate goal of developing a systematic plan and funding approach to addressing the wildlife-highway mitigation needs by the WSWPS.

Expand the WSWPS to the Eastern Slope and Plains.

In 2018, the Jacobs Team was tasked with producing a white paper to evaluate how the WSWPS may be expanded into a statewide study (Kintsch et al., 2018b). Expanding the WSWPS to the Eastern Slope and plains would 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 across Colorado.

An Eastern Slope and Plains study would benefit from cost-efficiencies and lessons learned from the WSWPS but must consider notable differences, including varied geography from the Continental Divide through the eastern plains, major human population centers and extensive development, and differences in wildlife behavior and movement patterns in these landscapes. 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, and a data sharing agreement between CDOT and CPW would not be required. However, given the more open topography and minimal cover of the eastern plains relative to the Western Slope, a poorer model fit may be expected, and the WSWPS prioritization criteria may require adjusting accordingly. The launch of this study and the formation of a study panel is pending approval and dedicated funding.

Link WSWPS priorities to the Colorado Wildlife and Transportation Alliance.

In 2018, the Colorado Wildlife and Transportation Alliance (Alliance) was established as a statewide coalition consisting of CDOT, CPW, and federal, tribal, academic, nonprofit, biologist, and engineering partners. The Alliance is a collaborative effort with a vision to improve human safety while fully integrating wildlife movement needs into Colorado's transportation system. This effort includes measures that institutionalize wildlife considerations into transportation projects and build partnerships and awareness to protect wildlife movements across the landscape, with the goal of reducing WVCs while maintaining wildlife populations.

As of January 2019, the Alliance formed an oversight steering committee and two technical teams: (1) the Education and Outreach Team, and (2) the Partnerships and Funding Team. The Alliance has also developed comprehensive outreach materials to begin educating the public on the issues around safe passage for both people and wildlife across Colorado. Currently, the Alliance is coordinating with concurrent efforts, including the Department of Interior's Secretarial Order 3362, CDOT's Rural Roads RoadX Challenge, U.S. Geological Survey, Southern Ute Tribe, and local wildlife and transportation initiatives in Summit and Eagle counties.

Members of the Alliance are working closely with WSWPS researchers to find creative ways to implement the findings from the study and identify funding sources for a similar East Slope and Plains study. The Alliance will use the WSWPS and potential East Slope Wildlife Prioritization Study results to identify statewide priority projects and begin to integrate these projects into local and regional planning efforts. The Alliance is focused on securing additional funding for internal operations, project design and implementation, and community outreach efforts to support these priority projects. The Alliance is also developing agreements between key state and federal agencies to institutionalize wildlife mitigation and high permeability considerations in the transportation planning process.

Develop a Best Practices and Procedures Manual.

Current best practices and recommended minimum dimensions for wildlife crossing structures and other mitigation features (for example, Clevenger and Huijser, 2011) tend to be overly generalized and may be difficult for transportation planners and biologists to apply to specific project areas with varying conditions. The development of a best practices manual specific to the species and landscapes of Colorado would provide more useful guidance during project development. Rather than basing crossing structure dimensions simply on the minimum recommended dimensions for a target species, an updated manual should provide a range of dimensions and the conditions that influence which portion of that range applies under which circumstances. While every situation is unique and requires site-specific consideration, such a manual will reduce this effort by providing a credible starting point for determining appropriate specifications at a given location, and therefore would save money.

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 Western Slope for a minimum of 10-20 years. In general, identified regional priority areas are expected to remain consistent over this timeframe, although some local shifts due to changes in land use or habitat conditions are likely. However, components of the decision-support tool should be updated more frequently. These include,

- *Benefit-Cost Analysis Tool*—Update crash costs annually as provided CDOT Traffic and Safety; Update mitigation costs and mitigation effectiveness every 2-5 years.
- *Implementation Considerations Matrix*—Every 3 years update transportation plans, projects, EIS/EA commitments and other considerations that may influence mitigation implementation in priority highway segments.
- *Prioritization of Highway Segments*—Every 10 years update the prioritization of highway segments across the Western Slope with updated data, including new collar data, traffic demand forecast models and updated WVC data and pattern recognition analyses from Traffic and Safety. 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 (see section 5.1).

5.4 Implementation Statement

This research developed implementation tools and provided recommendations for implementation. Section 4 synthesizes these tools in a decision-support framework that demonstrates how these tools can be used to determine where to focus wildlife-highway mitigation. The framework also guides users through major steps in the implementation process to provide cost effective, ecologically-effective wildlife-highway mitigation.

Section 5.3 outlines specific actions that are recommended for CDOT and CPW to advance this research. These 'next steps' propose to expand the research outcomes for the Western Slope and statewide; integrate the WSWPS priority areas into local and regional planning efforts; and coordinate with efforts to increase partnerships and funding for wildlife-highway mitigation. Accordingly, the WSWPS positions CDOT, CPW and their partners to better address the problems of driver safety due to WVC and connectivity for wildlife across Colorado's Western Slope. The long-term benefit of this research will be a decrease in WVC and improved connectivity for wildlife across roads.

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APPENDICES

APPENDIX A: Literature Review

MEMO

TO: WSWPS Study Panel **DATE:** Updated 6/12/18

FROM: WSWPS Study Team

SUBJECT: **Western Slope Wildlife Prioritization Study – Literature Review**

COPIES:

1.0 TOPIC: PRIORITIZATION PROCESS

The research summarized in this topic area includes prioritization processes developed in surrounding states such as Idaho and Montana, and other countries such as Botswana, France, Italy and Canada to inform and aid transportation and resource agencies in scientific and stepwise processes to establish priority areas to focus limited transportation funding to address reducing wildlife vehicle collisions and maintain or enhance wildlife connectivity at a larger landscape scale

Abrahms, B., S. C. Sawyer, N. R. Jordan, J. W. McNutt, A. M. Wilson, and J. S. Brashares, J. S. 2016. Does wildlife resource selection accurately inform corridor conservation? Journal of Applied Ecology. DOI :10.1111/1365-2664.12714.

1.1 Location: Botswana

1.1.1 Summary:

The authors review 16 years of connectivity studies employing resource selection functions (RSF) to evaluate the extent to which researchers have incorporated animal behavior (i.e., behavioral state) into corridor planning. Their review indicates that most connectivity studies conflate resource selection with connectivity requirements, which may result in misleading estimates of landscape resistance. None of the 28 studies reviewed focused explicitly on movement-related habitat use, and fewer than half made any effort to incorporate consideration of movement behavior into their analyses. Furthermore, most (23) lacked validation of proposed connectivity models with movement data. The authors highlight promising new approaches for identifying wildlife corridors and recommend strategies for developing more realistic connectivity models, namely including only directed movement behavior when estimating resistance to movement for connectivity models

An empirical case study tests behavior-specific predictions of connectivity with long-distance dispersal movements of African wild dogs by fitting and validating two RSF models – one that ignores behavioral state and one that isolates and focuses on wild dogs' 'traveling' movement state. This case study shows that measuring resource selection based only on directed movements reveals markedly different, and more accurate, connectivity estimates than a model measuring resource selection independent of behavioral state. The authors highlight the importance of global positioning system (GPS) and very high frequency (VHF) collar technology that allows measurement of an animal's behavioral state (e.g., accelerometers) and/or analytical methods of distinguishing behavioral states based on attributes of movement paths in order to appropriately separate data collected during distinct behavioral states prior to RSF model fitting. However, they also point to the difficulty of collecting sufficient amounts of locational data to adequately represent long-distance movement processes for many species.

1.1.2 Relevance to Western Slope Wildlife Prioritization Study (WSWPS):

- This study's findings suggest the importance of modeling resource selection during migration movements separately from resource selection during home range use, as we have proposed to do in this study. Specifically, using RSFs developed from data collected during mule deer home range movements to estimate resistance to movement during migration movements may not accurately predict migration corridors, with important implications for effective identification and prioritization of potential highway mitigation sites.
- The results of this study's literature review indicate the importance of validating connectivity model predictions in order to ensure that RSFs have been used appropriately to identify corridor locations and to provide an error estimate on these predictions.

Ament, R., P. McGowan, M. McClure, A. Rutherford, C. Ellis, and J. Grebenc. 2014. Highway mitigation for wildlife in northwest Montana. Sonoran Institute, Northern Rockies Office, Bozeman, MT. 84 pp.

1.2 Location: Northwest Montana

1.2.1 Summary:

In this report the authors investigated the potential impacts of future housing development on traffic to determine where increased traffic from housing development will impact habitat connectivity for large carnivores and other key species. The focus of this study was Flathead and Lincoln counties in northwestern Montana. This effort was unique in that it projects development into the future and identifies potential problem sites before the impacts arrive. This planning effort focused on carnivores, particularly grizzly bear, *Ursus arctos*, as an umbrella species. The emphasis of this study is to maintain connected habitat and wildlife corridors for greatest ecological benefit, by proposing mitigation opportunities for the highest priority sites for wildlife connectivity within the region.

The specific steps for the project were:

- Develop two growth scenarios, each based on past growth patterns that are projected with a 20-year forecast into the future. Each growth scenario will differ based on future development patterns; one will assume more growth near existing population centers and one will model new housing based on historic growth patterns with no accommodation for a potential change in development patterns (i.e., a *business-as-usual* scenario). (Chapter 4)
- Use the growth scenarios to develop future traffic projections. (Chapter 5)
- Use existing wildlife connectivity data to identify priority linkage areas. (Chapter 6)

- Overlay future traffic projections onto connectivity data to identify areas of potential future wildlife-transportation conflict. (Chapter 6)
- Check model results with local experts and conduct an on-the-ground evaluation. (Chapter 7)

Traffic Demand Forecast Model (TDFM) trip generation rates were established based on current research and the number of trips was then calculated for each new and existing home in the housing projection. Standard occupancy rates and the shortest route were assumed for all trips. The traffic model was calibrated using existing traffic and adjusted so that future traffic could be predicted. Seasonality of traffic is a factor in the two-county study area, with more traffic during the summer months. Due to focal species being grizzly bears, the study identifies annual average daily traffic (AADT) of 200 or above as cause for some concern, and over 3,000 AADT as cause for heavy concern. Using these thresholds, most of the road network was eliminated as areas of concern because there were not more than 200 AADT projected on them. However, all major highways in the study area (i.e., Highway 2, Highway 93 and Highway 37) were identified as segments that were estimated to have over 3,000 AADT by 2030.

The project is focused on major transportation routes in Flathead and Lincoln counties in northwestern Montana. A large portion of both counties is unavailable to development due to public ownership, conservation easements, or other interests. As a result, only about 20 percent of all lands in the two counties are available for residential development. The large areas of undeveloped land provide habitat for an array of species, including large carnivores such as grizzly and black bear, mountain lions, and wolverines. Other species also use these areas, including moose, elk, bighorn sheep, deer, and smaller animals such as salamanders and boreal toads. This study focuses on connectivity of habitat in and between these large areas of land, recognizing that animals will likely travel outside of the study area to adjacent habitat and beyond.

Two sources of grizzly bear connectivity data, three connectivity models (least-cost distance models) for other wide-ranging carnivores with similar habitat needs (black bear, wolverine, Canada lynx), and two landscape integrity-based connectivity models (MFWP/CAPS, WGA/CHAT) with relevance to grizzly habitat needs were identified in the study area. Map data layers were available for both landscape integrity-based connectivity models, while all other data sources were available in image form only and were thus georeferenced and digitized.

Initially ten high-value road segments were identified based upon their value for wildlife connectivity. Of these, one was excluded from further analysis for potential mitigation emphasis due to low current and projected traffic volumes, despite evidence of frequent grizzly crossings. This decision was supported by evidence from Montana Department of Transportation (MDT) carcass data which showed very little wildlife and no grizzly carcasses collected over the previous 10 years. Within the remaining nine roadway segments 13, priority sites were selected based upon site-level connectivity values, topography and/or human settlement patterns. Field visits with well qualified local biologists to each mitigation site were conducted and prioritizations generated based upon ranking system. Ranking system matrix included metrics such as detailed location information, wildlife model support, connectivity value, non-modeled species conservation value, wildlife mitigation feasibility, adjacent land ownership, land security value, and current and projected traffic volumes. Each site was analyzed and given detailed write up for each metric within the ranking matrix to generate overall priority list.

1.2.2 Relevance to WSWPS:

- Project looked at multiple GIS modeling efforts for multiple species over a larger landscape using existing GPS and telemetry data to help validate important movement corridors.
- Project did not generate new wildlife data, used existing data sources.
- Project looked at existing and future habitat connectivity scenarios based upon current and projected traffic and housing development, similar to the task being undertaken for the WSWPS.
- Project used data that MDT Planning Division uses to generate traffic projections and growth/development, which is in line with what the research team is proposing for the WSWPS with Colorado Department of Transportation (CDOT) data.
- Project generated process and justification for prioritization of important connectivity areas across transportation corridors, thus providing valuable decision support tool.

Benz, R. A., M. S. Boyce, H. Thurfjell, D. G. Paton, M. Musiani, C. F. Dormann, and S. Ciuti. 2016. Dispersal ecology informs design of large-scale wildlife corridors. PLOS ONE 11(9): e0162989. DOI: 10.1371/journal.pone.0162989.

1.3 Location: Southwest Alberta, southeast British Columbia, and northwest Montana

1.3.1 Summary:

Elk dispersal and gene flow occurs when young males migrate with their mothers from winter to summer range, then migrate alone to a new summer range. The authors developed an approach to incorporate elk dispersal ecology into corridor design that is particularly suitable for young, male dispersers, and that also helps in identifying movement corridors that may have been lost due to the presence of major highways, which highlights segments that may be impeding dispersal movements of young, male elk.

Specific steps undertaken included:

- Young male elk were fitted with GPS collars prior to dispersal.
- GPS collar data were split into summer and winter residency periods and spring and autumn migration periods.
- Habitat selection during summer and winter residency periods was modeled using resource selection functions (RSFs).
- Habitat selection during spring and autumn migration was modeled using step selection functions (SSFs).
- Models of habitat selection during migration were adapted to represent expected habitat selection in the absence of roads by maximizing the models' distance from roads' variable.
- Elk corridors were modeled as least-cost corridors among winter and summer core areas, both with roads and without roads.
- The highway length crossed by corridors in both scenarios was estimated and compared.

The authors found that the total length of highway intersected by corridors was significantly lower in the scenario that included roads than in the scenario run as if no roads were present. This finding suggests that potential elk migration corridors may have been lost due to elk avoidance of roads. However, note that assumptions regarding the plasticity of elk migration paths and road avoidance in response to traffic volume or other road attributes are not discussed, and no independent validation of the predicted corridor network was conducted. Importantly, this study normalized all least-cost corridors among winter-summer range pairs rather than retaining information about the relative cost-distance value of corridors, which does not lend itself to prioritization of high-value corridors within the network.

1.3.2 Relevance to WSWPS:

- The study uses GPS collar data from a migratory ungulate to model core habitat suitability and migration habitat suitability/connectivity independently.
- The study illustrates application of habitat suitability modeling approaches that are tailored to space use of the focal species at different times of year, i.e., use of resource-selection functions for non-directional movements during summer and winter residency periods and

use of step selection functions for directional movements during spring and autumn migration.

- The study explicitly identifies highway segments intersected by corridors predicted to be important for elk migration and dispersal among winter and summer ranges.
- The absence of independent validation of predicted corridors in this study perhaps emphasizes the importance of doing so in the WSWPS.
- This study does not incorporate traffic volume into estimates of habitat resistance to movement, which is perhaps a shortcoming that should be addressed in the WSWPS.

Cramer, P. C., S. Gifford, B. Crabb, C. McGinty, D. Ramsey, F. Shilling, J. Kintsch, K. Gunson, and S. Jacobson. 2014. Methodology for Prioritizing Appropriate Mitigation Actions to Reduce Wildlife-Vehicle Collisions on Idaho Highways. Report RP 229 to the Idaho Transportation Department, Boise, ID.

1.4 Location: Idaho

1.4.1 Summary:

The objective of this research was to advance the effectiveness and efficiency of Idaho Transportation Department's (ITD's) project planning to reduce vehicle collisions with wildlife and to provide wildlife connectivity options across and under roads. A Wildlife-Vehicle Collision (WVC) Prioritization Process was developed through lessons learned from other U.S. States and Ontario Canada's efforts, and GIS modeling of data and maps already available in Idaho. The result was a 13-step process developed for ITD. The GIS maps were based on WVC crash and carcass data, Average Annual Daily Traffic (AADT) volume, Wildlife Highway Linkages maps, and species' habitat maps. The resulting maps of WVC priority areas statewide and within ITD districts were developed for the project. This WVC Prioritization Process was a huge step along a series of actions which ITD has undertaken and will continue to take to reduce risks associated with WVC and provide wildlife connectivity along Idaho roads.

There were six steps identified that were relatively uniform across efforts undertaken in several states and the province of Ontario in Canada. These include:

1. Identify reported accident data.
2. Collect and geo-reference state Department of Transportation (DOT) maintenance carcass data.
3. Map both accident data and maintenance carcass data.
4. Determine AADT for all routes examined.

5. Include maps of target species habitats.

6. Include maps of potential wildlife linkages during the evaluation process.

ITD's 13-step process integrates these six items above to develop a baseline, which is Step 1 of their process. The steps are listed below:

Step 1 Perform modeling to create a Statewide Priorities Map
Step 2 Identify priority areas within an ITD district-based Needs Assessment document created in conjunction with IDFG
Step 3 State objectives of the proposed mitigation actions that can be quantified and monitored
Step 4 Examine land ownership maps for feasibility of creating wildlife treatment actions or mitigations in protected areas
Step 5 Compare WVC priorities with future ITD transportation projects for potential opportunities of including mitigation options
Step 6 Analyze existing infrastructure for retrofits
Step 7 Build consensus with public and private partners through field visits
Step 8 Select wildlife mitigation actions based on short and long-term possible solutions
Step 9 Evaluate how cost-effective these wildlife treatment options are projected to be over the long-term
Step 10 Identify potential funding partners
Step 11 Establish performance measures, state constraints, and estimate likelihood of success
Step 12 Annually select projects at ITD District levels and state level
Step 13 Announce state and district level priorities, begin building wildlife mitigation

Users of this process further identify priority areas in ITD Districts based on other data such as: Idaho Fish and Game (IDFG) knowledge of wildlife populations, transportation plans, land ownership, field surveys of existing structures, mitigation options such as fencing, bridges, and culvert, and their cost-effectiveness. However, it should be noted that when weighting and scoring roadway segments as priority areas, only 6 of the 13 steps in ITD's process contribute to the weighted score for prioritization. Subsequent follow-up with ITD staff revealed that ITD is looking to consolidate steps 5-9 in the 13-step process developed in this research project for simplification and ease of implementation by staff.

This research project should be commended for its exhaustive review of prioritization processes used in various states and Canadian province of Ontario and mitigation options commonly available and their relevance to a DOT performing wildlife mitigation. The ITD process ultimately ended up integrating bits and pieces from several other state processes, notably Washington. There were and continue to be several challenges that ITD and IDFG must work through to get this process implemented consistently and with improved data statewide. Some of those challenges include:

- Institutional resistance from within ITD to accept habitat fragmentation and wildlife connectivity as issues that ITD should be addressing with their transportation program, unless tied specifically to safety issues. This is not uncommon among state DOTs.
- Data gaps, due to inconsistent data collection/reporting of roadkill along Idaho roads by ITD maintenance forces statewide. Because this effort is still done voluntarily and reported by filling out paper forms, spatial inaccuracies and a lack of ease of reporting continue to be issues hindering data collection and quality.
- Wildlife-Vehicle Collision (WVC) accident data reported by Idaho State Police is somewhat limited. Accident data is required to be collected for: 1) Accidents that have > $1500.00 worth of damage to the vehicle, and 2) All accidents with any injuries.
- Lack of maintenance roadkill and Idaho highway patrol accident data is hindering ability to generate Benefit / Cost (B/C) analysis sufficient to justify wildlife vehicle collision mitigation projects.
- ITD GIS staff is having problems updating and replicating GIS maps produced in this research.
- Data gaps, primarily due to IDFG data for habitat, winter/summer ranges, home ranges and movement of key wildlife species is not empirically derived data.
- Due to inconsistencies of maintenance carcass reporting statewide, some districts projects are elevated in scoring over other districts at the statewide level, thereby resulting in some districts being under-represented in the overall statewide prioritization despite having several very important wildlife linkage areas.

1.4.2 Relevance to WSWPS

- Research found six commonalities among prioritization efforts done elsewhere, whether in the United States or Canada (noted above).
- Research provided examples of and generated its own weighted matrix for scoring priority roadway segments.
- Mitigation options provided are similar to options to be considered in WSWPS.
- Species considered during evaluation are similar to those in WSWPS.
- Research provided insights into strengths and weaknesses of Idaho process and where and how weaknesses could be improved (e.g. lack of consistency in level of effort and process among state DOT maintenance crews for collecting and reporting carcass data–improved

through use of smart phones and downloadable apps that provide geo-referenced data collection, standardized format and greater ease of collection/reporting of data)

- Use of GIS for analyzing features such as wildlife habitat features, linkage modeling, reported accident data and maintenance carcass data, transportation plans/projects, AADT etc.
- Report emphasized critical importance of ITD and IDFG working together and sharing data to develop priorities for each district, which will have to happen on WSWPS as well.
- This report also recommended further research in pre-post construction monitoring to scientifically evaluate effectiveness of mitigation measures in both ecological connectivity terms and safety terms. This could help validate efficacy of wildlife mitigation in terms of ecological connectivity and in B/C terms thereby improving data in decision support toolbox available to decision makers.

Crooks, K., C. Haas, S. Baruch-Mordo, K. Middledorf, S. Magle, T. Shenk, K. Wilson, and D. Theobald. 2008. Roads and connectivity in Colorado: Animal-vehicle collisions, wildlife mitigation structures, and lynx-roadway interactions. Research Report Number CDOT-2008-4. Colorado Department of Transportation, Denver, CO. 175 pp.

1.5 Location: Colorado

1.5.1 Summary:

This CDOT-funded research study addresses three research questions with regards to highway impacts on landscape connectivity in Colorado: 1) the identification of WVC hotspots and the landscape characteristics associated with these hotspots; 2) a review of efforts to design and implement field monitoring of road-wildlife interactions at three locations slated for the construction of new wildlife crossing structures; and 3) an evaluation of wildlife use of seven underpasses specifically installed as mitigation for Canada lynx, and a general review of the relationship between radio-collared lynx movements and roads in the state.

Characteristics of WVC hotspots in Colorado. The researchers analyzed WVC data from CDOT Traffic and Safety accident reports (1986-2004) resulting in fatalities or injuries (combined) or property damage by mile. They then mapped WVC hotspots using the Getis-Ord G_i* statistic, highlighting the top 1% and 5% of hotspots resulting in fatalities/injuries and hotspots resulting in property damage. The researchers found that forest cover and disturbed lands (e.g., recently burned, logged, mined) were associated with high WVC areas. Forested areas provide cover for ungulates, suggesting that where highways bisect forested areas are likely to sustain higher WVC. Disturbed areas may increase foraging opportunities for ungulates, and may attract wildlife near roads. High WVC counts were associated with topographic features such as riparian corridors, which are conducive to animal movement. The top 1% of WVCs occurred in areas that had higher traffic volume, speed limit, road width and traffic volume adjusted road density, suggesting that areas with higher human activity and increased barrier or roads result in a higher probability of WVC.

Development of mitigation goals and pre-construction data collection. For this portion of the research, three studies areas that are slated for multiple-phased highway improvement projects were selected: US 285 between Conifer and Bailey; US 160 between South Fork and Wolf Creek Pass; and US 160 between Durango and Bayfield. For each site, detailed data collection protocols were developed for pre- and post-construction monitoring using a before-after-control-impact (BACI) design to account for natural variability and reduce the likelihood of unmeasured covariants influencing the observed effect. Monitoring was conducted using motion-triggered infrared cameras and WVC data analyses. For each study area, detailed analysis of wildlife activity at the roadway, habitat characteristics, mitigation recommendations, and monitoring recommendations are provided.

Canada lynx use of wildlife underpasses. The researchers developed and implemented a monitoring plan at seven underpass locations to evaluate their use by lynx and other wildlife. Two locations were on Muddy Pass; two at Berthoud Pass; two north of Silverthorne; and one on Wolf Creek pass. Motion-triggered infrared cameras were deployed at each study location. Lynx are rare, wide-ranging and have large home-ranges, and no lynx were detected at any of the structures during this study. Therefore, the degree to which the studied structures are suitable or unsuitable for lynx passage is undetermined. However, a variety of wildlife, humans and domestic animals were captured at the study locations.

Finally, the researchers conducted a GIS kernel density analysis of telemetry locations of collared lynx to evaluate their distribution and movement in relation to roadways and to identify potential highway crossing zones throughout the state. The resulting maps offer a general overview of the distribution of 125 collared lynx across the state relative to major highways from October 2000 to January 2006, and further, map potential areas of lynx highway crossings based on straight-line connections between consecutive lynx spatial locations collected less than two weeks apart. More recent analyses provide a more recent and detailed analysis of the probability of lynx highway crossings (see Baigas et al. 2017, this literature review). The researchers conclude that there is some evidence that lynx in Colorado selectively avoid major highways.

1.5.2 Relevance to WSWPS:

- The WVC hotspot analysis conducted in this study and the characteristics associated with high WVC areas may be compared with the WVC hotspot analysis to be conducted for the WSWPS.
- For the specific sites included in this study (two of which are in the WSWPS study area), detailed analysis of wildlife activity at the roadway, habitat characteristics, mitigation recommendations, and monitoring recommendations are provided.
- Monitoring results at all locations included in this study may provide site-specific information of value to the WSWPS.

Cushman, S.A., J. S. Lewis, and E. L. Landguth. 2013. Evaluating the intersection of a regional wildlife connectivity network with highways. Movement Ecology 1:12.

1.6 Location: Montana and Idaho

1.6.1 Summary:

The authors use a previously published estimate of regional-scale resistance to movement of black bears derived from empirical genetic data in a factorial least cost path (LCP) approach to predict the location and intensity of black bear movement corridors. Factorial LCP maps the least cost routes among all combinations of source location pairs which, for this study, were distributed at 5 kilometer (km) intervals across all forested areas in the analysis area. These pairwise LCP are then summed to estimate corridor intensity, or the number of paths passing through any given pixel. A resistant kernel estimate is then used to smooth the network as a function of corridor intensity and the cumulative cost of traveling from any given source, which helps to account for maximum dispersal ability of the focal species. After this smoothing step, corridor intensity values represent predicted relative frequency of expected use of the corridor, assuming organisms move across the landscape following low-cost routes.

The model results were validated against black bear highway crossing locations observed via GPS collar data (n = 56, with 20-minute relocation frequency), and high intensity corridors were found to be associated with crossing sites. (Crossing sites had higher corridor intensity estimates than all but 7.5% of randomly selected potential crossing sites). Corridor-highway intersections were ranked based on corridor intensity as a means of prioritizing potential locations for wildlife crossing structures or other mitigation efforts. The approach lends itself to identifying critical core areas and linkages, mapping potential barriers to movement, and prioritizing locations for mitigation, restoration, and conservation actions.

1.6.2 Relevance to WSWPS:

- The approach provides a means of estimating the predicted relative frequency of expected use of each potential corridor, which offers a straightforward, objective, easily interpretable metric for prioritizing highway crossing locations for mitigation.
- The study offers a statistical method of validating predicted highway crossing locations against independent data.
- The approach offers a transparent, flexible way of selecting source locations for connectivity models that allows connectivity value to be estimated within patches of core habitat or seasonal home ranges.
- The modeling approach performed well in predicting highway crossing locations that were used by elk, according to independent, high-relocation frequency GPS collar data.

Mimet, A., C. Clauzel, J. C. Flotête. 2016. Locating wildlife crossings for multispecies connectivity across linear infrastructures. Landscape Ecology. DOI: 10.1007/s10980-016-0373-y.

1.7 Location: Greśivaudan Valley, France

1.7.1 Summary:

The authors develop a method for identifying the best locations for wildlife crossings along highway infrastructure for species with varying degrees of mobility and living in different habitats. They model ecological networks for eight hypothetical species attributed with different dispersal abilities and habitat preferences that were selected to represent real species. Resistance of each land cover type to movement of hypothetical species was classified based on ecological knowledge of similar species from the literature, then weighted by slope. Linkages between suitable habitat patches were modeled using least-cost distance, and ecological networks were constructed at multiple spatial scales to account for different movement processes among patches occurring over different temporal scales (e.g., daily and seasonal interpatch movements versus annual or decadal dispersal movements).

Two scenarios were evaluated: one identifying optimal locations for future wildlife crossings before a highway is built, and one identifying optimal locations for improving permeability of an existing highway. To evaluate potential crossing locations, a global index of the initial connectivity value of the network was computed, then the potential increase in network connectivity provided by a crossing site was estimated. Sites yielding the greatest increase in network connectivity were deemed the best locations for maintaining or creating permeability by installing a crossing structure. The value of each potential crossing location was estimated independently, i.e., as if it were the only available crossing site.

Connectivity gain associated with each potential crossing site was calculated for each species independently. To evaluate multispecies connectivity value, connectivity gains were run through principle components analysis (PCA) to identify sites with overall high values with contributions from multiple species. This approach may be particularly valuable for identifying optimal sites for crossing structures intended to enhance connectivity for multiple species with different dispersal ability and habitat requirements. However, there are unavoidable limitations on the ability of a small number of crossing locations to provide for the needs of all species: no 'compromise' locations could be found that would provide for movement of forest and mountain species as well as those species preferring open habitats.

1.7.2 Relevance to WSWPS:

- This study offers a method of evaluating the potential gain in connectivity that might result from installation of a crossing structure at any given point along a highway for multiple species, and provides a means of prioritizing sites that would offer the greatest increase in connectivity for the greatest number of species if multiple species are considered.
- This prioritization based on potential increase in connectivity is valuable because it does not prioritize mitigation sites based strictly on the localized connectivity value of the site in isolation; instead, it estimates the total gain in connectivity across the road network as a whole expected to result from any potential mitigation action, taking into account the position of the site relative to the rest of the road network and multiple species' corridor networks.
- The study highlights an inevitable limitation of multi-species conservation planning in that no sites could be identified that would provide crossing opportunities for multiple species with fundamentally different habitat needs. Multiple mitigation sites are required to provide crossing opportunities for species using very different habitats (e.g., forested vs. open). This is important to keep in mind if the WSWPS aims to consider the connectivity needs of other species in addition to mule deer.

Santini, L., S. Saura, and C. Rondinini. 2016. A Composite Network Approach for Assessing Multi- Species Connectivity: An Application to Road Defragmentation Prioritisation. PLoS ONE 11(10): e0164794. DOI: 10.1371/journal.pone.0164794.

1.8 Location: Italy

1.8.1 Summary:

This study demonstrates an approach for simultaneously assessing connectivity for many species and optimizing conservation or restoration priorities for the entire species assemblage that is far more analytically efficient than assessing each species individually yet produces very similar results. The approach is tested in the context of identifying mitigation priorities across the Italian road network, with a focus on medium and large terrestrial mammals.

The authors first develop an ecological network for each of 20 individual species using graph theory, then generate eight alternative composite networks using different aggregation approaches. They test these aggregation approaches by estimating the increase in connectivity that would be expected to result from mitigation of individual highway segments across the road network based on each of the composite networks compared to the summation of each of the individual species networks. They find that the composite networks provide results that are highly correlated with priority mitigation sites identified from the cumulative results of individual species. The best aggregation method produced results that were 97.6% correlated with the cumulative individual species approach, while cutting the computation time required by 75% (computational efficiency is likely to increase even more dramatically for larger species assemblages, larger geographic areas, and/or higher spatial resolution).

Areas with the highest restoration priority tended to have higher amounts of natural habitat and lower road density. This makes sense because restoring areas with high road impacts but little probability of being reached by dispersers has a marginal effect on connectivity, while mitigating roads disrupting otherwise intact areas that are likely to be part of a primary dispersal corridor can greatly increase connectivity of the network. The set of identified mitigation priorities was most strongly driven by the needs of species occupying large habitat areas and dispersing long distances (i.e., large generalist species), but this pattern could be countered by weighting species by conservation status or assessing the importance of narrowly-distributed species at more local scales.

1.8.2 Relevance to WSWPS:

- This study is similar to Mimet et al. (2016) in that it aims to identify priorities for mitigation that will optimize gains in connectivity for multiple species, but differs in that it explores a much more efficient strategy of simultaneously assessing connectivity gains for an entire species assemblage rather than compiling results from optimization for many individual species.

- If the WSWPS ultimately aims to optimize prioritization of mitigation sites for mule deer as well as other species (e.g., elk, moose, lynx), the success of this approach here means it could offer a highly efficient means of assessing multi-species connectivity value. This could be particularly useful for optimizing mitigation sites over a large area at high resolution.
- The default approach presented here tended to weight large-bodied generalist species more heavily in the multi-species result, which could be appropriate given the WSWPS focus on mule deer. However, this weighting can also be adjusted as needed.

McClure, M. L., B. G. Dickson, and K. L. Nicholson. 2016. Modeling connectivity to identify current and future anthropogenic barriers to movement of large carnivores: A case study in the American Southwest. Ecology and Evolution. doi: 10.1002/ece3.2939

1.9 Location: Arizona, USA

1.9.1 Summary:

The objective of this study was to estimate and map habitat quality and connectivity for puma across Arizona, in particular, those that are the most likely to be impacted by current and future urban development and associated increases in traffic volume. Brownian bridge movement models based on GPS collared pumas and linear mixed models were used to model habitat quality for puma movement. Circuit theory models were then used to produce a continuous statewide estimate of connectivity for puma movement and to identify pinch points. Specifically, the study identified pinch points expected to be most vulnerable to development that could adversely impact puma movements, both under existing conditions and with project development out to 2030.

1.9.2 Relevance to WSWPS:

- The authors integrated several modeling techniques (Brownian bridge movement models and circuit theory models) to develop estimates of habitat quality relative to puma movement and dispersal, thereby avoiding the need for assumptions about the relationship between habitat quality and resistance to movement.
- Circuit theory is a useful tool for identifying movement and dispersal pinch points.
- These methods allowed the authors to analyze connectivity for puma under existing conditions as well as future projected conditions. Similarly, the WSWPS aims to prioritize highway segments that can be integrated into CDOT’s short- and long-range planning processes.

Teixeira, F. Z., A. Kindel, S. M. Hartz, S. Mitchell and L. Fahrig. 2017. When road-kill hotspots do not indicate the best sites for road-kill mitigation. Journal of Applied Ecology. doi: 10.1111/1365-2664.12870

1.10 Location: N/A

1.10.1 Summary:

Roadkill hotspots, i.e., road segments of high roadkill relative to other road segments, are often used to prioritize mitigation locations. However, two empirical studies have found more road-killed amphibians on road segments with lower traffic than on segments with higher traffic, whereas the per capita mortality rate was higher on the high-traffic segments where populations had been depressed by past mortality. This suggests that roadkill hotspots might not always indicate the best locations for mitigating the population impacts of road mortality. Instead, mitigation may be most effective where per capita mortality (the chance of an individual in a population being killed by road traffic) is highest.

The authors developed a stochastic, individual-based model to determine whether the location of roadkill hotspots can change over time, and to understand how this change is related to population size. The model is not species-specific and is intended to be general to a variety of wildlife. The authors tested three predictions: 1) that a roadkill hotspot should move in time from a high-traffic segment to a low-traffic segment due to population depression near the high-traffic segment; 2) this shift should occur earlier for species with higher mobility because they interact more often with the road; 3) this shift can occur even if the low-traffic segment runs through lower quality habitat than the high-traffic segment, indicating that high-traffic roads near wildlife habitat would need mitigation. Prediction 1 was supported and Prediction 3 was partially supported by the results of the simulation model, while Prediction 2 was not supported.

Accordingly, the authors conclude that there are some circumstances in which roadkill hotspots are not appropriate indicators for the selection of the best road-kill mitigation sites, specifically, where the impact of roadkill on population size is higher near a high-traffic segment with lower roadkill counts than near a low-traffic segment with higher roadkill counts. However, these model results may not be applicable for species that exhibit road avoidance behavior in response to traffic volume (i.e., roadkill rates decrease as road traffic increases because animals will be less likely to attempt to cross the road). In these situations, roadkill hotspots on low-traffic road segments may indicate a threshold of traffic avoidance, in which case mitigation at the hotspot location would be more beneficial than on a high-traffic segment where lower road mortality is due to road avoidance rather than population depletion.

1.10.2 Relevance to WSWPS:

- Estimating road mortality in relation to population abundance in the surroundings instead of identifying roadkill hotspots alone is preferable for informing mitigation priorities on older roads, due to the effects of past mortality.

- Per capita road mortality should be considered when evaluating potential mitigation sites and may be a more important indicator that roadkill hotspots. To obtain an estimate of per capita mortality, roadkill information must be combined with population data.
- Where a population next to a high-traffic segment is depressed due to road mortality, the benefits of mitigation may be significant provided the habitat quality remains high and is not additionally impacted by road effects or associated impacts.
- Understanding the causes of temporal and spatial shifts in roadkill hotspots is important to placing mitigation for the greatest population benefit.
- This paper targets biological conservation and does not address a DOT's mandate to provide safe roads for the travelling public.

2.0 TOPIC: WILDLIFE STUDIES

The research summarized in this topic area includes studies of target wildlife species in Colorado or surrounding states, and addresses species movement patterns, seasonal habitat use, and use of wildlife crossing structures and associated mitigation features.

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 157:200-213. DOI: 10.1016/j.landurbplan.2016.06.007.

2.1 Location: Colorado

2.1.1 Summary:

Development of two resource selection function (RSF) models derived from collared Canada lynx to evaluate the degree to which fine-scale and landscape-scale environmental covariates predict the probability of lynx crossings over two-lane highways. Fine-scale covariates evaluated included forest structure and composition, presence of highway guard-rails and barriers, and distance that oncoming traffic is visible. The landscape-scale model evaluated environmental heterogeneity quantified with remotely-sensed data. The models were validated with GPS points from collared lynx programmed to collect locations every 20 or 30 minutes from January to April. These independently collected crossing locations were generally associated with high-probability crossing zones identified by the models.

At the fine scale, lynx selected highway crossings that were closer to vegetative cover and had greater mean basal area, and were not influenced by topographic or highway infrastructure. At the landscape scale, lynx crossings were in areas with nearby forest canopy cover, predominately on north-facing slopes and in drainage bottoms. These results are consistent with previous studies of preferred crossing areas (e.g., Clevenger et la. 2003; Grilo et al., 2009). The analysis is based on the crossing patterns of resident lynx in established winter-spring home ranges bisected by highways. Crossing activity by dispersing lynx making long-distance or exploratory movements may not be captured by this analysis, and animals making these types of movements may be more susceptible to vehicle collisions.

The authors found that while lynx exhibited road avoidance behavior, they did not appear to avoid crossing 2-lane highways (traffic volumes of 2,000-4,000 vehicles per day) in their territories. Lynx seemed to minimize exposure by crossing roads at greater frequency at dusk and night when traffic volumes are lower.

2.1.2 Relevance to WSWPS:

- Vehicle collisions are the cause of 20% of all lynx mortalities and an important mortality factor for reintroduced lynx in Colorado.
- Lynx regularly cross highways present in their home ranges, particularly during dusk and night when traffic volumes are lower. Home ranges bisected by extensive highway sections are likely to have multiple crossing zones.
- Preferred crossing areas have vegetative cover and are in drainage bottoms, primarily on north-facing slopes. The authors suggest that mitigation actions promote adjacent forest cover.
- The authors suggest various mitigation techniques, including, reduced night-time speed limits and vegetation management. Because of individual variation in crossing behavior and the presence of multiple crossing zones in some home ranges, more intensive investments in wildlife crossing structures may be warranted only in selected circumstances.
- The study's model output identifies the probability of lynx crossing 2-lane highway segments across the West Slope, and the results were also extrapolated to I-70.
- Based on the results of this study, the WSWPS should evaluate traffic volumes by time of day. Nighttime traffic volumes on highways in western Colorado decrease to <200 vehicles/hour and were generally less than 5% of peak early-afternoon volumes (200-400 vehicles/hr; (CDOT OTIS traffic data, 2014).
- Anecdotal observations of lynx crossing I-70 at East Vail Pass indicate that lynx crossed along natural drainages under eastbound span bridges at night, particularly during low traffic periods.

2.2 Follow-up:

- Obtain GIS data layer of prioritized lynx highway crossing segments from authors.

Johnson, H. E., J. R. Sushinsky, A. Holland, E. J. Bergman, T. Balzer, J. Garner, and S. E. Reed. 2016. Increases in residential and energy development are associated with reductions in recruitment for a large ungulate. Global Change Biology. DOI: 10.11.1111/gcb.13385.

2.3 Location: Colorado, west of I-25

2.3.1 Summary:

This study seeks to quantify the impacts of land-use change on large ungulate population dynamics in the context of high rates of human population growth and oil and gas development. The authors used 10 years (1980-2010) of broad-scale spatiotemporal data to investigate temporal patterns of land-use change with the demographic performance across multiple mule deer populations. The authors also considered weather variables (temperatures and precipitation) known to influence maternal condition and juvenile survival to compare the impacts of these weather variables relative to the influence of land-use changes.

Over the course of the study period, the amount of deer habitat affected by energy and residential development increased significantly over time at all spatial scales, with winter ranges experiencing the greatest impacts. The authors found that these increases in residential and energy development in deer habitat were correlated with declining recruitment rates, particularly within seasonal winter ranges. Residential development had two times the magnitude of effect of other factors, while energy and weather variables had similar effects. However, because the analysis was based on long-term, coarse observational data, these correlations between recruitment and habitat conditions do not determine causation. Nor were the authors able to identify effects of different types of residential or energy development or levels of disturbances on recruitment.

The authors speculate that habitat loss and fragmentation associated with development likely reduces the carrying capacity of the landscape, and may result in alterations to established migration routes at increased energetic costs. Increases in wildlife-vehicle collisions, harvesting, poaching and accidents are also associated with increased development and may also play a role in declining deer populations. The specific mechanisms responsible for the association of residential and energy development with declining fawn survival are unknown. The authors conclude that further habitat loss, unfavorable climate conditions, and managed high male ratios add to the challenges for maintaining deer recruitment rates in the future.

2.3.2 Relevance to WSWPS:

- The study area encompasses the WSWPS study area and its findings are directly relevant to declining deer populations on the West Slope.
- While not specifically analyzed in this study, roads are associated with both residential and energy development and are a major component of habitat fragmentation due to land-use change.
- The study's findings support the hypothesis that adequate, high-quality winter range is the primary factor limiting mule deer in Colorado, i.e., land-use changes on winter ranges were more strongly correlated with declining recruitment than changes on summer ranges.
- By 2010, 31% of winter ranges were affected by residential development and 24% were affected by energy development. Notably, these impacts were not evenly distributed across the study area. For WSWPS, the research team should consider analyzing impacts by deer analysis units.

- The impacts of residential development are most relevant on private lands and may increase over time as human populations and housing densities increase.
- Energy development occurs primarily on public lands, and these impacts may ultimately decline over time as new drilling and infrastructure construction wanes.
- The authors note that further increases in these types of development are not compatible with the goal of highly productive deer populations, and if healthy mule deer populations are going to be maintained, conservation practitioners, policy makers, and land-use planners will need to work together to ensure that deer habitat and winter ranges are well preserved.

Lendrum, P. E., C. R. Anderson, Jr., R. A. Long, J. G. Kie, and R. T. Bowyer. 2012. Habitat selection by mule deer during migration: effects of landscape structure and natural-gas development. Ecosphere 3(9):82. http://dx.doi.org/10.1890/ES12-00165.1

2.4 Location: Northwestern Colorado

2.4.1 Summary:

This study used resource-selection functions to determine if the presence of natural-gas development altered patterns of resource selection by migrating mule deer. They compared spring migration routes of adult female mule deer fitted with GPS collars (n = 167) among four study areas that had varying degrees of natural-gas development from 2008 to 2010 in the Piceance Basin of northwest Colorado, USA. The Piceance Basin supports one of the largest populations of migratory mule deer in North America, estimated at 21,000 to 27,000 animals. This region also includes one of the largest natural-gas reserves in North America, with projections of energy development throughout northwestern Colorado over the next 20 years to increase from approximately 500 to 15,000 wells. Within the Piceance Basin, levels of natural-gas development varied markedly. **North Ridge** (low development) contained no development on either winter or summer range; however, the transition between those ranges included increased levels of human activity from vehicle traffic and housing infrastructure because of proximity to the town of Meeker, Colorado. **North Magnolia** (medium-low development) exhibited a low density of active well pads on winter range (0.05 pads/km^2) and along migration paths (0.17 pads/km^2), and no active well pads on summer range, although deer crossed one major highway with scattered ranch holdings along their migration path. **Ryan Gulch** (medium-high development) exhibited moderate development on winter range (0.37 pads/km^2), and throughout the transition range (1.54 pads/km^2), with a decreased density of development on summer range as deer spread across the landscape (0.06 pads/km^2). **South Magnolia** (high development) had the highest level of development activity on winter range (0.70 pads/km^2), and along migration corridors (1.99 pads/km^2), with low levels of development on summer range (0.04 pads/km^2).

Patterns of resource selection and movement differed between deer that migrated through areas of highest well-pad density and those that migrated through the least-developed areas. Patterns of behavior exhibited by deer that migrated through the sites of intermediate development did not differ from those of deer that migrated through either the highly developed or the least-developed study areas. Consequently, the authors hypothesized that mule deer may exhibit a threshold response to natural-gas development in which behavior is altered only after a relatively high degree of development occurs on the landscape.

The authors did note that a study in Wyoming found that mule deer changes in habitat selection appeared to be immediate, with no evidence of well-pad acclimation occurring over the 3 years during which their study took place. Furthermore, mule deer in the Wyoming study selected areas further from well pads as development progressed, which is the opposite of what this study found. However, it should be noted that the Pinedale Anticline in Wyoming is a very different landscape than the Piceance Basin. Deer do not have concealment cover on the Anticline because of wide open, flat, sagebrush winter range versus the topographic and vegetative diverse conditions present in the Piceance Basin, and these conditions may have minimized deer behavioral responses as development progressed.

Mule deer selected for moderate slopes with less-rugged terrain, but avoided south-facing slopes, across development levels. Although other studies have noted migration routes often include stopover sites in the Piceance Basin migration was rapid and traditional stopovers did not occur. The authors felt that perhaps such fidelity and the rapid rate at which migrations occurred in the Piceance Basin (median spring migration periods = 3-8 days), overrode the behavioral response to avoid anthropogenic disturbances. Mule deer migrating through the most developed area had longer step lengths (straight-line distance between successive GPS locations) compared with deer in less developed areas. The difference in habitat selection observed in this study between development levels also could have resulted from the long, continuous forest stands along migration corridors in the least-developed areas, which contrasted with the most-developed areas, where a patch-work mosaic of forest stands resulted in pinyon-juniper being the more accessible cover type. Additionally, deer migrating through the most developed study areas tended to select for habitat types that provided greater amounts of concealment cover, whereas deer from the least developed areas tended to select habitats that increased access to forage and cover. Deer selected habitats closer to well pads and avoided roads in all instances except along the most highly developed migratory routes, where road densities may have been too high for deer to avoid roads without deviating substantially from established migration routes. Finally, the authors noted several studies documenting interspecific competition with North American elk also might explain behavioral responses of mule deer during migration. These studies documented that mule deer demonstrate strong avoidance of elk and elk occur in large herds throughout the Piceance Basin. In addition, elk tend to avoid roads and other human activities. If mule deer are displaced because of interference or exploitatiive competition, mule deer would be expected to distribute themselves into lower-quality habitats, which might result in deer using areas closer to roads to avoid elk. These results indicate that behavioral tendencies toward avoidance of anthropogenic disturbance can be overridden during migration by the strong fidelity ungulates demonstrate towards migration routes. If avoidance is feasible, then deer may select areas further from development, whereas in highly developed areas, deer may simply increase their rate of travel along established migration routes.

2.4.2 Relevance to WSWPS

- This recent study used empirically-derived data to document mule deer resource selection in the Piceance Basin which lies within the WSWPS area.
- This study could serve as a huge data source for the WSWPS specific to one of the largest migrating herds of mule deer in North America, let alone northwestern Colorado.
- This study documents behavioral response of four mule deer herds in the Piceance Basin, to roads as well as gas and oil development, which is a component of the WSWPS.
- The WSWPS will have to consider not only "road effect" zones impact on mule deer resource selection but also interspecific competition with species such as elk when modeling existing and future habitat data and wildlife vehicle collision zones.
- This study demonstrates that mule deer fidelity to known migration routes is so strong that it can override avoidance of anthropogenic disturbances on the landscape to a point. This indicate there may be thresholds which, when exceeded, the long-term viability of a migratory mule deer population could likely decline or eventually cease to exist.

2.5 Follow-up:

- WSWPS research team will continue to seek permission to use some form of data sharing from this study with Colorado Parks and Wildlife (CPW) Charles Anderson.
- Request population-level migration routes and proportional level of use datasets from authors to identify highway crossing zones over SR 64 and SR 13 around Meeker.

Sawyer, H. and R. Nielson. 2014. Rosa mule deer study, Phase I (2011-2013) Progress Report. Report to the Bureau of Land Management, New Mexico Department of Game and Fish, and WPX Energy Production, LLC. Farmington, NM. 25 pp.

2.6 Location: Northern New Mexico, southwest Colorado

2.6.1 Summary:

This research study was designed to assess the impacts of proposed winter drilling in the Bureau of Land Management's Rosa Unit in northwest New Mexico. In Phase I, the researchers collected GPS points from 50 collared mule deer over two years/three winters, and used Brownian bridge movement models to estimate individual and population-level migration between the herd's winter range in New Mexico and summer range in the mountains of southwest Colorado around Pagosa Springs. Specifically, this study identified habitat selection patterns in winter range influenced by oil and gas development, individual and population-level migration routes including level of use patterns among different migration routes, and stopover sites where deer spend more than 90% of their time during migration. Stopovers are important to migratory mule deer because they allow animals to maximize energy intake by migrating in concert with plant phenology.

Migration routes extended 45 to 60 miles from the Rosa Unit northeast into the San Juan Mountains of Colorado. Stopover habitat was nearly contiguous from the Rosa Unit north to the New Mexico Colorado state line, but became more isolated as deer neared their summer ranges in the San Juan Mountains of Colorado. Two to three major routes were identified that most animals used to move from winter to summer range. Throughout the study, spring migration began in late April lasting 21 days on average, and the fall migration started in mid-October, lasting 14 days. In general, deer selected winter range at moderate elevations with low slopes, abundant sage brush, and moderate distances from well pads. High and moderate-use migration routes as well as stopovers may be prioritized as areas for conservation action.

2.6.2 Relevance to WSWPS:

- The high-use route extended approximately 20 miles from the Rosa Unit up the San Juan River, near Montezuma Mesa. Several other high-use route segments were located on various branches of the population-level route, including: 1) the Eightmile Mesa area east of the San Juan River and upstream from the confluence with the Rio Blanco, 2) the Montezuma Mesa area north to Trujillo Canyon and lower Valle Seco, and 3) an area just west of the Navajo river, near La Huida and Barrella Canyons. The moderate-use routes extended approximately 35 miles from the Rosa, before they splintered into other, less-traveled routes near summer range.
- Winter habitat characteristics identified by this study may help inform mule deer winter range habitat use in the WSWPS study area, particularly in areas similarly influenced by energy development although, notably, no winter habitat in this study was more than 750 meters from a well pad and the mean distance was 210 meters.

2.7 Follow-up:

- Request population-level migration routes, stopover sites and proportional level of use datasets from authors to identify highway crossing zones over US 84 and US 160 around Pagosa Springs.
- Ask authors whether fall migration routes followed the same paths as the spring migrations.

3.0 TOPIC: BENEFIT-COST ANALYSES

The research studies reviewed in this topic area will help to inform the development of a benefit-cost analysis process for CDOT wildlife mitigation projects.

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, SD.

3.1 Location: South Dakota

3.1.1 Summary:

For the purposes of the WSWPS study, the literature review focuses on the report's methods for calculating benefit-cost analyses of wildlife mitigation measures.

Wildlife-vehicle collisions (WVC) are a safety and financial concern for motorists, as well as an ecological problem for wildlife populations. An assessment of the monetary and ecological costs of WVC can be helpful in framing the extent of the WVC problem in the state. South Dakota uses the U.S. Department of Transportation values as the base for costs of each crash type (human fatality, injury, and property damage only). These costs include medical bills, vehicle repair and towing, loss of income, crash clean-up and other factors. Based on these costs, this study calculated that reported WVC crashes in South Dakota cost the public an average of $107.9 million each year.

Notably, this calculation of WVC crash costs does not include the value of wildlife to society. Nor does it consider that reported WVC crashes are a fraction of the actual number of WVC. Estimates from other locations found from 5.6 carcasses (Utah) to 9.7 white-tailed deer (Virginia) for every reported WVC crash. The authors sought to address these gaps by: 1) deriving an estimate of the total number of wildlife killed by WVC using the correction value of 5.26 from the Utah study (Olson et al. 2014), and 2) incorporating the monetary value of ungulates, as set by the state legislature when the state is prosecuting poaching cases. As 95% of insurance claims for WVC are with deer, for calculating benefit-cost, the authors assumed that all WVC are with deer and that 5% of the total killed in WVC were trophy deer. Because WVC also involve elk and bighorn sheep, which are valued more highly, it is likely that this method produces a conservative estimate of the lost value of wildlife due to WVC.

The authors propose the following steps for conducting a benefit-cost analysis of WVC mitigation:

1. Estimate costs of WVC from WVC crash data.
2. stimate cost of WVC on wildlife populations estimated from WVC carcass data.
3. Estimate the percentage decrease in WVC crashes that the proposed mitigation is expected to provide (typically estimated at 75% for benefit-cost analyses).
4. Estimate the life span of the mitigation (e.g., 50 years or more for bridges and culverts; shorter for wildlife fencing).
5. Estimate cost savings over life of mitigation, in terms of WVC prevented.
6. Estimate the costs of the mitigation plus its maintenance over time (i.e., added cost of wildlife mitigation, or cost of stand-alone project).
7. Input values into a benefit-cost equation to find the value of the project and calculate the cost-benefit ratio. If the ratio is 1 or greater, the project is predicted to pay for itself.
8. Determine how long it will take for the mitigation project to pay for itself.

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 14(2): 15.

3.2 Location: United States and Canada

3.2.1 Summary:

In this research paper, the authors compare the monetary costs and benefits of a range of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada. All costs and benefits were based in real terms (e.g. constant 2007 US dollars). The authors excluded inflationary effects in their benefit-cost streams over time and they used real (as opposed to nominal) discount rates. Presenting the analysis in nominal terms with inflation included in future values and an inflation component in the discount term were felt to be mathematically equivalent. In order to correctly compare benefit and cost elements, which are distributed asymmetrically over time, the authors computed present discounted values and amortized these into equivalent annual terms. The typical pattern for the mitigation measures examined in this research was that costs were largely construction oriented in the present (e.g., an investment in a fence with an underpass in the first year of a 75-year period) whereas benefits are distributed more uniformly over the life of the project (i.e., a certain reduction in collisions and associated costs each year). In this situation, the cost-benefit analysis is sensitive to the discount rate chosen. The discount rate simply corrects for the time value of money.

For this research the authors used the guidance provided in the U.S. Office of Management and Budget (OMB) Circular A-94 (U.S. OMB 1992) and other federal guidelines (U.S. Environmental

Protection Agency 2000), to conduct the analyses for real discount rates of 7%, 3%, and 1%. The 7% rate is required by OMB for federal benefit–cost analyses and is based on a shadow price of capital theory. Specifically, (at least in 1992) 7% is OMB's estimate of the real after-tax return on investment in the private sector (essentially the opportunity cost of instead investing in public projects). However, the authors felt that a more widely accepted discount parameter for at least intra-generational accounting was choosing a social discount rate based upon the rate at which individuals translate consumption through time with reasonable certainty (e.g., a consumption rate of interest theory). For this, historical returns on safe assets such as U.S. Treasury securities are used (post-tax and corrected for inflation), with empirical estimates for rates in the 1% to 3% range (U.S. Environmental Protection Agency, 2000).

The authors calculated the costs associated with the average deer-, elk-, and moose-vehicle collision, including vehicle repair costs, human injuries and fatalities, towing, accident attendance and investigation, monetary value to hunters of the animal killed in the collision and the cost of disposal of the animal carcass. The benefits are a combination of the effectiveness of the mitigation measures in reducing collisions with large ungulates and the costs associated with the average collision. They also reviewed the effectiveness and costs of 13 types of mitigation measures for reducing collisions with large ungulates, and conducted a cost-benefit analysis to calculate the number of collisions per kilometer per year needed for a mitigation measure to start generating economic benefits in excess of costs. These dollar-value thresholds were translated into break-even points for deer-elk-, and moose–vehicle collisions per kilometer-per-year. If a road section has costs or wildlife–vehicle collision numbers that exceed these threshold values, then the benefits of that mitigation measure exceed the costs over a 75-year time period (measured in 2007 US$). When comparing the costs per kilometer per year to the threshold values given in paper, please note that these threshold values were based on a divided four-lane road, and that two-lane roads have lower threshold values for some of the mitigation measures (e.g., those that include under- or overpasses).
Relevance to WSWPS:

- Benefit-cost model presented in this paper can be useful in working with CDOT to discuss and analyze appropriate formulation for benefit-cost analysis relative to implementation of wildlife mitigation measures in Colorado.
- Species considered in the research paper include several of the species the WSWPS will be taking into consideration.
- Tailoring a benefit-cost formula specific to Colorado could produce a decision-support tool for CDOT and natural resource agencies when deciding on the prioritization of mitigation measures to reduce ungulate–vehicle collisions.

- Mitigation options considered during cost analysis are appropriate for consideration in the WSWPS, although the costs will need to be updated.

3.3 Follow-up:

- Work with CDOT Traffic Safety Engineers regarding current CDOT benefit-cost formula relative to wildlife vehicle collisions (WVC's), WVC costs, wildlife valuations and cost-benefit lifespan of mitigation within formula.

4.0 TOPIC: MITIGATION TECHNIQUES AND BEST MANAGEMENT PRACTICES

As many mitigation documents are very broad, the research team determined these documents would be more useful as reference documents for the WSWPS, rather than being included in the literature review. The exception is the following study was conducted in Northwest Colorado, which is reviewed below.

Harrington, J. L. and M. R. Conover. 2006. Characteristics of ungulate behavior and mortality associated with wire fences. Wildlife Society Bulletin 34(5):1295-1305.

4.1 Location: Northwestern Colorado and Northeastern Utah

4.1.1 Summary:

This study was designed to assess characteristics of ungulate mortality from fences and fence crossing behavior in juvenile and adult elk, mule deer, and pronghorn associated with a variety of fence types found in wildlife habitat. The authors objectives were to determine 1) how frequently mule deer, pronghorn, and elk are killed by wire fences, 2) what characteristics increase lethality of wire fences to these ungulate species, 3) how species differ in their fence-crossing behavior, and 4) where ungulates are most likely to be killed by fences.

