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ROADS AND CONNECTIVITY IN COLORADO: ANIMAL-VEHICLE COLLISIONS, WILDLIFE MITIGATION STRUCTURES, AND LYNX-ROADWAY INTERACTIONS

Kevin Crooks, Chris Haas, Sharon Baruch-Mordo, Kris Middledorf, Seth Magle, Tanya Shenk, Ken Wilson, and Dave Theobald

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16. Abstract

This report investigates the impact of highways and landscape connectivity in Colorado. To do so, it describes three complementary research questions. Given the threat of roads to both wildlife populations and human safety, describing the distribution of animal-vehicle collisions (AVC) is a necessary step in understanding potential roadway impacts.

In the first section, hotspots of AVC occurrence on highways throughout Colorado are identified, and the characteristics associated with such areas are described. To address roadway impacts, mitigation efforts are increasingly common, although rigorous assessments of the functionality of such mitigation treatments are relatively rare.

The second section reviews research efforts to design and implement field monitoring of roadway-wildlife interactions at three road segments in Colorado slated for construction and installation of wildlife crossing structures. This corresponds to CDOT's Highway Corridor Wildlife Mitigation/Habitat Connectivity Research Study Phases II & III: Development of Mitigation Goals and Pre-Construction Data Collection.

Rare carnivores such as lynx may be particularly susceptible to roadway impacts, but the effects of roadways on lynx reintroduced in Colorado are largely unknown. The third section reviews wildlife use of seven underpasses specifically installed as mitigation for the potential impacts of road construction on lynx; this research project corresponds to CDOT's Wildlife Underpass (Lynx) Monitoring Research Study. It examines the relationship between the movements of radio-collared lynx to roadways throughout the state and provides evidence that lynx in Colorado are selectively avoiding highways.

Implementation:
The study results should be used for determining future locations of underpasses and other road-related mitigation for wildlife species, and future developments should continue to minimize impacts to rare and imperiled species.

17. Keywords
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Roads and Connectivity in Colorado: Animal-Vehicle Collisions, Wildlife Mitigation Structures, and Lynx-Roadway Interactions

Roads and Connectivity in Colorado: Animal-Vehicle Collisions, Wildlife Mitigation Structures, and Lynx-Roadway Interactions

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Executive Summary

Herein, we review the impact of highways and landscape connectivity in Colorado. To do so, we describe three complementary research questions. Given the threat of roads to both wildlife populations and human safety, describing the distribution of animal-vehicle collisions (AVC) is a necessary step in understanding potential roadway impacts. In our first section, we identify hotspots of AVC occurrence on highways throughout Colorado, and describe the characteristics associated with such areas. To address roadway impacts, mitigation efforts are increasingly common, although rigorous assessments of the functionality of such mitigation treatments are relatively rare. In our second section, we review our research efforts to design and implement field monitoring of roadway-wildlife interactions at three road segments in Colorado slated for construction and installation of wildlife crossing structures in the near future. This research effort corresponds to CDOT's Highway Corridor Wildlife Mitigation/Habitat Connectivity Research Study Phases II & III: Development of Mitigation Goals and Pre-Construction Data Collection. Finally, rare carnivores such as lynx may be particularly susceptible to roadway impacts, but the effects of roadways on lynx reintroduced in Colorado are largely unknown. In our third section, we first review wildlife use of seven underpasses specifically installed as mitigation for the potential impacts of road construction on lynx; this research project corresponds to CDOT's Wildlife Underpass (Lynx) Monitoring Research Study. We then more generally review the relationship between the movements of radio-collared lynx to roadways throughout the state.

1.0 Introduction

The impacts of roads on wildlife populations continue to receive increased attention from ecologists and wildlife professionals (Forman et al. 2003). Depending on the species behavior, feeding strategies, and mobility, roads can have either negative or positive effects for wildlife populations. By fragmenting the landscape, roads serve as physical barriers to wildlife that can result in direct negative effects such as injury or mortality when animals cross roads, or indirect negative effects such as habitat degradation near roads due to noise, pollution, and human activity (Spellerburg, 1998; Alexander et al. 2000; Trombulak and Frissell 2000; Ouren et al. 2007). The latter often lead to avoidance behavior by wildlife. Roads can also have positive effects attracting wildlife to forage on disturbed habitat patches, road kills, or human food sources such as garbage; however such attractants often cause increased risk of animal-vehicle collisions (AVCs) and ultimately can also negatively affect wildlife.

Road impacts can be substantial. Current estimates suggest that tens of millions of vertebrates are killed on roadways each year, including an estimated 0.5 to 1.5 million deer in the United States alone (Clevenger 2002). Road kill rates for certain species may exceed natural causes of mortality due to predation and disease (Forman et al. 2003). In addition, the "barrier effect" of highways to wildlife movements can result in a loss of functional connectivity that, if left unmitigated, may result in the decline of susceptible populations over time due to demographic and genetic isolation (Clevenger 2002; Forman et. al. 2003; Crooks and Sanjayan 2006). In addition to impacting wildlife populations, AVCs can cause human injury and fatality and are of considerable concern for highway safety. Animal-vehicle collisions are estimated to cause approximately 29,000 human injuries, 211 human fatalities, and over $1 billion in property damage annually in the U.S. (Forman et. al. 2003). Conover et al. (1995) estimated the mean vehicle repair value as $1,577, a figure that may represent higher damage accidents which tend to be reported and recorded more often. Still, adjusted for inflation based on the consumer price index (US Bureau of Labor Statistics 2007), mean vehicle repair value might currently exceed $2,000.

Given the threat of roads to both wildlife populations and human safety, describing the distribution of AVC occurrences is a first necessary step in understanding the potential impacts. Further, we must also understand road and habitat characteristics associated with AVC hotspots in order to adequately predict where they may occur and to aid in mitigation efforts in such sites. This is the focus of our first section. In it, we identify hotspots of AVC occurrence on highways throughout Colorado, and describe the characteristics associated with such areas.

The ecological, economic, and safety impacts of AVC's mitigation efforts are increasing in North America in the last decades (Mansergh and Scotts 1989; Foster and Humphrey 1995; Yanes et al. 1995; Rodriguez et al. 1996; Clevenger 1998; Danielson and Hubbard 1998; Forman et al. 2003). However, mitigation projects are often expensive and the question becomes where to invest and what modifications to implement. The Colorado Department of Transportation (CDOT) has relied on several designs of wildlife underpasses (e.g. concrete box culvert, corrugated steel pipe, and natural span bridge) and fencing as means to reduce AVCs and mitigate impacts to specific wildlife species (including lynx and others). Although prior studies have evaluated underpass use in relation to landscape features and other variables after construction at several sites (Barnum 2003; Alldredge 1998; Alldredge and Phillips 2000*a,b*; Haas 2000; Clevenger et al 2001), less common are rigorous efforts in Colorado to conduct pre- and post-construction monitoring of highway corridors and underpasses to determine: 1) where structural wildlife crossings might be most effectively used on existing highway corridors; and 2) how installation of structural wildlife crossings influence crossing locations, crossing frequencies, and AVCs along highway corridors where they are installed.

Further, more information is needed regarding the effectiveness of different designs of structural wildlife crossings in Colorado as they relate to the mitigation goals at particular project sites. Several authors have reported that different wildlife species and species groups react to different crossing designs in distinct ways (Clevenger and Waltho 2000; Forman et al. 2003). Thus, a structural crossing designed to mitigate impacts to a particular species or species group may prove to be ineffective if evaluated for a different species or group. This makes design and placement of structural wildlife crossings along highway corridors particularly challenging where regulatory requirements may dictate the placement of structural wildlife crossings to mitigate highway effects on multiple species. For highway corridors in Colorado with upgrades planned in the next 2 to 5 years, there is an urgent need to provide site-specific guidance to Regional Environmental Managers and Design Engineers regarding the proper design and placement of structural wildlife crossings. This is the focus of our second section. In it, we review our efforts to design and implement field monitoring of roadway-wildlife interactions at 3 road segments in Colorado slated for construction and installation of wildlife crossing structures in the near future. This research effort corresponds to CDOT’s Highway Corridor Wildlife Mitigation/Habitat Connectivity Research Study Phases II & III: Development of Mitigation Goals and Pre-Construction Data Collection.

Rare carnivore populations may be particularly susceptible to the effects of highways due to their long-distance movements, large area requirements, and low recruitment rates (Brody and Pelton 1989; Foster and Humphrey 1995; Beier 1996; Land and Lotz 1996; Paquet and Callahan 1996; Gibeau and Herrero 1998; Ruediger 1998; Crooks and Sanjayan 2006). Lynx represent such a species in Colorado. Lynx were reintroduced from Canada to southwestern Colorado in 1999. However, mortality rates of these lynx have been relatively high, generating concern about the long-term welfare of lynx in the state (Kloor 1999). Mortality by vehicle collision has been found to be a significant mortality source for lynx in other parts of their range (Brocke et al. 1991; Aubry et al. 2000). Roads and highways are sometimes found to be a barrier to lynx movements (Alexander and Waters 2000; Apps 2000), and some researchers have found that lynx avoid roadways (Apps 2000). However, some studies have also found that lynx may have a neutral relationship with roads, meaning that they are neither avoiding nor attracted to roadways (McKelvey et al. 2000; Carroll et al. 2001). Further, a recent study suggested that road density in a given area did not have a detectable effect on lynx land use (Hoving et al. 2005). The effects of roadways on lynx in Colorado are largely unknown. This is the focus of our final section. In it, we first review wildlife use of seven underpasses specifically installed as mitigation for the potential impacts of road construction on lynx; this research project corresponds to CDOT’s Wildlife Underpass (Lynx) Monitoring Research Study. We then more generally review the relationship between the movements of radio-collared lynx to roadways throughout the state.

2.0 Animal-Vehicle Collision Hotspots

2.1 Goals and Objectives

Our goal was to analyze AVC occurrences in Colorado from 1986-2004. Our specific objectives were to: 1) describe the spatial distribution of AVCs in Colorado by determining significant AVC hotspot locations, and 2) characterize high AVC locations in relations to attributes affecting the probability of an animal crossing a road including: a) factors facilitating wildlife presence near road such as habitat type and cover, b) factors facilitating wildlife movement such as topographic characteristics near the road, and distance to streams with riparian corridors that provide ease of movement and resources, c) human activity measured by the surrounding road density, traffic volume, and speed limit, and d) factors associated with the barrier effect of roads such as road width and distance to the nearest available crossing structure.

2.2 Methodology

The Colorado Department of Transportation maintains a database of animal-vehicle collisions that are reported by the Colorado State Patrol, and from which we obtained 1986-2004 AVC records. CDOT also maintains a species-specific database in which the animal species is identified; these records were available from 1993-2004 and were augmented to the non-species-specific database. We used only AVCs occurring on Interstate, US highways and State highways, and plotted AVC occurrence by mile marker using dynamic segmentation procedures in ArcGIS 9.1 (ESRI 2004). AVC severity is categorized as fatality, injury, or property damage. Since there were very few fatality related AVCs (see results), we combined fatality and injury records together (FAT/INJ) and conducted separate analyses for fatality and injury AVCs and for property damage (PDO) AVCs. Analyses were conducted on, and reported by, the unique route and mile marker combinations that were reported for each AVC record and were available from a highway GIS layer from the CDOT (2003). Reported mile markers were rounded to the nearest mile, therefore analyses represent a road segment that surrounds the mile marker.

2.2.1 Mapping of Animal-Vehicle Collision Hotspots

Visual examination of conflict patterns can be subjective, and can not determine the significance of the observed patterns (Bailey and Gatrell 1995). We mapped significant AVCs hot-spots using the Getis-Ord G_i^* statistic in ArcMap 9.0 spatial statistics tools (ESRI 2004). Getis and Ord (1992) defined G_i^* as:

$$G_i^* = \frac{\sum_j w_{ij}(d)x_j}{\sum_j x_j}$$

j may equal *I* where G_i^* compares the degree of association in variable *x* between all points within the study extent, and all points located within a neighborhood distance *d* of the focal point *i*, including *i*. In this study, we measured the degree of association for the AVC count (*x)* summarized for the 1986-2004 year span for each route and mile marker combinations (*i*), within a distance band of 2.5-miles (*d*). We used a binary weight matrix w_{ij} to determine if the value of x_j is summed, in which w_{ij} resumes a value of one if *j* lies within distance *d* of *i*, or zero if it is not. Once G_i^* is calculated for each point, it is redefined as a standard deviate value by subtracting the mean, or expected G_i^*, and dividing it by the standard deviation (Getis and Ord 1996). The resulting G_i^* statistic will assume positive or negative values when clustering is higher or lower than expected, respectively, and significant hot spots can be defined if they are within more than ±2 SD of the mean (the two-sigma rule) (Anselin 1995). All counts for mile markers within the distance band were included in the calculations, even if relating to different routes. Once all Getis-Ord statistics were calculated for FAT/INJ and PDO records, we ranked them and present results for the top 1% and 5% G_i^* hotspot values. To compliment these results, we also present results for the mile markers with the top 1% and 5% AVCs count.

2.2.2 Attributes of Animal-Vehicle Collision Hotspots

In addition to identifying significant hot spots of AVCs across Colorado, we summarized attributes associated with mile markers with high AVC count. Table 1 lists the attributes used in this analysis, and the following provides a short description of each attribute's abbreviation, methods of calculation, and data source:

Percent land cover – Land cover types were obtained from the SWReGAP raster data at 30 m resolution developed by the US Geological Survey using geospatial data (USGS National Gap Analysis Program 2004). Based on detailed description available for each land cover type, we classified the following major land cover categories: forest (deciduous and coniferous), shrub/scrub, grassland/prairie, riparian/wetland, human development, agriculture, disturbed land, and other (see Appendix A.1 for detailed reclassification table). We created a raster layer for each land cover classification, and summarized the percent land cover for each type within a 0.5-mile circular neighborhood.

Canopy cover – Canopy cover raster at 30 m resolution was available from the Multi-Resolution Land Characteristics Consortium – National Land Cover Database (USGS 2007). Average canopy cover values were calculated for each mile marker within a 0.5-mile circular neighborhood.

Topographic Position Index (TPI) – TPI is a measure of elevation differences between a focal point *i* and the average elevation within a neighborhood of *i* (Jenness 2006). Positive and negative values of TPI indicate the focal point is on average higher or lower than its surroundings, and values of zero indicate that the point is on a flat terrain or the mid point of a slope (Figure 1). TPI is very scale dependent; for example, a point on a hill in a large valley may have a positive small neighborhood TPI, but a negative large neighborhood TPI (Figure 2). Therefore, a combined comparison of >1 neighborhood values is recommended. We calculated TPI values for each mile marker location at 250 (small) and 1000 m (large) scale neighborhoods. We present results as a continuous 3D representation of AVC hotspots in relations to TPI values, rather than in a classification scheme.

Distance to streams – Wildlife species will often travel along streams due to ease of movement, or the availability of resources such as water, food, and cover. It is feasible to hypothesize that areas which are closer to streams will result in higher AVCs. We used a stream hydrology layer available for the National Diversity Information Source (CDOW 2004), rasterized the shape file, and calculated for each mile marker the distance to the closest stream feature using the Euclidean distance tool in ArcGIS 9.1 (ESRI 2004).

Road density – We calculated road density weighted by traffic volume (Average Annual Daily Traffic – AADT) within a 0.5-mile neighborhood using the Line Density tool in ArcGIS 9.1 (ESRI 2004). Weighing was achieved by multiplying line length for each segment by its associated AADT, such that a road segment of length *x* will receive a higher density value if the associated AADT is high as compared with other segments of length *x*.

Traffic volume (AADT), speed limit, and road width – AADT and speed limits values were available for each mile marker from the highway layer (CDOT 2006). In addition, the highway layer provides the number of lanes and lane width for each road segment, therefore we calculated total road width as a multiplication of the 2 attributes and converted results to meters.

Distance to crossing structure – Existing bridges and culverts can serve as crossing structures for wildlife even if not specifically designed for that task (Forman et al. 2003). Federal law requires the collection of detailed measurements on all bridge structures, and we obtained from CDOT a shape file of all bridge structures for Colorado (including culvert structures). However, some bridges may occur in high-density and high-AADT areas (e.g., the Denver mouse-trap or above major highways), thus may not serve as effective crossing structures. Therefore we eliminated all structures with highway service type definition for under the bridge, and maintained all structures above railroads, pedestrian-bicycle, waterway, and other types (including game underpasses). We maintained in the database highway-waterway combinations, assuming that the waterway will allow crossing access to wildlife. In addition to service type under the structure, we also examined the size of the opening. Ruediger et al. (2006) recommended that under-crossings targeted for elk should be a minimum of 12 ft high. Since mule deer and elk compose a major component of AVCs in Colorado (see results), we eliminated all bridges with <4 m clearance. Lastly, the amount of openness in relationship to the crossing length is an important factor facilitating animal movement (Forman et al. 2003). We examined the size of opening in relations to underpass length by calculating their ratios. None of the structures had width-to-length ratio >1, therefore we assumed all remaining structures would be conducive to wildlife crossings.

Table 1. Summary of attributes used to characterize areas of high AVCs in Colorado from 1986-2004.

Variable	*Abbreviation*	*Description*	*Source*
Percent Land Cover			
Forest	%FRST	Land cover types were based on criteria by the National Gap Analysis Program provided by the SWReGAP data. Percent cover was calculated within a 0.5 mile radius for each mile marker. All rasters at 30 m cell resolution.	SWReGAP project Utah State University (USGS National Gap Analysis Program 2004).
Shrub/Scrub	%SHRB		
Grassland/Prairie	%GRAS		
Riparian/Wetland	%RIP		
Human Development	%HUM		
Agriculture	%AG		
Disturbed land	%DIST		
Other land cover types	%OTHR		
Canopy Cover	CC	Average percent canopy cover calculated within a radius of 0.5 mile. Raster resolution at 30 m.	National Land Cover Database (USGS 2007).
Topographic Position Index	TPI	A topographic index that is based on the difference in elevation between the focal point and the average elevation of the surrounding area. TPI allows inference to the relative topographic location of the focal point, e.g., a deeply-incised canyon, small hill or mid-slope ridge. Calculations were based on an elevation layer at 27 m resolution.	USGS Seamless elevation layer (USGS 2007).

Variable	*Abbreviation*	*Description*	*Source*
Distance to streams	D_STRM	Distance in meters to streams including: intermittent, perennial, artificial flow paths, and ditches. Distance raster created at 30 m resolution.	National Diversity Information Source (CDOW 2004).
Traffic volume	AADT	Annual Average Daily Traffic count for each highway segment in both directions.	CDOT Geographic Data Download – Highway layer (CDOT 2006).
Road width	RD_WDTH	Total road width in meters calculated based on the number of lanes x lane width as reported by CDOT.	CDOT Geographic Data Download – Highway layer (CDOT 2006).
Speed limit	SPD	Speed limit for each highway segment as reported by CDOT.	CDOT Geographic Data Download – Highway layer (CDOT 2006).
Road density adjusted by traffic volume	RD_AADT	Road density within a 0.5 mile radius of each mile marker, adjusted by Annual Average Daily Traffic volume counts such that each line length is multiplied by its associated AADT count. Raster output at 30 m resolution.	CDOT Geographic Data Download – Highway layer (CDOT 2006).
Distance to crossing structures	D_CRS	Distance to structures facilitating crossing including bridges and culverts. All structures were >4m high, and the width to crossing length ratio was ≤1. Distance raster created at 30 m resolution.	Bridge shape file provided by Steven White of CDOT (CDOT 2007).

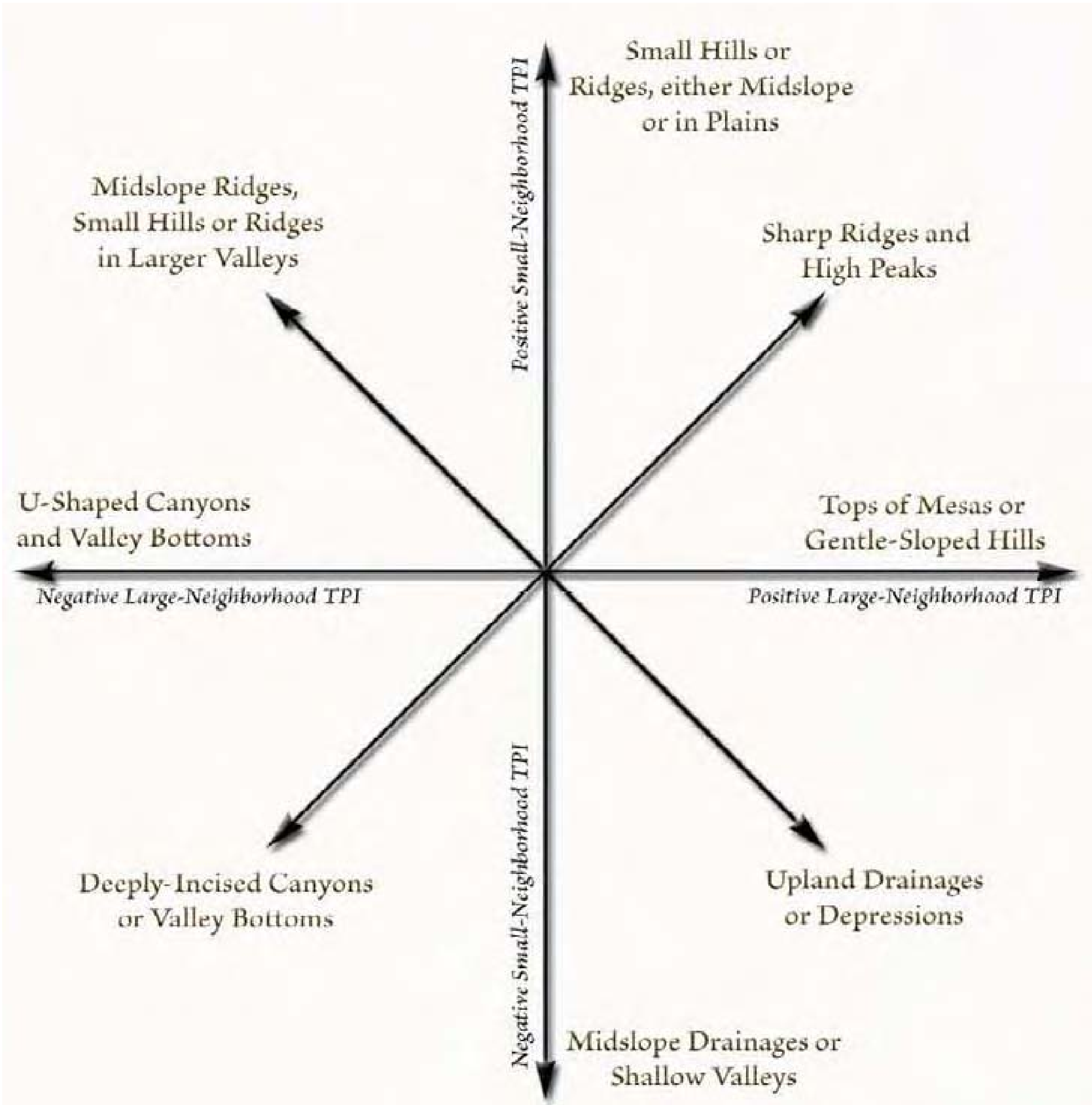


Figure 1. Topographic Position Index (TPI) suggested classifications based on 2 scale neighborhood analysis (Figure adopted from Jenness 2006).

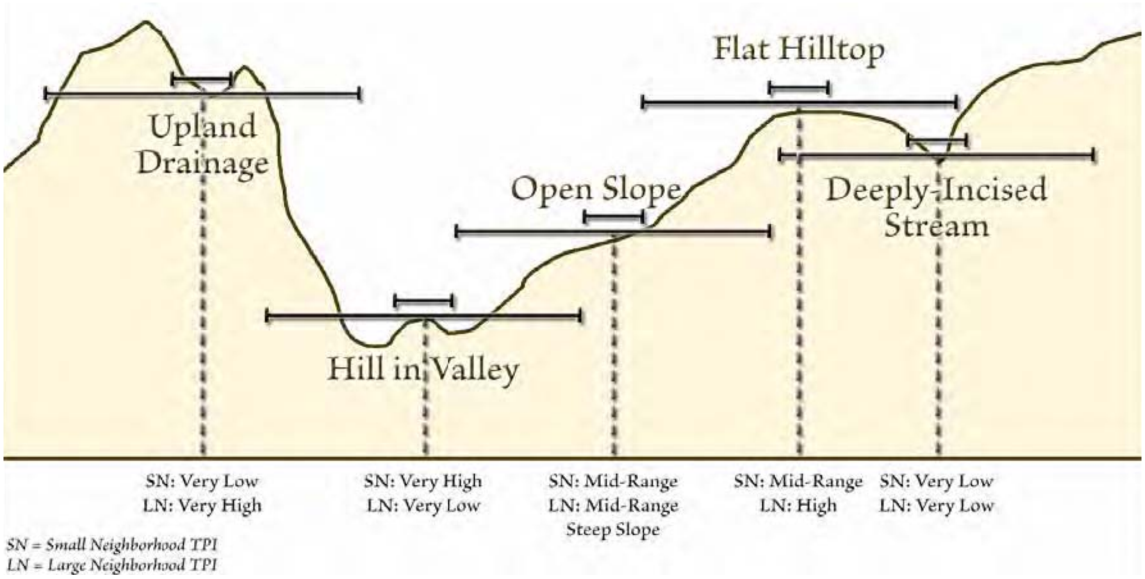


Figure 2.Examples for topographic classifications using TPI values from 2 neighborhood scales (Figure adopted from Jenness 2006).

2.3 Results and Discussion

There were a total of 35,302 AVC records for 1986-2004 with the majority of records relating to PDO (Table 2). Using the unique route and mile marker combinations for state and US highways and interstates (a total of 9,365), we were able to plot 81.5% of the database in GIS (Table 2). Non-plottable records included those with lack of locational info (8.5%), and those not occurring on state and US highways, and Interstate (10%). Average percent of records plotted by year was 87% (SD = 16%, n = 19), with the lowest percentage (28%) occurring in 2003. Therefore, the spatial results presented may not reflect 2003 AVC trends in their entirety.

Table 2. Summary of the number of AVC records available, plottable, and with missing information by type of accident for Colorado from 1986-2004 and the % records of the total for each type.

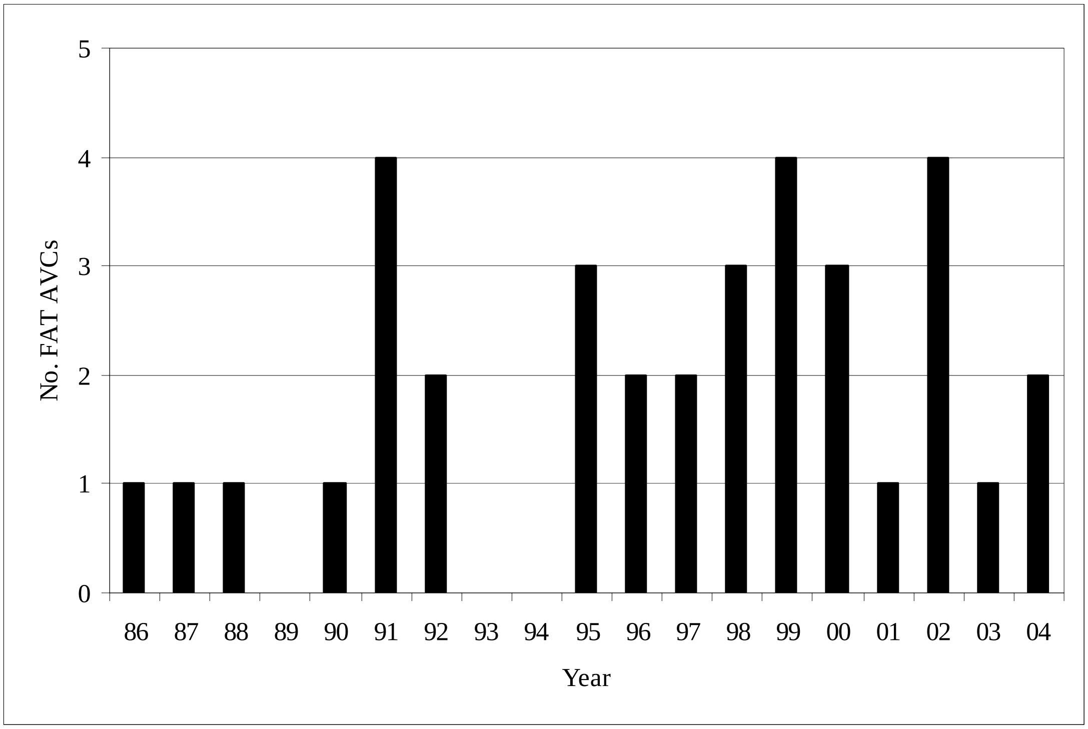
Records Description	*No. of records (%)*	*No. of FAT (%)*	*No. of INJ (%)*	*No. of POD (%)*
County rds/City streets or incomplete info (not plottable)	3,654 (10)	6 (<1)	295 (8)	3,353 (92)
No locational info	3,059 (8.5)	0 (0)	159 (5)	2,900 (95)
Plottable	28,589 (81.5)	29 (<1)	2,648 (9)	25,912 (91)
Total	35,302 (100)	35 (<1)	3,102 (9)	32,165 (91)

A total of 35 events, or <1% of all records, resulted in a fatality, followed by 3,102 and 32,165 events resulting in injuries and property damage, respectively. The unknown categorization consisted of the majority (61%) of species classifications followed by mule deer (31%) and elk (6%) AVCs (Table 3). Focusing only on records with species categorizations, >95% of all AVCs were related to mule deer and elk (Table 3).

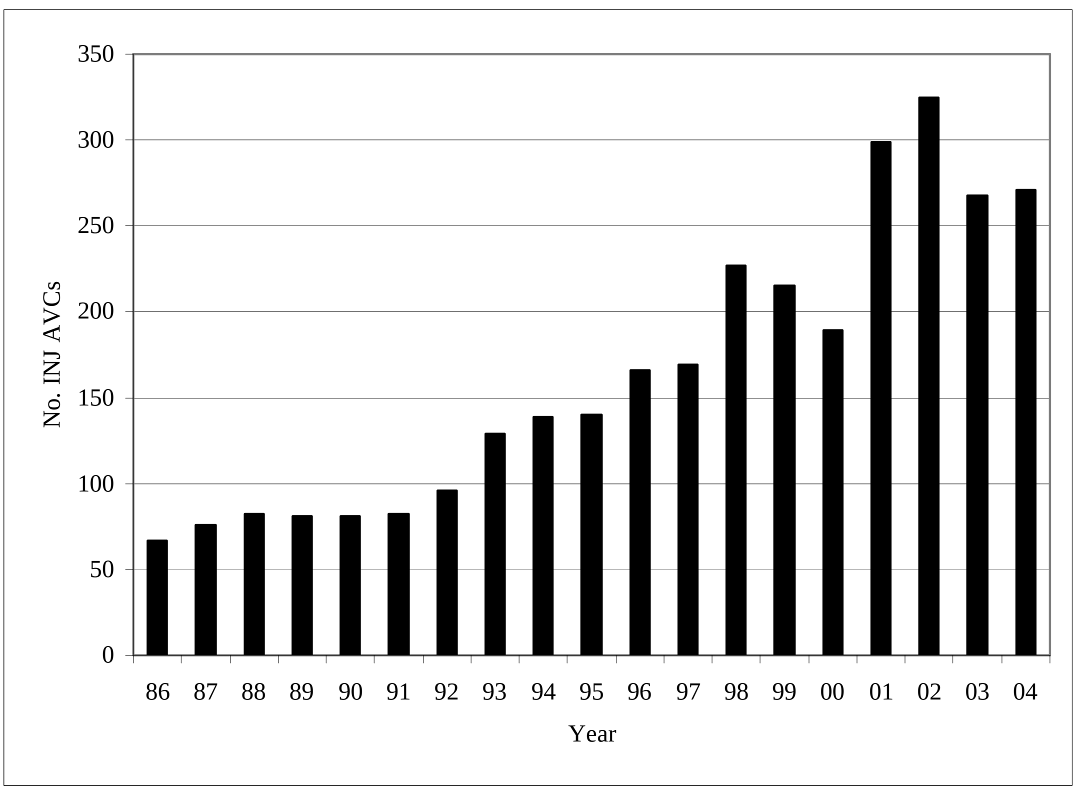
The temporal trends of INJ- and PDO-related AVCs where increasing from 1986 to 2004, while the number of FAT-related AVCs showed varying annual trends (Figure 3). The highest Getis-Ord hotspot occurred west of Denver on state highway 74, mile marker 0 for both FAT/INJ and PDO AVCs (Figures 4 and 5). In general the majority of the top 1% of FAT/INJ AVC hotspots occurred west of Denver, north of Colorado Springs on interstate 25, near the town of Durango on highways 160 and 550, and on highway 82 south of Glenwood Springs (Figure 4). Similar trends were detected for the top 1% of PDO AVC hotspots that occurred west of Denver, on highway 82 south between Glenwood Springs and Aspen, and on highway 160 east of Durango and northwest of Alamosa (Figure 5). In addition, top 1% of PDO hotspots occurred on highway 40 east of Steamboat Springs and highway 36 between Lyons and Boulder. Lastly, we highlight the locations of all mile markers for which a fatality-related AVC has occurred from 1986-2004 (Figure 6).

Table 3. Number and percent of AVC species-specific records for Colorado from 1986-2004.

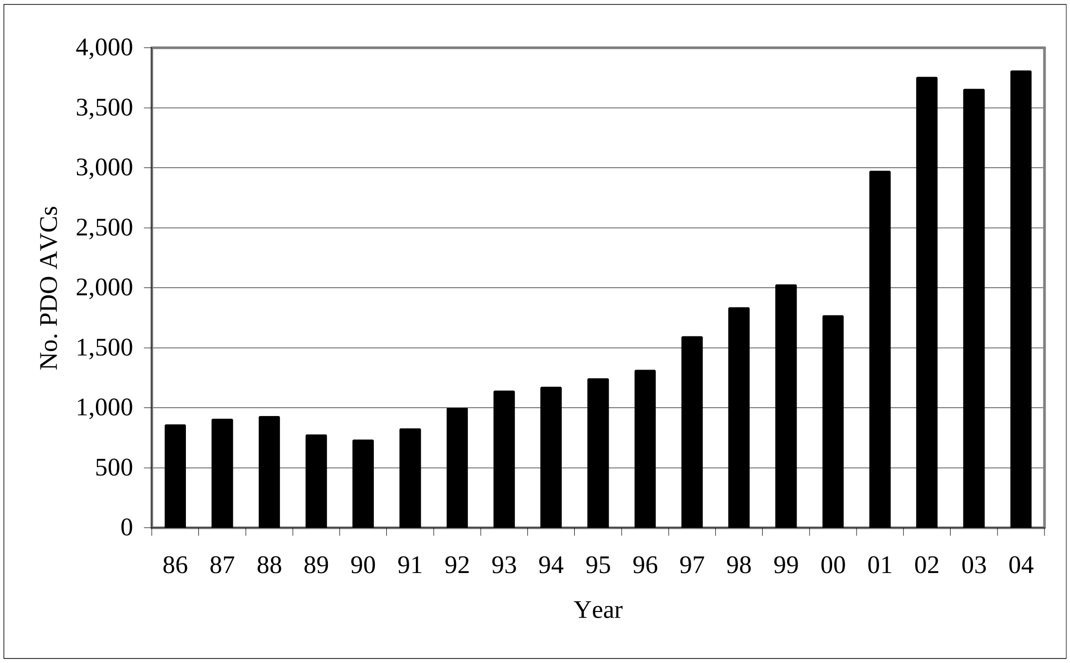
	Animal	*No. of records (% of total)*	*% of categorized records (13,732)*
Birds	Crane	1 (<1)	<1
	Eagle	10 (<1)	<1
	Hawk	2 (<1)	<1
	Pheasant	2 (<1)	<1
	Owl	5 (<1)	<1
	Turkey	7 (<1)	<1
	Bird	7 (<1)	<1
Mammals	Antelope	118 (<1)	<1
	Badger	1 (<1)	<1
	Bear	184 (<1)	<1
	Beaver	3 (<1)	<1
	Coyote	48 (<1)	<1
	Deer	11,089 (31)	81
	Elk	2,118 (6)	15
	Fawn	1 (<1)	<1
	Fox	10 (<1)	<1
	Goat	1 (<1)	<1
	Horse	15 (<1)	<1
	Lion	23 (<1)	<1
	Moose	16 (<1)	<1
	Porcupine	3 (<1)	<1
	Rabbit	6 (<1)	<1
	Raccoon	18 (<1)	<1
	Sheep	44 (<1)	<1
Unknown	.	21,570 (61)	
Total		35,302 (100)	100


5
4
3
2
1
0
No. FAT AVCs
86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04
Year

a)


350
300
250
200
150
100
50
0
No. INJ AVCs
86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04
Year

b)



c)

Figure 3. Temporal trends of all AVCs by accident type resulting in a) fatalities, b) injuries, or c) property damage.

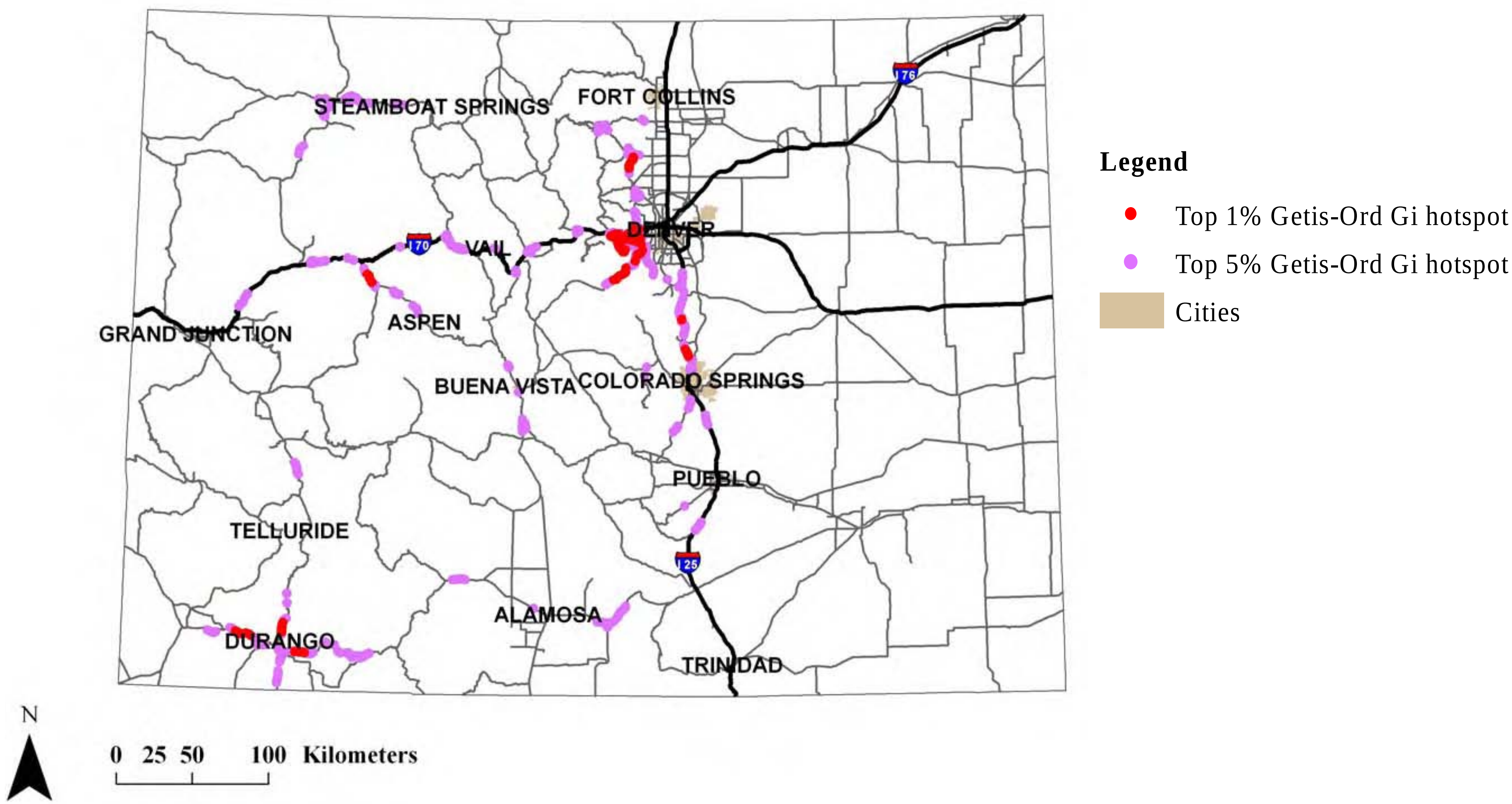


Figure 4. Distribution of top 1% and 5% Getis-Ord G_i^* hotspots AVCs resulting in fatality and injury in Colorado from 1986-2004. The G_i^* neighborhood statistic was calculated using a distance band of 2.5-miles.