Research was conducted on 1850 sq/km^2 in northwestern Colorado and 200 sq/km^2 in northeastern Utah. Survey areas in Colorado were concentrated in Rio Blanco and Moffitt Counties. This large survey area allowed researchers to define fence mortalities over a broad landscape and a variety of wire fence types, in that they surveyed 621 km of roadway and 1046 km of fence along roadway right-of-way, public lands, and private agricultural land.

The authors of this study estimated an average annual mortality occurrence of 0.25 mortalities/km for the wire fences studied (0.08 mule deer mortalities/km, 0.11 pronghorn mortalities/km, and 0.06 elk mortalities/km) or 0.5 mortalities/km of road. This is roughly equivalent to 1 ungulate mortality per 2.4 miles of fence or 1 mortality per 1.2 mile of roadway. The highest wire fence-mortality rates in the study area occurred during August, which coincided with weaning of fawns. A second peak mortality rate occurred in January likely associated with snow depth and energy expenditure per jump attempt. Mule deer and pronghorn jumped fences in 81% of observed crossings. The authors did note that the observed rate of pronghorn jumping fences was higher in this study than most previous studies. When all species were combined, more adults (98%) jumped fences than juveniles. Mortalities were largely caused by animals getting caught between the top two wires. Mule deer experienced higher fence-mortality rates than elk or pronghorn because they crossed fences more frequently, had higher density in the study area and spent more time in road rights-of-way than the other species. Juveniles were 8 times more likely to die in fences than adults. Juveniles made up 79%, 58% and 80% of all mule deer, pronghorn and elk mortalities respectively. Woven-wire fences topped with a single strand of barbed wire were more lethal to ungulates than woven wire with two strands of barbed wire above it or four-strand barbed-wire fences. There was a direct relationship between the frequency of fence mortalities and ungulate abundance. Traffic volumes were inversely related to fence-mortality frequencies and ungulate densities along the right-of-way. Higher traffic volume roadways had less ungulates along the right of way whereas lower volume dirt roads had higher ungulate densities. The authors also found 1.3 ungulate carcasses/km <10m from a fence but not attached to it. In addition, they found higher rates of fence mortalities within 200m of water sources and where they frequently observed ungulates crossing fences.

Implications from this study recommend mitigation should begin in areas where fence mortalities are highest. These are:

1. in summer ranges where juveniles are concentrated (limit woven wire, implement forms of wildlife friendly fencing).
2. in areas with known high densities of ungulates.
3. near watering sources.
4. known ungulate fence crossing locations.
5. consider wildlife friendly fencing along known roads with low traffic volumes and higher ungulate densities. This could allow wildlife to escape the roadway and right of way quicker with less difficulty getting through fence.

4.1.2 Relevance to WSWPS:

- Majority of study is in Rio Blanco and Moffitt Counties in northwestern Colorado
- Two of the three ungulate species studied are to be addressed in the WSWPS
- Habitat connectivity can be addressed in some instances in other ways than wildlife crossing structures and wildlife exclusion fencing
- Fence types should be looked at when reviewing priority areas selected for field reviews in the WSWPS.
- CDOT and CPW can use findings from this study to educate and inform private land owners and right of way agents about wildlife friendly fencing recommendations.
- Study can educate and inform CDOT biologists in ways to prioritize wildlife-friendly fencing recommendations along upcoming or future CDOT projects.

Cramer, P. and R. Hamlin. 2017. Evaluation of wildlife crossing structures on US 93 in

Montana's Bitterroot Valley. Report No FHWA/MT-17-003/8194. Montana Department of Transportation. Helena, MT. 74 pp.

4.2 Location: Montana, USA

4.2.1 Summary:

Long-term monitoring of crossing structures under US 93 was conducted to evaluate wildlife activity and road-crossing movement pre- and post-construction following a highway widening and wildlife mitigation construction project. In this report, the authors evaluate white-tailed deer (WTD) use of crossing structures; the relationships between WTD use of crossing structures and explanatory variables; and relationships between wildlife-vehicle collisions (WVC) and wildlife crossing structures; and, finally, provide recommendations for future mitigation projects, monitoring and adaptive management. Camera monitoring was conducted using a Before-After-Control-Impact study design. Statistical analyses were used to assess the influence of explanatory variables on WTD use of the crossing structures, including structure characteristics and environmental factors.

In addition, WVC crash rates at pre-construction wildlife crossing and control sites were compared to WVC crash rates post-construction. The researchers found that wildlife crossing structures had no statistically significant effect on WVC crash rates; instead, they suggest that WVC crash rates in this study are primarily related to changes in WTD abundance.

4.2.2 Relevance to WSWPS:

The findings of this study may have applicability to wildlife mitigation design and monitoring projects in Colorado:

- Pre- and post-construction monitoring is recommended using a BACI study design to tease out the influence of different variables over space and time, providing a more robust evaluation of mitigation effectiveness.
- WTD success rates and successes per camera day were higher for bridges than for culverts. Success rate increased with increasing width, openness, guardrail length and shrub cover, and decreased with increasing structure length. Width was determined to be the most important structure dimension affecting success rates, and the authors recommend that this dimension be maximized in any situation.
- Rate of repellency decreased with increasing height, width, openness and shrub cover. However, structure height above a minimum threshold had no influence on success rate for WTD.
- The rate of parallel movements decreased with increased structure width and openness; parallel rage increase with increasing structure length. However, the authors note that there are exceptions to the norm, as was found with one particularly long culvert in the study area.

- Consistent with what was found on US 93 North (Huijser et al 2016 the researchers found little evidence that fence length affected wildlife crossing structure use by WTD; however, extended fence segments may have an effect on reducing WVC rates near crossing structures.
- The authors confirm previous findings that wildlife crossing structures in a suburban-wildland setting are used by a variety of wildlife, despite close proximity to human activity.

Huijser, M. P., W. Camel-Means, E. R. Fairbank, J. P. Purdum, T. D. H. Allen, A. R. Hardy, J. Graham, J. S. Begley, P. Basting, and D. Becker. 2016. US 93 North post-construction wildlife-vehicle collision and wildlife crossing monitoring on the Flathead Indian Reservation between Evaro and Polson, Montana.

4.3 Location: Montana, USA

4.3.1 Summary:

Long-term monitoring was conducted to evaluate the effectiveness of highway mitigation measures in reducing wildlife-vehicle collisions (WVC) and providing habitat connectivity for wildlife across 56 miles of US 93 through the Flathead Indian Reservation, including 39 wildlife crossing structures (one wildlife overpass) and 8.7 miles of wildlife exclusion fencing. The researchers used a Before-After-Control-Impact study design to evaluate the effectiveness of the mitigation in reducing WVC in a manner that addresses the potential influence of other factors in both time and space. Monitoring methods include camera traps, sand tracking beds, and WVC crash and carcass data analysis.

Of the total 56-mile long transportation corridor between Evaro and Polson where highway improvements were made, only 17% received wildlife mitigation treatments. The mitigation measures implemented in the three main study areas (Evaro, Ravalli Curves and Ravalli Hill) substantially reduced WVCs (71.4% reduction in MDT Maintenance carcass reports; 80% reduction in WVC accidents reported to law enforcement) when compared to unmitigated control segments. Where the highway was reconstructed, but no wildlife mitigation implemented, overall accidents decreased, except WVCs increased, likely due to wider lanes, higher traffic volumes, and no wildlife mitigation. The implementation of longer stretches of wildlife fencing was hindered by concerns about aesthetics, landowner concerns regarding wildlife guards, and DOT concerns about fence maintenance.

Mitigation was successful in meeting connectivity objectives for deer and black bear, the two primary large mammal species in the study area. The researchers also reported on the effectiveness of wildlife guards in keeping large fauna from accessing the fenced road corridor; wildlife jump-outs in allowing animals trapped inside the fenced road corridor to escape back to the habitat side; and a Y-shaped human access point through the fence. The authors conducted a cost-benefit analysis based almost exclusively on human safety parameters, though they acknowledge that the mitigations were installed also to address cultural and natural resource value.

4.3.2 Relevance to WSWPS:

The findings of this study may have applicability to wildlife mitigation design and monitoring projects in Colorado:

- The small number of documented elk and moose crossings occurred on the wildlife overpass 75% of the time, with 25% of crossings by these species through bridges or large culverts.
- White-tailed deer (WTD), mule deer and black bear use was high immediately after construction and continued to increase over five years, demonstrating high adaptability to new structures.
- The authors suggest that the length of the wildlife exclusion fencing associated with crossing structures did not influence use of crossing structures by large mammals, and that other variables are responsible for the variability in wildlife use of crossing structures. However, they continue to advise that for an individual crossing location, longer fence lengths (> 3.1 miles) are more likely to reduce WVCs by reducing fence-end effects. Very short segments of fencing (<0.4 miles) are unlikely to reduce WVCs.
- Wildlife guards effectively barred WTD and mule deer from entering the fenced right-of-way, however they proved permeable for other wildlife and are not recommended where mountain lion, bobcat or bears are the target species – for these species, electric mats may be a better alternative. Note, these guards are constructed with concrete ledges that facilitated wildlife breaches. The researchers observed deer falling through the metal grate on several occasions but could not determine whether animals were injured as a consequence of these falls.
- Wildlife jump-outs ranged from 6-7' in height. Use by WTD was very low (7%), suggesting the jump-out height may be too high for this species, while mule deer use was higher (32%).
- A human access point through the wildlife exclusion fencing was frequently breached by deer, allowing them to pass through the fence in both directions.
- This study found a fence end effect that extended up to 0.2 miles beyond the fence end into unfenced road sections. This finding suggests that other complementary mitigation (e.g., short-distance animal-detection system or targeted signage) may be beneficial to warn driver of the increased likelihood of WVC through these segments.
- The authors recommend considering the location of potential collision hotspots, the surrounding landscape and the sizes of the home ranges of the target species when designing mitigation measures and deciding where fences should start and end. Ideally,

fencing should include a 'buffer zone' on either side of a WVC hotspot, and extend longer than the radius of a target species' home range. Fence design ultimately depends on local topography and habitat.

- The authors recommend establishing a wildlife fence inspection and maintenance program to ensure the long-term functioning of the mitigation.
- BACI study design is recommended for teasing out the effectiveness of wildlife mitigations in space and time relative to the influence to other variables.
- Camera monitoring (vs. track beds) is advantageous for monitoring large fauna in that cameras record the time of crossing; have relatively fast response times and can capture behavior, are less labor intensive (do not need to be checked daily or near daily) and may be more accurate in detecting some species.

5.0 TOPIC: DECISION-SUPPORT TOOLS

The research summarized in this topic area discusses policies that aided in the development of systematic prioritization processes with weighted scoring and means of integrating these processes within respective transportation planning in Ontario, Canada and the state of Washington.

Carruthers, B., and K. Gunson. 2015. Development of a province-wide wildlife mitigation strategy for both large and small animals on Ontario's highways. Proceedings of the International Conference on Ecology and Transportation, Raleigh, NC.

5.1 Location: Ontario, Canada

5.1.1 Summary:

The main objective of the Wildlife Mitigation Strategy (WMS) is to integrate available data, expertise, and tools into a first-generation framework that will help define where road mitigation should be prioritized along Ontario's 19,000 km of highways for both large and small animals. Animals targeted include Species at Risk (SAR) turtles, snakes, small mammals, and birds that are protected under the Endangered Species Act (2007) as well as large animals, e.g. moose, deer, and black bears that pose a public safety risk. Other components of the WMS include evaluation of Wildlife Habitat Awareness (WHA) signs for turtles and snakes, a review of tools used for data collection and management, and public awareness strategies. These tools are detailed in this paper as:

1. Small Animal Mitigation Planning Tool (SAMPT)
2. Large Animal Mitigation Planning Tool (LAMPT)

The impetus for development of the Ontario Ministry of Transportation (MTO) Wildlife Mitigation Strategy was the Wildlife Habitat Awareness (WHA) sign policy developed by the MTO Traffic Office in partnership with the MTO Environmental Policy Office in consultation with the Ontario Ministry of Natural Resources, Forestry (MNRF) and the Ontario Road Ecology Group. The policy qualifies the placement of a sign with the following criteria:

1. The road must bisect habitat for an Endangered or Threatened SAR where road mortality is a threat;
2. The target species habitually cross the road, or have been documented as living next to the right of-way, based on monitoring surveys and field investigations.

MTO believes that implementation of wildlife mitigation is an added cost to road projects, and uncertainty exists about effectiveness and implementation, and thus feels it is critical that mitigation decisions be made based on sound strategy and data. Currently, MTO highway improvements are planned for and implemented based on engineering, safety and /or capacity issues and planning for wildlife is done on a project-by-project basis through the environmental assessment process. Project-by-project based mitigation is very costly and inefficient and can lead to mitigation that does not address the most critical needs for wildlife conservation and public safety.

Small Animal Mitigation Planning Tool (SAMPT):
SAMPT is a five step process that targets species at risk noted above in preceding paragraphs. The objective of SAMPT is to define hotspots along the provincial highway network that can be evaluated in a Geographic Information System (GIS) using best available data. The five steps are as follows:

1. Assemble observations of target species on roads
2. Correlate habitat predictors from FRI and SOLRIS layers using logistic regression models
3. Extrapolate to entire road network
4. Validate Model performance using Area Under Curve
5. Define a Hotspot: Two methods used to prioritize where mitigation was most needed using probability scores from predictive models. (Bonferroni Confidence Interval & Maximum Kappa Threshold statistic

Large Animal Mitigation Planning Tool (LAMPT):
LAMPT is an eight step process targeted towards White-tailed deer, Moose, Black Bear and Wolves. The objective is to define hotspots along the provincial highway network that can be evaluated in a GIS using best available data. The eight steps are as follows:

Step 1 - Identify unique identification for each LHRS key station	The first step was to obtain an understanding of the Ontario Ministry of Transportation (MTO) Linear Highway Referencing System (LHRS) that is used to geo-reference features on the provincial highway network. The LHRS uses a key reference listing or unique ID to reference stations at specific offset distances from landmarks along the highway network. Examples of landmarks are a highway intersection or bridge crossing.
Step 2 - Assemble and map the crash data	In the field, the Ontario Provincial Police measures the distance from a crash location to a referenced landmark. This distance is then transcribed by MTO to an offset value or distance measurement to the nearest hundredth decimal place from the reference landmark. The MTO then uses a special mapping tool to translate the key reference plus the offset value to latitude and longitude coordinates (decimal degrees) for mapping in a GIS.
Step 3 - Delineate hotspots	A cluster analysis was used to aggregate WVCs that were within

on provincial road network	500 m of each other. Each of these clusters were then defined as WVC hotspots along the road and varied in length from 1 km to 24 km.
Step 4 - Join road segment where no WVCs occurred	Line segments without WVCs, i.e. not defined as hotspots were joined to the hotspots to have a complete provincial road network.
Step 5	Relative Incidence of WVCs per km/year
Step 6 – Severity	From 2006-2009 there were 11 (2.75 per year) reported fatalities, 1,079 injuries, and 17,678 reported incidents of property damage associated with WVCs. For severity, a categorical metric, crashes were classified into property damage, injury and fatality.
Step 7 - Risk of WVC; WVC/AADTV (2010)	This metric is equivalent to the risk of a vehicle being involved in a WVC per hotspot. The Annual Average Daily Traffic Volume Data (AADTV) was obtained from the MTO Traffic Office for 2010 for highway segments defined by the LHRS. Jenks optimization method was used to classify the continuous values into Very Low, Low, Moderate, High and Very High. High values represent a high count of WVCs and low traffic volumes.
Step 8 - Percentage of all crash types that involve wildlife	This is important information because there may be a large number of WVCs on a highway segment relative to other crash types. In such cases the respective jurisdiction may focus safety budgets on highway maintenance and mitigation efforts that reduce these types of crashes. Equal intervals were used to classify these road segments into Very Low, Low, Moderate, High and Very High. The percentage of WVCs per hotspot ranged from 0.48 to 1 and the average percentage of WVCs was 63%.

At this point it is important to note the limitations of data used in this process, which were fairly substantial. For example, there is a five-year time lag, the study lacks species-specific information, and spatial errors may be as high as 2,154 meters ± 1,620 meters, according to a study that compared 26 paired WVC locations that were georeferenced into an Alberta Transportation geodetic system and also measured with a GPS. There is also under-reporting because crash locations need to be reported to the Ontario Provincial Police (OPP), and result in over $1,000 of damage; therefore crashes involving heavy commercial trucks would largely go unreported. The tool does not include any ecological measures such as connectivity or habitat models, therefore its applicability to prioritizing where connectivity mitigation measures such as underpasses and overpasses are required to reconnect habitat is limited. The tool is a first-generation framework that can inform where mitigation is required to reduce the rate of WVCs at hotspots. In addition the cluster analysis includes one WVC as a "cluster" because it is tied to other WVCs within 500 m.

5.1.2 Relevance to WSWPS:

- LAMPT considered similar species found in the WSWPS
- Steps 6-8 are features that could be integrated into the prioritization process for the WSWPS

McAllister, K. and M. Carey. 2011. Integrating habitat connectivity in WSDOT practices. Pages 87-93 in P. J. Wagner, D. Nelson, and E. Murray (eds.). Proceedings of the 2011 International Conference on Ecology and Transportation. Center for Transportation and the Environment, Raleigh, NC.

5.2 Location: Washington

5.2.1 Summary:

This conference paper discusses the steps the Washington Department of Transportation (WSDOT) has taken to better define its approach to deciding where to invest in wildlife-friendly infrastructure. The authors outline WSDOT processes for integrating habitat connectivity principals into the agency's policies, research, planning, best practices development and budgeting in a way that ensures that limited resources are directed toward the most important wildlife areas and most problematic wildlife-vehicle collision (WVC) areas.

Policies. Agency practices are supported by an Executive Order identifying environmental protection as a priority within the agency and that establishes principles and guidance to help synchronize activities across the agency. In addition, WSDOT's Highway System Plans acknowledge strong public support for, and an agency commitment to, ecologically-based transportation planning and projects; the need to apply scientific principles to the creation of more wildlife-friendly transportation systems; and emphasizes the importance of collecting road kill data to identify problem areas and measure the effectiveness of implemented mitigation measures.

Research. WDOT's research program has funded habitat connectivity research for over a decade. Myers et al. (2008) identified factors associated with concentrations of deer and elk carcass removals including: areas with high animal numbers; increasing traffic volume in rural areas; higher speed limits; and poor driving conditions in the fall and winter, during seasonal migrations and breeding season movements and when hunting activities influence animal movements. Wang et al. (2010) similarly found an increased risk of WVC on highways in rural areas and highways within white-tailed deer range. They found a reduced risk of WVC on highways with more traffic lanes, restrictive access control, higher truck traffic, and median widths over 2 m (6') wide.

In 2010, WSDOT and partners completed a statewide analysis of wildlife habitat connectivity to identify highway segments that bisect wildlife habitat or movement areas. The agency contributes to telemetry studies for species such as mountain lion and elk to gather specific information about habitat use and wildlife movements. The agency also funded research to develop a tool for assessing the permeability of existing bridges and culverts (Kintsch and Cramer 2011). This tool and ranking system helps WSDOT identify when (and how) an existing structure can be improved to facilitate wildlife movement and when a new wildlife passage is needed. WSDOT research projects are developed to support informed decision-making.

Integration. Habitat connectivity information is made available to planners and biologists via a GIS workbench that supports the integration of wildlife-friendly highway concepts into WSDOT operations. These GIS capabilities allow WSDOT staff to do initial assessments of any segment of the highway system to better understand its potential value to wildlife and the importance of considering improvements. In addition, WSDOT's Environmental Retrofit Program provides a funding allocation and defined criteria for addressing environmental problems associated with noise, stormwater runoff, fish passage barriers, chronic environmental deficiencies and barriers to terrestrial wildlife movements. Finally, WSDOT uses defined criteria to determine how highway construction projects and highway corridor plans address highway connectivity to identify the best opportunities and locations for investing in habitat connectivity. These criteria consider WVC carcasses and crash data, the statewide connectivity analysis, public lands, and the context of the project being evaluated.

The authors provide two flow charts for determining how to address habitat connectivity during the evaluation of highway construction projects and corridor plans, and for determining which best practices are appropriate for highways with different traffic volumes.

Citations:

Kintsch, J. and P. Cramer. 2011. Permeability of Existing Structures for Wildlife: Developing a Passage Assessment System. Research Rept. WA State Dept. of Transportation. 66pp.

Myers, W.L., W.Y. Chang, S.S. Germaine, W.M. Vander Haegen, and T.E. Owens. 2008. An analysis of deer and elk- vehicle collision sites along state highways in Washington State. Completion Report, Washington Department of Fish and Wildlife. Olympia, WA 40pp.

Wang, Y., Y. Lao, Y. Wu, and J. Corey. 2010. Identifying High Risk Locations of Animal-Vehicle Collisions on Washington State Highways. Completion Report, University of Washington, Department of Civil and Environmental Engineering. Seattle, WA 93pp.

5.2.2 Relevance to WSWPS:

- The WSWPS can learn from WSDOT policies, research, and integration practices in the development of a decision support process. This would allow CDOT and its partners to determine where to pursue wildlife mitigation and which strategies work best under which circumstances.

5.3 Follow-up:

- Interview lead author regarding the GIS workbench and other decision-support mechanisms that facilitate the integration of wildlife-friendly highway concepts into transportation planning, budgeting and projects.

6.0 Other References for the WSWPS

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APPENDIX B: Interviewees

Appendix B
Interview Participants

Name	Affiliation
Eric Bergman	CPW
Tony Brindisi	CDOT Traffic and Safety
Tim Cramer	Idaho Transportation Department
Oana (Deselnicu) Ford	CDOT Economist
Krista Hiener	CPW Policy & Planning
Jon Holst	CPW Southwest Region
Scott Jackson	USDA Forest Service
Aran Johnson	Southern Ute Tribe
Heather Johnson	CPW Southwest Region
Michael King	CDOT Planning
Katie Lanter	CPW Policy & Planning
Mark Lawler	CDOT Region 5
Cinnamon Levi-Flinn	CDOT Region 3
Kelly McAllister	Washington Department of Transportation
Jeff Peterson	CDOT Environmental Programs Branch
David Reeves	CDOT Applied Research and Innovation Branch
Dean Riggs	CPW Northwest Region
Mark Rogers	CDOT Region 3
Erik Sabina	CDOT Information Management Branch
Hall Sawyer	West, Inc.
Michelle Scheuerman	CDOT Statewide Planning Section
Bill Semmens	Montana Department of Transportation
David Swenka	CDOT Traffic and Safety
Mike Vanderhoof	CDOT Region 3
Rodney van der Ree	University of Melbourne
Casey Visintin	University of Melbourne
Aaron Willis	CDOT Statewide Planning Section
Mark Watson	NM Department of Game and Fish
Wayne Kasworm	U.S. Fish and Wildlife Service

APPENDIX C: Data Synthesis and Sources

WSWPS Data Used

Wildlife Movement/Space Use Data (CSP)									
Species	*Data Type*	*Extent*	*Resolution*	*Data Source*	*Dataset Link*	*Contact*	*Expected Uses*	*Status*	*Notes*
Mule deer	GPS relocations - home range			CPW			Parameterize RSFs, verify/validate landscape permeability models		
Mule deer	GPS relocations - migratory			CPW			Parameterize RSFs, verify/validate seasonal migration corridor models		
Mule deer	GPS relocations - home range			Sawyer et al.		Hall Sawyer	Parameterize RSFs, verify/validate landscape permeability models		
Mule deer	GPS relocations - migratory			Sawyer et al.		Hall Sawyer	Parameterize RSFs, verify/validate seasonal migration corridor models		
Mule deer	Summer/winter range polygons			CPW			Nodes for modeling seasonal migration corridors		
Mule deer	DAU boundaries & herd size estimates (2016)			CPW		Andy Holland	Estimation and mapping of wildlife criteria		
Elk	GPS relocations - home range			CPW			Parameterize RSFs, verify/validate landscape permeability models		
Elk	GPS relocations - 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 Holland	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 generate models)		

Wildlife Habitat Data (CSP)									
Attribute	*Data Type*	*Extent*	*Resolution*	*Data Source*	*Dataset Link*	*Contact*	*Expected Uses*	*Status*	*Notes*
SAM habitat layers	Existing species habitat layers			CPW					
Land cover	Gridded land cover type		30m	NLCD (USGS)			RSF model variables (percent cover type, forest edge distance, etc.)		
Topography	Digital elevation model		30m	LandFire Topographic			RSF model variables (elevation, slope, aspect, ruggedness, TPI)		
Water sources	Point sources, stream lines, and water body polygons			NHD+			RSF model variables (distance to water)		
Well pads	Point locations of well pads			CDOT Study			RSF model variable (distance to nearest well)		
Roads	Road network polylines			CDOT			RSF model variable (density/distance to roads)		

Collision Risk Data (Jacobs GIS)									
Attribute	*Data Type*	*Extent*	*Resolution*	*Data Source*	*Dataset Link*	*Contact*	*Expected Uses*	*Status*	*Notes*
Animal-vehicle collisions	Collision point locations			CDOT			Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		
Animal-vehicle collisions	Collision point locations			CPW			Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		
Animal-vehicle collisions	Collision point locations			CO State Patrol			Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		
Animal carcass data	Wildlife carcass point locations			CDOT			Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		
Animal carcass data	Wildlife carcass point locations			CPW			Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		
WVC Pattern Recognition	Shapefile with elevated WVC			CDOT Traffic and Safety Branch		D.Swenka	Identify collision risk hotspots, cost-benefit analysis, validate connectivity models		

Current/Projected Human Infrastructure Data (CSP)									
Attribute	*Data Type*	*Extent*	*Resolution*	*Data Source*	*Dataset Link*	*Contact*	*Expected Uses*	*Status*	*Notes*
Roads	Road network polylines			CDOT			Reference/alignment		
Mileposts	Milepost point locations/identifiers			CDOT			Reference/alignment		
Number of lanes, surface type,	Attribute data for road network			CDOT			Circuitscape resistance surface		
Current annual traffic	Traffic volume road attribute			CDOT			Circuitscape resistance surface		
Future annual traffic	Projected traffic volume (2040)			CDOT DTD E. Sabina			Circuitscape resistance surface		
Highway fencing	Fenced road section line polylines			CDOT			Circuitscape resistance surface and/or contextual		
Crossing structures	Point locations of bridges, underpasses, overpasses, etc.			CDOT			Circuitscape resistance surface and/or contextual		
Current/future land use	Current & projected (2040) housing density			ICLUS/SERGoM			Circuitscape resistance surface (projected)		
Energy Corridors - Basins	Energy basin polygons and key energy corridors			COGCC			Criterion for potential energy development impacts		
Protected areas	Protected area polygons status/ownership			PADUS			Criterion for status of road-adjacent lands		
Lakes, Streams, Rail Lines	Lake polygons, stream lines and rail lines			CDOT OTIS			Mapping Priority Segments showing natural and built features		

APPENDIX D: Pre-Analysis Methods

- **Road Segmentation Process**
- **Seasonal Analysis of WVC Carcass Data**
- **WVC Accident Cluster Analyses**
- **Brownian Bridge Movement Model Maps**

Data Processing Overview

Baseline modeling data was derived from the Highway_Traffic feature class provided by the CDOT DTD Information Management branch. This dataset covers road segments within all CDOT regions and was reduced to just include roadways within Regions 3 and 5. The original feature class contains traffic volume counts and other attributes identified as being important in the wildlife vehicle collision modeling process.

Road Segment Determination

The road segments were divided into smaller segments using mile marker points provided by CDOT. The points were provided in the Milepoints_Tenths shapefile and the 0.5 mile and 1 mile marker points were extracted from the source shapefile.

The mile marker points did not align perfectly with the road segments and were snapped to the road polyline edges using the Snap tool in ArcGIS Toolbox. The realigned points were then used to create smaller segments in the road segment layer using the Split Line at Point tool in ArcGIS Toolbox. The goal was to create road segments as close to 0.5 mile as possible while maintaining the integrity of the traffic volume data contained in the original data set. The re-segmented road data set contains 7331 features where 6971 features are between 0.23 and 0.63 mile in length, or 95%. Many of the segments that are smaller than 0.23 mile result from the remainders of the original segments after being re-segmented. Segments were merged with adjacent segment(s) to achieve the desired length but only if they originated from the original CDOT defined segment. This was done to maintain the original traffic volume and speed attributes. Any segments longer than 0.9 mile were split by half, if possible, to achieve the desired lengths. Each final segment was then assigned a unique identifier (SegmentID) by combining the Route Name and the ObjectID.

Association of Collision and Carcass Data to Road Segments

Wildlife Vehicle Collision (WVC) and wildlife carcass data sets were provided by CDOT for use in the modeling process. The data used in the process spans the 10 years between 2006 and 2015 and focuses on Deer, Elk, Moose, and Antelope. The GIS data points provided did not align perfectly with the road segments and were snapped to the road polyline edges using the Snap tool in ArcGIS Toolbox. The points that remained outside of the 1000 foot radius were then reviewed to see if a correct position could be determined. Of the 16,724 WVC reports, 16,639 (99.4%) were associated with 3,962 road segments. A one-to-one spatial join was performed to associate the closest road segment with each point. The road segment name was then added to the WVC point data as an attribute.

The carcass points, based on maintenance records, were run through a similar process. The carcass data contained 284 records that did not contain a spatial location. In reviewing these records with Pat Basting, we decided that the records appeared suspect and that the records would not be included in the analysis. They were removed from the count, leaving a total carcass count of 24,361 associated with the same with 3,970 road segments with the segment name added to the points as an attribute.

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. In order to identify and remove maintenance carcasses that are duplicates of the WVC accident reports, the two datasets 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. One potential problem became evident during this process, the carcasses appear to be entered in batches with the event date being the data entry date, not the date the maintenance department picked up the animal. To reduce false duplicates (type I error) each potential match for duplicates were also reviewed for the milepost at which the WVC and carcass was reported. Any carcass identified as a potential duplicate within 1/3 mile of the WVC point was considered a duplicate, between 1/3 and 2/3 mile was considered as probable and given further consideration using all available information including other data points, and carcasses more than 2/3 mile from the WVC point was considered to not be a duplicate. A total of 1670 carcasses were removed as being apparent duplicates with three additional carcasses removed due to association with backroads not part of the CDOT system. This final analysis of the carcass data resulted in 22,688 carcasses on 3,748 road segments.

Each output data layer, the WVC spatially joined points and the purged carcass data, was then generalized back down to the original segments using the Dissolve tool in ArcGIS Toolbox using the SegmentIDs. This process also summarized the total WVC and carcass counts, total Deer, total Elk, total Moose, and total Antelope counts into separate attribute fields. The table from the dissolved data set was joined with the road segment layer using the SegmentID and the total counts for each category were added to each road segment.

Table 1: Summary of Animal Counts by Species

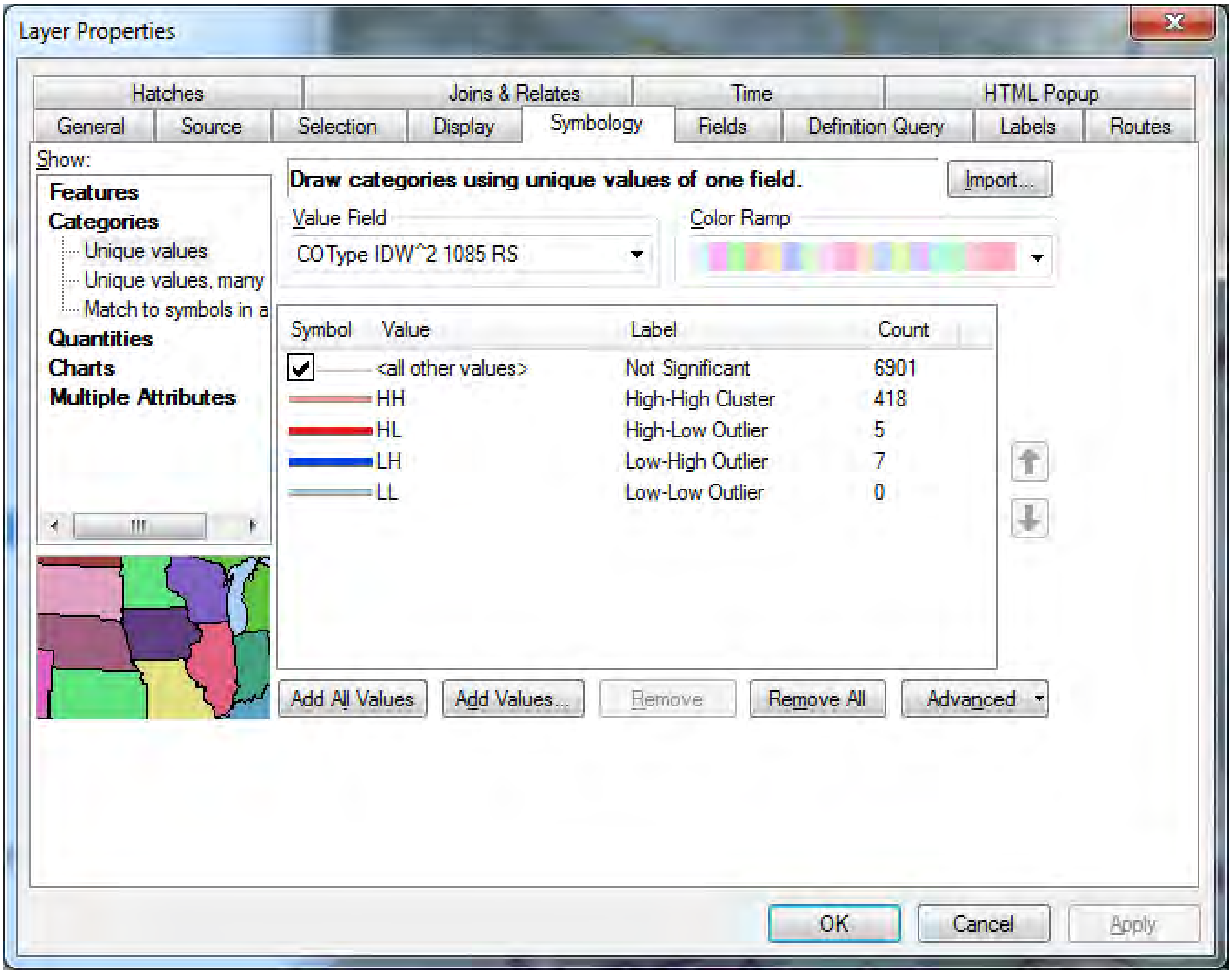
WILDLIFE VEHICLE COLLISIONS & CARCASS COUNTS BY SPECIES						
	WVC		**Carcass**		**Other WVC Animal Count**	
	Animal Count	% of Total	Animal Count	% of Total		
Antelope	80	0.5%	-	0.0%	Bear	285
Deer	13,795	85.9%	20,315	89.5%	Beaver	4
Elk	2,101	13.1%	2,373	10.5%	Bird	8
Moose	83	0.5%	-	0.0%	Bobcat	7
					Cattle	22
Total Animal Count (select animals)	16,059		22,688		Coyote	40
					Eagle	14
Other	580				Fawn	4
Total Reports	**16,639**		**22,688**		Fox	9
					Goose	1
					Hawk	1
					Horse	45
					Lion	21
					Owl	2
					Porcupine	2
					Rabbit	7
					Raccoon	27
					Sheep	18
					Turkey	8
					Unknown	55
						580

Note: The CDOT_WVC_R3R5 feature class contains 16,724 records. Eighty-five (85) records in the feature class were not used because their distance from the road is greater than 1000 feet or they are associated with a road not in the state highway system.

Cluster Analysis of the Collision and Carcass Data

Wildlife Vehicle Collision (WVC) and the maintenance carcass data were run through two different cluster analyses; hot spot analysis and Anselin Local Moran's I, respectfully. The Hot Spot Analysis tool was run on the WVC data in ArcMap 10.3. According to the description by ESRI, the hot spot analysis tool "calculates the Getis-Ord Gi statistic for each feature in a dataset. The resultant z score tells you where features in 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 much different than the expected local sum, and 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 has an impact on your analysis. Once that critical distance is exceeded, the level of impact quickly drops off. The distance used to hold all events equal was 1086 meters, approximately 2/3 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.

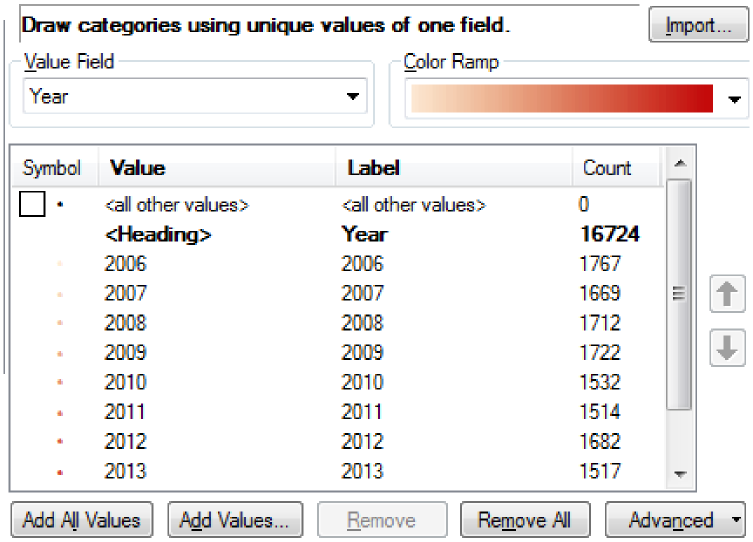
The carcass data was run through the Cluster and Outlier Analysis (Anselin Local Moran’s I) tool in ArcMap 10.3. This cluster analysis tool identifies where high or low values cluster spatially. Features with values that are very different from surrounding feature values are identified as outliers. The method chosen for the carcass clustering was Inverse Distance Squared (IDS) using Euclidean distances and ROW standardization. The default neighborhood search threshold was 1086 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.

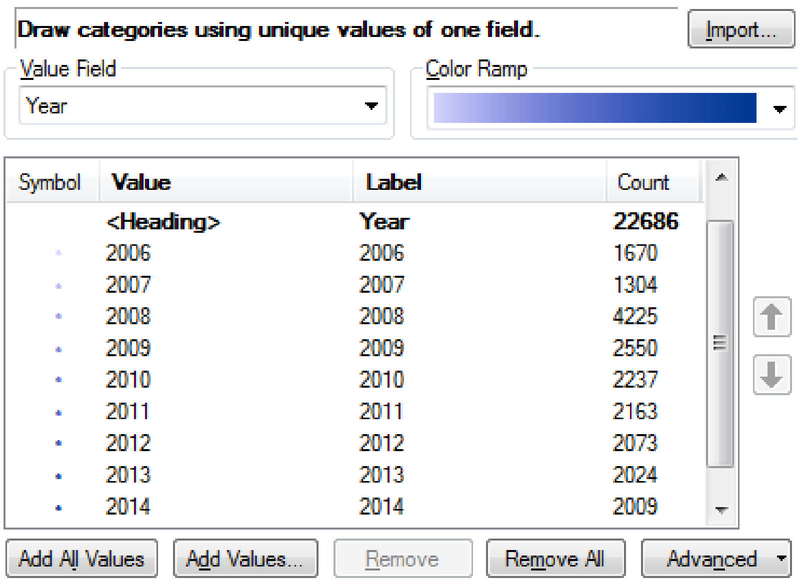


Seasonal and Annual Patterns

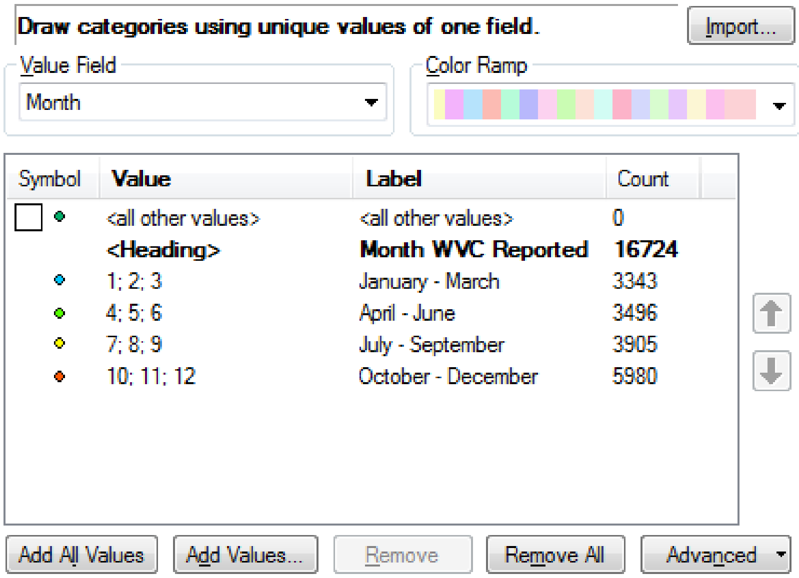
The WVC and carcass point data was filtered to show seasonal and annual trends as a supplement. The intent of showing the adjusted raw datasets in this way is to help identify if changes might be occurring during the 10-year data collection period due to construction of mitigation structures or other sudden events (annual filter). It is also to help identify if the WVC and carcass reports occur during particular movement periods or impacts herds within seasonal ranges (quarterly filter). These data sets do not stand alone, but are used only as supplement to the other models. The carcass dataset was queried to remove all records that had an animal count of zero resulting from the duplication analysis, and an effort was made to create duplicate records in order to create a point for each animal count (2 records were lost during this effort, but the resultant dataset is not used in any other analysis).

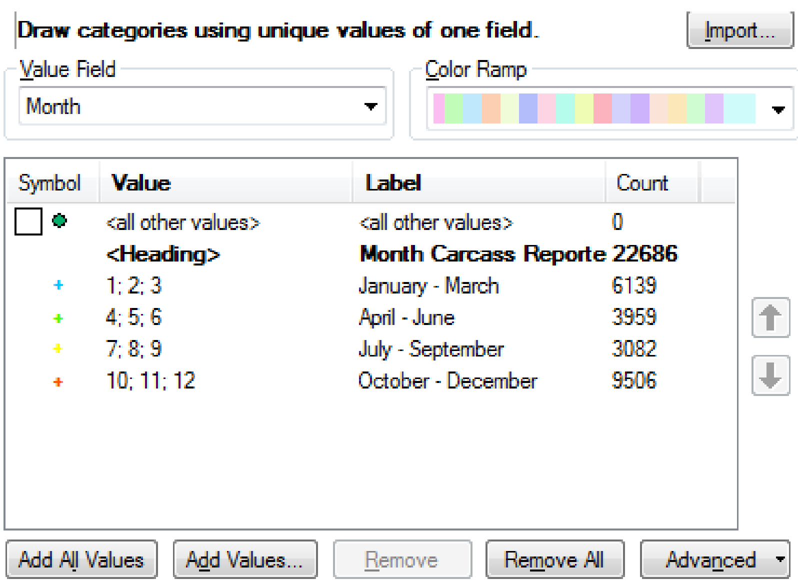
Symbology for identifying WVC and carcass (respectfully) events by year:





Symbology for identifying WVC and carcass (respectfully) events by season:


Draw categories using unique values of one field.
Import...
Value Field
Month
Color Ramp
Symbol
Value
Label
Count
<all other values>
<all other values>
0
<Heading>
Month WVC Reported
16724
1; 2; 3
January - March
3343
4; 5; 6
April - June
3496
7; 8; 9
July - September
3905
10; 11; 12
October - December
5980
Add All Values
Add Values...
Remove
Remove All
Advanced


Draw categories using unique values of one field.
Import...
Value Field
Month
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Value
Label
Count
<all other values>
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0
<Heading>
Month Carcass Reporte
22686
1; 2; 3
January - March
6139
4; 5; 6
April - June
3959
7; 8; 9
July - September
3082
10; 11; 12
October - December
9506
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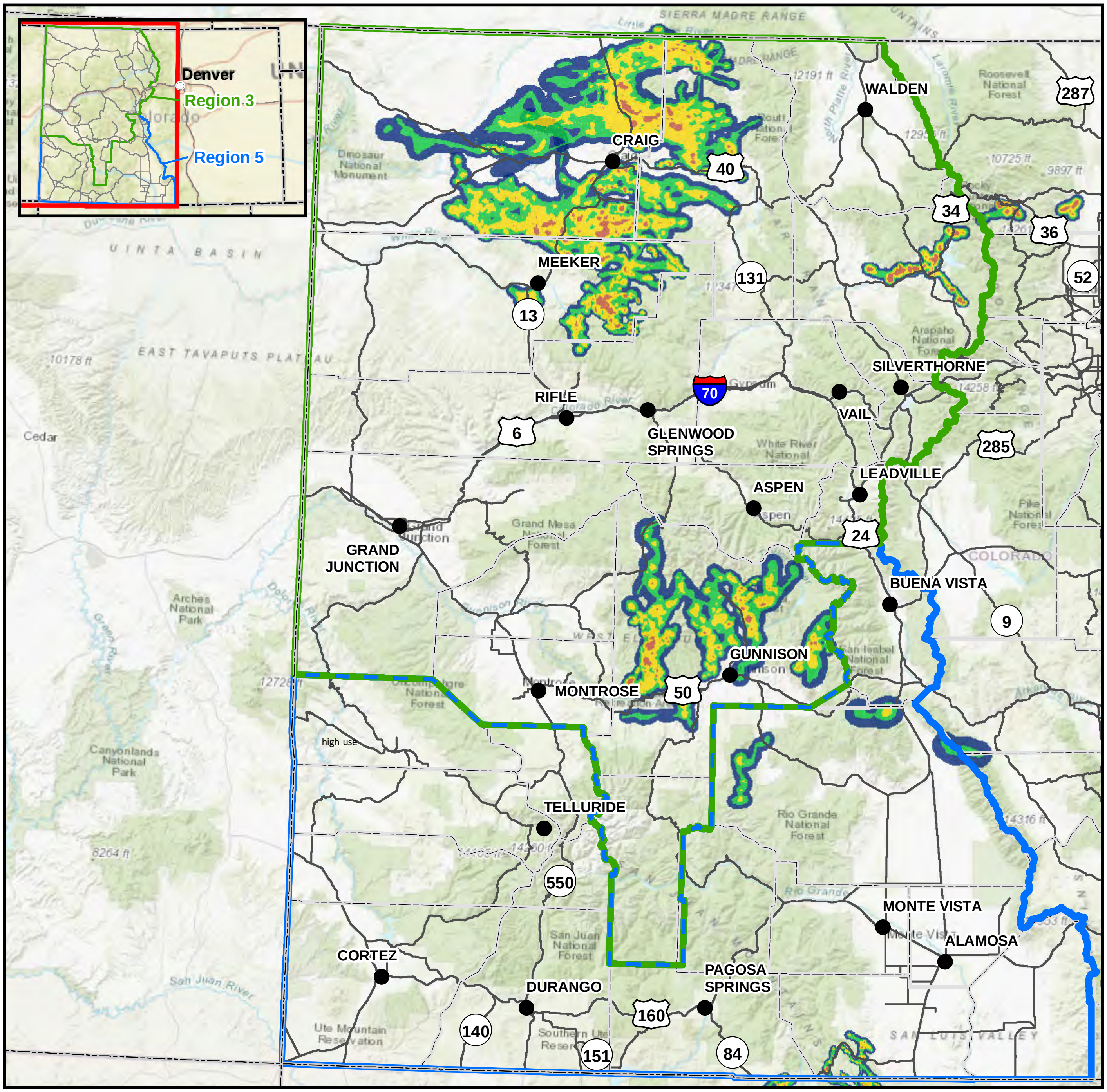
Add Values...
Remove
Remove All
Advanced



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_BBMM_ELKMIGRATION_A.MXD

Legend

- City
- Highway

CDOT Region

- 3
- 5
- County Boundary
- State Boundary

BBMM Elk Migration

- Low Use
- Moderate-Low Use
- Moderate-High Use
- High Use

Western Slope Wildlife Prioritization Study

Brownian Bridge Movement Model Elk Migration

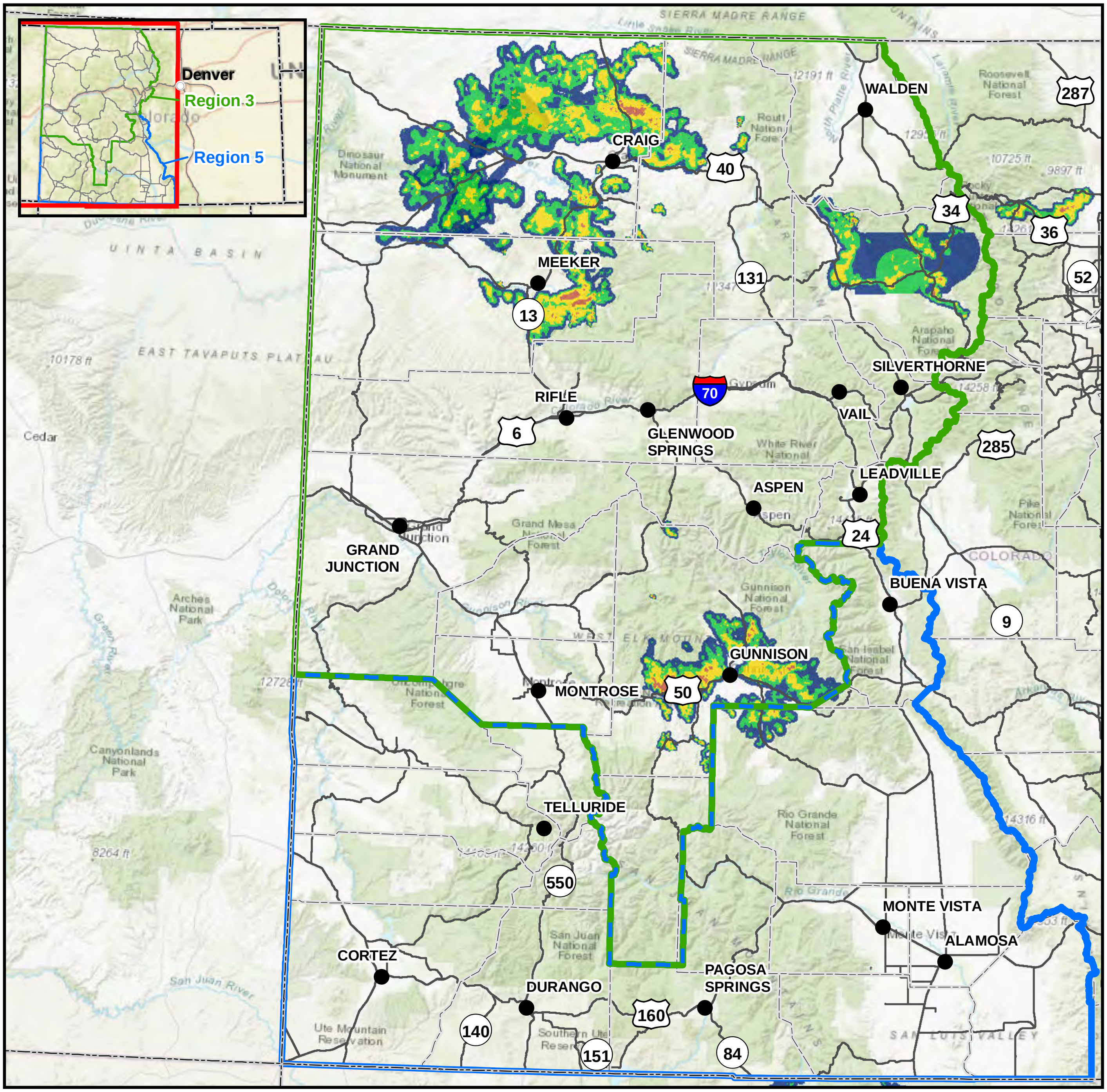
N

0 20 40 Miles

1 inch = 40 miles

JACOBS

Date: 4/15/2019



Base Map Date: ESRI 2018

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Legend

- City
- Highway

CDOT Region

- 3
- 5
- County Boundary
- State Boundary

BBMM Elk Winter Range

- Low Use
- Moderate-Low Use
- Moderate-High Use
- High Use

Western Slope Wildlife Prioritization Study

Brownian Bridge Movement Model Elk Winter Range

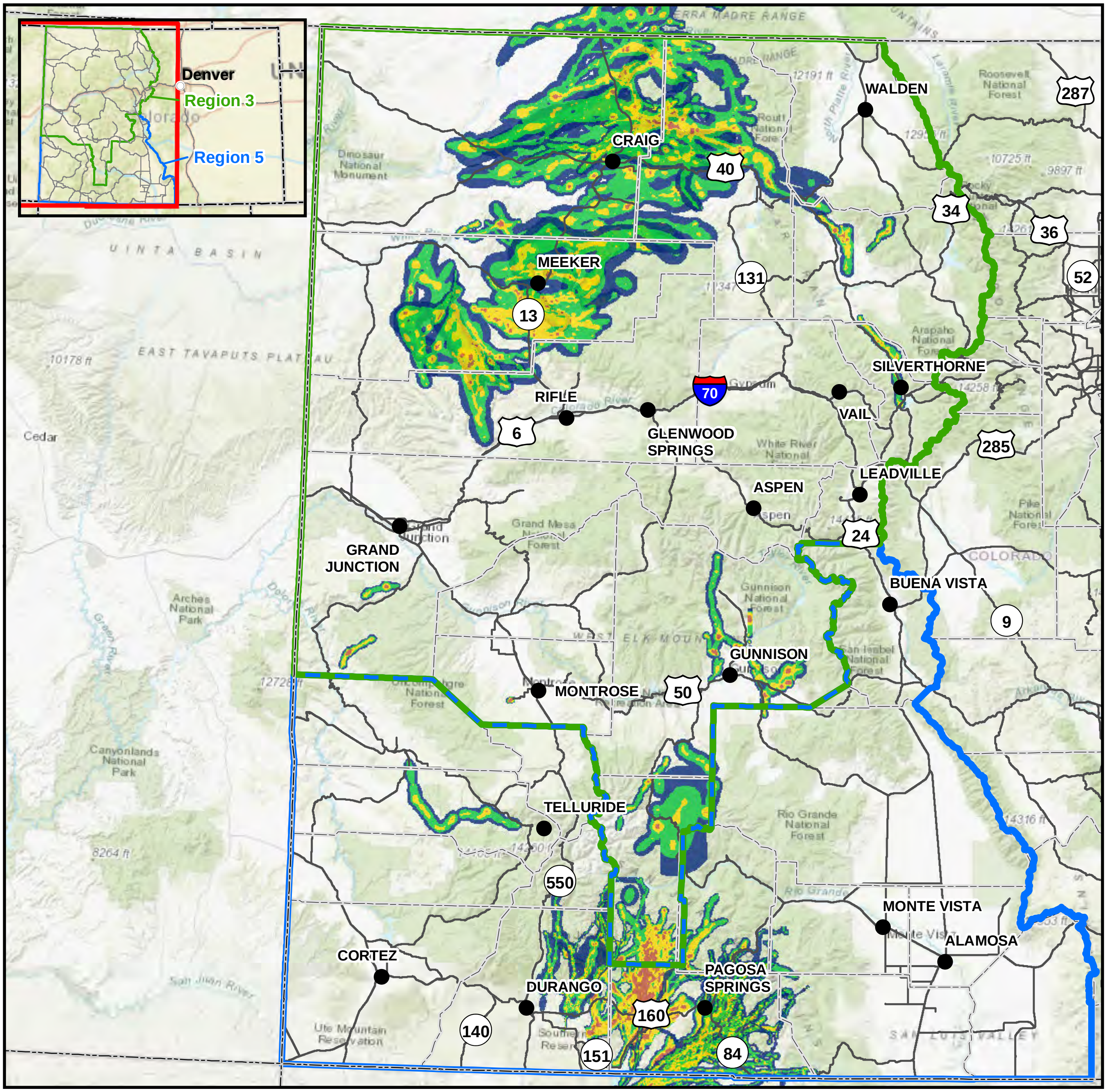
N

0 20 40 Miles

1 inch = 40 miles

JACOBS

Date: 4/15/2019



Base Map Date: ESRI 2018

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Legend

- City
- Highway

CDOT Region

- 3
- 5
- County Boundary
- State Boundary

BBMM Mule Deer Migration

- Low Use
- Moderate-Low Use
- Moderate-High Use
- High Use

Western Slope Wildlife Prioritization Study

Brownian Bridge Movement Model Mule Deer Migration

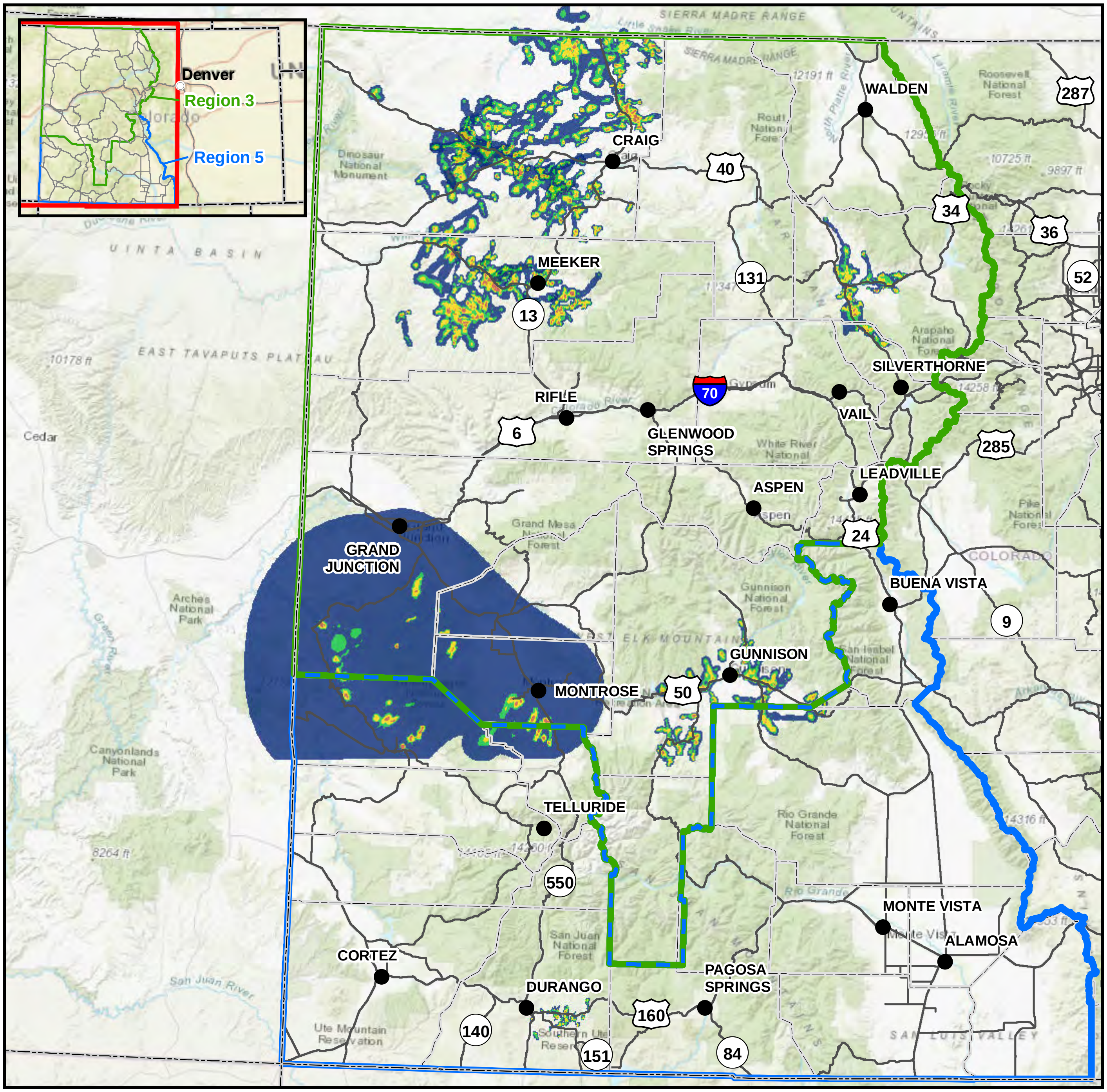
N

0 20 40 Miles

1 inch = 40 miles

JACOBS

Date: 4/15/2019



Base Map Date: ESRI 2018

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Legend

City

Highway

CDOT Region

3

5

County Boundary

State Boundary

BBMM Mule Deer Winter Range

Low Use

Moderate-Low Use

Moderate-High Use

High Use

Western Slope Wildlife Prioritization Study

Brownian Bridge Movement Model Mule Deer Winter Range

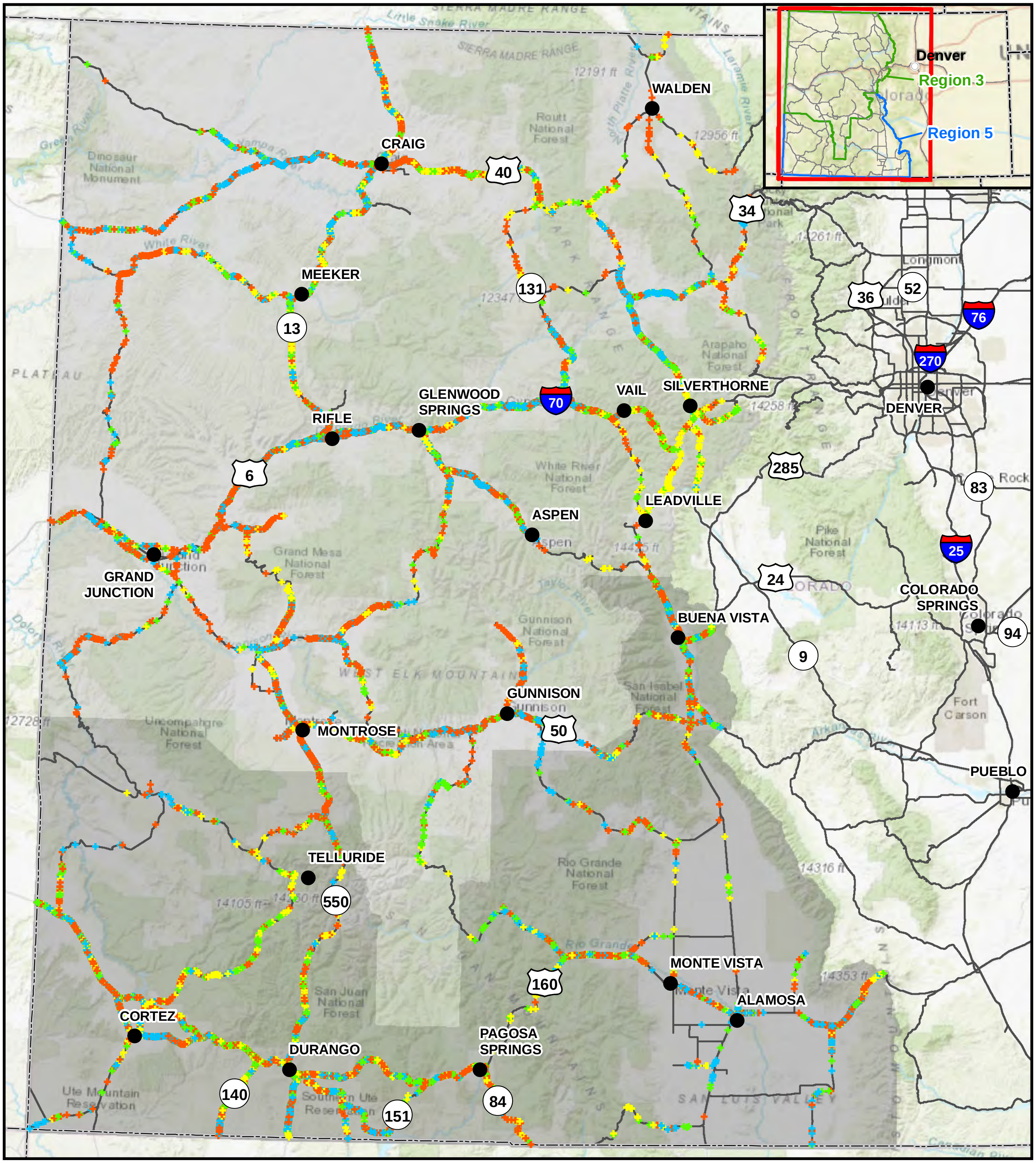
N

0 20 40 Miles

1 inch = 40 miles

JACOBS

Date: 4/15/2019



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Legend

- City
- Highway

CDOT Region

- 3
- 5
- State Boundary

CDOT Carcass Seasonal Analysis

- January - March
- April - June
- July - September
- October - December

N

0 10 20 Miles

1 inch = 35 miles

Western Slope Wildlife Prioritization Study

CDOT Carcass Seasonal Analysis 2006-2015

JACOBS

Date: 4/15/2019

APPENDIX E: CSP Risk Modeling Report

CONSERVATION
SCIENCE PARTNERS

FINAL REPORT

9 November 2018

For the project entitled:

Western Slope Wildlife Prioritization Study: Modeling Risk of Wildlife-Vehicle Collisions

Submitted to:

Jacobs Engineering
Colorado Department of Transportation

By:

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Background & Purpose

Colorado's Western Slope is home to several of the largest herds of migratory mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*) in North America, among many other wildlife species, although mule deer herds across much of the Western Slope have been on the decline since the 1980s. In response to this declining trend, Colorado Parks and Wildlife (CPW) has initiated the West Slope Mule Deer Strategy with the goal of increasing deer populations by 100,000+ animals.