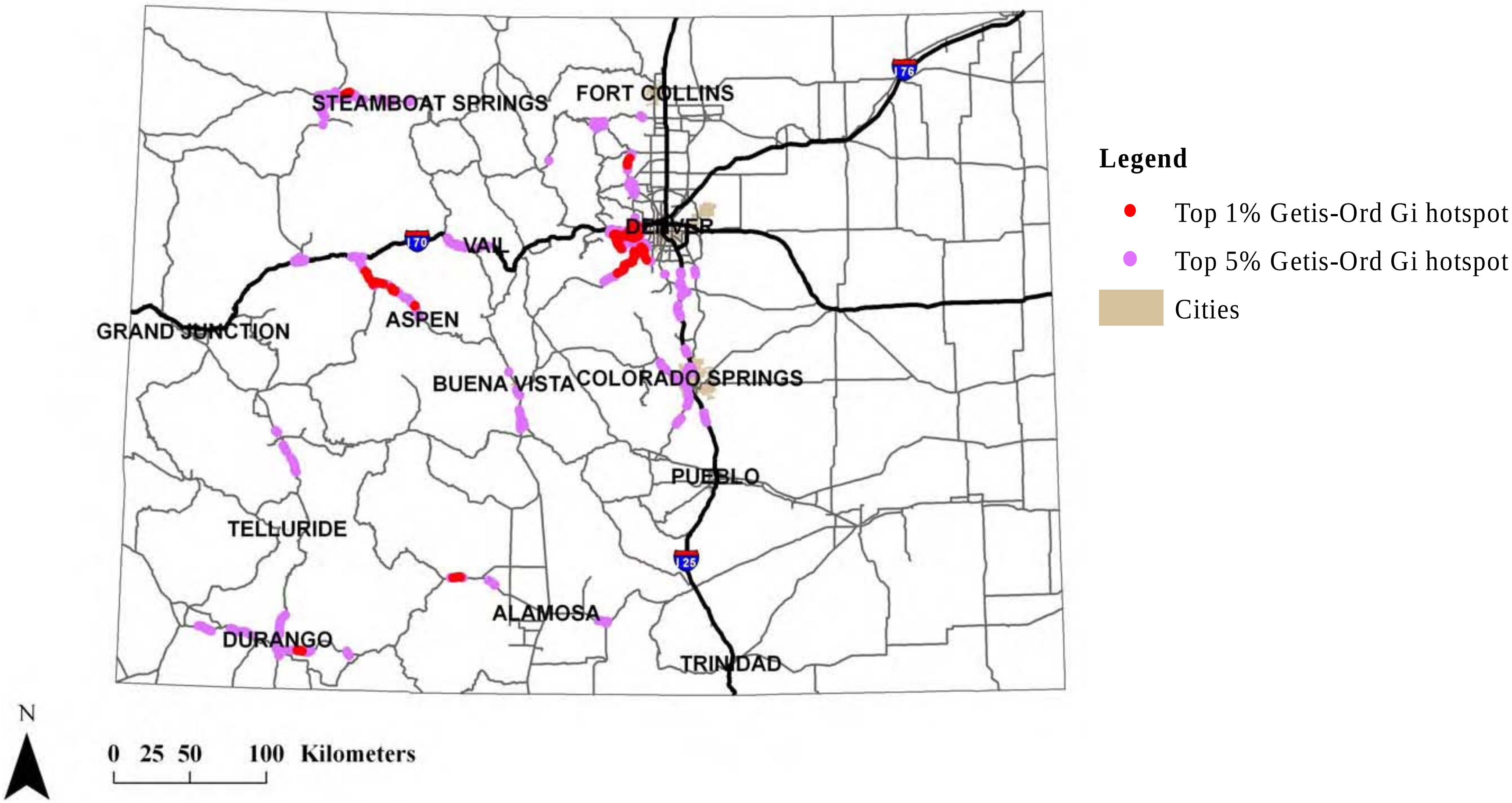


Figure 5. Distribution of top 1% and 5% Getis-Ord G_i^* hotspots of AVCs resulting in property damage in Colorado from 1986-2004. The G_i^* neighborhood statistic was calculated using a distance band of 2.5-miles.

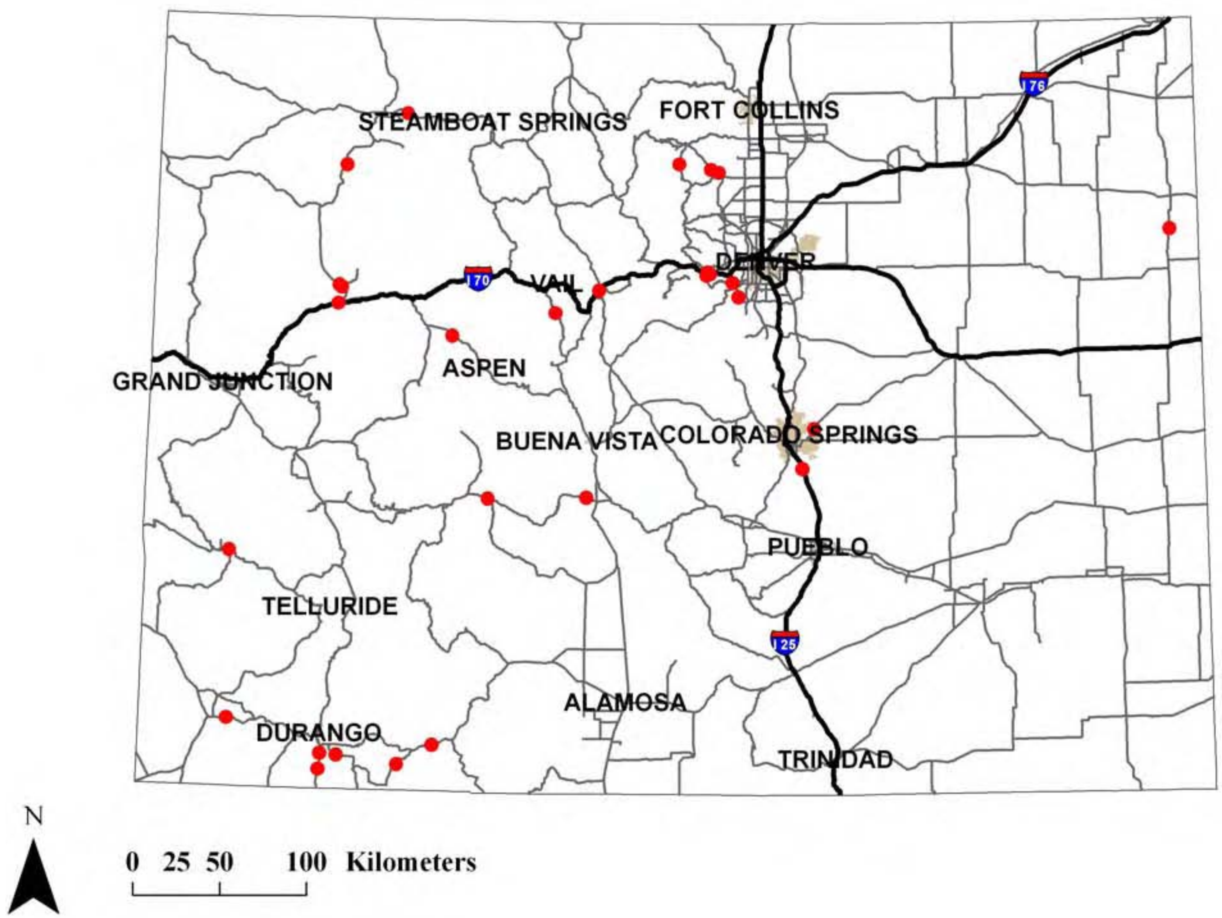


Figure 6. Distribution of all mile markers with AVC resulting in human fatality in Colorado from 1986-2004.

Caution must be used when interpreting the results of the Getis-Ord G_i^* clustering statistic. While the advantage in using a neighborhood statistic is the identification of regionally significant AVC hot spots, the limitation of the statistic is the inclusion of mile markers with low count of AVCs due to their proximity to other locations with high AVCs, sometime in neighboring routes. Readers should be careful in interpreting the Getis-Ord G_i^* results and are encouraged to examine AVC count distribution (Figures 7 and 8) and count summaries (Appendices A.2 and A.3) in addition to the clustering statistic results. We view the Getis-Ord G_i^* statistic as a first step in directing mitigation efforts to *areas* of concern involving more than one route and mile marker locations. The AVCs count summaries then allow further identifications of specific mile markers with high AVC count that are located within the hot spot regions.

Examination of the attributes associated with high AVC count has to occur in the context of availability in order to start detecting trends. Otherwise it is unclear if the patterns observed are simply a function of availability across the study site. To this end, we provide for each attribute the mean values for the entire study site (i.e., availability) and for the top 1% AVC count for each FAT and INJ and PDO records (Tables 4 and 5, Figures 9-12).

The percent forest and disturbed land cover types were almost twice as large in high AVCs areas as compared to the availability (Tables 4 and 5, Figures 9 and 11) for both FAT/INJ and PDO datasets. In addition, the percent grass and agriculture land covers types were lower for high AVCs areas. It is likely that forested areas provide cover for ungulates, and that areas with high forest cover intersecting roadways will sustain more AVCs. Mile markers with high AVC counts also had higher mean percentage of disturbed lands, including areas that were recently burned, logged, mined, or those including invasive plant species (Appendix A.1). This may be the result of increased foraging opportunity for ungulates near lands that experienced mechanical disturbance. These areas could therefore attract wildlife near roads and increase the probability of AVCs.

We used in this study TPI as an index for the topographic characteristics of areas near roads and used Jenness (2006) classification scheme. For both FAT and INJ and PDO analyses, high AVC counts occurred mostly near upland and midslope drainages (Figures 10 and 12). In addition, the mean distance to streams was smaller for areas near top 1% AVC counts as compared to the study site availability (Tables 4 and 5). Both variables may represent areas that are conducive to animal movements along riparian corridors, and suggest that these areas are more likely to have a high degree of AVCs.

In addition, we examined variables associated with human activity and the barrier effect of roads. Examination of the means for each attribute indicates that top 1% of AVCs occurred in areas that had higher traffic volume, speed limit, road width, and traffic volume adjusted road density (Tables 4 and 5). This supports the intuitive assumption that areas with higher human activity and increased barrier of roads will result in higher probability for AVCs.

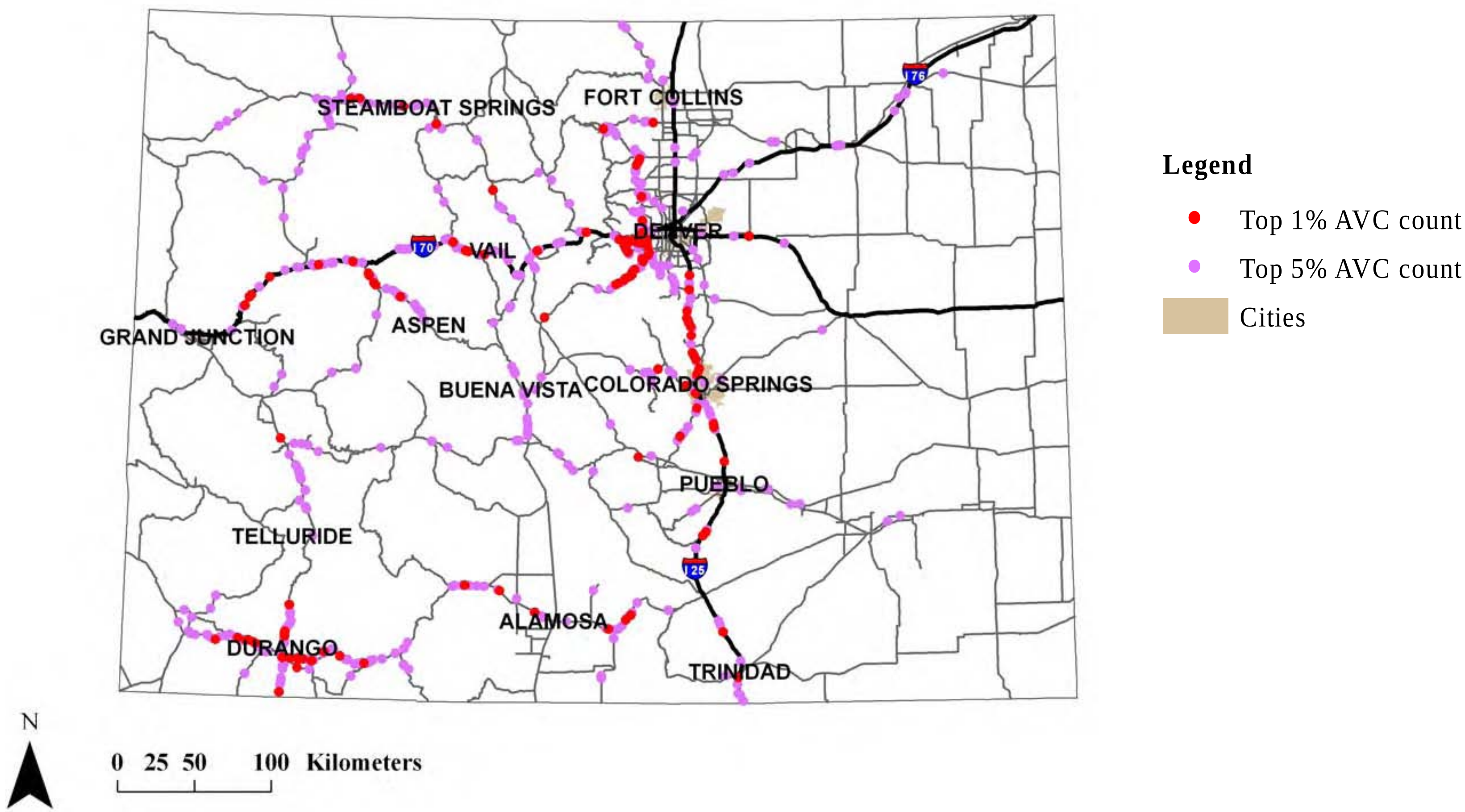


Figure 7. Distribution of top 1% and 5% counts of AVCs resulting in fatality and injury in Colorado from 1986-2004.

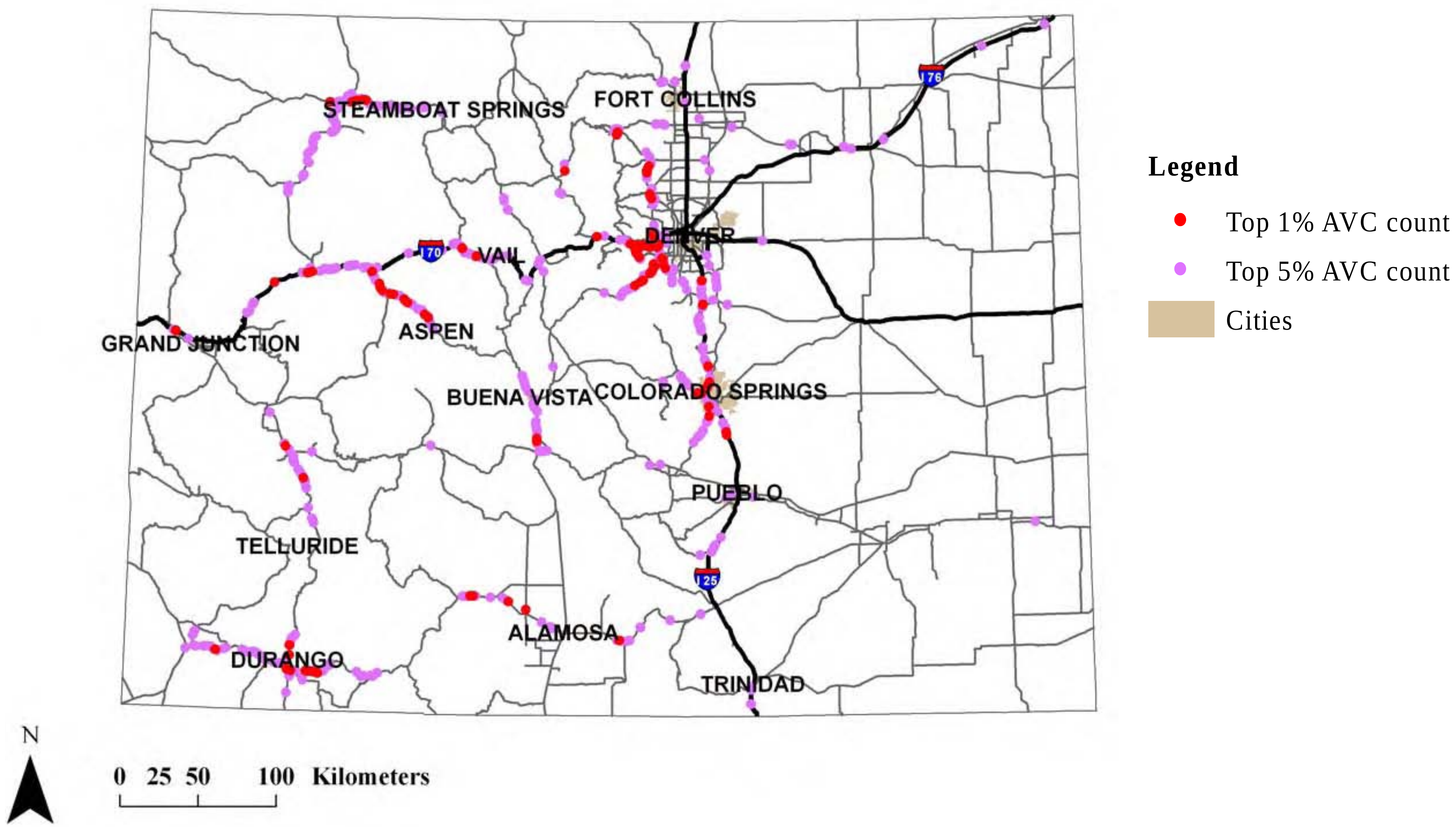


Figure 8. Distribution of top 1% and 5% counts of AVCs resulting in property damage in Colorado from 1986-2004.

Table 4. Summary of all of attributes associated with unique route and mile marker combinations for the top 1% AVCs resulting in fatality and injury in Colorado from 1986-2004, and for the total mile markers available in Colorado.

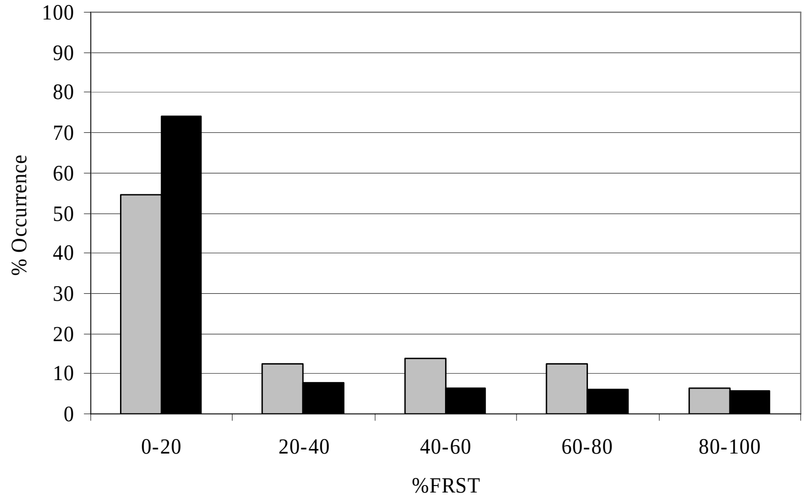
		Land Cover Types							
		%FRST	*%SHRB*	*%GRAS*	*%RIP*	*%HUM*	*%AG*	*%DIST*	*%CC*
Availability	Mean	16.1	12.8	21.7	5.5	9.6	29.5	2.9	9.5
	SD	27.4	21.9	29.3	9.6	22.1	33.7	7.2	16.4
Top 1% AVC	Mean	32.9	15.8	13.7	6.3	11.6	12.4	5.3	16.8
	SD	30.5	18.6	15.6	8.9	17.6	17.4	9.8	15.4

		Distance to streams (km)	*AADT*	*Road Width (m)*	*Speed Limit*	*AADT adjusted Road density*	*Distance to crossing structure (km)*
Availability	Mean	0.7	8,667	7.7	58	8,575.1	3.7
	SD	1.4	18,889	3.4	11	19,602.4	4.2
Top 1% AVC	Mean	0.2	28,179	11.5	62	23,768.0	2.9
	SD	0.2	24,563	4.0	7	21,476.0	2.9

Table 5. Summary of all of attributes associated with unique route and mile marker combinations for the top 1% AVCs resulting in property damage in Colorado from 1986-2004, and for the total mile markers available in Colorado.

		Land Cover Types							
		%FRST	*%SHRB*	*%GRAS*	*%RIP*	*%HUM*	*%AG*	*%DIST*	*%CC*
Availability	Mean	16.1	12.8	21.7	5.5	9.6	29.5	2.9	9.5
	SD	27.4	21.9	29.3	9.6	22.1	33.7	7.2	16.4
Top 1% AVC	Mean	31.2	12.1	12.1	6.8	15.8	14.4	4.7	15.4
	SD	29.6	12.6	15.2	10.1	22.1	18.0	8.9	14.8

		Distance to streams (km)	*AADT*	*Road Width (m)*	*Speed Limit*	*AADT adjusted Road density*	*Distance to crossing structure (km)*
Availability	Mean	0.7	8,667	7.7	58	8,575.1	3.7
	SD	1.4	18,889	3.4	11	19,602.4	4.2
Top 1% AVC	Mean	0.2	28,386	11.6	59	25,107.0	2.2
	SD	0.2	24,389	4.1	9	22,646.0	2.0


100
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% Occurrence
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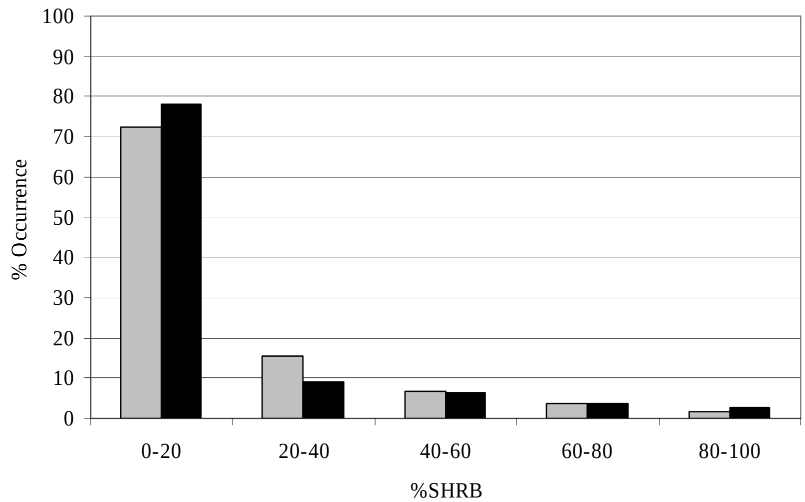
80-100
%FRST

a)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% Occurrence
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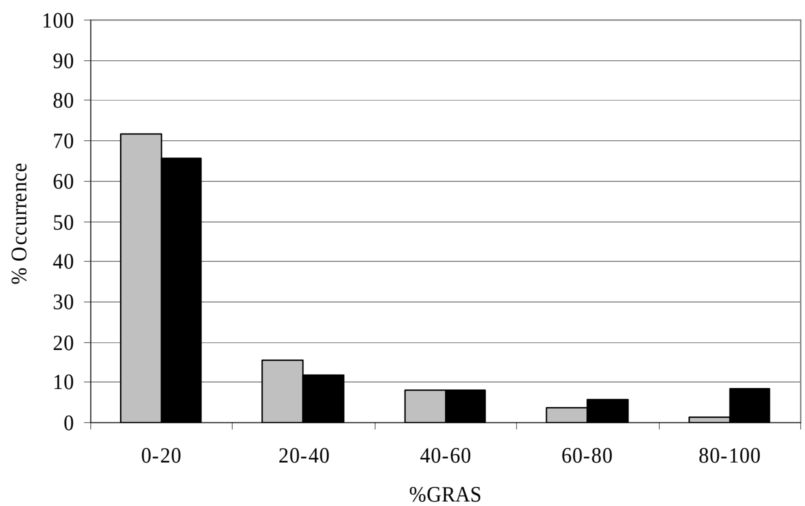
60-80
80-100
%SHRB

b)


100
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20
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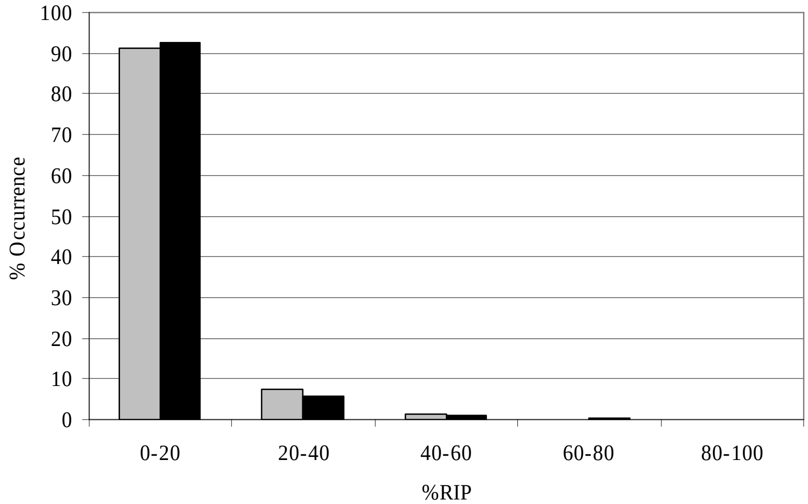
0
% Occurrence
0-20
20-40
40-60
60-80
80-100
%GRAS

c)



100
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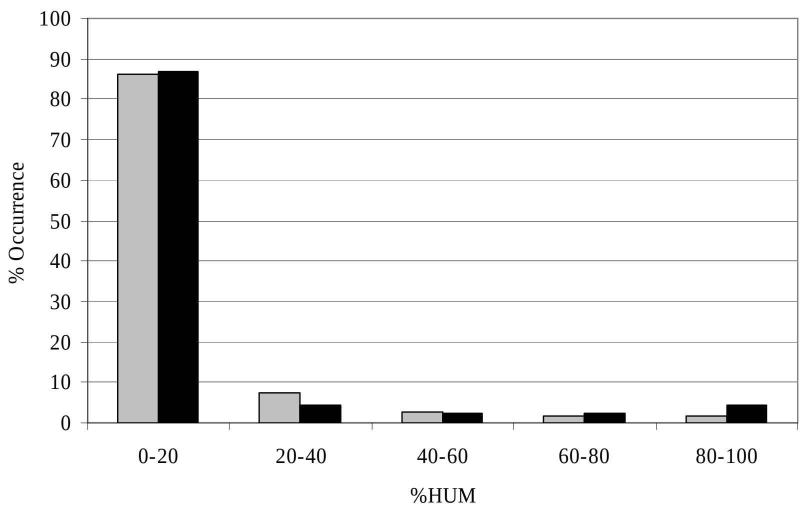
% Occurrence
0-20
20-40
40-60
60-80
80-100
%RIP

d)



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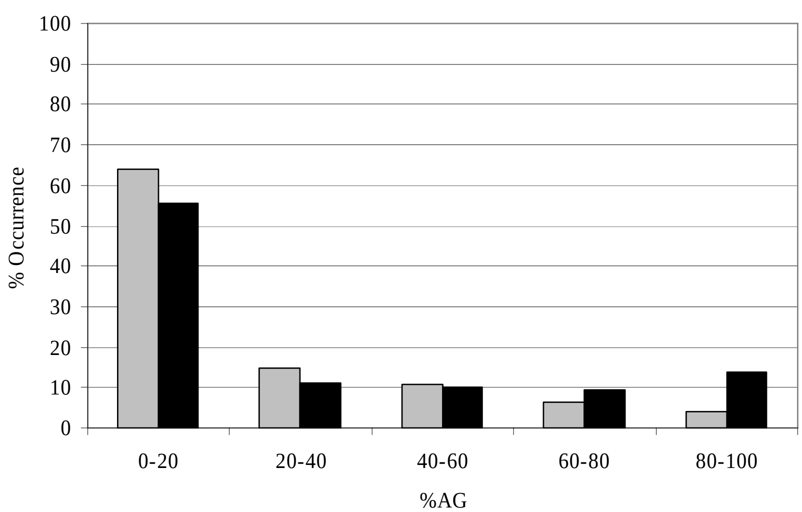
80-100
%HUM

e)



100
90
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0
% Occurrence
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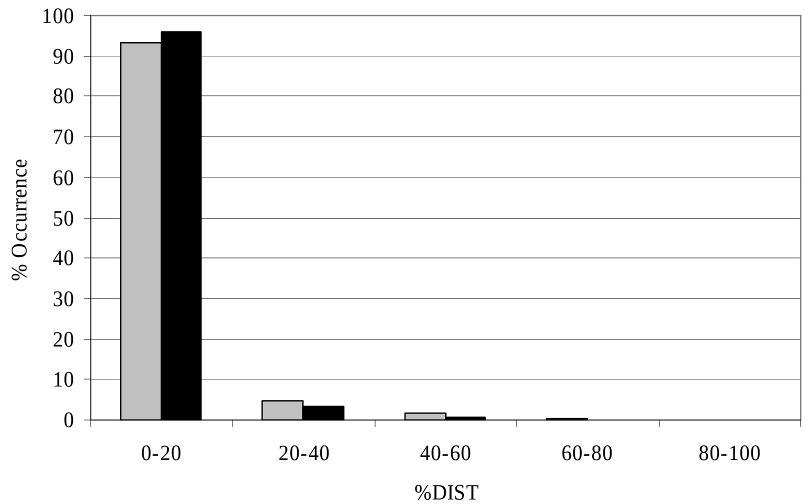
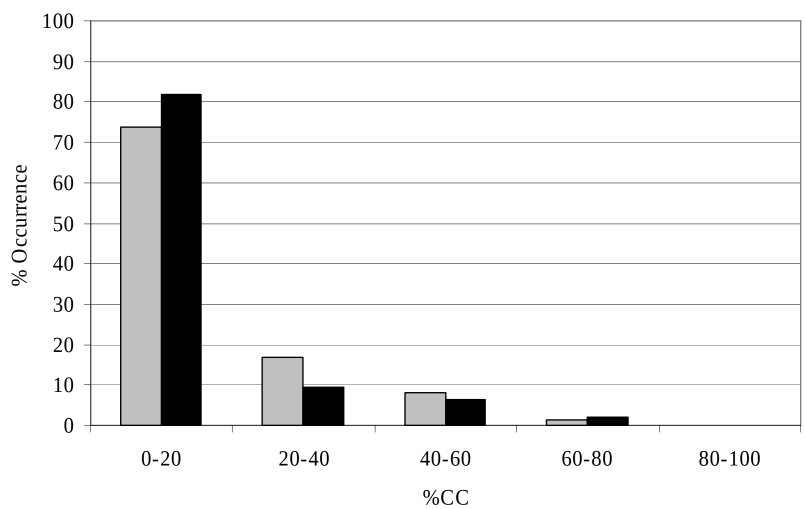
20-40
40-60
60-80
80-100
%AG

f)



g)



h)

Figure 9. Summary of the relationship between percent occurrence of AVCs (Grey) resulting in human fatality and injury in Colorado from 1986-2004 and percent availability (Black) for each land cover attribute and average percent canopy cover calculated within a 0.5-mile radius of each mile marker. Land cover types are based on USGS National Gap Analysis Program (2004) classifications to include: a) forest, b) shrub/scrub, c) grassland/prairie, d) riparian/wetland, e) human development, f) agriculture, and g) disturbed land. Average percent canopy cover (h) is based on National Land Cover Database (USGS 2007).

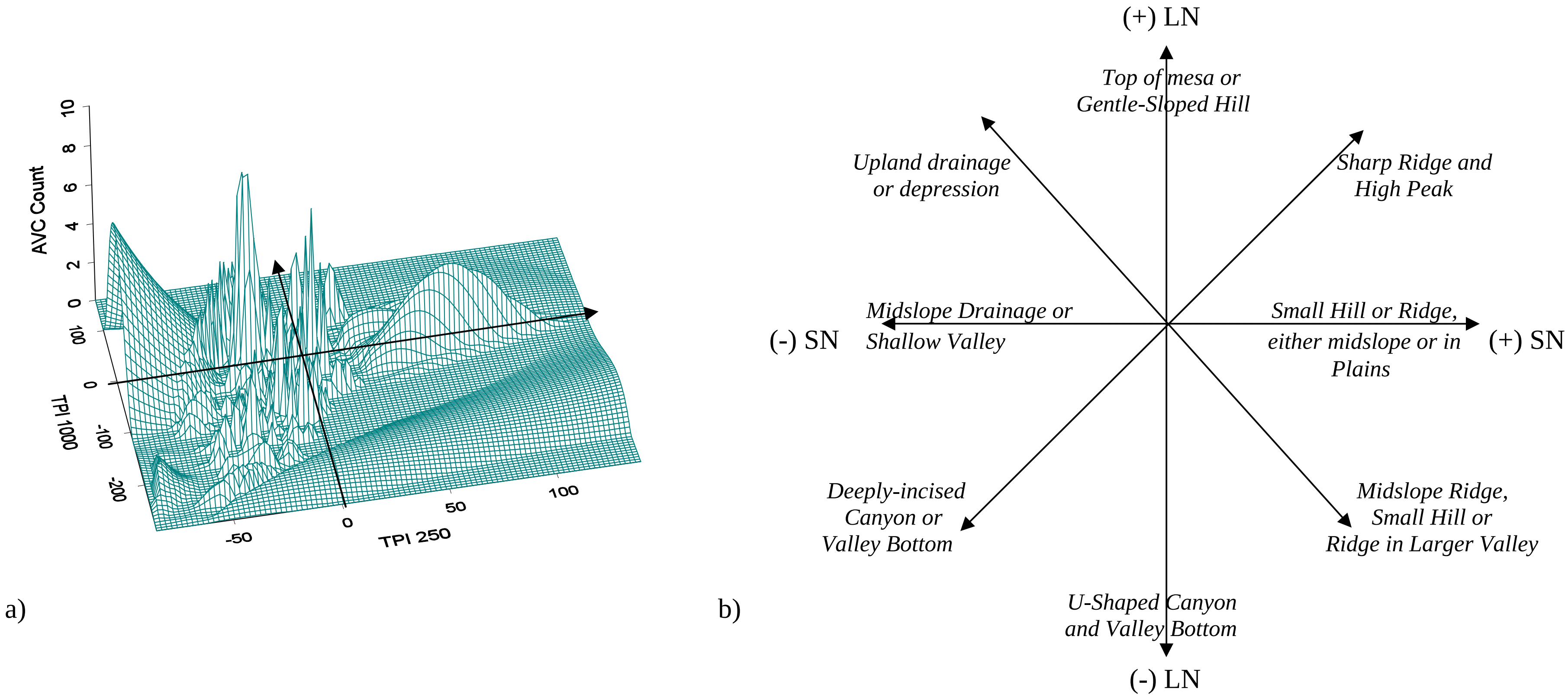
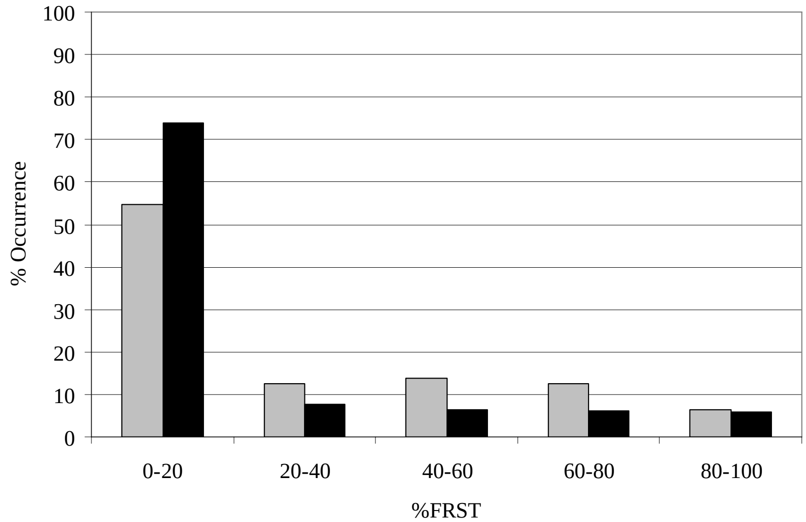


Figure 10. a) a 3D representation of the relationship between AVCs resulting in human fatality and injury in Colorado from 1986-2004 (AVC count), and small- (250 m) and large-neighborhood (1000 m) Topographic Position Index (TPI); b) a reference classification scheme (adopted from Jenness 2006) as combination of positive and negative small- and large-scale neighborhood TPI can indicate the topographic type where AVCs are occurring. Large neighborhood (LN) values are represented by the TPI 1000 scale and small neighborhood (SN) values are represented by the TPI 250 scales.


100
90
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% Occurrence
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20-40
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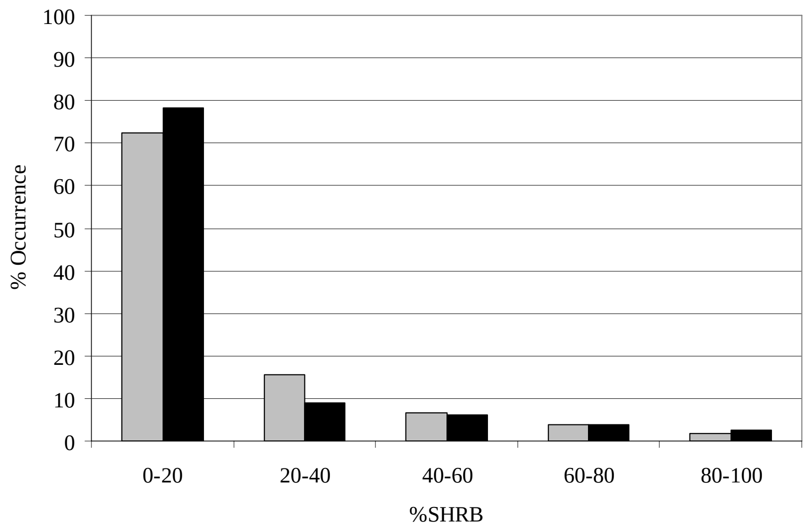
80-100
%FRST

a)


100
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10
0
% Occurrence
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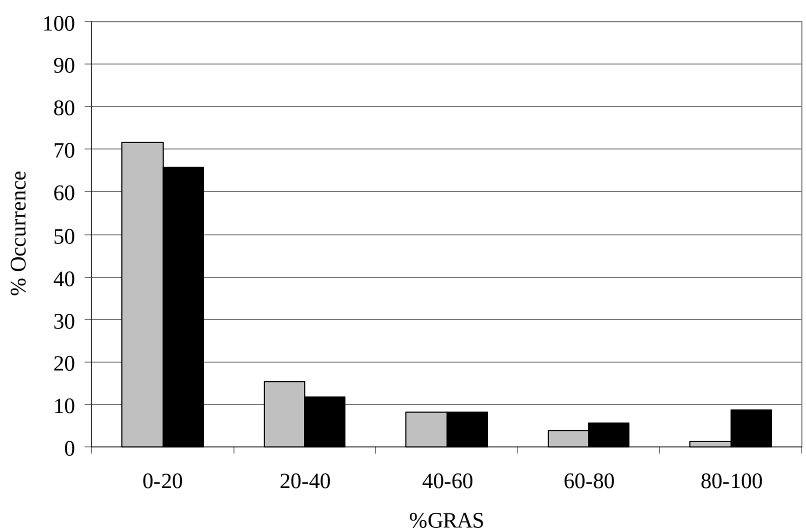
80-100
%SHRB

b)


100
90
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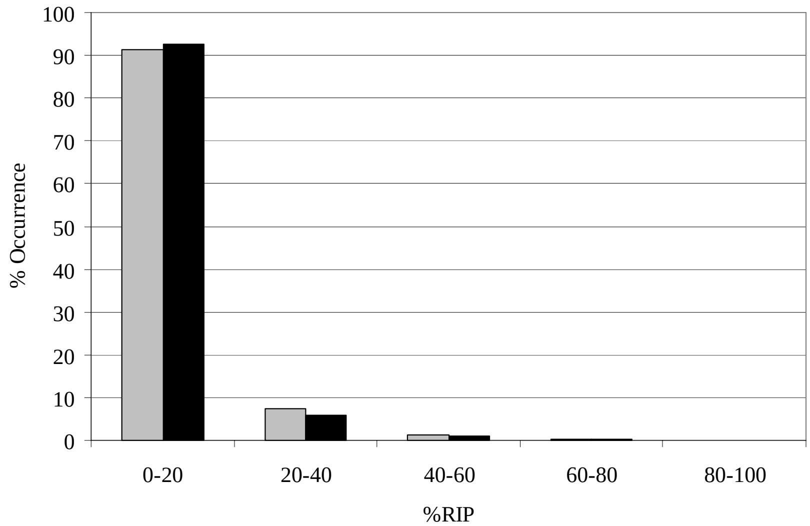
20
10
0
% Occurrence
0-20
20-40
40-60
60-80
80-100
%GRAS

c)



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% Occurrence
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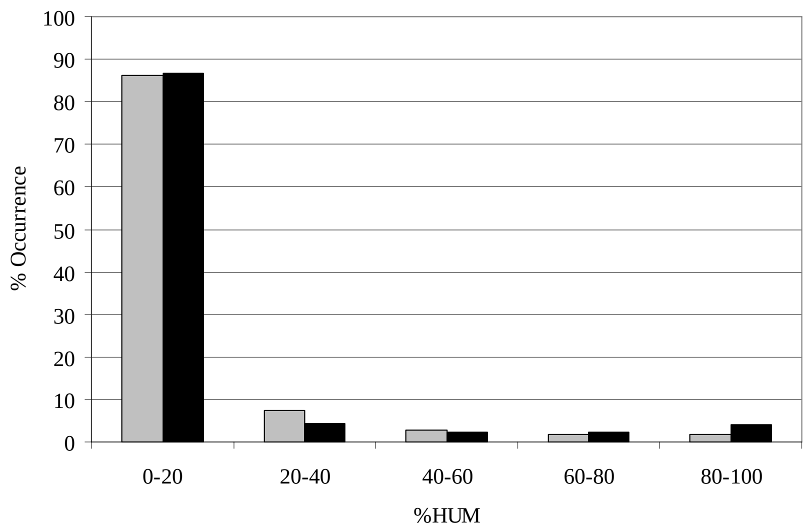
20-40
40-60
60-80
80-100
%RIP

d)



100
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% Occurrence
0-20
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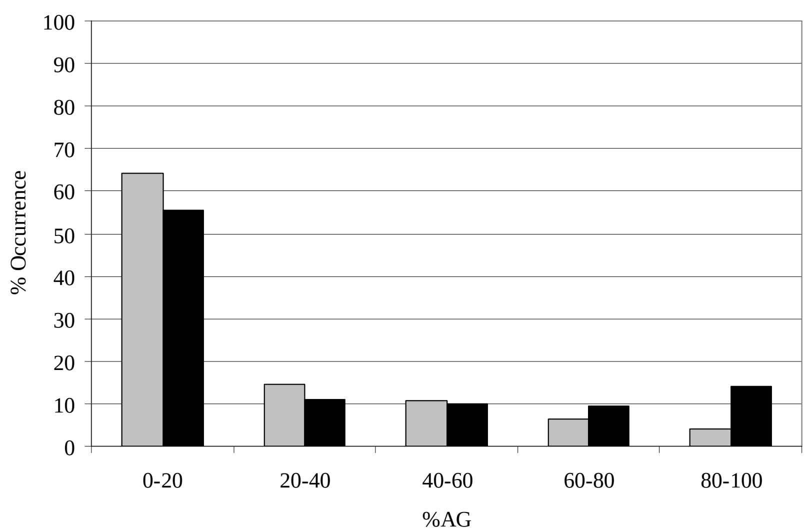
80-100
%HUM

e)



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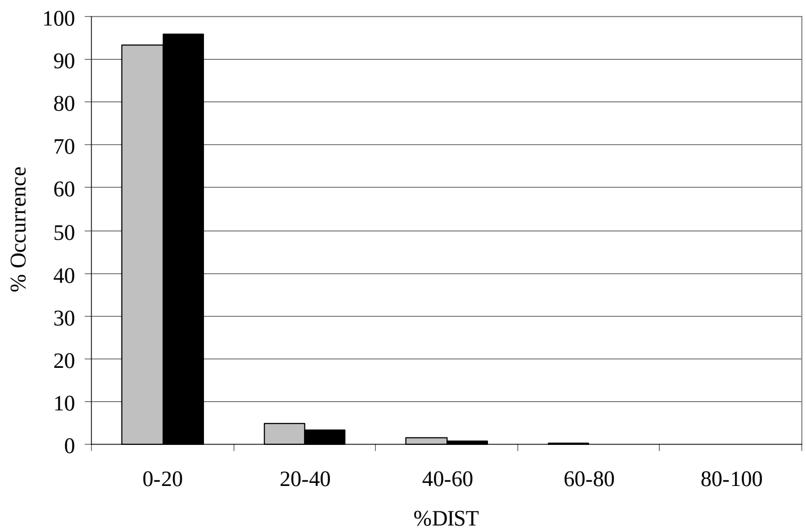
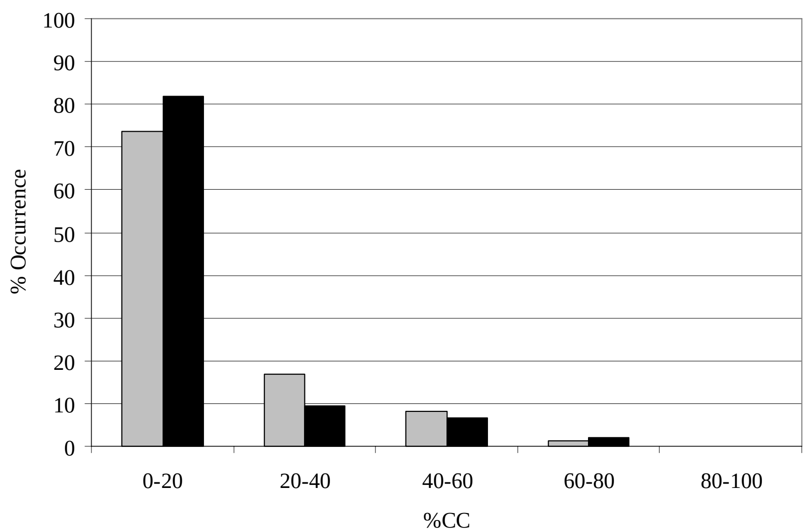
% Occurrence
0-20
20-40
40-60
60-80
80-100
%AG

f)

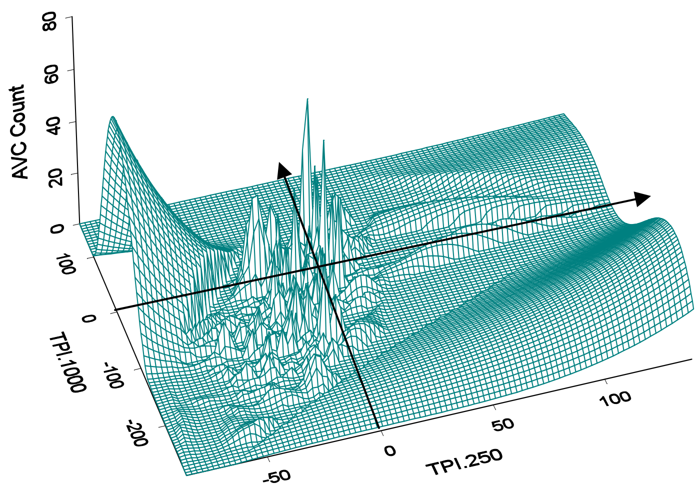


g)

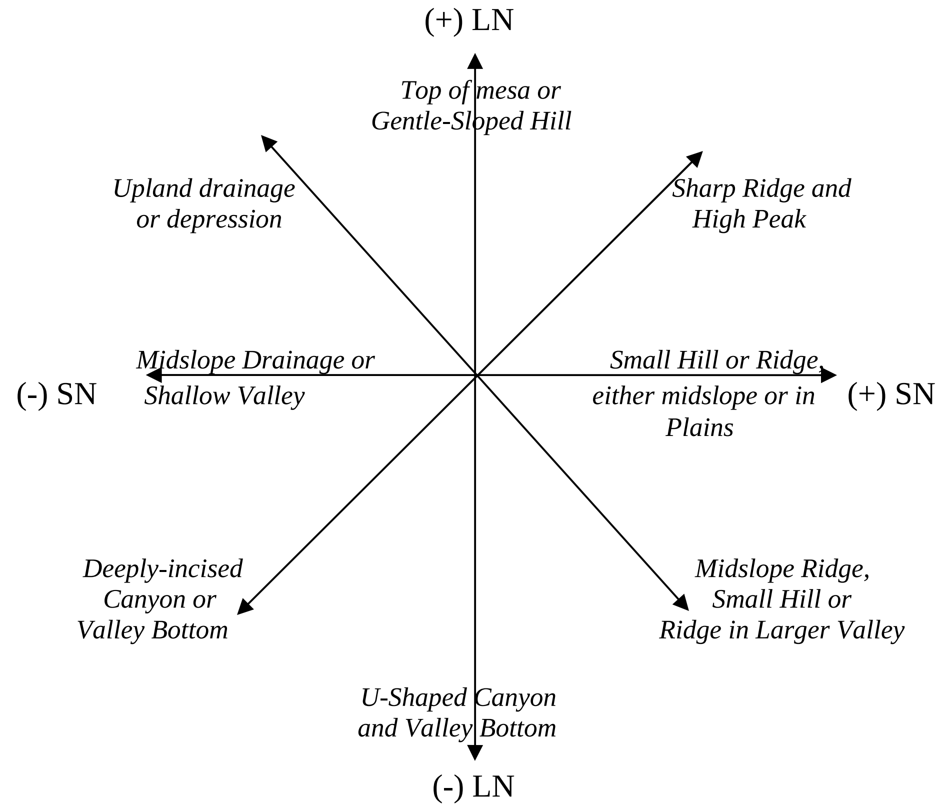


h)

Figure 11. Summary of the relationship between percent occurrence of AVCs (Grey) resulting in property damage in Colorado from 1986-2004 and percent availability (Black) for each land cover attributes and average percent canopy cover calculated within a 0.5-mile radius of each mile marker. Land cover types are based on USGS National Gap Analysis Program (2004) classifications to include: a) forest, b) shrub/scrub, c) grassland/prairie, d) riparian/wetland, e) human development, f) agriculture, and g) disturbed land. Average percent canopy cover (h) is based on National Land Cover Database (USGS2007).



a)



b)

Figure 12. a) a 3D representation of the relationship between AVCs resulting in property damage in Colorado from 1986-2004 (AVC count), and small- (250 m) and large-neighborhood (1000 m) Topographic Position Index (TPI); b) a reference classification scheme (adopted from Jenness 2006) as combination of positive and negative small- and large-scale neighborhood TPI can indicate the topographic type where AVCs are occurring. Large neighborhood (LN) values are represented by the TPI 1000 scale and small neighborhood (SN) values are represented by the TPI 250 scales.

3.0 Wildlife Mitigation Structures

3.1 Selection of Highway Corridors and Proposed Highway Improvement Plans

This research effort corresponds to CDOT's Highway Corridor Wildlife Mitigation/Habitat Connectivity Research Study, which CSU commenced in summer 2004. Development of Mitigation Goals and Pre-Construction Data Collection. Based on the prioritization completed during a Phase I statewide analysis of highway segments and animal-vehicle collisions (see Crooks et. al 2006), combined with CDOT's construction plans for specific highway corridors across the state, the CDOT Study Panel selected the following three highway corridors for further study in Phases II and III (Development of Mitigation Goals and Pre-Construction Data Collection). These three study areas included:

1) U.S. 285 between Conifer and Bailey

2) U.S. 160 between South Fork and Wolf Creek Pass

3) U.S. 160 between Durango and Bayfield

At the time of the study site selection process (November 2005), each of these stretches of highways were slated for multiple-phased highway corridor improvement projects initiating within the next 2-3 years (U.S. 285 Conifer-Bailey: construction beginning April 2006; U.S. 160 Wolf Creek Pass: construction was slated to begin in Fall 2006 but delayed until further notice; U.S. 160 Durango-Bayfield: construction start date not determined). Following is a description of the proposed highway improvement projects for each of the three highway corridors:

3.1.1 U.S. 285: Conifer-Bailey

The portion of U.S. 285 slated for highway corridor improvement adds to a previously widened stretch of highway from Parmalee Gulch Road to Conifer, and extends south from Foxton Road (MP 235.2; south of Conifer) to Bailey (MP 220.5). The first phase of this study is at the northern end of the project: from Foxton Road (MP 235.2) to Richmond Hill (MP 233). Within this phase, one new wildlife underpass (Green Valley Grill wildlife underpass, MP 233.6) was scheduled to be placed at a high AVC location; this underpass was completed in October 2006. The installed structure was 120 ft long x 28 ft wide x 14 ft high and complemented a 3 ft diameter pipe culvert (which replaced the existing 2 ft diameter metal pipe culvert) situated for drainage purposes. Project alternatives, affected environment, and environmental consequences are provided in the U.S. 285 Foxton Road to Bailey Environmental Assessment (Carter & Burgess, Inc. and Colorado Department of Transportation 2004). Table 6 provides structural data for proposed underpasses along U.S. 285 between Conifer and Bailey. Of these underpasses, only the Green Valley Grill underpass has been constructed at the time of this report.

Table 6. Proposed underpasses along U.S. 285, Conifer-Bailey study site. Dimensions are in feet and are only listed if provided in the Environmental Assessment.

Milepost	*Structure Name*	*Length*	*Width*	*Height*	*Openness*[a]
225.3	Deer Creek				
226.4	Roland Gulch		600	30-40	
228.1	Wisp Creek		3	3	
231.0	Shaffer's Crossing[b]		24	12	
233.6	Green Valley Grill[c]		28	14	

[a] openness is calculated as underpass (width x height)/length
[b] a bridge may replace proposed arch culvert
[c] completed in October 2006

3.1.2 U.S. 160: Wolf Creek Pass

The portion of U.S. 160 slated for highway corridor improvement is intended to provide safe and efficient travel for increased traffic loads in the future. This project would widen a 7-mile stretch of U.S. 160 to a 2- and 3-lane roadway, and extends from where the footprint width of the highway narrows 5 miles west of South Fork (MP 181) to 1 mile west of the U.S. 160/Big Meadows Road intersection (MP 174). The western portion of this zone has already undergone construction activities, including the construction of a highway tunnel to bypass a sharp curve and major excavation/rock removal to straighten a segment of the roadway.

The phase of highway improvement tested during this study is at the eastern end of the project: from the eastern boundary of the project area, 5 miles west of South Fork (MP 181) to MP 178. Within this phase, two new wildlife underpasses (specifically designed to promote lynx movement under the roadway) are scheduled to be constructed at pre-determined locations: Lynx Crossing Site G (MP 179) and Lynx Crossing Site H (MP 179.4). Lynx Crossing Site G will accommodate both water and a terrestrial passage for wildlife and will be a 147 ft long x 10 ft wide x 8 ft high concrete box culvert (the terrestrial portion of the structure will be 6 ft wide x 6 ft high); it will replace a temporary 121 ft long x 5 ft 10 in wide x 4 ft 2 in high metal culvert which was installed specifically for lynx movement and has been monitored since May 2005 as part of the CSU Wildlife Underpass (Lynx) Monitoring Research Study (see section below). Lynx Crossing Site H will be situated immediately west of Decker Creek and will be a 95 ft long x 10 ft wide x 10 ft high concrete box culvert. Cumulative impacts on threatened and endangered species as well as mitigation techniques, including lynx passageway designs, are provided in the Final Biological Assessment: Proposed Improvements to U.S. Highway 160 East of Wolf Creek Pass – Mineral and Rio Grande Counties, Colorado (ERO Resources Corporation 2001). Table 7 provides structural data for proposed underpasses along U.S. 160 between South Fork and Wolf Creek Pass. To date, the construction of these proposed underpasses have been delayed until further notice.

Table 7. Proposed underpasses along U.S. 160, Wolf Creek Pass study site. Dimensions are in feet.

Milepost	*Structure Name*	*Length*	*Width*	*Height*	*Openness* [a]
175.5	Lynx Crossing K (Lake Fork)[b]	~115	10	8	~0.70
176.6	Lynx Crossings B1, B2, and B3 (chain station)	110-115	~6	~4	~0.22
179.0	Lynx Crossing Site G	147	10	8	0.54
179.4	Lynx Crossing H (Decker Creek drainage)	95	10	10	1.05

[a] openness is calculated as underpass (width x height)/length

[b] structure is a double box culvert; dimensions provided are for a single box

3.1.3 U.S. 160: Durango-Bayfield

The portion of U.S. 160 slated for highway corridor improvement is intended to increase travel efficiency/capacity to meet current and future needs, improve safety, and control access. This project would extend the existing 4-lane highway from Grandview east to Bayfield and improve existing intersections with multiple state and county roadways; the entire project length is a 16.2-mile stretch of U.S. 160 from MP 88.0 just east of Durango to MP 104.2 east of Bayfield.

Although a construction date has not been determined for this stretch of U.S. 160, the phase of highway improvement slated for this stretch of road occurs east of the U.S. 160/SH 172 intersection, where U.S. 160 transitions from four lanes to two lanes (MP 92), and extends east to a point around MP 95 (the exact terminus of this future construction/highway improvement phase has not been determined to date). Within this phase, two existing crossing structures are planned to be enlarged to provide movement for wildlife, particularly elk and mule deer. The Florida River bridge (MP 93.7) is currently a 32 ft long x 98 ft wide x 11 ft 6 in high bridge that spans both banks of the drainage and currently provides a sufficient terrestrial movement route for wildlife passing through the structure. This structure will be replaced with a split bridge, each span providing a 12 foot high by 60 foot wide passage for wildlife (the total underpass width would be 220 ft; underpass height is recommended to be 18-24 ft). The second location for a structure would be located at the Pioneer Irrigation Ditch (MP 94.65). The proposed structure would be a 240 ft long x 36 ft wide x 14 ft high arch culvert. Wildlife fencing is proposed to complement these structures (and additional structures to the east and west which are proposed during later phases of this highway corridor improvement project) between MP 93.4-100. Project alternatives, affected environment, and environmental consequences and mitigation are provided in the Draft Environmental Impact Statement/Draft Section 4(F) Evaluation for US Highway 160 from Durango to Bayfield La Plata County, Colorado (Colorado Department of Transportation and U.S. Department of Transportation Federal Highway Administration 2005). Table 8 provides structural data for proposed underpasses along U.S. 160 between Durango and Bayfield.

Table 8. Proposed underpasses along U.S. 160, Durango-Bayfield study site. Dimensions are in feet.

Milepost	*Structure Name*	*Length*	*Width*	*Height*	*Openness* [a]
93.7	Florida River	120[b]	220	12[c]	220
94.6	Pioneer Irrigation Ditch	240	36	14	2.10
95.7	Fill Slope	240	36	14	2.10

[a] openness is calculated as underpass (width x height)/length
[b] length calculated as 2 spans, each 60 ft wide
[c] minimum height; recommendations include a 18-24 ft. high structure

3.2 Mitigation Goals and Data Collection Protocols

For each of three study sites selected by the CDOT Study Panel, a series of detailed data collection protocols and study plans were developed to collect pre- (and eventually post-) construction data in impact and control sites to evaluate the effectiveness of installed mitigation structures. Post-construction mitigation goals include decreases in road mortality, decreases in surface-crossings, and increases in underpass usage (e.g. functional connectivity) in comparison to pre-construction survey data.

For each site, we also developed recommendations for the design and placement of structural wildlife crossings, fencing, and/or other methods to meet the mitigation goals for each corridor. Recommendations were based on pre-construction field surveys in each corridor, as well as guidelines available in the existing scientific and technical literature. Mitigation recommendations include guidelines for structural mitigation (e.g. design of structural wildlife crossings, fencing, vegetative cover) as well as non-structural mitigation (e.g. human-use management, education). Several of the monitoring locations in this study were already identified in previous Environmental Assessments and Environmental Impact Statements for each respective roadway as recommended locations for some type of wildlife mitigation structures.

3.3 Sampling Methodology

3.3.1 BACI Sampling Design

An excellent design for environmental studies of this type is a before-after-control-impact design, or BACI (Stewart-Oaten et. al 1986). By definition, the 'impact' site is that portion of roadway subjected to the first phase of highway improvement (construction). As such, our 'before' monitoring occurred prior to any highway improvement activities on the impact site. During site selection, each impact site was slated to undergo the first phases of construction in the near future (although see Section 3.1 for description of delays in construction plans), including the establishment of new underpasses or the upgrading of present structures. The 'after' component of such a study design is defined as monitoring that occurs after all initial construction activities within the impact site cease. Alternatively, our 'control' site was a stretch of road not slated for immediate highway improvement activities. Although the control sites, also included locations where underpasses are proposed to be installed or upgraded, these stretches of roadway are slated for construction during later phases of the highway improvement plans.

Therefore, within each of the 3 selected sites, we identified paired stretches of highway for monitoring. A pair consisted of 1) a 2 km "treatment" (impact) site where an underpass was slated to be either constructed (in situations where no such structure was currently present) or modified (in situations where an existing structure was slated to be enlarged or replaced with a larger structure) and 2) a 2 km "control" site where no construction was planned in the near future.

By incorporating both time before and after at impact and control sites, BACI designs reduce the chance that unmeasured covariates are influencing observed effects and thus overcome the problem of ascribing changes to impact rather than natural variability (Stewart-Oaten et al. 1986; McDonald et al. 2000; Stewart-Oaten and Bence 2001). An advantage of BACI analyses is that they do not assume that the environments of the control and impact sites are the same in all respects other than the impact, but only that their dynamics in time would be concordant had there been no impact (Wiens et al. 2001). For this study, each control site was within 1.5-10 km of the associated impact site and was similar to the impact site in terms of adjacent habitat, topography, elevation, and presumably the dynamics of the surrounding wildlife communities. As such, monitoring control sites concurrently with impact sites before and after construction allowed for stronger inference as to the effects of construction and the success of associated mitigation structures.

3.3.2 Monitoring Techniques

Once approved by the CDOT Study Panel, the research team implemented the pre-construction portions of the study plan on specific highway corridors as provided for in Phase II. At key existing underpasses along each corridor, pre-construction field monitoring focused on below (underpass) and, where logistically possible, at-grade (surface) highway crossings of wildlife. At proposed crossing structure locations where there was no existing underpass, where possible, field monitoring focused on at-grade highway crossings along road shoulders. Wildlife crossings were quantified through:

Remotely-triggered infrared digital cameras

Because cameras provide a relatively low-maintenance means of remotely surveying wildlife populations, remotely-triggered cameras were our primary survey tool. Digital cameras were placed along key underpasses at each corridor. If possible, at proposed crossing structure locations where there was no existing underpass, digital cameras were placed along likely animal movement routes that bisected the roadway where the crossing structure was proposed.

Animal-vehicle collision data

We used several data sources to aid in our determination of critical wildlife crossing zones. These data sources included AVC data from Colorado State Patrol (CSP) records, CDOT maintenance records, and other independent sources. It is important to note that many species go undetected as a result of being struck by vehicles. Therefore, these data underestimate the total number of individuals being killed along the highway.

In addition, for all surveyed underpasses, we recorded data on a variety of structural, contextual, and environmental parameters. Variables quantified for each underpass included structure type (e.g. bridge or culvert), composition (e.g. concrete or steel), substrate (e.g. soil, concrete, corrugated steel), width, height, length, and openness (width×height/length). We also measured local vegetative cover (type and proportion within 100 m radius of each underpass entrance).

3.3.3 Design of Monitoring Stations and Data Analysis

Within each control and impact site, we established a series of monitoring stations to record wildlife activity in relation to the roadway and to the proposed and existing structures. Monitoring stations were established along transects situated perpendicular to the roadway. Each transect consisted of four monitoring stations, including two approach stations and two stations on the roadside at the site of the existing or proposed structure. These transects served to quantify the level of activity by a variety of species encountering the area in the immediate vicinity of the roadway and underpasses. Several metrics of wildlife activity were established and calculated in the following manner:

Determining activity at approaches to existing and proposed underpasses

Remotely-triggered cameras were established along game trails leading to the location of the existing or proposed underpasses. Each "approach" camera was stationed within 20-30m (depending on the width of the highway right-of-way) of the existing or proposed underpass location on either side of the roadway. This distance was selected to determine the level of activity in the immediate vicinity of the existing/proposed underpass and represents the potential for a species to utilize the underpasses. If cameras were stationed father away from the existing/proposed underpass location, animals might be less likely to actually encounter the structure.

From these two "approach" camera stations, we derived two indices of wildlife activity associated with the approach to the existing/proposed structure. One metric measured the numbers of visits by a species to a camera station (i.e. the number of photographs of a species), divided by the total sampling effort. The other metric measured the number of nights the species was detected at the camera station, divided by the sampling effort (i.e. multiple pictures of a species in a given night were pooled into a simple yes/no index). Thus, indices for the approach camera (I_{APP}) for each species were calculated using the following equations:

$I_{APP} = \{v_j/N_j\}$ and $I_{APP} = \{n_j/N_j\}$

where, I_{APP} = metric of activity at underpass approaches
v_j = number of passes (photographs) by species at camera j
n_j = number of nights a species visited camera j

N_j = number of nights that camera j was active

In addition to these camera surveys, we also conducted opportunistic surveys for wildlife sign along the approach routes to the existing/proposed underpass locations. These surveys included track and scat surveys at 100m-long transects, occurring along both highway shoulders, as well as 20-50m parallel to the roadway shoulder (see *Determining at-grade crossings above existing underpasses or proposed underpasses* section below). Data from these surveys provided supplemental information for the presence of species in the vicinity of the existing and proposed underpass approaches.

Determining successful below-grade crossings (or potential below-grade crossings for future underpasses)

Remotely-triggered cameras in the control and impact sites in each study area monitored both existing underpasses and locations where new underpasses were to be established. For existing underpasses, a pair of "underpass" cameras, one positioned at each underpass entrance, recorded species use of the structure; the direction of movement was recorded for each pass through the structure. For locations where there was currently no underpasses, but a structure was planned as part of the construction project, we established a pair of cameras, one on each side of the roadway, to emulate how cameras would be positioned in the event of a structure at that location. Each "underpass" (roadside) camera was situated on the fill slope at the location where the underpass entrance would be constructed, with the camera oriented parallel to the roadway. These cameras therefore monitored the future "entrances" of the new underpass, with each photograph of an animal considered as a "pass" through the location. In some instances, there was a small pipe culvert (less then 1m diameter; too small a diameter for most species) that will eventually be replaced by a larger structure compatible with wildlife movement. In these situations, cameras were situated at the small culvert entrance, although movement beyond the culvert entrance (in the background of the remotely-triggered camera photo) also could be documented.

From these camera stations, we derived two indices of wildlife activity associated with successful below-grade crossings (or potential below-grade crossings for future underpasses). To calculate each metric (I_{UND}), the a) number of visits by each species and b) number of nights visited were divided by the total sampling effort using the following equations:

$$I_{UND} = \{und_j/N_j\} \qquad \text{and} \qquad I_{APP} = \{un_j/N_j\}$$

where, I_{UND} = metric of successful below-grade crossings or passes by camera stations established at proposed underpass locations
und_j = number of passes by species through each underpasses j or at each proposed underpass location
un_j = number of nights a species passed through an underpass j or by a proposed underpass location
N_j = number of nights that camera j was active

To evaluate the effectiveness of improved or newly constructed mitigation structures in each study area (the 'after' portion of the BACI analysis), we statistically tested for differences in the following categories:

- Activity across sampling stations within a transect

    Hypotheses: For sites where there was no available passage under the roadway, we would expect there to be a difference in species activity on opposite sides of the road, and/or lower visitations along the road shoulder than at the approach cameras. However, once a structure was built to accommodate species movement, we would expect activity to be similar among stations due to the ability of wildlife to move successfully under the roadway and along the transect. Therefore, in the impact site, we hypothesized that there would be a difference in visitations among sampling stations within a transect pre-construction, but no difference among stations post-construction. Alternatively, in cases where there was no suitable structure present, we expected significant variation in the number of visits among sampling stations within a transect.

    Data: Differences in activity among stations within a transect were tested within the control and impact sites both before and after construction. Metrics included a) number of visits by each species and b) number of nights visited.

    Statistical Analysis: Single Factor ANOVA (visits) and Chi-Square (nights)

- Mean number of visits within a transect before and after construction

    Hypotheses: In the impact site, we expected a post-construction increase in activity along the transect in the impact site due to the construction of an underpass that allows for wildlife movement. In the control site, we expected no significant difference in activity along the transect before and after construction.

    Data: Activity along the transect was tested for differences before and after construction for both the control and impact site. Visits were pooled among stations to obtain a mean index for each station within a transect.

    Statistical Analysis: Paired Sample t-test (visits)

- Activity at underpass stations before and after construction

    Hypotheses: In the impact site, we would expect to see an post-construction increase in activity after the underpass station. In the control site, we would expect there to be no difference in visits to roadside stations pre- and post-construction.

Data: Activity at underpass stations were tested for differences before and after construction for both the control and impact site. Metrics included a) number of visits by each species and b) number of nights visited.

Statistical Analysis: Student's t-test (visits) and Chi-Square (nights)

Determining unsuccessful at-grade crossings

In collaboration with CDOT maintenance crews, we initiated an effort to collect year-round animal-vehicle collision (AVC) data along both control and impact portions of the highway during the study. It should be noted, however, these collection efforts were not conducted in a systematic fashion and represent an opportunistic approach to gathering AVC data. Comparing AVC rates before and after highway improvements is difficult in the absence of standardized AVC collection techniques. These data do, however, provide useful data on the location of AVCs and species being struck. In fact, AVC data collected by maintenance crews appears to be twice the value reported by Colorado State Patrol (J. Holst, pers. comm.). We provide data collected during our study for each of the three study sites. The interpretation of these data is limited to the locations of where animals are being struck by vehicles.

Determining at-grade crossings above existing underpasses or proposed underpasses

We conducted at-grade track surveys in the immediate vicinity of each existing/proposed underpass location in order to obtain a metric of species activity across the roadway. A 100m transect extending parallel to the highway shoulder and centered on a) the underpass b) each approach station was surveyed for tracks to determine if at-grade crossings were occurring. Track transects were sampled during visits to the monitoring stations (i.e. to replace film and/or batteries at cameras). These 100m transects were walked and tracks of species were recorded as either crossing or not crossing. Transects surrounding each underpass were walked at least twice per sampling season/quarter. Any signs of scat were also recorded.

It should be noted that the detection of tracks was largely restricted to those opportunistically recorded in natural substrate along the roadway (e.g. dirt, mud, snow) at the time of sampling; tracking conditions therefore likely varied across sites and time, were likely weighted for heavier species that are more likely to register a print in the substrate (i.e. elk and mule deer), and some locations may not have yielded tracks even if wildlife are present. Thus, we used the track surveys as opportunistic sampling that was supplemental to the camera and AVC data.

3.4 Site Descriptions

Site visits and assessments were conducted between June and August 2006. For each site, we characterized potential roadway barriers through the following variables: number of lanes, shoulder barriers, median barriers, and other features. The number of lanes was represented by the number of through-travel lanes; we did not consider a turn-out lane or merging lane as a lane of travel. Shoulder barriers were defined as any "structure" paralleling the roadway that could impede wildlife movement across the roadway and were categorized as chain link fence, barbed wire fence, or soundwalls. We did not include guard rails as shoulder barriers, since they were commonly present at locations above drainage structures and steep shoulder slopes where vehicle safety is a factor. We did, however, identify specific locations within potential wildlife crossing zones where guard rails were present. Median barriers were defined as any structure between opposing lanes of traffic and were categorized as jersey walls, guard rails, or divided highway. We also identified other features along the roadway that could hinder wildlife movement across the road or serve as potential soft barriers to species movement.

Within the impact and control sites, we identified specific situations that could potentially serve as a wildlife crossing locale. These situations included both existing structures and fill slopes. Structures were defined as any bridge or culvert that could provide a safe passage for wildlife species underneath the roadway. Structure types were characterized as open span bridges, box culverts, arch culverts, and pipes. We also identified certain overpass structures (i.e. structures that spanned over the roadway) that could facilitate or serve to facilitate species movement over the roadway. Finally, we recorded locations of structures along each roadway designed to allow animals to escape the highway right-of-way, such as one-way deer gates and ramps. While we attempted to identify the majority of potential crossing structures within each site, certain ones were excluded based on their size or position within the landscape. We did not consider any structures with a diameter less than 1m as a potential crossing structure for our target species. In addition, certain structures in close proximity to development or other activities that would prevent wildlife species from using the structure were also not considered. Fill slopes were defined as any location where the roadway was elevated above the surrounding land. These locations typically occurred where the roadway bisected drainages, but were also common along topographic depressions lacking a hydrological component. While it was not uncommon to have some sort of drainage structure under the roadway to allow for water flow, these structures (typically corrugated pipes) were almost always under 1m in diameter, thus forcing wildlife up the fill slope to attempt a surface crossing of the roadway.

For each situation, we measured a suite of variables unique to the situation type. For structures, we recorded, when possible, the length, width, height, and openness. We also denoted whether there was water present within the structure. If there was, we quantified the proportion of terrestrial passage through the structure. For major aquatic systems, we recorded the condition of the inlet and outlet, the substrate type, and the proportion of vegetation within the structure. Vegetation was also measured within a 100m radius of each end of the structure and averaged to yield a % category of cover for vegetation less than and greater than 1m in height. For fill slopes, we measured the fill height and fill imprint. Fill height was defined as the height of fill between the roadway and the natural, non-fill slope on either side of the roadbed. Fill imprint was the distance along the roadway occupied by the fill. We also recorded any incidental sign of species activity at each situation location. This included species use of structures, tracks and scat, game trails, and roadkill.

We also characterized each study area's importance to large mammal critical habitat. We obtained data from the Colorado Division of Wildlife (CDOW; CDOW 2007) that identified important habitat features and/or areas of concern for local ungulate and carnivore populations. Examples include calving grounds for elk populations, severe winter range habitat for ungulates, fall concentration areas for black bears, and human-mountain lion conflict zones. Such data provide reference to the seasonal activity patterns that may be associated with movement and AVC patterns for a particular species of interest. Furthermore, although we acknowledge that smaller-bodied species are also subjected to AVC incidents, we only report data for large mammals and other species of critical conservations concern, as these species make up the majority of reported AVCs and the structures designed in the 'Before' phase of this project were designed to meet connectivity needs of those species.

3.4.1 U.S. 285: Conifer-Bailey

Roadway characteristics and structural data

For much of its length between Conifer and Bailey, U.S. 285 is a rural 2-lane highway, with occasional passing lanes (three lanes total) in areas of hilly topography. At Shaffer's Crossing, there is a short stretch with four traffic lanes. There are also stretches where the highway footprint widens to accommodate turn-out lanes to side roads; these lanes occur on both the shoulder and in the median of U.S. 285. The highway is subject to Average Annual Daily Traffic flows (AADT) ranging from 6,400 vehicles at the southern end of the study area (MP 222: U.S. 285/Co Road 64, Bailey) to 20,800 vehicles at the northern end (MP 235: U.S. 285/Foxton Road) (Colorado Department of Transportation, 2006 AADT). These volumes are expected to increase to 9,000-40,000 vehicles over the next 20 years. Four-strand barbed wire fence borders both sides of the highway ROW throughout the study area and no median or shoulder barriers are present along this stretch of highway.

Table 9 provides a list of the physical and structural data for U.S. 285 between MP 222 (Bailey) to MP 235.2 (Foxton Road). At the start of the pre-construction monitoring, only one existing structure, the Deer Creek span bridge, provided a potential movement route for larger ungulate species. The Green Valley Grill underpass was constructed in the impact site during monitoring. Two structures, the Deer Creek bridge and Roland Gulch pipe, contained water flow through the structure. In the spring, Deer Creek had high velocity and there was no terrestrial passage through the structure. During the summer months, the flow of Deer Creek decreased dramatically, but water pooled inside the structure and no terrestrial passage was provided. The Roland Gulch galvanized pipe culvert had a small terrestrial passage on the south side of the structure, but this passage was typically less then 1 foot in width. Stream flow patterns mirrored those of Deer Creek, with peak flow occurring between March-June and pooling of water during the remainder of the year. All of the structures had some sort of vegetative cover leading up to the entrances. The fill slope at MP 233.1 had the greatest amount of cover greater than 1m in height leading up to the roadway.

Table 9. Physical and structural properties along U.S. 285, Conifer-Bailey study site. Due to the length of this site, identified locations are only between mileposts 225-227 and 233-235.

Milepost	*Description*	*Site Name*	*Length*	*Width*	*Height*	*Openness* [a]	*% Veg Cover* [b]	*Water* [c]
225.3	Deer Creek span	Control Site 1	40	15	8	3	5,2	Y, 0
226.4	Roland Gulch pipe	Control Site 2	65	8	8	0.98	5,3	Y, 1
233.1	Fill Slope	Impact Site 1	~650		~25		5,5	N
233.6	Green Valley Grill wildlife underpass[d]	Impact Site 2	120	28	14	3.27	4.5,4.5	N

[a] openness is calculated as underpass (width x height)/length

[b] % category of vegetated cover within a 100m radius of the underpass entrance (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%); value is an average of % vegetated cover surrounding each underpass entrance with the first value being vegetative cover <1m in height and the second value being >1m in height

[c] indicates whether structure contains water and the percent category of terrestrial passage through the structure (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%)

[d] at the beginning of the study this location had a galvanized pipe culvert less than 3 ft in diameter; new structure was replaced between April-October 2006

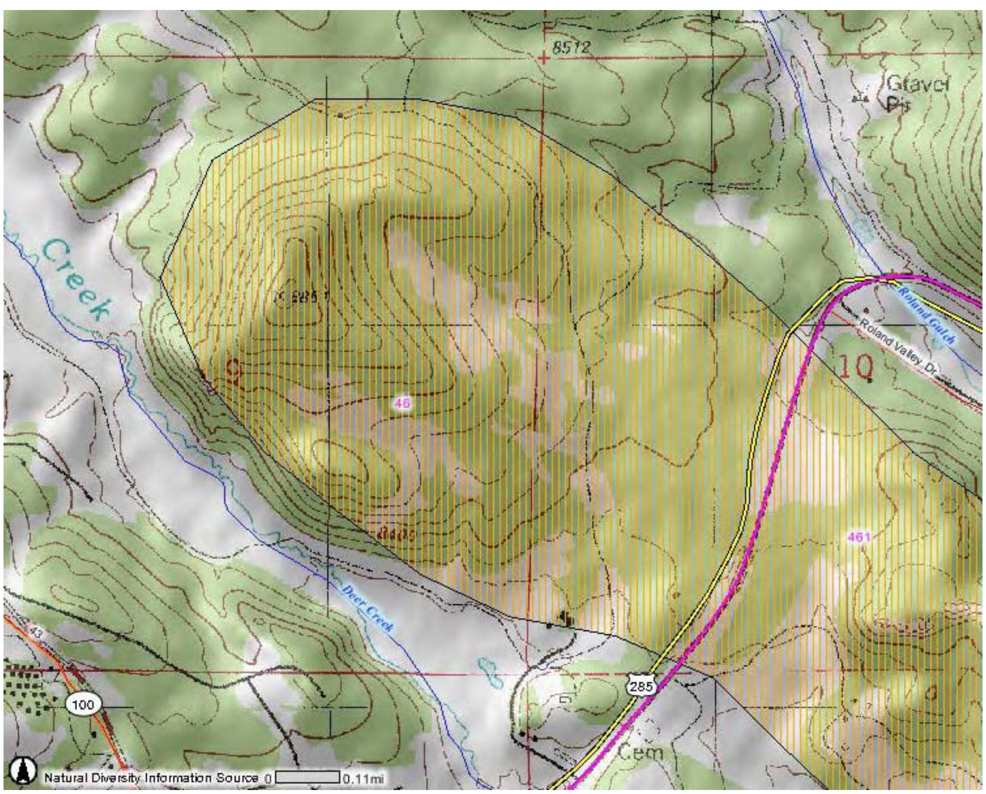
Large mammal distribution along U.S. 285

The portion of U.S. 285 in this study area travels through mule deer summer and winter range. Severe winter range occurs to the south and east of the roadway between Bailey and Shaffers Crossing. There is also a mule deer winter concentration area just south of Pine Junction along the Pine Gulch drainage. This area is bounded to the west by Roland Gulch and to the east by Elk Creek. In addition, the portion of US 285 between Bailey and Pine Junction and between Gooseberry Gulch (just north of Elk Creek) and Conifer has been identified by the Colorado Division of Wildlife (CDOW) as an area where mule deer movements traditionally cross the road (CDOW 2007).

This stretch of U.S. 285 also travels through elk summer and winter range. Severe winter range occurs in two general areas: 1) the north and west side of the roadway (along the Deer Creek and Roland Gulch drainages) and 2) the south and east side of the roadway (along the Pine Gulch drainage between Roland Gulch and Elk Creek). These two locales are also identified as winter concentration areas; a summer concentration area occurs in the Elk Creek headwaters just north of Shaffers Crossing, along the southern slopes of Black Mountain. Three elk calving areas also occur in the vicinity of the study area, including two areas south of Conifer along the Kennedy Gulch and Last Resort Creek drainages and a third area along the Deer Creek drainage north and west of where it crosses U.S. 285. In addition, the portion of US 285 between Crow Hill (just south of Deer Creek) and Shaffers Crossing has been identified by CDOW as an area where elk movements traditionally cross the road. Two elk migration routes are identified in this area: 1) an area between Deer Creek and Roland Gulch and 2) an area immediately north of Shaffers Crossing along the Elk Creek drainage (Figure 13; CDOW 2007).