However, deer and elk movement across highways, particularly as herd sizes increase, results in high rates of wildlife-vehicle collisions (WVCs), presenting challenges for herd management and safety to the travelling public. Currently, the Colorado Department of Transportation (CDOT) addresses WVCs largely on a project by project basis, integrating mitigation as transportation projects arise in road segments observed to have high WVCs. Yet this project-focused approach does not consider CPW's Mule Deer Strategy goals or how migratory ungulates and other wildlife that must cross roads move across the broader landscape to access seasonal resources or disperse to new areas – meaning that wildlife mitigation efforts do not necessarily capture those areas outside proposed project limits where such mitigation could have the greatest impact on reducing WVCs, increasing driver safety, and maintaining connectivity linkages.

The Western Slope Wildlife Prioritization Project (WSWPS) is a collaborative effort between CDOT and CPW, conducted by Jacobs Engineering and its partners, Eco-Resolutions and Conservation Science Partners. 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 West Slope. Ultimately, the methodology developed here could be adopted and applied statewide.

As part of the WSWPS, Conservation Science Partners was tasked with modeling WVC risk for mule deer and elk throughout the road network in CDOT Regions 3 and 5 (largely coincident with the Western Slope) 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.

Methods

Study area. The study area was comprised of CDOT's Regions 3 and 5, which encompass the state of Colorado west of the Continental Divide, generally referred to here as the Western Slope. Our focus was on the CDOT-maintained road network.

Approach Overview. We explored three general approaches to estimate WVC risk ranging from state-of-the-art, data-intensive models to a simpler model informed directly by recorded WVCs. In this report, we focus on providing detailed methods and results of our selected approach, though details of alternative approaches, as well as issues encountered with these approaches, are provided in Appendix A. In each of the three approaches, we aimed to estimate WVC risk separately for mule deer and elk, as well as estimating risk specific to migration periods (spring and fall) and to winter range use, yielding a total of four risk models.

Initially, we followed the approach of Visintin et al. (2016), estimating *exposure* (presence of wildlife on roads) and *hazard* (presence of vehicles on roads) separately as two distinct components of risk. We provide an overview of the approach here; see Appendix A for further methodological details. We sought to estimate *exposure* as the probability of animals crossing a given road segment, after McClure et al. (2017). We obtained GPS collar data from CPW biologists, Aran Johnson (Southern Ute Indian Tribe) and Dr. Hall Sawyer (West, Inc.), representing 10 mule deer collaring efforts and 5 elk collaring efforts throughout the Western Slope. These data were cleaned and filtered to migration and winter periods. We then fit Brownian bridge movement models (Horne et al. 2007) to each individual movement period to estimate the probability of movement through each raster cell between observed GPS relocations, then summed these probabilities across individuals in each herd to estimate population-level probability of movement (after Sawyer et al. 2009). We fit models of habitat suitability specific to migration periods and winter range use, using population-level probability of movement as the response variable and a variety of landscape attributes identified from published literature on mule deer and elk habitat selection and by prioritization sub-committee members as explanatory variables. We then aimed to use the resulting habitat suitability maps as resistance surfaces for circuit theory-based connectivity models (e.g., McClure et al. 2017, Littlefield et al. 2017) predicting likely migration paths between summer and winter range areas and likely movement paths within winter range areas.

We sought to estimate *hazard* as a product of the volume and speed of vehicle traffic on roads. We obtained estimates of average annual daily traffic (AADT) per road segment, as well as spatial data on posted speed limits, from CDOT. We planned to test alternative hypotheses for the most appropriate means of combining traffic volume and speed to estimate hazard (i.e., relative weights on each component), and of combining exposure and hazard to estimate risk, by evaluating each alternative risk estimate against observed patterns of WVCs.

We next explored a similar approach, except that rather than estimating wildlife movement probability continuously throughout the Western Slope in response to landscape attributes, we focused on probability of movement immediately adjacent to and across roads in response to road-adjacent landscape attributes. In other words, we restricted analysis and inference to the road network, buffered by a distance sufficient to encompass attributes that may influence animals' selected path of approach to the road (see Appendix A).

Lastly, we settled on an approach that differed substantially from the first two in that it modeled WVC risk directly based on observed WVC data rather than using GPS collar data on animal movements to model exposure as a distinct component of risk. We followed the work of Kolowski & Nielsen (2008), comparing road and road-adjacent attributes of known WVC locations to 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.

Data. We used a combination of reported accident data on WVCs and animal carcass data as the response variable in our risk models. We obtained WVC data for the years 2005 to 2015. These data are collected from accident reports, and are geo-located to the nearest mile on the highway routing map. In addition, wildlife carcass data are collected by the CDOT maintenance crew, and are also typically georeferenced to the nearest mile (or sometimes tenth-of-mile) marker.

We assumed that many of the carcasses collected by maintenance crews were the same animals identified in accident reports. In order to identify and remove duplicate records, the two datasets were joined by segment, date, and species. If maintenance crews and accident reports recorded the same species on the same road segment less than two days apart, then the carcass reported by maintenance was assumed to be the same as that included in the accident report. A total of 1670 carcass records were removed from the dataset as apparent duplicates, with three additional records removed due to association with backroads outside the CDOT system (T. Smithson, Jacobs Engineering). This resulted in a final dataset consisting of 22,688 combined WVC and carcass records on 3,748 approximately half-mile length road segments.

In Table 1, we summarize all explanatory variables considered as potential drivers of WVC risk. These variables were selected based on review of similar published analyses of WVC risk (e.g., Baigas et al. 2017, Coe et al. 2015, Kolowski & Nielsen 2008) as well as further input from the study team and prioritization subcommittee.

Table 1. Names, source data, and descriptions of all explanatory variables considered as drivers of WVC risk.

Name	Description	Resolution	Source
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 2010, 2017
Magnitude of migration movement	Distance between DAU centroid and DAU highest point, multiplied by DAU population size estimate, as proxy for relative magnitude of migration movement	DAU	CPW 2017
Traffic volume	Annual average daily traffic (number of vehicles/day)	CDOT segment	CDOT 2017
Traffic speed	Posted speed limit	CDOT segment	CDOT 2017
Road corridor width	Total width of road corridor (sum of all lane, shoulder, and median widths)	CDOT segment	CDOT 2017
Highway curve class	Highway curvature class as determined by CDOT (6 classes)	CDOT segment	CDOT 2017
Absolute highway grade	Absolute value of grade recorded by CDOT for primary right of way	CDOT segment	CDOT 2017
Distance from speed transition	Road-miles from nearest point of change in speed limit	30 m	CDOT 2017
Distance from stream intersection	Road-miles from nearest point at which road intersects a stream	30 m	USGS 2014
Percent impervious surface	Percent impervious surface cover within 1 km grid cell	1 km	US EPA 2013
Distance from suburban housing density	Distance from nearest area classified as suburban or greater housing density	100 m	US EPA 2013
Distance from tree edge	Distance from nearest tree cover	30 m	USGS 2011
Percent aspen	Percent aspen cover within 270 m x 270 m moving window	30 m	USGS 2011
Percent conifer	Percent conifer cover within 270 m x 270 m moving window	30 m	USGS 2011
Percent pinyon	Percent pinyon juniper cover within 270m x 270m moving window	30 m	USGS 2011
Percent oakbrush	Percent oakbrush cover within 270m x 270 m moving window	30 m	USGS 2011

Slope adjacent to road surface	Slope of 30 m pixel intersected by road polyline	30 m	USGS 1999
Terrain ruggedness	Standard deviation of elevation values within 270 m x 270 m moving window	30 m	USGS 1999
Topo position (multiscale)	Relative topographic position (canyon = low, ridge = high) averaged across 5 spatial scales	30 m	USGS 1999
Topo position (local)	Relative topographic position within 90 m	30 m	USGS 1999

*DAU=Data Analysis Unit

Model. We used logistic regression and multi-model inference in an information theoretic framework to estimate the relative risk of WVCs (Akaike 1973, Burnham & Anderson 2002). Formally, our model can be described as a logistic discrimination function (Keating & 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 to others. Similarly, we cannot assume that locations in which no carcasses are recorded are in fact free of WVCs due to underreporting or spatially inaccurate reporting. We therefore judged the assumptions of a logistic discrimination function 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 and elk, as well as separate risk models for migration and winter periods, resulting in four risk models. We defined migration periods as September – November and April – June; winter was defined as December – March, based on the distribution of migration start and end dates observed across GPS collar datasets provided by CPW biologists (see Appendix A). We used all available elk WVC data to fit risk models for migration and winter periods (n = 1,082, n = 1,092, respectively). Due to the volume of mule deer WVC records (i.e., migration: n > 11,000, winter: n > 7,000), we thinned the data and fit risk models by randomly selecting a subset (n = 2,500) of migration and winter points in order to avoid excessive repeat sampling of segments and sampling ‘saturation’ of the road network, which presents challenges for model fitting and interpretation. We compared attributes of these locations to 2,500 random locations generated throughout the Western Slope road network.

Our global model included all explanatory variables described in Table 1, as well as an interaction term between traffic volume and speed, as well as quadratic terms for traffic volume, speed, herd density (from DAUs and Elk Management Units), and distance from tree cover. 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 multi-model inference.

We used the MuMIn package (Barton et al. 2014) for R (R Development Core Team 2017) to fit all additive subsets of these reduced models and to compute model-averaged regression coefficients, unconditional standard errors (SEs), cumulative AIC weights of evidence as a measure of variable importance (Burnham & Anderson 2002), and 95% confidence intervals. Model averaging and multi-model inference allows for more robust inference than selection of a single 'best' model, producing coefficient estimates and standard errors 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. We assessed the relative importance of each explanatory variable based on: 1) effect size indicated by each regression coefficient; 2) 95% confidence intervals on each regression coefficient; and 3) AIC weights of evidence.

Finally, we assessed future WVC risk by applying the above risk models using data layers representing future traffic volume and future distance from suburban housing density. We used AADT projections for the year 2045 to best match CDOT's planning horizon, and housing density projections for the year 2050, the closest available time increment, under a 'baseline case' (i.e., 'business as usual' scenario; EPA 2013).

Results

Although inferential risk models performed far better than null models for each of the four species-season combinations, as indicated by very high ΔAIC values ranging from 798.5 to 1843.7, the relative variance explained by each was fair to moderate (Nagelkerke r^2: 0.292 - 0.427) (Table 2). 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 mule deer winter range use, while performance of the risk model for elk migration periods was lowest.

Table 2. Summary of model fits.

Species	Season	Nagelkerke r^2	(Null) - (Fitted) ΔAIC
Mule deer	Migration	0.287	1179.3
	Winter	0.421	1869.8
Elk	Migration	0.285	785.0
	Winter	0.343	956.4

We observed several generalizable trends across models in drivers of WVC risk, while other risk factors varied across species and seasons (Tables 3-6). Distance to tree cover, traffic volume and speed, and a measure of herd density were most often the strongest drivers of risk. WVC risk decreased with distance to tree cover. Risk increased with traffic volume, but levels off as volumes approach approximately 21,000 vehicles/day, perhaps reflecting a threshold at which traffic volume becomes a barrier and individuals are less likely to attempt to cross roads. Risk also increased with traffic speed, though in mule deer, the effect of speed was nonlinear and maximum risk was estimated to occur at approximately 60 mph (Tables 3-4). Again, this finding may reflect a threshold at which high-speed traffic becomes a barrier to movement. We also observed increases in WVC risk with distance from points at which speed limit changes. In the case of mule deer WVC risk during winter range use, there was a positive interaction between traffic volume and speed, such that risk is higher than expected on roads with high-speed, high-volume traffic than would have been expected based on either of these variables alone (Table 4).

Vegetation composition adjacent to the road and topographic characteristics had variable effects on WVC risk. Risk decreased with greater percent aspen and conifer cover for mule deer (Tables 3-4), but these effects were not detected for elk (i.e., 95% confidence interval spanned zero; Tables 5-6). In contrast, risk decreased with greater percent pinyon juniper cover for elk (Tables 5-6), but this effect was not present for mule deer (Tables 3-4). Where oakbrush cover was more extensive, risk for mule deer during winter range use decreased (Table 4), while risk for elk migration movements increased (Table 5); other oakbrush effects were not detected (Tables 3, 6). Higher multi-scale topographic position conferred increased risk for mule deer (Tables 3-4), but tended to have lower risk for elk (Tables 5-6). Risk for elk during winter range use was higher at higher local (90-m) topographic positions (Table 6). More rugged areas carried greater risk for elk migration (Table 5), but ruggedness had no detectable effect on risk for other movements (Tables 3-4, 6). Mule deer experienced higher WVC risk closer to points at which roads crossed streams (Tables 3-4); the position of stream crossings had no detectable effect on risk for elk (Tables 5-6).

The effects of CPW data analysis unit (DAU) herd density, as well as metrics describing 'magnitude' of winter and migration movements, had variable effects on risk. In winter, risk for both mule deer and elk increased with increasing winter range herd density, but approached a maximum at densities of 31.9 and 13.2 individuals/mi^2, respectively (Tables 4, 6). The effects of migration movement magnitude are less straightforward to interpret; risk for elk was highest at low and high migration magnitude values (0.2 standard deviations above mean; Table 5), and we found no relationship with mule deer migration risk (Table 3). The effects of overall DAU herd density were highly variable and thus similarly difficult to interpret. As DAU herd density increased, risk increased up to a point for mule deer migration (12.5 individuals/mi^2; Table 3), declined for mule deer winter range use (Table 4), was lowest at intermediate density for elk winter range use (5.6 individuals/mi^2; Table 6), and was not affected in the case of elk migration (Table 5).

The effect of distance to suburban or greater housing density did not contribute strongly to risk. Mule deer migration risk tended to decline with greater distance from high housing density, though the confidence limit on our coefficient estimate spanned zero (Table 3); housing density had no effect on risk in other models (Tables 4-6). Road corridor width, highway curve class, highway grade, and slope adjacent to the road surface were consistently uninformative in estimating risk and were not included in any final inferential models summarized here.

Table 3. Summary of WVC risk model for mule deer migration periods.

Variable	Term	AIC weight	Estimate	Adjusted SE	Lower CI	Upper CI
Distance to tree cover	x	1.00	-0.764	0.092	-0.944	-0.585
	x^2	0.69	0.034	0.029	-0.023	0.091
Traffic volume (AADT)	x	1.00	0.682	0.048	0.588	0.777
	x^2	1.00	-0.210	0.033	-0.275	-0.145
DAU herd density	x	1.00	0.264	0.040	0.186	0.342
	x^2	0.93	-0.059	0.028	-0.113	-0.005
Topo position (multiscale)	x	1.00	0.247	0.041	0.167	0.326
Distance to speed transition	x	1.00	0.221	0.045	0.134	0.308
Percent conifer	x	1.00	-0.218	0.046	-0.307	-0.128

Traffic speed (mph)	x	1.00	0.195	0.045	0.108	0.282
	x^2	1.00	-0.107	0.028	-0.161	-0.052
Percent aspen	x	0.99	-0.146	0.048	-0.240	-0.052
Distance to stream crossing	x	0.99	-0.127	0.040	-0.206	-0.049
Percent pinyon	x	0.90	0.080	0.043	-0.004	0.163
Distance to suburban housing density	x	0.88	-0.117	0.068	-0.251	0.016
Topo position (90m)	x	0.56	0.030	0.037	-0.042	0.102

Table 4. Summary of WVC risk model for mule deer winter use periods.

Variable	Term	AIC weight	Estimate	Adjusted SE	Lower CI	Upper CI
Winter range herd density	x	1.00	1.111	0.061	0.991	1.232
	x^2	1.00	-0.241	0.030	-0.299	-0.183
Traffic volume (AADT)	x	1.00	0.979	0.047	0.887	1.071
	x^2	1.00	-0.186	0.038	-0.261	-0.110
Distance to tree cover	x	1.00	-0.429	0.049	-0.524	-0.333
Topo position (multiscale)	x	1.00	0.424	0.046	0.334	0.515
Percent conifer	x	1.00	-0.330	0.077	-0.481	-0.179
Percent aspen	x	1.00	-0.286	0.086	-0.454	-0.118
Percent oakbrush	x	1.00	-0.210	0.048	-0.303	-0.116
Distance to speed transition	x	1.00	0.186	0.038	0.112	0.259
DAU herd density	x	0.99	-0.151	0.048	-0.245	-0.057
Distance to stream crossing	x	0.96	-0.114	0.047	-0.206	-0.021
Traffic speed (mph)	x	0.94	-0.038	0.053	-0.142	0.066
	x^2	1.00	-0.111	0.032	-0.174	-0.049
Traffic volume x speed	x	0.91	0.112	0.053	0.009	0.216

Table 5. Summary of WVC risk model for elk migration periods.

Variable	Term	AIC weight	Estimate	Adjusted SE	Lower CI	Upper CI
Traffic volume (AADT)	x	1.00	0.642	0.049	0.546	0.738
Traffic speed (mph)	x	1.00	0.637	0.066	0.507	0.767
Distance to tree cover	x	1.00	-0.549	0.073	-0.693	-0.405
Migration mvmt magnitude	x	1.00	-0.385	0.083	-0.547	-0.223
	x^2	1.00	0.255	0.042	0.173	0.337
Distance to speed transition	x	1.00	0.370	0.044	0.284	0.455
Ruggedness	x	1.00	0.261	0.059	0.147	0.376
Percent oakbrush	x	1.00	0.179	0.040	0.101	0.258
Percent pinyon	x	0.96	-0.130	0.056	-0.241	-0.020
Traffic volume * speed	x	0.86	-0.098	0.061	-0.217	0.021
Percent conifer	x	0.78	-0.083	0.064	-0.208	0.042
Topo position (multiscale)	x	0.61	-0.056	0.061	-0.177	0.064

Table 6. Summary of WVC risk model for elk winter use periods.

Variable	Term	AIC weight	Estimate	Adjusted SE	Lower CI	Upper CI
Winter range herd density	x	1.00	0.885	0.071	0.746	1.024
	x^2	1.00	-0.198	0.043	-0.281	-0.114
Traffic volume (AADT)	x	1.00	0.609	0.055	0.500	0.717

	x^2	0.72	-0.060	0.052	-0.161	0.042
Traffic speed (mph)	x	1.00	0.604	0.073	0.462	0.747
	x^2	1.00	0.175	0.040	0.097	0.253
Distance to speed transition	x	1.00	0.282	0.046	0.193	0.372
DAU herd density	x	1.00	-0.235	0.059	-0.352	-0.118
	x^2	1.00	0.346	0.037	0.274	0.418
Percent pinyon	x	0.98	-0.150	0.056	-0.260	-0.041
Topo position (multiscale)	x	0.97	-0.164	0.064	-0.290	-0.039
Topo position (90m)	x	0.92	0.116	0.057	0.004	0.227
Percent aspen	x	0.91	-0.167	0.094	-0.350	0.016
Percent oakbrush	x	0.83	-0.094	0.064	-0.220	0.031
Percent conifer	x	0.82	-0.141	0.101	-0.339	0.058
Traffic volume * speed	x	0.43	0.028	0.050	-0.069	0.126
Distance to tree cover	x	0.34	0.035	0.089	-0.140	0.209
	x^2	1.00	-0.185	0.050	-0.283	-0.087

We used the exponential forms of each final inferential model to predict relative WVC risk across the entire Western Slope road network, rasterized at 30-m resolution, then summarized mean risk along each half-mile road segment (Figs. 1-4). High-risk segments were distributed as ‘hotspots’ throughout the Western Slope, but tended to be most concentrated in the Craig area of Region 3; mule deer risk was also high on the Southern Ute Reservation in Region 5. We also mapped future WVC risk by substituting projected 2045 traffic volume for current traffic volume, and projected 2050 distance from suburban housing density for current distance, where applicable, when applying our inferential models. Spatial patterns of relative future risk were extremely similar to those observed for current risk.

These data layers were compiled with data representing additional prioritization criteria identified by a committee of CDOT and CPW representatives, to enable weighted sum calculation of priority scores for each half-mile road segment. The complete prioritization criteria dataset is available from CDOT as a shapefile, and its attributes and prioritization outcomes are further described in Appendix B.

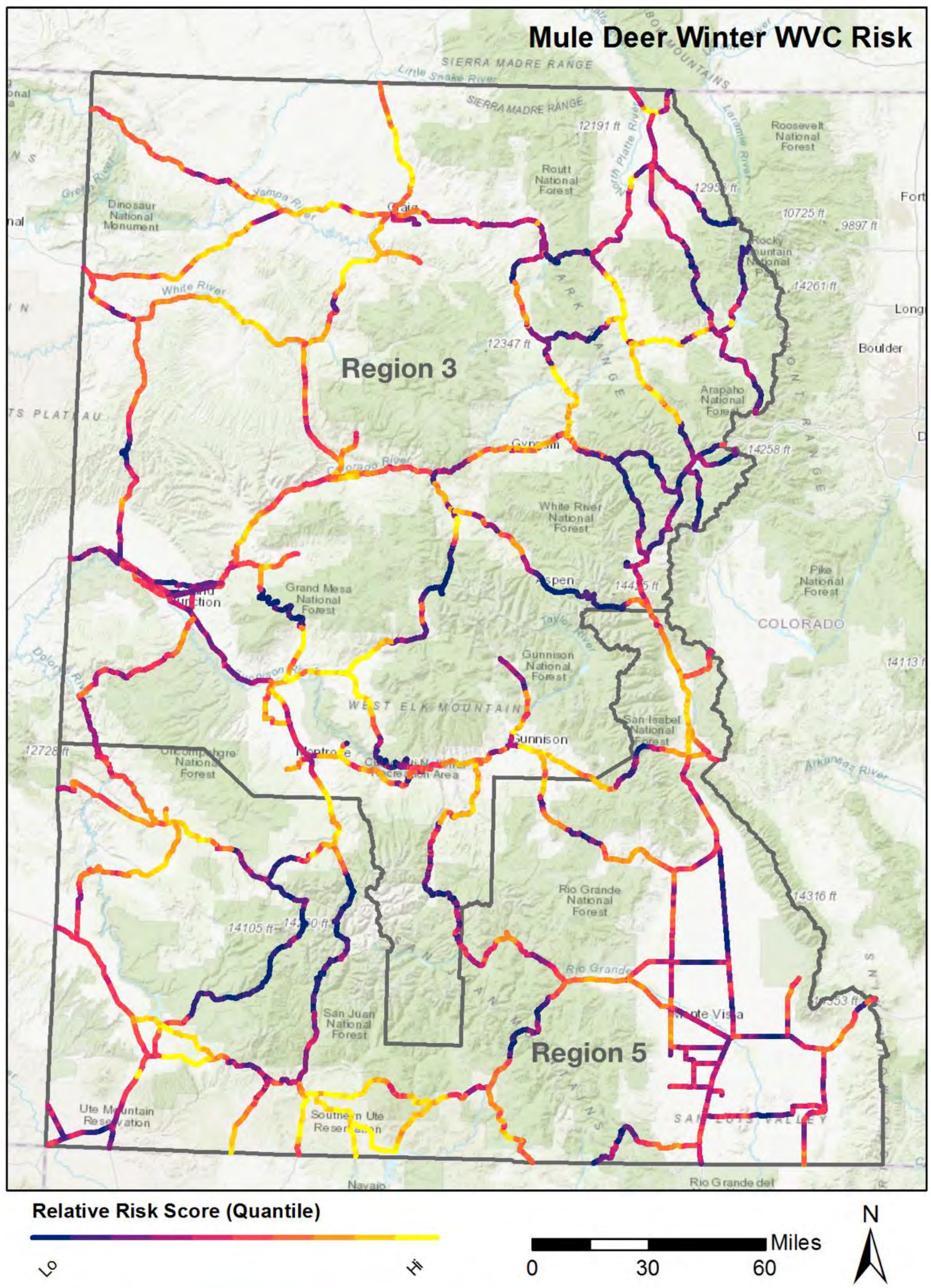

Figure 1. Relative WVC risk for mule deer during migration movements across the Western Slope road network. Risk is shown using 10 quantile breaks.

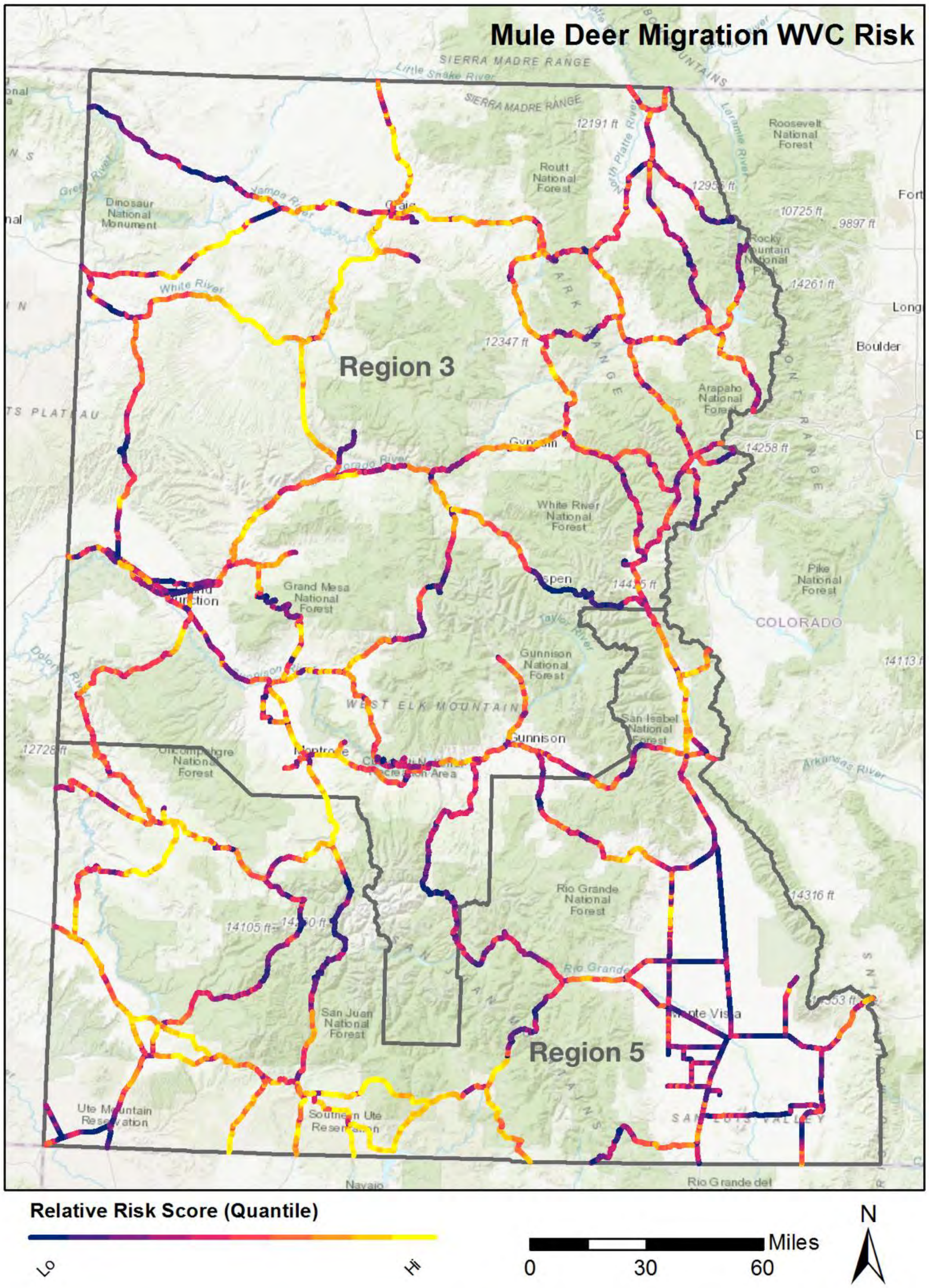

Figure 2. Relative WVC risk for mule deer during winter range use across the Western Slope road network. Risk is shown using 10 quantile breaks.

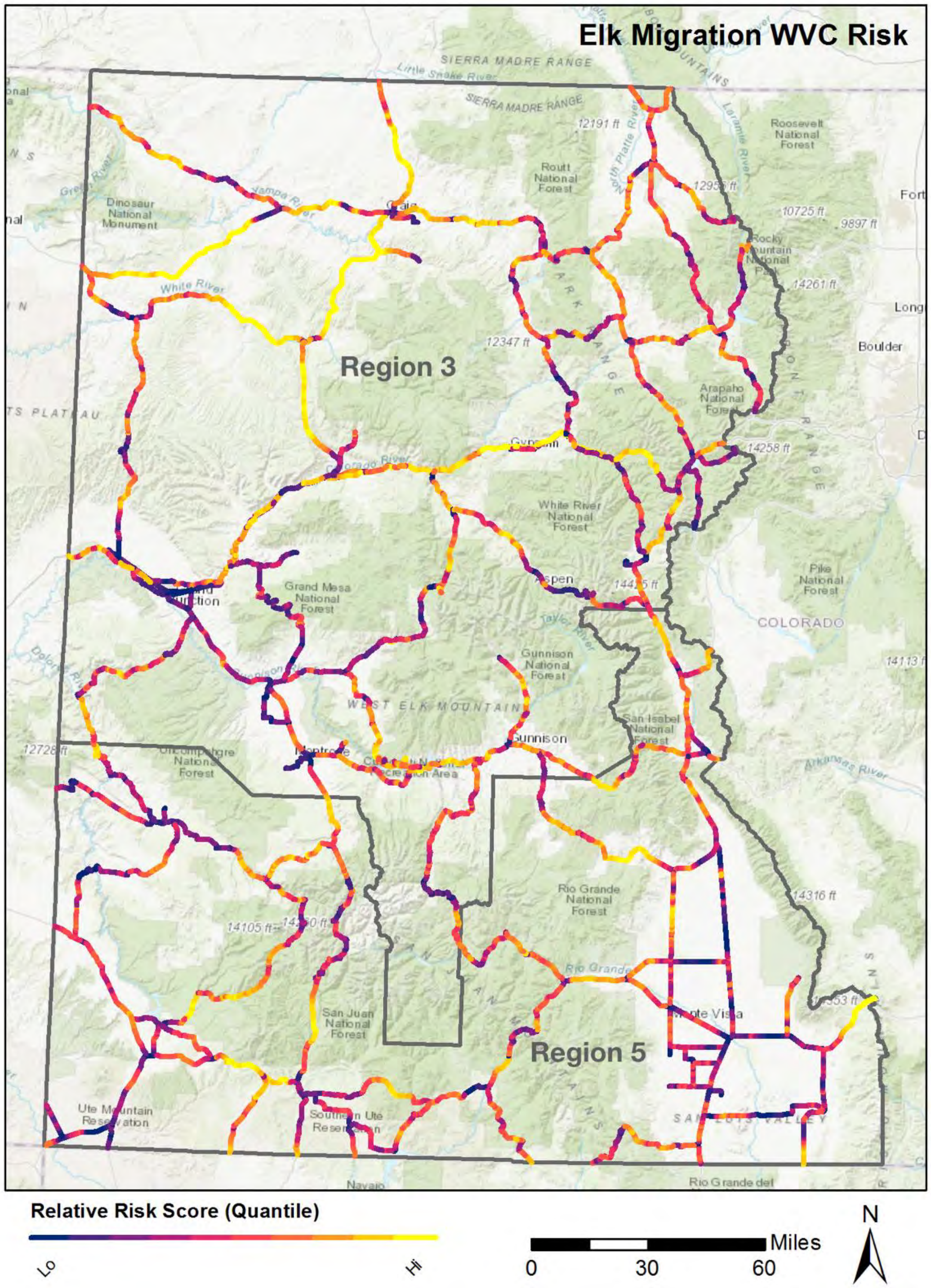

Figure 3. Relative WVC risk for elk during migration movements across the Western Slope road network. Risk is shown using 10 quantile breaks.

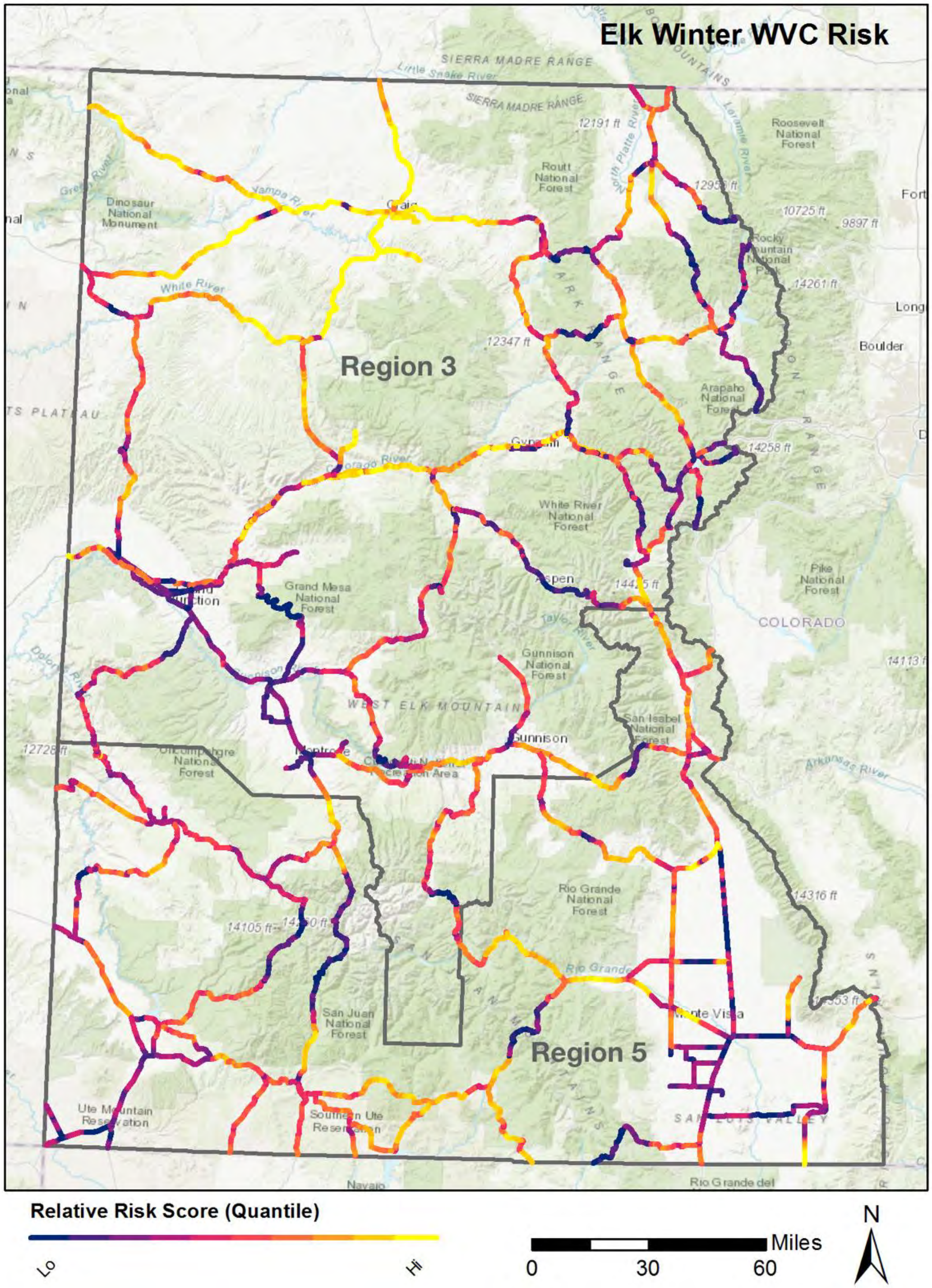

Figure 4. Relative WVC risk for elk during winter range use across the Western Slope road network. Risk is shown using 10 quantile breaks.

Discussion

We estimated WVC risk throughout the Western Slope road network based on relationships between patterns in observed WVCs and characteristics of roads and the adjacent landscape. We found that roads carrying higher traffic volume, faster-moving traffic, and where tree cover encroached closer to the road tended to have higher risk of WVCs, for both species and both seasons of interest. These patterns are to be expected; greater traffic volume increases the odds that a deer or elk and vehicle will encounter each other on the road, and greater traffic speeds decrease available reaction time to avoid a collision. Shorter distances between hiding cover and the road may increase the presence of deer and elk near the road and the likelihood of road crossing attempts, while also decreasing driver reaction time when animals enter the roadway. We also observed some evidence for threshold effects, such that risk of WVCs leveled off as traffic volumes approached 20,000 vehicles/day. We suggest this may indicate that very high traffic volumes act as a "barrier", so that animals choose not to attempt to cross the road, thereby reducing collision rates. However, it is also possible that very high-volume road segments also tend to have more substantial infrastructure in place (e.g., jersey barriers, wildlife fencing) to prevent WVCs and other collisions. Due to incomplete data on placement and attributes of fencing, as well as changes in highway infrastructure over the course of the WVC dataset analyzed, the effect of barriers on WVC rates could not be accurately assessed with the modeling approaches presented here, and it was beyond the scope of our effort to assess changes in temporal trends in WVCs following installation of fencing or other barriers. Such an analysis may help to distinguish the effects of traffic volume itself from those of highway infrastructure associated with high-volume highways on WVCs in the future. We suggest it is critical that CDOT compile and regularly update information on highway barriers, including wildlife fencing, in order to understand their effects on wildlife movement and WVCs.

Although our models performed far better than random at predicting WVC risk (based on dAIC scores), they explained only fair to moderate levels of variability in observed WVCs (based on pseudo-r^2 metrics). It is possible that low proportions of variance explained are the result of failing to include a key driver of WVC risk. However, based on the ecology of these species, their ubiquity on the Western Slope, the nature of the Western Slope landscape, and our experiences working with these and other data (see below), we suggest it is far more likely that high levels of 'noise', or random variability, are inherent to the occurrence of elk- and mule deer-vehicle collisions in the Western Slope, and that our models' fair to moderate proportions of variance explained is simply a reflection of this reality. Both elk and mule deer are generalist species, capable of and willing to use a wide variety of habitats, resulting in likely use of many different paths when approaching and crossing highways. Furthermore, the Western Slope offers extensive high-quality habitat for both species, further reducing the odds that animals will be restricted to particular routes when approaching and crossing roads. Variability in driver behavior (e.g., attentiveness, adherence to posted speed limits, response to animals on or approaching road) may also be significant and cannot be reasonably represented in our risk models. Other potentially important sources of variability that could not be captured here may include alignment of patterns in temporal variability (e.g., hourly, seasonally) of traffic volume relative to ungulate movements, and, as discussed above, the presence and configuration of fencing and other infrastructure at the time that each collision occurred (or did *not* occur, in the case of random point locations to which WVC observations were compared).

We also briefly note here that the other two approaches that we initially examined, which integrated GPS collar data collected during migration and winter range movements to estimate the exposure component of risk (i.e., probability of wildlife on roads), were not viable because of the naturally high variability (i.e., random noise) in the study system described above. Despite availability of a very high volume of data from multiple herds and many individuals with extensive geographic coverage, our preliminary exposure models failed to explain a meaningful proportion of variance in these data (see Appendix A). Stated simply, we could discern no selection of particular topographic, vegetative, or other landscape characteristics, either by individuals (Fig. A3) or as an emergent property of herd space use (Fig. A4). Despite evidence in the literature for patterns of habitat selection by deer and elk in some landscapes at some spatial and temporal scales, our findings are consistent with many other previous studies (e.g., Ager et al. 2003, D'Eon & Serrouya 2005, Lendrum et al. 2012), and re-emphasizes the generalist nature of both species and the almost ubiquitous habitat suitability of the Western Slope.

Although the WVC risk models presented here explain fair to moderate levels of variance in the WVC data, we suggest they offer important insights beyond those offered by simple hotspot analyses (e.g., pattern recognition, Getis-Ord analysis) of spatial patterns in WVCs. Although hotspot analyses 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, they do not allow identification of underlying drivers of patterns in WVCs. In contrast, regression-based risk models provide insights regarding potentially effective mitigation measures that address specific drivers of risk, as well as potential future risk associated with changes in traffic or landscape characteristics. Understanding drivers of risk may also help to identify road segments that are high-risk based on traffic and landscape characteristics, but where WVCs have been underreported. We also note that statistics associated with hotspot analyses (e.g., 0.95 confidence level in a site constituting a 'pattern') are not directly comparable with risk model fit statistics (i.e., Nagelkerke r^2) describing the relative proportion of variance explained in characteristics of WVC sites. Hotspot and risk analyses represent fundamentally different approaches, addressing different questions, and with fit metrics describing very different aspects of model performance; we suggest they provide complementary information for understanding WVC risk and prioritizing mitigation actions.

Recommendations

As this prioritization effort is extended statewide to encompass Colorado's East Slope and Plains, we suggest that our initial approaches informed by GPS collar data are not likely to succeed in these landscapes. This is in part due to what we understand to be a relative paucity of GPS collar data capturing focal species movements in these landscapes, but perhaps even more due to lack of spatial variability in characteristics of these landscapes. We believe that it is highly unlikely that constricted, high-use movement pathways with characteristics distinct from the surrounding landscape exist, and thus little pattern for the models used in our initial approaches to capture. It is possible that subtle landscape features (e.g., draws, small ridges, water, fencing) may be disproportionately important in directing movement across the more open East Slope and Plains. However, we suggest instead that our final approach described above is likely to be more useful than initial approaches, to the extent that variability in WVC frequency across the East Slope and Plains road network is driven by characteristics of roads and the traffic they carry that can be captured with available data. Still, given the more open, rolling, homogeneous nature of these landscapes relative to the Western Slope, we suggest it is likely that these models will explain less variability in WVC risk than those we have presented here.

More broadly, we suggest that future studies of ungulate habitat use and movement patterns, particularly those that may focus on road impacts, would benefit from increased coordination among CPW researchers working in different regions, as well as coordination between CPW and CDOT staff to understand and meet data needs for research and monitoring related to road impacts on wildlife. We recognize that the GPS collar data provided for use in our initial study approach were not collected for this purpose, and thus were accompanied by several caveats from CPW staff. Namely, sampling effort across the Western Slope was known to be highly skewed toward particular herds, and avoidance of major highways in collaring efforts due to safety concerns is likely to have biased the datasets toward individuals that did not occupy ranges near highways or interact with highways. We suggest that if regional-scale studies of road impacts on ungulate movements are of future interest, coordination of collaring efforts to ensure more even sampling using consistent methods that include individuals that interact with roads will be essential to proper inferences.

We also reiterate the importance of maintaining comprehensive, up-to-date data on highway barriers, including wildlife fencing, to support statistical analysis of the impacts of barriers on movement and WVCs. Data produced by such efforts may help to better understand selection of highway crossing sites and associated WVC risk, as well as where highways are and are not barriers to movement.

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Appendix A. Details of Risk Model Approaches and Methodologies

We pursued three approaches to estimating WVC risk after difficulties were encountered in our first approach. The approach we ultimately selected is described in detail in the body of this report; here we further describe our initial approaches based on deer and elk GPS collar data, which we refer to as Approaches A and B.

Approach A

Summary. We modeled Approach A after Visintin et al. (2016), estimating *exposure* (presence of wildlife on roads) and *hazard* (presence of vehicles on roads) separately as two distinct components of risk (Fig. A1).

We sought to estimate *exposure* as the probability of animals crossing a given road segment, after McClure et al. (2017). We obtained GPS collar data from CPW biologists and Dr. Hall Sawyer (West, Inc.), representing 10 mule deer collaring efforts and 5 elk collaring efforts throughout the Western Slope. These data were cleaned and filtered to migration and winter periods. We then fit Brownian bridge movement models (Horne et al. 2007) to each individual movement period to estimate the probability of movement through each raster cell between observed GPS relocations, then summed these probabilities across individuals in each herd to estimate population-level probability of movement (after Sawyer et al. 2009). We fit models of habitat suitability specific to migration periods and winter range use, using population-level probability of movement as the response variable and a variety of landscape attributes identified from published literature on mule deer and elk habitat selection as explanatory variables. We then aimed to use the resulting habitat suitability maps as resistance surfaces for circuit theory-based connectivity models (e.g., McClure et al. 2017, Littlefield et al. 2017) predicting likely migration paths between summer and winter range areas and likely movement paths within winter range areas.

We sought to estimate *hazard* as a product of the volume and speed of vehicle traffic on roads. We obtained estimates of average annual daily traffic (AADT) per road segment, as well as spatial data on posted speed limits, from CDOT. We planned to test alternative hypotheses for the most appropriate means of combining traffic volume and speed to estimate hazard (i.e., relative weights on each component), and of combining exposure and hazard to estimate risk, by evaluating each alternative risk estimate against observed patterns of WVCs.

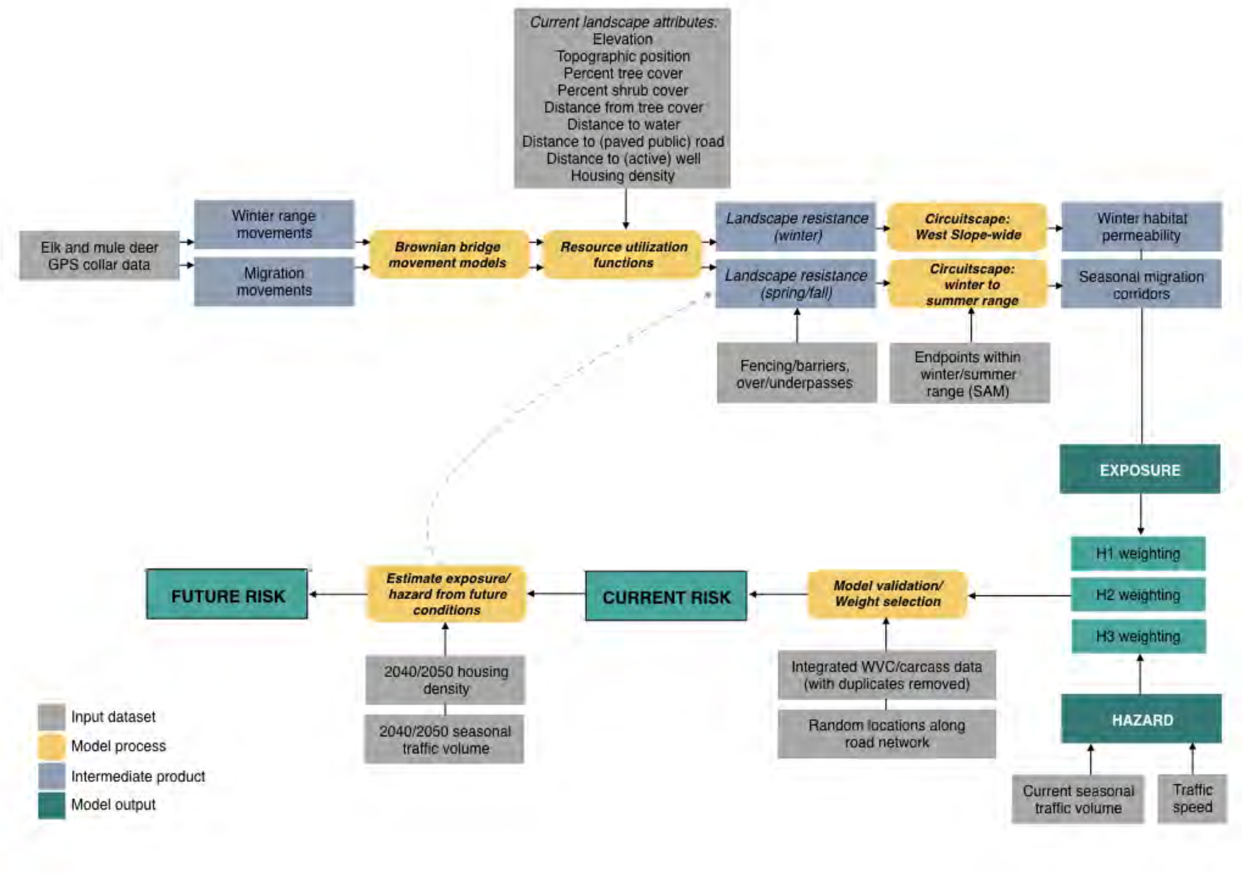


Figure A1. Flowchart depicting planned steps in Approach A.

Methods. Approach A used GPS collar data compiled from multiple CPW mule deer and elk collaring efforts throughout the Western Slope to estimate the exposure component of WVC risk. These data were requested from CPW research biologists and were provided in tabular or shapefile format. We began by cleaning the data to produce a consistent format across all datasets and remove obvious date or location errors. We then filtered and grouped the data into migration movements and winter range use periods based on plots of net displacement (Euclidean distance) of each successive GPS location relative to the starting location (Fig. A2; Rainey 2012). The resulting datasets are summarized in Table A1 and mapped in Fig. A3.

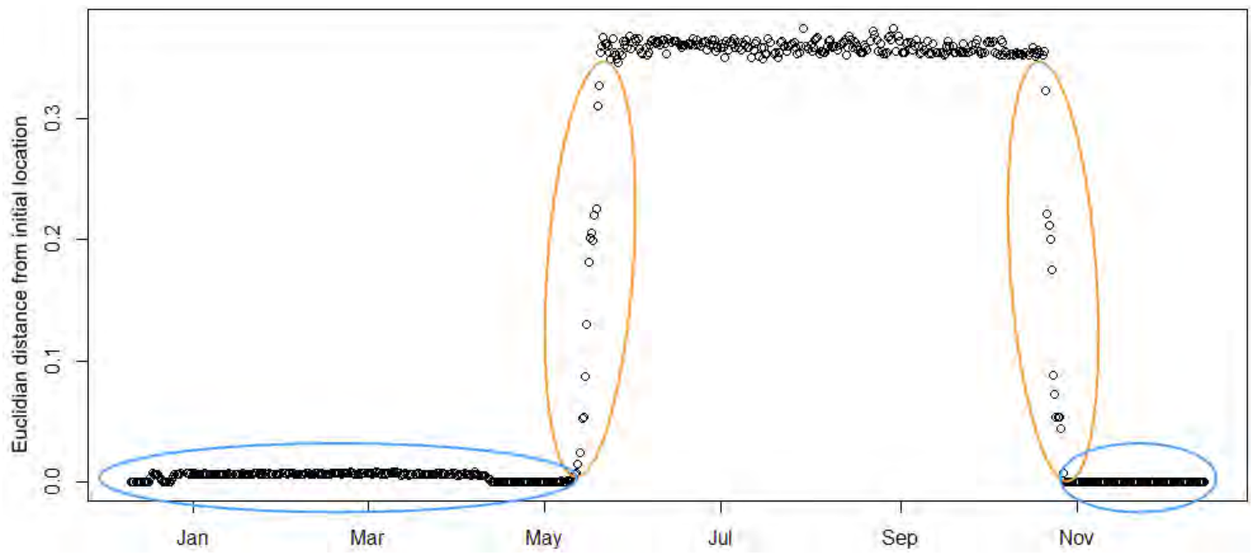


Figure A3. Plot of net displacement distance from starting location over time for an example individual, illustrating means of isolating migration movements (orange) and winter periods (blue) from GPS collar datasets.