Black bear and mountain lion habitat also occur along this stretch of road, and this area has been identified by CDOW as a human conflict area. A bear-human conflict area is defined as an area where two or more confirmed black bear complaints per season were received which resulted in a CDOW investigation, damage to persons or property (cabins, tents, vehicles, etc), and/or the removal of the problem bear(s). This does not include damage caused by bears to livestock. A mountain lion-human conflict area is defined as an area where there have been incidents between humans and mountain lions that may have serious results, including an attack on a human, predation on domestic pets, or depredation on livestock held in close proximity to human habitation (CDOW 2007). Two black bear human conflict areas occur along this stretch of U.S. 285: 1) an area between Crow Hill and Pine Junction, including the Deer Creek and Roland Gulch drainages, 2) area just north of Shaffers Crossing between Gooseberry Gulch and West Resort Creek. The first area described above is also a black bear summer concentration area. Three mountain lion human conflict area occur within the study area, including: 1) the Crow Hill vicinity, 2) an area north and east of Pine Junction, and 3) the portion of U.S. 285 north and east of Shaffers Crossing. Other medium-bodied mammals, such as coyotes, bobcats, and red fox, are common within the study area.

a)



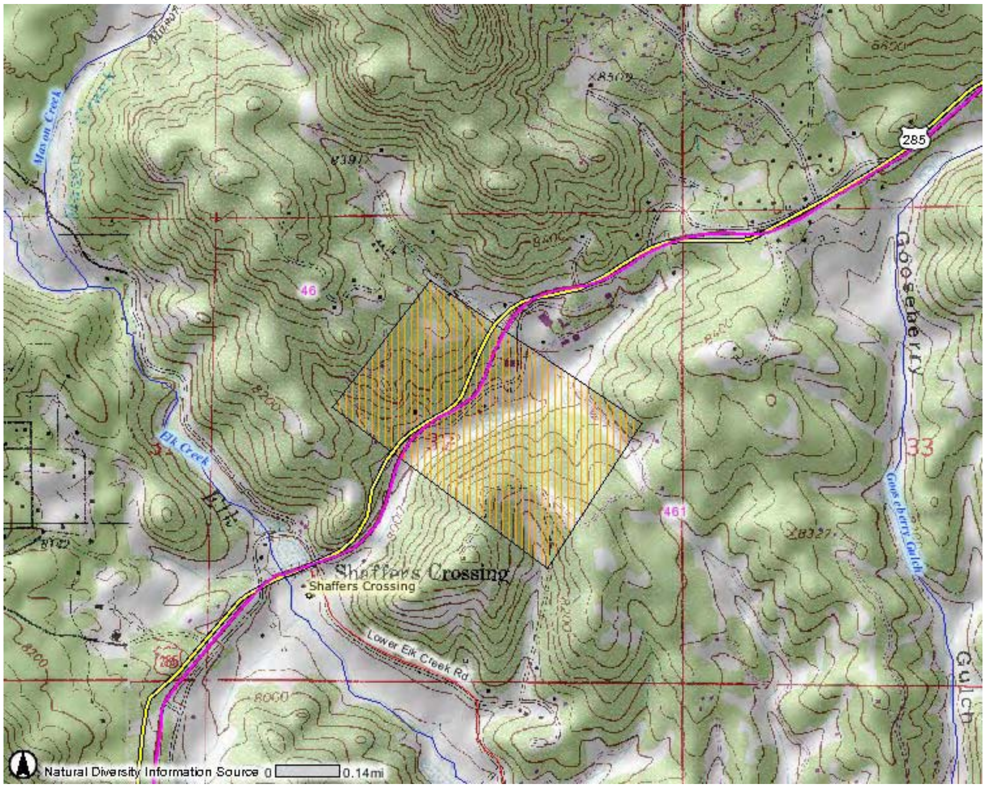
b) 

Figure 13. Elk migration corridors (yellow shading) across U.S. 285, Conifer-Bailey. Data obtained from CDOW Natural Diversity Information Source.

Animal-vehicle collisions

Deer and elk AVCs are recorded along this segment of U.S. 285 (Colorado State Patrol, 1993-2003; Figure 14). Mule deer are the most common species identified in association with vehicle collisions (48 reported AVCs). These collisions are distributed along the entire stretch of U.S. 285, although the northern portion of the study area has a higher rate of collisions. Within a 2-mile stretch of road between MP 233.5-235.5, twenty-two deer were reported in AVCs. Reported elk collisions were also more common in the northern portion of the study area, with 16 incidents occurring between MP 233.5-235.5.

The areas of highest reported AVCs/mile occurred in the northern portion of the study area, specifically, north of MP 233.5, which is just north of the intersection with Richmond Hill Road and the location of the Green Valley Grill wildlife underpass that was constructed during this project (MP 233: 30 AVCs/mile; MP 234: 33 AVC/mile; MP 235: 30 AVCs/mile). Smaller peaks in AVCs occurred around Wisp Creek (MP 228) and Elk Creek/Shaffers Crossing (MP 231).

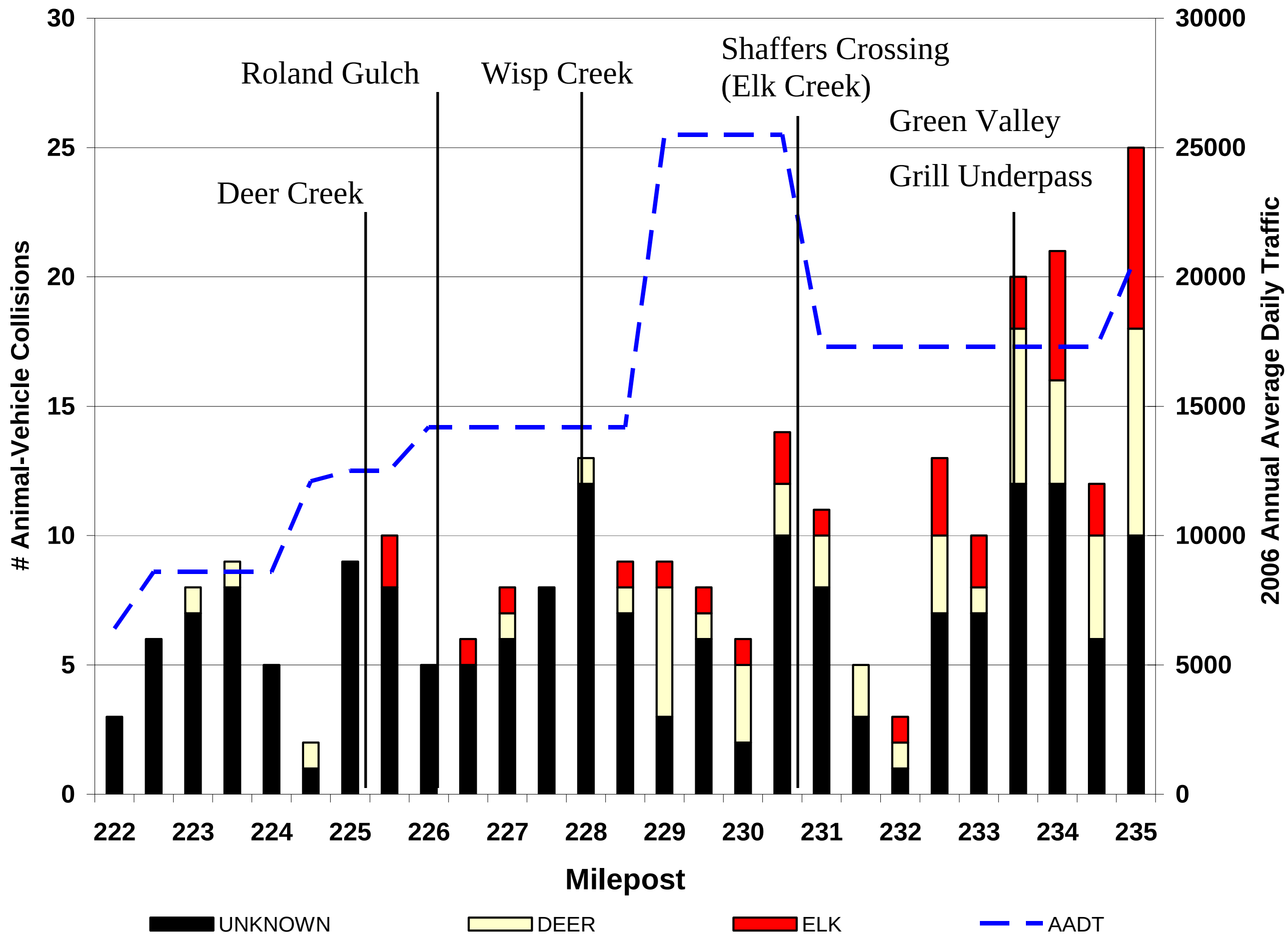


Figure 14. Reported number of animal-vehicle collisions/milepost (1993-2003) and 2006 average annual daily traffic volume (AADT) for U.S. 285, Conifer-Bailey study site.

Impact site

The impact site for this study area is between MP 233-234.5. The southern boundary (MP 233) is at the western end of a north-south running canyon, which bisects U.S. 285 0.7 km south of its intersection with Richmond Hill Road. The northern boundary (MP 234.5) is at the intersection of U.S. 285 and Wagon Trail.

Three locations were monitored at the impact site:

- Impact Site 1: MP 233.1, a large north-south drainage that is bisected by U.S. 285 approximately 0.5 miles south of its intersection with Richmond Hill Road
- Impact Site 2: MP 233.6, location of the newly installed Green Valley Grill wildlife underpass
- Impact Site 3: MP 234.4, a small ridgeline between U.S. 285 and Old U.S. 285

Figures 15 (aerial image) and 16 (schematic diagram) show the locations of the impact site monitoring stations. Figure 15 provides detail of the positioning of the camera stations relative to the surrounding habitat, and GPS coordinates of each station are provided in Appendix B.1. Impact Site 1 had two cameras (one roadside camera and one approach camera) on the western side of the highway. Cameras were not placed on the eastern side of the highway due to ongoing construction activities (see *Monitoring Schedule* section below). Impact Site 2 consisted of four camera stations placed along a transect perpendicular to the highway. Two of these cameras were located at approaches on both the east and west side of the highway and two cameras were placed at opposing entrances to a small 2 ft diameter metal pipe culvert. The location of this culvert was planned for the Green Valley Grill underpass designed to provide movement for a variety of larger-bodied wildlife species, particularly elk and mule deer. This underpass was constructed during the course of this study. Impact Site 3 consisted of a single camera located at the western approach to the highway at MP 234.4. Representative site photos are shown in Appendix B.2.

Control site

The control site is located approximately 6 miles south of the impact site between MP 225-226.5 and includes two locations where underpasses will be upgraded in future years: the Deer Creek bridge and Roland Gulch culvert. The southern boundary (MP 225) is just south of the Deer Creek bridge at the U.S. 285/Rosalie Road intersection. The northern boundary (MP 226.5) is at the northern edge of Roland Gulch, just north of the intersection of U.S. 285 and Roland Valley Drive. Two locations were monitored at the control site:

- Control Site 1: MP 225.3, Deer Creek
- Control Site 2: MP 226.4, Roland Gulch

Figures 15 (aerial images) and 16 (schematic diagram) show the locations of the impact site monitoring stations. Figure 15 provides detail of the positioning of the camera stations relative to the surrounding habitat, and GPS coordinates of each station are provided in Appendix B.1. Control Site 1 consisted of four camera stations placed along a transect perpendicular to the highway. Two of these cameras were located at approaches on both the east and west side of the highway and two cameras were placed at opposing entrances to the Deer Creek bridge. Control Site 2 also consisted of four camera stations placed along a transect perpendicular to the highway. Two of these cameras were located at approaches on both the east and west side of the highway and two cameras were placed at opposing entrances to the 8 ft diameter metal pipe culvert. Although these two structures were not be redesigned during the current phase of construction in the impact site, they are slated for improvement during future phases of the U.S. 285 highway improvement project between Conifer and Bailey. While the dimensions of the proposed Deer Creek bridge structure have not been presented, the Roland Gulch culvert will be replaced by a bridge approximately 600 ft in width and approximately 30-40 ft in height. Although it is unknown as to when this phase of highway construction will begin, monitoring these sites will provide valuable baseline data as to the rate of wildlife movement through and surrounding the existing underpass locations. Representative site photos are shown in Appendix B.2.

a) Impact site overview and transects (no transect at Impact Site 3)

b) Control site overview and transects

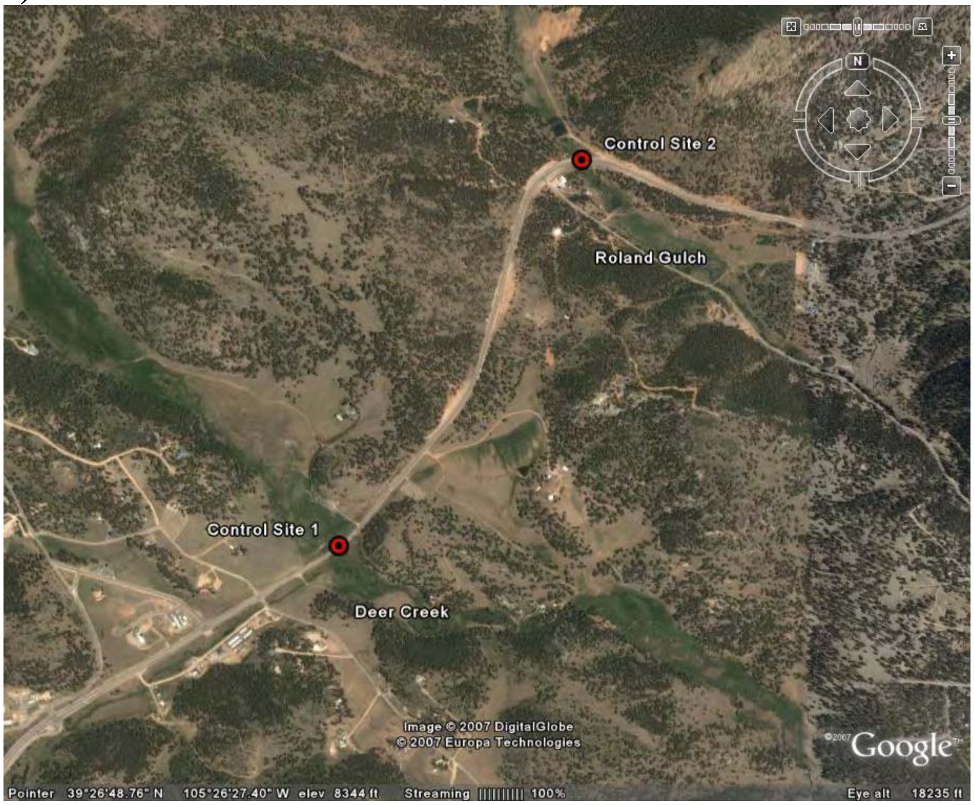


Figure 15. Aerial images of U.S. 285 Conifer-Bailey a) impact site and b) control site, including a site overview and transect close-up. Station labels include: west approach (WA), west underpass (WU), east underpass (EU), and east approach (EA).

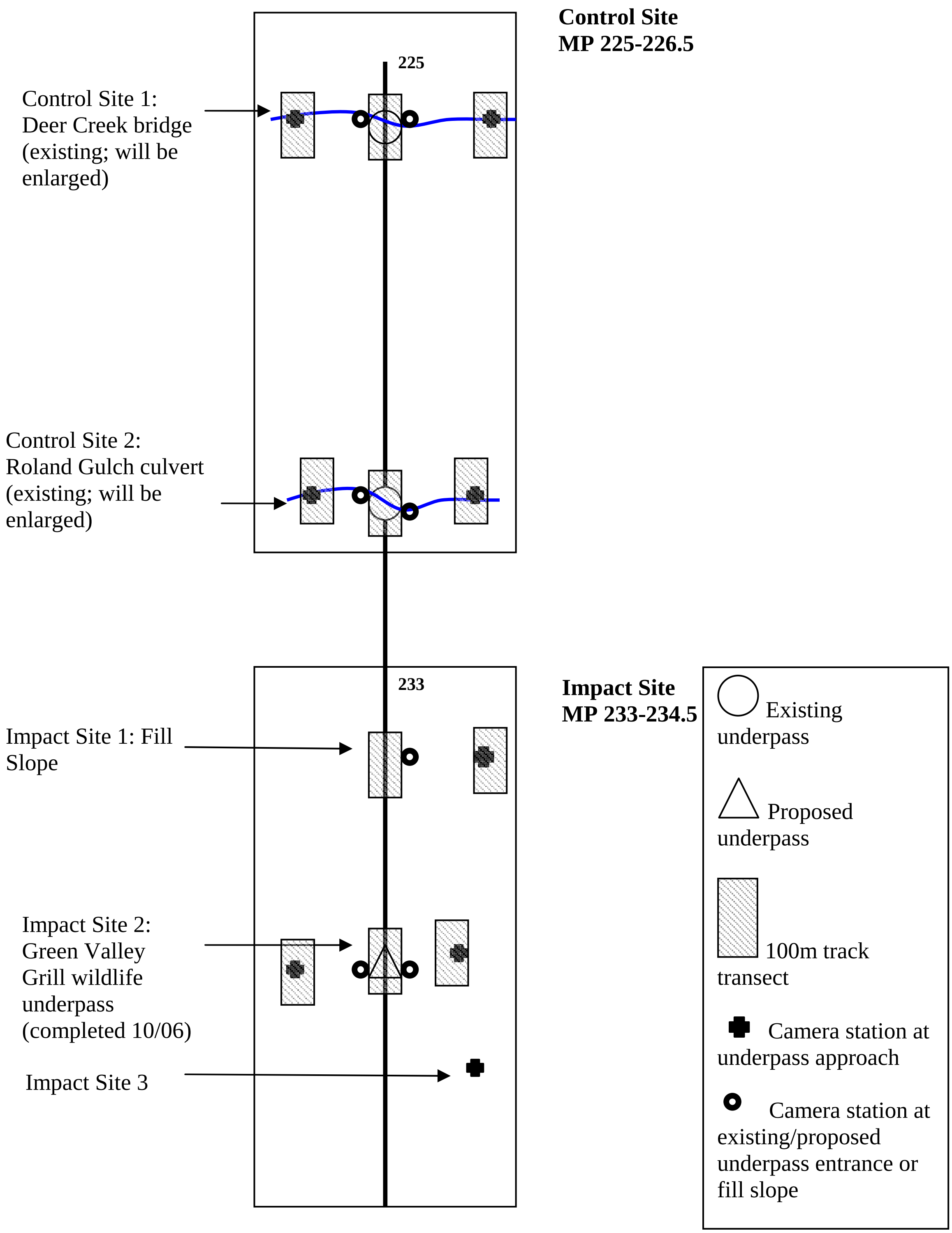


Figure 16. Schematic diagram of U.S. 285 Conifer-Bailey monitoring stations.

Construction activities and monitoring schedule

The Conifer-Bailey site was unique from the other two study sites in that the first phase of construction was slated to occur only five months from when the CDOT Study Panel selected the site. As such, this only allowed for four months of pre-construction (or 'before') data. Therefore, there was a limited amount of data collected for the 'before' portion of the study, since monitoring at the impact site only occurred between early January 2006-April 2006. Between the months of April – October 2006, monitoring was limited within the impact site due to ongoing construction activities; data on the control sites were collected through the summer of 2006. With the completion of the Green Valley Grill wildlife underpass in October 2006, a full transect was again established at the underpass location, including the installation of remotely-triggered video cameras to monitor wildlife behavior both through and surrounding the entrances of the structure. Limited construction occurred through November 2006 and ceased completely until April 2007 (although no construction activities occurred in the immediate vicinity of the underpass).

At the beginning of this study (January 2006), due to the limited number of cameras, sampling was confined to the impact site to gather as much data as possible along the stretch of U.S. 285 scheduled to be constructed. Therefore, the six cameras were distributed between the Impact Site 2 transect (4 cameras), the Impact Site 1 transect (1 camera at the roadside station), and the Control Site 1 transect (1 camera at the east approach station). The two cameras positioned at opposing entrances to the 2 ft diameter pipe culvert (future Green Valley Grill wildlife underpass) at the Impact Site 2 transect recorded 57 sampling days prior to construction. The two cameras positioned at the two approach stations monitored the same number of sampling days as the underpass cameras, plus an additional 28 days during construction (85 days total). These cameras were initially out of the immediate construction activity area, thus were able to continue monitoring through construction activities. The east side of the Impact Site 1 transect was never monitored due to construction activities; intensive grading occurred along the east side of the highway (northbound lane) to extend a large fill slope to the eastern ROW along U.S. 285. Therefore, a roadside and approach camera could not physically be established on the east side of the highway.

With the addition of cameras during summer 2006, 4-camera station transects were established at Control Site 1 and 2 and at Impact Site 2 (after construction activities ceased in November 2006). The newly-constructed fill slope at Impact Site 1 negated an opportunity to establish an approach and roadside station on the east side of the highway, as the toe of the fill slope (the location of the roadside camera) occurred on the ROW line, thus preventing the establishment of an approach monitoring station (which would have been on private property).

Unlike the Wolf Creek Pass and Durango-Bayfield sites, the Conifer-Bailey site provides insight into the type of analysis that will be conducted for pre- and post-construction data. The limited number of sampling days prior to construction is not desirable due to the short time period between the selection of the site and construction, and there is no seasonal data during the pre-construction phase (as opposed to the other two study sites). Nonetheless, we provide results of preliminary BACI analyses for Conifer-Bailey to provide an example of the types of analyses that could be conducted at the other two study sites once the respective highway projects are completed and post-construction data has been gathered.

3.4.2 U.S. 160: Wolf Creek Pass

Roadway characteristics and structural data

The portion of U.S. 160 west of South Fork is a rural, mountainous 2-lane highway, with tight curves and limited shoulder widths. The highway is subject to Average Annual Daily Traffic flows (AADT) of 2,500 vehicles (Colorado Department of Transportation, 2006 AADT). There are significant seasonal variations in traffic volume across seasons, with a peak-season (June – August) traffic volume of 3,500 vehicles/day; off-season traffic volume was recorded at 800 vehicles/day (ERO Resources Corporation 2001). These volumes are expected to increase to 3,200 vehicles over the next 20 years.

Portions of the highway are bordered by four-strand barbed wire fence and there are several portions of the roadway that are bounded by steep cliffs and vertical rock faces to the north and the South Fork Rio Grande River to the south.

Table 10 provides a list of the physical and structural data for U.S. 160 between MP 174.5 (Big Meadows Road) to MP 180 (east of Decker Creek). The majority of structures along this stretch transport water and, for most of the year, are completely inundated, providing no terrestrial route under the roadway. Furthermore, this study site is subjected to high levels of snowpack, sometimes in excess of 3 ft, thus preventing animals from negotiating the structure during winter and spring months due to a restricted clearance at the entrance to the structure or, when combined with snowplowing activities, the complete burial of structure (Tabler & Associates 2001). All of the structures have a moderate to high amount of low vegetative cover leading to the structures; the Park Creek Campground and Decker Creek culverts have the greatest amount of tall shrub/tree cover (> 1m) surrounding the underpass entrances.

Table 10. Physical and structural properties along U.S. 160, Wolf Creek Pass study site.

Milepost	*Description*	*Site Name*	*Length*	*Width*	*Height*	*Openness* [a]	*% Veg Cover* [b]	*Water* [c]
175.5	Lake Fork culvert	Control Site 1	92	7.5	6	0.49	3,2.5	Y, 0
178.3	Park Ck Cmpgd culvert	Impact Site 2	50	2.5	2.5	0.13	5,3.5	Y, 0
178.9	Temporary lynx structure	Impact Site 3	121	5’10”	4’2”	0.20	4.5,3	N
179.4	Decker Creek culvert	Impact Site 4	82	9.5	5	0.58	3.5,5	Y, 0

[a] openness is calculated as underpass (width x height)/length

[b] % category of vegetated cover within a 100m radius of the underpass entrance (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%); value is an average of % vegetated cover surrounding each underpass entrance with the first value being vegetative cover <1m in height and the second value being >1m in height

[c] indicates whether structure contains water and the percent category of terrestrial passage through the structure (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%)

Large mammal distribution along U.S. 160

The portion of U.S. 160 in this study area travels through mule deer summer and winter range. Goodrich Creek, which is the next drainage east of Decker Creek, serves as the general dividing line between these two ranges. Winter range is located north and east (downvalley) of this drainage, with severe winter range concentrated north and east of South Fork. Summer range occurs west of Goodrich Creek, in the upper portions of the South Fork Rio Grande valley (CDOW 2007).

This stretch of U.S. 285 also travels through elk summer and winter range. Park Creek, which meets the South Fork Rio CDGrande River from the southwest at the Park Creek Campground, serves as the general dividing line between these two ranges. Winter range occurs north and east (downvalley) of Park Creek, and a winter concentration area is concentrated along the lower South Fork Rio Grande valley downstream of Goodrich Creek. Severe winter range occurs north and east of South Fork. Summer range occurs west of Park Creek, in the upper portions of the South Fork Rio Grande. Summer concentration areas occur in the upper drainages of Decker and Lake Creeks on Metroz Mountain. In addition, the portion of US 160 between Park Creek Campground and Goodrich Creek has been identified by CDOW as an area where elk movements traditionally cross the road (CDOW 2007).

Black bear, moose, and mountain lion habitat also occur along this stretch of road. The lower slopes of the South Fork Rio Grande valley downstream of Lake Creek are identified as a black bear fall concentration area. This area is defined as that portion of the overall range occupied from August 15 until September 30 for the purpose of ingesting large quantities of mast and berries to establish fat reserves for the winter hibernation period (CDOW 2007). The entire study area is contained within moose summer and winter range.

Other medium-bodied mammals, such as coyotes, bobcats, and red fox, are common within the study area. In 1999, the area north of this study site experienced efforts to reintroduce Canada lynx to Colorado. Since then, the reintroduced lynx population has expanded its range to take up areas north and south of U.S. 160. A detailed synthesis of lynx responses to roadways throughout Colorado, and their interactions with this stretch of U.S. 160, is provided in Section 4.0.

Animal-vehicle collisions

Only one mule deer, in addition to 5 individuals where species information was not recorded, were reported in AVCs along this segment of U.S. 160 (Colorado State Patrol, 1993-2003; Figure 17). Low AVC rates are likely due to slower traffic speeds, lower traffic volumes, and lower densities of wildlife species.

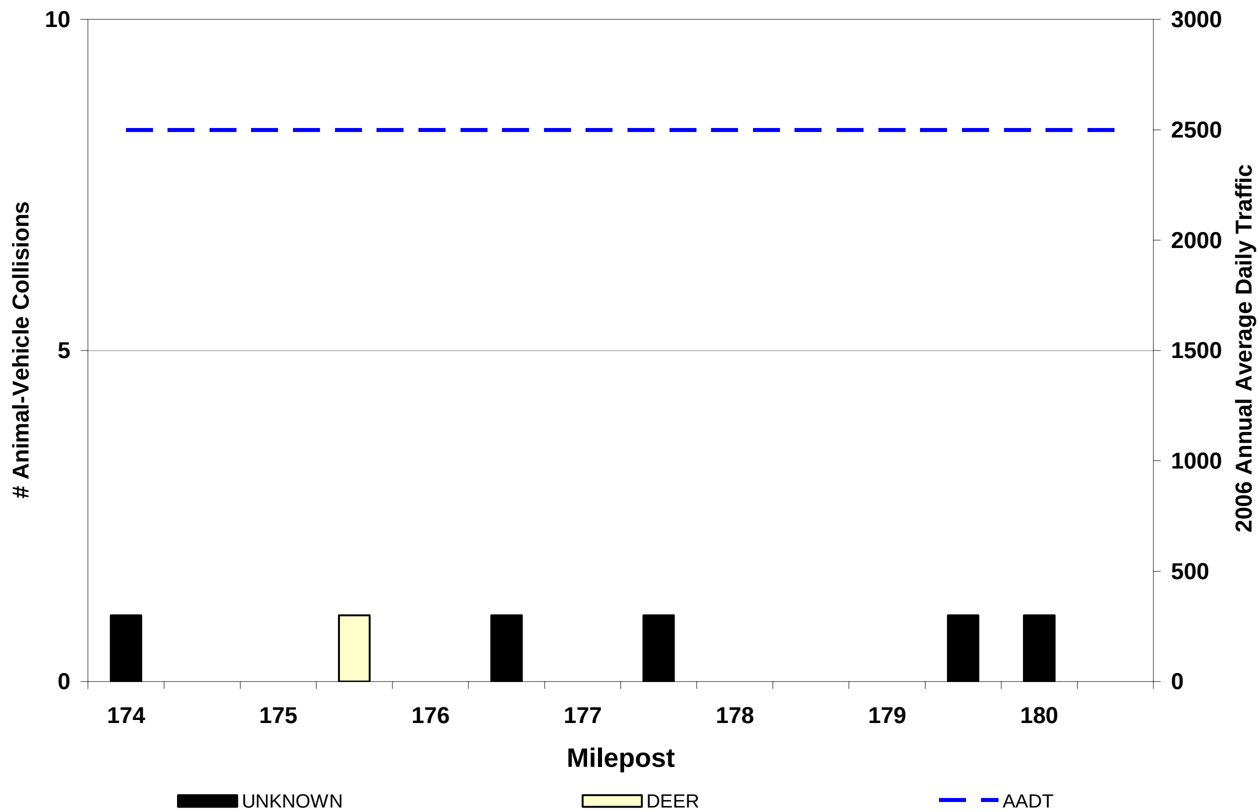


Figure 17. Reported number of animal-vehicle collisions/milepost (1993-2003) and 2006 average annual daily traffic volume for U.S. 160, Wolf Creek Pass study site.

Impact site

The impact site for this study area occurs between MP 178-179.5. The western boundary is approximately 0.3 mi west of the entrance to Park Creek Campground at MP 178. The eastern boundary is immediately east of Decker Creek at MP 179.5. Four locations were monitored at the impact site:

- Impact Site 1: MP 178.0, a powerline corridor on the west side of U.S. 160 0.3 mi west of the Park Creek Campground
- Impact Site 2: MP 178.3, Park Creek Campground
- Impact Site 3: MP 178.9, Lynx Crossing F (temporary lynx crossing structure)
- Impact Site 4: MP 179.4, Lynx Crossing H (immediately west of Decker Creek)

Figures 18 (aerial images) and 19 (schematic diagram) show the locations of the impact site monitoring stations. Figure 18 provides detail of the positioning of the camera stations relative to the surrounding habitat, and GPS coordinates of each station are provided in Appendix B.3. Impact Site 1 had one camera positioned along a powerline corridor on the western side of the highway.

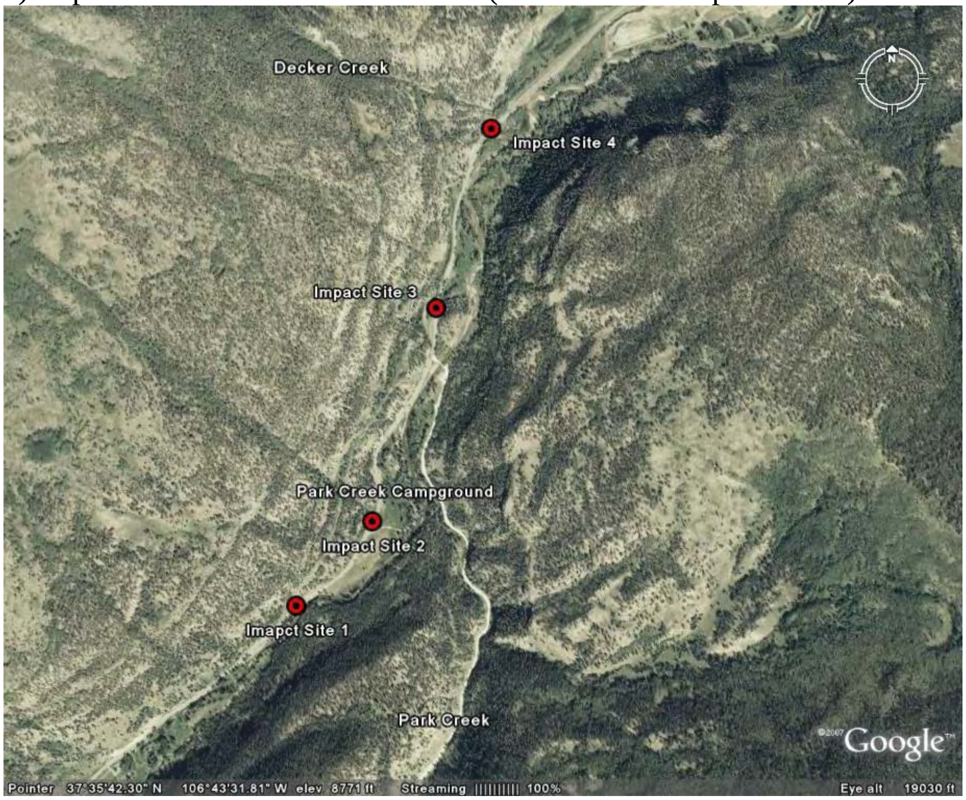
Impact Site 2 consisted of four camera stations placed along a transect perpendicular to the highway. Two of these cameras were located at approaches on both the east and west side of the highway and two cameras were placed at opposing entrances to a small 2.5 ft diameter metal pipe culvert. This culvert drains an unnamed tributary at the Park Creek Campground, which had extremely high flows during the spring and early summer months, providing no terrestrial passage for wildlife. During late summer, the creek had dried and passage was possible, but due to the small diameter of the structure (less than 3 ft) use by target species was unlikely. Impact Site 3 consisted of three camera stations placed along a transect perpendicular to the highway, with the midpoint station represented by the temporary lynx crossing structure (Lynx Crossing F). A single camera was placed inside this structure in May 2005 to monitor wildlife movement through the structure as part of the Colorado State University Wildlife Underpass (Lynx) Monitoring Research Study (see Section 4). Two additional cameras were stationed at approach locations on either side of the underpass. Impact Site 4 consisted of four camera stations placed along a transect perpendicular to the highway at Lynx Crossing H. The proposed location for Lynx Crossing H is immediately west of an existing structure that carries Decker Creek under U.S. 160. Since the Decker Creek structure will not be designed to accommodate wildlife movement (there is no terrestrial route through the existing structure), we focused monitoring in the area immediately west of this culvert, where the underpass constructed specifically for lynx movement will be placed. Two cameras were located at approaches to both the east and west side of the highway and two cameras were placed on opposing fill slopes where the proposed structure would be installed.

In April 2006, an additional segment of U.S. 160 was added to the construction phase incorporating the stretch of roadway described above. This stretch of highway was initially included in the Control Site stretch and includes the area immediately west of the CDOT chain station (MP 176.58-176.70). Included in this short stretch of roadway are three proposed wildlife underpasses: Lynx Crossings B1, B2, and B3. These structures are slated to undergo construction the same time as the impact segment of this study area. Therefore, we monitored this short highway segment and treat it as an "impact" monitoring site:

- Impact Site 5: MP 176.6, Lynx Crossings B1, B2, and B3 (immediately west of the CDOT chain station)

These three structures will each measure 3 ft 11 in high x 5 ft 11 in wide and range in length from 100 to 115 ft. This site consisted of four camera stations placed along a transect perpendicular to the highway. The proposed location for Lynx Crossing B is immediately west of the CDOT chain station. Two cameras were located at approaches to both the east and west side of the highway and two cameras were placed on opposing fill slopes where the proposed structure would be installed. Representative site photos are shown in Appendix B.4.

a) Impact site overview and transects (no transect at Impact Site 1)




Impact Site 3SA
Impact Site 3U
Impact Site 3NA
Park Creek Road
©2007 Google
Pointer 37°35'51.37" N 106°43'37.61" W elev 8539 ft Streaming |||||||||| 100%
Eye alt 9807 ft


Decker Creek
Impact Site 4NA
Impact Site 4 NU
Impact Site 4SU
Impact Site 4SA
©2007 Google
Pointer 37°36'17.10" N 106°43'30.97" W elev 8481 ft Streaming |||||||||| 100%
Eye alt 9696 ft

b) Control site overview and transects, including Impact Site 5

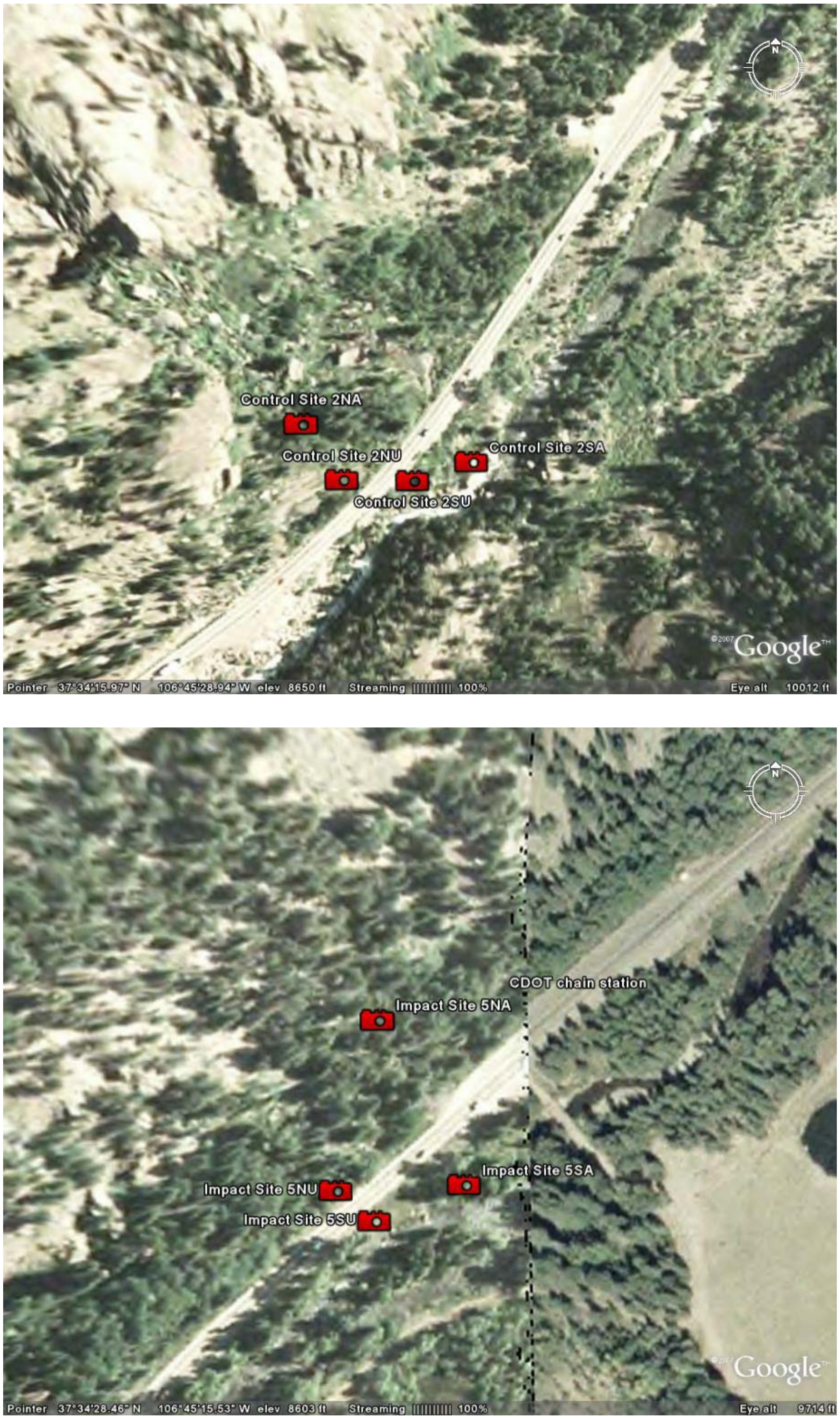


Figure 18. Aerial image of U.S. 160 Wolf Creek Pass a) impact site and b) control site, including a site overview and transect close-up. Station labels include: north approach (NA), north underpass (NU), south underpass (SU), and south approach (SA).