Table A1. Summary of GPS collar data from a) mule deer and b) elk provided for use in Approach A.

a) Mule deer

Study	No. Individuals	No. Relocations	No. Indiv. Migration Periods	No. Migration Relocations	No. Indiv. Winter Periods	No. Winter Relocations
Bears Ears	131	130,098	258	6,803	230	34,895
Durango	65	273,666	42	3,881	50	58,349
Gunnison	51	33,184	62	1,085	71	15,753
Middle Park	60	115,164	42	813	66	41,852
Piceance Basin	99	54,420	158	3,356	162	30,147
Uncompahgre	30	35,733	54	596	64	16,812
White River	127	131,157	225	5,380	206	42,952
Rosa	62	63,132	92	24,598	NA	NA
S. Ute East	19	5,022	32	2,350	NA	NA
S. Ute West	36	25,201	67	9,316	NA	NA
Total	**680**	**866,777**	**1,032**	**58,178**	**849**	**240,760**

b) Elk

Study	No. Individuals	No. Relocations	No. Indiv. Migration Periods	No. Migration Relocations	No. Indiv. Winter Periods	No. Winter Relocations
Bears Ears	66	80,716	183	5,892	161	23,852
Gunnison	75	84,706	208	4,972	157	29,628
Middle Park	54	39,155	20	573	20	4,088
San Luis Valley	12	58,676	18	1,953	14	9,317
White River	75	90,228	179	4,933	170	30,296
Total	**282**	**353,481**	**608**	**18,323**	**522**	**97,181**

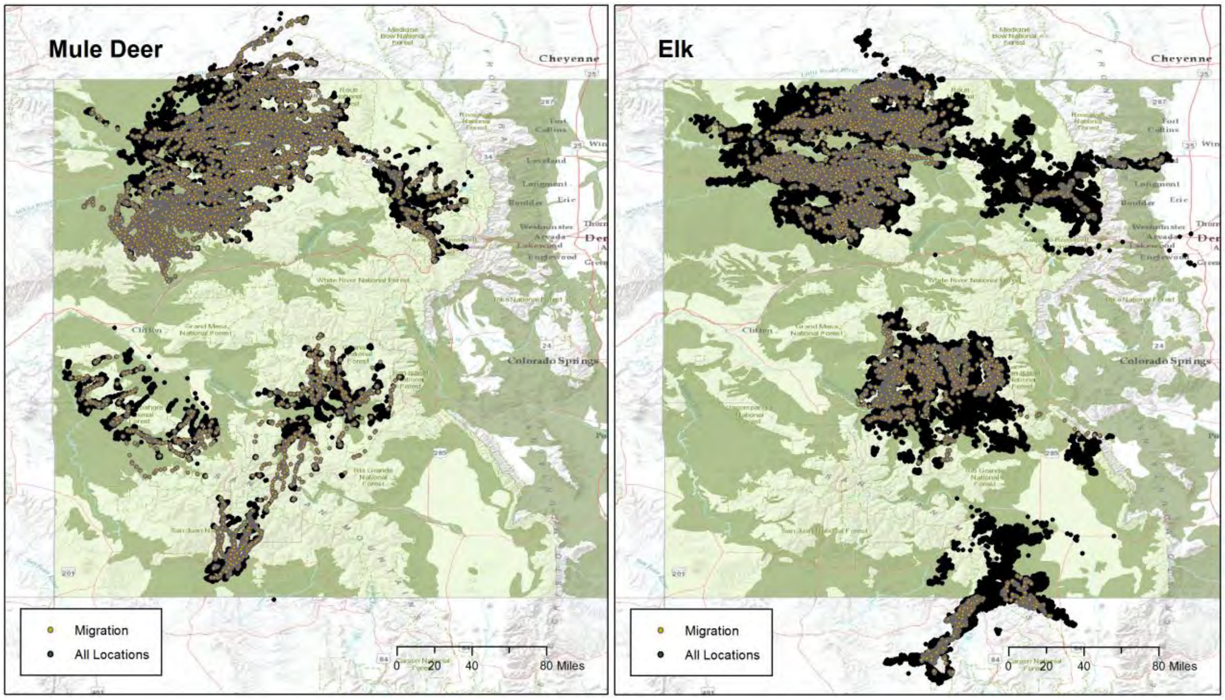


Figure A3. Mapped distribution of GPS collar data provided for a) mule deer and b) elk.

We used the filtered migration and winter use GPS collar datasets to fit Brownian bridge movement models (BBMM), estimating the probability of an individual passing through any given raster cell between observed GPS collar relocations (e.g., Fig. A4; Horne et al. 2007). BBMMs were fit to each movement ‘bout’ (i.e., migration movement or winter period) observed for each individual using the “brownian.bridge” function in the BBMM package (Nielson et al. 2013) for R (R Core Team 2017) and parameter settings described in McClure et al. (2017). We also summed all migration BBMMs and all winter BBMMs for each herd to produce herd-level estimates of movement probability, following methods described by Sawyer et al. (2009). Probability of use values sampled from both individual- and herd-level BBMMs were considered as response variables in resource utilization function (RUF) models, described below.

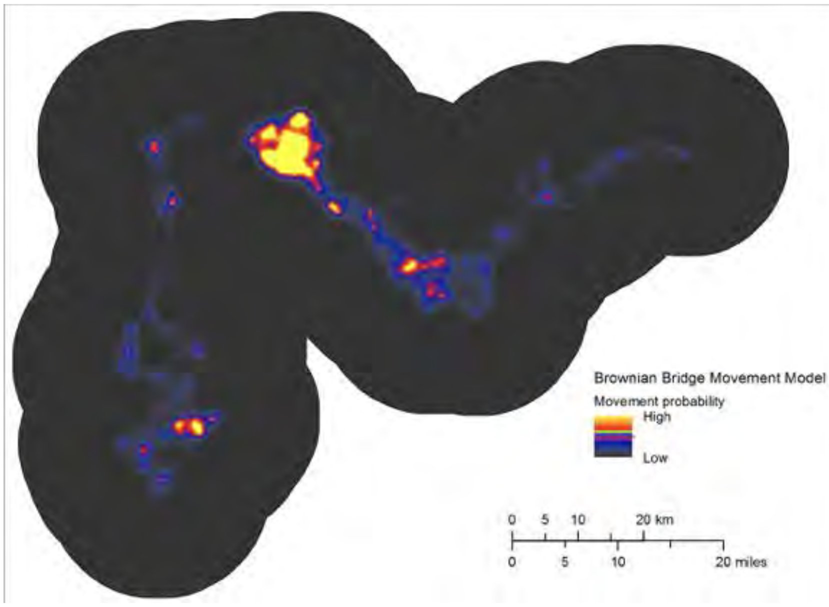


Figure A4. Example Brownian bridge movement model surface representing probability of an individual moving through a given raster cell between GPS relocations.

Spatial data used to derive explanatory landscape attribute variables for RUF models were obtained from a variety of sources (Table A2). These variables were identified based on published literature on mule deer and elk habitat selection, as well as additional input from the CPW biologists serving on the WSWPS study panel, and included aspects of vegetation cover, topography, access to water, and human disturbance. We derived each 30-m resolution variable at three scales (i.e., summarizing values across moving windows 90 m, 270 m, and 810 m wide) in order to assess potential for mule deer and elk to respond to landscape attributes at different scales.

Table A2. Summary of landscape covariates used in Approach A resource utilization functions.

Category	Name	Description	Resolution	Source Data
Vegetation cover	Distance from tree edge	Distance from nearest tree cover	30 m	USGS 2013
	Percent aspen	Percent aspen cover within moving window (3 extents tested)	30 m	USGS 2013
	Percent conifer	Percent conifer cover within moving window (3 extents tested)	30 m	USGS 2013
	Percent pinyon	Percent pinyon cover within moving window (3 extents tested)	30 m	USGS 2013
	Percent oakbrush	Percent oakbrush cover within moving window (3 extents tested)	30 m	USGS 2013
Topography	Elevation	Elevation in meters	30 m	USGS 1999
	Aspect	Northness and eastness, calculated and sin/cosine of aspect in degrees	30 m	USGS 1999
	Topographic position (multiscale)	Relative topographic position (canyon = low, ridge = high) averaged across 5 spatial scales	30 m	USGS 1999
	Terrain ruggedness	Standard deviation of elevation values within 270	30 m	USGS 1999

		m x 270 m moving window		
Water Access	Distance from water	Distance from nearest perennial water source (flow > 3cfs)	270 m	US EPA & USGS 2012
	Irrigated agriculture	Presence/absence of irrigated agriculture	250 m	Pervez & Brown 2010
Human Disturbance	Distance from nearest road	Distance from nearest paved road	30 m	USCB 2017
	Distance from nearest active well	Distance from nearest well pad classified as active	30 m	COGCC 2017
	Distance from suburban housing density	Distance from nearest area classified as suburban or greater housing density	100 m	US EPA 2013

The relationship between each BBMM and the landscape attribute variables described above was modeled to estimate habitat quality for movement. We first generated the same number of random points from each individual BBMM as the number of GPS locations used to estimate the BBMM (e.g., Willems & Hill, 2009). At each random point, we sampled the probability estimate from the BBMM along with all landscape covariates. We then estimated habitat quality for movement using linear mixed models (LMMs) and multimodel inference (Fig. A5; Burnham & Anderson, 2002). LMMs were fitted using individuals within herds as a nested random effect, and an exponential spatial covariance structure was used to account for residual spatial autocorrelation (Dormann et al., 2007), though simpler model structures were explored as well (e.g., use of herd-level BBMMs as response variable to reduce nesting). We fit all subsets of a global model that contained linear terms for the habitat variables described above, as well as quadratic terms where appropriate (i.e., distance variables, elevation, ruggedness). Maximum likelihood and values of Akaike's Information Criterion (AIC; Burnham & Anderson, 2002) were used to determine how well the global model approximated the data, compared to a null model that included only nested random effects. For each landscape covariate, we estimated model-averaged regression coefficients (β), unconditional standard errors, and weights of evidence in favor of a given variable (w+; Burnham & Anderson, 2002; Lukacs, Burnham, & Anderson, 2006). The empirical Huber-White "sandwich" estimator was used to compute the variance-covariance matrix of fixed-effects parameters (Wooldridge, 2009). All analyses were conducted in SAS (v9.3; SAS Institute, Inc., Cary, North Carolina, USA) and R (R Core Team 2017).

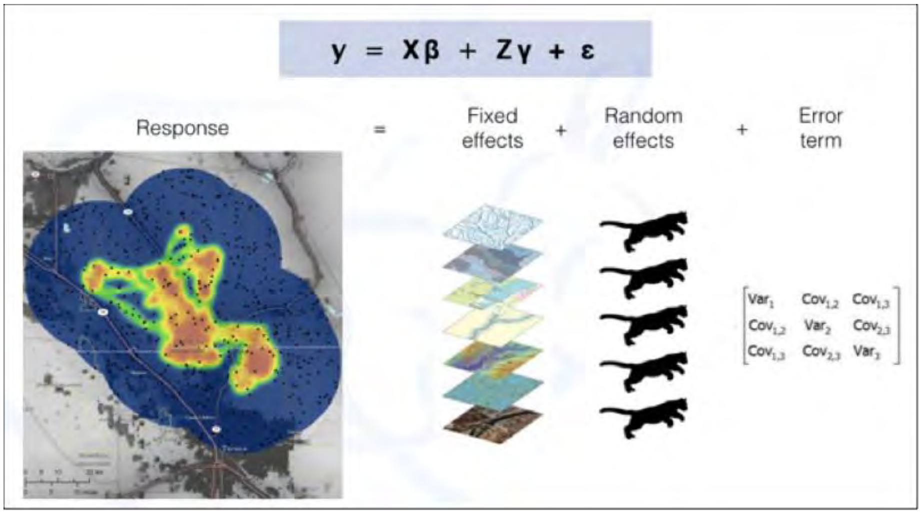


Figure A5. Overview of intended resource utilization function model structure.

Results. Although many of the fitted RUF models estimated patterns of space use considerably better than null models (dAIC >> 100), we found that they consistently explained very little variance in probability of use given landscape attributes. We achieved the best results using summed BBMMs representing herd-level probability of movement as our response variable, with landscape attributes derived at an 810-m scale, but even at best, the proportion of variance explained was quite low (i.e., adjusted $r^2 = 0.22$). Furthermore, a comparison of our global model with a null model containing only the herd-level random effect and spatial covariance term demonstrated that our landscape covariates explained very little of this variance ($r^2 = 0.08$); most of the variance explained was attributable to differences among herds and proximity of observation to one another.

This lack of explanatory power of our models appears to be due to high variability in the landscape attributes selected by mule deer and elk in the Western Slope landscape. We plotted probability of use sampled from BBMMs against individual landscape covariates, for both individual BBMMs (Fig. A5) and summed herd-level BBMMs (Fig. A6), and observed no discernable relationship between probability of use and any landscape attribute. This finding is consistent with our interpretation of the relatively low levels of variance explained by the final risk models presented above, and was the deciding factor in our decision to pursue alternative approaches.

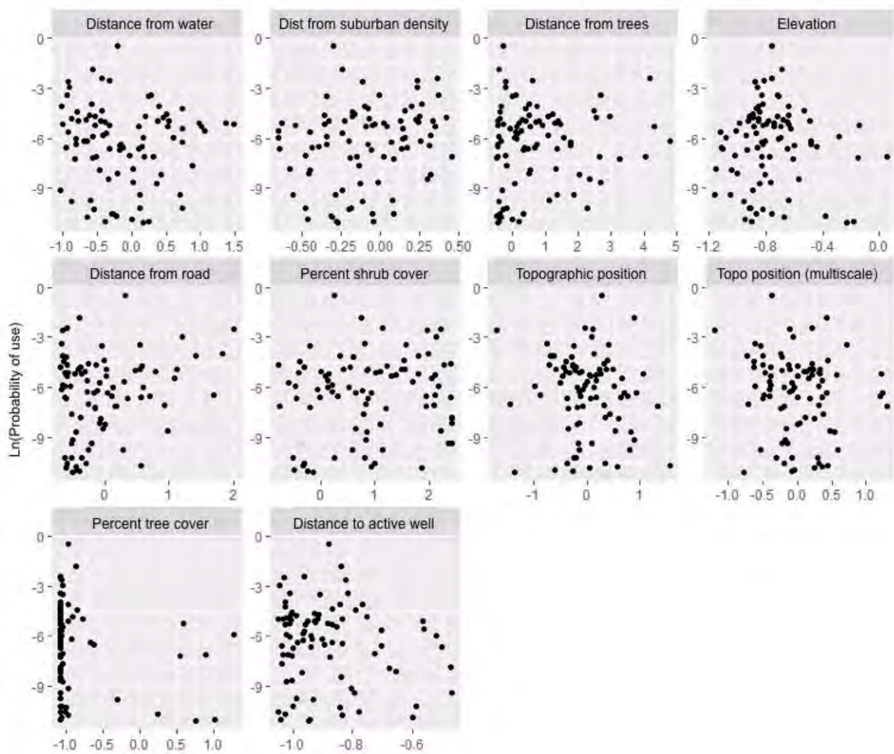


Figure A5. Scatterplots of relationships between movement probability (from BBMM) and habitat covariates for a representative sample individual.

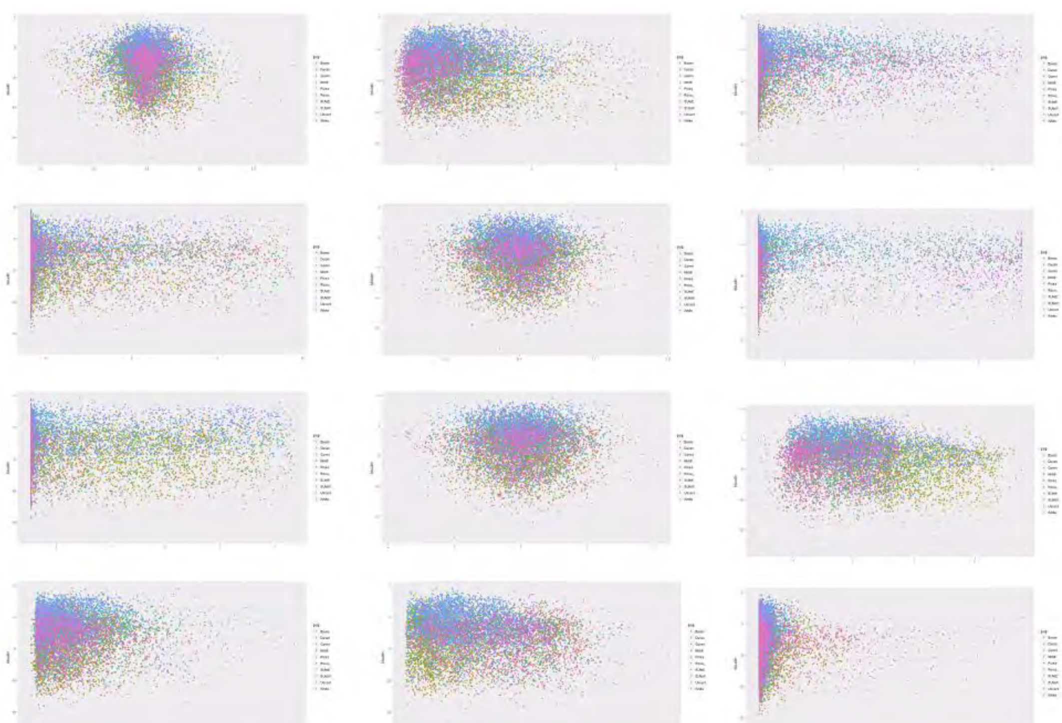


Figure A6. Scatterplots of relationships between herd-level movement probability during migration (summed from individual BBMMs) and habitat covariates for all mule deer herds (color-coded by herd).

Approach B

Summary. Approach B was similar to approach A, except that rather than estimating wildlife movement probability continuously throughout the Western Slope in response to landscape attributes, we focused on probability of movement immediately adjacent to and across roads in response to road-adjacent landscape attributes. In other words, we restricted analysis and inference to the road network, buffered by a distance sufficient to encompass attributes that may influence animals' selected path of approach to the road.

Methods. Our methods were identical to those of Approach A, except that when sampling BBMMs and associated landscape attributes for fitting RUF models, we restricted our sample to a buffered distance from roads. We fit models to observations sampled from buffered areas extending 5 km, 1 km, and 500 m from roads.

Results. We found that restricting the scope of our models to areas adjacent to roads improved overall model fit (Table A3). We saw improvement in proportion variance explained (adjusted r^2) as we further restricted sampling distance from roads, though this improvement appeared to begin to level off. However, we also observed the same issue noted in the results of Approach A: the majority of the variance explained by these models was attributable to differences among herds and proximity of sampled points to one another. Only 6-7% of the variance was attributable to the landscape covariates of interest. Again, this finding led us to turn to Approach C.

Table A3. Model fit statistics for road-focused resource utilization function (RUF) models compared to a Western Slope-wide model.

Buffer Distance	adjusted r^2
None (West Slope-wide)	0.2217
5 km	0.2373
1 km	0.3269
500 m	0.3369

Appendix B. Prioritization Criteria Data Summary

Prioritization Criteria

The attribute table for the shapefile 'CDOT HighwaySegments_PriCrit.shp' contains values for all half-mile highway segments across the Western Slope representing the following prioritization criteria:

WVC Risk for Elk & Mule Deer (Current). Modeled relative probability of WVCs based on relationship between recorded WVC/carcass locations and attributes of roads and surrounding landscape. Separate risk models were produced for each species and each season of interest: migration periods and winter range use.

WVC Risk for Elk & Mule Deer (Future: 2045). Modeled relative probability of WVCs based on relationship between recorded WVC/carcass locations and attributes of roads and surrounding landscape. Models of current risk were projected forward by replacing current conditions with projected traffic volume (2045) and projected distance to suburban or greater housing density (2050). 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 and Mule Deer. Density of winter herds in winter concentration areas and other portions of winter range, calculated by attributing DAU herd size estimates such that density in concentration areas is twice that of other winter range areas within each DAU.

Magnitude of migration movement for elk and mule deer. Distance between the point of highest elevation within each DAU and the centroid of winter concentration area areas in the DAU multiplied by the DAU herd size estimate.

WVC Mortality as a Proportion of Population. Five-year average annual WVC count in each DAU divided by the DAU herd size estimate.

Connectivity Value for Lynx. Modeled lynx highway crossing probability (continuous values 0-1) estimated by Baigas et al. 2017 based on the relationship between observed lynx crossing locations and road and adjacent landscape attributes.

CDOT Wild Animal Accident Pattern Recognition. WVC hotspot value calculated by CDOT's WVC pattern recognition algorithm.

Energy Development Threat. Presence of an energy basin (0 or 1).

Land Security Value. Percent land area within a 0.5 x 0.5 mile moving window that is managed by a public agency or that is otherwise protected (e.g., private easement).

Applying prioritization weights

Values for each of the above criteria have been scaled 0-1 and attributed to each half-mile segment of CDOT-maintained highway across the Western Slope. The field 'PriScore' is a placeholder for priority scores calculated using committee-defined weights for each criterion. To calculate and visualize priority scores for each highway segment given a particular set of weights, right click the field's header in the attribute table and select 'Calculate Field…' (Fig. 1). Calculate the priority score as a weighted sum using the formula:

Priority = Weight1 * Criteria1 + Weight2 * Criteria2 + ….

The data, as currently scored, can also be explored in a currently private gallery on Data Basin. The map titled 'CDOT WSWPS Prioritization' includes a layer displaying priority scores calculated using current criteria weights, along with layers displaying each of the current WVC risk models. Other criteria values can be queried for a given segment of interest using the 'Information' tool in the map interface header.

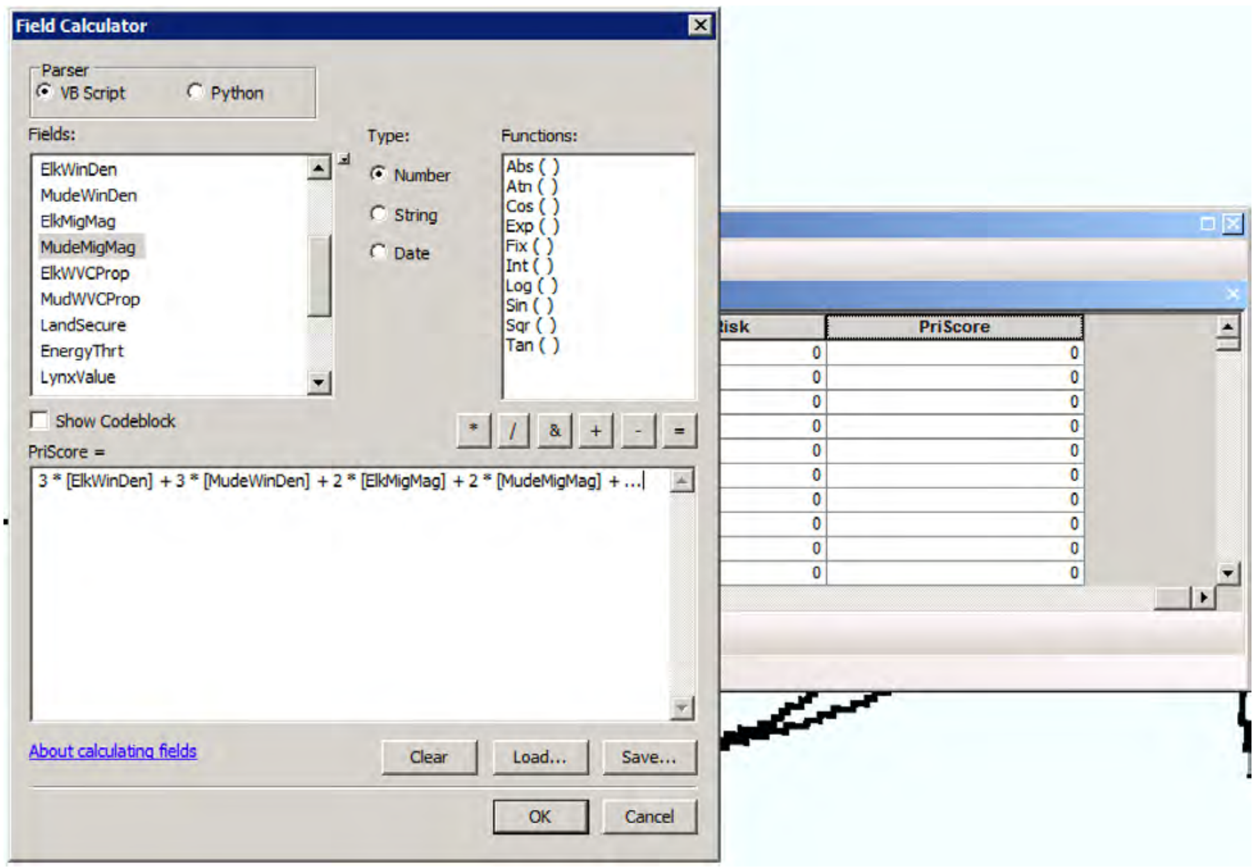
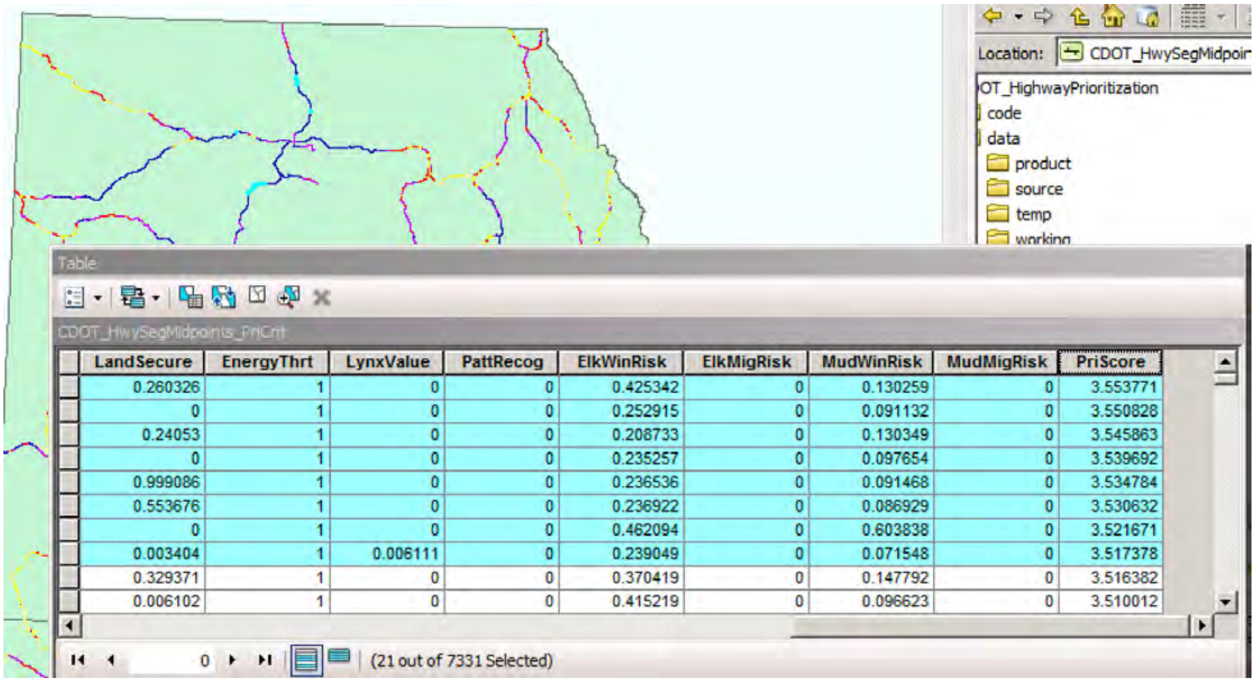


Figure 1. Example of calculating priority scores as a weighted sum in ArcGIS.

To visualize relative scores across all highway segments, symbolize the data layer based on the 'PriScore' field; we suggest using the 'Quantities: Graduated Colors' symbology option. A simple way to quickly highlight only the top-scoring road segments is to open the attribute table and sort priority scores in descending order by double clicking the 'PriScore' field header twice, then selecting a desired number of top-ranked half-mile segments (Fig. 2). Or, to visualize scores for only priority segments that exceed a defined threshold score, choose 'Quantile' classification under the 'Classify…' dialog box, choose a threshold value based on the desired percentile cutoff (e.g., top 1%, top 5%), then use the 'Exclude values…' option to set the threshold (i.e., exclude the range of values from the minimum to the value associated with the threshold you set).



LandSecure	EnergyThrt	LynxValue	PattRecog	ElkWinRisk	ElkMigRisk	MudWinRisk	MudMigRisk	PriScore
0.260326	1	0	0	0.425342	0	0.130259	0	3.553771
0	1	0	0	0.252915	0	0.091132	0	3.550828
0.24053	1	0	0	0.208733	0	0.130349	0	3.545863
0	1	0	0	0.235257	0	0.097654	0	3.539692
0.999086	1	0	0	0.236536	0	0.091468	0	3.534784
0.553676	1	0	0	0.236922	0	0.086929	0	3.530632
0	1	0	0	0.462094	0	0.603838	0	3.521671
0.003404	1	0.006111	0	0.239049	0	0.071548	0	3.517378
0.329371	1	0	0	0.370419	0	0.147792	0	3.516382
0.006102	1	0	0	0.415219	0	0.096623	0	3.510012

Figure 2. Example of exploratory selection of top-ranked segments.

APPENDIX F: Wildlife Valuation Methods

Appendix F
Wildlife Valuation Using Contingent Valuation Methods

Developed by the Jacobs Team in collaboration with CDOT and CPW:

CPW: Krista Heiner, Katie Lanter, Dean Riggs, Christine Zenel
CDOT: Oana (Deselnicu) Ford
Jacobs: Pat Basting
ECO-resolutions: Julia Kintsch

Colorado Department of Transportation (CDOT) and Colorado Parks and Wildlife (CPW) desire a verifiable approach for assigning a dollar value to wildlife, specifically to mule deer and elk. Wildlife valuations will be integrated into benefit-cost analyses for evaluating potential wildlife-highway mitigation projects. Currently in Colorado wildlife values are not included in benefit-cost analyses for these types of projects.

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 (WVC). The most commonly 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. 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 WVC 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, accident attendance and investigation, the hunting value of the animal, and the cost of disposal of the animal carcass. The assigned values of $142 for each deer killed in a collision and $486 for elk (in 2018 dollars) are the hunting values expressed as the probability that an animal will be successfully harvested by a hunter derived from the U.S. Fish and Wildlife Service's 2001 national survey of fishing, hunting and wildlife-associated recreation (UWSFS 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, intrinsic values). In addition, when compared to the statutory values set by the Colorado legislature, this wildlife valuation further underestimates the benefits to society.

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 non-market resources, such as wildlife or other environmental values, including both use and non-use values. Using this method, wildlife value is calculated as:

Wildlife Value = Willingness to Pay Value (deer/elk) + Weighted Average Fee Value (deer/elk) + Average Expenditure per Non-resident 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 or elk, beyond hunting fees or trip expenses. WTP values are derived from the net economic values addendum to the U.S. Fish and Wildlife Service's national survey of fishing, hunting and wildlife-associated recreation (USWFS 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 2018 dollars using the U.S. Bureau of Labor Statistic Consumer Price Index Inflation Calculator (Table 1).

Table 1. Willingness to Pay (WTP) mean aggregate values for deer and elk in 2011 and 2018 dollars (USFWS 2011).

Species	**WTP (2011)**	**WTP (2018)**
Deer	$843	$949
Elk	$1,025	$1,154

The Weighted Average Fee Value for deer and elk is based upon CPW's most recently available data (2014 – 2016) of deer and elk hunting licenses sold in Colorado and license fees for 2018. For elk, the non-resident 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 x Resident License Fee) + (3-Year Average Number of Nonresident Licenses Sold) x Non-Resident License Fee)] / 3-Year Average Total Number Licenses Sold

Weighted Average Fee Value for Deer = [(58,600 x $31) + (15,100 x $396)] / 73,700 = $105.78

Weighted Average Fee Value for Elk = [(141,200 x $46) + (66,500 x $627.50)] / 207,700 = $232.18

Average Expenditures for non-resident 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; hunting fees were also excluded to avoid double counting). Only non-resident 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 weren't 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 2011 dollars, which converts to $1,002.84 in 2018 dollars.

Each of the values that comprise the Wildlife Value equation are presented in Table 2.

Table 2. Wildlife Value equation components for deer and elk.

Species	WTP Value	Weighted Average Fee Value	Average Expenditures
Deer	$949	$106	$1,006
Elk	$1,154	$232	$1,006

Accordingly, we calculated the following values for deer and elk in Colorado:

Deer Value = $949 + $106 + $1,006 ***= $2,061***

Elk Value = $1,154 + $232 + $1,006 ***= $2,392***

Advantages of this approach:

- Based upon accepted economic theory and used in other published reports.
- While still a conservative estimate of deer and elk values, this approach provides a more comprehensive wildlife valuation than either of the alternative approaches;
- The input values may be updated when more refined data become available, for example, Colorado-specific WTP values for deer and elk.
- Input values derived from two primary data sources: the USFWS and Colorado Parks and Wildlife.

Disadvantages:

- This method still does not address all of the potentially quantifiable benefits of wildlife, as comprehensive, discrete data do not currently exist; nor does it address the numerous unquantifiable benefits of wildlife (e.g., passive values; reproductive value of cows/does; ecosystem value of connectivity), and these non-monetary 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.

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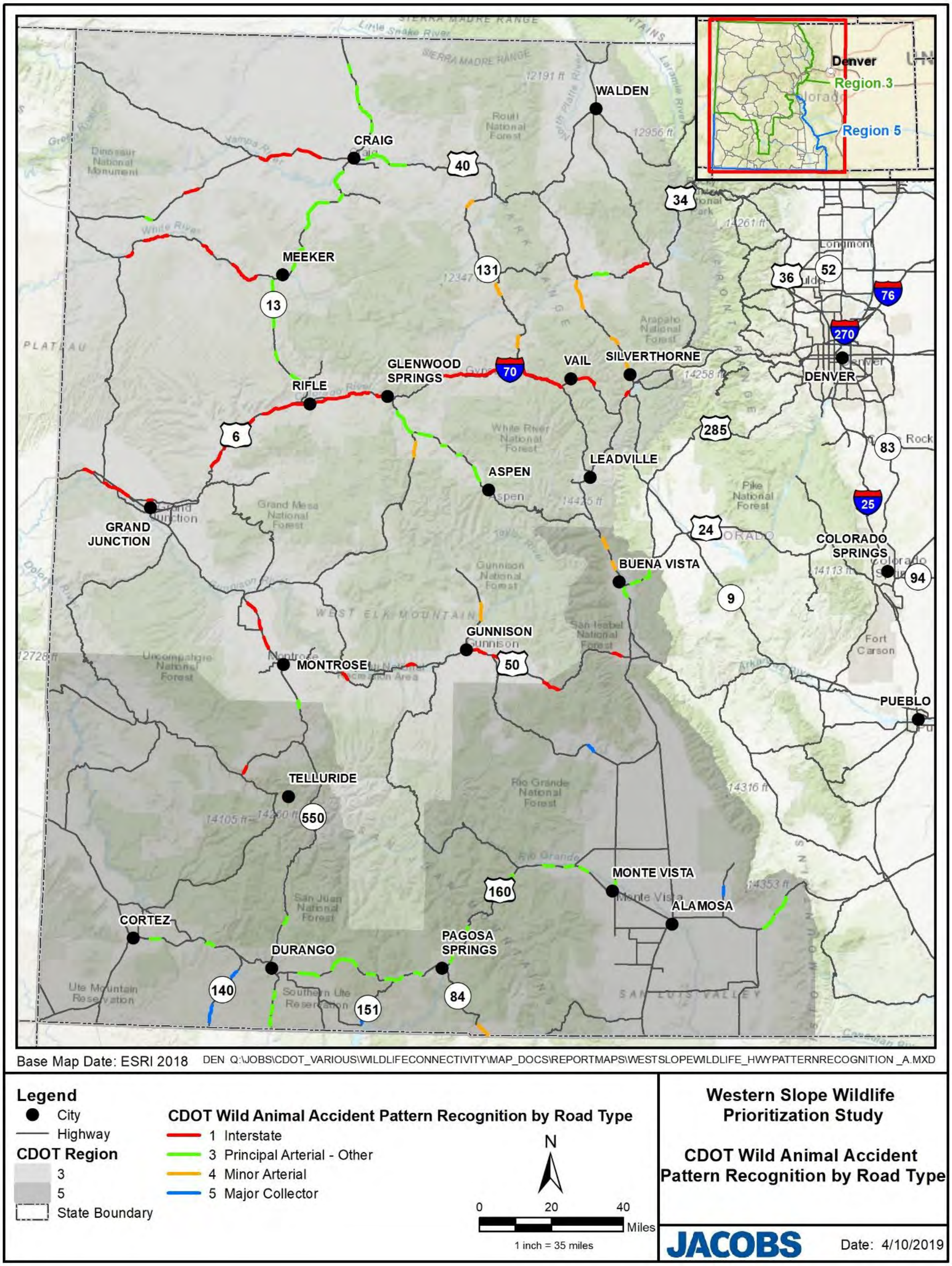
Wakeling,B.F., J.W. Gagnon, D.D. Olson, D.W. Lutz, T.W. Keegan, J.M. Shannon, A. Holland, A. Lindbloom, and C. Schroeder. 2015. Mule deer and movement barriers. Mule Deer Working Group, Western Association of Fish and Wildlife Agencies, USA.

APPENDIX G: Prioritization Criteria Output Maps



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CDOT Wild Animal Accident Pattern Recognition by Road Type
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4 Minor Arterial
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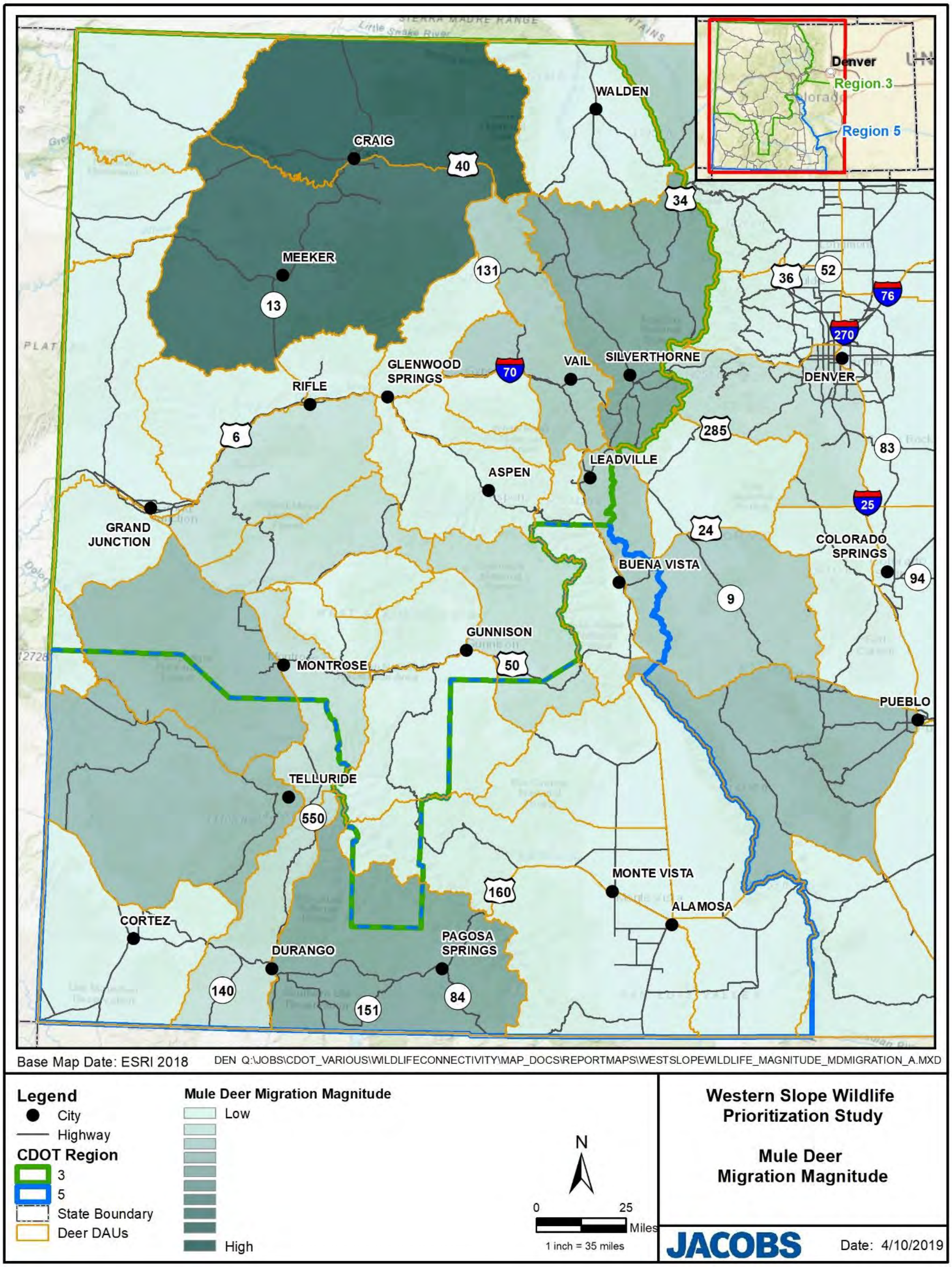
1 inch = 35 miles
Western Slope Wildlife Prioritization Study
CDOT Wild Animal Accident Pattern Recognition by Road Type
JACOBS
Date: 4/10/2019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Deer DAUs
Mule Deer Migration Magnitude
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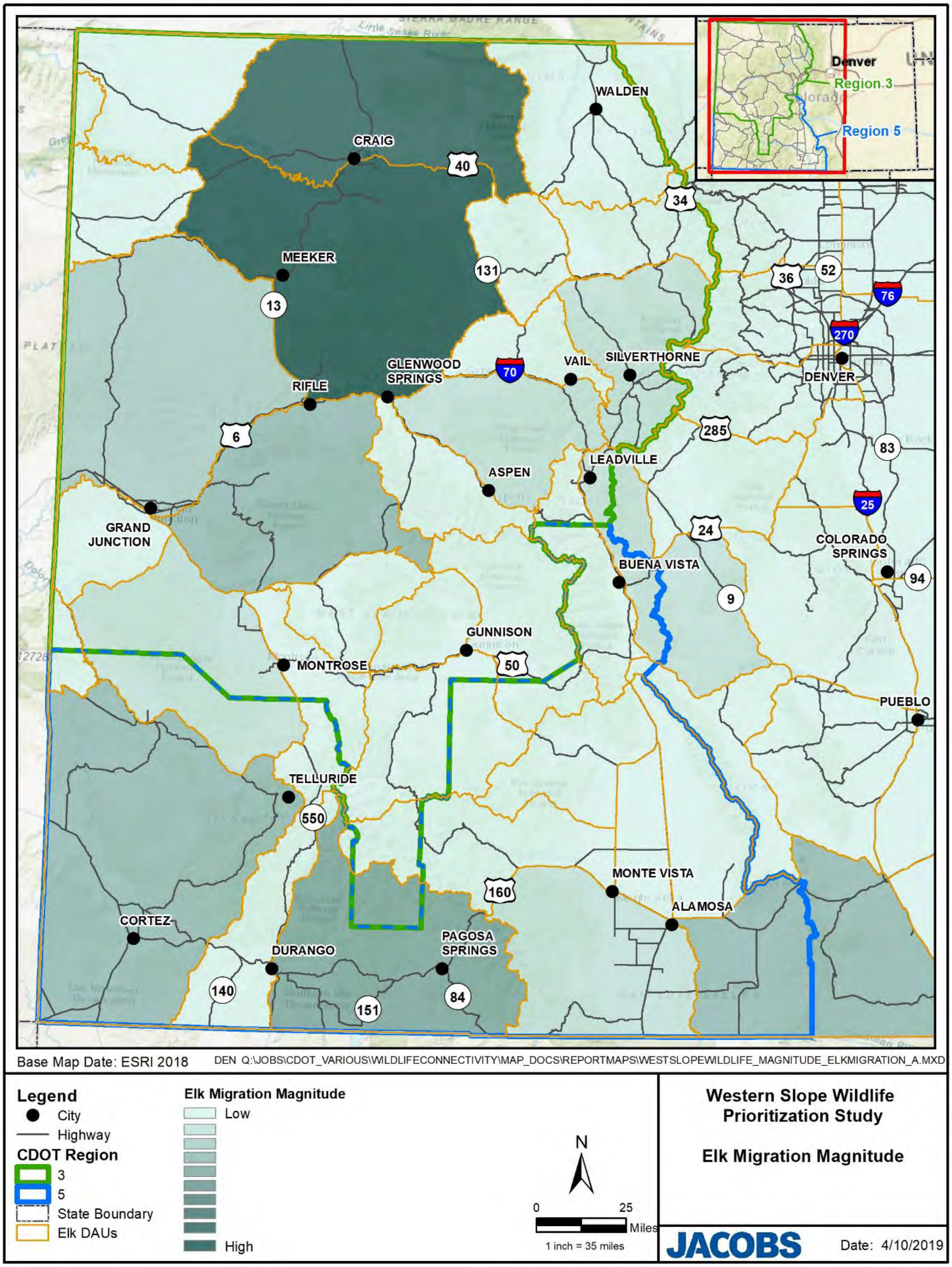
Western Slope Wildlife Prioritization Study
Mule Deer Migration Magnitude
JACOBS
Date: 4/10/2019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Elk Migration Magnitude
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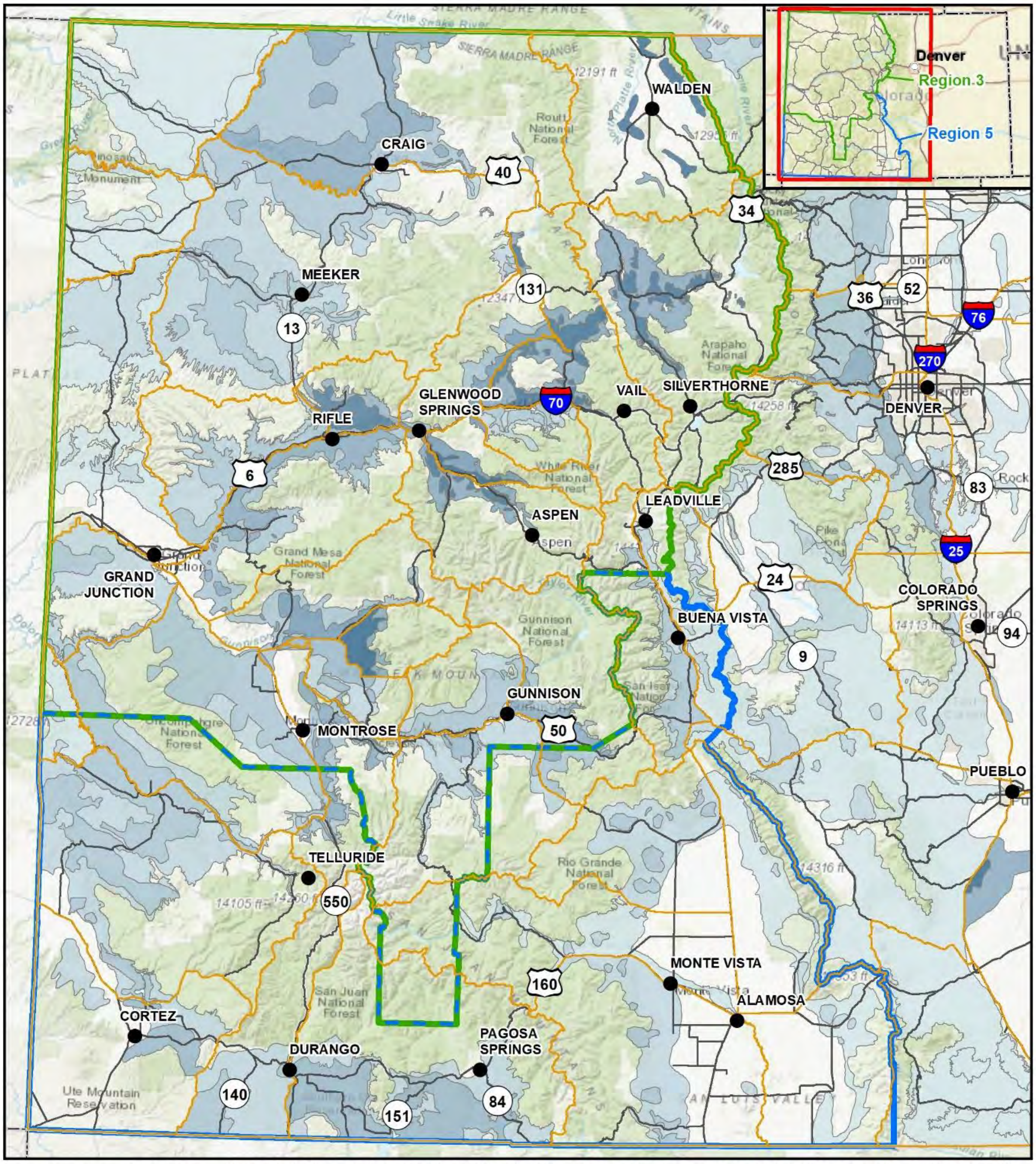

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- State Boundary
- Deer DAUs

Mule Deer Winter Population Density

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High

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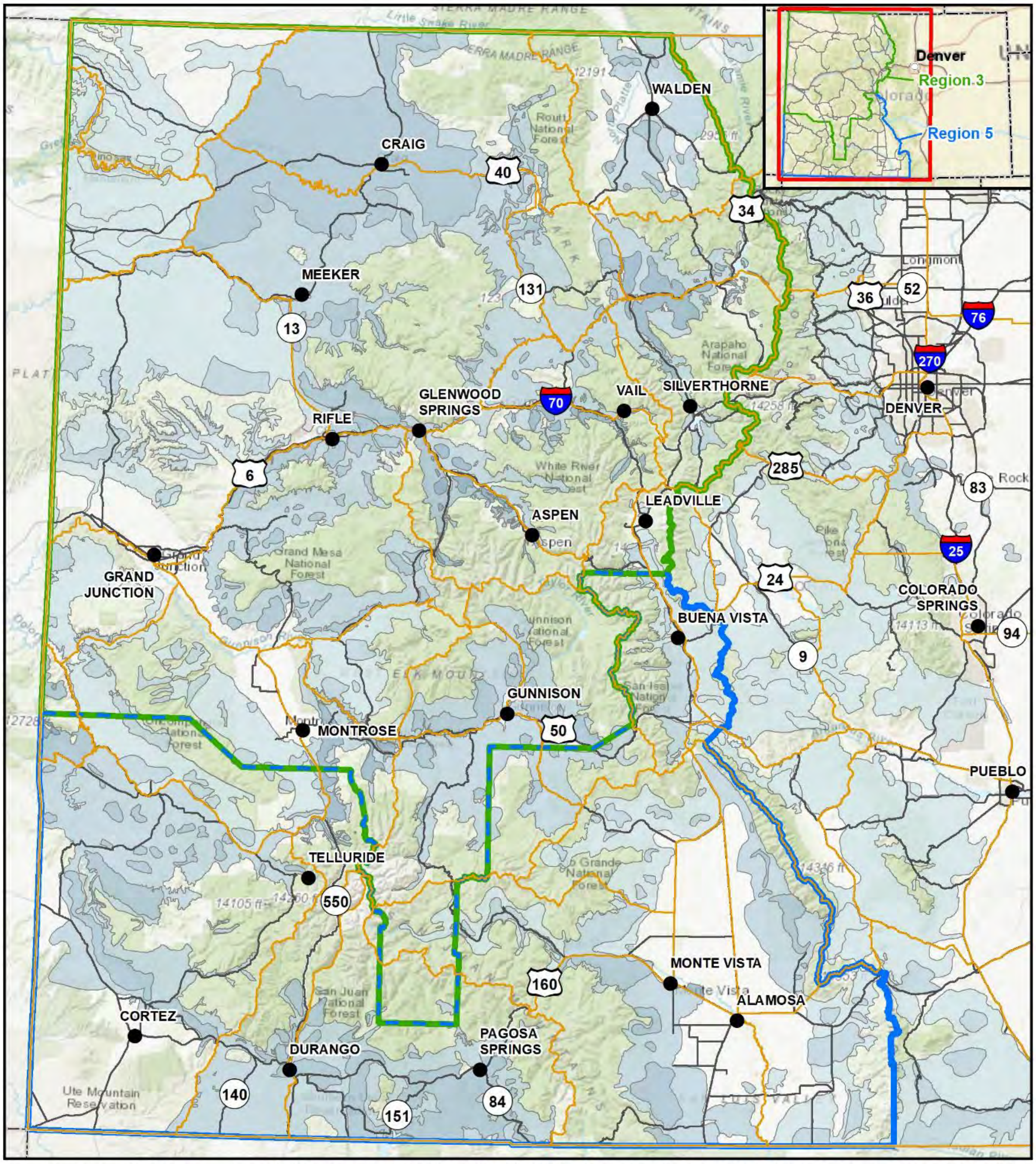
1 inch = 35 miles

Western Slope Wildlife Prioritization Study

Mule Deer Magnitude of Winter Range Use

JACOBS

Date: 4/10/2019



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CDOT Region

- 3
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- State Boundary
- Elk DAUs

Elk Winter Population Density

Low

High

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0 25 Miles

1 inch = 35 miles

Western Slope Wildlife Prioritization Study

Elk Magnitude of Winter Range Use

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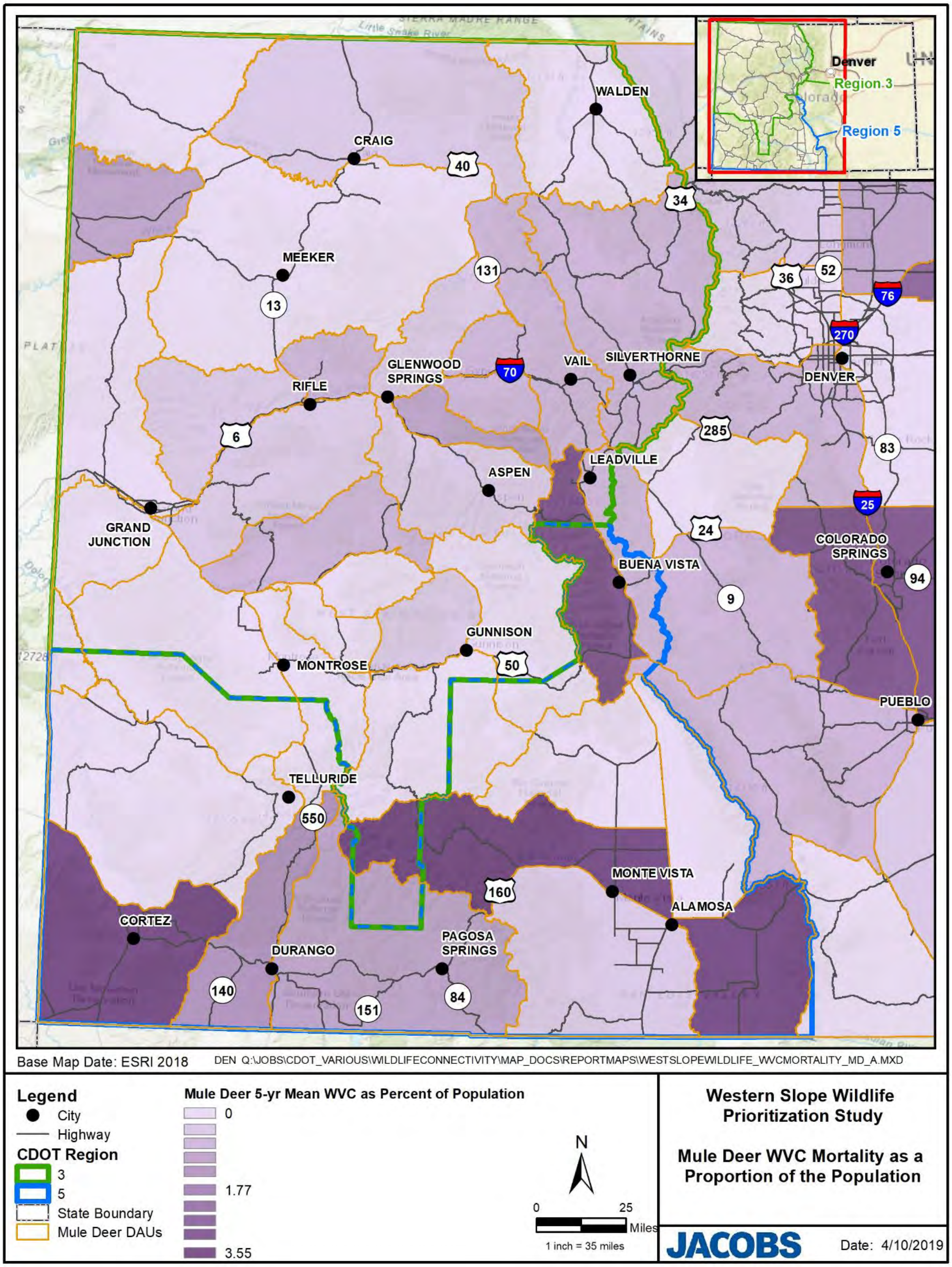
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Mule Deer DAUs
Mule Deer 5-yr Mean WVC as Percent of Population
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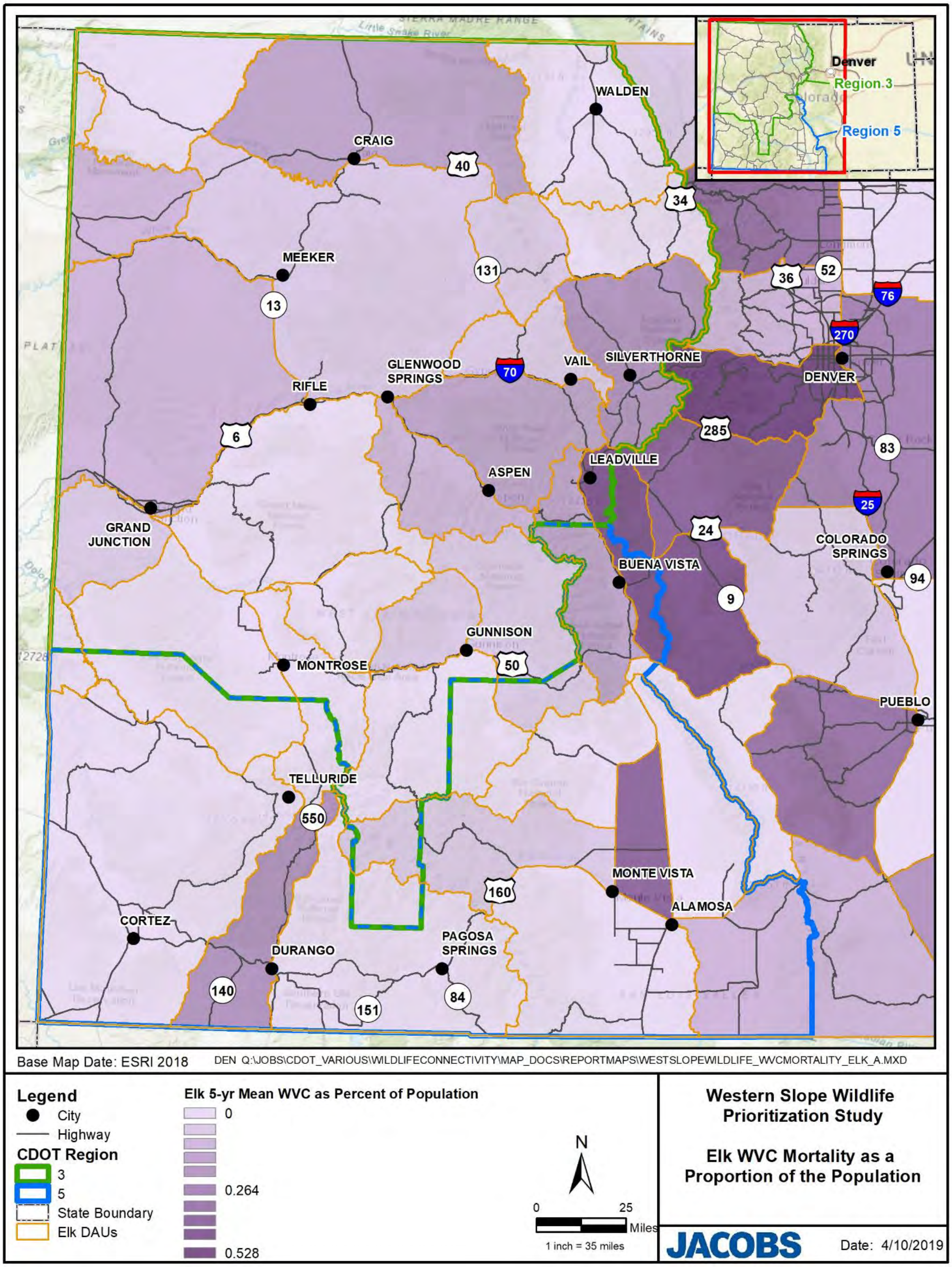
Miles
1 inch = 35 miles
Western Slope Wildlife Prioritization Study
Mule Deer WVC Mortality as a Proportion of the Population
JACOBS
Date: 4/10/2019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Elk DAUs
Elk 5-yr Mean WVC as Percent of Population
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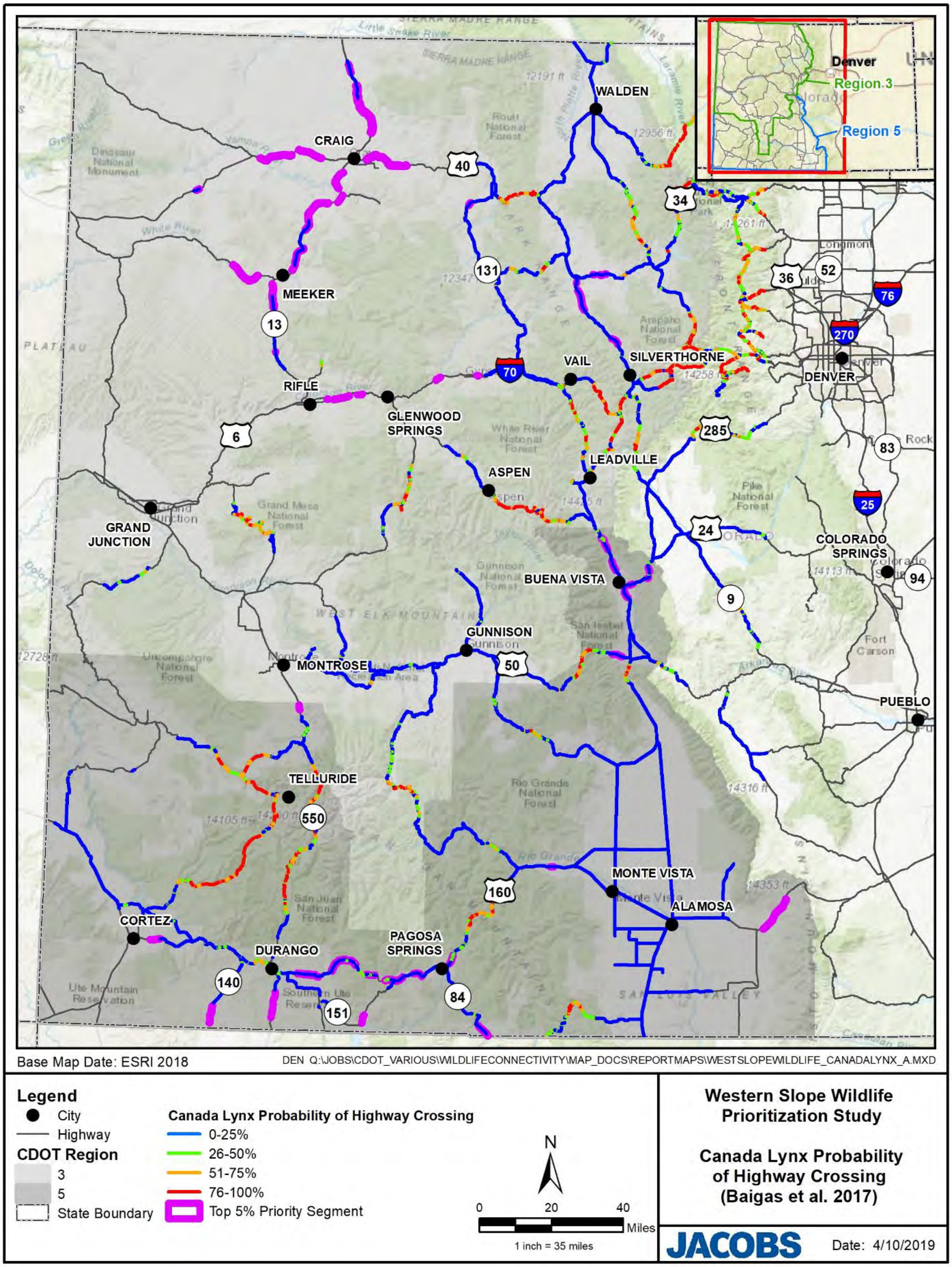
Miles
1 inch = 35 miles
Western Slope Wildlife Prioritization Study
Elk WVC Mortality as a Proportion of the Population
JACOBS
Date: 4/10/2019



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Canada Lynx Probability of Highway Crossing
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26-50%
51-75%
76-100%
Top 5% Priority Segment
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0 20 40 Miles
1 inch = 35 miles
Western Slope Wildlife Prioritization Study
Canada Lynx Probability of Highway Crossing (Baigas et al. 2017)
JACOBS
Date: 4/10/2019

APPENDIX H: Wildlife-Highway Mitigation Recommendations

APPENDIX H: WILDLIFE-HIGHWAY MITIGATION RECOMMENDATIONS

How to Use this Appendix

This appendix contains preliminary recommendations for wildlife crossing structures and other mitigation within each of the high priority segments identified in the WSWPS. Because of the large amount of information included in the appendix, a table of contents is provided on the following pages to allow users to search for 'click' and jump to a particular segment of interest. The table of contents is organized by CDOT region, highway and milepost.