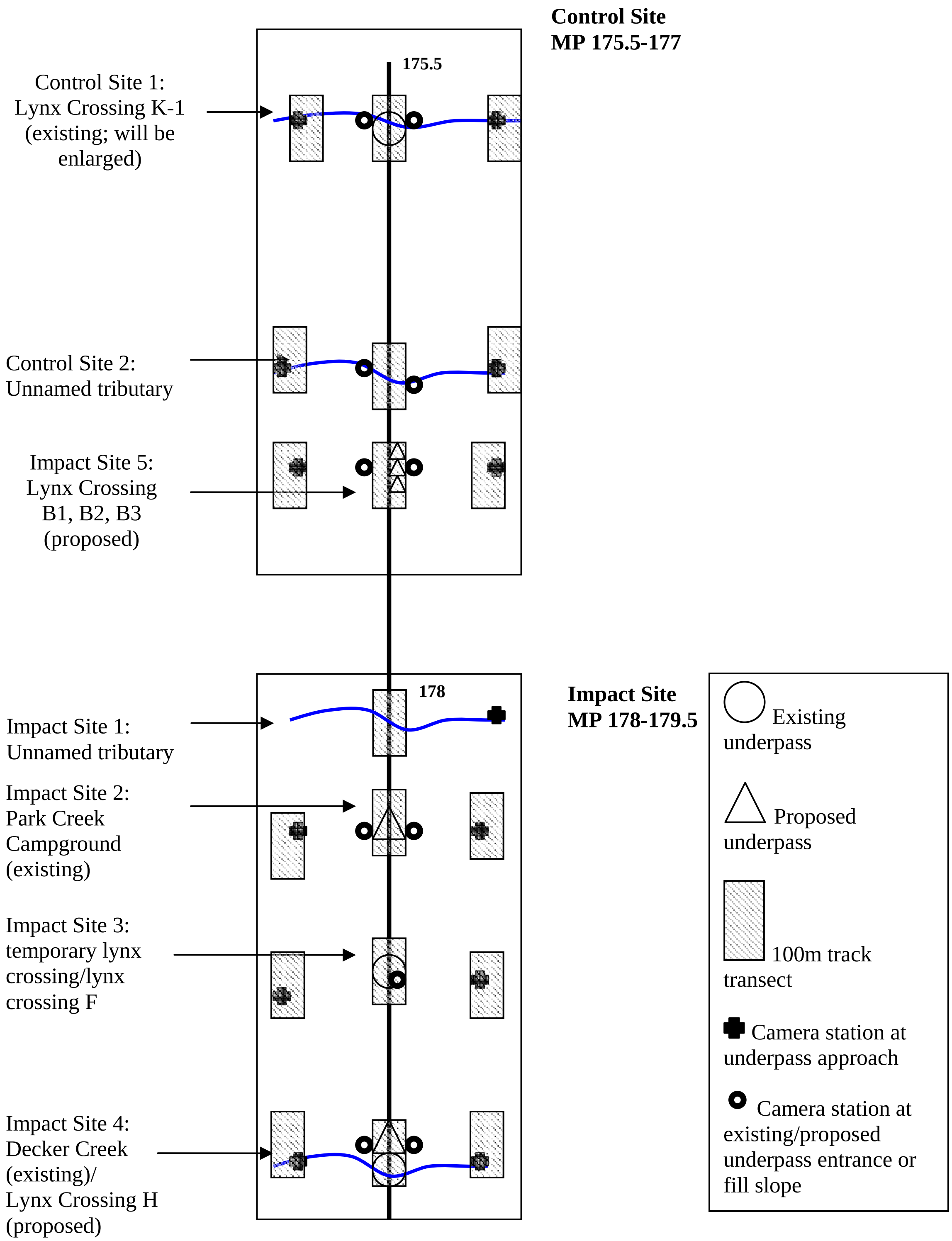


Figure 19. Schematic diagram of U.S. 160 Wolf Creek Pass monitoring stations.

Control site

Lynx Crossings B1, B2, and B3, described in the *Impact Site* section above, were initially included in the control site, but recent changes to the construction schedule now have this stretch of highway slated for construction with the impact site. As such, the boundaries of the control site are reduced to MP 175.5-176.5. The western boundary (MP 175.5) is just west of Lake Fork, where there is a large parking area on both sides of the roadway. This site was also the staging area for the earlier phase of construction (which commenced in summer 2006) between Lake Fork and Big Meadows Road to the west. The eastern boundary (MP 176.5) is at the western end of the CDOT chain station, immediately west of the added segment to undergo construction with the impact site. Two locations were monitored at the control site:

- Control Site 1: MP 175.5, Lynx Crossing K (Lake Fork)
- Control Site 2: MP 176.0, an unnamed tributary that drains a small side canyon west of the roadway

Figures 18 (aerial images) and 19 (schematic diagram) show the locations of the impact site monitoring stations. Figure 18 provides detail of the positioning of the camera stations relative to the surrounding habitat, and GPS coordinates of each station are provided in Appendix B.3. Control Site 1 consisted of four camera stations placed along a transect perpendicular to the highway, with the midpoint represented by the Lake Fork culvert (Lynx Crossing K). Two of these cameras were located at approaches on both the east and west side of the highway and two cameras were placed at opposing entrances to the 7 ft 7 in wide x 6 ft high metal culvert. This culvert drains Lake Fork, which occupies the entire width of the structure, thus providing no terrestrial passage for wildlife. Although this structure will not be redesigned during the current phase of construction in the impact site, it is slated to be constructed during a future phase of the U.S. 160 improvement project east of Wolf Creek Pass (dates not yet determined). The structure will be a double concrete box culvert, with one box cell carrying Lake Fork and the other providing a terrestrial passage for wildlife. Each box will be 8 ft high x 10 ft wide x approximately 115 ft long. Thus, monitoring the structure at this location will provide valuable baseline data as to the rate of wildlife movement surrounding the existing underpass location. Control Site 2 consisted of four camera stations placed along a transect perpendicular to the highway at a point where a small tributary to the South Fork Rio Grande crosses the roadway. Cameras were established at two opposing approach locations and along the opposing shoulders of the highway. Representative site photos are shown in Appendix B.4.

Monitoring schedule

Since no construction activities occurred during the study, all of the data collected will be analyzed as the ‘before’ portion of the BACI analysis. At the beginning of this study (Spring 2006), due to the limited number of cameras, sampling was restricted to only six locations along this stretch of highway. With the addition of cameras during summer 2006, the 4-camera station transects were established at the impact and control sites described above. Impact Site 1 (one camera station) was not sampled after spring 2006, as the location it sampled was not part of any proposed mitigation activities. The remaining transects were sampled alternatively through the remainder of the study.

3.4.3 U.S. 160: Durango-Bayfield

Roadway Characteristics and Structural Data

The area surrounding U.S. 160 between Durango and Bayfield has experienced rapid population growth over the last 25 years. As such, traffic volume has increased in response to this rapid development and tourism has also contributed to increased traffic loads along highway corridor. The highway is subject to Average Annual Daily Traffic flows (AADT) ranging from 24,400 vehicles at the western end of the study area (MP 88: U.S. 160/U.S. 550 intersection) to 4,600 vehicles at the eastern end (MP 104: east of U.S. 160/ U.S. 160 Business intersection) (Colorado Department of Transportation, 2006 AADT). These volumes are expected to increase to 6,500-38,000 vehicles over the next 20 years.

Four-strand barbed wire fence borders both sides of the highway ROW throughout the study area and no median or shoulder barriers are present along this stretch of highway.

Table 11 provides a list of the structural data for the U.S. 160 between MP 92 (just east of the U.S. 160/SH 172 intersection) to MP 96.5 (just east of a long fill slope with 2 culverts). This is only a portion of the 16.2-mile stretch that is slated for improvement; wildlife fencing is proposed between MP 93.4-100 and will complement these proposed wildlife underpasses. Only one structure, the Florida River bridge, provides a potential movement route for larger ungulate species. However, the east bank contains rip-rap and is densely vegetated; the west bank provides an easier route underneath the structure. The Long Hollow structure frequently had running water passing through it, leaving no terrestrial passage through the structure. During the summer months, however, the flow decreased dramatically, although water pooled inside of the structure; some terrestrial passage was provided. All of the structures had some sort of vegetative cover leading up to the entrances. The Florida River bridge had the greatest amount of vegetative cover greater than 1m in height surrounding the bridge entrance. Several fill slopes were also present along this stretch of road. The largest of these was the fill slope at MP 93.2, which started on the western bank of the Florida River and rose to a height of 25 feet just east of the CR 222/CR223 intersection. The fill slope at MP 95.7 contained a small culvert less than 3” in diameter, although a camera monitored this structure as it is the site for a proposed larger structure as part of future improvements to this stretch of U.S. 160.

Table 11. Physical and structural properties along U.S. 160, Durango-Bayfield study site.

Milepost	*Description*	*Site Name*	*Length*	*Width*	*Height*	*Openness* [a]	*% Veg Cover* [b]	*Water* [c]
93.2	Fill slope	Impact Site 1	~1300		25			
93.7	Florida River bridge	Impact Site 2	32	98	11.5	35.2	5,5	Y, 3
94.4	Long Hollow	Impact Site 3	88.5	10’8”	7.5	0.92	5,1.5	Y, 0-2
94.6	Pioneer Irrigation Ditch		78	6.5	5	0.42	4.5,1	N
95.4	Brice Draw culvert		111.5	7’2”	7’2”	0.45	5,2	N
95.7	Fill slope	Control Site 1			10			
96	Fill slope with 2 culverts	Control Site 2	144	5’9”	5’9”	0.23	2.5	N
			150	7’2”	7’2”	0.34	1.5	N

[a] openness is calculated as underpass (width x height)/length

[b] % category of vegetated cover within a 100m radius of the underpass entrance (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%); value is an average of % vegetated cover surrounding each underpass entrance with the first value being vegetative cover <1m in height and the second value being >1m in height

[c] indicates whether structure contains water and the percent category of terrestrial passage through the structure (0: 0%; 1: < 10%; 2: 11-25%; 3: 26-50%; 4: 51-74%; 5: > 75%)

Large mammal distribution along U.S. 160

The portion of U.S. 160 in this study area travels through mule deer summer and winter range. Severe winter range and winter concentration area occurs along the entire stretch of U.S. 160 between Durango and Bayfield. In addition, the entire stretch of U.S. 160 within the study area has been identified by CDOW as an area where mule deer movements traditionally cross the road (CDOW 2007).

U.S. 160 also travels through elk winter range and is the southern boundary of elk summer range (Figure 20). The entire area is considered severe winter range and a winter concentration areas extends between Durango and Gem Village. The stretch of roadway west of the Florida River and between Dry Creek and Hartman Canyon (just west of Gem Village) has been identified by CDOW as an area where elk movements traditionally cross the road. One elk migration route occurs just east of the MP 96 fill slopes and extends east to Hartman Canyon; this route follows the Dry Creek drainage (Figure 13; CDOW 2007).

Black bear and mountain lion habitat also occur along this stretch of road. U.S. 160 east of the Florida River forms the southern boundary of black bear fall concentration area. Other medium-bodied mammals, such as coyotes, bobcats, and gray fox are common within the study area.

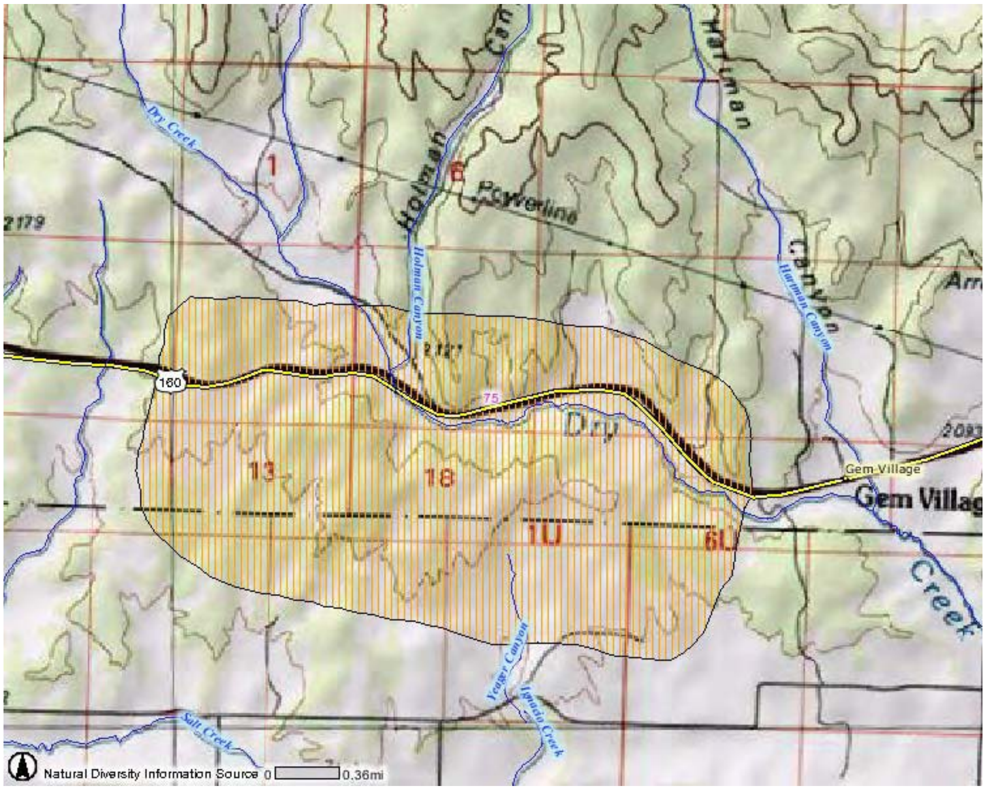


Figure 20. Elk migration corridor across U.S. 160, Durango-Bayfield. Data obtained from CDOW Natural Diversity Information Source.

Animal-Vehicle Collisions

This stretch of highway is subject to some of the highest AVC rates in the state and 27% of vehicle accidents involve collisions with wildlife (Colorado Department of Transportation 2006; Section 2). Mule deer are recorded in AVCs reported along this segment of U.S. 160 (Colorado State Patrol, 1993-2003; Figure 21); elk-vehicle collisions have also been reported within this stretch (Jon Holst, pers. comm.). These collisions are distributed along the entire stretch of U.S. 160, although certain mileposts had a higher level of collisions. Between MP 94.5-95.5, 18 mule deer were reported in vehicle collisions; 14 collisions were reported between MP 99.5-100.5. When including the roadkills that were not identified to species, the stretches of highway with the highest number of AVCs include MP 94.5-96 (48 AVCs) and MP 99-100.5 (40 AVCs).

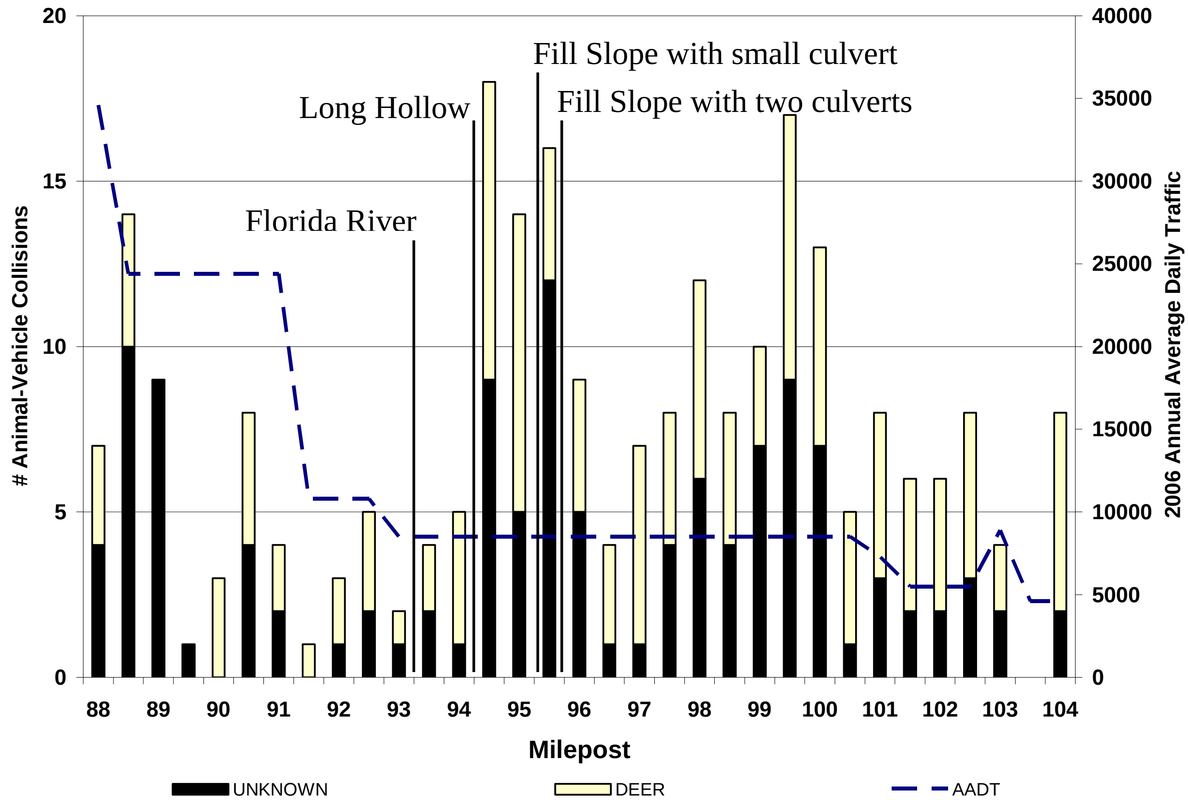


Figure 21. Reported number of animal-vehicle collisions/milepost (1993-2003) and 2006 average annual daily traffic volume for U.S. 160, Durango-Bayfield study site.

Impact Site

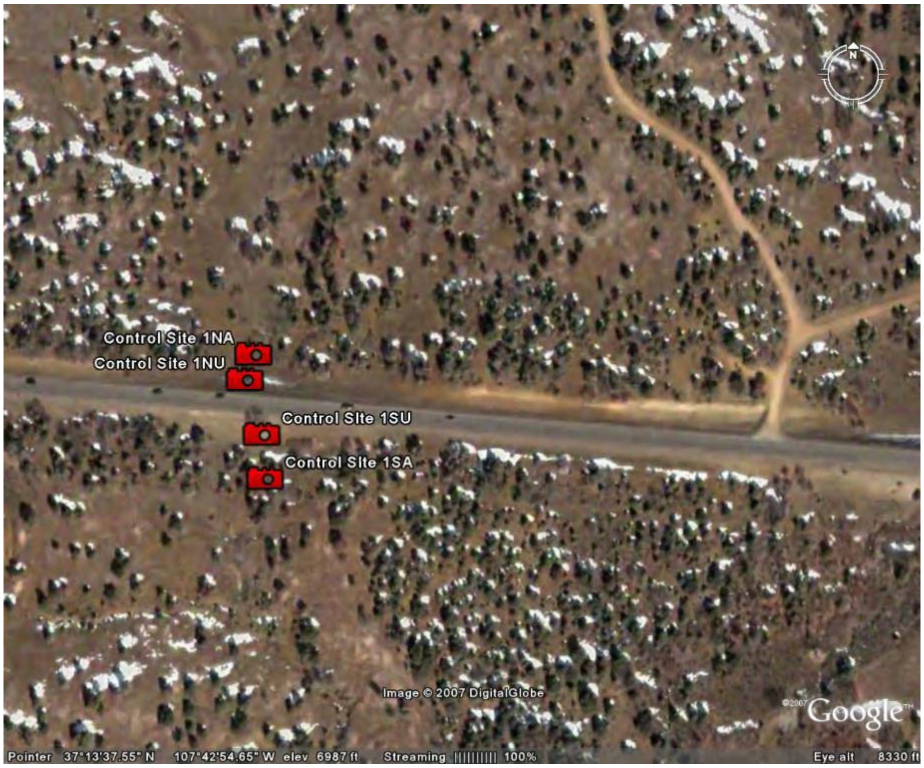
The impact site for this study area occurs between MP 93-94.5. The western boundary is just east of the U.S. 160 intersection with CR 222 and CR 223 at MP 93. The eastern boundary is immediately west of the Pioneer Irrigation Ditch at MP 94.5. Three locations were monitored at the impact site:

- Impact Site 1: MP 93.2, fill slope on western side of Florida River valley
- Impact Site 2: MP 93.7, Florida River
- Impact Site 2: MP 94.4, Long Hollow

Figures 22 (aerial images) and 23 (schematic diagram) show the locations of the impact site monitoring stations. Figure 22 provides detail of the positioning of the camera stations relative to the surrounding habitat, and GPS coordinates of each station are provided in Appendix B.5. Impact Site 1 consisted of a single camera positioned at the base of a long fill

a) Impact site overview and transects (no transect at Impact Site 1)

b) Control Site overview and transects



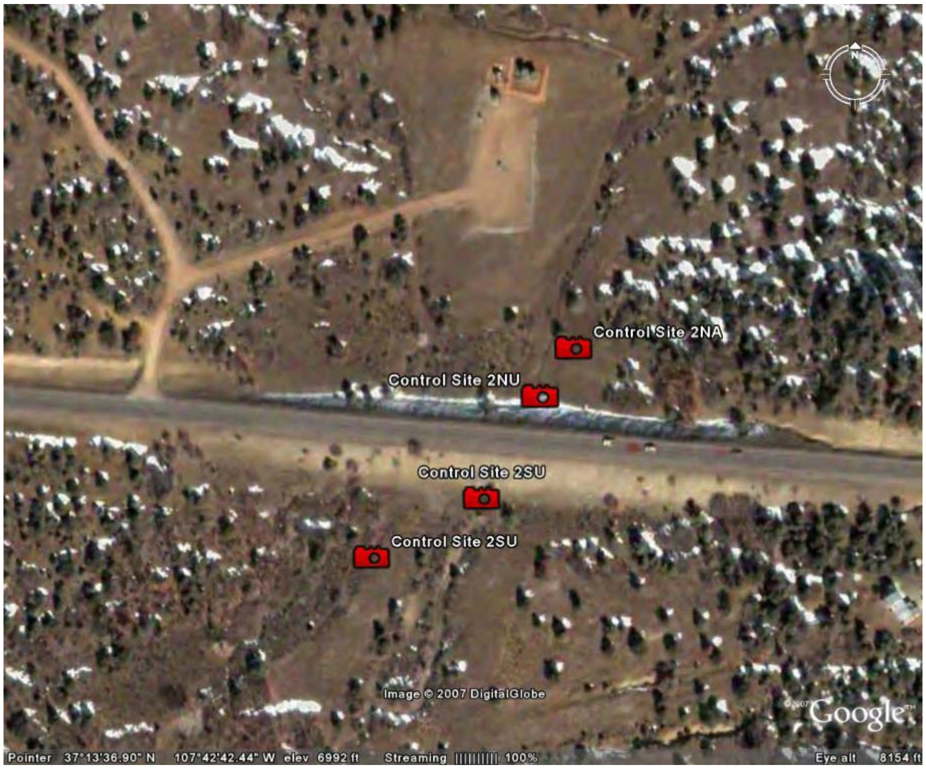


Figure 22. Aerial image of U.S. 160 Durango-Bayfield a) impact site and b) control site, including a site overview and transect close-up. Station labels include: north approach (NA), north underpass (NU), south underpass (SU), and south approach (SA).

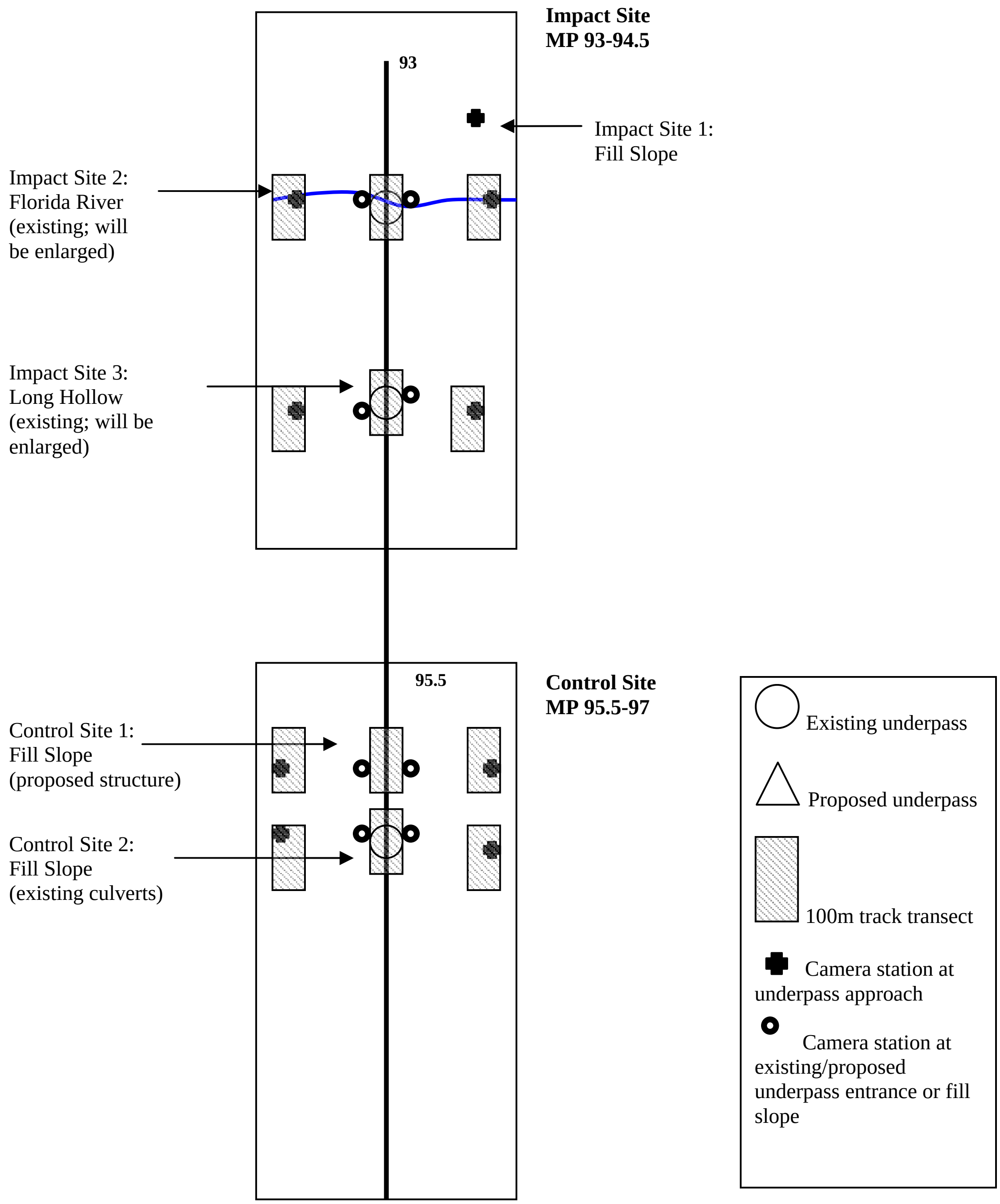


Figure 23. Schematic diagram of U.S. 160 Durango-Bayfield monitoring stations.

slope which carries U.S. 160 out of the Florida River valley to the mesa bordering the valley to the west. Impact Site 2 consisted of three camera stations placed along a transect perpendicular to the highway, with the midpoint station represented by the Florida River bridge. A single camera was placed under this structure on the west bank of the river.

Two additional cameras were stationed along the western banks at approach locations to opposite sides of the underpass. Impact Site 3 consisted of four camera stations placed along a transect perpendicular to the highway. Two of these cameras were located at approaches on both the north and south side of the highway and two cameras were placed at opposing entrances to an 89 ft long x 10 ft 6 in wide x 7ft 6 in high metal pipe culvert. This culvert drains Long Hollow, and a small, seasonal wetland was present at both entrances to the culvert, providing no terrestrial passage for wildlife. This wetland was seasonal, however, and during late summer visits there was a terrestrial passage through the structure. This drainage and associated structure was selected as a monitoring location over a similar structure to the east: the Pioneer Irrigation Ditch (MP 94.65). Although the Pioneer Irrigation Ditch is a proposed location for a new and larger wildlife crossing structure (the existing structure is a 79 ft long x 6 ft 6 in wide x 5 ft high metal pipe), we selected the Long Hollow drainage to the west of this site since there is a wider ROW habitat to place approach cameras and, more importantly, there is a greater amount of vegetative cover leading to the entrances of this structure. Representative site photos are shown in Appendix B.6.

Control Site

The control site is located approximately 1 mile east of the impact site between MP 95.5-97 and includes two fill slopes that could represent potential locations for underpasses to be constructed during future phases of the U.S. 160 corridor improvement project. The western boundary is immediately west of a long fill slope (MP 95.7) at MP 95.5. The eastern boundary is at a private drive that leaves U.S. 160 to the south (MP 97). Two locations were monitored at the control site:

- Control Site 1: MP 95.7, fill slope with small culvert
- Control Site 2: MP 96, fill slope with two culverts

Figures 22 (aerial images) and 23 (schematic diagram) show the locations of the impact site monitoring stations. Figure 22 provides detail of the positioning of the camera stations relative to the surrounding habitat and GPS coordinates of each station are provided in Appendix B.5. Control Site 1 consisted of four camera stations placed along a transect perpendicular to the highway, with the midpoint represented by a small pipe culvert 2 ft in diameter. Two of these cameras were located at approaches on both the north and south side of the highway and two cameras were placed at opposing entrances to the structure. Two remotely-triggered video cameras were also placed on each side of the highway between the underpass and approach digital cameras in order to record surface crossings over U.S. 160 by wildlife. This fill slope is proposed to have a 120 ft long x 36 ft wide x 14 ft high arch culvert installed during a future construction phase on this segment of the highway. Control Site 2 consisted of four cameras placed along a transect perpendicular to the highway, with the midpoint represented by a 145 ft long x 7 ft wide x 7 ft high metal culvert. Two remotely-triggered cameras were located at approaches on both the north and south side of the highway and two cameras were placed at opposing entrances to the culvert. This long fill slope bisects a wide drainage (almost 900 ft wide) and contains another culvert to the west of the structure described above. This second, smaller structure (145 ft long x 6 ft wide x 6 ft high) was not monitored due to limitations in camera equipment. However, the proximity of the approach cameras to this structure allows us to infer that animals in the vicinity of the larger culvert would also have the opportunity to utilize the other structure, particularly if a new, larger structure was installed in this drainage during future construction phases.

With respect to future opportunities for a structure in this drainage (Control Site 2), consideration is being given to whether this fill slope or the fill slope at Control Site 1 may be a more appropriate location if only one underpass was proposed for this stretch of road. By monitoring these two locations, we not only obtained valuable baseline data as to the rate of wildlife movement in the vicinity of these fill slopes, but which drainage may serve as a better location for the creation of a larger underpass to facilitate the movement of larger animals, particularly mule deer and elk, that is not provided by the current structures. Representative site photos are shown in Appendix B.6.

Monitoring Schedule

Since no construction activities occurred during the study, all of the data collected will be analyzed as the 'before' portion of the BACI analysis. At the beginning of this study (Spring 2006), due to the limited number of cameras, sampling was restricted to only six locations along this stretch of highway. With the addition of cameras during summer 2006, the 4-camera station transects were established at the impact and control sites described above. Impact Site 1 (one camera station) was not sampled after spring 2006, as the location it sampled was not part of any proposed mitigation activities.

3.5 Results

3.5.1 U.S. 285: Conifer-Bailey

Pre-construction activity

Between January-October 2006, five native species were detected at the Conifer-Bailey study site, including elk, mule deer, red fox, raccoon, and squirrel. Non-native species detected included domestic dog, domestic cat, and domestic livestock (Table 12). Humans were detected at all sites except Control Site 2; we did not include detections of construction crews as 'Human' visits in the Impact Sites, as this area was under continuous construction activity. Appendix B.7 provides representative photos of species detected at the study site.

Interestingly, no species were detected within the control site during pre-construction surveys and a limited amount of activity was recorded in the impact site. This pattern could be interpreted in several ways. Within the control site, cameras were active during various seasons and some species, particularly ungulates, may not have been within the vicinity. For example, during pre-construction, cameras at Control Sites 1 and 2 were active during May and between July and November 2006. However, during post-construction monitoring, cameras were active during winter (November 2006-January 2007) and spring (April-June 2007). Most of the ungulates detected were during the late spring season (May-June), which coincides with migratory activity patterns. Therefore, it is possible that the cameras monitoring the control site during pre-construction may not have captured the increase in ungulate activity during this time frame. Secondly, cameras may have been positioned in areas where there simply was no mule deer or elk activity. The Roland Gulch cameras detected no elk and only two mule deer over the entire course of this study.

Within the impact site, initially low activity levels may have been due to construction activity. Due to the limited time to monitor pre-construction activity (January and February 2006) we only captured a limited amount of ungulate activity. Additionally, there were fewer detections during actual construction operations and Impact Site 2 (Green Valley Grill underpass) was only monitored at the approach sites during May 2006 due to construction activities in the immediate vicinity of the transect. Thus, the combination of fewer available sampling days combined with ongoing construction activities along the entire length of the impact site may have caused species visitations to cameras to be lower than expected.

Elk and deer were detected at the western underpass station at Impact Site1. Impact Site 2, the Green Valley Grill underpass location, had deer, fox, and raccoon activity, although deer and raccoons were only detected on the eastern side of the highway. No visits were recorded to the underpass station at Impact Site 2, which was a small pipe culvert less than 2 feet in diameter pre-construction. Elk and mule deer were also detected at Impact Site 3 (Table 12).

Table 12. Activity indices of species detected at camera stations along transects perpendicular to U.S. 285, Conifer-Bailey study site prior to construction activities

	# sampling days	Elk	Mule Deer	Coyote	Red Fox	Raccoon	Muskrat	Squirrel	Domestic Dog	Domestic Cat	Horse	Domestic Cow	Human	Total Native Species	Total Non-native Species
Impact Site 1															
WA	**119**													**0**	**0**
WU	**169**	0.047 0.012	0.030 0.018		0.012 0.012								0.024 0.006	**3**	**1**
Total Species:														***3***	***1***
Impact Site 2															
WA	**85**				0.082 0.047								0.094 0.059	**1**	**1**
WU	**57**													**0**	**0**
using underpass at entrance[a]															
EU	**57**													**0**	**0**
using underpass at entrance															
EA	**85**		0.071 0.071		0.118 0.082	0.012 0.012		0.012 0.012						**4**	**0**
Total Species:														***4***	***1***
Impact Site 3															
WA	**28**	0.071 0.036	0.250 0.179										0.036 0.036	**2**	**1**
Control Site 1															
WA	**182**													**0**	**0**
WU	**147**													**0**	**0**
using underpass at entrance															
EU	**147**													**0**	**0**
using underpass at entrance															
EA	**169**												0.018 0.006	**0**	**1**
Total Species:														***0***	***1***
Control Site 2															
WA	**182**													**0**	**0**
WU	**147**													**0**	**0**
using underpass at entrance															
EU															
using underpass	**147**													**0**	**0**
at entrance															
EA	**147**													**0**	**0**
Total Species:														***0***	***0***

[a] this index is for species detected at the entrance of the underpass but did not travel through the underpass

Post-construction activity

After construction of the underpass, seven native species were detected at the study site between November 2006-June 2007, including elk, mule deer, coyote, red fox, raccoon, muskrat, and squirrel. Non-native species detected included domestic dog, domestic cat, horses, and domestic livestock (Table 13). Appendix B.7 provides representative photos of species detected at the study site.

The control sites saw an increase in activity compared to the pre-construction monitoring period. Both elk and mule deer were detected at Control Site 1, although elk were only detected on the east side of the highway. Mule deer were recorded utilizing the Deer Creek bridge and traveled through the creek when passing through this structure (Figure 24). This site also documented the presence of great blue herons in Deer Creek. No elk were detected at Control Site 2 and there were only 2 deer visits. Coyotes were documented at this site, but were not recorded using the structure. The structure was utilized by raccoons and muskrats, as it was typically inundated with either flowing or pooled water.

The impact sites also saw an increase in activity, particularly at Impact Site 2 where the new underpass was constructed (Figure 24). Mule deer, red fox, and raccoons were documented using the structures. In fact, mule deer tracks were observed in the structure when highway paving activities were occurring above the structure along U.S. 285. Coyotes were also documented at the approach to the structure but were never recorded traveling through the underpass by either tracks or photos. No mule deer or elk were recorded at Impact Site 1 after construction. Impact Site 3 was not surveyed (Table 13).

BACI analysis

We recorded limited number of elk visits to stations over the course of this study; they were only detected at Impact Site 1 west underpass (I1WU) station and Impact Site 3 west approach (I3WA) station before construction and at Control Site 1 east approach (C1NA) after construction. We therefore limited our BACI analysis to mule deer. Furthermore, since a complete transect at Impact Site 1 was not feasible due to construction activities, and since there were only two deer detected at Control Site 2 during the course of this study, we limit our analysis to Control Site 1 and Impact Site 2.

Table 13. Activity indices of species detected at camera stations along transects perpendicular to U.S. 285, Conifer-Bailey study site after construction activities. The first value is the index for number of visits to a station as a function of sampling nights; the second value is the index for the number of nights a species was detected at a station as a function of sampling nights.

	# sampling days	Elk	Mule Deer	Coyote	Red Fox	Raccoon	Muskrat	Squirrel	Domestic Dog	Domestic Cat	Horse	Domestic Cow	Human	Total Native Species	Total Non-native Species
Impact Site 1															
WA	**109**													**0**	**0**
WU	**109**				0.460 0.460				0.018 0.009	0.009 0.009			0.009 0.009	**1**	**3**
Total Species:														***1***	***3***
Impact Site 2															
WA	**88**		0.159 0.114		0.023 0.023								0.193 0.102	**2**	**1**
WU	**88**													**3**	**2**
using underpass			0.159 0.114		0.023 0.023	0.011 0.011				0.023 0.023			0.193 0.102		
at entrance [a]			0.159 0.114		0.023 0.023	0.011 0.011				0.023 0.023			0.193 0.102		
EU	**88**													**2**	**2**
using underpass			0.159 0.114		0.023 0.023	0.011 0.011				0.023 0.023			0.193 0.102		
at entrance			0.159 0.114		0.023 0.023	0.011 0.011				0.023 0.023			0.193 0.102		
EA	**88**		0.261 0.125	0.023 0.023	0.068 0.034								0.193 0.102	**3**	**1**
Total Species:														***4***	***2***
Impact Site 3															
WA	**0**													**Not**	**Surveyed**
Control Site 1															
WA	**144**			0.014 0.014							0.174 0.028			**1**	**1**
WU	**144**													**0**	**0**
using underpass			0.049 0.049												
at entrance			0.049 0.049												
EU	**144**													**0**	**0**
using underpass			0.049 0.049												
at entrance [b]			0.167 0.104												
EA	**144**	0.160 0.056	0.333 0.139	0.097 0.090	0.014 0.014							0.500 0.090		**4**	**1**
Total Species:														***4***	***2***
Control Site 2															
WA	**144**			0.028 0.028										**1**	**0**
WU	**144**													**3**	**0**
using underpass						0.014 0.014	0.014 0.014	0.007 0.007							
at entrance						0.014 0.014	0.042 0.035	0.007 0.007							
EU															
using underpass	**144**					0.014 0.014	0.014 0.014	0.007 0.007						**4**	**0**
at entrance				0.014 0.014		0.021 0.021	0.028 0.028	0.007 0.007							
EA	**144**		0.014 0.014	0.014 0.014										**2**	**0**
Total Species:														***5***	***0***

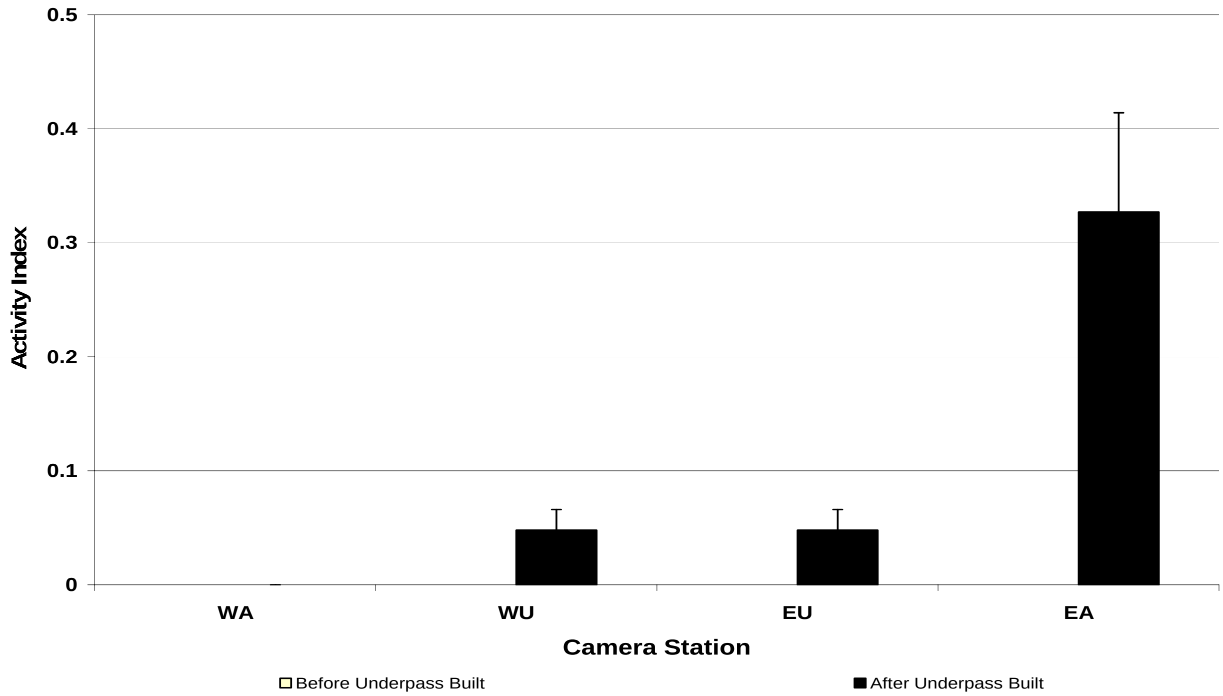
[a] this index is for species detected at the entrance of the underpass but did not travel through the underpass

[b] this site also recorded 4 photos of a great blue heron

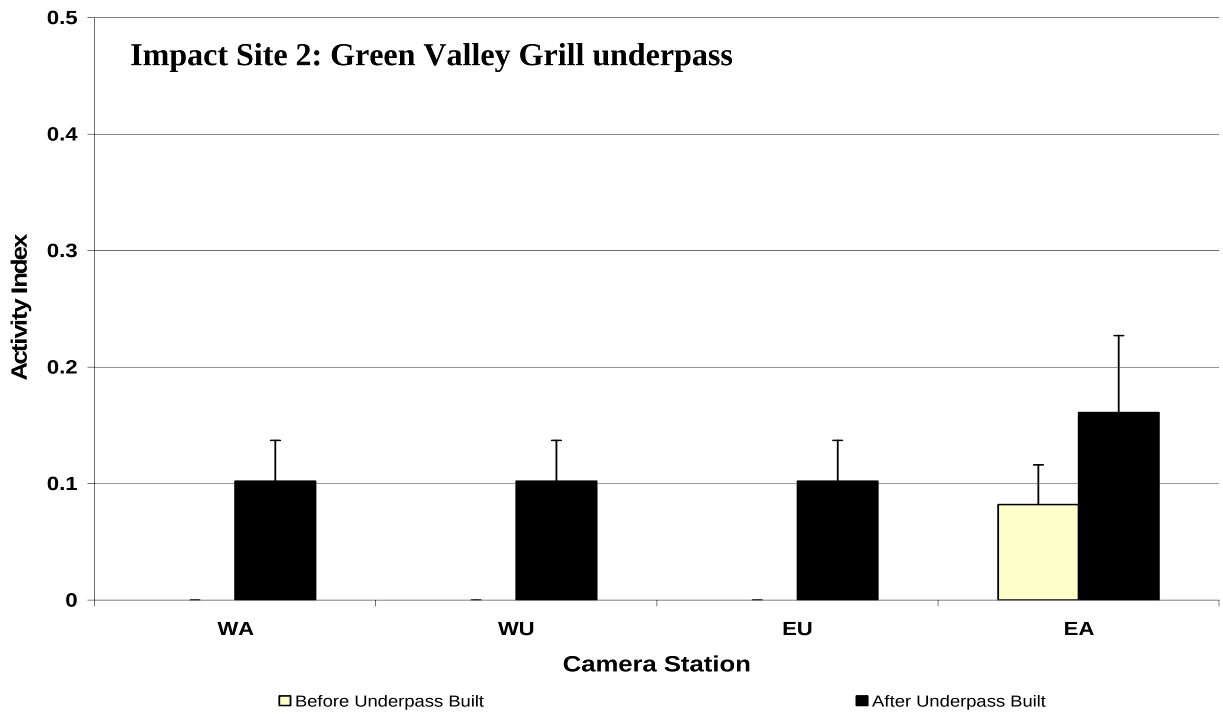
We tested for differences in mule deer activity across the sampling stations within Control Site 1 and Impact Site 2. Figure 24 depicts mule deer activity at sampling stations for both of these sites. Prior to construction, no deer were detected at Control Site 1, resulting in no significant difference in deer photographs or nights detected across sampling stations. After underpass construction, deer photographs ($F = 11.02$, $df = 584$, $p < 0.001$) and nights detected ($x^2 = 24.59$, $df = 3$, $p < 0.001$) significantly varied across sampling stations, with the highest deer activity at the east approach station and no activity recorded at the west approach. Similar to Control Site 1, at Impact Site 2 there was a significant difference in deer photographs ($F = 5.75$, $df = 339$, $p < 0.001$) and nights detected ($x^2 = 18$, $df = 3$, $p < 0.001$) among stations prior to construction, with deer detected only at the east approach station. In contrast to Control Site 1, however, after underpass construction we recorded no difference in photographs ($F = 0.43$, $df = 543$, $p = 0.73$) or nights ($x^2 = 0$, $df = 3$, $p > 0.05$) among stations. These results suggest that underpass construction facilitated continuous movement of deer under the roadway in the treatment site compared to the control.