For each highway segment, general crossing structure types and dimensions are provided based on the identified target species and the current roadway footprint as preliminary guidance for project planning and budgeting. More precise structure designs and dimensions will need to be determined by CDOT during project development and design. The recommended minimum crossing structure dimensions for deer or elk may not be feasible in all locations. For example, where the fill height beneath the road is insufficient for a 14-foot-high structure (recommended minimum height for an elk crossing structure), CDOT, in coordination with CPW biologists, may propose a shorter (for example, 12-foot-high) structure with a wider span to compensate for a reduction in height. Typical wildlife overpass structures include bridge or arch designs spanning the roadway; however, in some locations a non-standard hourglass shape may be proposed (e.g., 66 feet wide at the center and 100 feet wide at the approaches) to reduce structure costs. These adjustments and decisions are best determined at the project level in the context of a given roadway project, which may also allow for increasing fill heights at select locations to accommodate the installation of effective wildlife underpasses.

Multiple potential locations for wildlife crossing structures may be suggested for a given priority segment to provide project planning teams with flexibility to balance project needs. In several cases, the research team conducted a continuous survey along a given roadway with multiple top 5 percent priority segments close by. Recommendations for these combined segments are presented jointly where noted. Tenth-milepost locations were recorded in the field with a car odometer calibrated to milepost signposts.

For some highway segments discussed in this chapter, the locations for potential wildlife crossing structures fall beyond a top 5 percent segment boundary; however, that location may offer the best opportunity for a wildlife crossing structure. In other instances, an existing structure that could function for wildlife passage (for example, a large span bridge over a river corridor) lies outside of a top 5 percent segment, yet wildlife exclusion fence could be connected to the structure for a more comprehensive mitigation approach.

Wildlife exclusion fencing is always recommended in conjunction with wildlife crossing structures to guide animals to a structure. In general, long stretches of continuous fencing are recommended over shorter segments, which are less effective at reducing WVC rates (Huijser et al., 2016). Escape ramps, deer guards, gates, and fence end treatments are integral components of a wildlife-highway mitigation system; however, specific recommendations for these types of features are not included because they are best addressed at the project level.

The maps and discussion for each high priority segment highlight, where relevant, where highway segments overlap with Brownian Bridge Movement Models for deer and elk winter range and migration, as well as the Getis-Ord WVC cluster analysis. While these data were not ultimately used in the prioritization process, they may help inform mitigation decision-making at the project level. For example, the movement models provide additional detail regarding target species movements during migration or within winter range where these data are available. The Getis-Ord WVC cluster analyses are useful at the local scale for determining where WVC hotspots may be located within a high-priority segment to ensure that these hotspots are sufficiently mitigated. Accordingly, it should be noted that where a segment is identified as being not significantly different from the surrounding segments, this does not mean that the WVC rate is necessarily low. Rather, these areas should be interpreted as having a consistent WVC rate relative to the surrounding segments, and the WVC data should be consulted to determine whether the WVC rate is consistently low, medium, or high for a stretch of highway.

Wildlife crossing mitigation may not be feasible or currently advisable in all priority segments, such as in the following examples: where the terrain or other landscape conditions are not conducive to wildlife crossing structures, or where there is a high level of permeability across a road because of low traffic volumes (less than 2,000 AADT) that are expected to remain low into the foreseeable future. In such instances, replacing existing right-of-way (ROW) fencing, particularly when dealing with woven wire topped with barbed wire, with wildlife-friendly fencing help decrease the fencing barriers along the roadway. Doing so is likely to decrease the amount of time during which an animal is temporarily trapped within the ROW and the likelihood of WVC. AADT and future predicted AADT (CDOT, 2017) are provided for each highway segment and may be used to judge the barrier effect of a that segment.

High Priority Highway Segments

H-1 CDOT REGION 3 (NORTHWEST REGION)

H-1.1 Interstate 70 Priority Segments

H-1.1.1 INTERSTATE 70, MILEPOSTS 96.5 TO 107, RIFLE TO NEW CASTLE

I-70 is a major east-west corridor through the Rocky Mountains. This stretch of I-70 is a four-lane divided highway. The railroad and U.S. 6 run parallel to the interstate on the north side. The Colorado River also runs parallel, mostly along the south side of the interstate through this segment. Much of this combined segment and, in particular, MPs 96.5 to 100.5, was identified as a WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. Eight-foot-high wildlife exclusion fence is present throughout the segment; no deer guards are present at the interchanges. For the purposes of the field assessment and recommendations development, three top 5 percent priority segments were combined: MPs 96.5 to 97; MPs 98.5 to 103; MPs 105.5 to 107.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
4	24,000	34,080	Elk, Mule Deer	Migration and Winter Range	Moderate	19.5

* Average score for three top 5 percent priority segments

Preliminary Mitigation Recommendations

Multiple crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. No additional wildlife exclusion fencing is needed; however, gaps in the fencing at interchanges should be controlled with deer guards to prevent wildlife incursions into the fencing and reduce incidence of WVC on I-70. In addition, one-way gates with escape ramps should be removed and replaced.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
96.4	Large span bridge over the Colorado River. Bridge spans terrestrial banks on both sides except at high water levels.	This location is outside of the top 5 percent segment but already has a functional structure for wildlife passage with wildlife exclusion fencing. No additional recommendations at this location.	N/A
100.7	Frontage road access bridge over I-70.	Explore whether this bridge could be widened to create a multi-use overpass.	N/A
102.4	Frontage road access bridge over I-70.	Explore whether this bridge could be widened to create a multi-use overpass.	N/A
104	Elk Creek. Multiple creek bridges under I-70 and railroad. Riprap banks. River immediately on south side.	Widen all three bridges to span terrestrial banks when bridges being replaced.	N/A
107	One lane concrete road bridge over I-70. Gated access to Dept. Ag. Facility on south side. Potentially useable by deer and other wildlife. Nursery/orchard on north side of U.S. 6.	Replace gate with single bar gate to make the bridge more accessible to wildlife. Explore retrofit potential to improve wildlife friendliness (place a softer, non-slippery surface over the concrete).	

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

I-70
MP 96.5-97

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

I-70
MP 98.5-103

N

0 0.75 Miles

1 inch = 0.75 miles

JACOBS

Date: 1/9/2019

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

I-70
MP 105.5-107

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-1.1.2 INTERSTATE 70, MILEPOSTS 131 TO 132.5, WEST OF DOTSERO

This stretch of I-70 is a four-lane divided highway west of Dotsero. The Colorado River and the railroad run parallel along the south side of the interstate through this segment. Eight-foot-high wildlife exclusion fence is present throughout the segment.

Segment Characteristics

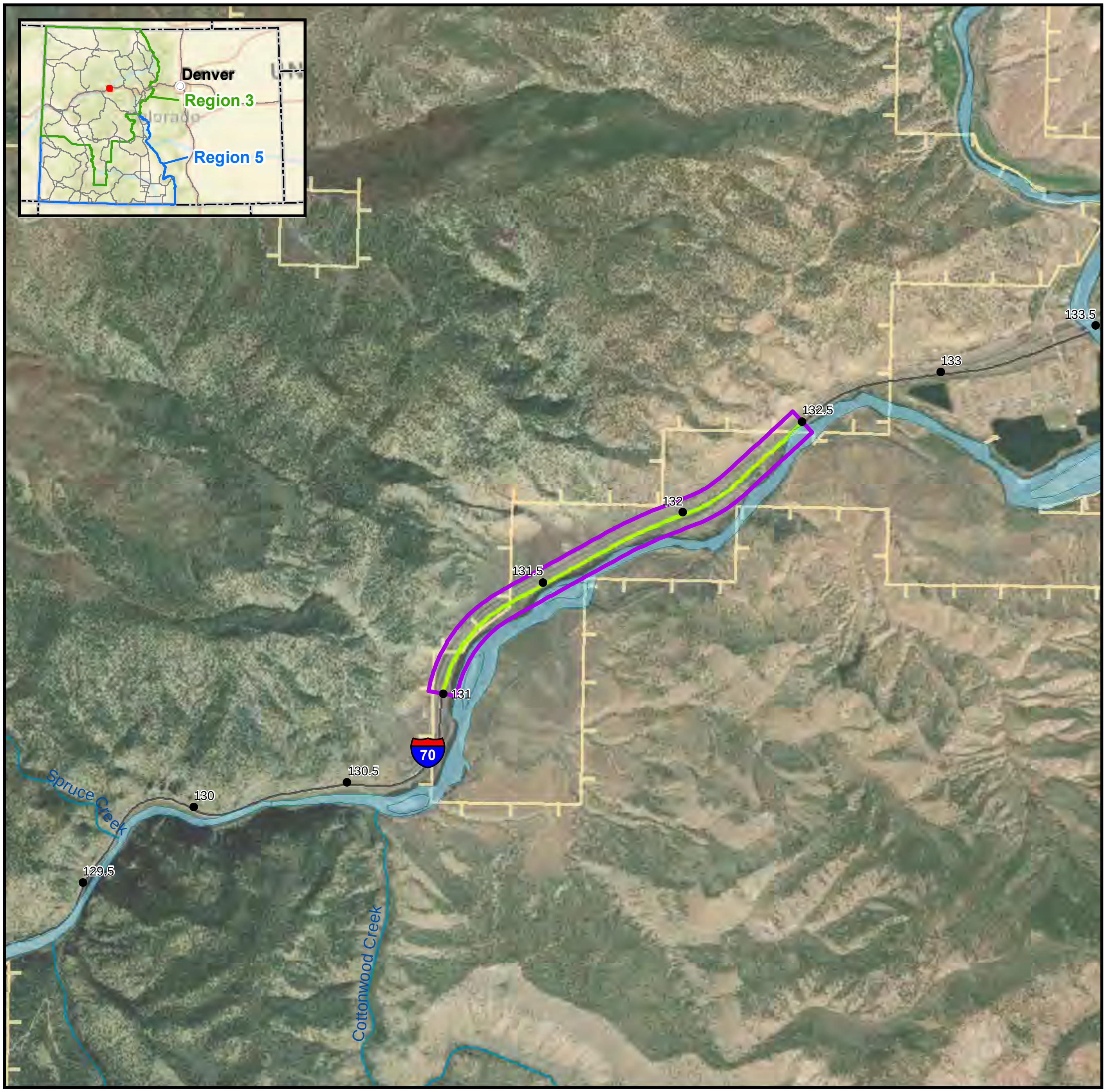
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
4	17,000	22,712	Elk and Mule Deer	Migration and Winter Range	Moderate	19.4

Preliminary Mitigation Recommendations

While there is no connectivity for wildlife across the interstate in this segment, no additional mitigation is recommended. The existing fencing is successful in preventing WVC.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
131.6	CMPs; small draws from north drops into Colorado River on south side.	None	N/A
132.1	CMPs; small draws from north drops into Colorado River on south side.	None	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
132.4	CMPs; small draws from north drops into Colorado River on south side.	None	
132.7	One-lane CBC, local access road.	None	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence

Cold Spot - 95% Confidence

Cold Spot - 90% Confidence

No Significant Difference

Hot Spot - 90% Confidence

Hot Spot - 95% Confidence

Hot Spot - 99% Confidence

Streams

Lakes

Land Management

Federal (BOR, FWS, NPS)

USFS

BLM

State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

I-70
MP 131-132.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-1.1.3 INTERSTATE 70, MILEPOSTS 143 TO 143.5, WEST OF EAGLE

This stretch of I-70 is a four-lane divided highway between Eagle and Gypsum. The Colorado River, railroad, and U.S. 6 run parallel to the interstate through the valley. Eight-foot-high wildlife exclusion fence has been present throughout the segment since 1979.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
4	19,000	26,182	Mule Deer and Elk	Winter Range and Migration	Moderate	19.06

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. No additional wildlife exclusion fencing is needed; however, the fence ends at the Eagle interchange east of this location should be tightened and deer guards added (or at a minimum rumble strips to alert drivers). While this interchange is outside of the priority segment, improvements to the interchange fencing will prevent wildlife from becoming trapped in the fenced ROW.

The segment of I-70 from MPs 143 to 144 was also identified as a high-priority segment in the Eagle County Safe Passages for Wildlife Plan (Kintsch and Singer, 2018). Wildlife-highway mitigation in this segment should be conducted in collaboration with the local stakeholder group engaged in that planning process.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
143.1	Existing double span bridge. Camera monitoring conducted over two summers by Singer et al. (2011) detected human and livestock use and only four mule deer passing under this structure.	Coordinate with the land owner to ensure land use that is compatible with wildlife movement. Identify habitat improvements to improve the functionality of this structure. Survey fence for gaps and fix gaps in fencing.	
143.9 and 144.5	Additional double span bridges outside of the top 5 percent segment.	While these locations are outside of the top 5 percent segment, these existing bridges contribute to connectivity for wildlife in the broader landscape and, by providing functional passageways, may help contribute to a reduced WVC rate in this segment. Coordinate with land owners to ensure land use that is compatible with wildlife movement.	N/A

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence

Cold Spot - 95% Confidence

Cold Spot - 90% Confidence

No Significant Difference

Hot Spot - 90% Confidence

Hot Spot - 95% Confidence

Hot Spot - 99% Confidence

Streams

Lakes

Land Management

Federal (BOR, FWS, NPS)

USFS

BLM

State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

I-70
MP 143-143.5

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-1.2 U.S. Highway 40 Priority Segments

H-1.2.1 U.S. HIGHWAY 40, MILEPOSTS 40 TO 41.5, EAST OF UTAH BORDER

This segment of U.S. 40 is a two-lane highway through rolling terrain of sagebrush and juniper. This segment overlaps with the Brownian Bridge Movement Models for elk winter range.

Segment Characteristics

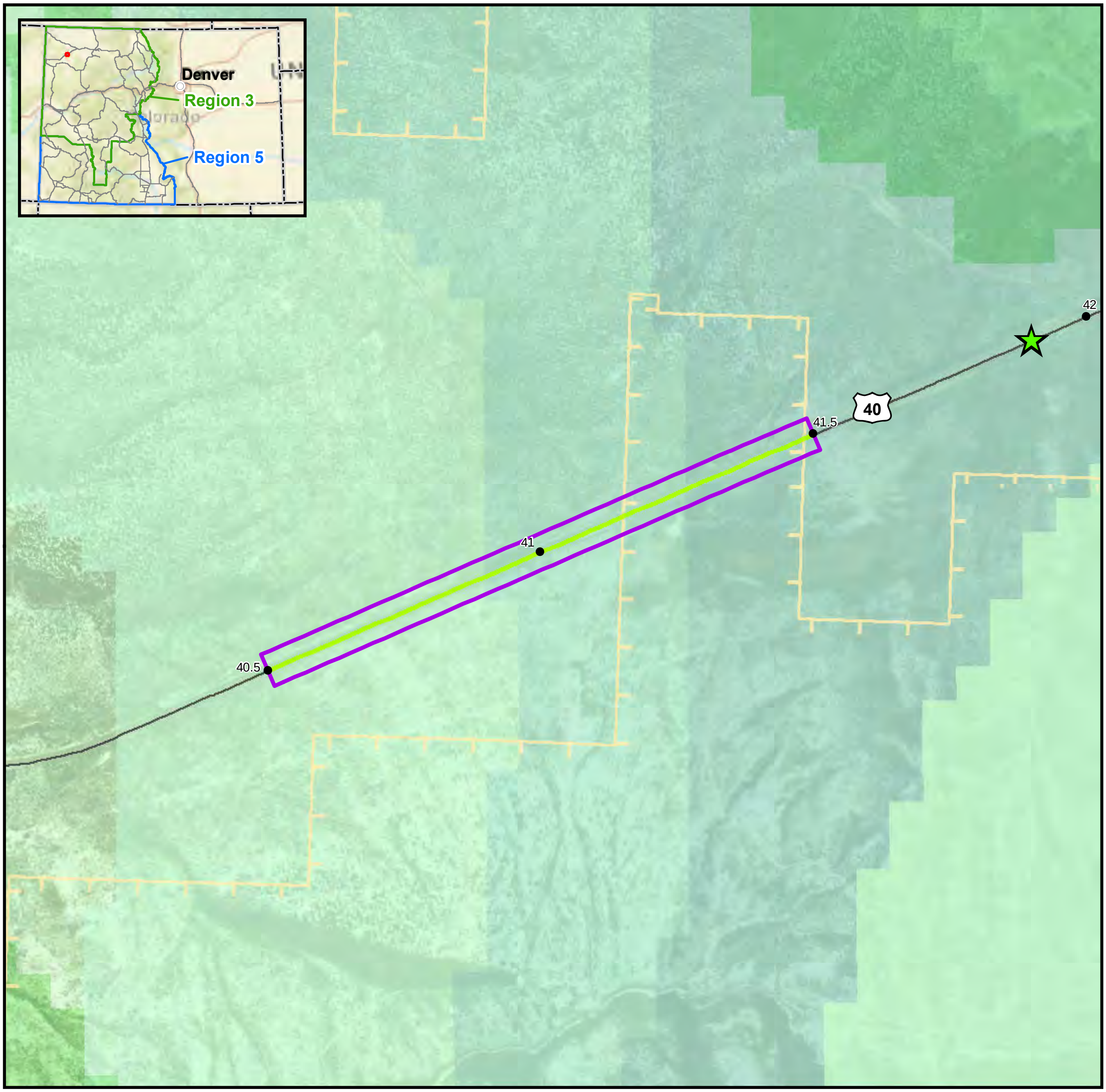
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,100	1,689	Elk and Mule Deer	Winter Range and Migration	Moderate	21.22

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
39-39.5	Cut and fill slopes.	Multiple possible opportunities for a new structure (underpass 14 feet high x 36 feet wide, suitable for deer and elk).	N/A
41.9	Large fill and cut slopes.	Multiple possible opportunities for a new structure (underpass 14 feet high x 36 feet wide, suitable for deer and elk). This area is outside of	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		the top 5 percent segment but may offer the best opportunity for a wildlife crossing structure.	
45	Landscape view looking west from MP 45		



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

US 40
MP 40.5-41.5

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-1.2.2 U.S. HIGHWAY 40, MILEPOSTS 61.9 TO 81, MAYBELL TO CRAIG

This segment of U.S. 40 is a two-lane highway through rolling terrain of sagebrush and juniper. The highway follows a riparian drainage that feeds into the Yampa River in the western portion of the segment. This segment overlaps with the Brownian Bridge Movement Models for elk winter range and migration as well as mule deer winter range and migration. The 0.5-mile segment from MPs 63.5 to 64 was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. For the purposes of the field assessment and recommendations development, two top 5 percent priority segments were combined: MPs 61.9 to 71.5 and MPs 74 to 81.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,200	1,540	Elk and Mule Deer	Migration and Winter Range	High - elk	22.07[a]

[a]Average score for two top 5 percent priority segments

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
63	Yampa River – large-span bridge. Yampa River State Park is at the southeast corner of this span. West of this location is mostly irrigated pasture land.	Connect to this bridge with wildlife exclusion fencing.	
63.5-64	Local WVC hotspot where road curve and a ridge from the north drops down to the river.	WVC may be mitigated with wildlife exclusion fencing around the curve tied into wildlife crossing structures.	N/A
66.1	6-foot CMP in long fill slope. Adjacent pasture on south side	Potential wildlife underpass (14 feet high x 36 feet wide).	

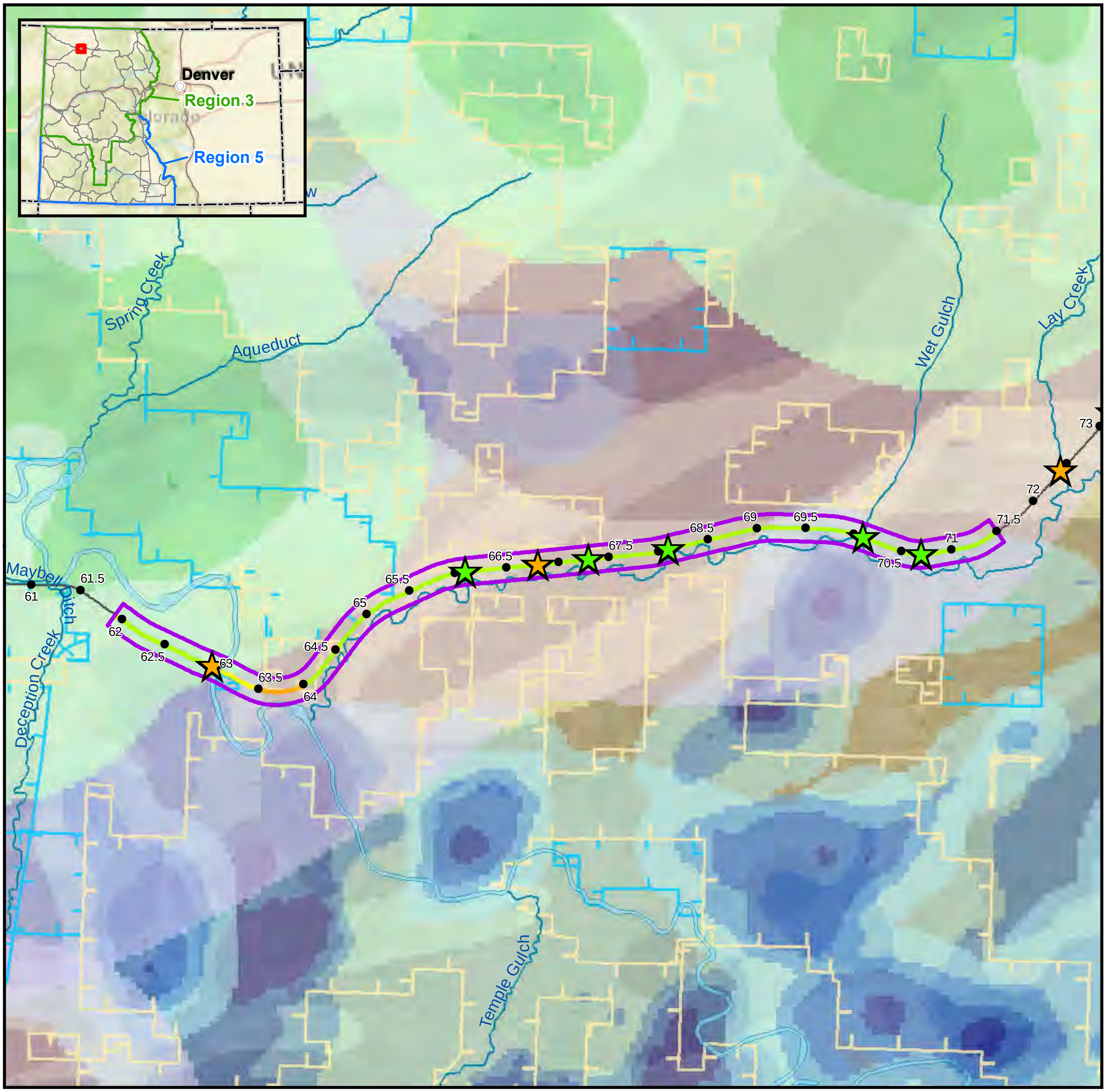
Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
66.8	8- x 8-foot CBC. Outlet eroded; wildlife-friendly fence across north entrance (inlet); fence set back at south entrance.	Improve existing structure: repair erosion at outlet; install small baffles to retain sediment on culvert floor throughout the culvert; repair fencing and set back farther from culvert entrances.	
67.3	4- x 4-foot CBC in large fill slope (25 feet high). Well-worn game trails in adjacent hillsides. Lay Creek drainage to south.	Good location for a wildlife underpass (14 feet high x 36 feet wide) with high-quality habitat adjacent.	
67.5-68	Small fill slopes.	Several opportunities for small culverts.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
68.1	6- x 6-foot CBC in large fill slope. Wetlands, Lay Creek drainage to south. Cattle pasture to north.	Good location for a wildlife underpass (14 feet high x 36 feet wide) with high-quality habitat adjacent.	
70.1	Wet Gulch pipe and fill slope. Farm road parallel on north side.	Potential wildlife underpass (14 feet high x 36 feet wide); location not as good as other due to farm road/entry.	N/A
70.7	4- x 4-foot CBC in fill slope. Culvert is at a skewed angle under road.	Good location for a wildlife underpass (14 feet high x 36 feet wide) with high-quality habitat adjacent	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
72.4	Lay Creek double box culvert. Gate across entrance. Farms/residences on both sides.	Improve existing structure for wildlife passage.	N/A
73.2	Big Gulch – low bridge. Riprap slopes, but drainage is passable by ungulates during most flow levels. Farms/residences on south side.	Improve existing structure for wildlife passage.	N/A
73.9	Cut slope.	Potential wildlife overpass (14 feet high x 36 feet wide).	N/A
74.1	Fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
77	Raised road, low fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
78.5	Long, high fill slope. Sheep fencing.	Good location for a wildlife underpass (14 feet high x 36 feet wide).	
80.1	Sand Spring Gulch, fill slope. Heavily grazed.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
80.8	Large fill slope. Heavily grazed.	Potential wildlife underpass (14 feet high x 36 feet wide).	
80.8	Fill slope at MP 80.8		
81.2	Small fill slope. Pond south side; residences to north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
81.7	Small pipe and stock pass in large fill slope. Sheep fence.	Potential wildlife underpass (14 feet high x 36 feet wide). This area is outside of the top 5	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		percent segment but offers a good opportunity for a wildlife crossing structure.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

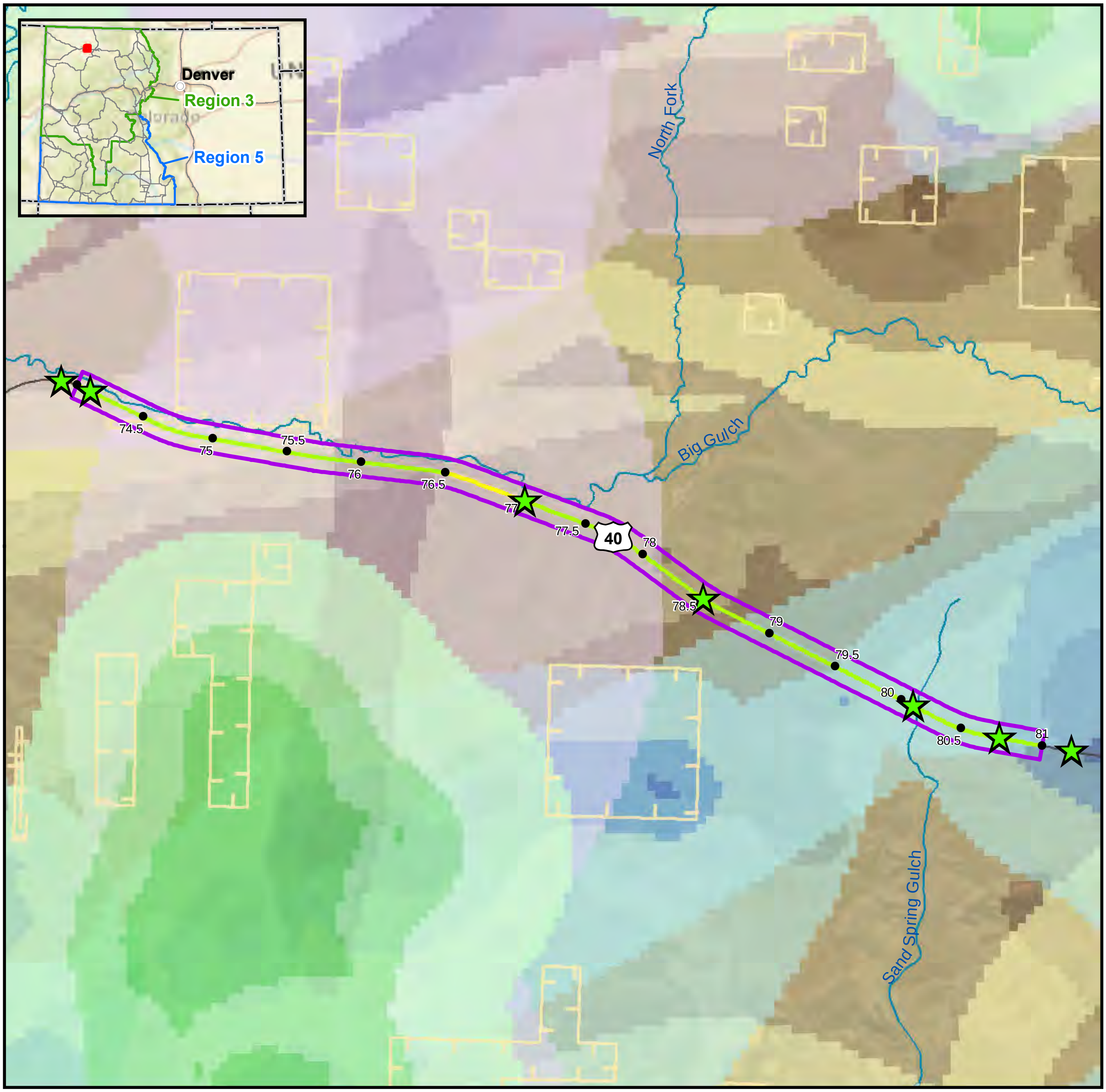
US 40
MP 61.9-71.5

N

0 1 Miles
1 inch = 1.5 miles

JACOBS

Date: 1/9/2019



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 3

US 40
MP 74-81

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-1.2.3 U.S. HIGHWAY 40, MILEPOSTS 93.7 TO 106.5, EAST OF CRAIG

This segment of U.S. 40 is a two-lane highway that runs along the broad Yampa River valley. The valley is dominated by farming and pasture lands. This segment overlaps with the Brownian Bridge Movement Models for elk winter range and migration as well as mule deer migration. Much of this segment was also identified as a local WVC hotspot in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,000	6,110	Elk, Mule Deer	Migration and Winter Range	High – elk and deer	20.63

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

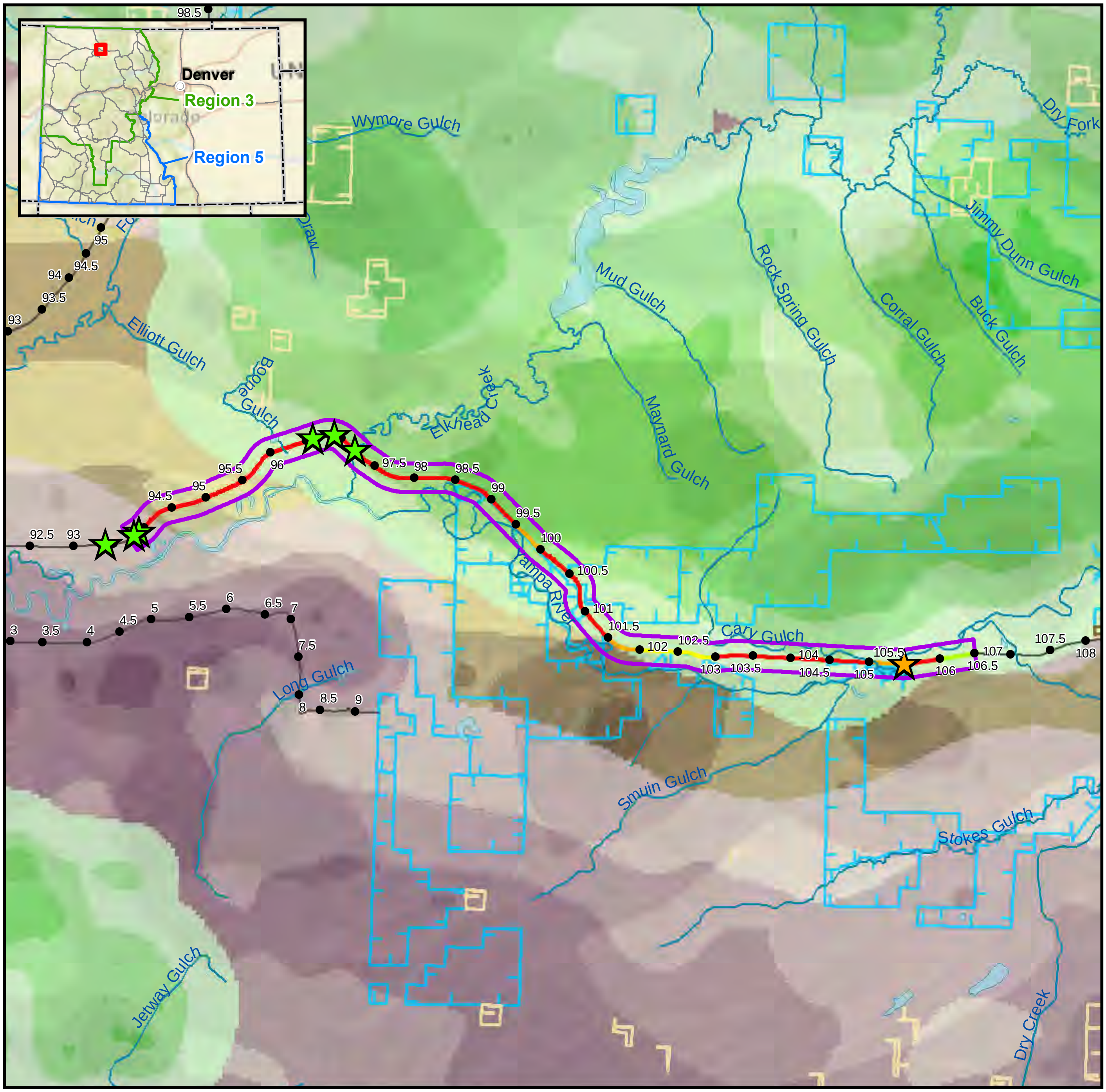
Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
93.4	Small drainage. Railroad runs parallel to highway on south side.	Potential wildlife underpass (14 feet high x 36 feet wide). This area is outside of the top 5 percent segment but offers a good	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		opportunity for a wildlife crossing structure.	
93.8	Small drainage skewed under roadway.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
93.9	Small drainage. 15-foot high fill slope. Ranch building on south side.	Good terrain for a potential wildlife underpass (14 feet high x 36 feet wide).	
96.6	Small drainage and fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
96.9	8- to 10-foot high fill slope with pasture on both sides. Elk roadkill observed.	Good location for a low, wide bridge underpass suitable for elk.	
97.2	Elkhead Creek three-chamber box culvert. Terrestrial bench through one of the chambers at low/moderate flows.	Existing structure functional for deer on one side of creek during low flows. Replace with a wide bridge spanning both banks.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
97.2	Bench under bridge at MP 97.2		
98-105	Low roadbed relative to surrounding terrain. Railroad runs parallel to highway along north side. Sheep fence on south side; cattle fence on north side. Pasture on both sides of highway.	Little opportunity for crossing structures in this segment. Mitigation options may include: • Install animal detection system provided the technology has sufficiently improved, • Install wildlife exclusion fencing with wildlife crosswalks if known, discrete crossing locations are identified, • Replace ROW fence with wildlife-friendly alternatives and • Remove vegetation/brush.	
105.5	Yampa River. Multi-span bridge. Terrestrial bank on east side under most flow conditions.	Existing structure offers some functionality for wildlife passage. Ultimately, replace with a wider	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
	Riprap bank on west side. Built 1967.	bridge spanning both terrestrial banks.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 3

US 40
MP 93.7-106.5

N

0 1 2 Miles

1 inch = 2 miles

JACOBS

Date: 1/9/2019

H-1.2.4 U.S. HIGHWAY 40, MILEPOSTS 190 TO 194, EAST OF KREMMLING

This segment of U.S. 40 is a two-lane highway that runs along the northern edge of the Colorado River valley. The railroad runs parallel through this segment, crossing under the highway from the south side, west of MP 190.4, to the north side. This segment overlaps with the Brownian Bridge Movement Models for elk and mule deer winter range. For the purposes of the field assessment and recommendations development, two top 5 percent priority segments were combined: MPs 190 to 190.5 and MPs 192 to 194.

Segment Characteristics

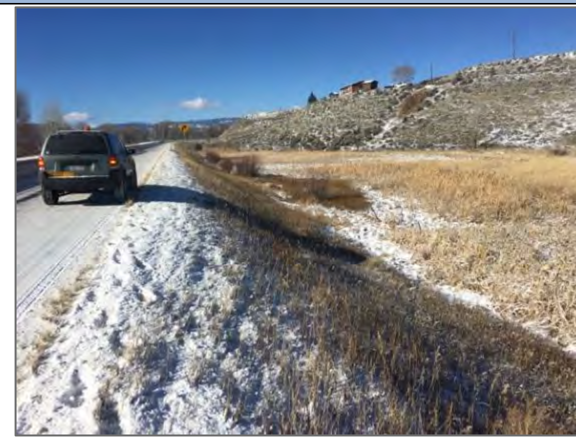
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	2,100	2,365	Elk, Mule Deer	Winter Range	High – elk and deer	19.44[a]

[a]Average score for two top 5 percent priority segments

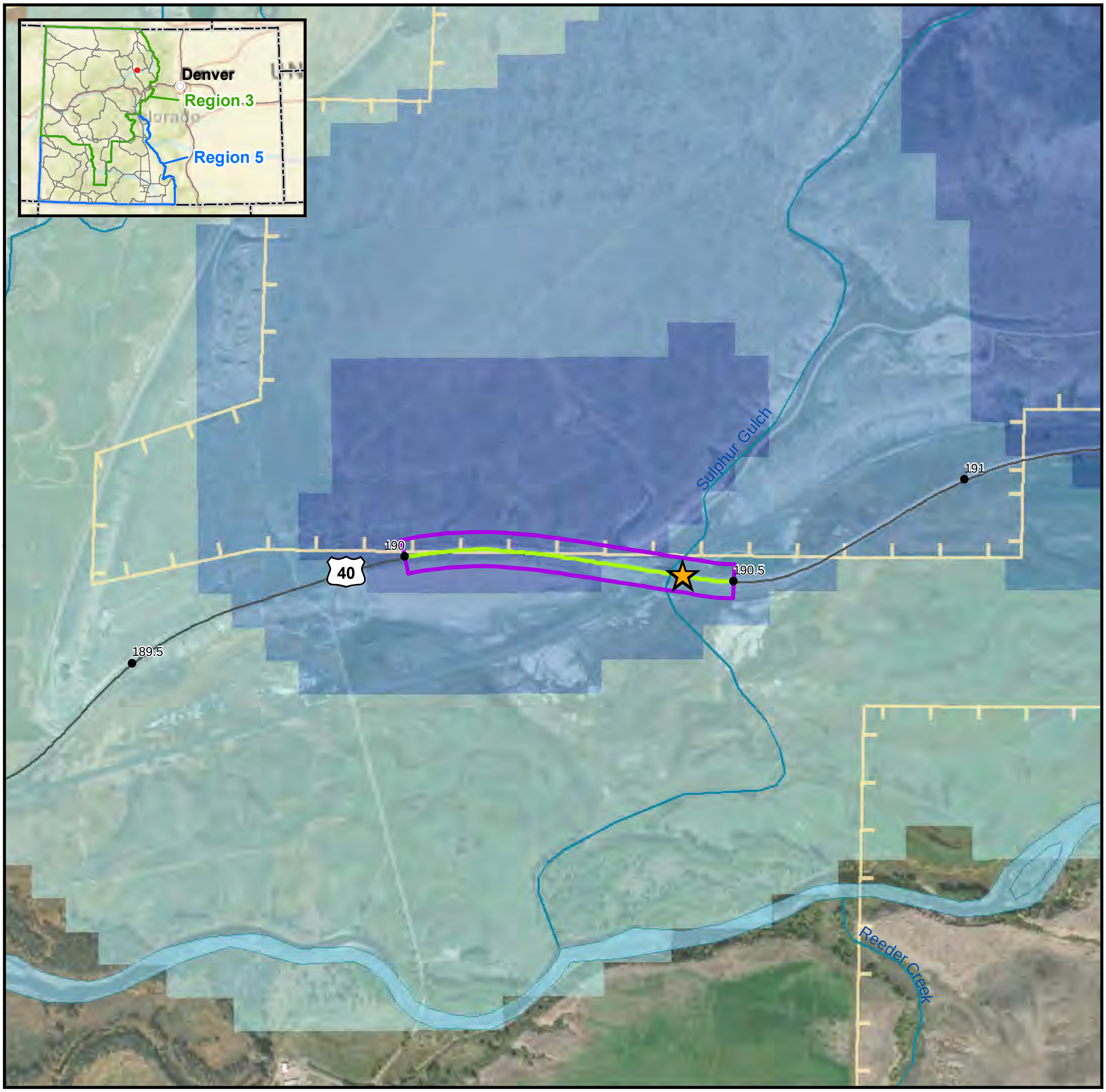
Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
190.4	Railroad bridge. High-span bridge also crosses over a small drainage. Abutment slopes/retaining walls may cause a predator ledge effect.	Connect wildlife exclusion fencing to this location.	
192.1	Very low fill slope where river bends towards the highway. Winter feedlot on the south side of the highway may act as a wildlife attractant.	Potential wildlife underpass; however, may require raising roadbed.	N/A
192.5	Low fill slope. Lots of game trails on adjacent hillsides.	Potential wildlife underpass; however, may require raising roadbed.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
192.7	Long 10-foot high fill slope with a small pipe culvert. Wetlands on both sides. Many game trails on adjacent hillsides. Homes and pasture lands present on both sides.	Potential wildlife underpass (14 feet high x 36 feet wide).	
193.6	7 feet high x 6 feet wide CBC in a long fill slope. Wetlands.	Maintain existing box and install a large underpass (14 feet high x 36 feet wide) in the fill slope farther to the east where the fill is higher.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
194	Looking west from MP 194		



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

US 40
MP 190-190.5

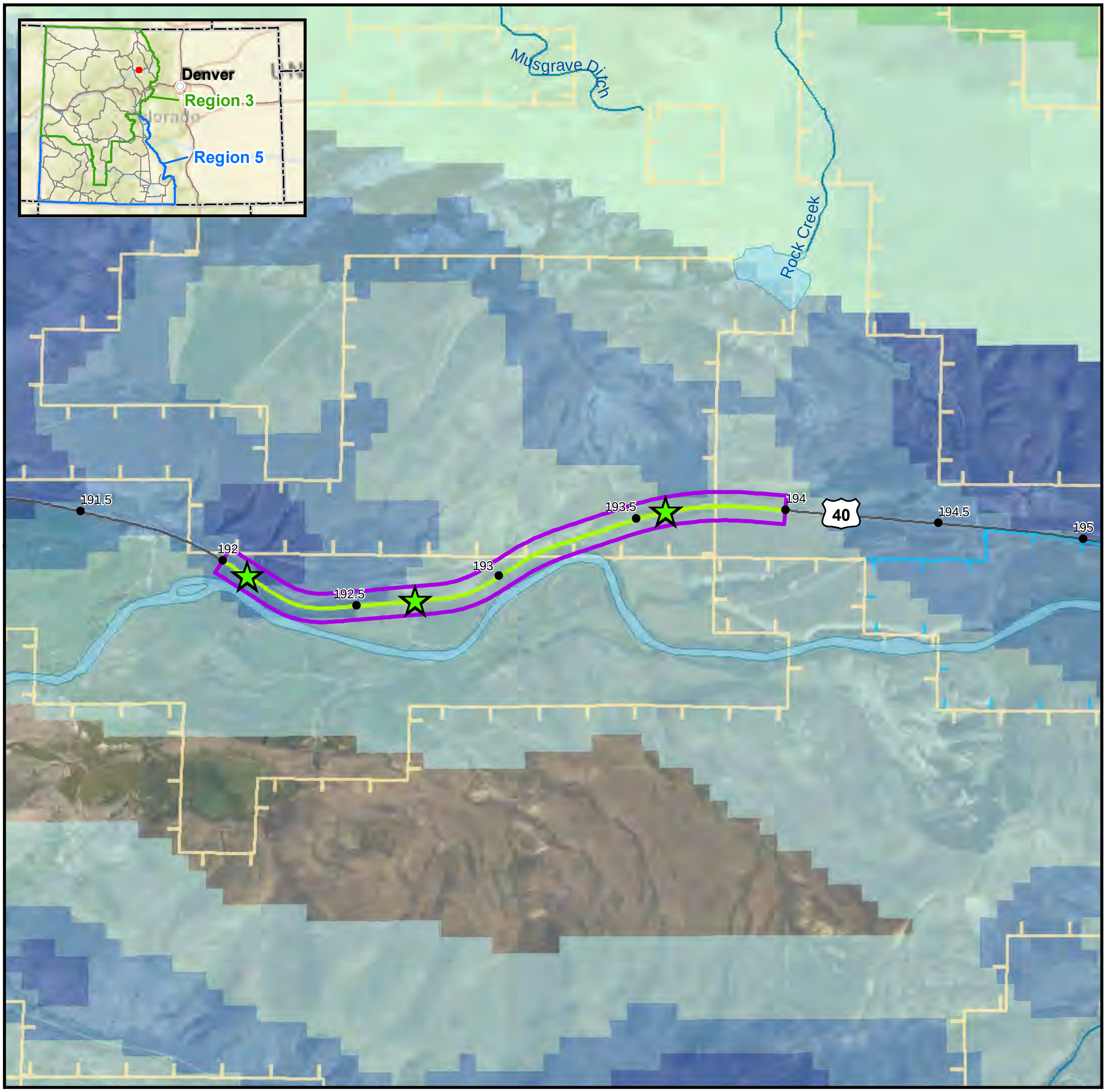
N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

US 40
MP 192-194

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-1.3 State Highway 9 Priority Segments

H-1.3.1 STATE HIGHWAY 9, MILEPOSTS 114.2 TO 116.5, NORTH OF SILVERTHORNE

This segment of State Highway 9 runs through the Lower Blue River valley, a broad valley composed of extensive agricultural fields and aspen and sagebrush steppe. This segment overlaps with the Brownian Bridge Movement Model for mule deer migration.

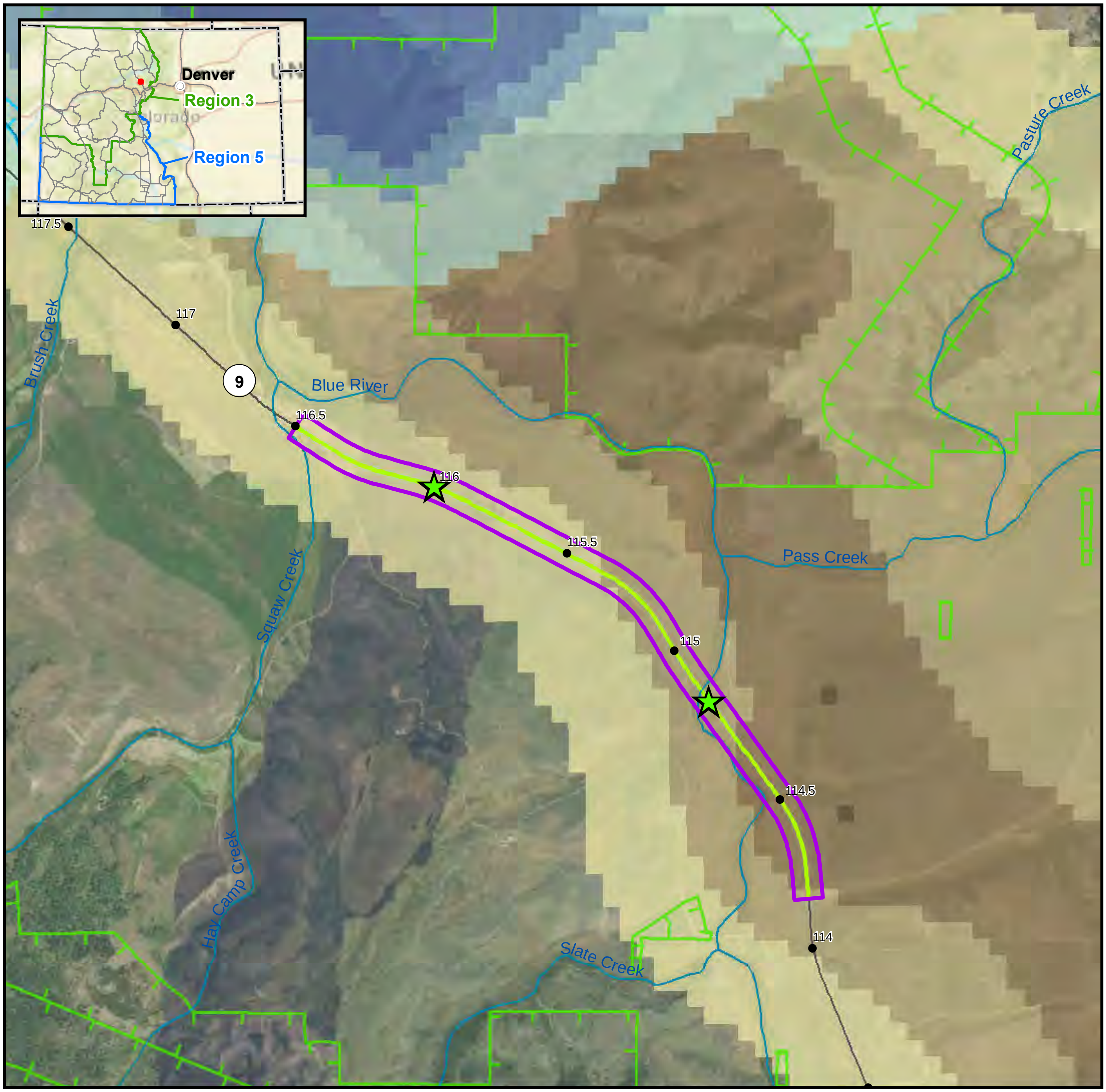
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	3,600	4,621	Mule Deer and Elk	Winter Range	Very High – elk and deer	19.46

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
114.9	Existing span bridge over the Blue River is marginally passable by deer and elk. Wildlife access to bridge confounded by sheep and cattle fences around the approaches to the bridge.	Replace the existing bridge with a wider span to provide pathways for terrestrial wildlife on either side of the river. Replace existing fencing with wildlife exclusion fencing that ties into the bridge.	
115.5	Flat, straight segment of highway adjacent to agricultural fields. This is a known crossing area for elk as well as deer.	Install a wildlife crosswalk consisting of wildlife exclusion fencing and a gap in the fence with an associated driver warning system.	N/A
116	Small road cut through ridgeline at the top of a small hill. The ridge is skewed relative to roadway and the hill drops off somewhat steeply on the east side.	Potential wildlife overpass. Most of wildlife movement is across the meadow south of this hill (about MP 115.4); however, the terrain there is not conducive to a wildlife crossing structure.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 9
MP 114.2-116.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-1.3.2 STATE HIGHWAY 9, MILEPOSTS 128 TO 136.6, SOUTH OF KREMMLING

This segment of State Highway 9 is a two-lane road through rolling sagebrush terrain. Wildlife mitigation was constructed in 2015 and 2016, including two wildlife overpasses, five large underpasses, and 10.4 miles of fencing (MPs 126 to 136). This segment overlaps with the Brownian Bridge Movement Model for mule deer winter range. A portion of this segment, from MPs 129.5 to 131.5, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. For reporting purposes, two top 5 percent priority segments were combined where mitigation has already been constructed along the entire segment: MPs 128 to 134 and MPs 136 to 136.6.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,200	6,493	Mule Deer and Elk	Winter Range	High – elk and deer	19.74[a]

[a]Average score for two top 5 percent priority segments

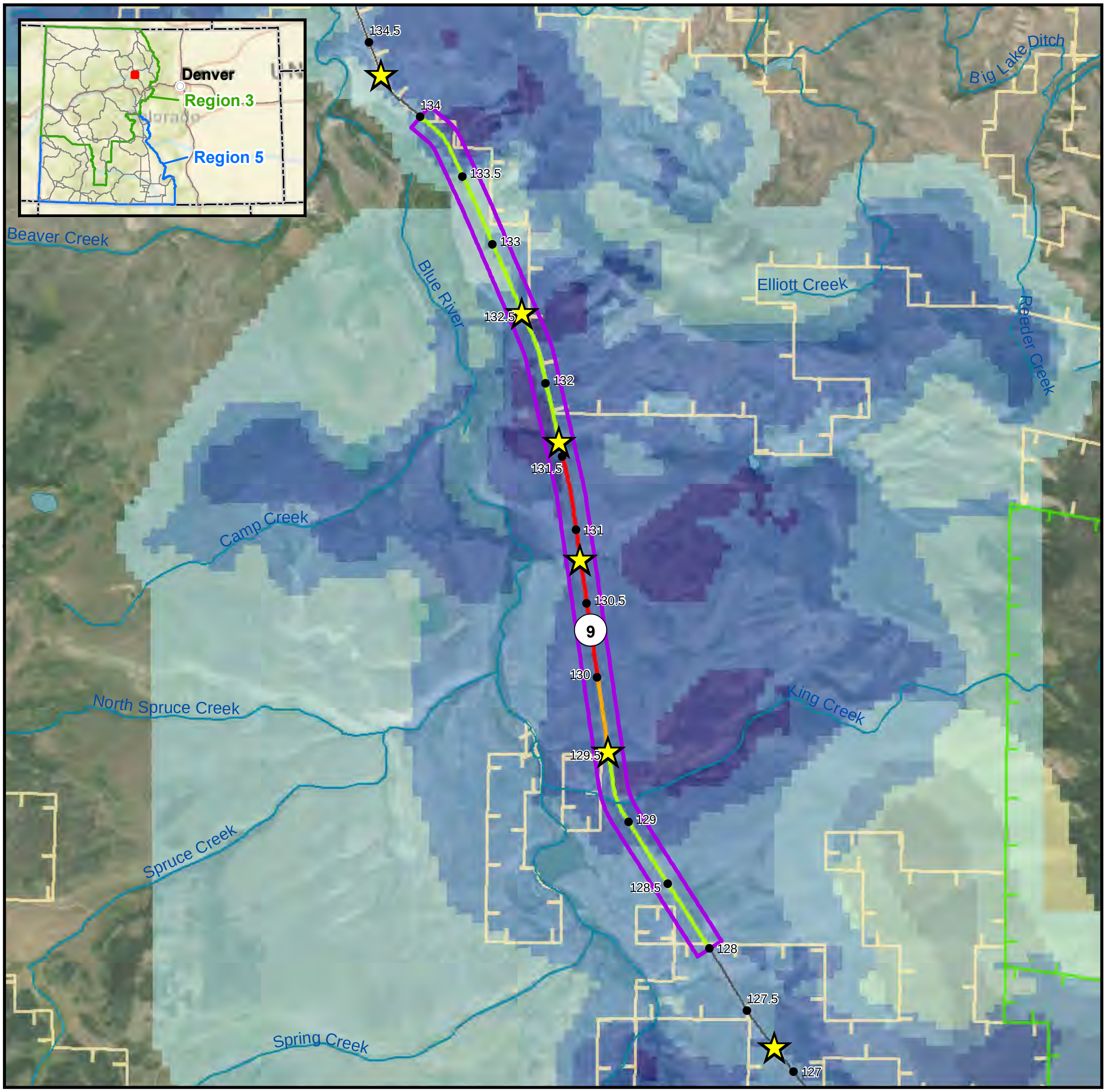
Preliminary Mitigation Recommendations

This segment of roadway already has comprehensive wildlife-highway mitigation, and long-term monitoring of these mitigation features is underway. No further mitigation is recommended.

Milepost	Situation	Mitigation Recommendation	Milepost Photo
127.2	Williams Peak Underpass (44 feet wide x 14 feet high x 66 feet long).	None	N/A
129.5	South Overpass (100 feet wide x 66 feet long).	None	N/A

Milepost	Situation	Mitigation Recommendation	Milepost Photo
130.8	Blue Valley Acres Underpass (44 feet wide x 14 feet high x 66 feet long).	None	N/A
131.6	Harsha Gulch Underpass (44 feet wide x 14 feet high x 66 feet long).	None	
132.5	Middle Underpass (44 feet wide x 14 feet high x 66 feet long).	None	N/A
134.3	North Overpass (100 feet wide x 66 feet long).	None	N/A

Milepost	Situation	Mitigation Recommendation	Milepost Photo
136	North Underpass (44 feet wide x 14 feet high x 66 feet long).	None	
137	Colorado River. Existing large span bridge with terrestrial pathways on both sides of the river.	None	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 9
MP 128-134

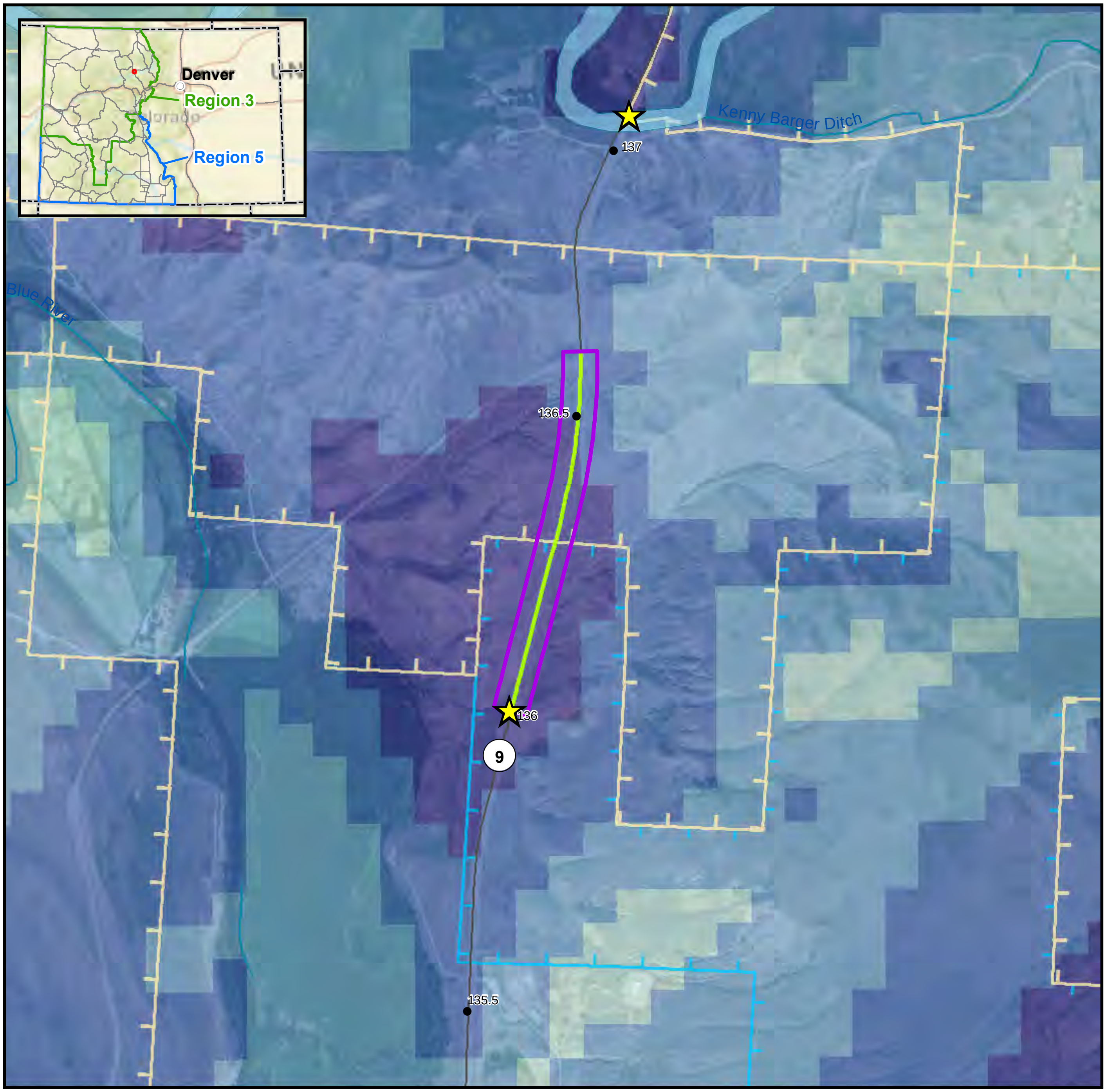
N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 9
MP 136-136.6

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-1.4 State Highway 13 Priority Segments

H-1.4.1 STATE HIGHWAY 13, MILEPOSTS 18 TO 18.3, NORTH OF RIFLE

This segment of State Highway 13 is a two-lane highway through rolling sagebrush and ranch lands. Sheep fence is present along both sides of the highway throughout the segment. This segment overlaps with the Brownian Bridge Movement Model for mule deer migration.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	2,700	3,862	Mule Deer and Elk	Migration	Low	19.55

Preliminary Mitigation Recommendations

While no potential wildlife crossing locations were identified in this segment, opportunities for crossing structures were identified in the immediately adjacent segments to the north and south. Wildlife exclusion fencing would be needed through this segment to connect to crossing structures at either end, directing animals to these locations.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
17.9	Fill slope and cut slope. This location is immediately south of 95th percentile priority segment in 92nd percentile segment.	Potential wildlife underpass (in fill slope) or overpass at cut slope on top of hill. This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	
18.5	Fill slope and cut slope on north side of Piceance Creek. Sagebrush habitat is present along the small ridge where the road cuts through; cow pastures to the south are degraded.	Potential wildlife underpass (in fill slope) or overpass at cut slope on top of small rise. This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 3

SH 13
MP 18-18.3

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-1.4.2 STATE HIGHWAY 13, MILEPOSTS 30 TO 37.5, SOUTH OF MEEKER

This segment of State Highway 13 is a two-lane highway along the Sheep Creek drainage through rolling high-quality sagebrush and ranch lands. Sheep fence is present along both sides of the highway throughout the segment. This segment overlaps with the Brownian Bridge Movement Models for mule deer migration as well as elk migration and winter range.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	2,600	3,556	Mule Deer and Elk	Migration and Winter Range	Low	19.29

Preliminary Mitigation Recommendations

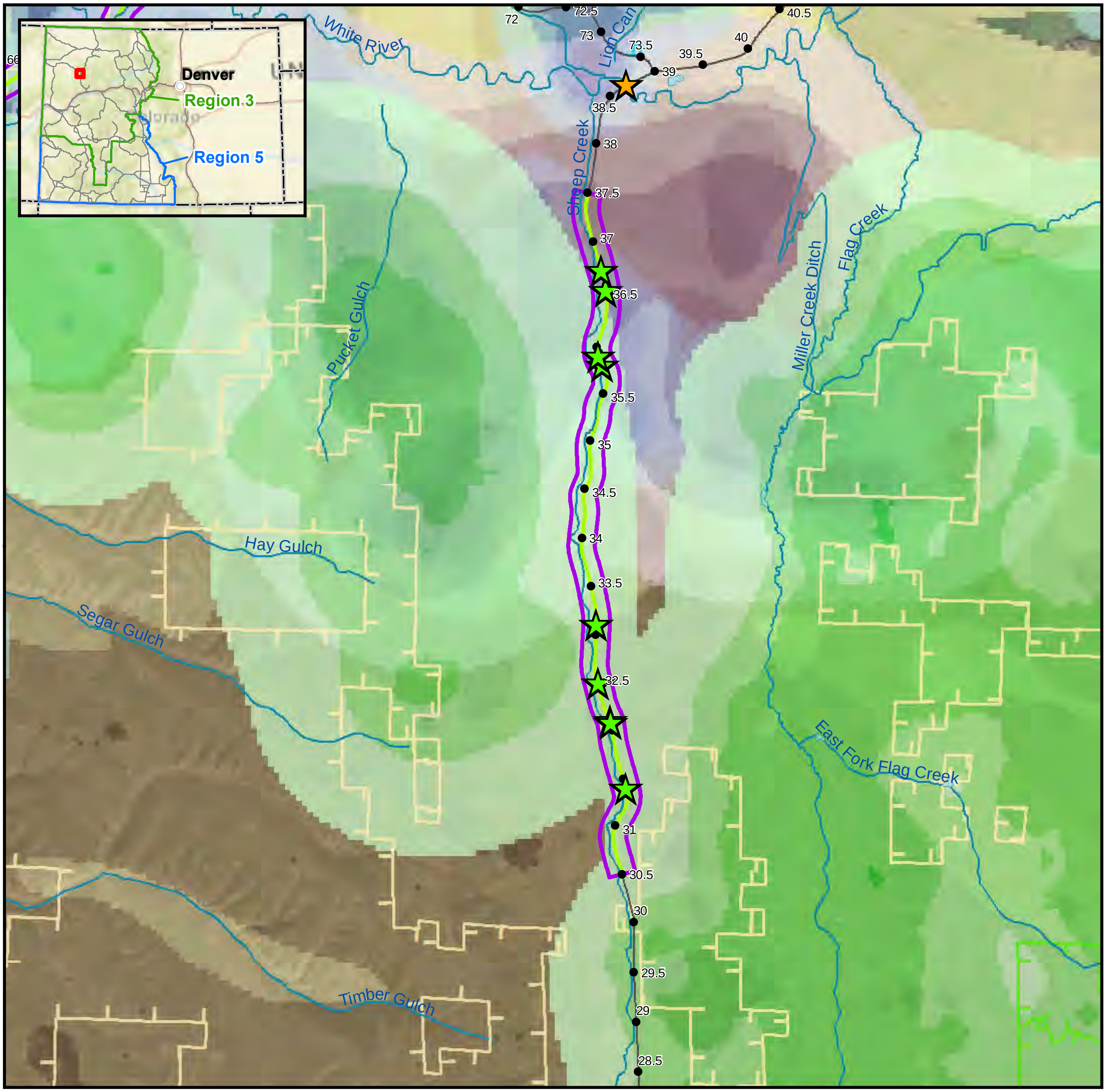
Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
31.4	Raised roadbed where two ephemeral drainages feed into Sheep Creek from the east. Fill height is about 8 feet on the east side and 20 feet on the west side.	Potential wildlife underpass (14 feet high x 36 feet wide).	
32.08	7-foot-diameter CMP in fill slope. Ephemeral drainage feeds into Sheep Creek on the west side of the highway.	Potential wildlife underpass (14 feet high x 36 feet wide), or construct new wildlife crossing at MP 32.1 and maintain this pipe as is; consider adding baffles to trap sediment along the floor of the pipe.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
32.1	Small CMP in fill slope. Ephemeral drainage feeds into Sheep Creek on the west side of the highway.	Potential wildlife underpass (14 feet high x 36 feet wide).	
32.5	Small fill slope at dip in road.	Potential wildlife underpass (14 feet high x 36 feet wide). Would require moving fill from hills on either side of the dip to flatten the road and increase the fill height at this location.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
33.1	Fill slope where two ephemeral drainages feed into Sheep Creek from the east. Fill height is about 15 feet. Ranch and pasture lands on west side.	Potential wildlife underpass (14 feet high x 36 feet wide).	
35.8	Small pipe where roadbed is slightly elevated on east side feeds into Sheep Creek on west side.	Potential wildlife underpass (14 feet high x 36 feet wide). May require raising roadbed or digging out east side approach.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
35.9	Forested ridgeline on east side where road cut transitions to flat terrain on the west side of the highway.	Potential wildlife overpass (14 feet high x 36 feet wide).	
36.5	Narrow drainage from east feeds into Sheep Creek.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
36.7	Small drainage from east feeds into Sheep Creek. Shooting range behind ridge immediately east of this location.	Potential wildlife underpass (14 feet high x 36 feet wide); however, adjacent shooting range renders this location less viable.	N/A
38.7	White River. Low bridge spans terrestrial bank on north side.	This location is outside of the top 5 percent segment; however, wildlife exclusion fencing should connect this location to new wildlife crossing structures to the south.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing
Improve Existing Structure
Potential Wildlife Crossing
Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
No Significant Difference
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence

Streams
Lakes

Land Management

Federal (BOR, FWS, NPS)
USFS
BLM
State

BBMM – Elk Winter

High
Low

BBMM – Elk Migration

High
Low

BBMM – Mule Deer Winter

High
Low

BBMM – Mule Deer Migration

High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 30.5-37.5

N

0 1 Miles

1 inch = 1.5 miles

JACOBS

Date: 1/9/2019

H-1.4.3 STATE HIGHWAY 13, MILEPOSTS 45 TO 52.5, NORTH OF MEEKER

This segment of State Highway 13 extends from the top of Ninemile Gap towards Meeker. Sagebrush characterizes the landscape. Sheep fence is present along both sides of the highway throughout the segment. This segment overlaps with the Brownian Bridge Movement Models for mule deer migration and winter range as well as elk winter range and migration in the northern portion of this segment.

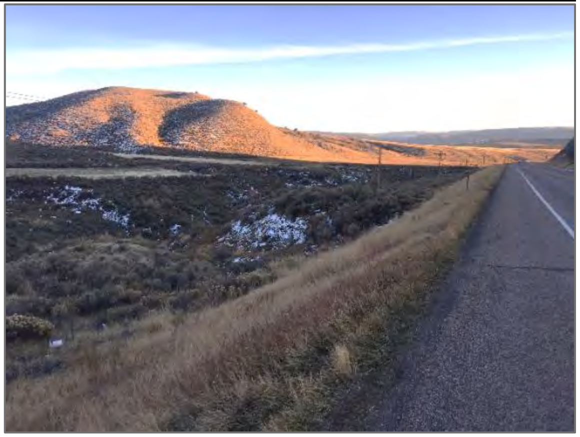
<u>Segment Characteristics</u>

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,600	2,222	Mule Deer and Elk	Migration	Low	20.70

<u>Preliminary Mitigation Recommendations</u>

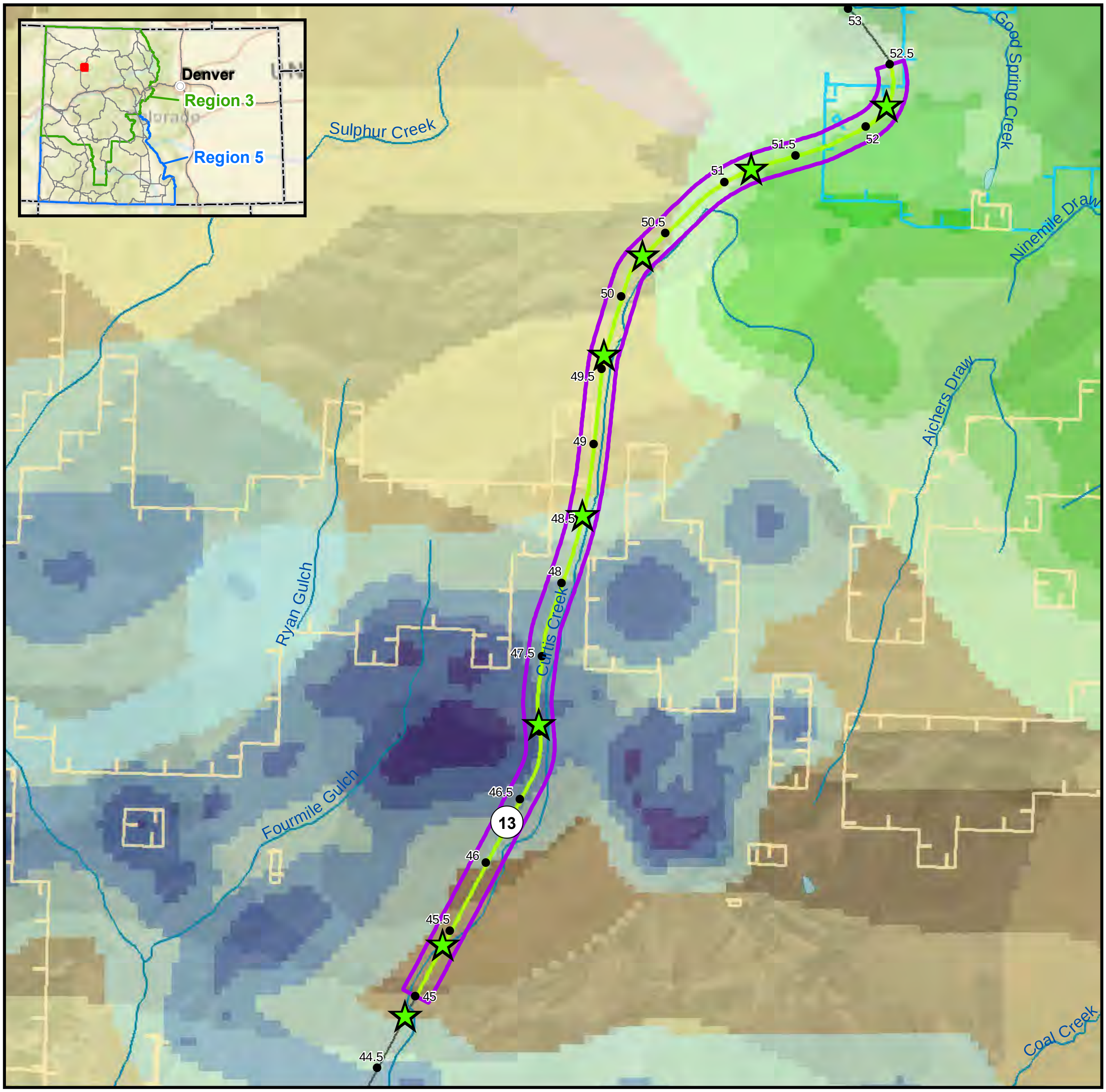
Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
44.9	Curtis Creek, three-chamber CBC.	Replace CBC with a single chamber CBC suitable for deer (10 to 12 feet high x 20 feet wide). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	N/A
45.4	Curtis Creek, three-chamber CBC (5.5 feet high). Low flows during much of year; however, flow spreads out through the three chambers, which may become icy in winter.	Replace CBC with a single chamber CBC suitable for deer (10 to 12 feet high x 20 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
47.1	Fill slope (15 to 20 feet high) with small CBC.	Potential wildlife underpass (12 feet high x 20 feet wide).	
48.5	Small fill slope, higher on south side than on north side.	Potential wildlife underpass (12 feet high x 20 feet wide).	N/A
49.6	Small fill with small CMP; cow pastures.	Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
50.3	Fill slope (>10 feet high); pastures both sides.	Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide).	
51.2	Large fill slope, small CMP. Pond on west side.	Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
51.2	Roadkill buck along ROW fence at MP 51.2		
52.2	Small fill slope at the top of Ninemile Gap. Access road to State Wildlife Area on east side.	Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide).	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 45-52.5

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-1.4.4 STATE HIGHWAY 13, MILEPOSTS 58.5 TO 70.5, COLOWYO MINE, NORTH OF MEEKER

This segment of State Highway 13 extends north from Ninemile Gap along Good Spring Creek. Through much of the segment, the roadbed is flat or only slightly raised above the surrounding landscape. This segment overlaps with the Brownian Bridge Movement Models for elk and mule deer migration as well as winter range. A portion of this segment from MPs 61.5 to 64.5 was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. A portion of this segment around MP 68 has posted signages as a wildlife zone by CDOT and CPW, with the potential for double fines for speeding between October and June.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,700	2,323	Mule Deer and Elk	Migration and Winter Range	Low	26.07

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Given the topography in this segment relative to the roadbed, wildlife underpasses in this segment will likely require raising the road bed to install structures suitable for elk. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment. Existing seasonal signage should be replaced with flip-down signs so that they are active only during the targeted seasons.

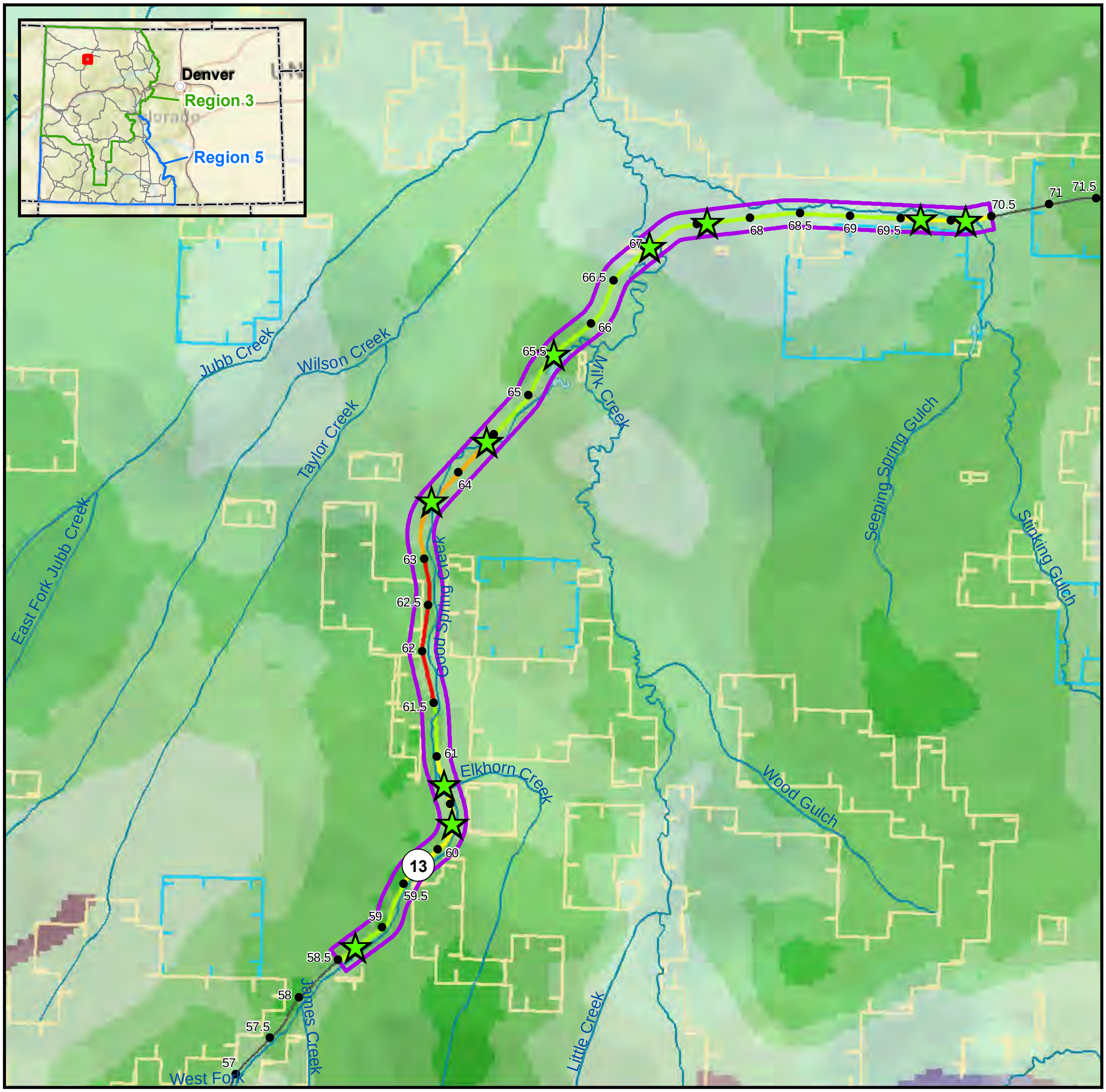
Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
58.7	CBC (6 feet high x 6 feet wide) with wood fence across east entrance. Pasture, ranch buildings on east side.	Replace CBC with a larger wildlife underpass, as high as possible and wide (e.g., 10 to 12 feet high x 60 feet wide).	
60.3	CBC (6 feet high x 6 feet wide) filled with sediment so that effective height is 4.5'. Game trails on hillsides west of highway	Replace CBC with a larger wildlife underpass, as high as possible and wide. Will likely require raising roadbed to make this location suitable for elk.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
60.7	Draws from the east and west feed into this location.	Potential wildlife overpass.	
63.6	Good Spring Creek. Drainage, CMP is skewed relative to roadway.	Potential wildlife underpass, as high as possible and wide. Will likely require raising roadbed to make this location suitable for elk.	
64.4	Good Spring Creek. CMP 7 feet in diameter. Roadbed is slightly elevated.	Potential pipe or bridge wildlife underpass (10 feet high x 60 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
65.5	Fill slope at south end of Wilson Reservoir. Wetlands around lake on east side of highway.	Potential wildlife underpass (14 feet high x 36 feet wide). Put in game trails to transition wildlife to upland habitat south of the lake.	
67	Mill Creek. Double box culvert (each chamber 10 feet high x 10 feet wide) at dip in road.	Potential wildlife underpass (14 feet high x 36 feet wide). May require moving fill from hills on either side of the dip to flatten the road and increase the fill height at this location.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
67	Looking east from dip in road above culvert at MP 67		
67.6	Stinking Gulch. CBC (6 feet high x 6 feet wide) in a fill slope (15 to 20 feet high).	Potential wildlife underpass (14 feet high x 36 feet wide).	
69.7	Elk Ridge Ranch. Small road cut.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
68	Wildlife zone with sign indicating double fines for speeding October through June.		
70.2	Box culvert (6 feet high x 8 feet wide). Hay fields on west side of highway; wetlands to east. County road immediately to north.	Maintain as a carnivore crossing or, if needed, upsize to a larger culvert.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

Streams

Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 58.5-70.5

N

0 1 Miles

1 inch = 1.5 miles

JACOBS

Date: 1/9/2019

H-1.4.5 STATE HIGHWAY 13, MILEPOSTS 73 TO 75.5, SOUTH OF HAMILTON

This segment of State Highway 13 extends south from Hamilton along Mariposa Creek. The highway runs along the north side of the valley with pasturelands along the creek. Sheep fence is present along both sides of the highway throughout the segment. This segment overlaps with the Brownian Bridge Movement Models for elk migration and winter range and mule deer migration. Much of the segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

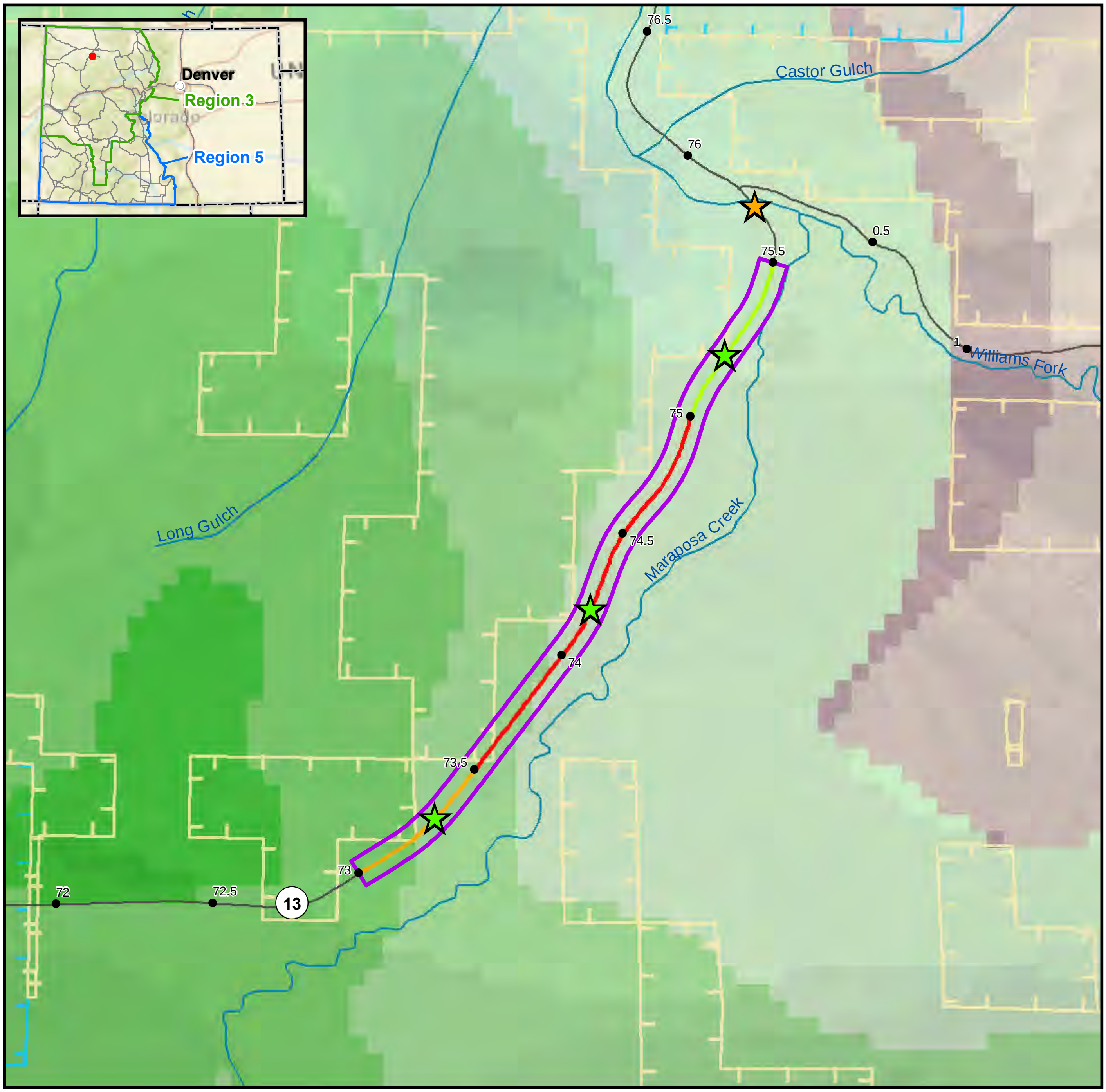
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,800	2,424	Mule Deer and Elk	Migration and Winter Range	Low	23.53

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Given the topography in this segment relative to the roadbed, wildlife underpasses in this segment will likely require raising the road bed to install structures suitable for elk. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
73.3	Fill slope, CBC. South of Mariposa Creek Road.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
74.2	CBC (8 feet high x 6 feet wide) in deteriorating condition. Fence across culvert entrance.	Potential wildlife underpass (14 feet high x 36 feet wide). Will likely require raising roadbed to make this location suitable for elk.	N/A
75.2	Small fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
75.5	High sheep fence in the approach to the bridge at MP 75.5		

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
75.7	Williams Fork. Bridge underpass has a dry bench with 8-foot-high clearance on the south side of the span. Deer tracks observed. High (4.5 feet) sheep fence runs along the river corridor.	This location is outside of the top 5 percent segment; however, wildlife exclusion fencing should connect this location to the new wildlife crossing structures to the south. Work with landowner to replace high sheep fence with a wildlife-friendly alternative.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 3

SH 13
MP 73-75.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-1.4.6 STATE HIGHWAY 13, MILEPOSTS 78 TO 84, HAMILTON TO CRAIG

This segment of State Highway 13 extends from the small hamlet of Hamilton north towards Craig along the Williams Fork River. This segment overlaps with the Brownian Bridge Movement Models for elk and mule deer migration, and much of the segment overlaps with elk and mule deer winter range. The southern portions of the segment, from MP 78 to 82, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. Sheep fence is present along both sides of the highway. Heavy truck traffic is common through this segment. This segment has posted signages as a wildlife zone by CDOT and CPW, with the potential for double fines for speeding between October and June.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,800	2,594	Mule Deer and Elk	Migration and Winter Range	Low	22.59

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment. Existing seasonal signage should be replaced with flip-down signs so that they are active only during the targeted seasons.

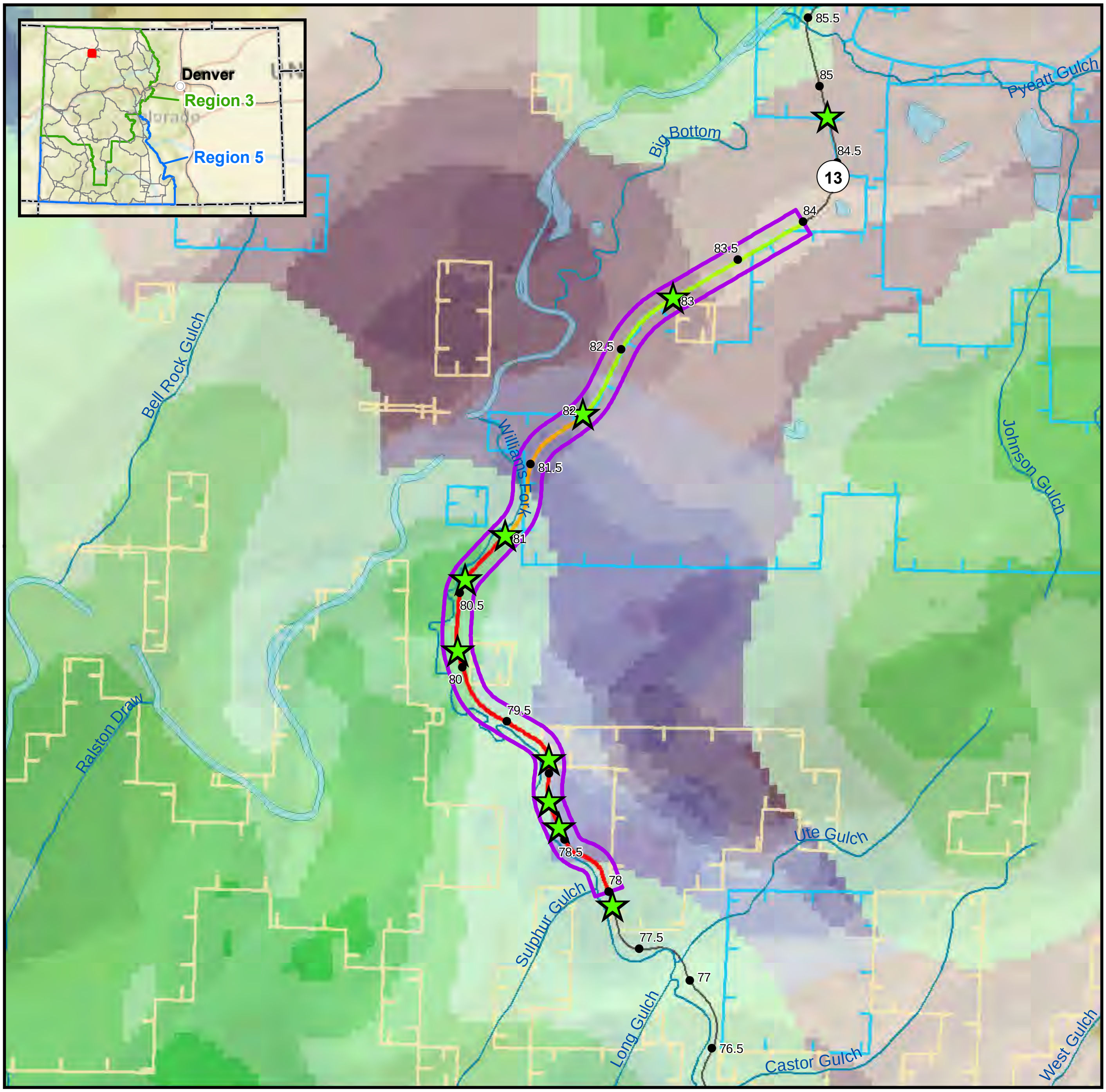
Existing wildlife zone signage.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
77.9	Fill slope where roadbed raised (about 6 feet high on east side; 10 to 12 feet high on west side). Residences to north.	Potential wildlife underpass (low, wide bridge or arch culvert [14 feet high x 36 feet wide]). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	N/A
78.6	Small rise in road. Ranch access with hay fields and storage west side of highway.	Potential wildlife overpass.	N/A
78.8	6-foot-diameter CMP/stock pass in a fill slope. Both entrances to the culvert are fenced off. Hay field on west side; ranch home to northwest of this location.	Potential wildlife underpass (14 feet high x 36 feet wide).	
79.1	Gulch from east feeds into riparian zone along the Williams Fork. Residences to southwest.	Potential wildlife underpass (low, wide bridge or arch culvert [14 feet high x 36 feet wide or, if lower, then make the crossing wider]).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
80.1	Slightly raised road bed. Deepest fill about 12 feet on west side and about 6 feet on east side. Multiple roadkill deer and elk observed.	Potential wildlife underpass (low, wide bridge or arch culvert [14 feet high x 36 feet wide]).	
80.6	Cut slope. Industrial infrastructure on west side.	Potential wildlife overpass.	N/A
81	Fill slopes (about 20 feet high) where a narrow drainage from east feeds into the Williams Fork corridor.	Good location for a large wildlife underpass suitable for elk (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
82	Cut slope at top of hill.	Potential wildlife underpass (14 feet high x 36 feet wide).	
83	Fill and cut slopes.	Multiple possible opportunities for a new structure (overpass or underpass).	
84.7 – 85	Trapper mine processing plant on east side of the highway.	Multiple potential opportunities for a wildlife underpass in this segment (minimum 14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
85.9	Yampa River. Large span bridge.	This location is outside of the top 5 percent segment; however, wildlife exclusion fencing should connect this location to the new wildlife crossing structures to the south.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 78.0-84.0

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-1.4.7 STATE HIGHWAY 13, MILEPOSTS 99 TO 114, NORTH OF CRAIG

This segment of State Highway 13 crosses an important migration route between summer range to the east and winter range to the west and is identified by CPW as an elk migration corridor. Because of the presence of continuous high-quality habitat, the migration tends to be dispersed rather than a discrete corridor. During the fall migration, animals tend to cross the highway at once in large groups of up to 1,000 individuals. The spring migration tends to be more dispersed, both temporally and spatially. This landscape is also home to both wintering and resident deer and elk herds. This segment overlaps with the Brownian Bridge Movement Models for elk and mule deer migration and winter range.

The segment from MP 111 to 116 is currently under design for a shoulder widening project. No wildlife crossing structures are included in these designs. Instead, CDOT and CPW have agreed to install segments of wildlife exclusion fence around curves and in areas with poor driver visibility to reduce WVC. Interspersed between the segments of high wildlife exclusion fencing would be sections of low wildlife-friendly fence to allow wildlife to cross the roadway in areas with better driver visibility. This project is scheduled to be constructed in 2021.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,300	1,641	Mule Deer and Elk	Migration and Winter Range	High – elk	23.64

Preliminary Mitigation Recommendations

The planned high/low fence concept is planned for installation from MPs 111 to 116 as a part of the 2021 highway widening project. Wildlife crossings may be considered at a later date as a part of a longer-term vision for maintaining connectivity for wildlife across the highway. The following potential crossing structure locations are presented for further consideration. Crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
98	Cut slope and adjacent fill slope to south.	Potential wildlife overpass or underpass. This location is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	N/A
98.7	Long fill slope with 12-foot-high x 12-foot-wide CBC. Outlet is perched with concrete apron. Wetlands on both sides.	Potential wildlife underpass (14 feet high x 36 feet wide). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	N/A
99	Cut slope.	Potential wildlife overpass.	
100.6	Fortification Creek. Four pipe culverts.	Replace existing culverts with a wider single chamber crossing structure spanning the creek and terrestrial banks (14 feet high x 36 feet wide, or if lower height, then make crossing wider).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
101.8	Stock pass in fill slope. Pasture both sides.	Potential wildlife underpass (a low, wide bridge or arch [14 feet high x 36 feet wide, or if lower height, then make crossing wider]).	
102.5	CBC in small fill.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide)	
103	Cut slope.	Potential wildlife overpass.	N/A
103.5	CBC.	Potential wildlife underpass (a low, wide bridge or arch [14 feet high x 36	N/A

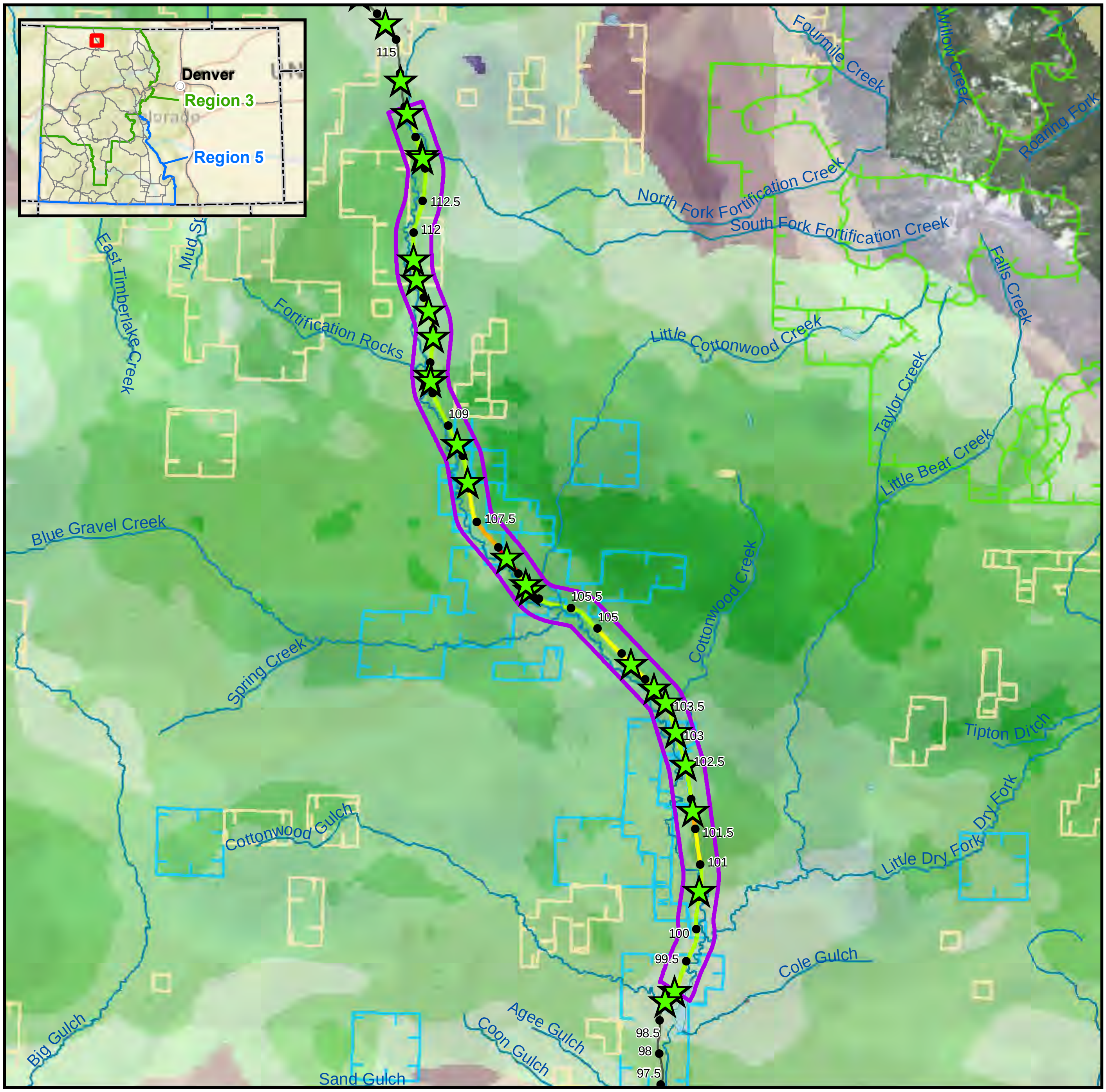
Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		feet wide, or if lower height, then make crossing wider]).	
103.8	CBC.	Potential wildlife underpass (a low, wide bridge or arch [14 feet high x 36 feet wide, or if lower height, then make crossing wider]).	N/A
104.3	Drainage gully.	Potential wildlife underpass (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
106.2/3	Small fill slopes. Many deer tracks observed around this location where slopes on the east side of the highway lead down into the creek drainage.	Potential wildlife underpass (14 feet high x 36 feet wide, or if lower height, then make crossing wider).	
106.8	Cut slope on east side. Creek adjacent on west side.	Potential wildlife overpass.	N/A
108.1	Cut slope on east side. State Land Board.	Potential wildlife overpass.	N/A
108.5	Looking north		

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
108.6-108.8	Roadbed raised relative to surrounding terrain.	Potential wildlife underpass in this area (a multi-span landscape bridge between high points in the road to accommodate large, migratory herds).	N/A
109.7	CBC, stock pass. Wetlands on west side.	Potential wildlife underpass (14 feet high x 36 feet wide, or if lower height, then make crossing wider).	N/A
109.8	Ridge cut from east. Wetlands on west side	Potential wildlife overpass May be difficult with wetlands.	N/A
110.4	Drainage, fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
110.8	Small fill slope.	Potential wildlife underpass, limited fill height on east side.	N/A
111.6	Small drainage with existing CBC.	Potential wildlife underpass (14 feet high x 36 feet wide, or if lower height, then make crossing wider).	N/A
113.15	Fill slope at the bottom of a hill. Existing double box culvert where Fortification Creek crosses under road immediately to south.	Potential wildlife underpass suitable for elk (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
113.2	Cut slope at the top of hill.	Potential wildlife overpass.	
113.9 – 114	Road cuts.	Two locations for a potential wildlife overpass.	N/A
114.4	Long fill slope where the road is elevated above the surrounding terrain.	Potential wildlife underpass (a low, wide bridge). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
114.8 – 115.8	Multiple cut and fill slopes.	Multiple options for a wildlife underpass or overpass. This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 99-114

N

0 1 2 Miles

1 inch = 2.3 miles

JACOBS

Date: 1/9/2019

H-1.4.8 STATE HIGHWAY 13, MILEPOSTS 118 TO 120.5, CRAIG TO WYOMING

This segment of State Highway 13 crosses an important migration route between summer range to the east and winter range to the west as well as winter ranges for both elk and mule deer. This segment overlaps with the Brownian Bridge Movement Models for elk and mule deer migration and winter range.

This segment was designed for a highway widening project in 2018 and is scheduled to go to construction in 2019. During the design process, no wildlife crossing structures were recommended; instead, the project will make the roadway more permeable to wildlife movement and reduce the time that animals spend on the road by replacing the ROW fence with a more wildlife-friendly alternative and working with landowners to keep stock passes open for wildlife use.

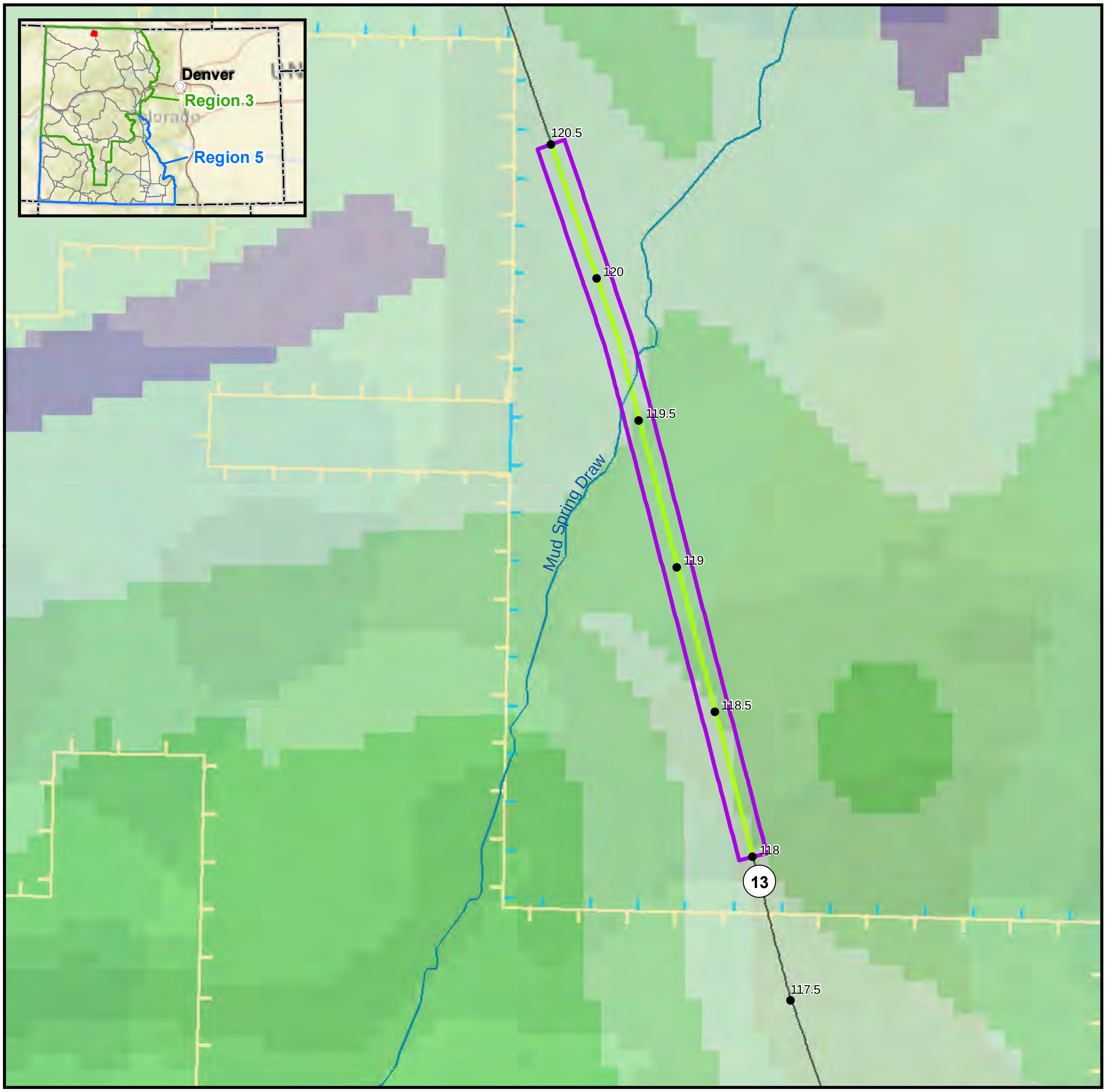
<u>Segment Characteristics</u>

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,110	1,331	Mule Deer and Elk	Migration and Winter Range	High – elk	20.80

<u>Preliminary Mitigation Recommendations</u>

Due to the *open* rangelands and good sight distances, there are no wildlife crossing recommendations for this segment. Instead, it is recommended that CDOT and CPW work with landowners in this segment to rotate livestock off of range lands adjacent to the highway during key migration periods (November and December, April), and install sections of laydown fence to open gaps during these time periods.

Example of wildlife-friendly sheep fence on State Highway 13 north of this priority segment



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 13
MP 118-120.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-1.5 State Highway 64 Priority Segments

H-1.5.1 STATE HIGHWAY 64, MILEPOSTS 59 TO 68.5, WEST OF MEEKER

State Highway 64 through this segment is a low volume two-lane road that runs along the northern edge of the White River valley. Multiple canyons feed into the valley from the mesas to the north. This segment overlaps with the Brownian Bridge Movement Models for mule deer migration and winter range as well as elk migration and winter range in the eastern portions of the segment.

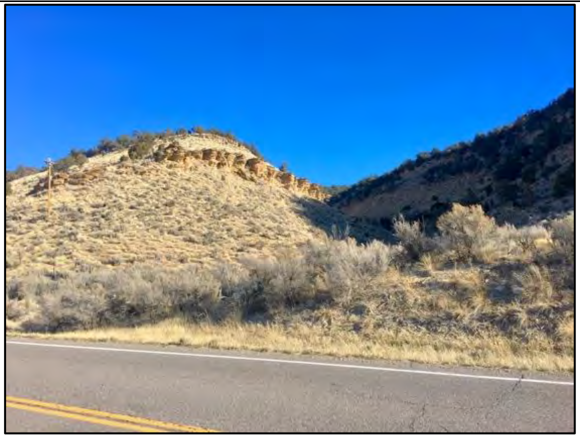
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	990	1,645	Mule Deer and Elk	Migration	Low	21.61

Preliminary Mitigation Recommendations

This segment presents few opportunities for constructing wildlife crossing structures suitable for migrating elk and deer. Given the current low traffic volumes, wildlife crossing mitigation may not be necessary in the near-term. However, as traffic volumes and truck traffic increase on this corridor, wildlife crossings should be incorporated into future road improvement projects. The rolling nature of the roadway could allow for some of the hills to be cut down to raise the road grade in other locations during a major reconstruction project. This could be done to create sufficient height beneath the road to construct wildlife underpasses in these areas. In the near-term, remove ROW fencing or, where needed, replace ROW fencing with wildlife-friendly fencing throughout the segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
59	Roadbed slightly elevated. Hayfields to south likely attract wildlife.	Potential wildlife underpass (12 feet high x 20 feet wide). Would require raising roadbed.	N/A
63.4	Beefsteak Gulch. Small pipe, partially sediment filled. Flashy drainage, high erodibility. BLM lands present on both sides of the highway	Potential wildlife underpass (14 feet high x 36 feet wide). Would require raising roadbed or digging out north side approach.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
63.7	From MP 63.7 looking south at the White River Valley		
63.7	Feeder canyon from the north at MP 63.7		

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
67.4	Windy Gunch. Narrow drainage. BLM land is on the north side of this location.0	Potential wildlife underpass (14 feet high x 36 feet wide). Would require raising roadbed.	

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 64
MP 59-68.5

N

0 1 Miles

1 inch = 1.5 miles

JACOBS

Date: 1/9/2019

H-1.6 State Highway 131 Priority Segments

H-1.6.1 STATE HIGHWAY 131, MILEPOSTS 57 TO 58, SOUTH OF STEAMBOAT

This segment of State Highway 131 runs through a narrow canyon along Oak Creek. This segment overlaps with the Brownian Bridge Movement Model for elk migration.

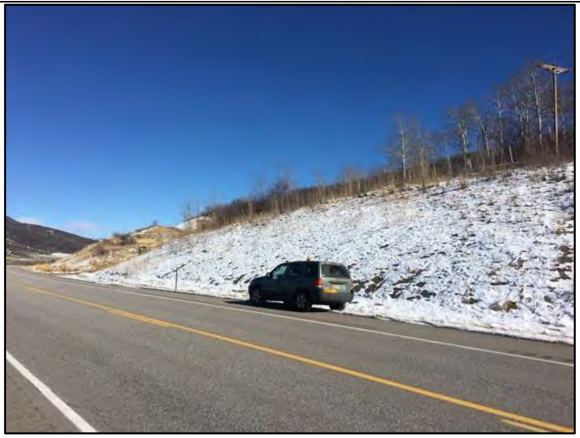
Segment Characteristics

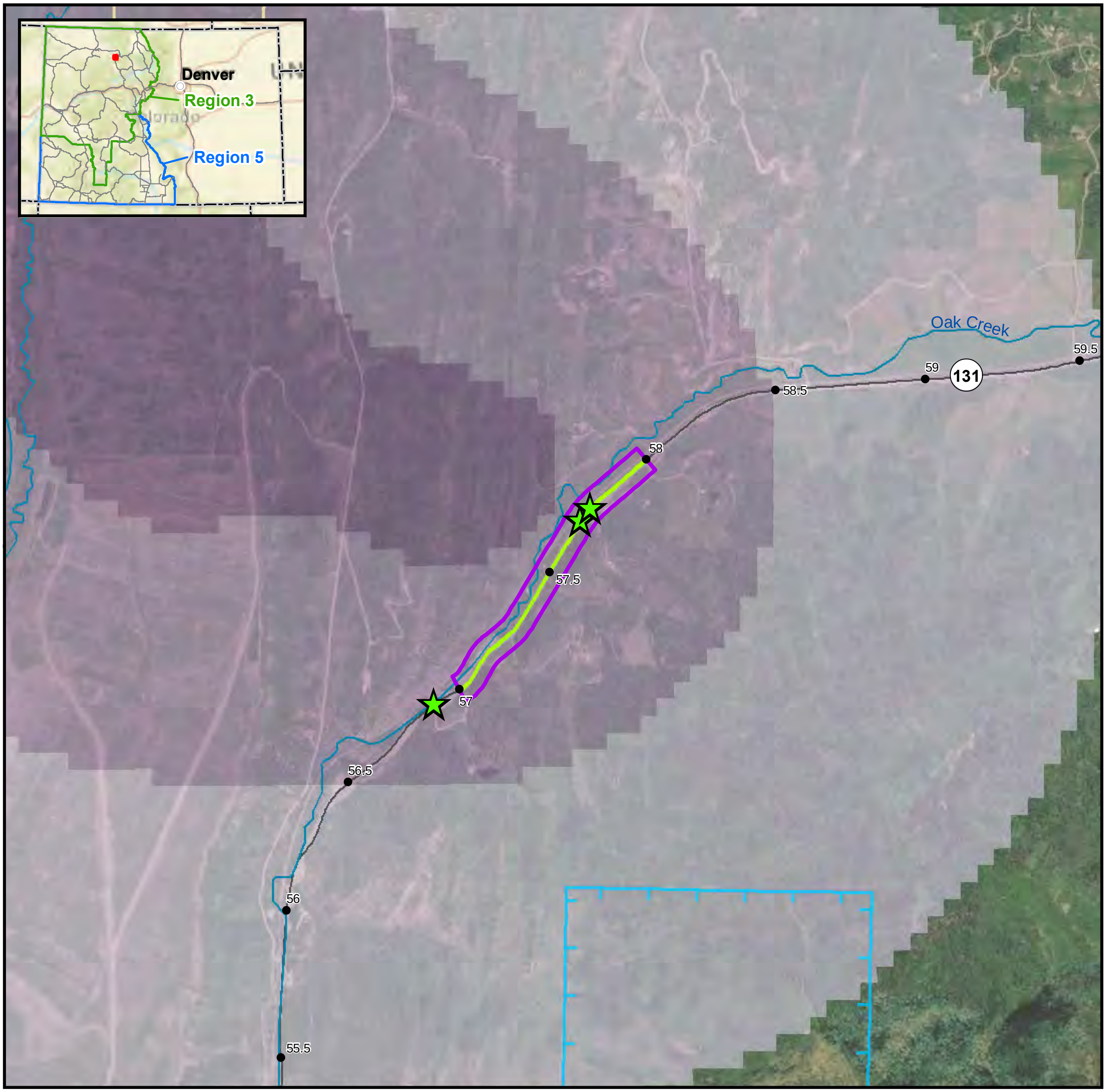
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,700	2,164	Elk and Mule Deer	Migration	Low	19.34

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures through the entire segment.