Figure 25 shows the mean index, averaged across sampling stations within a transect, for Control Site 1 and Impact Site 2 before and after underpass construction. Control Site 1 showed no significant increase in mule deer photographs before and after construction (paired $t = -1.42$, $df = 3$, $p = 0.25$). Alternatively, Impact Site 2 had a significant increase in mule deer photographs after the underpass was constructed (paired $t = -16.74$, $df = 3$, $p < 0.001$), again suggesting the underpass construction contributed to increased deer activity along the transect compared to the control.

Prior to the construction of the Green Valley Grill underpass at Impact Site 2, only a pipe culvert less than 2 feet in diameter was present. The underpass station at Control Site 1 was the Deer Creek Bridge, which was not modified during the course of this study. Interestingly, both underpass stations saw an increase in mule deer visits (Control Site 1: $t = -2.70$, $df = 292$, $p < 0.01$; Impact Site 2: $t = -2.31$, $df = 220$, $p = 0.02$) and nights detected (Control Site 1: $x^2 = 7.15$, $df = 1$, $p < 0.075$; Impact Site 2: $x^2 = 6.82$, $df = 1$, $p = 0.008$) after construction of the Green Valley Grill underpass. Increased post-construction activity at both the control and impact



a) Control Site 1: Deer Creek



b) Impact Site 2: Green Valley Grill underpass

Figure 24. Mule deer activity at a) Control Site 1 and b) Impact Site 2 before and after underpass construction, Conifer-Bailey study site.

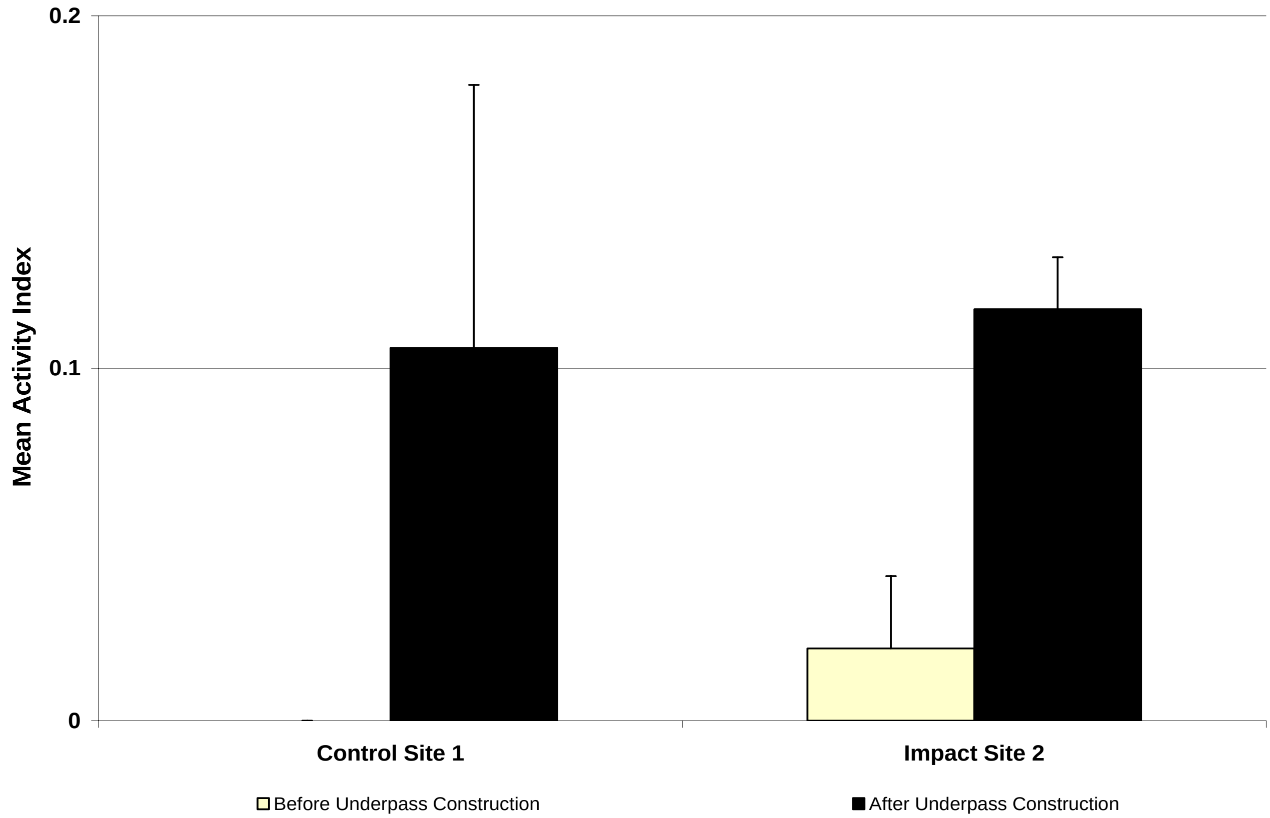


Figure 25. Mean mule deer activity at Control Site 1 and Impact Site 2 before and after underpass construction., Conifer-Bailey study site.

underpasses may be due in part to the seasonal differences in activity as a result of when the cameras were actually monitoring these sites (i.e. post-construction surveyed a longer duration over a wider range of seasons). Nonetheless, although the increase was observed at underpasses in the control and impact site, the Green Valley Grill transect (impact site) experience an increase an overall activity across the entire transect, with consistent activity on both sides of the road, whereas the entire Deer Creek transect in the control site did not. We attribute this difference to the creation of the Green Valley Grill underpass.

Determining at-grade crossings

Due to inconsistencies in tracking substrate, it was difficult to record any tracks along the shoulder of U.S. 285. For example, some stretches of the shoulder consisted of fine dirt (which allowed for excellent tracking substrate), fine gravel, packed soil, and rocks. In some instances, the shoulder width was extremely limited to not present at all, particularly where the highway passed over fill slopes. Snowfall events provided a better opportunity to detect tracks, but variations in snow cover (particularly along south-facing slopes) created an inconsistent tracking surface as well. These variations in shoulder width and tracking medium prevented a systematic track survey from being conducted, thus preventing any statistical analysis in species activity along the side of road.

Along the approach station transects, tracking medium was more consistent. However, due to the nature of the soils tracks barely registered. Other factors that affected detection rates included lack of a wildlife trail and high amounts of vegetated ground cover. For these transects, scat was a more reliable source for detecting species presence.

Table 14 provides the pooled results of track and scat detections by species. The majority of detections included mule deer and elk, which is expected due to the higher probability of their tracks registering in soil and being detected. Other species tracks were detected less frequently, due to their lower body weight preventing a track from being registered during typical soil conditions; track detections were more frequent in the snow however. Although results from these surveys can not be compared in a before/after analysis or be used to compare surface crossing between control/impact sites, the do provide supplementary observational information on species activity in these areas.

Table 14. Opportunistic track and scat data, U.S. 285, Conifer-Bailey.

	Tracks detected	*Scat detected*
Impact Site 1		
WA		mule deer
WU	mule deer, elk	mule deer
Impact Site 2		
EA	mule deer	
EU	mule deer, coyote	
WU	mule deer, coyote	
WA	mule deer	
Impact Site 3		
WA		mule deer
Control Site 1		
EA		mule deer
EU	mule deer	
WU		
WA		
Control Site 2		
EA		mule deer
EU		
WU		
WA		

Animal-vehicle collisions

Elk and mule deer were collected by maintenance crews during this study. The highest number of road killed mule deer occurred at MP 228, which is the Wisp Creek area (Figure 26). Other stretches of U.S. 285 ranged between 0-5 road-killed individuals per half mile. Six individuals were collected along MP's 231 and 232, which is the area immediately surrounding and north of Shaffers Crossing. Six road kills of mule deer were documented within 1 mile in either direction of the Green Valley Grill underpass (Milepost 233.6). Since AVCs were reported by maintenance crews in 2005 and 2006, these data represent the number of AVC's prior to (2005 – April 2006) and during (April – November 2006) construction of the Green Valley Grill underpass. In total, six and three road kills were detected in the impact and control site, respectively, for an annual rate of recorded road kill of approximately 3/year in the impact site and 1.5/year in the control site. This 2-year total can be compared to AVC data collected between 1993-2003 (Figure 14), in which 51 and 24 road kills were reported in the impact and control site, respectively. Interestingly, there appears to be a 2:1 ratio of AVC between the impact and control site.

There are several reasons why we were unable to formally test whether the installed Green Valley Grill underpass effectively reduced AVCs at this time. For example, the sampling effort was not standardized for either of the sampling sessions (1993-2003 data and 2005-2006 data), and collection methods by CDOT maintenance crews were different than those used by CHP during previous years. Additionally, the underpass was completed in October 2006, and we along monitored through spring 2007, so we would expect there to be some lag time in how individuals respond to using the structure.

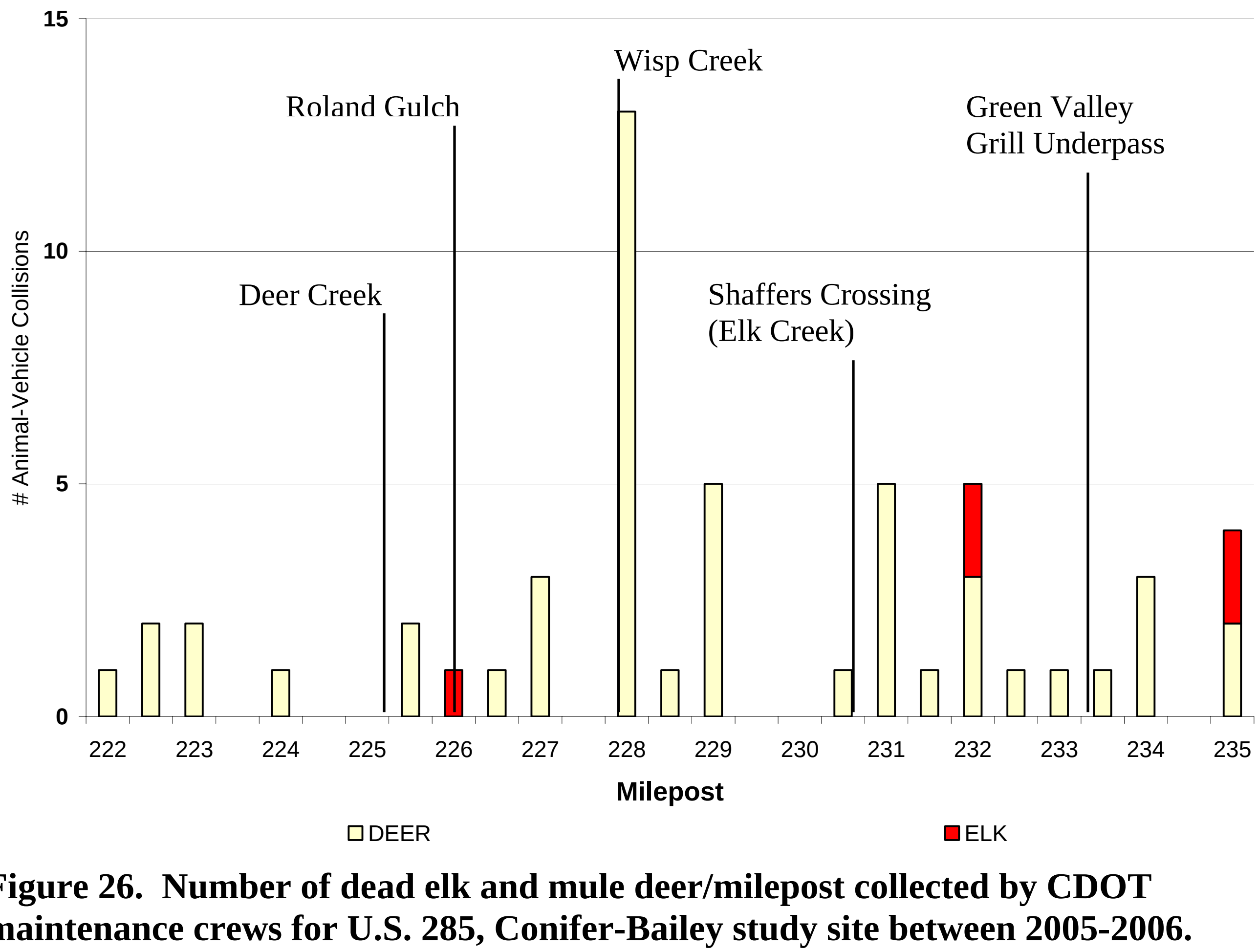


Figure 26. Number of dead elk and mule deer/milepost collected by CDOT maintenance crews for U.S. 285, Conifer-Bailey study site between 2005-2006.

3.5.2 U.S. 160: Wolf Creek Pass

Fourteen native species were detected at the Wolf Creek Pass study site, including elk, mule deer, coyote, red fox, bobcat, raccoon, striped skunk, marmot, pine marten, porcupine, long-tailed weasel, rabbit/hare, squirrel, and chipmunk. Non-native species detected included domestic dog, domestic cat, and horse (Table 15). Impact Sites 2 and 5 had the highest number of native species (8 and 7 species per transect, respectively). Appendix B.8 provides representative photos of species detected at the study site.

Marmots, porcupine, and cottontail rabbits were the only species detected actually traveling through the temporary lynx underpass at Impact Site 3, although other species were detected at the entrance to the underpass (see Section 4.3 in the Lynx-Roadway Interactions section). The other structures monitored were not used by any species, as these underpasses were frequently inundated with water, thus allowing no terrestrial route under the highway.

Elk were detected only along the east side of U.S. 160 (at approach stations) in the willow habitat along the South Fork Rio Grande; mule deer were detected on both sides of the highway. A variety of carnivore species were detected throughout the study area, including coyotes at five of the six transects, red fox at four transects, and bobcat at two transects. A pine marten was detected at the northern approach station at Impact Site 5. Human activity was prevalent across the entire study area, with peak activity occurring at Control Site 1 and Control Site 5. The majority of these detections were people hiking or fishing.

No construction occurred at the Wolf Creek study area during the course of the study. Therefore, all of these data serve as pre-construction data. Furthermore, due to the relatively low number of detections of wildlife species, no statistical analyses were conducted.

Determining at-grade crossings

Due to inconsistencies in tracking substrate and limited shoulder widths on which to conduct surveys, it was difficult to record any tracks along the shoulder of U.S. 160. For example, most of the shoulder of U.S. 160 either dropped off sharply to the South Fork Rio Grande or was bordered by large cliffs and rock faces. Snowfall events provided a better opportunity to detect tracks, but variations in snow cover (particularly along south-facing slopes) created an inconsistent tracking surface. These variations in shoulder width and tracking medium prevented a systematic track survey from being conducted, thus preventing any statistical analysis in species activity along the side of road.

Along the approach station transects, tracking medium was more consistent. However, due to the nature of the soils tracks barely registered. Other factors that affected detection rates included lack of a wildlife trail, high amounts of vegetated ground cover, and sudden and dramatic changes in topography. For these transects, scat was a more reliable source for detecting species presence.

Table 15. Activity indices of species detected at camera stations along transects perpendicular to U.S. 160, Wolf Creek Pass study site. The first value is the index for number of visits to a station as a function of sampling nights; the second value is the index for the number of nights a species was detected at a station as a function of sampling nights.

	# sampling days	Species: Elk	Mule Deer	Coyote	Red Fox	Bobcat	Raccoon	Striped Skunk	Marmot	Pine Marten	Porcupine	Weasel	Rabbit/Hare	Squirrel	Chipmunk	Domestic Dog	Domestic Cat	Horse	Human	Total Native Species	Total Non-native Species
Impact Site 1																					
NA	27																		0.704 0.111	0	1
Impact Site 2																					
SA	132	0.008 0.008	0.091 0.083	0.061 0.053												0.008 0.008				3	1
SU	132																			0	0
NU	132																			0	0
NA	159		0.208 0.151	0.038 0.038	0.006 0.006	0.006 0.006	0.031 0.019	0.006 0.006					0.031 0.025				0.013 0.006			7	1
Total Species:																				*8*	*2*
Impact Site 3																					
SA	152		0.151 0.112	0.020 0.013															0.020 0.020	2	1
U[a]	503								0.008 0.008		0.002 0.002		0.002 0.002						0.006 0.006	3	1
NA	125		0.208 0.112	0.056 0.048															0.048 0.016	2	1
Total Species:																				*5*	*1*
Impact Site 4																					
SA	132	0.159 0.038	0.220 0.106																	2	0
SU	120		0.058 0.042	0.008 0.008							0.017 0.017	0.008 0.008	0.008 0.008		0.033 0.033					6	0
NU	132																			0	0
NA	132		0.076 0.030	0.061 0.061																2	0
Total Species:																				*7*	*0*
Impact Site 5																					
SA	132		0.023 0.015	0.008 0.008												0.008 0.008			0.129 0.061	2	2
SU	132		0.015 0.015	0.008 0.008															0.015 0.015	2	1
NU	120		0.017 0.017																	1	0
NA	171		0.094 0.041	0.035 0.035	0.041 0.029	0.012 0.012				0.006 0.006			0.018 0.018	0.018 0.018		0.029 0.018		0.041 0.018	0.088 0.041	7	3
Total Species:																				*7*	*3*
Control Site 1																					
SA	69		0.014 0.014													0.014 0.014			1.377 0.377	1	2
SU	69																		0.580 0.159	0	1
NU	69																		0.058 0.043	1	0
NA	96		0.083 0.042		0.021 0.021														0.073 0.063	2	1
Total Species:																				*2*	*2*
Control Site 2																					
SA	69															0.014 0.014			0.072 0.072	0	2
SU	39								0.077 0.051											1	0
NU	41		0.146 0.122	0.024 0.024					0.024 0.024											3	0
NA	66				0.015 0.015															1	0
Total Species:																				*4*	*2*

[a] this underpass was monitored as part of the Lynx Underpass Mitigation study (see Section 4.0). Data represented in this table is from January 2006-June 2007, when the camera was inside the underpass. Complete data is presented in Table 19.

Table 16 provides the pooled results of track and scat detections by species. The majority of detections included mule deer and elk, which is expected due to the probability of a track registering in soil and being detected. Other species tracks were detected less frequently, due to their lower body weight preventing a track from being registered during typical soil conditions; track detections were more frequent in the snow however. Although results from these surveys can not be compared in a before/after analysis or be used to compare surface crossings between control/impact sites, they do provide supplementary information on species activity.

Table 16. Observational track and scat data, U.S. 160, Wolf Creek Pass.

	Tracks detected	*Scat detected*
Impact Site 1		
NA		mule deer
Impact Site 2		
SA		mule deer, elk
SU		
NU		
NA	mule deer, coyote	
Impact Site 3		
SA		mule deer
U		
NA		
Impact Site 4		
SA	elk	elk
SU		
NU	mule deer	
NA		
Impact Site 5		
SA	mule deer	
SU		
NU		
NA	mule deer, coyote	mule deer, coyote
Control Site 1		
SA		
SU		
NU		
NA		mule deer
Control Site 2		
SA		
SU		
NU		
NA		

Animal-vehicle collisions

Maintenance crews collected three mule deer during the course of the study. All three were collected just east of the study area, including one at MP 180.5 and two at MP 181.

3.5.2 U.S. 160: Durango-Bayfield

Ten native species were detected at the Durango-Bayfield study site, including elk, mule deer, coyote, gray fox, bobcat, raccoon, striped skunk, badger, rabbit/hare, and squirrel. Non-native species detected included domestic dog, domestic cat, and domestic livestock (Table 17). The two control transects had the highest number of native species (6 species per transect). Appendix B.9 provides representative photos of species detected at the study site.

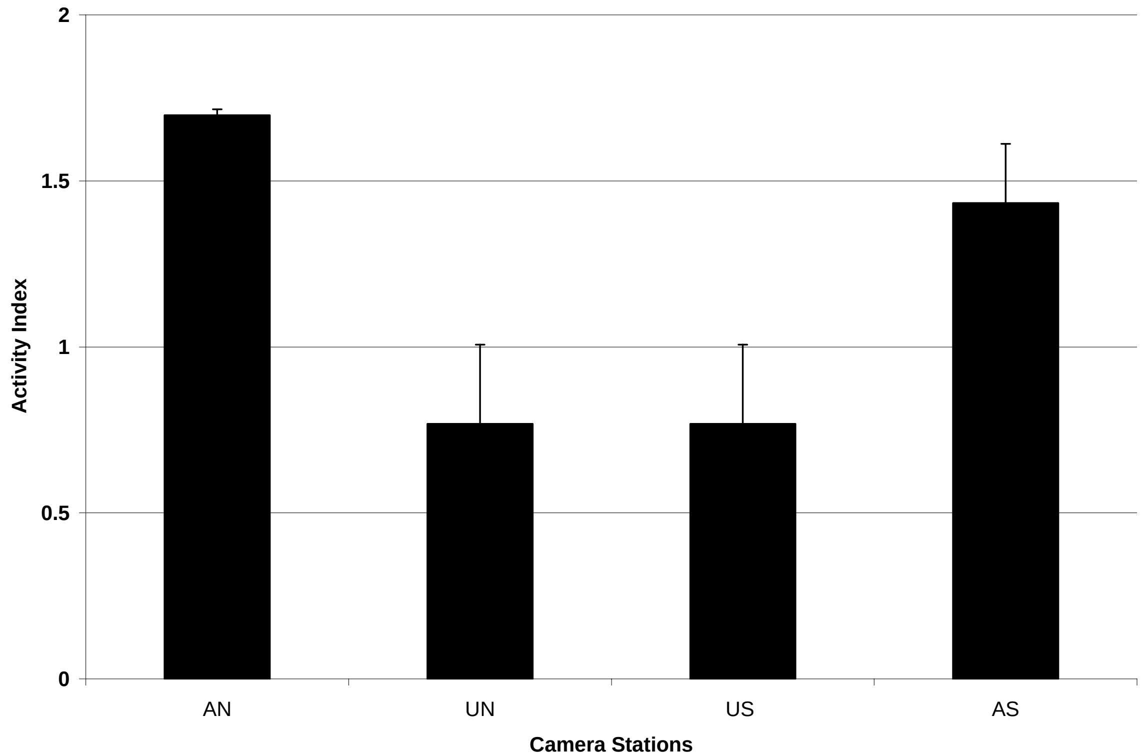
Several species were detected using the two underpass structures in the Impact Site. Impact Site 2, the Florida River bridge, was used regularly by mule deer (Figure 27), as well as raccoon and striped skunk. The Long Hollow structure was utilized by bobcats. In the Control Site, bobcats were detected using the culverts in both Control Site 1 and 2; a badger and several coyotes also used the structure at Control Site 2. Elk, mule deer, and gray fox were detected at the Control Site 2 underpass entrance, although the structure was too small to be used by either of the ungulate species.

Elk were detected only along the north side of U.S. 160 (at approach stations); mule deer were detected on both sides of the highway, although their activity was higher at the approach stations than at the roadside/underpass stations. The exception to this pattern was at Impact Site 2, the Florida River. This structure has a sufficiently high clearance for mule deer, thus activity indices were higher than for the respective underpass stations in the other transects. Figure 27 shows the activity indices of mule deer for each of the four transects.

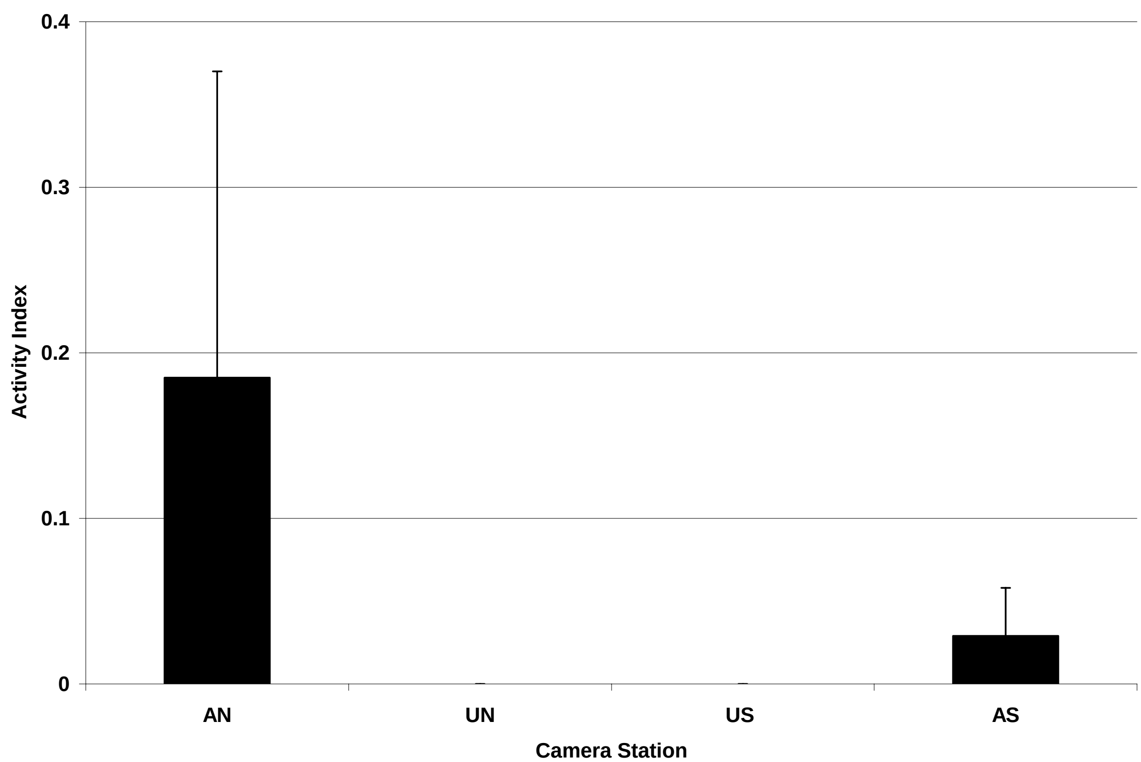
Table 17. Activity indices of species detected at camera stations along transects perpendicular to U.S. 160, Durango-Bayfield study site. The first value is the index for number of visits to a station as a function of sampling nights; the second value is the index for the number of nights a species was detected at a station as a function of sampling nights.

	# sampling days	Elk	Mule Deer	Coyote	Gray Fox	Bobcat	Raccoon	Striped Skunk	Badger	Rabbit/Hare	Squirrel	Domestic Dog	Domestic Cat	Domestic Cow	Human	Total Native Species	Total Non-native Species
								Species									
Impact Site 1																	
NA	**23**												0.13 0.087			**0**	**1**
Impact Site 2																	
SA	**125**		1.496 0.248												0.040 0.024	**1**	**1**
U	**276**		0.888 0.377				0.004 0.004	0.029 0.029				0.011 0.004			0.036 0.014	**3**	**2**
NA	**90**		1.733 0.756				0.100 0.067						0.011 0.011			**2**	**1**
Total Species:																***3***	***3***
Impact Site 3																	
SA	**163**		0.055 0.037	0.025 0.018												**2**	**0**
SU	**146**																
using underpass						0.027 0.027										**1**	**0**
at entrance [a] *:*																**0**	**0**
NU	**146**																
using underpass						0.027 0.027										**1**	**0**
at entrance:										0.027 0.027						**1**	**0**
NA	**146**		0.103 0.007			0.007 0.007										**2**	**0**
Total Species:																***4***	***0***
Control Site 1																	
SA	**147**		0.082 0.061	0.007 0.007								0.027 0.007			0.041 0.041	**2**	**2**
SU	**146**					0.021 0.021				0.027 0.014			0.014 0.014			**2**	**1**
NU	**141**					0.021 0.021				0.085 0.057	0.014 0.007		0.014 0.014			**3**	**1**
NA	**179**	0.112 0.022	0.777 0.263	0.011 0.011		0.006 0.006									0.045 0.039	**4**	**1**
Total Species:																***6***	***3***
Control Site 2																	
SA	**190**		0.700 0.221	0.016 0.011											0.005 0.005	**2**	**1**
SU	**213**																
using underpass				0.009 0.009		0.009 0.009			0.005 0.005			0.009 0.005			0.155 0.052	**3**	**2**
at entrance:			0.141 0.061	0.009 0.009										0.901 0.07		**2**	**1**
NU	**213**																
using underpass				0.009 0.009		0.009 0.009			0.005 0.005			0.009 0.005			0.155 0.052	**3**	**2**
at entrance:			0.662 0.221	0.028 0.014	0.005 0.005										0.033 0.033	**3**	**1**
NA	**245**	0.069 0.016	1.547 0.380	0.020 0.008											0.086 0.033	**3**	**1**
Total Species:																***6***	***3***

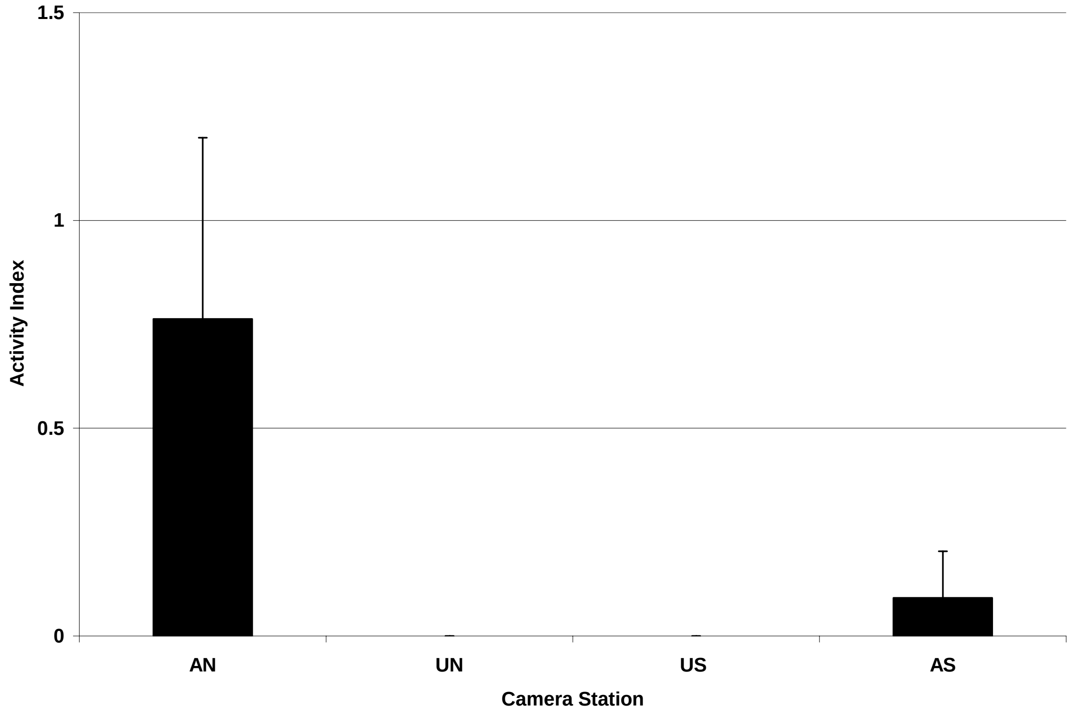
[a] this index is for species detected at the entrance of the underpass but did not travel through the underpass



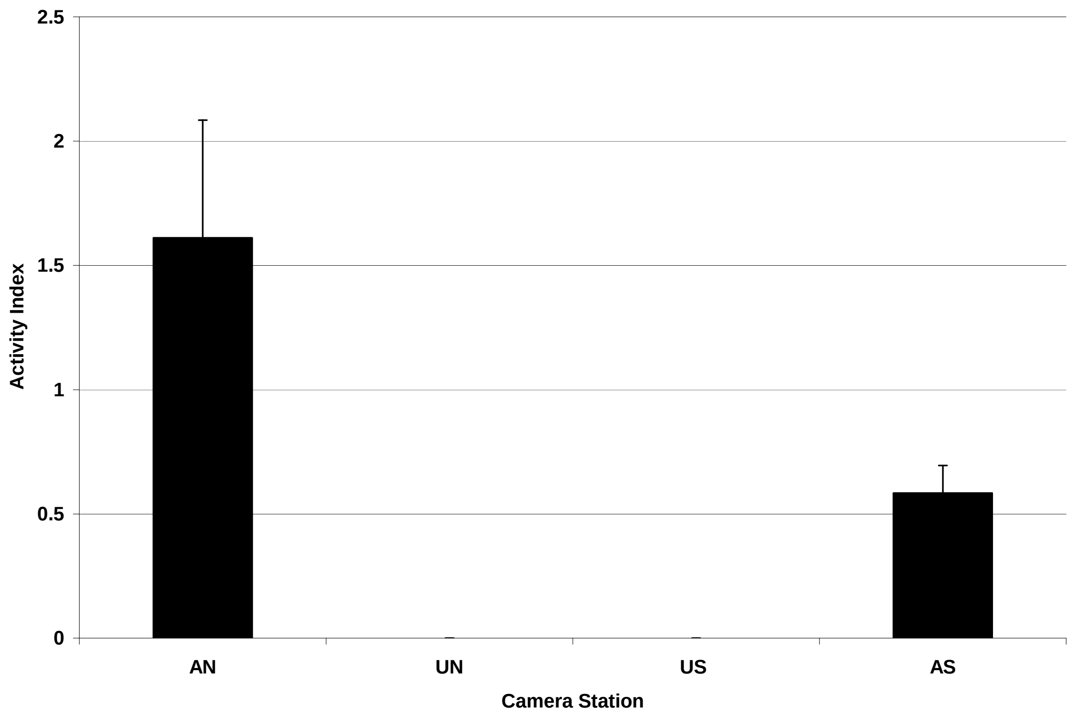
a) Impact Site 2 (Florida River)



b) Impact Site 3



c) Control Site 1



d) Control Site 2

Figure 27. Mean mule deer activity at sampling sites along U.S. 160, Durango-Bayfield study site.

Analysis of pre-construction data

Although these data only serve as the pre-construction portion of the study, we had sufficient mule deer visitations to test for pre-construction differences in deer activity among stations within each of the four transects. Impact Site 2, the Florida River bridge, was the only underpass suitable for deer activity. Although cameras detected activity across the entire transect, there was a significant difference in photographs between camera stations ($F = 9.17$, $df = 766$, $p < 0.001$; Figure 27a), with higher activity at the approach than at the underpass stations. Although deer activity also was significantly different among stations for the other three transects, no activity was documented at any of the underpass stations. Mule deer were detected in the vicinity of the culvert at Control Site 2, although they were not recorded passing through the structure.

Determining at-grade crossings

Due to inconsistencies in tracking substrate, it was difficult to record any tracks along the shoulder of U.S. 160. For example, some stretches of the shoulder consisted of fine dirt (which allowed for excellent tracking substrate), fine gravel, packed soil, and rocks. In some instances, the shoulder width was extremely limited to not present at all, particularly where the highway passed over fill slopes. Snowfall events provided a better opportunity to detect tracks, but variations in snow cover (particularly along south-facing slopes) created an inconsistent tracking surface as well. These variations in shoulder width and tracking medium prevented a systematic track survey from being conducted, thus preventing any statistical analysis in species activity along the side of road.

Along the approach station transects, tracking medium was more consistent. However, due to the nature of the soils tracks barely registered. Other factors that affected detection rates included lack of a wildlife trail and high amounts of vegetated ground cover. For these transects, scat was a more reliable source for detecting species presence.

Table 18 provides the pooled results of track and scat detections by species. The majority of detections included mule deer and elk, which is expected due to the probability of a track registering in soil and being detected. Other species tracks were detected less frequently, due to their lower body weight preventing a track from being registered during typical soil conditions; track detections were more frequent in the snow however. Although results from these surveys can not be compared in a before/after analysis or be used to compare surface crossing between control/impact sites, the do provide supplementary observational information on species activity in these areas.

Table 18. Observational track and scat data, U.S. 160, Durango-Bayfield.

	Tracks detected	*Scat Detected*
Impact Site 1		
NA		mule deer
Impact Site 2		
SA	mule deer	mule deer
U	mule deer, raccoon	
NA	mule deer	
Impact Site 3		
SA	mule deer	mule deer, coyote
SU		
NU	coyote	
NA		
Control Site 1		
SA	mule deer, elk	mule deer, elk
SU	mule deer	mule deer
NU	mule deer	mule deer
NA	mule deer, coyote	mule deer
Control Site 2		
SA	mule deer	mule deer, elk, coyote
SU	mule deer, coyote	mule deer, coyote
NU	mule deer	mule deer
NA	mule deer	mule deer

Animal-vehicle collisions

Only mule deer were collected by maintenance crews during this study. The patterns in road-killed mule deer collected between 2005-2006 were similar to the AVC patterns between 1993-2003 (Figure 20), with peaks in mule deer road kill occurring between MP 95-96 and 99.5-100.5 (Figure 28). AVCs around the Florida River bridge were relatively low compared to other stretches of U.S. 160. In contrast, the fill slope to the west (Impact Site 1) had nine recorded incidents of mule deer collisions. In total, 13 and 36 road kills were detected in the treatment and control site, respectively.