There are additional opportunities for wildlife underpasses and overpasses to the south of this segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
56.9	Large fill slope. Private access road on east side. Railroad parallels highway immediately to west, along Oak Creek.	Potential wildlife underpass (14 feet high x 36 feet wide). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure. May require skewing the culvert (northwest to southeast) so that it can be placed higher on the slope and to avoid dropping onto the railroad tracks.	
57.7	Low fill slope. Game trails along east side to road. Railroad parallels the highway on the west side.	Potential wildlife underpass (14 feet high x 36 feet wide). May be difficult to fit a structure large enough for elk without raising the roadbed.	N/A
57.75	Ridge from the southeast comes down to the road. Game trails.	Potential wildlife overpass. Could lessen rise in the road at this location to facilitate overpass construction. Private drive on the east side of the highway would need to be realigned.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 3

SH 131
MP 57-58

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2 CDOT REGION 5 (SOUTHWEST REGION)

H-2.1 U.S. Highway 24 Priority Segments

H-2.1.1 U.S. HIGHWAY 24, MILEPOSTS 197.5 TO 201.5, NORTH OF BUENA VISTA

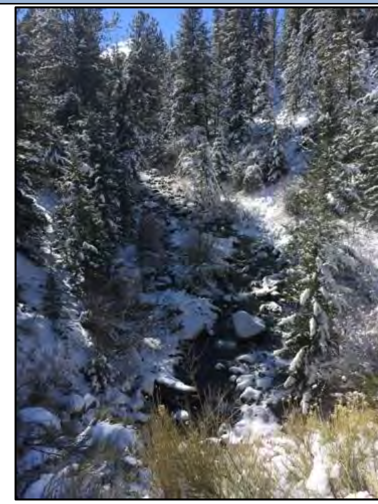
This segment of U.S. 24 is a two-lane highway through the Arkansas River Valley north of Buena Vista. The northern portion of this segment runs through a narrow canyon, which opens into a broad valley at the southern end of the segment. The southern portion of this segment, from MPs 200.5 to 201.5, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

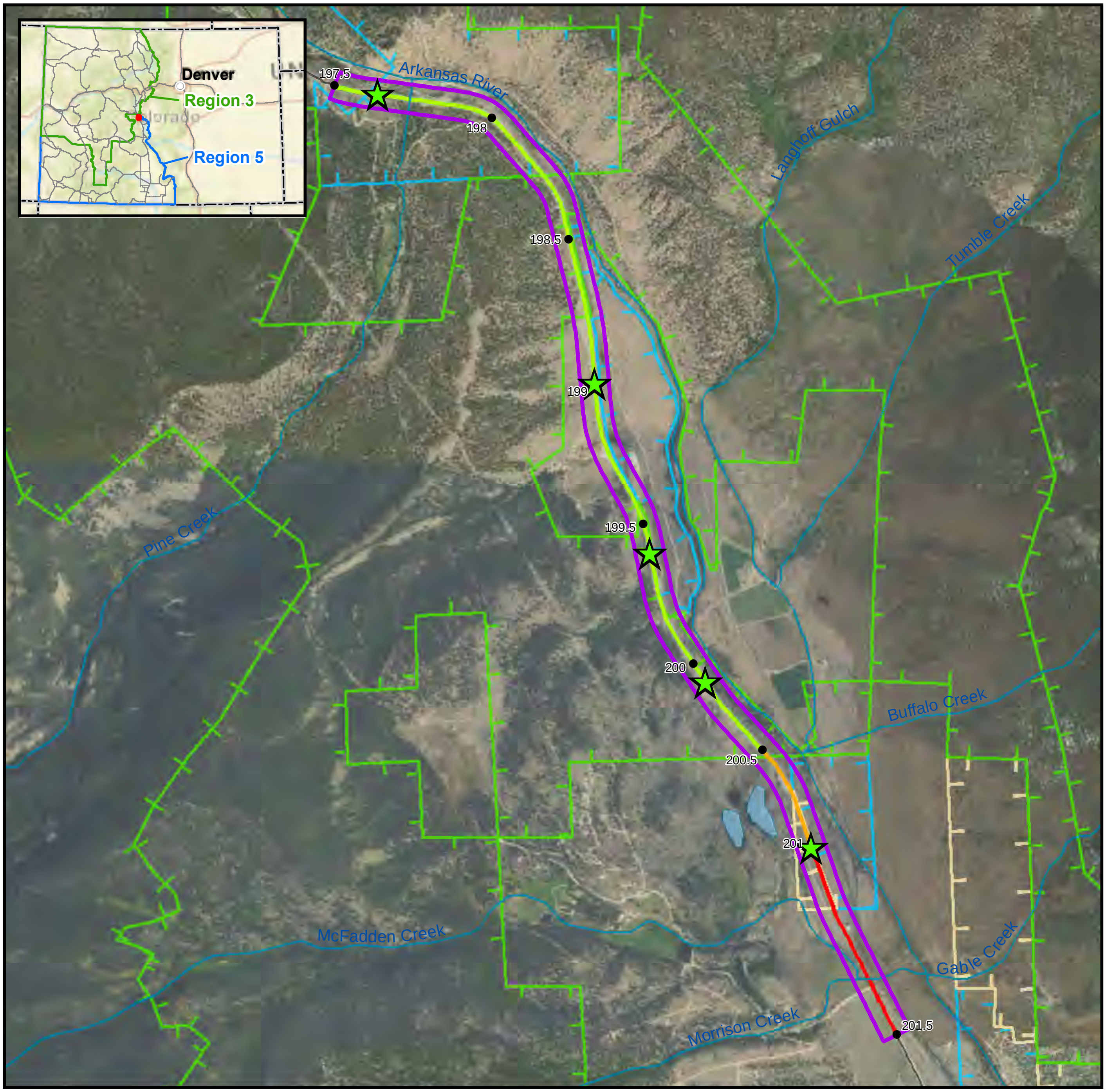
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	3,400	4,007	Mule Deer and Elk	Winter Range	High – elk and deer	17.36

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
197.8	Steep, narrow drainage with perennial stream. Existing large pipe culvert but does not span banks. Feeds into Arkansas River on north side. Rocky slopes surrounding culvert on south side. Railroad runs parallel to road on north side.	Replace with large bridge underpass (14 feet high x 36 feet wide) spanning terrestrial banks.	
199	Road runs parallel to Arkansas River and railroad through a narrow canyon.	Little opportunity for crossing structures. Consider an animal detection system provided the technology has sufficiently improved	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
199.6	Fill slope on both sides of road.	Install large underpass suitable for deer and elk (14 feet high x 36 feet wide).	
200.1	Small drainage from west, but no fill. Fill slope on east side. River and railroad parallel to east.	None	N/A
201	Large fill on west side with farm house and hay fields adjacent. No fill on east side.	Little opportunity for crossing structures. Consider an animal detection system provided the technology has sufficiently improved	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 24
MP 197.5-201.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.1.2 U.S. HIGHWAY 24, MILEPOSTS 205 TO 208, NORTH OF BUENA VISTA

This segment of U.S. 24 is a two-lane highway that runs along the broad Arkansas River Valley north of Buena Vista. The valley is dominated by farming and pasture lands, with increasing commercial and residential development towards Buena Vista. This entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

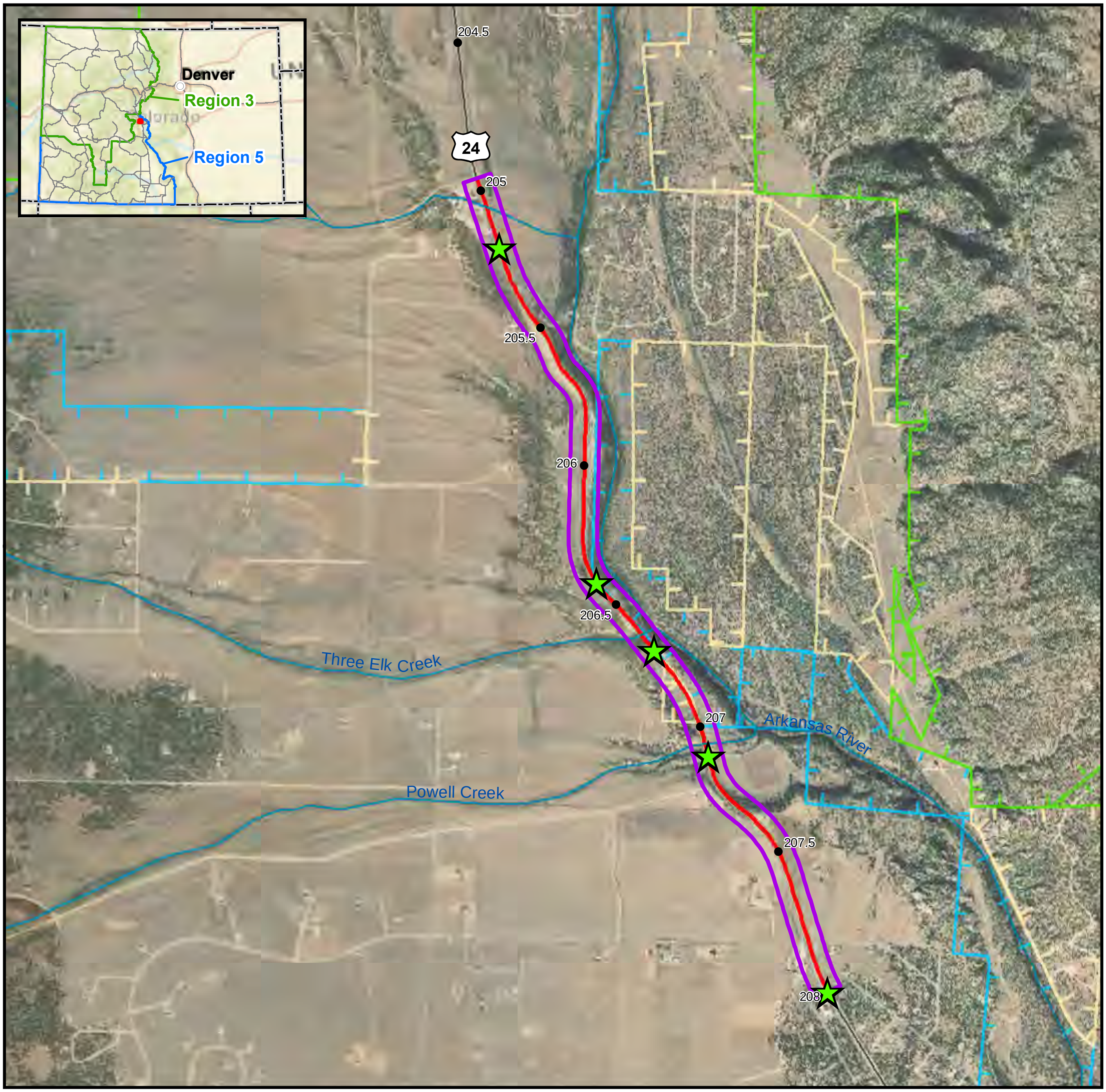
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	8,900	12,731	Mule Deer and Elk	Winter Range	High – elk and deer	17.69

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
205.2	Four Elk Creek. Small drainage with low fill (about 5 feet high). Well-used deer trails observed in snow at the end of the long cut slope on the west side. Campground to north.	Install large underpass suitable for deer (14 feet high x 36 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	
206.1	Small fill slope on south end of curve. Trailer home on east side; fill slope with game trails drops into Arkansas River drainage.	None	N/A
206.4	Small draw with fill on both sides.	Alternate to MP 206.7 for underpass (14 feet high x 36 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
206.7	Three Elk Creek. Narrow drainage from west feeds into the Arkansas River on the east side of the highway. Existing pipe culvert in 15-foot-high fill on west side; 25-foot fill on east side.	Replace with large bridge underpass suitable for deer and elk (14 feet high x 36 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	
207.1	Powell Creek. Small draw from west; hay fields on east side. Roadkill deer observed – deer likely coming around guard rail to access hay fields.	No recommended mitigation at this location if a large underpass is installed at MP 206.7. Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	N/A
208	RV storage; homes.	Replace sheep and cattle fence through this segment with a wildlife-friendly alternative.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence

Cold Spot - 95% Confidence

Cold Spot - 90% Confidence

No Significant Difference

Hot Spot - 90% Confidence

Hot Spot - 95% Confidence

Hot Spot - 99% Confidence

Streams

Lakes

Land Management

Federal (BOR, FWS, NPS)

USFS

BLM

State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 24
MP 205-208

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.1.3 U.S. HIGHWAY 24, MILEPOSTS 214.5 TO 215.5, EAST OF JOHNSON VILLAGE

This segment of U.S. 24 is a two-lane highway that drops into the Arkansas River Valley from the east. A mule deer migration route crosses the highway connecting winter range in the Arkansas River Valley to summer range around Leadville and southern Summit County. The half-mile segment from MPs 214.5 to 215 was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,000	6,628	Mule Deer	Migration and Winter Range	High – elk	19.37

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
215	Big Sandy Creek. Large bridge spanning ephemeral creek drainage constructed in 1938. Many deer tracks and well-used game trails observed through the structure. Cattle fence runs in front of the south entrance to the structure.	Connect this location to other crossing locations with wildlife exclusion fence. Remove cattle fence across the south structure entrance and, if needed, replace with wildlife-friendly fence. Given its age, the structure may be due for replacement; at that time, ensure that the replacement structure maintains similar dimensions and openness.	
215.3	Fill slope with CMP.	Potential wildlife underpass location; however, likely unnecessary because of proximity of structure at MP 215.4.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
215.4	Ephemeral drainage with three-chamber CBC (each chamber about 14 feet high x 8 feet wide x 70 feet long). Deer tracks observed around structure entrances; some likely move through the structure while others climb the fill and cross at grade.	Connect this location to other crossing locations with wildlife exclusion fence. In the long term, replace this structure with a large single chamber CBC or arch culvert.	

Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 24 MP 214.5-215.5

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.1.4 U.S. HIGHWAY 24, MILEPOSTS 220 TO 220.5, JOHNSON VILLAGE TO ANTERO JUNCTION

This segment of U.S. 24 lies in the Pike and San Isabelle National Forests near Mushroom Gulch. The highway traverses the southern flanks of Limestone Ridge, above the Trout Creek drainage.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,000	6,628	Mule Deer	Migration and Winter Range	High – elk	17.30

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Given the length of this priority segment, only one crossing structure is needed. A solo crossing structure should also have wildlife exclusion fence extending at least 0.5 mile but no more than 1 mile in either direction.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
220.2	Large fill slope where the road crosses over a drainage from the north.	Potential wildlife underpass (12 feet high x 20 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
220.5	Large fill slope where the road crosses over a drainage from the north.	Potential wildlife underpass (12 feet high x 20 feet wide).	

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 24
MP 220-220.5

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.1.5 U.S. HIGHWAY 24, MILEPOSTS 222 TO 223.5, JOHNSON VILLAGE TO ANTERO JUNCTION

This segment of U.S. 24 is a two-lane highway on the south side of Trout Creek Pass along Chubb Park Ranch (State Land Board and private conservation easement).

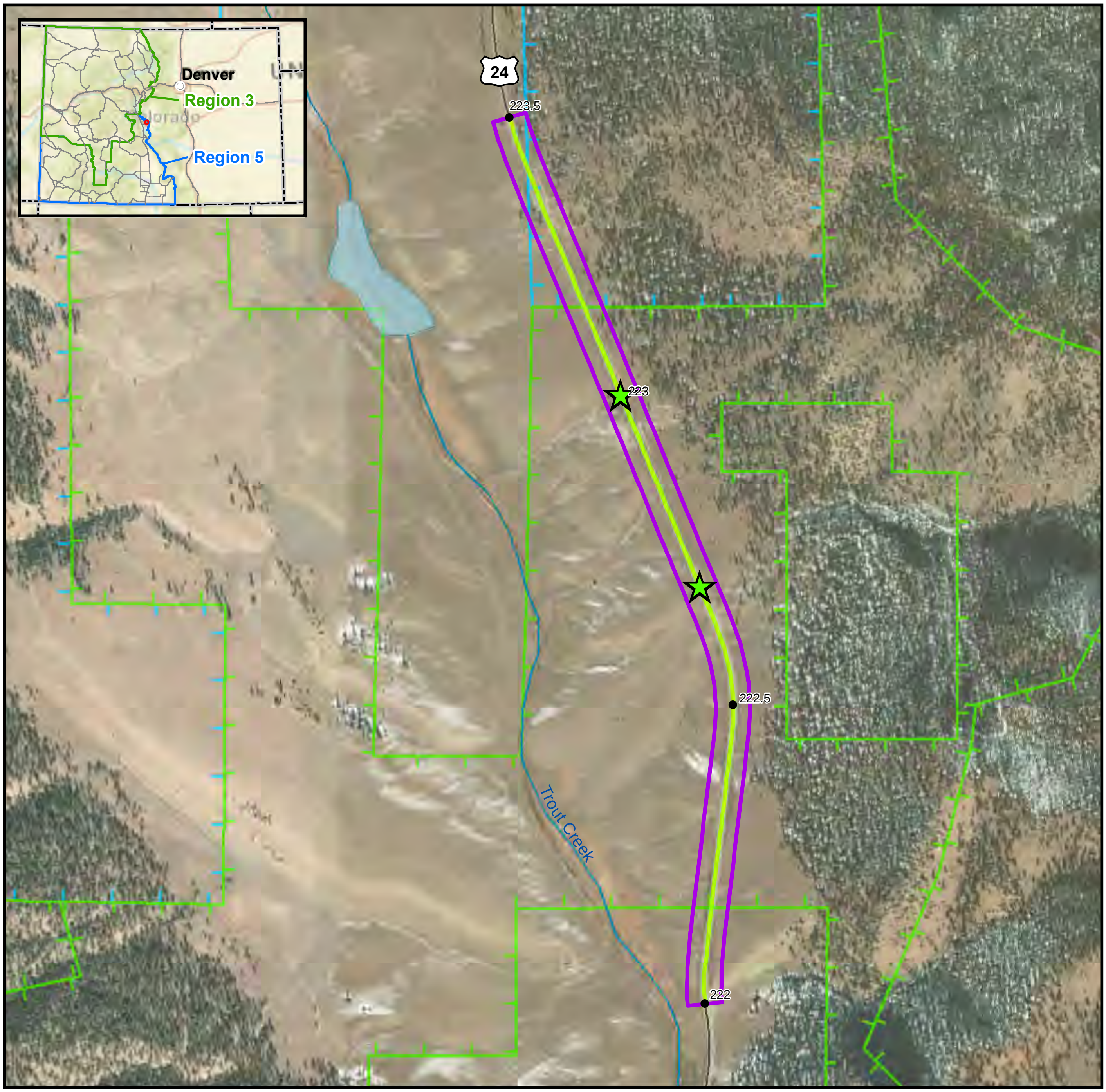
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,000	6,628	Mule Deer and Elk	Migration and Winter Range	High – elk	17.28

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
222.7	CBC (10 feet high x 14 feet wide x 78 feet long). Cattle fence across west entrance.	Connect this location to other crossing locations with wildlife exclusion fence. Remove cattle fence across the west structure entrance and, if needed, replace with wildlife-friendly fence.	
222.7	Looking west from box culvert at MP 222.7		
223	Small fill slope.	Potential wildlife underpass (12 feet high x 20 feet wide). Connect to this location with wildlife exclusion fence.	N/A



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 24
MP 222-223.5

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.2 U.S. Highway 50 Priority Segments

H-2.2.1 U.S. HIGHWAY 50, MILEPOSTS 211.5 TO 214.5, WEST OF PONCHA SPRINGS

This segment of U.S. 50 runs through a primarily agricultural valley on the east side of Monarch Pass. The western portion of the segment from MPs 211.5 to 213 was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	2,500	2,841	Mule Deer and Elk	Winter Range	High – deer and elk	17.45

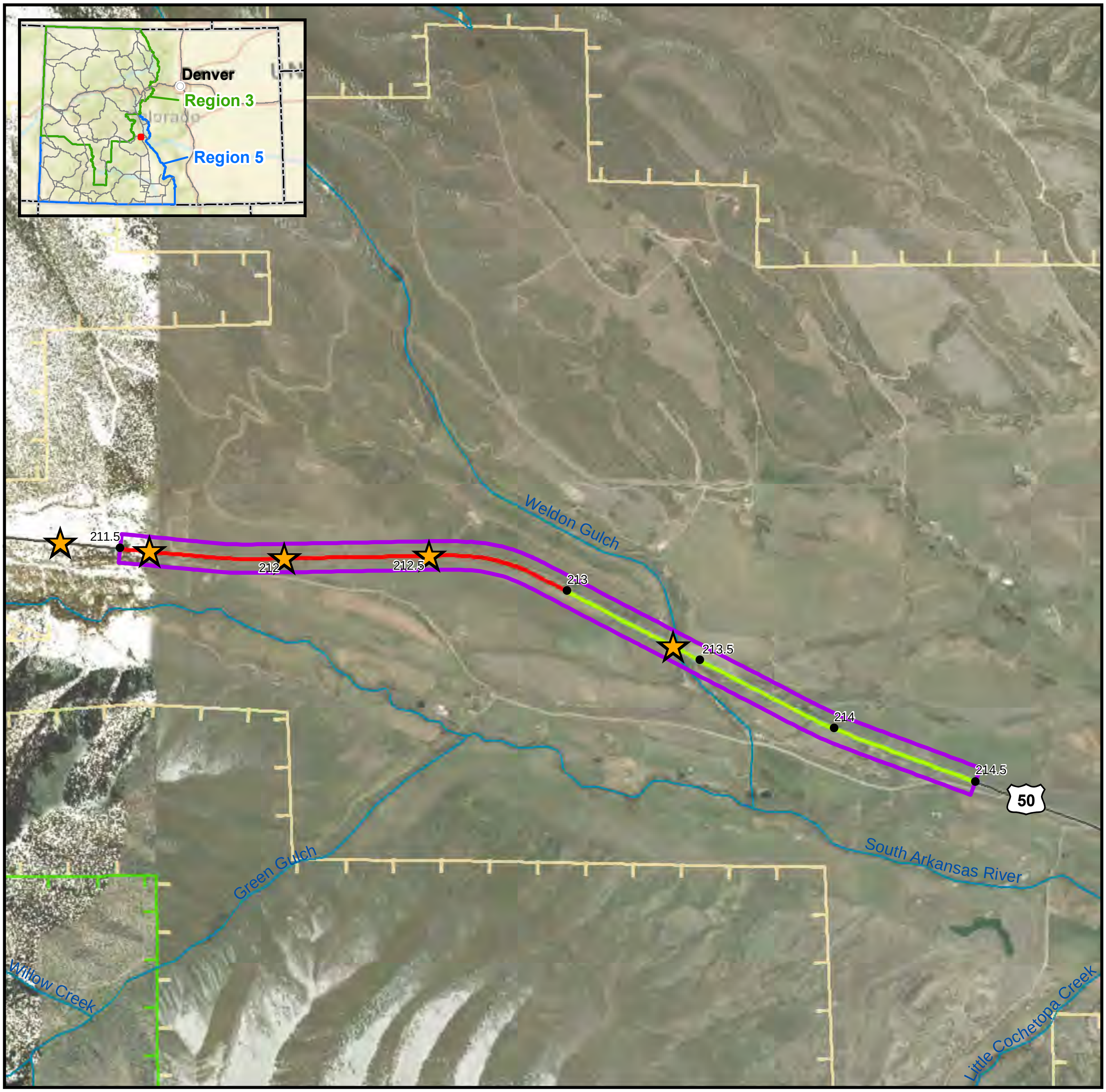
Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
211.3	Small CBC. Campground to north; private drive/home to south.	Maintain as a carnivore crossing. Connect this location to other crossing locations with wildlife exclusion fence. This location is outside of the top 5 percent segment; however, wildlife exclusion fencing should connect this	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		location to new wildlife crossing structures to the east.	
211.6	Double box culvert (each chamber 18 feet high x 12 feet wide x 50 feet long). Salt block placed in CBC. Sheep fence on south side. Old fencing in piles around approach.	Connect this location to other crossing locations with wildlife exclusion fence. Remove sheep fence and clean up old fence piles; if needed, replace with wildlife-friendly fence. Ultimately, replace this structure with a single-chamber structure suitable for elk (14 feet high x 36 feet wide).	
212	CBC (6 feet high x 12 feet wide) partially sediment-filled. Water pipe across north entrance. Deer tracks observed, appear to be crossing at grade.	Remove sediment from structure and connect this location to other crossing locations with wildlife exclusion fence. Remove cattle fence and, if needed, replace with wildlife-friendly fence.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
212.5	Small CBC (3 to 4 feet high x 4 feet wide) partially sediment-filled. Limited fill above structure. Pasture on south side; forested cover on north side.	Remove sediment from structure and connect this location to other crossing locations with wildlife exclusion fence. Remove cattle fence across structure entrances and, if needed, replace with wildlife-friendly fence.	
213.4	Welden Gulch. CBC (10 feet high x 20 feet wide). Half of the culvert is maintained as a drainage channel with cobble substrate; the other half is a low dirt terrestrial bench. Cattle fence and gate across the south side approach. Deer tracks observed through culvert.	Connect this location to other crossing locations with wildlife exclusion fence. Replace cattle fence with wildlife-friendly fence. Ultimately, replace this structure with a single-chamber structure suitable for elk (14 feet high x 36 feet wide).	



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 50
MP 211.5-214.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.3 U.S. Highway 84 Priority Segments

H-2.3.1 U.S. HIGHWAY 84, MILEPOSTS 0 TO 4, NEW MEXICO BORDER TO CHROMO

U.S. 84 is a two-lane, low-volume highway that runs south from Pagosa Springs towards Chama, New Mexico. The landscape is composed of open ranch lands and rolling hills with scattered homes. Much of this segment overlaps with the Brownian Bridge Movement Model for mule deer migration.

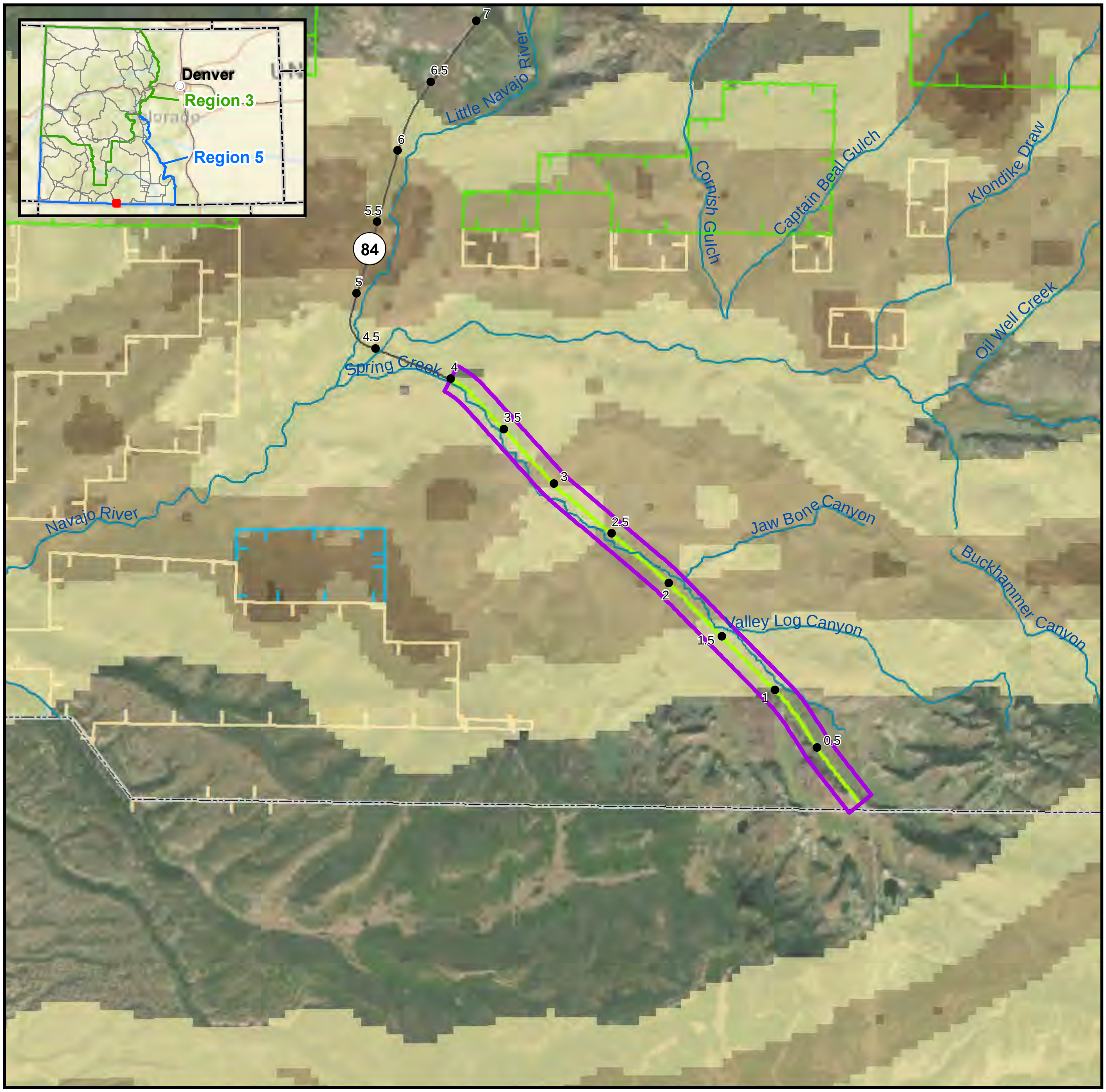
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	840	866	Elk and Mule Deer	Migration and Winter Range	Moderate – deer	17.95

Preliminary Mitigation Recommendations

Given the very low current and predicted future traffic volumes, there are no wildlife crossing recommendations for this segment at this time. Instead, it is recommended that CDOT and CPW work with landowners in this segment to remove the ROW fence where it is not needed and to replace it with wildlife-friendly fence, only where needed. This location may be considered for an animal detection system as the reliability and performance of those systems improve.

US 84 looking south in this segment



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 84
MP 0-4

N

0 1 Miles
1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.4 U.S. Highway 160 Priority Segments

H-2.4.1 U.S. HIGHWAY 160, MILEPOSTS 43.5 TO 46.5, EAST OF CORTEZ

U.S. 160 through this segment extends from the entrance to Mesa Verde National Park west towards Cortez. The entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment was also identified by Ruediger and FHU (2014), specifically the high-priority Fairgrounds-McElmo Linkage (MPs 42.5 to 45.1) and the medium-priority MP 46 Linkage.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	7,300	8,296	Mule Deer	Migration and Winter Range	High – deer	18.63

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
43.4	Double box culvert. Access road and trailhead on north side; fairgrounds on south side.	Potential wildlife underpass (12 feet high x 20 feet wide). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
44.25	CBC (12 feet high x 12 feet wide x 140 feet long) with 3-foot perch at outlet. Flashy, high volume flows.	Fix outlet perch and add baffles and outlet pools to minimize erosion; alternatively, replace CBC with a new wildlife underpass. Connect this location to other crossing locations with wildlife exclusion fence.	
44.25	Outlet, box culvert, MP 44.25		
46	Small drainage, CMP.	Potential wildlife underpass (12 feet high x 20 feet wide). Connect this location to other crossing locations with wildlife exclusion fence.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
47.3	3.5-foot-diameter pipe culvert with concrete headwall. Fill slope is higher on north side than on south side. Riprap around outlet slopes. Cattle fence.	This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure. Increase fill height on south side to install a wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect this location to other crossing locations with wildlife exclusion fence.	

Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 43.5-46.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.4.2 U.S. HIGHWAY 160, MILEPOSTS 94 TO 100.5, ELMORE'S CORNER TO GEM VILLAGE

This segment of U.S. 160 runs through a rural residential and agricultural landscape. Much of this segment overlaps with the Brownian Bridge Movement Models for mule deer winter range and migration. The entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment was also identified by Ruediger and FHU (2014), specifically the Florida River Linkage (medium priority; MPs 92.35 to 93.85), the Detection Zone Linkage (high priority; MPs 94.95 -96.5), the Dry Creek Linkage (high priority; MPs 96.6 to 98.1), and the Gem Village West Linkage (high priority; MPs 99.1 to 100.25).

Portions of this segment have been widened, and the remaining sections are planned for widening and wildlife mitigation. Several sections of roadway with wildlife exclusion fencing overlap with this segment (MPs 93.2 to 94.3 and MPs 97 to 97.8), and a large arched wildlife crossing was constructed at MP 97.5 as part of the highway widening. MPs 94.7 to 96.5 was a test zone for an electromagnetic wildlife detection and driver warning system installed in 2008. That system has since been completely disabled and its remaining components will be removed.

<u>Segment Characteristics</u>

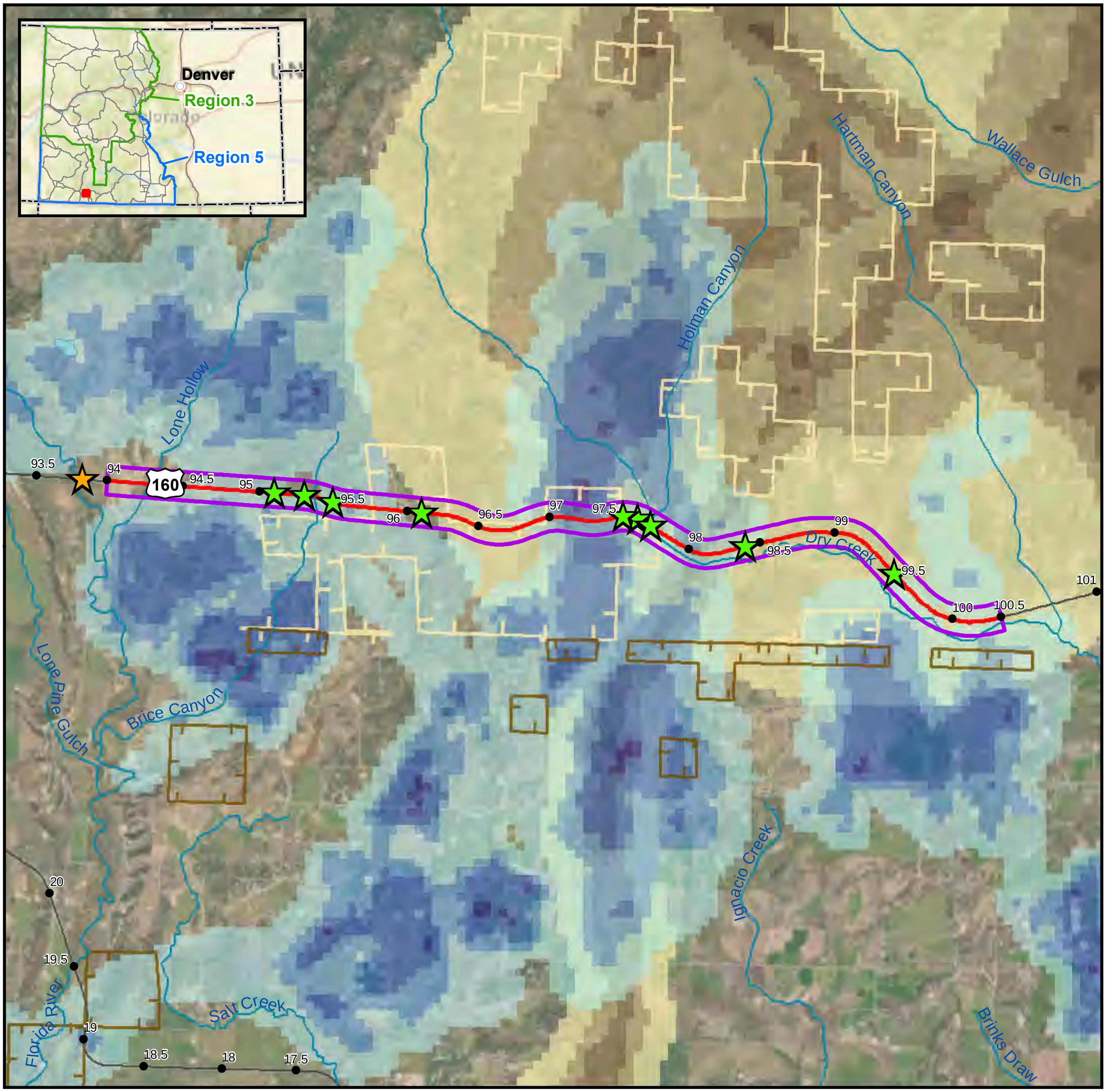
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2 to 4	12,000	17,796	Mule Deer and Elk	Migration and Winter Range	Low	20.19

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Depending on the construction timeline for the highway widening and wildlife mitigation east of the Dry Creek wildlife crossing, in the near term, remove ROW fence or, where needed, replace with wildlife-friendly fence from the end of the wildlife exclusion fence end at MP 97.8 east to Gem Village. Ultimately, wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
93.8	Florida River. Bridge underpass with wildlife exclusion fencing.	Per the EIS, the existing wildlife crossing will be replaced with a new bridge with an open median. Increase the height and span of the new structure to make this crossing more attractive to elk.	
95.1	Small cut slope at top of hill. Mobile home park on south side.	Potential wildlife overpass, although the presence of nearby homes makes this a less desirable location.	N/A
95.3	Small fill where road crosses over a small draw.	Potential wildlife underpass (14’H x 36’W).	
95.5	Small cut slope on north side.	Potential wildlife overpass (e.g., hourglass shape 60’W at the middle and 100’W at the approaches)	
96.1	Large fill slope. Oil rigs in adjacent landscape	Potential wildlife underpass suitable for elk and deer (14’H x 36’W). Extend wildlife exclusion fencing.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
97.5	Dry Creek wildlife underpass with wildlife exclusion fencing. This crossing is composed of two arch culverts (each 13’H x 37’W) with a small atrium in-between.	Existing wildlife crossing.	
97.6	Small fill slope	Existing small mammal crossing (concrete pipe).	
97.7	Dry Creek CMP.	Planned bridge underpass.	
98.4	Stock pass pipe culvert.	Planned bridge underpass. Road will be raised through this section to accommodate a 14’H bridge.	
99.5	Small drainage and stock pass.	Potential wildlife underpass. Location is identified in the EIS; will require raising the roadbed.	
	Los Pinos River.	This location is outside of the top 5% segment; however, it is included in the EIS for replacement with a larger span to accommodate wildlife.	
102.6	Small fill where road crosses over a small draw.	Potential wildlife underpass (14’H x 36’W).	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 94-100.5

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.4.3 U.S. HIGHWAY 160, MILEPOSTS 104.5 TO 113.5, BAYFIELD TO YELLOW JACKET PASS

This segment of U.S. 160 runs through a rural residential, agricultural, and forested landscape. Much of this segment overlaps with the Brownian Bridge Movement Models for mule deer migration. MPs 104.5 to 110.5 was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. The westernmost portion of this segment is included in the U.S. 160 Environmental Impact Statement (EIS) (CDOT, 2006). This segment was also identified by Ruediger and FHU (2014), specifically the Beaver Creek Linkage (high priority; MPs 103.95 to 109), Lange Canyon Linkage (medium priority; MPs 110.5 to 111.2), and Yellow Jacket Pass Linkage (medium priority; MPs 111.9 to 114.6).

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,800	5,707	Mule Deer and Elk	Winter Range and Migration	Low	19.11

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

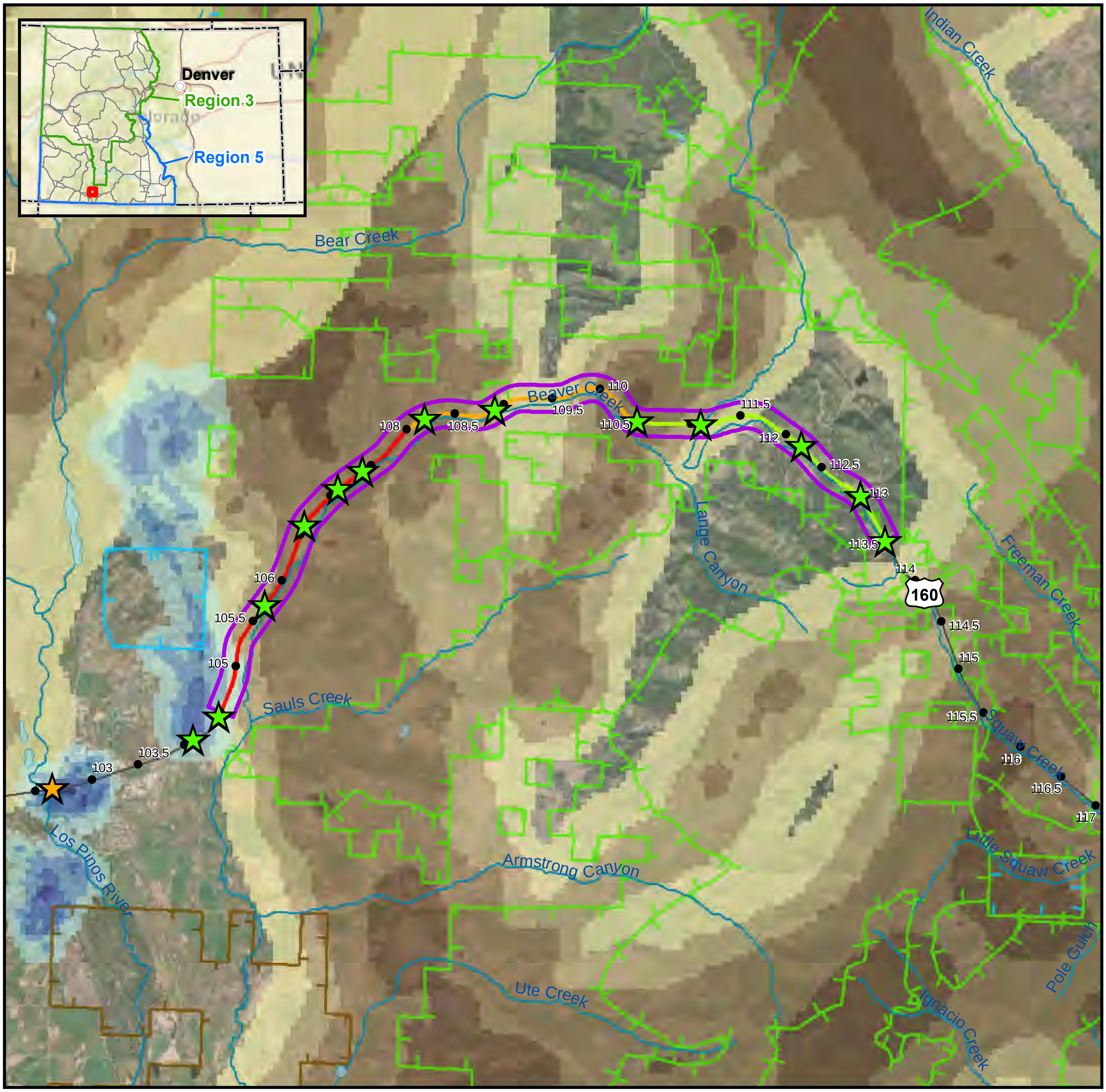
Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
104.1	Wooded draw with CMP.	This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure. Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide). Remove unneeded fencing and replace with wildlife-friendly fence where needed.	
104.45	Fill slope with CMP. Ponderosa pine forest adjacent to road with dispersed residences and forest openings.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	N/A
105.7	CMP stock pass. Open draw with adjacent ponderosa pine and oak woodland on north side.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
106.6	Cut slope. Heavily grazed pasture to north.	Potential wildlife overpass.	
107.1	Low fill slope where road crosses over a drainage from the north.	Potential wildlife underpass (12 feet high x 20 feet wide); will require raising the roadbed.	N/A
107.4	Low fill, stock pass.	Potential wildlife underpass (12 feet high x 20 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
107.8	Fill slope. Drainage is skewed relative to the road.	Potential wildlife underpass suitable for deer and elk (14 feet high x 36 feet wide). Consider placing the structure higher in the drainage (east) to provide a better approach from the north.	
108.2	Small fill where roadbed is raised relative to the surrounding terrain.	Potential wildlife underpass (12 feet high x 20 feet wide).	N/A
108.9	Small fill slope where road crosses over a drainage from the north.	Potential wildlife underpass (12 feet high x 20 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
110.5	Large fill slope where road crosses over a large draw from the north.	Potential wildlife underpass (12 feet high x 20 feet wide).	N/A
111.1	Beaver Creek. Large pipe culvert (6 feet in diameter).	Potential wildlife underpass (12 feet high x 20 feet wide).	N/A
112.2	Small fill where roadbed is raised relative to the surrounding terrain. Ponderosa/oak woodland to north and irrigated meadow to south are likely attractants for deer and elk.	Potential wildlife underpass suitable for elk and deer (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
113	Small fill slope. Hayden Creek runs parallel to this location immediately on the south side. Open woodland cover on both sides.	Potential wildlife underpass (14 feet high x 36 feet wide).	
113.5	Fill slope with small CMP. Heavily grazed pasture on both sides of this location.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 104.5-113.5

N

0 1 Miles

1 inch = 1.5 miles

JACOBS

Date: 1/9/2019

H-2.4.4 U.S. HIGHWAY 160, MILEPOSTS 118 TO 120.5, YELLOW JACKET PASS TO THE PIEDRA RIVER

This segment of U.S. 160 descends from Yellow Jacket Pass through a canyon to the Piedra River drainage. The landscape through this segment is forested with few additional roads and little development. This entire segment overlaps with the Brownian Bridge Movement Models for mule deer migration. Much of this segment, from MPs 119 to 120.5, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment was also identified by Ruediger and FHU (2014) as the Yellow Jacket Creek Linkage (high priority; MPs 118 to 120.6).

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,800	6,866	Mule Deer and Elk	Migration and Winter Range	Low	18.35

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
118.2	Yellow Jacket Creek. Three-chamber box culvert. Gate across culvert entrance.	Potential wildlife underpass (low bridge suitable for elk, 14 feet high x 36 feet wide). Set wildlife-friendly fence back away from entrance.	
119	Small fill on north side; larger fill on south side. Forested hillside to north.	Potential wildlife underpass (low bridge suitable for elk, 14 feet high x 36 feet wide. May require raising roadbed or digging out north side approach.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
120.2	Small fill. Draw from north between forested hillsides. Pasture on south side.	Potential wildlife underpass (14 feet high x 36 feet wide) or overpass.	
121.3	Piedra River. Large span bridge.	This location is outside of the top 5 percent segment; however, wildlife exclusion fencing should connect this location and new wildlife crossing structures to the south. Create pathways for wildlife through the structure. Ultimately, replace structure with a longer span over terrestrial banks.	

Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 118-120.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.4.5 U.S. HIGHWAY 160, MILEPOSTS 124.5 TO 129.9, STATE HIGHWAY 151 JUNCTION, SOUTHERN UTE TRIBE

This segment of U.S. 160 runs along the northern edge of the Southern Ute Tribal lands and through a National Forest. Much of this landscape is forested with limited development (residences, campgrounds). This entire segment overlaps with the Brownian Bridge Movement Model for mule deer migration. Much of this segment, from MPs 25.5 to 129, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment was also identified by Ruediger and FHU (2014), specifically the Piedra River Linkage (high priority; MPs 121 to 125) and the Lake Capote Linkage (high priority; MPs 125.5 to 134).

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,400	7,410	Mule Deer and Elk	Migration and Winter Range	Low	19.21

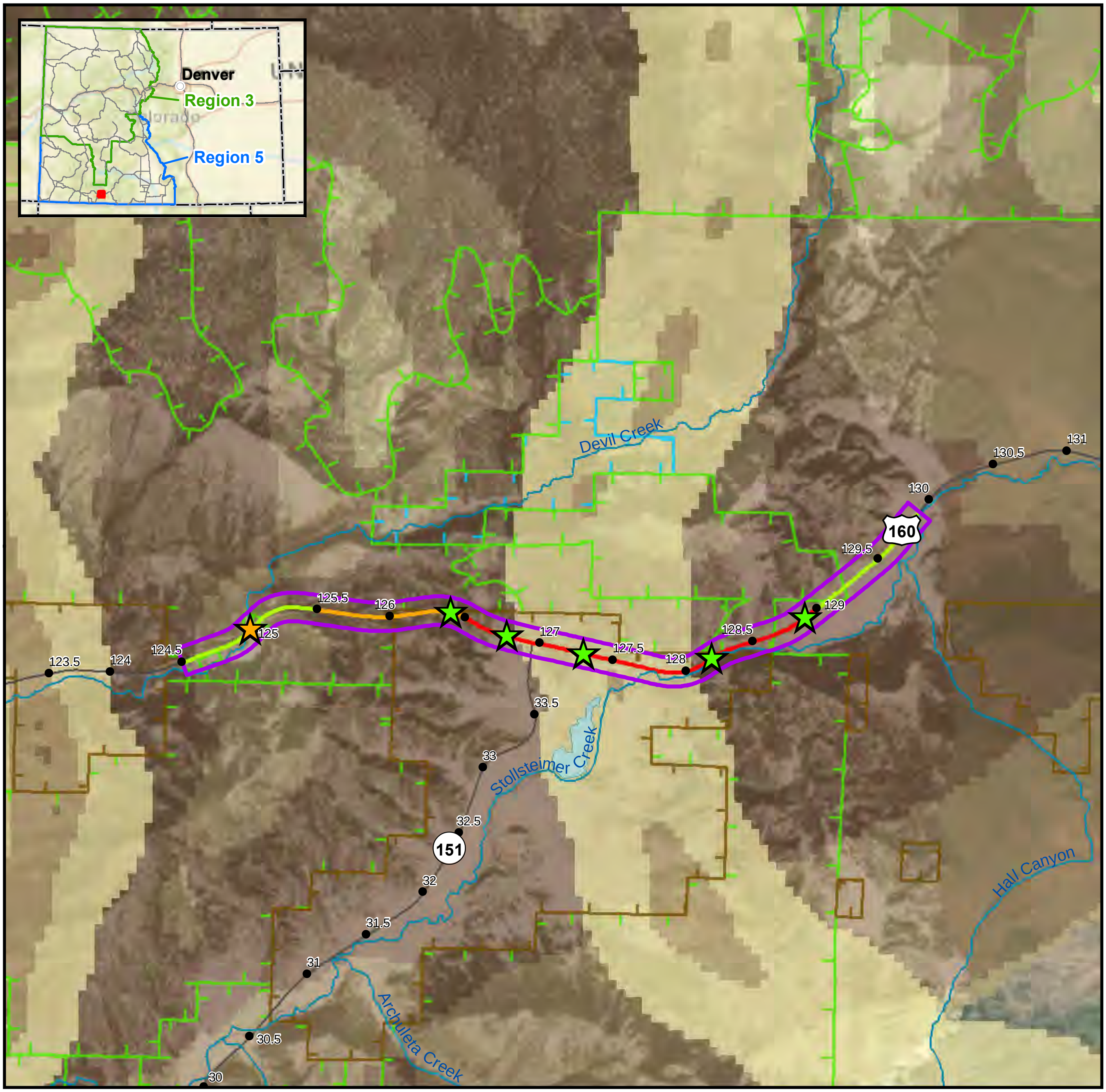
Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the entire segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
125	Devil Creek bridge. Riprap slopes, thick vegetation at entrances to the structure. Homes, driveway on the northeast side. A deer trail was observed immediately west of the bridge, through a gap in the ROW fence on the hillside north of the road and around the guard rail on the south side.	Cut a trail through the shrubs to improve wildlife access to the bridge. Connect wildlife exclusion fencing from other crossing structures east of here to this location. Consider extending fence west of the bridge to Chimney Rock Restaurant if deer continue to cross at-grade instead of under the bridge.	
126.4	Fill slope. Forest cover on both sides of road.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
126.8	Long fill slope immediately east of State Highway 151 junction.	Wildlife underpass (13 feet high x 37 feet wide x 78 feet long) planned at this location.	
127.3	Cut slope. Lake Capote on south side.	Wildlife overpass (84 feet wide x 72 fee long) planned at this location at the east end of the cut slope.	N/A
128.2	Fill slope, CMP. Stollsteimer Creek parallels the road on the south side.	Potential wildlife underpass (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
128.9	Small drainage, CMP.	Potential wildlife underpass (14 feet high x 36 feet wide).	



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 124.5-129.9

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.4.6 U.S. HIGHWAY 160, MILEPOSTS 133 TO 136, WEST OF PAGOSA SPRINGS

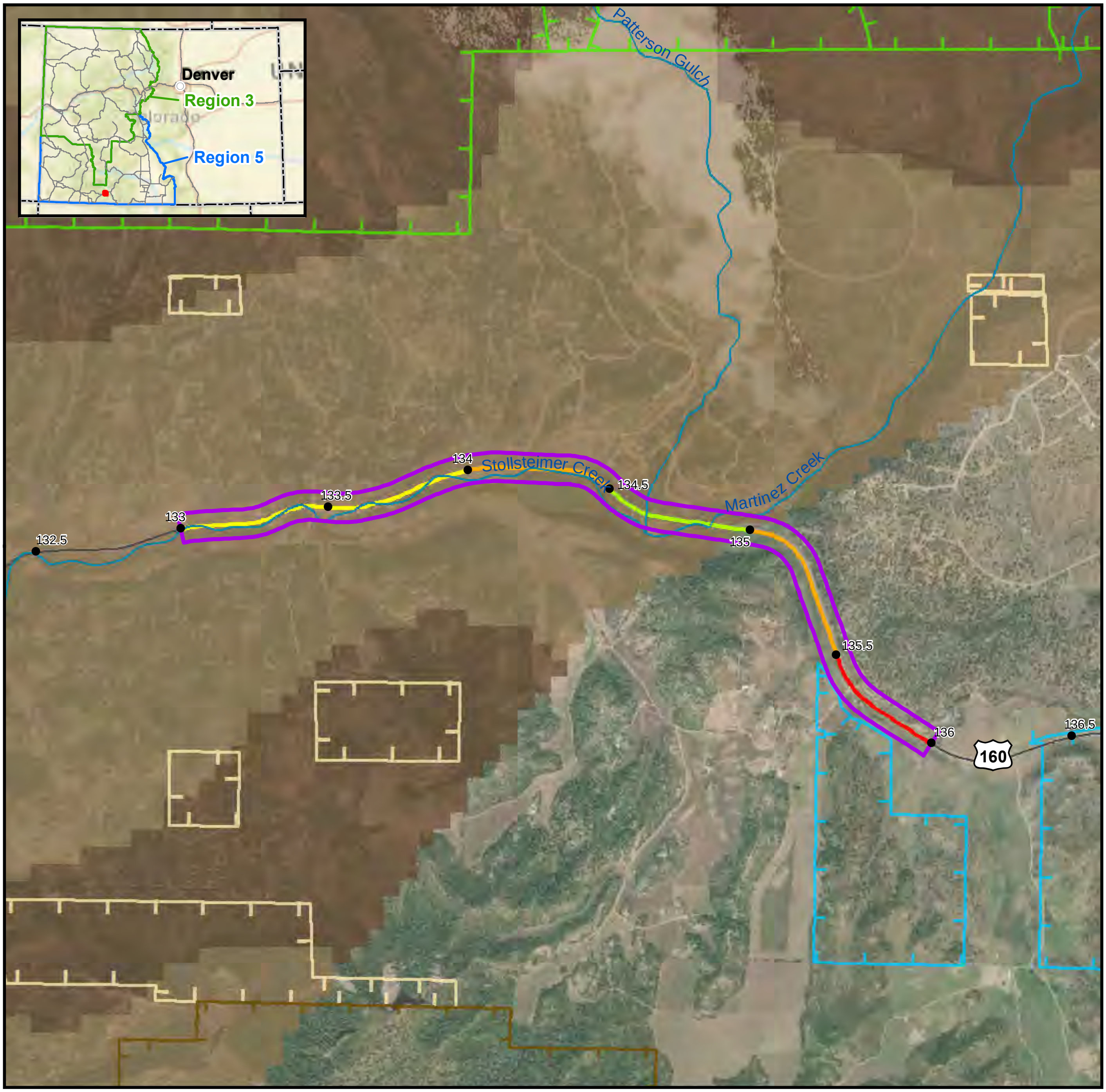
This segment of U.S. 160 runs through a complex landscape characterized by agricultural lands and residential development. Much of this entire segment overlaps with the Brownian Bridge Movement Models for mule deer migration. Portions of this segment were identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment was also identified by Ruediger and FHU (2014) and overlaps with the Lake Capote Linkage (high priority; MPs 125.5 to 134) and the Martinez Creek Linkage (medium priority; MPs 134.5 to 136.6).

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	8,500	11,892	Elk and Mule Deer	Migration and Winter Range	Low	18.04

Preliminary Mitigation Recommendations

Given the human uses of the landscape adjacent to this segment and the lack of grade under the road, which prevents the construction of wildlife underpasses without raising the road, wildlife crossing mitigation is not recommended in this segment at this time. Deer crossing structures and wildlife exclusion fencing may be constructible in this segment but would create a barrier for elk in this landscape. This location may be considered for an animal detection system as the reliability and performance of those systems improve, or other experimental mitigation strategies as new technologies evolve.



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 160
MP 133-136

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.4.7 U.S. HIGHWAY 160, MILEPOSTS 145.5 TO 148, EAST OF PAGOSA SPRINGS

This segment of U.S. 160 runs through the broad San Juan River valley east of Pagosa Springs. This entire segment overlaps with the Brownian Bridge Movement Models for mule deer migration.