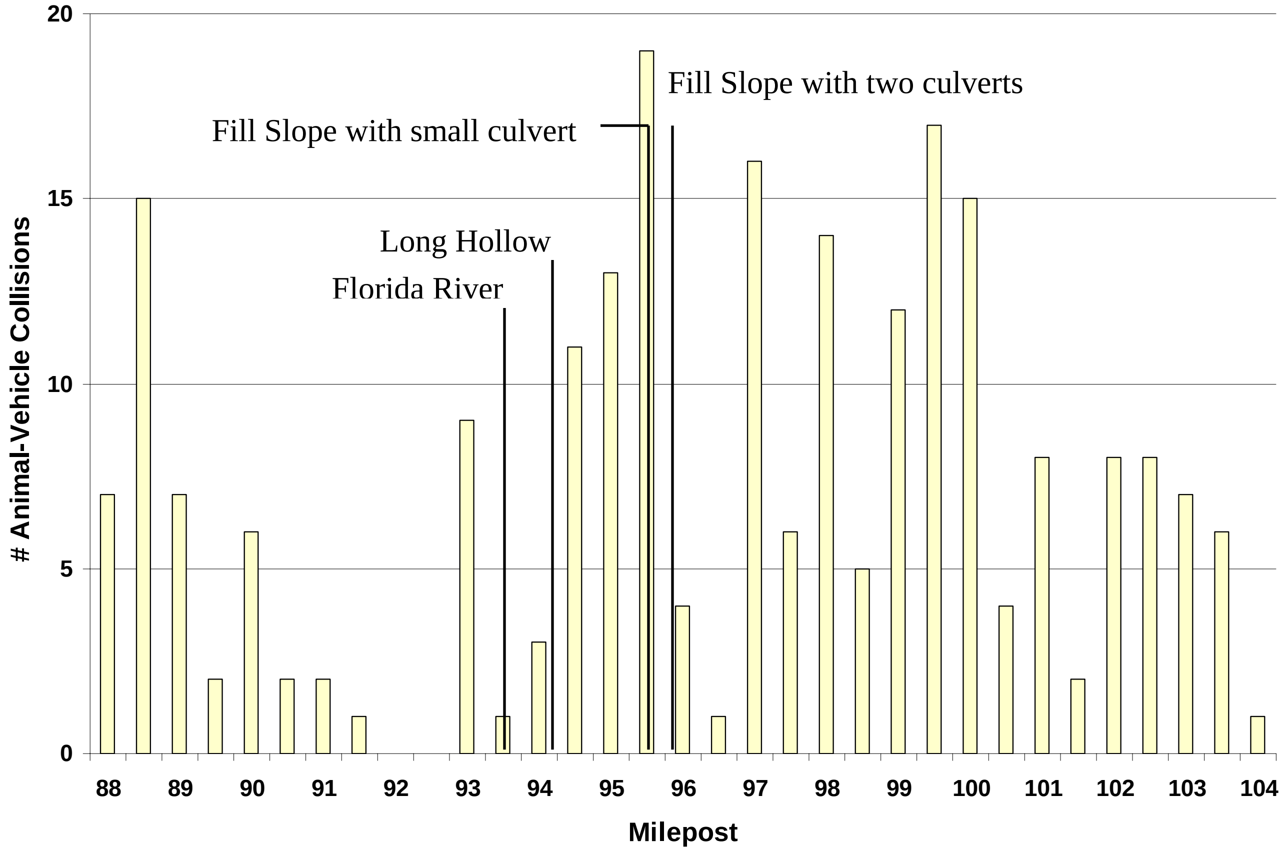


Figure 28. Number of dead mule deer/milepost collected by CDOT maintenance crews for U.S. 160, Durango-Bayfield study site between 2005-2006.

3.6 Discussion and Recommendations

3.6.1 U.S. 285: Conifer-Bailey

Within this study site, we monitored a range of structure types and situations, including:

- A fill slope with no structure present (Impact Site 1)
- The modification of a 2-foot diameter pipe to an arch culvert (Impact Site 2: Green Valley Grill wildlife underpass)
- A span bridge scheduled to be modified to a larger structure as part of future highway improvements (Control Site 1: Deer Creek bridge)
- A pipe culvert scheduled to be modified to a span bridge as part of future highway improvements (Control Site 2: Roland Gulch culvert)

While there are additional structures present between the Impact Site and Control Site, we focus our recommendations to those locations monitored. However, we do provide recommendations to specific stretches of highway that have been identified as connectivity areas of concern.

Underpass recommendations

The constructed Green Valley Grill underpass demonstrated the utility of such structures at successfully allowing animals to cross safely underneath the highway. Prior to construction of the underpass, only a 2 ft diameter pipe culvert was present and no species activity was recorded at the underpass entrance, although several species were detected at the approaches to the underpass location. Once the structure was completed, mule deer activity in particular was documented within the first week of construction activities ceasing. Furthermore, whereas only one station detected mule deer activity prior to construction of the underpass, mule deer were recorded at all four camera stations along the transect post-construction. Furthermore, even though mule deer activity increased post-construction at both the control and impact sites, the increase in mule deer activity across the entire Green Valley Grill transect was not evident at the Deer Creek bridge in the control site, which did not have any visits post-construction on the west approach station, and minimal visits at the roadside stations. Thus, the underpass appeared successful at facilitating uniform mule deer activity along the entire transect, with consistent mule deer activity across both sides of the road.

This ‘inconsistency’ in mule deer activity across the entire transect was evident in places where structures do not allow for the safe passage of wildlife species under the roadway. This pattern could be due to several reasons. First, the roadway may be acting as a partial barrier to movement. Although we confirmed that movement was occurring across roadways through the identification of road-killed animals, the trend of consistent visits along the Green Valley Grill transect was only seen at the only other site where mule deer were physically capable of utilizing an existing structure (the Florida River bridge at Durango-Bayfield). Secondly, activity at roadside locations without underpasses could have been reduced since there were many opportunities for surface crossings in the vicinity, whereas at sites with functional underpasses, animals might be funneled through the structure and past the associated camera station. Finally, animals may have been spending less time along transects without a structure capable of allowing passage. Consequently, animals attempting to make surface crossings might be detected less frequently than animals loitering around an underpass entrance or approach.

For species with fewer detections at camera stations, it is difficult to determine the degree of permeability of the roadway due to low sample size. However, for the Green Valley Grill underpass, certain measures can ensure that multiple species continue to utilize this structure, including:

- Create an area of vegetation (trees, shrubs, grasses) leading from the highway right-of-way to the underpass entrance. This will aid in directing smaller vertebrate species (i.e. rodents, birds) to the underpass entrance and increase the likelihood that they will enter and pass through the structure. The planted vegetation should not be dense; rather, it should be sufficient enough to allow species to navigate easily to the underpass entrance
- Limit parking opportunities along U.S. 285 so that the public can not gain access to this structure

- Continue to monitor animal-vehicle collisions along this stretch of U.S. 285 and determine whether wildlife fencing is appropriate (see *Future Monitoring Recommendations*) below

Within the control site, two underpasses were monitored that are proposed to be enlarged as part of future highway improvements. The first structure, the Deer Creek bridge (Control Site 1), has a low clearance but mule deer were recorded passing through the structure on occasion. Although elk were detected only on the east side of the highway, they were never detected using the structure, and tracks were observed crossing the roadway on multiple occasions. Currently, AVCs are not as high as stretches of U.S. 285 to the north, although future changes in traffic volumes, traffic speed, human development, and wildlife movement patterns may cause an increase in AVC rates in this area.

Other species may be more reluctant to use the Deer Creek bridge because there was no terrestrial passage through the structure, thus forcing animals to attempt surface crossings over the roadway. Although mule deer were detected wading in Deer Creek as they traveled through the structure, future bridge design should incorporate terrestrial passage for a broader array of wildlife. Due to the presence of the creek, there was a sufficient amount of vegetation leading to the structure. However, this vegetation ended abruptly at the highway ROW, and the areas to the east and west of this ROW were largely devoid of vegetation due to grazing activities by domestic cattle and horses. Future efforts should focus on providing additional vegetative cover within the private land to the east and, particularly, the west. The east side of the highway did contain a greater amount of vegetative cover (moderate patches of trees and shrubs) and elk were only detected on this side of the highway. ROW fencing should also be designed so as to restrict livestock activity in the immediate area of the underpass entrance. Although no dimensions were given to this structure in the EIS, we strongly encourage the minimum underpass height to be greater than 20 feet in order to provide adequate clearance for elk. Furthermore, we recommend that the structure be a span bridge rather than a box culvert so as to further increase the likelihood that elk will utilize this structure.

The Deer Creek drainage forms the southern boundary of a CDOW-recognized elk migration corridor; Roland Gulch represents the northern boundary (Figure 13). The Roland Gulch culvert is also slated for enlargement into a large span bridge as part of future highway improvements. In its current condition, the culvert is too small to allow for the movement of ungulate species through the structure. Furthermore, the culvert was almost completely inundated with water, and at times when there was a terrestrial passage through the structure the traversable area was not very wide. Not surprisingly, muskrats and raccoons were common visitors to this structure. Future improvements will greatly enhance this passage, as the proposed height of the structure is slated to be 30-40 feet high.

Between Deer Creek and Roland Gulch, future highway improvements should allow for the safe passage of elk and other species across this important stretch of roadway. Such measures may include a combination of wildlife fencing (to prevent animals from attempting surface crossings in the immediate vicinity of the Deer Creek and Roland Gulch drainages) and driver alert systems. CDOT is in the process of testing measures for increasing driver awareness of wildlife along a stretch of U.S. 160 in the Durango-Bayfield control site. These measures, which may include roadway lighting triggered by a wildlife detection system and vegetation removal along the ROW, will be tested for their effectiveness in reducing AVCs. Similar measures have been assessed and have had been determined to have varying effectiveness (Ward 1982; Feldhammer et al. 1996; Lehnert and Bissonette 1997; Belant et al. 1998; Danielson and Hubbard 1998; Peterson et al. 2003). Such a system of wildlife crossing infrastructure will contribute to the safe passage of animals, particularly ungulates, across this stretch of highway.

For example, wildlife fencing would be appropriate along the Deer Creek and Roland Gulch stretch of U.S. 285. To the south of Deer Creek, fencing could extend to a developed area just south of Rosalie Road. To the north of Roland Gulch, fencing could tie into the surrounding topography. Access roads off of these two stretches of fencing could be grated to prevent animals from accessing the highway. Between these two fencing zones, a wildlife warning system could be installed to alert drivers to wildlife on the highway. This would prevent the entire 1.5-mile stretch of highway from being fenced, which might create a significant barrier to elk migration. The relatively flat topography of U.S. 285 between Deer Creek and Roland Gulch renders it suitable for the installation of an active animal detection system. Such a system could complement the proposed structures and could help to minimize the need for longer stretches of wildlife fencing. This design of multiple mitigation measures offers a unique solution to maintaining connectivity along this stretch of highway.

Other potential opportunities

We highlight three additional mitigation opportunities along this stretch of U.S. 285. We point out that these are not the only locations to improve connectivity, and additional monitoring should identify other stretches of road that may warrant mitigation measures. The first opportunity is the fill slope at Impact Site 1, which represents an excellent opportunity to provide a sizable crossing structure for ungulates, particularly elk. Elk were not detected at the Green Valley Grill underpass to the north, although they have been struck by vehicles along this stretch and were detected in this drainage before construction activities began. Elk may favor Impact Site 1 due to the high amount of coniferous forest located on both sides of the roadway, the large drainage that may serve to funnel movement to this location (the Green Valley Grill underpass is not located in such a drainage), and the low level of residential land use surrounding the fill slope location (houses, buildings, and associated human activity are common in close proximity to the Green Valley Grill underpass). Furthermore, due to the large amount of fill between the roadway and canyon bottom, there is an excellent opportunity to construct a span bridge at this location. We recommend a span bridge in order to increase the probability that elk will utilize this structure in the future.

The second opportunity occurs north of Shaffers Crossing, a site of high AVCs and an elk migration zone (Figure 13). Although there is a proposed structure for the Elk Creek crossing, the EIS suggests this structure be similar in dimensions to the arch culvert installed at the Green Valley Grill underpass. The portion of U.S. 285 across Elk Creek is surrounded by a high level of residential development and human activity, and elk and other species may be avoiding this area and attempting to cross elsewhere. An alternative solution to the proposed structure at Elk Creek might be to situate a structure along the elk migration corridor just north of Shaffers Crossing, on the northeastern slopes of Elk Creek (Figure 13). We suggest monitoring this stretch of road to 1) determine the activity level of ungulates in the immediate vicinity of Elk

Creek, 2) determine the activity level of ungulates within the elk migration corridor located north of Shaffers Crossing, and 3) identify the best location for a large structure to accommodate ungulate movement under U.S. 285. The ideal structure would be a span bridge as opposed to an arch culvert.

Finally, we suggest a larger structure than the one proposed in the EIS for the Wisp Creek location. Currently, a 3 foot wide x 3 foot high structure is proposed. However, this stretch of U.S. 285 experiences high AVC rates and recent AVC records indicate a high level of roadkilled mule deer (Figure 26). Therefore, we recommend a large enough structure to accommodate the movement of mule deer and elk.

Future monitoring recommendations

Since this is the only study site that experienced the 'after' treatment, any additional monitoring should determine 1) possible surface crossings in the immediate vicinity of the Green Valley Grill underpass and 2) the best locations for future mitigation opportunities in the control and impact sites. While we have documented use of the Green Valley Grill underpass, the rate of ungulate movement over the highway is unclear. Ideally, telemetry studies of deer and elk in the vicinity (particularly GPS telemetry to provide high resolution, continuous data on movement patterns) would provide valuable information on potential crossing zones along the roadway; we recognize, however, that funding and logistics might preclude such a study. At minimum, AVC and/or track surveys should continue within the area immediately surrounding the Green Valley Grill underpass in order to assess whether surface crossings over U.S. 285 are still occurring, thus diminishing the effectiveness of the newly-created underpass. Since no fencing is present above the underpass, there is still a potential for AVCs along this stretch of road. We specifically suggest systematic AVC surveys between Richmond Hill Road (to the south) and Springs Road (to the north) to verify whether animals, particularly ungulates, are continuing to be struck by vehicles. We recommend establishment of a pre-determined AVC rate for mule deer and elk that is deemed unacceptable by an interdisciplinary team of biologists and transportation officials. If the AVC threshold is exceeded, this would prompt an adaptive management strategy to install wildlife fencing in order to decrease AVC rates and optimize the use of the structure.

Track surveys are another useful measure to determine the occurrence of highway surface crossings in the immediate vicinity of the underpass. However, due to the difficult tracking substrate present along this stretch of U.S. 285, assessing surface crossings may be difficult without the use of artificially created track beds. If track surveys are desired, we recommend creating an artificial tracking substrate parallel to the highway and along the shoulder for a distance of 100m in either direction of the underpass. Such efforts will be more successful in documenting potential at-grade crossing attempts. Winter tracking will also be a useful tool, although such efforts during our study yielded inconsistent tracking substrate due to variations in snow cover over winter.

Future monitoring should also focus on areas that our surveys did not target: specifically Shaffers Crossing and Wisp Creek. We recommend developing a similar monitoring strategy to the one conducted in this study to fully assess the distribution of species along U.S. 285 and the relative abundance of ungulates along critical stretches of this highway corridor. By using a

BACI approach, one may be able to determine the success, or lack thereof, of future mitigation structures and strategies.

3.6.2 U.S. 160: Wolf Creek Pass

The Wolf Creek Pass study site did not contain large structures to accommodate the movement of ungulate species and no such structures are planned as part of future highway improvements. As such, the accumulation of snowpack in front of the underpass entrances poses a major obstacle for species attempting to utilize these structures. Furthermore, with the exception of the temporary lynx crossing structure (Impact Site 3), all of the structures contained water during a major portion of the year, providing little to no terrestrial passage through the culvert.

Underpass recommendations

Given the current situation, there are few opportunities to improve the functionality of the existing structures due to their role in conducting streams under U.S. 160. However, the new structures associated with future highway improvements will likely provide a terrestrial route through the structure. It is important that this terrestrial route contain natural substrate along the culvert floor to increase the likelihood that a variety of species will utilize it. One of the most difficult challenges at this study site is increasing the probability that a given species, particularly lynx, will encounter a given structure. The habitat surrounding the study site is heavily forested and intact, thus there are potentially unlimited opportunities for species to cross U.S. 160. Furthermore, this roadway is two lanes wide, winding (thus slower traffic speeds), and has relatively low traffic volumes; species may simply attempt surface crossings at will regardless if a structure is there or not. Lynx have been recorded crossing U.S. 160 in the immediate vicinity of the study site (see Section 4.0 of this report) but have never been documented using any of the structures. Given that future structures might potentially provide terrestrial passages, combined with the potential for increased traffic volume and greater vehicle speeds (due to the straightening of the roadway during highway improvements), measures to funnel target species to the underpasses should largely focus on the creation of vegetation runways to lead the animals to the structure. Wildlife fencing may also direct animals into the crossing structures, but fencing this stretch of U.S. 160 may create more of a barrier for species, particularly ungulates who would be unable to cross the fenced highway due to the lack of any appropriate crossing structures.

To reduce the potential for thrown snow from snowplows to block underpass entrances, we recommend a design to prevent the blockage of the underpass entrance similar to the concrete walls established above the entrance to the temporary lynx underpass. Such a design at other structures may be useful in preventing the accumulation of snow at the entrances to underpasses.

Other potential opportunities and future monitoring recommendations

We recommend further coordination with the CDOW lynx reintroduction efforts to determine which habitat features and topographical characteristics may influence lynx movement patterns to provide more guidance on where to place structures to facilitate their movement across U.S. 160. Furthermore, any identified locations that arise from this process should receive high priority. A possible solution to add more structures is to utilize funding allocated for Lynx

Crossing B, which currently has three structures proposed within very close proximity to each other. Rather, one structure may be sufficient and the remaining two may be utilized elsewhere to improve the future permeability of this stretch of highway.

We recommend continued coordination with CDOW to identify where the most suitable crossing locations along this stretch of highway should be. Such coordination may involve the programming of lynx collars to gain further insight to the features that these animals use to cross the highway. Programming may occur in such a fashion as to obtain more frequent locations so as to pinpoint specific highway crossing locations.

We also recommend that future camera monitoring efforts consider the baiting of approach camera stations with an artificial scent lure to draw species to the station. Such efforts in forest habitats similar to this study site have detected twice as many species than unbaited stations, particularly less common species such as pine marten and porcupine (Bonaker et al. 2007). In the case of this study area, baited stations should be situated away for the highway and underpass so as not to draw individuals to the road or underpass. Rather, baited stations should be placed at approach stations, located at greater distances from the roadway. These baited stations may obtain data on more secretive species, such as lynx, and provide insight as to which drainages and movement routes they are using to cross U.S. 160.

Although this information is being collected prior to construction activities, we recommend that another round of monitoring begin one year prior to actual construction, as populations may alter their distribution and abundance between the period we surveyed this location and the actual construction date.

3.6.3 U.S. 160: Durango-Bayfield

This study site included the only other location where mule deer were detected using a structure: the Florida River bridge. The other sites were fill slopes containing various-sized structures, each with varying potential to accommodate species movement in the future.

Underpass recommendations

The Florida River bridge represents a suitable structure type for wildlife permeability, although the structure was less than 12 feet high. This dimension may be too small for elk use, although no elk were detected along this stretch of U.S. 160. Proposed dimensions associated with future highway improvements recommend a height of 18-24 feet; our recommendations are that this be the minimum height for this structure. One aspect of this structure that could be improved is the availability of a terrestrial passage through the structure, although mule deer were frequently seen walking down the Florida River as they passed under the bridge. One reason this may be occurring is that the underpass clearance is higher over the river portion of the structure. Nonetheless, smaller animals are utilizing the west bank of this structure, as the east bank contains riprap which would hinder, if not obstruct, the movement of animals on this side of the river. We recommend the future structure provide adequate movement along both of the Florida River banks. Finally, the future structure should maintain vegetation leading up to the structure so that the current vegetative cover is equaled or maximized. The river channel contains dense stands of vegetative cover, providing a natural movement route for several species.

Other potential opportunities and future monitoring recommendations

The remaining sites in this study area all contained various sizes of culverts under fill slopes, providing potential opportunities for structures in the future. One of the proposed sites for a future structure is the Pioneer Irrigation Ditch (MP 94.6). We did not monitor this location; rather, we monitored the Long Hollow drainage to the west. The Long Hollow drainage appeared to be better situated for wildlife movement due to its position along a drainage, the presence of vegetation leading to the underpass entrance, and its relative isolation from adjacent houses and human activity. We detected mule deer and coyote at the underpass approaches, and bobcat utilizing the existing structure. Therefore, this structure may be a more appropriate location for the proposed Pioneer Irrigation structure, although we recommend monitoring the proposed underpass site to help guide placement.

A similar situation exists to the east at the two control site fill slopes. The western of these fill slopes, MP 95.7, is the site of a proposed structure (a 36 foot wide x 14 foot high arch culvert) that we monitored as Control Site 1. The eastern fill slope, MP 96, contains two small culverts unsuitable for ungulate use (although coyotes, gray foxes, bobcats, and badgers were detected using this structure). Our findings suggest the eastern fill slope (MP 96) would be the better location for a structure, although we recommend the structure be a span bridge as opposed to an arch culvert to increase the probability of elk use. Although elk were more frequently detected at the western fill slope, creating a structure suitable for them at this location may be more difficult due to the lower fill slope height. Furthermore, the eastern structure is on the western boundary of an elk migration corridor (Figure 20). Additionally, the presence of coyote, gray fox, bobcat, and badger at the eastern fill slope make this an attractive location to situate a large structure. Finally, this fill slope is located on BLM land, so future development would not threaten this crossing location.

One negative aspect of the eastern fill slope is the high amount of human activity recorded along this transect, particularly the use of all-terrain vehicles through the culvert. This illegal activity was recoded along the entire CDOT ROW between both of these fill slopes. We recommend that efforts be made to prevent illegal use of this structure, particularly in the future if a large structure constructed specifically for wildlife movement is built.

Given the rate of AVCs along this short stretch of highway, another consideration may be to incorporate structures at both fill slope locations. These two structures may also be incorporated into CDOTs AVC reduction study, and a design similar to the one proposed along U.S. 285 between Deer Creek and Roland Gulch should be considered, particularly to the east toward Dry Creek (which was not surveyed in this study). Furthermore, the fill slope to the west of the Florida River presents another opportunity to install a wildlife crossing structure. This area also experiences relatively high AVC rates.

Although this information is being collected prior to construction activities, we recommend that another round of monitoring begin one year prior to actual construction, as populations may alter their distribution and abundance between the period we surveyed this location and the actual construction date.

4.0 Lynx-Roadway Interactions

4.1 Wildlife Underpass Monitoring

4.1.1 Goals and Objectives

The Colorado Department of Transportation, in cooperation with the Federal Highway Administration (FHWA), has conducted formal consultation under Section 7 of the Endangered Species Act (ESA) to assess impacts associated with highway improvements on the federally listed Canada lynx. Prior to and after the listing of the lynx, CDOT initiated informal and formal consultation with the U.S. Fish and Wildlife Service (USFWS) for the purpose of identifying the possibility of 'take' (as defined in the ESA) and conservation measures to reduce the likelihood of take. As a result of coordination, CDOT and FHWA incorporated underpasses into the design of the Muddy Pass Safety Improvement Project (two underpasses), the Berthoud Pass East Project (two underpasses), the State Highway 9 North of Silverthorne Improvement Project (two underpasses), and the Wolf Creek Pass Project (one underpass). These are the seven completed underpasses we monitored as part of CDOT's Wildlife Underpass (Lynx) Monitoring Research Study.

The objective of the project was to develop and implement a monitoring plan for these seven underpasses. Since lynx are rare, wide-ranging, and have large home ranges, the likelihood of this project to collect data on the use of the structures by lynx exclusively was small. Our survey techniques enabled us to assess not just possible lynx usage of the crossing structures, but also underpass use by a suite of wildlife species, as well as humans, domestic dogs, and domestic cats. Herein, we present data from our underpass surveys.

4.1.2 Methods

Remotely-triggered infrared digital cameras (Cuddeback Digital Scouting Game Camera) housed in weatherproof lockboxes, were stationed at underpass entrances at each of the seven study underpasses:

1) Muddy Pass (MP1): U.S. 40, MP 155.65, corrugated steel pipe (9' wide X 6' high X ~40' long)
2) Muddy Pass (MP2): U.S. 40, MP 156.2, concrete box (12' X 10' X ~40')
3) Berthoud Pass (BP1): U.S. 40, MP 245.9, concrete box (8' X 6' X ~70')
4) Berthoud Pass (BP2): U.S. 40, MP 246.9, concrete box (6' X 4' X ~80')
5) Silverthorne (S1): SH 9, MP 109.98, concrete box (8' X 8' X ~95')
6) Silverthorne (S2): SH 9, MP 111.58, concrete box (7' X 6' X ~158')
7) Wolf Creek (WC): U.S. 160, MP 179, corrugated steel pipe (5'10" X 4'2" X 121')

Figure 29 shows the locations of these underpass sites, as well as the U.S. 285 Conifer-Bailey and U.S. 160 Durango-Bayfield study sites from the Wildlife Mitigation Structures study described in Section 3; the U.S. 160 Wolf Creek Pass Impact Site 3 in the Wildlife Mitigation

Structures study is synonymous to Underpass 7 (WC) identified in the list above. GPS coordinates of each underpass are presented in Appendix C.1. One digital camera was stationed at each of the six study underpasses in CDOT Regions 1 and 3 (MP1, MP2, BP1, BP2, S1, S2) in October 2004. A digital camera was stationed at the study underpass in CDOT Region 5 (WC; Impact Site 3 in the U.S. 160, Wolf Creek Pass site described in Section 3) in May 2005, after snow cover that had buried the underpass entrances had cleared. Initially, all cameras were stationed outside and directed towards the underpass entrance. Due to increasing snow cover, however, all cameras were eventually moved inside the underpass entrance as noted below.

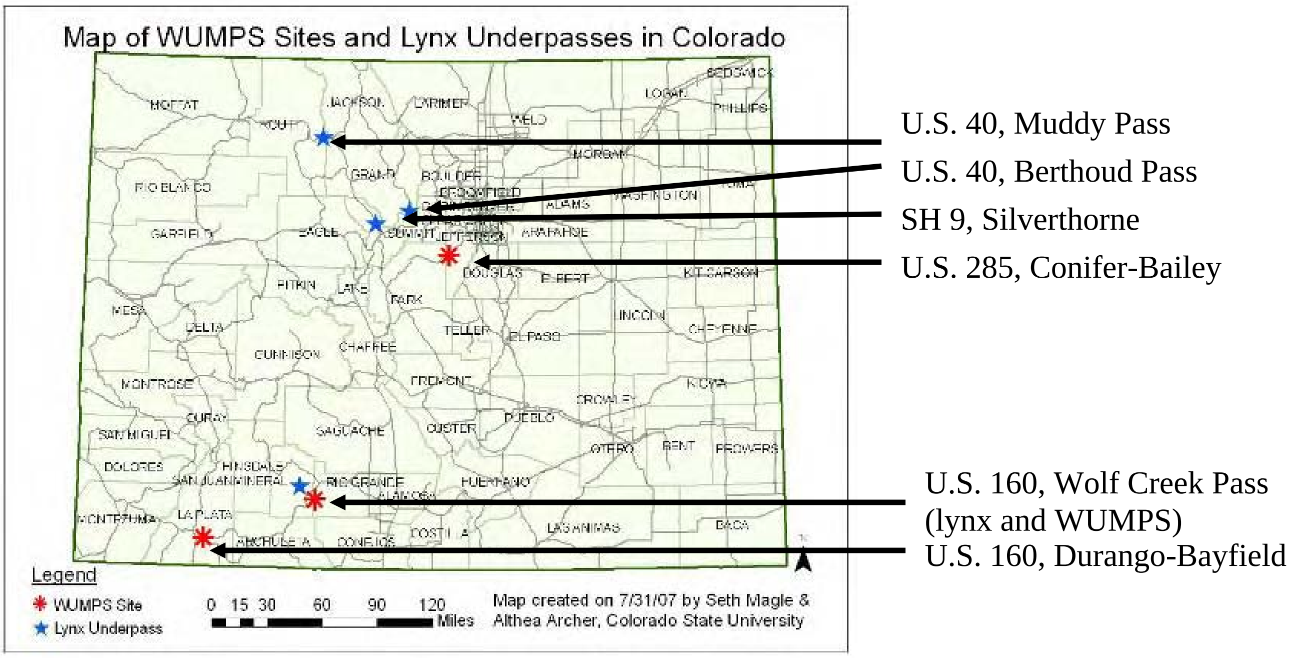


Figure 29. Map of lynx underpasses and WUMPS sites in Colorado.

The digital cameras take full-color, high-resolution photos, can store up to 400 pictures on a 128 MB removable SmartMedia card, and can last up to three months (depending on number of pictures taken) on one set of batteries. Each pass by the infra-red sensor triggers the camera, and date and time of pass are recorded on each print.

At each site, we totaled the number of sampling days the camera was active ("camera days"); this sampling effort included all days where the camera was operational, including days where snow partially or completely blocked the underpass entrances. For each underpass, we also totaled the number of pictures detected for each species; if multiple individuals (images) were captured within a photograph, each individual (image) was counted singularly. To augment camera surveys, wildlife tracks opportunistically encountered in and near the underpass were also recorded.

It is important to emphasize that the camera surveys at the underpasses should not be considered a true "census" of the total frequency of use by wildlife. In any camera survey, it remains a possibility that animals could pass by the camera without being photographed. However, to ensure cameras were functioning properly, typically when an underpass was visited by researchers, several (2-3) test photos were taken by passing by the camera and checking the resulting photograph. If the picture was not optimal, adjustments were made to the camera. Further, we have recorded only a few instances of animal tracks in the underpass without a resulting photograph.

4.1.3 Results and Discussion

Through May 2007, digital cameras stationed at the seven target underpasses sampled nearly 5400 camera days and recorded over 800 images of wildlife, humans, domestic dogs, or domestic cats (Table 19; Figure 30). No lynx were recorded using any of the seven study underpasses. Overall, the most images were recorded at the concrete box culvert at Muddy Pass (MP2: 495 pictures, 925 camera days), followed by the Silverthorne concrete box culvert at MP 111.58 (S2: 109 pictures, 934 camera days), the Silverthorne concrete box culvert at MP 109.98 (S1: 96 pictures, 945 sampling days), the steel pipe culvert at Muddy Pass (MP1: 57 pictures, 648 camera days), the steel pipe culvert at Wolf Creek (WC: 53 pictures, 685 sampling days), and the two underpasses along Berthoud Pass (BP1: 18 pictures, 932 camera days and BP2: 8 pictures and 828 sampling days) (Table 19; Figure 30).

Table 19. Number of pictures recorded by camera stations at seven roadway underpasses through May 2007*

	MP1	*MP2*	*S1*	*S2*	*BP1*	*BP2*	*WC*	*TOTAL*
Start Date	10/17/2004	10/17/2004	10/9/2004	10/9/2004	10/23/2004	10/23/2004	5/2/2005	
Camera Days	648	925	945	934	932	828	685	5394
mule deer	27	421	2	0	0	0	6	456
human	2	57	37	10	18	8	31	160
marmot	16	3	26	0	0	0	5	46
domestic cat	0	0	0	19	0	0	3	22
red fox	3	1	25	54	0	0	0	83
snowshoe hare	6	2	0	0	0	0	5	13
ground squirrel	0	1	1	10	0	0	0	12
domestic dog	0	0	0	8	0	0	0	8
cottontail	0	0	0	7	0	0	1	7
porcupine	2	5	0	0	0	0	1	7
coyote	0	0	0	0	0	0	1	1
black bear	1	0	2	0	0	0	0	3
raccoon	0	0	0	1	0	0	0	1
moose	0	2	3	0	0	0	0	5
bat	0	1	0	0	0	0	0	1
marten	0	1	0	0	0	0	0	1
long tail weasel	0	1	0	0	0	0	0	1
TOTAL	57	495	96	109	18	8	53	836

* see text for locations of each underpass

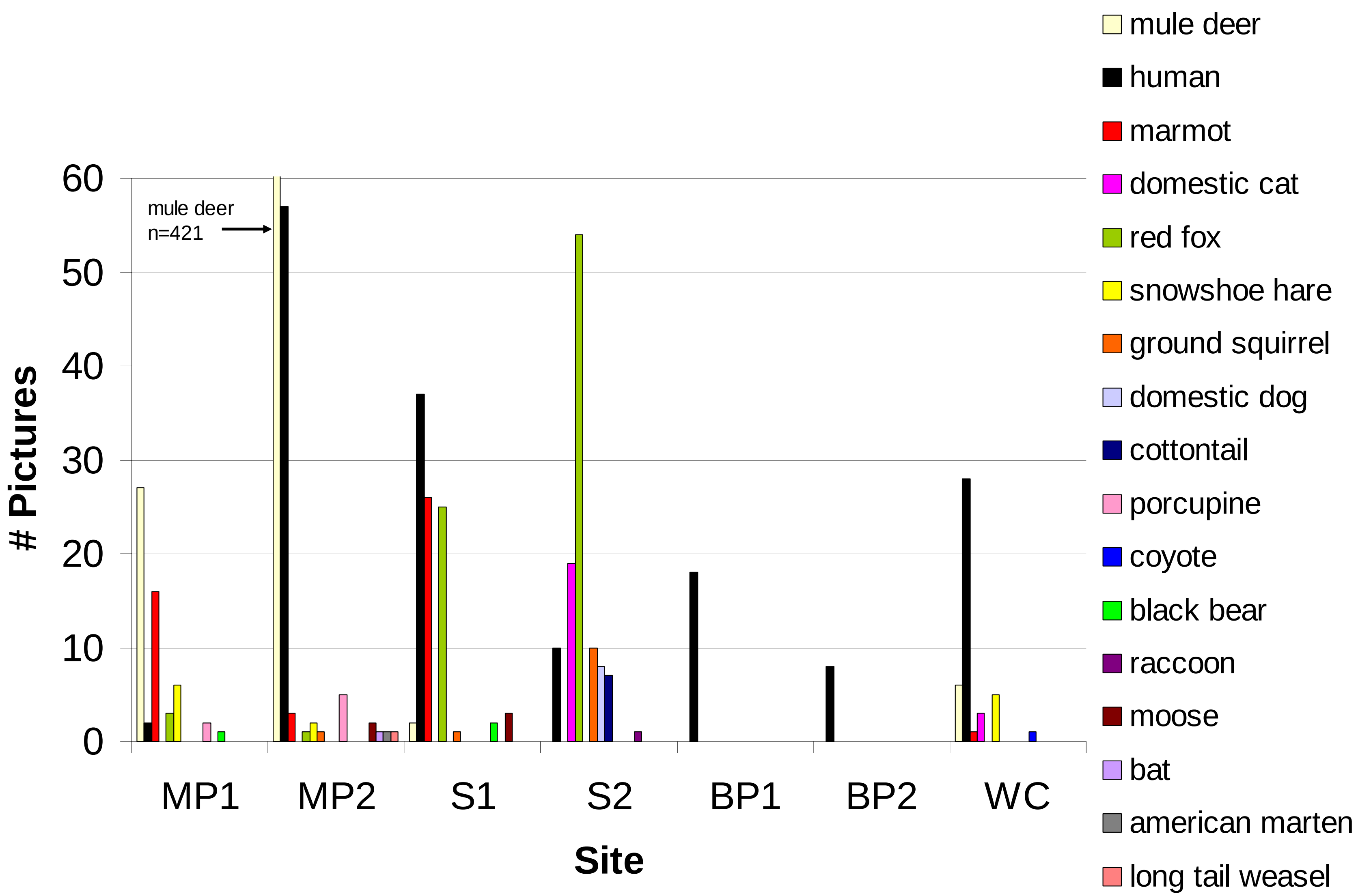


Figure 30. Summary of wildlife use at seven lynx underpasses.

Muddy Pass (MP1): U.S. 40, MP 155.65

For MP1, the digital camera recorded frequent pictures of mule deer and marmots, and occasional images of humans, red fox, snowshoe hare, porcupine, as well as one photograph of a black bear (Figure 31). It is important to emphasize, however, that all photographs were recorded prior to October 2005, when the MP1 digital camera was stationed outside the underpass, focused towards the underpass entrance. Consequently, for some images, it was not possible to determine if the animal actually traveled through the underpass or was simply crossing in front of the underpass entrance and camera station. Indeed, the underpass was likely not used by the large mammals photographed (e.g. black bear, mule deer) prior to October 2005, as no tracks were found of these species within the culvert, and no wildlife photographs were recorded after the camera was moved inside the underpass (Figure 31). Appendix C.2 provides representative photos of species detected at the underpass.

Most activity was recorded in summer, except for pictures of snowshoe hare and red fox December 2004-February 2005**.** The underpass was never totally blocked by snow during winter 2004-2005, but the tunnel entrance had a space of only 1-2 feet from the top of the tunnel to the snow, likely limiting animal use of the tunnel. Although the camera was stationed outside the underpass during this time, we adjusted it to remain operational as snow levels increased, thus allowing documentation of the few visits it did receive in winter. In November of 2005 the digital camera was moved into the culvert approximately 10 meters from the east entrance.

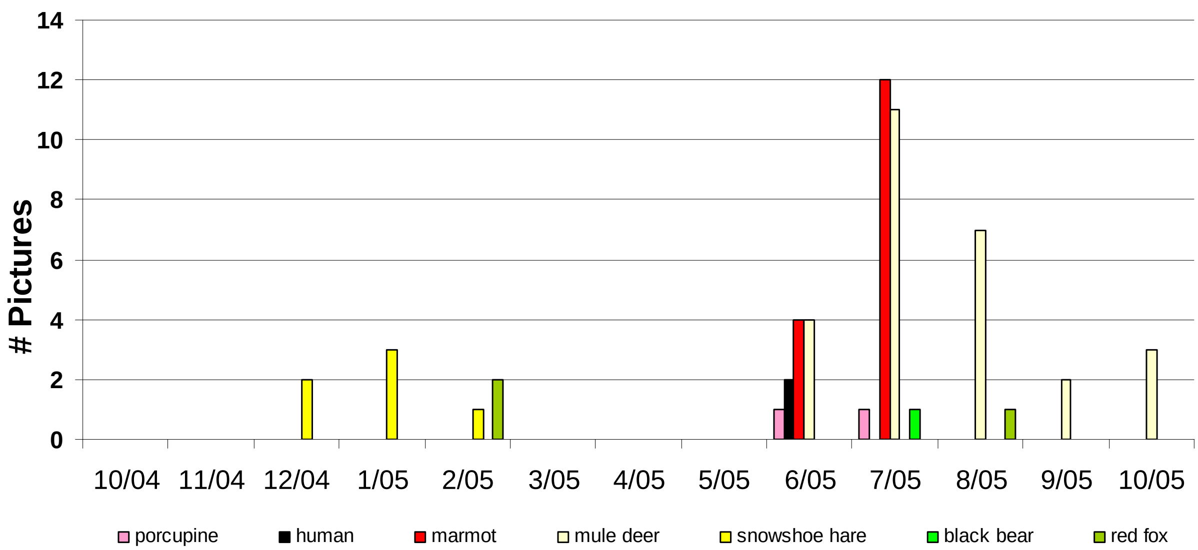


Figure 31. Monthly number of pictures taken by camera station MP1. Note: camera was placed inside after October 2005, no new pictures were recorded inside the underpass throughout the remainder of the study.

In early December 2005 both tunnel entrances were completely sealed off by snow. In May of 2006 the snow levels had receded enough to replace the camera that had been enveloped by ice and snow over the winter. The new camera was located in the same position as the last one for the following six months until environmental conditions similar to the previous winter became so severe that the camera was moved outside onto a tree approximately three meters from the east entrance. During the summer of 2006, heavy loads of mud and sediment filled the tunnel again and a perennial stream continued to run through the tunnel until late summer. The winter of 2006-2007 produced nearly the same amount of snow fall and ice in and near the tunnel. However, the tunnel entrances were not sealed off like the previous winter making it possible for small mammals to access the underpass.

Below is a brief review of conditions associated with MP1:

<u>Vegetation regeneration</u>

- Summer 2005: Grass growth high on east entrance; less grass regeneration on west side
- Summer 2006: Grass growth again was comparable to summer 2005 along the east entrance; grass regeneration on the west side was far higher than in summer 2005
- Spring 2007: Early grass growth looks promising for the summer of 2007, heavy snow comparable to the previous winter has helped saturate soils

<u>Drainage</u>

- Water flowing through tunnel during spring melt and through summer
- Mitigation for water drainage appears to have failed on west side of tunnel
- The level of mud and soil has increased dramatically over the past two years inside the tunnel
- Ice is present inside the tunnel throughout the winter and early spring reaching a thickness of approximately two feet during the coldest months of the year

<u>Environmental conditions</u>

- December 2004: Snow accumulation 4 ft (1.2 m) deep on east tunnel entrance
- Difficult to reach underpasses during winter months because of snow banks along road side, inhibiting parking vehicles safely
- January 2005: East tunnel entrance nearly blocked by drifting snow, likely limiting underpass usage by large mammals
- February 2005: Snow drifting inside west entrance
- Spring 2005: Tunnel floor covered in ice
- Late May 2005: All snow melted and water moving through tunnel
- Summer 2005: Heavy mud inside tunnel
- December 2005: East tunnel entrance completely closed off by snow, ice in tunnel 1.5-2 ft (0.5-0.6 m) thick
- Tunnel entrance sealed off until early May 2006 by snow

- Heavy snow run-off from the winter of 2005-2006 increased the amount water and sediment inside the tunnel
- Winter 2006-2007 was not as severe as 2005-2006. The tunnel entrance was never completely sealed off. However, snow levels and ice accumulation in the tunnel were again very high.