Segment Characteristics

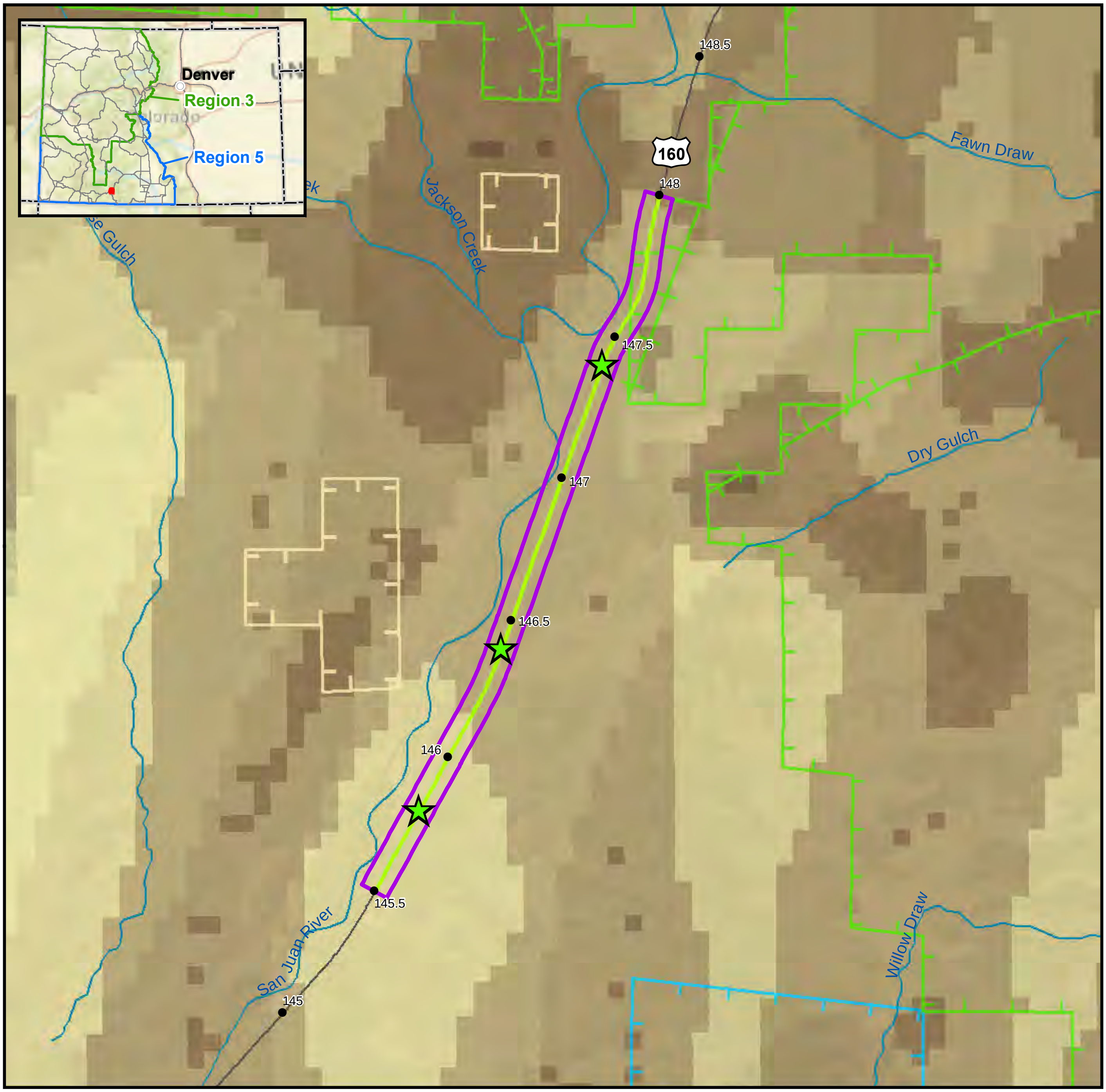
Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	5,000	5,735	Mule Deer and Elk	Migration and Winter Range	Low	18.07

Preliminary Mitigation Recommendations

There are limited opportunities for wildlife crossing structures suitable for elk in this segment because of the configuration of the road in the landscape. In the event of a future roadway improvement project, several locations for potential wildlife crossing structures are provided below for further consideration. If wildlife crossings are constructed in this segment, then wildlife exclusion fence should be used to connect wildlife crossing structures. Alternatively, other mitigation strategies may be explored, such as wildlife exclusion fencing and wildlife crosswalks (Gagnon et al., 2018). This segment may also be considered for an animal detection system as the reliability and performance of those systems improve. At a minimum, remove ROW fencing throughout this segment or, where needed, replace with wildlife-friendly fence.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
145.8	Small creek drainage, fill slope. Pagosa Riverside Campground on west side.	Potential wildlife underpass suitable for deer	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
146.4	A forested ridge from the east comes down to the road and likely acting as a wildlife movement corridor. A	Potential wildlife overpass suitable for elk	N/A
147.4	A forested ridge from the east comes down to the road and likely acting as a wildlife movement corridor. Residences in area	Potential wildlife overpass suitable for elk	N/A



Base Map Date: ESRI 2018

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Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 144-148

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.4.8 U.S. HIGHWAY 160, MILEPOSTS 195 TO 196.1, WEST OF DEL NORTE

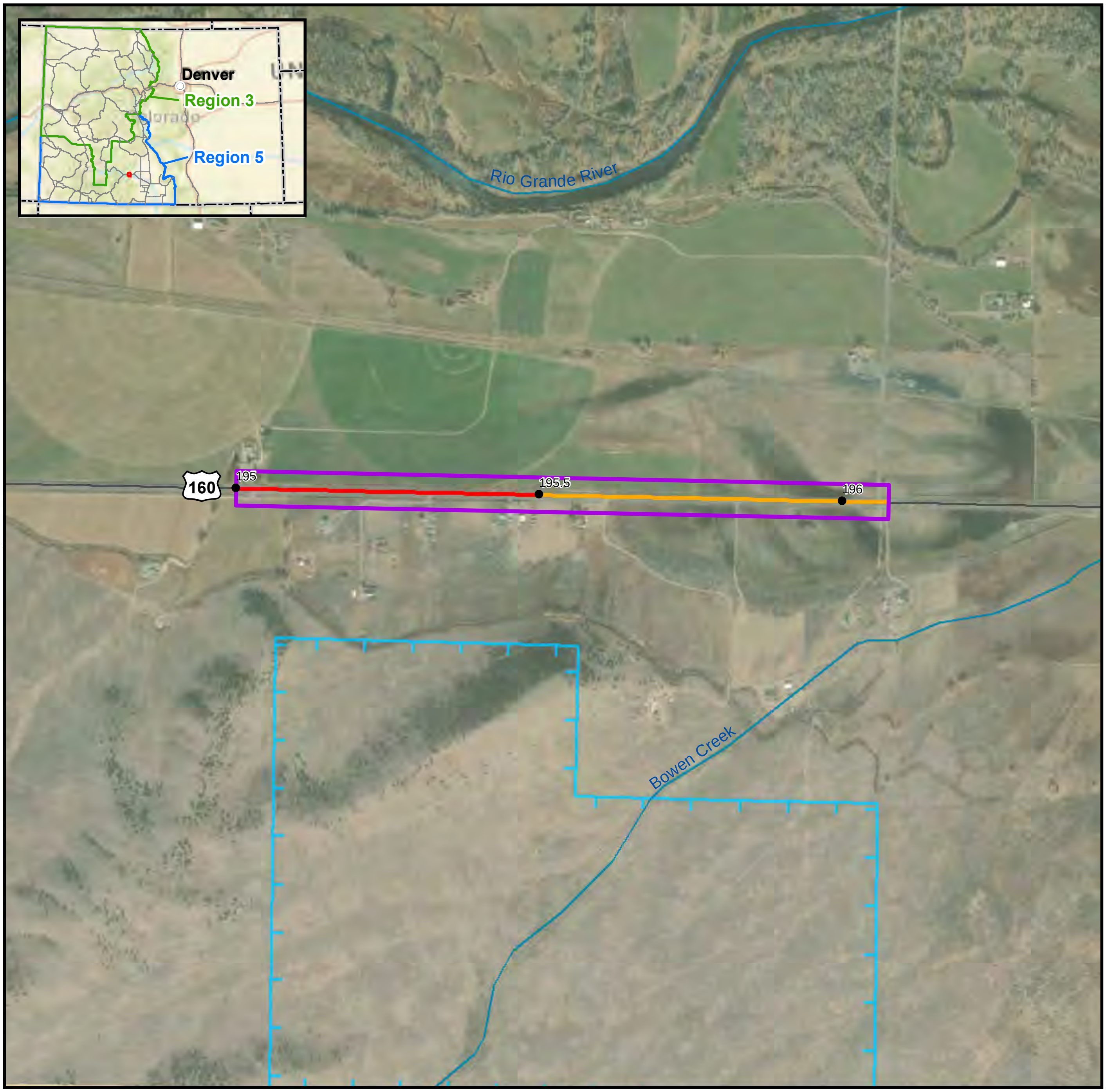
This short segment of U.S. 160 lies several miles west of Del Norte along the Rio Grande River. The valley bottom is largely agricultural. This segment is crossed by north-south mule deer and elk migrations, and the Rio Grande River corridor is home to a resident mule deer herd. The area also provides winter range for both deer and elk. This entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,800	5,707	Mule Deer and Elk	Migration and Winter Range	Very High – deer	17.36

Preliminary Mitigation Recommendations

While this 95th percentile segment is only a mile long, it should be considered in a larger context because adjacent highway segments fall in the 90th percentile. However, for this study, only the 95th percentile segments are considered. The highway through this segment is flat or slightly raised relative to the surrounding terrain, so wildlife underpasses are not feasible without raising the roadbed. Alternatively, other mitigation strategies may be explored, such as wildlife exclusion fencing and wildlife crosswalks (Gagnon et al., 2018). This segment may also be considered for an animal detection system as the reliability and performance of those systems improve. At a minimum, remove ROW fencing throughout this segment or, where needed, replace the ROW fencing with wildlife-friendly fence.



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 195-196.1

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.4.9 U.S. HIGHWAY 160, MILEPOSTS 260 TO 265, EAST OF FORT GARLAND

This segment of U.S. 160 is characterized by low, rolling hills of piñon pine and sagebrush. Sangre de Cristo Creek and the railroad run parallel to the highway on the south side. This segment is recognized by CPW as a mule deer concentration area and provides winter habitat for elk and mule deer.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,700	6,181	Mule Deer and Elk	Winter Range	Very High – deer	17.50

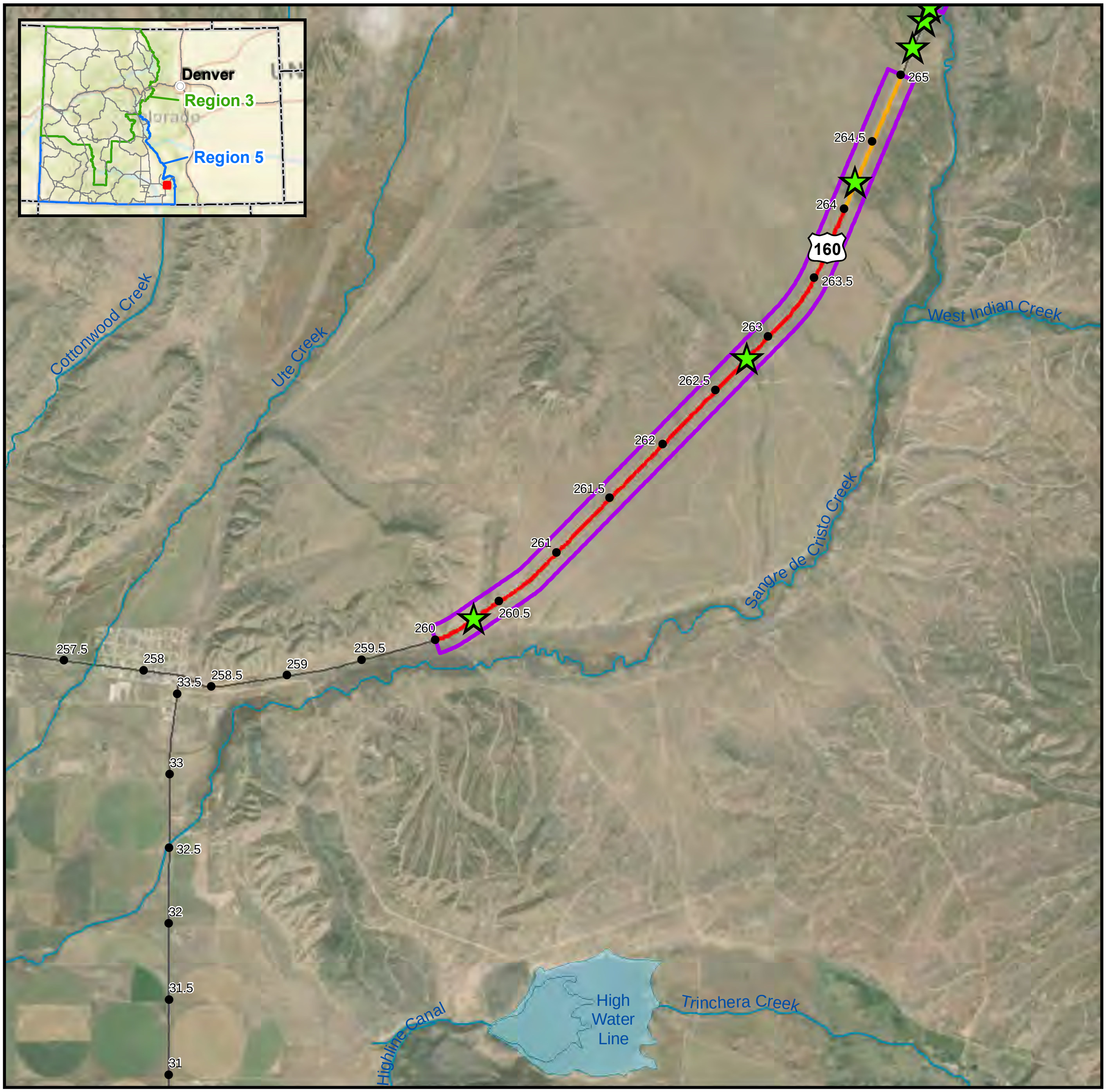
Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife crossing structures should be sized for mule deer and elk, and wildlife exclusion fencing should run continuously from one structure to the next.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
260.3	CBC (6 feet high x 6 feet wide) with perched outlet. Concrete floor and icing in culvert at time of survey.	Potential wildlife underpass (14 feet high x 36 feet wide).	
262.8	CBC (7 feet high x 6 feet wide) in a fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
264.1	CBC (7 feet high x 6 feet wide) in a fill slope. Cattle fence is strung across the south entrance.	Potential wildlife underpass (14 feet high x 36 feet wide).	
265.1	Large fill slope where the road crosses a narrow drainage that is skewed relative to the road bed.	Potential wildlife underpass (14 feet high x 36 feet wide).	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
265.4	Two adjacent drainages from the north with a large fill slope on the south.	Potential wildlife underpass (14 feet high x 36 feet wide). This area is outside of the top 5 percent segment but offers a good opportunity for a wildlife crossing structure.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

US 160
MP 260-265

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.4.10 U.S. HIGHWAY 160, MILEPOSTS 265.5 TO 271, FORT GARLAND TO LA VETA PASS

This segment of U.S. 160 is characterized by low, rolling hills of piñon pine and sagebrush along Sangre de Cristo Creek as it descends from La Veta Pass. This entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	4,700	6,181	Mule Deer and Elk	Winter Range	Very High – deer	17.74

Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife crossing structures should be sized for mule deer and elk, and wildlife exclusion fencing should run continuously between the structures. In the near term, remove ROW fence or, where needed, replace ROW fence with wildlife-friendly fence.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
265.5	Fill slope where the road crosses a drainage from the north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
267.1	Small fill where the road crosses a flat drainage from the north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
267.2	Small fill where the road crosses a flat drainage from the north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
267.3	Small fill where the road crosses a flat drainage from the north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
267.4	Fill slope with 5.5-foot-diameter pipe. Eroded channel on south side.	Potential wildlife underpass (14 feet high x 36 feet wide).	
267.9	Fill slope with 5-foot-diameter pipe.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
268	Narrow drainage with small pipe.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
268.2	Sangre de Cristo Creek. CBC (4 to 6 feet high x 10 feet wide). No terrestrial pathway through the culvert.	Potential wildlife underpass (14 feet high x 36 feet wide).	
269.1	Sangre de Cristo Creek. CBC (4 to 6 feet high x 10 feet wide). No terrestrial pathway through the culvert.	Potential wildlife underpass; may require raising roadbed to install a low, wide bridge at this location (14 feet high x 36 feet wide).	N/A
269.8	Small fill where the road crosses a narrow drainage from the north.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
270.3	Sangre de Cristo Creek. CBC (6 feet high x 10 feet wide). No terrestrial pathway through the culvert.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 160 MP 265.5-271

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.5 U.S. Highway 285 Priority Segments

H-2.5.1 U.S. HIGHWAY 285, MILEPOSTS 144.50 TO 147.5, JOHNSON VILLAGE TO NATHROP

Much of this segment of U.S. 285 was reconstructed in 2018, including the addition of a second southbound traffic lane and wildlife mitigation features. The highway runs parallel to the Arkansas River. In addition to its wildlife values, this landscape sustains many human uses, including a local airport at the northern end of the segment, ranch lands, residences, and fishing and rafting access to the river. This entire segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2 to 3	9,500	12,792	Mule Deer and Elk	Winter Range	High – elk and deer	17.74

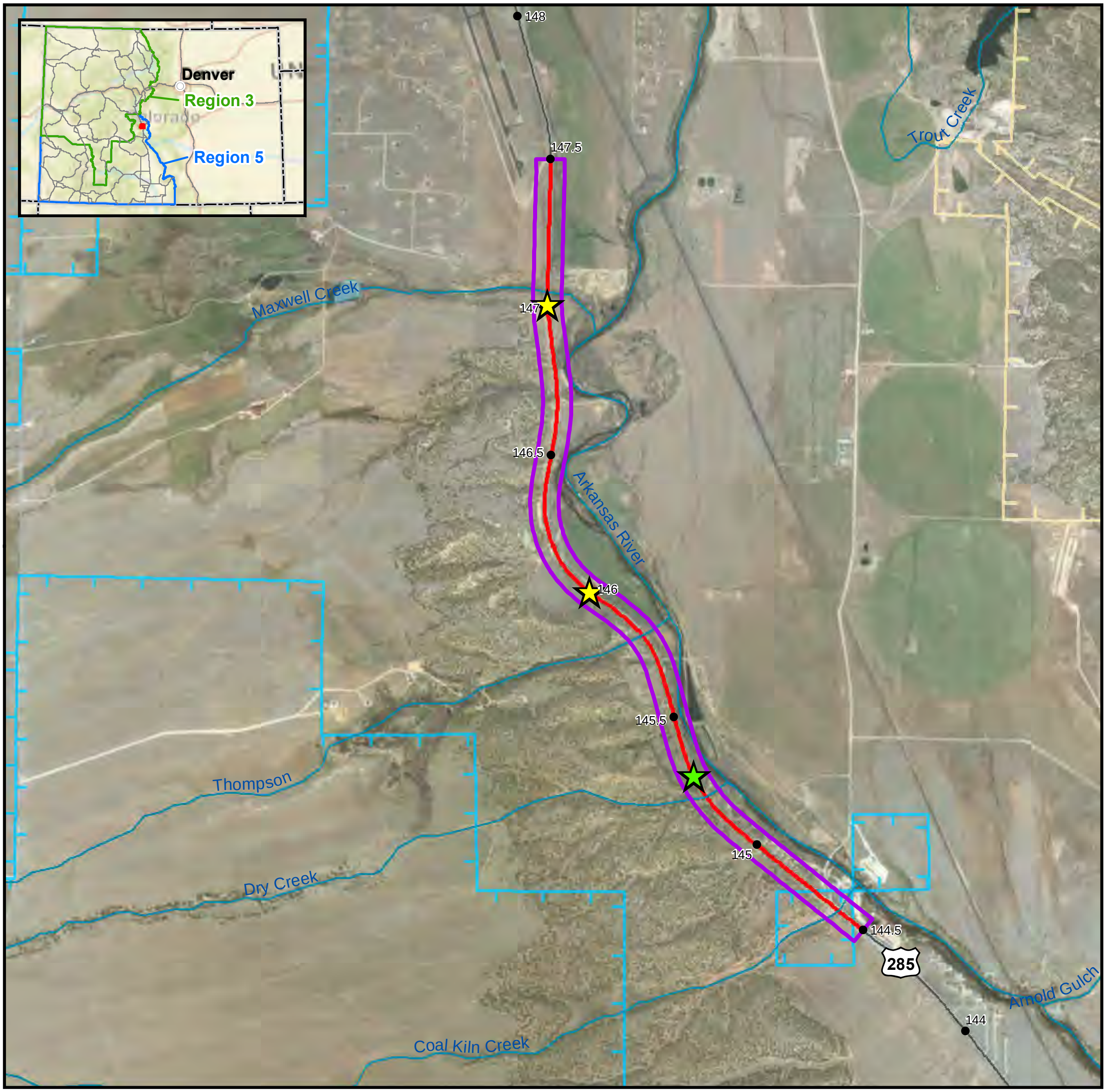
Preliminary Mitigation Recommendations

Much of this segment already includes wildlife mitigation features. An additional crossing structure and wildlife exclusion fencing are recommended to continue the mitigation through the southern portions of the segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
144.6	Coal Kiln Gulch. 5-foot-diameter pipe with perched outlet over a concrete apron. Summer rafting	Maintain as a carnivore crossing. Extend wildlife exclusion fence to this location.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
	operations along the Arkansas River on the east side of this location.		
145.3	Small fill slope north of residences on the east side of highway.	Potential wildlife underpass for deer (12 feet high x 20 feet wide). Extend wildlife exclusion fence to this location.	N/A
145.5	South end of wildlife exclusion fence.	Replace sheep fence with wildlife-friendly fencing from the south end of the wildlife exclusion fence to Nathrop.	N/A
145.8	CBC with local ranch access road.	Maintain as a carnivore crossing. Wildlife exclusion fence connects to this location.	N/A
146	Arch underpass for elk and deer constructed in 2018.	Replace top and bottom wires of cattle fence in front of structure entrances with smooth wire	
146.2	CBC (5 feet high x 5 feet wide).	Existing small animal crossing. Wildlife exclusion fence connects to this location.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
147	CBC (12 feet high x 10 feet wide x 65 feet long).	Existing CBC is suitable for deer and other medium-sized and small fauna. Wildlife exclusion fence connects to this location.	N/A
147.5	North end of wildlife exclusion fence.	Remove the ROW fence that connects to the exclusion fence around the airport and runs north to the U.S. 24 interchange to prevent animals from becoming trapped between the ROW fence and the airport exclusion fence.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

US 285
MP 144.5-147.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.6 U.S. Highway 550 Priority Segments

H-2.6.1 U.S. HIGHWAY 550, MILEPOSTS 3.5 TO 4, NORTH OF THE NEW MEXICO BORDER

This short segment of U.S. 550 is defined by the Animas River. Beyond the riparian corridor, the landscape is characterized by ranch and pasture lands. This segment was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. Wildlife mitigation, including wildlife crossing structures and wildlife exclusion fencing, was constructed south of this segment from the New Mexico border to MP 2.2 in 2006, when that section of the road was widened to four lanes.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	8,800	12,404	Mule Deer	Winter Range	Moderate – deer and elk	17.47

Preliminary Mitigation Recommendations

Connect mitigation in this segment to the existing mitigation to the south (MPs 0 to 2.2) and other potential mitigation projects to the north (MPs 4.5 to 11), if possible, or, at a minimum, guide fencing.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
3.7	Animas River. Large bridge spanning river and terrestrial banks on either side.	Connect to this location with wildlife exclusion fence.	

Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter
High
Low

BBMM – Elk Migration
High
Low

BBMM – Mule Deer Winter
High
Low

BBMM – Mule Deer Migration
High
Low

West Slope Wildlife Prioritization Study
CDOT Region 5

SH 550
MP 3.5-4

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.6.2 U.S. HIGHWAY 550, MILEPOSTS 4.5 TO 7, NEW MEXICO TO DURANGO

This segment of U.S. 550 descends from a mesa at the northern extent down into the La Plata River valley at the southern extent. The mesa lies between the Florida River valley to the east and the Animas River valley to the west. The segment is characterized by agricultural lands, dispersed residential, piñon-juniper and sagebrush. Resident and wintering mule deer frequently cross the highway in this segment. The northern portion of this segment, from MPs 6 to 7.5, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Wildlife mitigation, including crossing structures, was evaluated in the U.S. 550 Biological Assessment. Construction is anticipated to begin in 2019 or 2020.

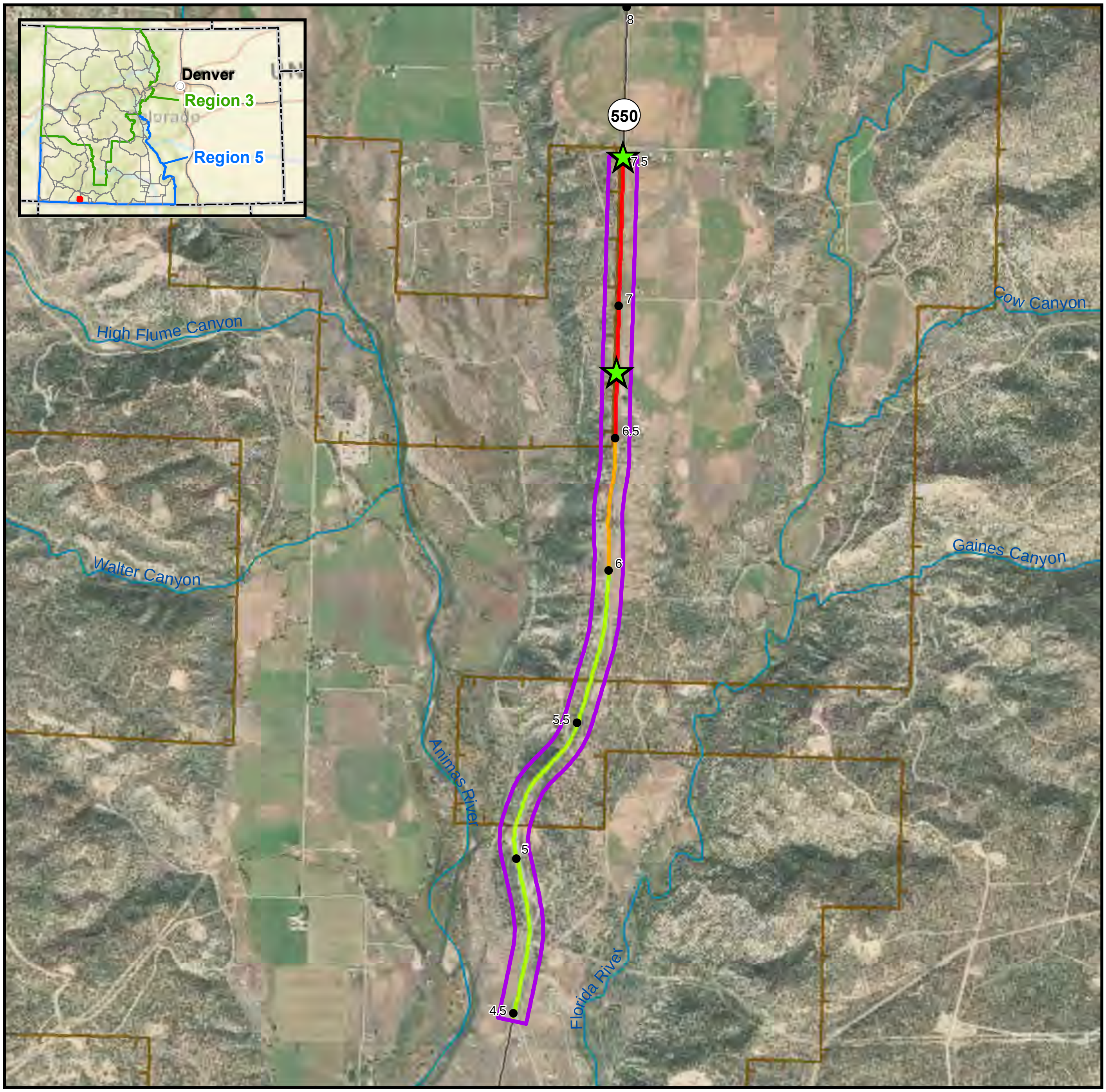
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	6,300	8,417	Mule Deer and Elk	Winter Range and Migration	Moderate – deer	19.31

Preliminary Mitigation Recommendations

Several wildlife crossing structures are proposed along US 550 as part of the interchange realignment and highway widening project. These additional wildlife crossings proposed beyond the high priority segment to the north are listed below for context. Wildlife exclusion fence should run continuously between wildlife crossing structures.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
4.85	Large fill slope as the road descends off a ridgeline from the north.	This location was evaluated for a large wildlife crossing structure but was later deemed un-constructible.	N/A
6.75	Flat mesa top.	Proposed wildlife underpass included in EA.	N/A
7.5	Flat mesa top; adjacent low-density residential and agricultural lands.	Proposed wildlife underpass. This location is outside of the top 5 percent segment, but wildlife mitigation is included in the EIS.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

SH 550
MP 4.5-7.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.6.3 U.S. HIGHWAY 550, MILEPOSTS 8.5 TO 11, SOUTH OF U.S. 160 JUNCTION

This segment of U.S. 550 runs atop the Florida Mesa. Resident and wintering mule deer frequently cross the highway. The southern portion of this segment, from MPs 8.5 to 9.5, was identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Wildlife exclusion fence is present north of this segment between MPs 11.8 and 12.4, including three small-mammal crossings (MP 11.9, MP 12.2, and MP 12.4) but no large fauna crossings. Fence end treatments installed to prevent deer and elk incursions into the fenced section have not performed sufficiently, and wildlife continue to enter into this section and cross the highway at the fence ends, resulting in higher rates of WVC than prior to the installation of wildlife exclusion fence.

This segment is included in a project that is currently under design for a roadway widening project. Wildlife mitigation is being integrated into the design, including a wildlife overpass near County Road 220 (MP 16). Wildlife exclusion fencing will extend south throughout the segment. These mitigation features were evaluated in the U.S. 550 Biological Assessment. Construction is anticipated to begin in 2019 or 2020. The mitigation recommendations listed below include locations within the segment as well as those to the north where wildlife mitigation is included in the EA.

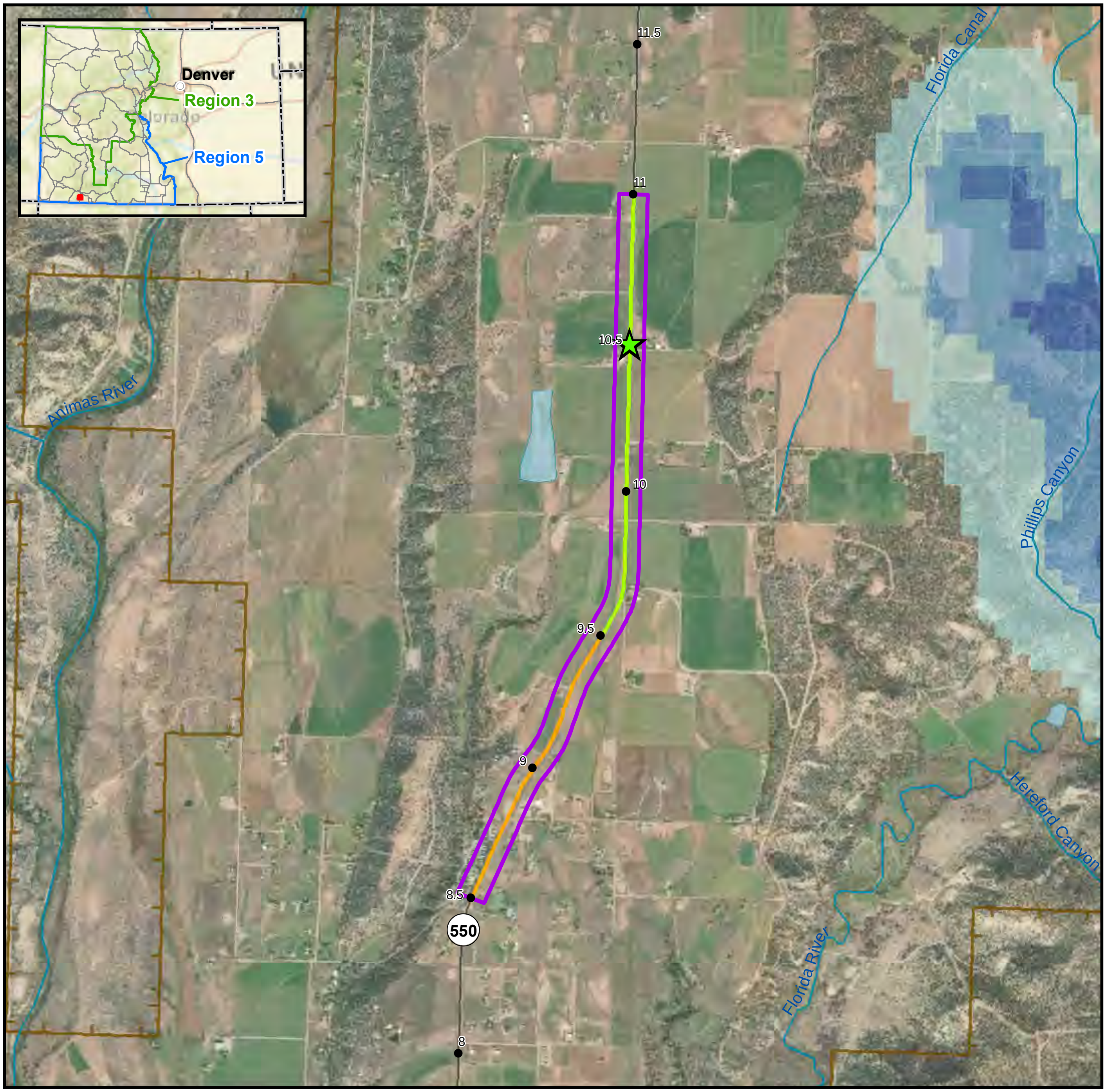
Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	6,300	8,417	Mule Deer and Elk	Migration and Winter Range	Moderate – deer	18.08

Preliminary Mitigation Recommendations

Several wildlife crossing structures are proposed in this segment as part of the interchange realignment and highway widening project. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
10.5	Flat mesa top; adjacent agricultural lands.	Proposed wildlife underpass.	N/A
14.2	Flat mesa top; adjacent low-density residential and agricultural lands.	Proposed wildlife underpasses (12 feet high x 32 feet wide concrete arches). This location is outside of the top 5 percent segment, but wildlife mitigation is included in the EIS.	N/A
15.1	Flat mesa top.	Proposed wildlife underpasses (12 feet high x 32 feet wide concrete arches). This location is outside of the top 5 percent segment, but wildlife mitigation is included in the EIS.	N/A
13.9	Flat mesa top; adjacent low-density residential and agricultural lands.	Proposed wildlife underpass. This location is outside of the top 5 percent segment, but wildlife mitigation is included in the EIS.	N/A
15.05	Flat mesa top; adjacent low-density residential and agricultural lands.	Proposed wildlife overpass. This location is outside of the top 5 percent segment, but wildlife mitigation is included in the EIS.	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence

Cold Spot - 95% Confidence

Cold Spot - 90% Confidence

No Significant Difference

Hot Spot - 90% Confidence

Hot Spot - 95% Confidence

Hot Spot - 99% Confidence

Streams

Lakes

Land Management

Federal (BOR, FWS, NPS)

USFS

BLM

State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

SH 550
MP 8.5-11

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

H-2.6.4 U.S. HIGHWAY 550, MILEPOSTS 114.5 TO 116, ELDRIDGE TO COLONA

This segment of U.S. 550 runs through a canyon along the Uncompahgre River with agricultural lands on either side of the highway. The segment overlaps with the Brownian Bridge Movement Models for mule deer winter range. The segment was also identified as a local WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis. This segment of U.S. 550 includes a wildlife crossing underpass at MP 116 and wildlife exclusion fencing from MPs 115.4 to 117, where the highway was widened to four lanes. The remainder of the segment has not been widened and does not include any wildlife mitigation. Wildlife exclusion fencing is also present south of this segment, from north of Ridgeway to the Uncompahgre River bridge at MP 112.8.

Segment Characteristics

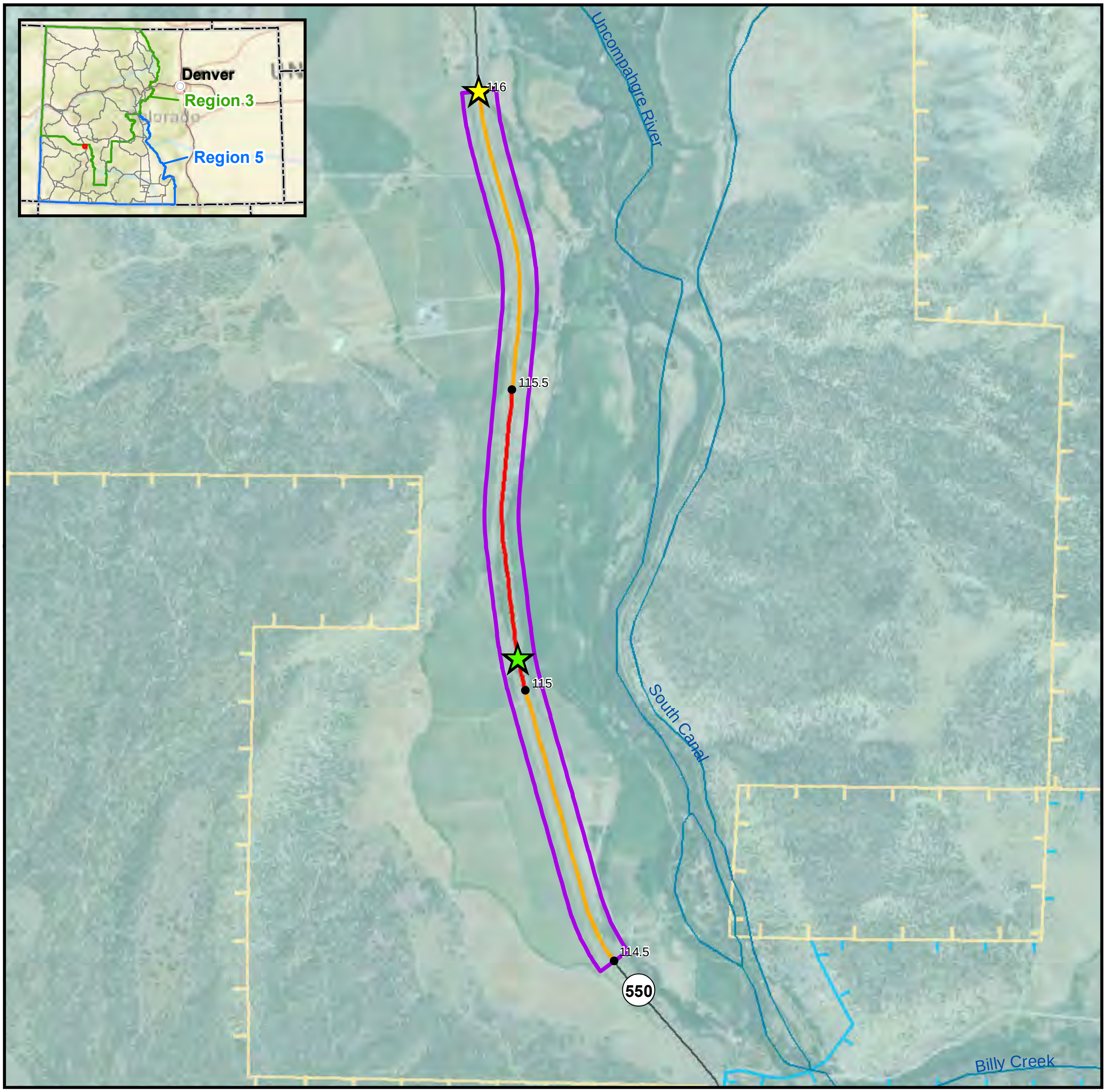
Lanes	AADT (2017)	Future AADT (2038)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	7,400	9,343	6,628	Mule Deer and Elk	Winter Range	Low	17.77

Preliminary Mitigation Recommendations

The construction of additional wildlife crossing structures between MP 112.8 and MP 115.4 would allow for the wildlife exclusion fencing to be extended throughout this segment to connect with existing fencing to the north and south. In the near-term, replace the ROW fence (sheep fence, 5-strand barbed, split rail) with wildlife-friendly fencing to improve the permeability of the fence for wildlife movement and reduce the time that crossing animals spend on the road.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
113.3	Fill slope.	Potential wildlife underpass (14 feet high x 36 feet wide). This location is outside of the top 5 percent segment, but wildlife mitigation is planned.	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
115.05	Small fill, irrigation ditch culvert.	Potential wildlife underpass (14 feet high x 36 feet wide).	N/A
115.4	Southern terminus of wildlife exclusion fencing.	None	N/A
116	Arch underpass for wildlife.	Existing wildlife crossing structure.	N/A
117	Northern terminus of wildlife exclusion fencing.	None	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

SH 550
MP 114.5-116

N

0 0.25 Miles

1 inch = 0.25 miles

JACOBS

Date: 1/9/2019

H-2.7 State Highway 140 Priority Segments

H-2.7.1 STATE HIGHWAY 140, MILEPOSTS 1.5 TO 6.5, NEW MEXICO BORDER TO SOUTH OF HESPERUS

State Highway 140 is a two-lane road between Hesperus and Farmington, New Mexico. This segment of the highway descends from a mesa at the northern extent down into the La Plata River valley at the southern extent. The 0.5-mile segment, from MPs 6 to 6.5, was identified as a WVC hotspot relative to surrounding segments in the Getis-Ord cluster analysis.

Segment Characteristics

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	2,200	2,985	Mule Deer	Winter Range	High – elk	17.64

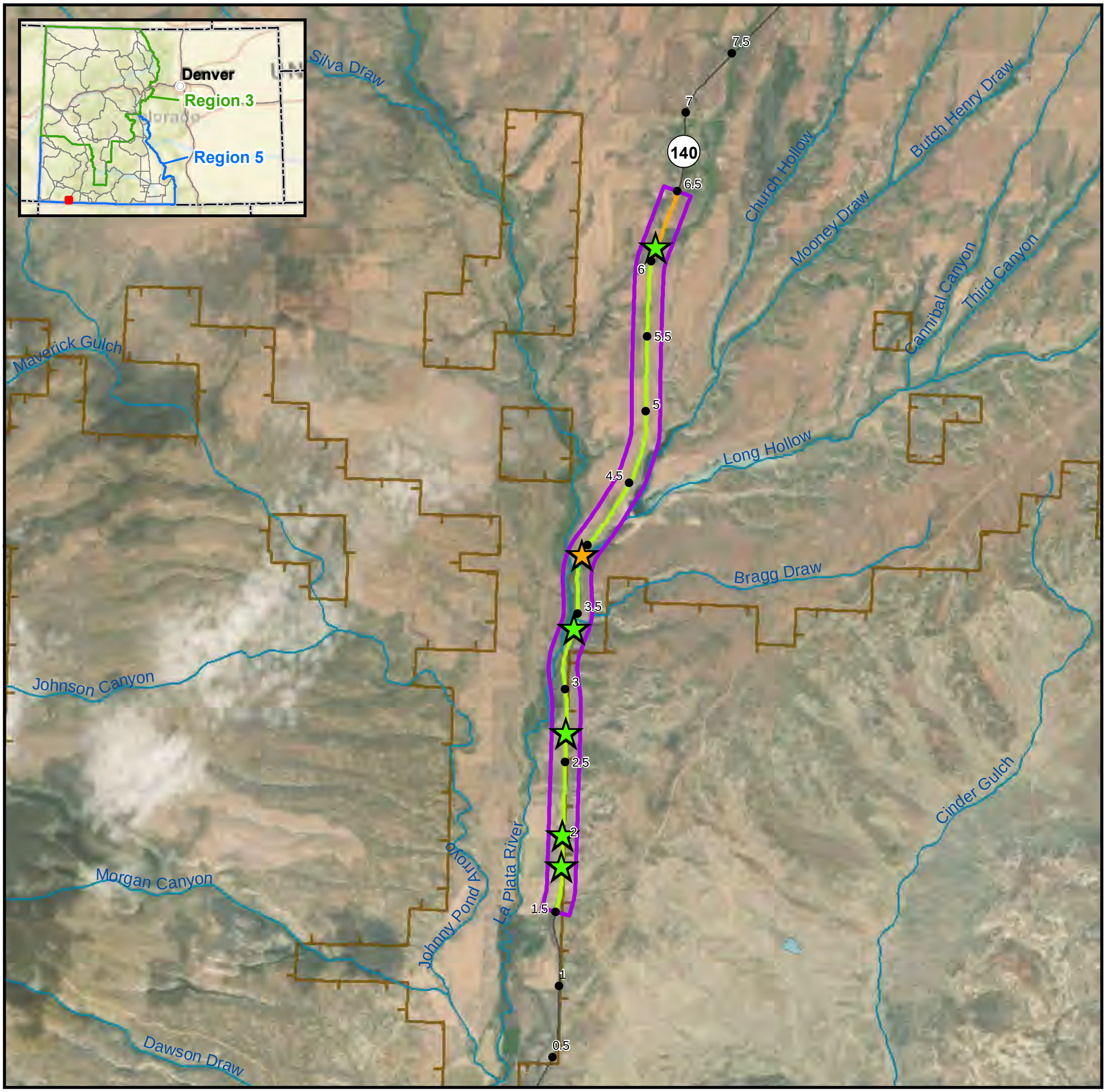
Preliminary Mitigation Recommendations

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on construction feasibility and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the segment.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
1.8	Long fill slope with pasture and irrigation pond on west side; sagebrush and juniper habitat on east side.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	
2	Fill slope where road bisects a draw from the east (about 6 feet high on the east side). Pasture to the west.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	
2.7	Large fill slope (about 15 feet high) with 5-foot-diameter pipe culvert.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect to other wildlife crossing structures in this	N/A

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
		segment with wildlife exclusion fence.	
3.4	Long fill slope with high quality sagebrush.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	
3.9	Long Hollow Creek. High bridge over creek drainage. Sheep fence runs across structure entrance. High quality sagebrush adjacent to this location.	Remove sediment from structure and connect this location to other crossing locations with wildlife exclusion fence. Remove sheep fence across structure entrances and, if needed, replace with wildlife-friendly fence set back from the structure.	

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
6.1	Fill slope with small pipe. Pond and wetlands on west side.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide). Connect to other wildlife crossing structures in this segment with wildlife exclusion fence.	



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

- Existing Wildlife Crossing
- Improve Existing Structure
- Potential Wildlife Crossing
- Top 5% Priority Segment

G-Ord WVC Cluster

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- No Significant Difference
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

- Streams
- Lakes

Land Management

- Federal (BOR, FWS, NPS)
- USFS
- BLM
- State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study
CDOT Region 5

SH 140
MP 1.5-6.5

N

0 1 Miles

1 inch = 1 miles

JACOBS

Date: 1/9/2019

H-2.8 State Highway 151 Priority Segments

H-2.8.1 STATE HIGHWAY 151, MILEPOSTS 17 TO 19.5, SOUTHERN UTE TRIBE

State Highway 151 traverses the Southern Ute Tribal lands from Ignacio to Chimney Rock. This segment of the highway extends from the town of Arboles north through Navajo State Park, along Navajo Reservoir. The area is used by resident, migratory, and wintering populations of mule deer as well as a resident elk herd. This segment overlaps with the Brownian Bridge Movement Models for mule deer migration. WVCs are severely underreported, and carcasses tend to be scavenged quickly. The entire highway is in the 85th percentile for Region 5 based on the Tier 1 prioritization.

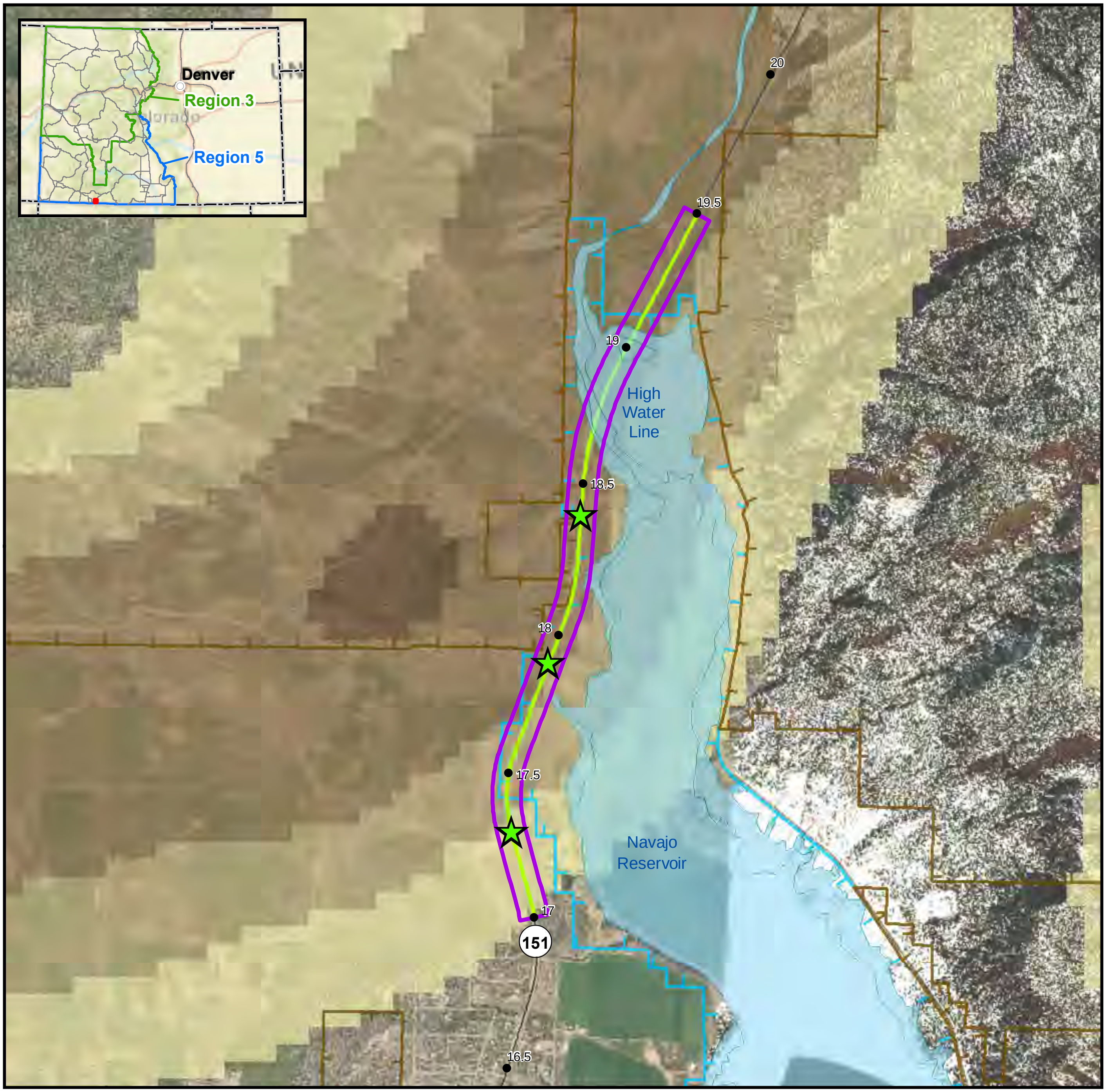
<u>Segment Characteristics</u>

Lanes	AADT (2017)	Future AADT (2038)	Target Species	Primary Movement Type	WVC Population Impacts	Prioritization Score
2	1,000	1,599	Mule Deer and Elk	Winter Range and Migration	Low	19.79

<u>Preliminary Mitigation Recommendations</u>

Multiple potential crossing structure locations are presented for further consideration. The final selection of crossing locations will depend on project limits, construction feasibility, and the spacing between structures. Wildlife exclusion fence should run continuously between wildlife crossing structures throughout the segment. A carcass reporting program instituted by the Southern Ute Tribe would help to improve WVC reporting across tribal lands.

Milepost	Existing Conditions	Mitigation Recommendation	Milepost Photo
17.3	Fill slope where the road bisects a draw.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	N/A
17.9	Fill slope where the road bisects a draw.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	N/A
18.4	Fill slope where the road bisects a draw.	Potential wildlife underpass suitable for deer (12 feet high x 20 feet wide).	N/A



Base Map Date: ESRI 2018

DEN Q:\JOBS\CDOT_VARIOUS\WILDLIFECONNECTIVITY\MAP_DOCS\REPORTMAPS\WESTSLOPEWILDLIFE_PRIORITIZATION_A.MXD

Legend

Existing Wildlife Crossing

Improve Existing Structure

Potential Wildlife Crossing

Top 5% Priority Segment

G-Ord WVC Cluster

Cold Spot - 99% Confidence

Cold Spot - 95% Confidence

Cold Spot - 90% Confidence

No Significant Difference

Hot Spot - 90% Confidence

Hot Spot - 95% Confidence

Hot Spot - 99% Confidence

Streams

Lakes

Land Management

Federal (BOR, FWS, NPS)

USFS

BLM

State

BBMM – Elk Winter

High

Low

BBMM – Elk Migration

High

Low

BBMM – Mule Deer Winter

High

Low

BBMM – Mule Deer Migration

High

Low

West Slope Wildlife Prioritization Study CDOT Region 5

SH 151
MP 17-19.5

N

0 0.5 Miles

1 inch = 0.5 miles

JACOBS

Date: 1/9/2019

APPENDIX I: Implementation Considerations Matrix

Implementation Considerations Matrix

Region	Highway	Mileposts	EA or EIS Commitments to Wildlife Crossings Mitigation	Funded Wildlife Crossings Mitigation in STIP	Other Transportation Project in STIP	Wildlife Crossings Mitigation in the RTP or SWP	Transportation Project in Development Plan	Wildlife Crossing Mitigation Identified in PEL, I-70 LIZs, or Comparable	Secretarial Order 3362 Priority Herd	Feasibility/Constructability of Wildlife Crossings Mitigation	Land Security	Energy Development Corridor
3	I-70	96.5 - 97	No	No	Yes	No	Yes	No	No	Medium	Low	Yes
3	I-70	98.5 - 103	No	No	Yes	No	Yes	No	No	Medium	Low	Yes
3	I-70	105.5 - 107	No	No	Yes	No	Yes	No	No	Medium	Low	Yes
3	I-70	131 - 132.5	No	No	Yes	Yes	No	No	No	Low	High	No
3	I-70	143 - 143.5	No	No	Yes	Yes	No	Yes	No	High	Medium	No
3	US 40	40.5 - 41.5	No	No	No	Yes	No	No	Yes	High	Low	Yes
3	US 40	61.9 - 71.5	No	No	No	Yes	No	No	Yes	High	Low	Yes
3	US 40	74 - 81	No	No	No	Yes	No	No	Yes	High	Low	Yes
3	US 40	93.7 - 106.5	No	No	No	Yes	No	No	Yes	Medium	Low	Yes
3	US 40	190 - 190.5	No	No	No	Yes	Yes	No	Yes	Medium	Medium	Yes
3	US 40	192 - 194	No	No	No	Yes	Yes	No	Yes	Medium	Medium	Yes
3	SH 9	114.2 - 116.5	No	No	No	Yes	Yes	Yes	No	Medium	Low	No
3	SH 9	128 - 134	n/a	n/a	No	Yes	Yes	n/a	No	n/a	Low	No
3	SH 9	136 - 136.6	n/a	n/a	No	Yes	Yes	n/a	No	n/a	High	No
3	SH 13	18 - 18.3	No	No	No	Yes	No	No	No	High	Low	Yes
3	SH 13	30.5 - 37.5	No	No	Yes	Yes	No	No	Yes	High	Low	Yes
3	SH 13	45 - 52.5	No	No	No	Yes	No	No	Yes	High	Low	Yes
3	SH 13	58.5 - 70.5	No	No	No	Yes	No	No	Yes	Medium	Low	Yes
3	SH 13	73 - 75.5	No	No	Yes	Yes	No	No	Yes	Medium	Low	Yes
3	SH 13	78 - 84	No	No	No	Yes	No	No	Yes	High	Low	Yes
3	SH 13	99 - 114	No	No	Yes	Yes	Yes	No	Yes	High	Low	Yes
3	SH 13	118 - 120.5	No	No	Yes	Yes	No	No	Yes	High	High	Yes

Region	Highway	Mileposts	EA or EIS Commitments to Wildlife Crossings Mitigation	Funded Wildlife Crossings Mitigation in STIP	Other Transportation Project in STIP	Wildlife Crossings Mitigation in the RTP or SWP	Transportation Project in Development Plan	Wildlife Crossing Mitigation Identified in PEL, I-70 LIZs, or Comparable	Secretarial Order 3362 Priority Herd	Feasibility/Constructability of Wildlife Crossings Mitigation	Land Security	Energy Development Corridor
3	SH 64	59 - 68.5	No	No	No	No	No	No	Yes	Medium	Medium	Yes
3	SH 131	57 - 58	No	No	No	Yes	No	No	No	High	Low	No
5	US 24	197.5 - 201.5	No	No	No	Yes	No	No	No	Medium	Medium	No
5	US 24	205 - 208	No	No	No	Yes	No	No	No	High	Low	No
5	US 24	214.5 - 215.5	No	No	No	Yes	No	No	No	High	High	No
5	US 24	220 - 220.5	No	No	No	Yes	No	No	No	High	High	No
5	US 24	222 - 223.5	No	No	No	Yes	No	No	No	High	High	No
5	US 50	211.5 - 214.5	No	No	No	Yes	No	No	No	High	Low	No
5	US 84	0 - 4	No	No	No	Yes	No	No	Yes	High	Low	No
5	US 160	43.5 - 46.5	No	No	Yes	Yes	No	No	No	Medium	Medium	Yes
5	US 160	94 - 100.5	Yes	No	Yes	Yes	Yes	No	Yes	High	Low	Yes
5	US 160	104.5 - 113.5	No	No	No	Yes	Yes	No	Yes	High	Low	Yes
5	US 160	118 - 120.5	No	No	No	Yes	Yes	No	Yes	High	Low	Yes
5	US 160	124.5 - 129.9	Yes	Yes	Yes	Yes	Yes	No	Yes	High	High	Yes
5	US 160	133 - 136	No	No	No	Yes	Yes	No	Yes	Low	Low	Yes
5	US 160	145.5 - 148	No	No	No	Yes	Yes	No	Yes	Medium	Low	Yes
5	US 160	195 - 196.1	No	No	No	No	No	No	No	Low	Low	No
5	US 160	260 - 265	No	No	No	Yes	Yes	No	No	High	Low	No
5	US 160	265.5 - 271	No	No	No	Yes	Yes	No	No	Medium	Low	No
5	US 285	144.5-147.5	No	No	No	Yes	No	No	No	High	Low	No
5	US 550	3.5 - 4	Yes	No	No	Yes	No	No	Yes	High	High	Yes
5	US 550	4.5 -7.5	Yes	No	No	Yes	No	No	Yes	Medium	High	Yes
5	US 550	8.5 - 11	Yes	Yes	Yes	Yes	Yes	No	Yes	Medium	High	Yes
5	US 550	114.5 - 116	No	Yes	Yes	Yes	Yes	No	No	High	Low	No

Region	Highway	Mileposts	EA or EIS Commitments to Wildlife Crossings Mitigation	Funded Wildlife Crossings Mitigation in STIP	Other Transportation Project in STIP	Wildlife Crossings Mitigation in the RTP or SWP	Transportation Project in Development Plan	Wildlife Crossing Mitigation Identified in PEL, I-70 LIZs, or Comparable	Secretarial Order 3362 Priority Herd	Feasibility/Constructability of Wildlife Crossings Mitigation	Land Security	Energy Development Corridor
5	SH 140	1.5 - 6.5	No	No	No	No	Yes	No	No	High	High	No
5	SH 151	17 - 19.5	No	No	No	Yes	No	No	Yes	High	High	Yes