Representative site photos and underpass conditions are shown in Appendix C.3.

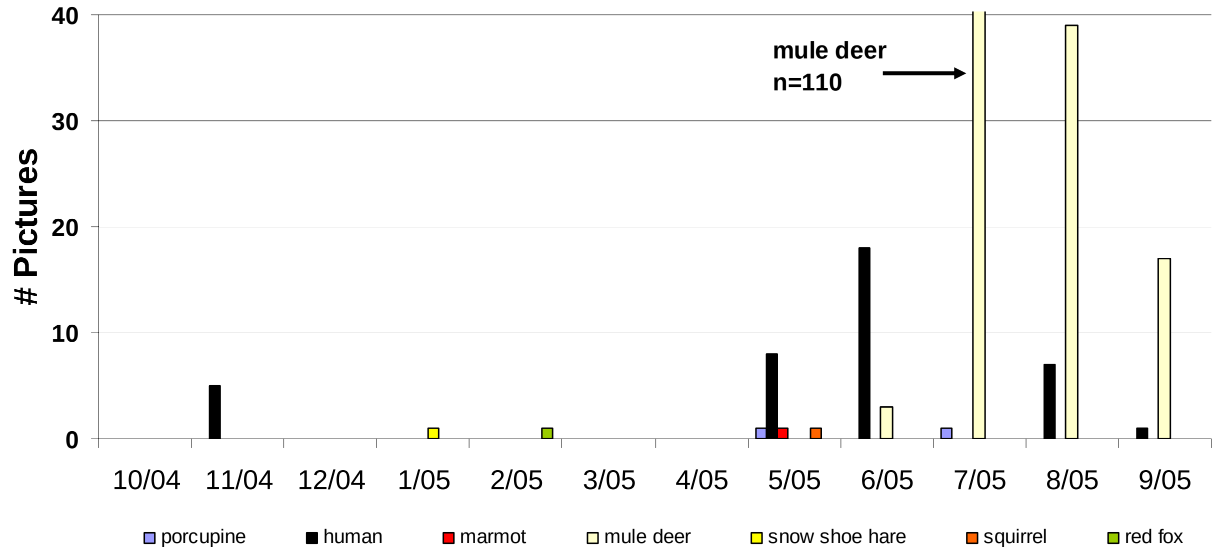
Observations and management suggestions

The location of the underpass seemed appropriate with forested edges on both sides of the tunnel. Access to water resources for wildlife was available on both sides of the underpass. The corrugated steel tunnel was fairly small in diameter limiting access to large mammals including deer, bear, elk, and moose. A larger tunnel may be more beneficial for larger wildlife, and extending the ends of the tunnel farther from the highway edge would reduce the chance of sealing off the tunnel during the winter months. Snow throw from plows increased the level of snow at and around the underpass well above natural levels during the winter. The drainage system in place to mitigate water failed in the spring of 2005. Water continues to flow throughout the summer and high accumulations of ice form in the winter, reducing the overall height of the tunnel by two feet and making it even more difficult for large mammals to access the underpass. Ice inside the tunnel may impact ungulate movement because of the slope and slippery conditions. Leveling the tunnel and reducing the amount of ground water flow through the tunnel may make it more accessible during the fall and early winter months for larger mammals.

Muddy Pass (MP2): U.S. 40, MP 156.62

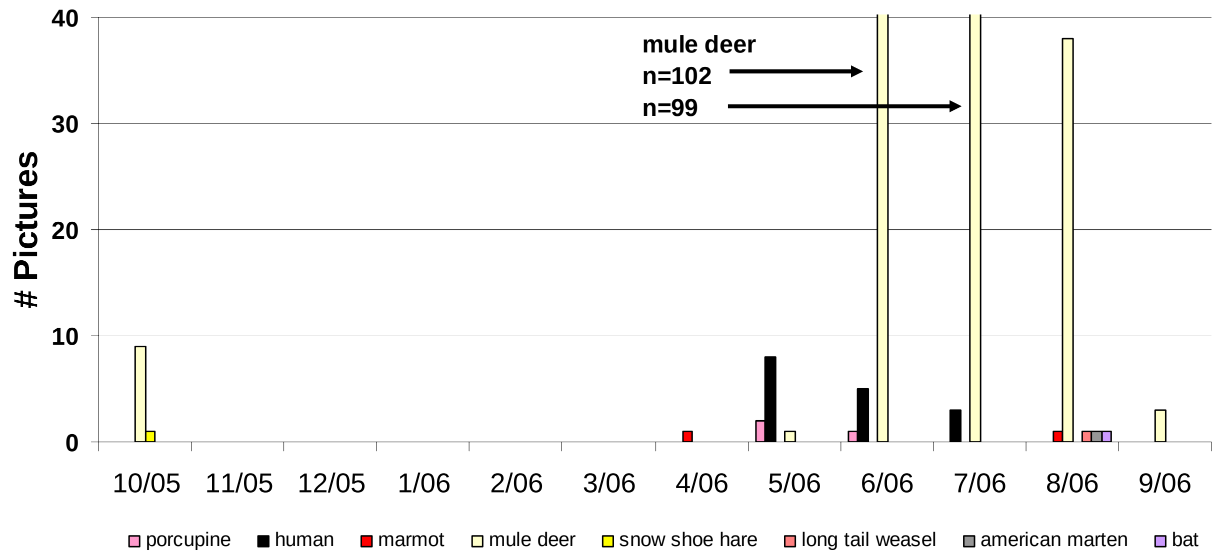
For MP2, the majority (85%) of pictures were of mule deer, most of which were of a single doe and her fawns (Table 19). It appeared that the same doe from the summer of 2005 returned again in the summer of 2006, visiting the underpass frequently. On several occasions while checking the camera station the doe was inside the tunnel or very near on the east side in an aspen stand. Humans frequently used the underpass during both summers of 2005 and 2006. Additionally, we have recorded snowmobile tracks outside both entrances of MP2 during the winters, but in only one case did we capture pictures of a snowmobile using the tunnel in the winter of 2006-2007. Digital cameras also recorded pictures of a marmot, a golden-mantled ground squirrel, a red fox, snowshoe hare, porcupine, a bat (family Vespertilioindae), an American marten, a moose, and a long tailed weasel. Appendix C.4 provides representative photos of species detected at the underpass. The camera station never recorded coyotes, but coyote tracks have been recorded outside the tunnel. As with MP1, underpass usage was low or absent in winter, and higher in summer (Figure 32). The number of wildlife visits during the summers remained constant through both years and the number of species increased in the summer and winter of 2006 with the visitations of a marten, long-tailed weasel, moose and a bat. This underpass was never completely blocked by snow, with at least a 6-8 foot (1.8-2.4 m) high opening at the underpass entrances available throughout the winters.

a)



mule deer
n=110
# Pictures
40
30
20
10
0
10/04
11/04
12/04
1/05
2/05
3/05
4/05
5/05
6/05
7/05
8/05
9/05
porcupine
human
marmot
mule deer
snow shoe hare
squirrel
red fox

b)



mule deer
n=102
n=99
# Pictures
40
30
20
10
0
10/05
11/05
12/05
1/06
2/06
3/06
4/06
5/06
6/06
7/06
8/06
9/06
porcupine
human
marmot
mule deer
snow shoe hare
long tail weasel
american marten
bat

c)

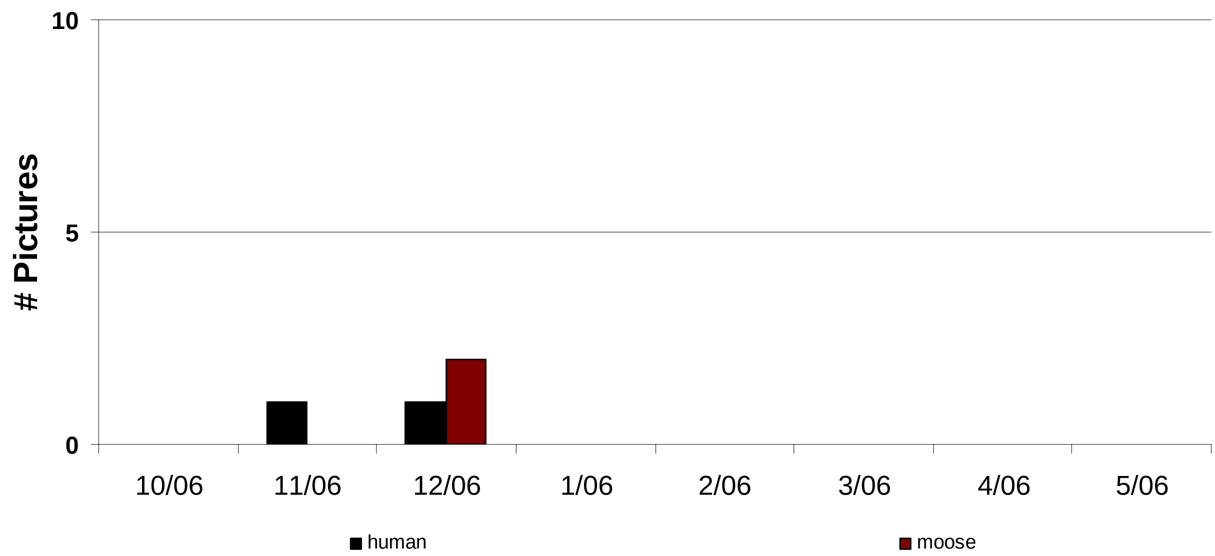


Figure 32. Monthly number of pictures taken by camera station MP2 from a) October 2004 to September 2005, b) October 2005 to September 2006, and c) October 2006 to May 2007.

Below is a brief review of conditions associated with MP2:

<u>Vegetation regeneration</u>

- East and west entrances appear to have more natural vegetation after summer 2005 compared to October 2004
- Summer 2005: Grass cover reaches both entrances
- Summer 2006: Grass cover exceeded the height and density of 2005 on the east side, however, the west side of the tunnel has not changed much from 2005 and is still fairly sparse in areas

<u>Drainage</u>

- No moving water through tunnel during summer of 2005
- In the spring of 2006 some water was moving through the tunnel between the ice sheet left over from the past winter snow
- Overall water drainage has not been a major issue for this underpass
- Heavy snow accumulation throughout the winter leaves the soils inside the tunnel heavily saturated throughout the spring, making it very muddy but not enough to limit wildlife use

<u>Environmental conditions</u>

- Mid-December 2004: snow outside tunnel 3-4 ft (0.9-1.2 m) deep, likely at least partially inhibiting large mammal movement

- January 2005: Heavy drifting snow inside tunnel, up to 20 ft (6.1 m) inside west entrance, 10 ft (3.0 m) inside east entrance
- March 2005: 4-8 ft (1.2-2.4 m) snow outside tunnel
- April 2005: Tunnel floor almost completely covered in ice 1-2 inch (2.5–5.1 cm) due to snow melt
- May 2005: Most snow and all ice gone
- Tunnel floor muddy through June 2005
- Dry conditions inside the tunnel throughout late summer and early fall of 2005
- Heavy snow during the winter of 2005-2006, difficult to access tunnel from highway due to high snow drifts from snow plows and natural accumulation
- Snow levels were high (six feet) at both entrances until May of 2006
- Drifting snow (five to six feet) inside west entrance
- Ice levels were higher than the previous year but were gone by May of 2006
- The tunnel was muddy again through the early summer months
- Dry conditions were present again throughout the summer months and early fall of 2006
- Snow levels during winter 2006-2007 were not as high as the previous winter

Representative site photos and underpass conditions are shown in Appendix C.5.

Observations and management suggestions

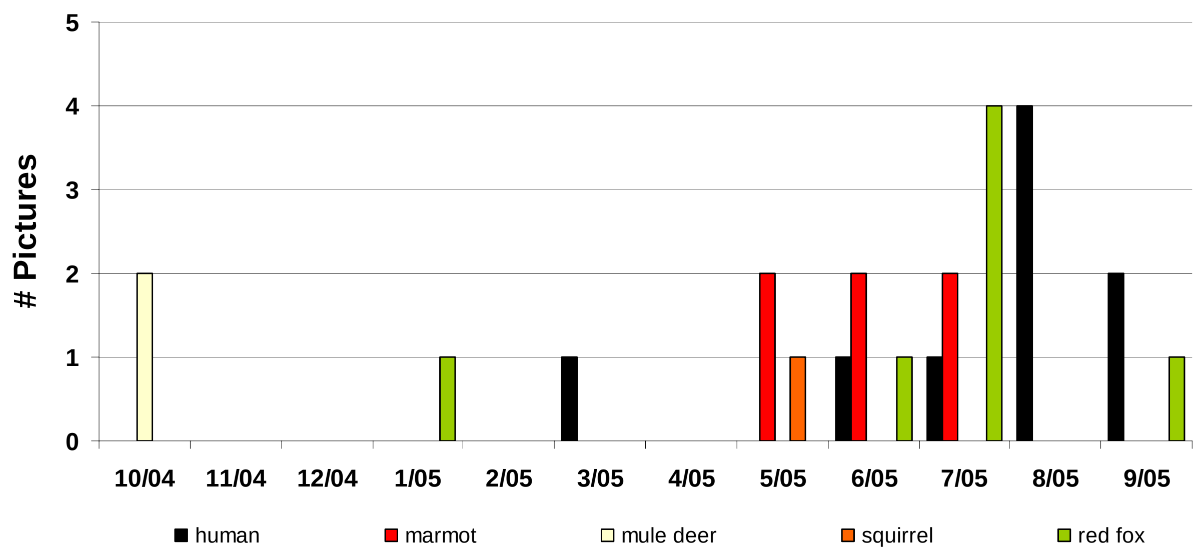
The concrete tunnel near Muddy Pass I seemed well placed. Much like the corrugated steel tunnel, there is a forested edge on both sides. The vegetation around the tunnel had a higher level of regeneration compared to the other tunnels surveyed. Water resources were abundant near the underpass with beaver ponds and a small stream only 50 meters away. The drainage in the tunnel was not an issue. There is a small berm along the west tunnel entrance that blocks water from flowing freely into the underpass. During the spring the only minor problem that existed was snow melt leaving high levels of mud in the tunnel. Sediment loads inside the tunnel did not increase during this study. Ice levels in the tunnel during the spring made conditions slippery which may limit ungulate passage in the early spring months. The dimensions of this tunnel seemed well suited for wildlife use. The height of the tunnel provided sufficient room for large ungulates such as moose and elk. The length:width ratio of the tunnel was short, allowing light to penetrate and illuminate the entire tunnel. A problem observed with such a short tunnel, however, was the snow throw from the plows leaving high drifts near the tunnel entrance during the winter months. During the hot summer months, the temperature within the tunnel was much lower, a potential factor for the single doe that spent a large amount of the time inside the tunnel during the summer. Pedestrian use was fairly high compared to the other tunnels surveyed, which may have a negative impact on wildlife using the tunnel. During the winter months snowmobile use was high. Visible tracks were found at both entrances and on one occasion a snow mobile was photographed using the tunnel, contradictory to the sign restricting human and motorized use of the tunnel. Overall, this underpass seemed to be one of the most functional underpasses that were monitored during this study. Many of the factors that plagued other tunnels were not present at this underpass (e.g. drainage, mud, water, ice and poor revegetation).

Wildlife use was high and the overall design of the tunnel was well suited for a wide range of species.

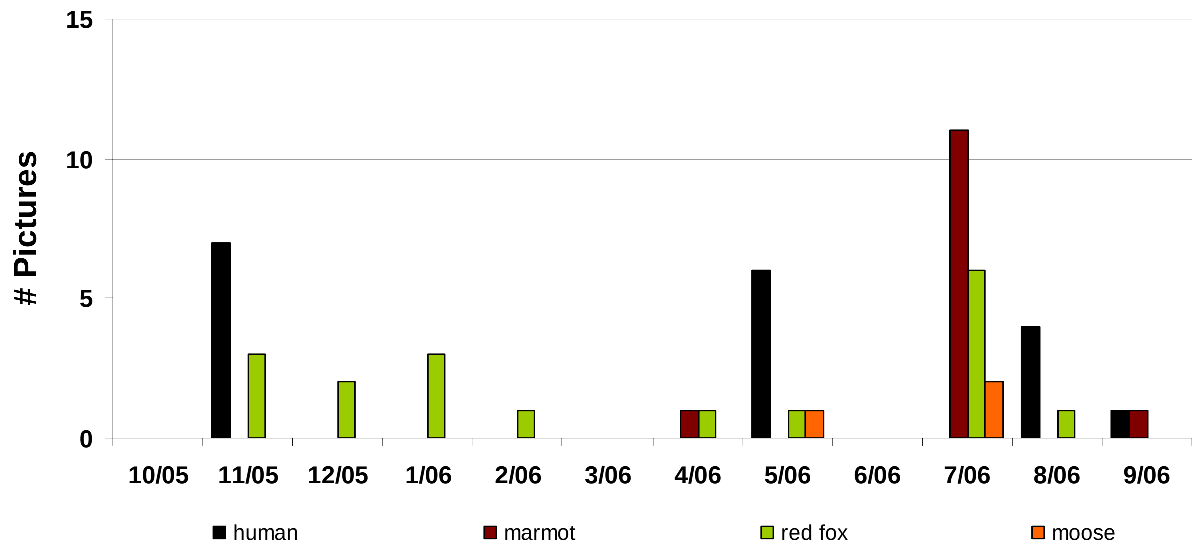
Silverthorne (S1): SH 9, MP 109.98

For S1, the digital camera recorded moderate human traffic, mostly anglers using the tunnel to access the Blue River, as well as several hunters in fall. The camera station also recorded underpass usage by red fox, marmot, mule deer, moose, black bear and a ground squirrel (Table 19). Appendix C.6 provides representative photos of species detected at the underpass. Coyote tracks were also noted outside the tunnel, and a deer road mortality was recorded ca. 200 ft north of the underpass on the southeast side of the road. Except for red fox and human visits during winter, most locations were recorded during summer months (Figure 33). Due to rising snow, the digital camera was moved inside the underpass November 23rd 2004.

a)



b)



c)

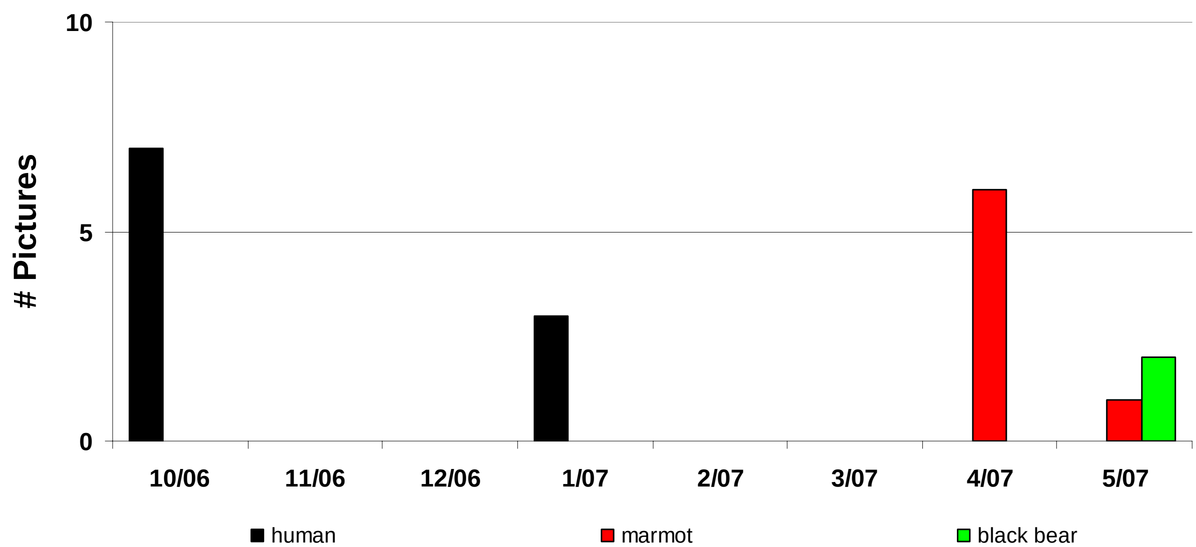


Figure 33. Monthly number of pictures taken by camera station S1 from a) October 2004 to September 2005, b) October 2005 to September 2006, and c) October 2006 to May 2007.

Below is a brief review of conditions associated with S1:

Vegetation regeneration

- Summer 2005: Little grass regeneration up to 15 ft (4.6 m) outside both tunnel entrances
- Summer 2006: Grass regeneration did not increase much from the previous summer

Drainage

- No moving water through tunnel
- Ice forms along underpass floor during winter and early spring

Environmental conditions

- January – April 2005: 2-4 ft (0.6-1.2 m) snow outside west entrance
- Winter 2005: Low snow accumulations at east entrance: 0-1 ft (0-0.3 m)
- April- May 2005: Tunnel floor covered in ice, likely inhibiting human and animal movement
- May 2005: All snow gone outside tunnel
- Winter 2006: 4-5 ft snow outside west entrance
- Spring 2006: Ice on tunnel floor

Representative site photos and underpass conditions are shown in Appendix C.7.

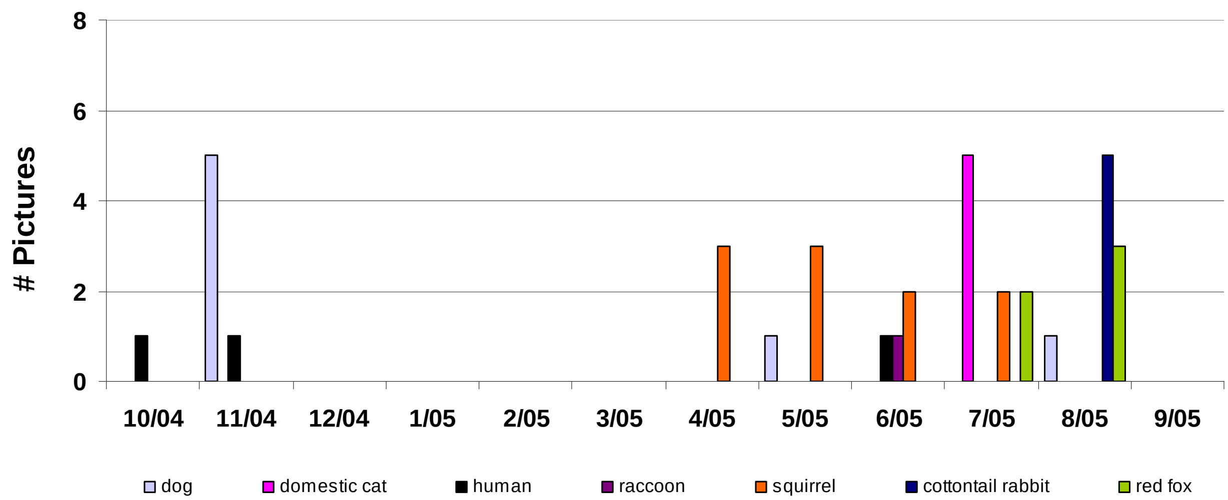
Observations and management suggestions

The local topography was well suited for wildlife movement on the west side of the underpass. The hills and gully that border the west side naturally channel wildlife towards the underpass. However, the east side of the underpass borders the Blue River, which may act as a barrier for smaller animals, especially during periods of high runoff. The height and width of the tunnel was suitable for all species of wildlife and the length of the tunnel was sufficiently short for light to penetrate and illuminate the interior of the underpass. During the winter and spring months the icy conditions and slight slope of the underpass made it difficult to walk through the tunnel to check the camera station. This may be a limiting factor for larger bodied animals using the tunnel. Snow conditions were mild compared to other underpasses. Constant solar radiation along the east side of the tunnel kept snow levels fairly low and the only deep snow occurred on the west side in the shade. Similar to the underpass at Muddy Pass (MP1), human use was noticeable. Anglers and hunters and other pedestrians used the underpass often. Graffiti was found inside the east entrance in the spring of 2007. There are no signs outside the tunnel notifying the public that the tunnel is for wildlife use only. Overall, S1 seemed to be one of the best tunnels suited for wildlife passage.

Silverthorne (S2): SH 9, MP 111.58

For S2, red fox was the most photographed species followed by domestic cat, including a photograph of a cat with a prey item (ground squirrel) in its mouth. The camera station also recorded pictures of ground squirrels, domestic dog, cottontail rabbits, and a raccoon; the underpass received relatively low human traffic (Table 19). Appendix C.8 provides representative photos of species detected at the underpass. No photographs were recorded December 2004-March 2005 (Figure 34); this lack of activity was not due to total blockage of the underpass entrance by snow. Due to rising snow, the digital camera was moved inside the underpass November 23rd 2004. Pictures of domestic cats declined after 2005 and red fox became the most frequent visitor. Similar to the other underpasses, activity was highest during the summer months and nearly absent during the winter and early spring.

a)



b)

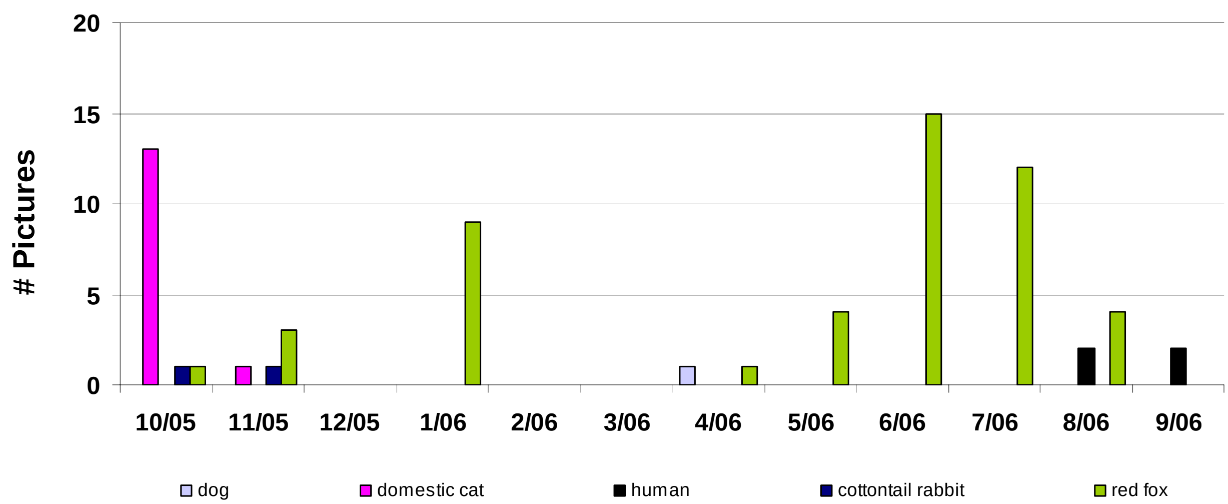


Figure 34. Monthly number of pictures taken by camera station S2 from a) October 2004 to September 2005 and b) October 2005 to September 2006. Only three human photos were recorded between October 2006 to May 2007.

Below is a brief review of conditions associated with S2:

Vegetation regeneration

- Summer 2005: Grass regeneration on east side of tunnel; little to no grass regeneration on west side
- Summer 2006: Excellent grass regeneration on east side; marginal grass regeneration on west side due to poor soils and late spring runoff

Drainage

- May 2005: Tunnel floor covered in debris (gravel and mud) because of runoff
- August 2005: tunnel floor clear of debris
- March to May 2006: ice inside tunnel; approximately eight inches in thickness
- Summer 2006: tunnel clear of sediment

Environmental conditions

- January 2005: West entrance of tunnel: 2 ft (0.6 m) of snow
- February 2005: Heavy drifting snow up to 15 ft (4.6 m) inside west tunnel entrance. East tunnel entrance: 1-3 ft (0.3-0.9 m) snow, moderate drifting snow inside entrance
- April 2005: West entrance of tunnel: 4 ft (1.2 m) of snow; floor of tunnel covered in ice
- May 2005: Ice and snow gone
- Winter 2005-2006: Moderate to heavy drifting snow inside both tunnel entrances; heavy snow accumulation on outside tunnel on west side
- Spring 2006: runoff cleared out all debris and sediment
- Winter 2006-2007: Moderate drifting of snow on east and west side, comparable to winter 2004-2005.

Representative site photos and underpass conditions are shown in Appendix C.9.

Observations and management suggestions

The S2 underpass was fairly similar in topography as the S1 tunnel. The hillside and forested edge along the west entrance provided cover for wildlife before accessing the underpass along SH 40. However, the east entrance was bordered by the Blue River similar to the S1 tunnel. The Blue River along this section is narrower and water flows are more turbulent with large rocks in the river bed. Wildlife crossing this section of the river appears to be more difficult compared to the section bordering the S1 tunnel, which is wider and less turbulent. The overall dimensions of the underpass were suitable for small to medium size wildlife species, whereas the fairly short height limited passage of ungulates. The overall length of the tunnel did not deter light from illuminating the inside walls of the tunnel, although the tunnel was relatively long compared to S1 and MP2. Snow throw from plows in the winter only affected the west side of the tunnel, which was never completely blocked off. The regeneration of grass on the east side of the underpass improved yearly and had the highest amount of regeneration of all tunnels surveyed. Ground water flow through the tunnel was a small issue during the spring and early summer months. Sediment from the hillside on the west entrance would flow into the underpass during the early spring months and would be washed out the east side during the heaviest portion of runoff in the late spring and early summer months. The hay bails along the west entrance did very little to prevent sediment and debris from entering the tunnel. A consideration for future planning would be to build a small berm outside the tunnel entrance to prevent sediment and ground water flow through the tunnel, or new hay bails placed at the tunnel entrance each year. Domestic pets including dogs and cats were frequent visitors at this underpass compared to the others surveyed. On one occasion the camera took a picture of a domestic cat with a ground squirrel in its mouth. With the close proximity to nearby residences and domestic animals, the underpass may have acted as a prey funnel and could have a negative impact on small mammals (e.g. rodents, squirrels and rabbits) using the underpass. Overall, S2 preformed well as a wildlife passage way for small animals.

Berthoud Pass (BP1): U.S. 40, MP 245.9

The digital camera at the upper Berthoud Pass underpasses (BP1) recorded eighteen visits by humans and no visits by any wildlife species (Table 19).   Deer tracks were recorded outside the north entrance in August 2005, and small mammal tracks were recorded inside the first 20 feet of north tunnel entrance over winter 2005.   Overall, there were no wildlife tracks or noticeable use throughout most of the tunnel. Due to rising snow, the digital camera was moved inside the underpass November 17th 2004.

Below is a brief review of conditions associated with BP1:

<u>Vegetation regeneration</u>

- Summer 2005: Planted pine trees appear to be growing, although one tree has died; grass regeneration on north side; vegetation beyond 4 ft (1.2 m) from south tunnel entrance appears to be regenerating
- Summer 2006: Grass regeneration on the south side slightly increased compared to 2005; grass regeneration on the north side did not increase from the previous summer

<u>Drainage</u>

- No moving water through tunnel
- Moderate to heavy ice inside the tunnel during winter and spring months

<u>Environmental conditions</u>

- December 2004 – January 2005: 2-4 ft (0.6 - 1.2 m) snow outside both tunnel entrances
- March 2005: Heavy snow accumulation: 5 ft (1.5 m) north entrance, 4 ft (1.2 m) south entrance
- Large mammal movement inhibited by deep snow during winter months
- March 2005: Heavy drifting of snow inside north entrance, up to 25 ft (7.6 m) inside tunnel
- Late May 2005: Tunnel floor covered in ice from snow melt
- July 2005: Heavy mud inside tunnel

- Late summer 2005: Mud inside tunnel no longer a problem
- Winter 2005 and 2006: Heavy drifting of snow inside north entrance, up to 30 ft inside tunnel
- Late spring 2006: Ice continues to build up over early spring months and lasts until late spring
- It is difficult to access the camera station on the north side due to the slope and ice conditions inside the tunnel which may also limit wildlife use
- Snow levels outside tunnel entrances ranged from 5ft to 6 ft in the winters of 2005 and 2006

Representative site photos and underpass conditions are shown in Appendix C.10.

<u>Observations and management suggestions</u>

There was only one occasion when animal tracks (snowshoe hare) were located inside the tunnel. The tracks went inside the north entrance and continued for approximately 20 feet before turning around and exiting the underpass. The camera station was five feet from the closest tracks and pointed in the opposite direction from the approach of the snowshoe hare. Human use increased in the summer of 2006 and several winter recreationists used the tunnel in January 2007. The underpass was the longest of all tunnels surveyed, which may have restricted wildlife use. Although light penetrated the tunnel from both entrances, it was relatively dark within the tunnel, perhaps decreasing the probability of wildlife using the underpass. The relatively short height of the tunnel may also limit ungulate use, especially antlered elk and deer. Although winter conditions at the underpass were severe enough to limit large mammal travel, most ungulates would have moved to lower elevations during this time. Ice and mud in the tunnel made it very difficult to check the camera in the underpass. It often took 15 to 20 minutes to crawl up to the camera station from the south entrance to the north entrance because of slippery conditions due to the ice and slight slope of the underpass. At the local topographic level, the tunnel was well placed considering the nearby stream running parallel to the underpass and the channeling effect created by highway 40. On one occasion, six mule deer were observed 25 meters from the north entrance. Overall, a shorter, taller, and wider underpass at this location would have been more beneficial, potentially facilitating wildlife use during the summer months.

Berthoud Pass (BP2): U.S. 40, MP 246.9

Digital cameras at the lower Berthoud Pass underpasses (BP2) recorded eight visits by humans and no visits by any wildlife species (Table 19). Black bear, mule deer, and other small mammal tracks were recorded outside the north entrance, with no apparent use of the tunnel. Due to rising snow, the digital camera was moved inside the underpass November 17th 2004. During the winters and springs of 2005 and 2006, the north entrance of the underpass was nearly sealed by snow primarily due to snow throw from the highway.

Below is a brief review of conditions associated with BP2**.**

<u>Vegetation regeneration</u>

- Summer 2005: North side of tunnel has some grass regeneration; south side of tunnel is steep rocky slope with little vegetation present

- Summer 2006: Grass regeneration continues to increase on the north side

Drainage

- No moving water through tunnel
- Heavy mud inside north entrance in the late spring and early summer due to snow melt

Environmental conditions

- January 2005: North tunnel entrance almost completely blocked by snow
- January- April 2005: 3-5 ft (0.9-1.5 m) snow outside tunnel
- May 2005: Complete snow melt; no ice present in tunnel
- May 2005: Heavy mud inside tunnel
- Winter and Spring 2006: North tunnel entrance almost completely blocked by snow

Representative site photos and underpass conditions are shown in Appendix C.11.

Observations and management suggestions

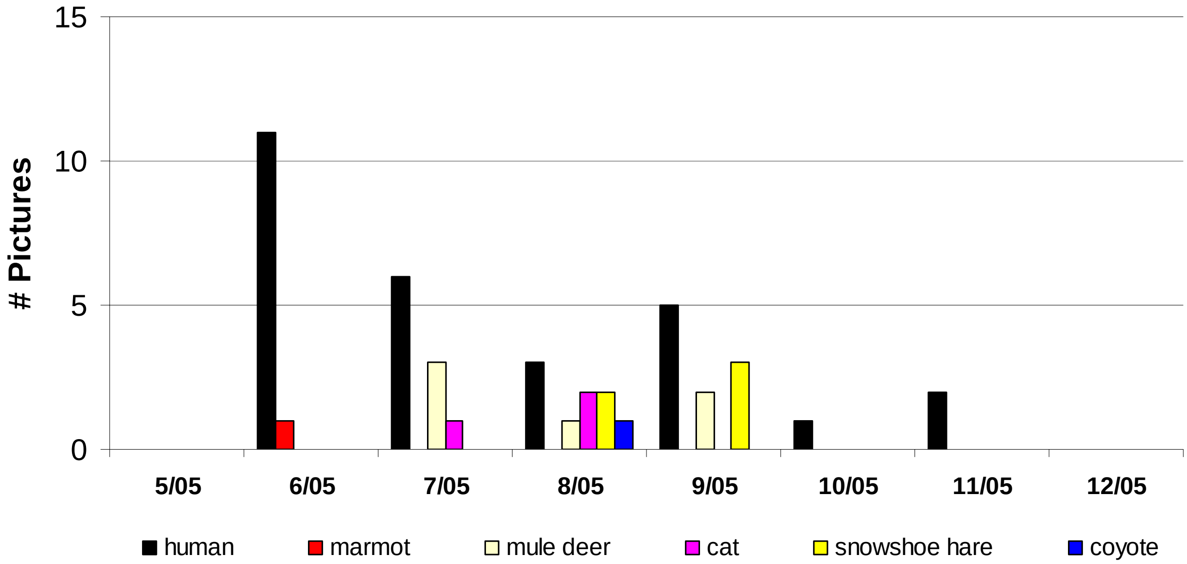
The small size of this tunnel eliminates the possibility of large mammals using the underpass. During this study, no animal tracks were ever recorded inside the tunnel. However, tracks were recorded along the wing fencing on the north side of the underpass on several occasions. The south side of the underpass ended abruptly onto a steep rocky slope which may have limited wildlife locating the crossing. Winter snow throw from plows was higher at this underpass compared to others because of the close proximity of the entrance to the highway, which led to the tunnel entrance nearly being sealed during the winter months. The local topography around the tunnel particularly the south side may have limited the building of a larger tunnel. However, it may have been more suitable if the height and width of the tunnel were larger to accommodate large mammals. The short length of the tunnel allowed light to penetrate through both sides and illuminate the interior walls of the tunnel.

Wolf Creek (WC): U.S. 160, MP 179

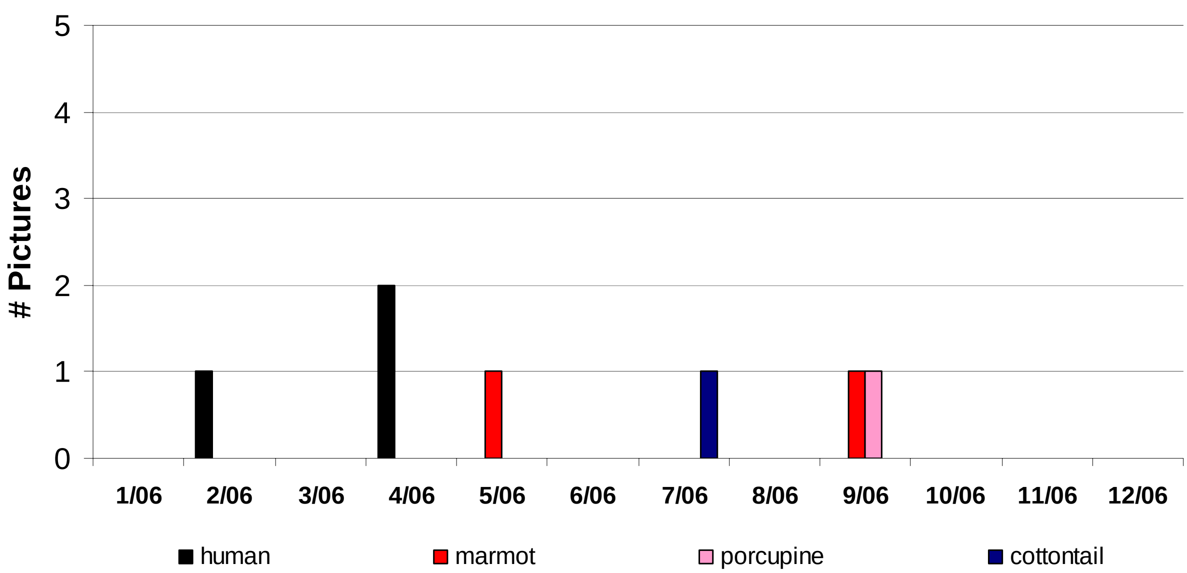
The digital camera at Wolf Creek MM 179 recorded frequent pictures of humans, mule deer, snowshoe hare, and a feral cat, and occasional images of a coyote. Appendix B.8 provides representative photos of species detected at the underpass. It is important to note that until December 2005, the Wolf Creek digital camera was stationed outside the underpass, focused towards the underpass entrance. Consequently, for some images, it was not possible to determine if the animal actually traveled through the underpass, or was simply crossing in front of the underpass entrance and camera station without using the underpass itself. The camera was moved into the underpass in December 2005, after which time it recorded pictures of only marmots, porcupines, and cottontail rabbits using the structure.

The camera showed a substantial decrease in wildlife use beginning in late October 2005, continuing through December 2005 (Figure 35). Some of this decrease may have been due to camera malfunctions with a delay in the photo triggering mechanism (perhaps due to extreme cold temperatures beginning in late October and extending through November). As a result, a number of photos were recorded with no animals visible, but snowshoe hare tracks apparent in the background of image. The sensitivity of the trigger sensor was adjusted in December 2005 to properly function with a test animal (dog) passing through the culvert. Additionally, construction at the site in October to mitigate snow blocking the culvert entrances may have contributed to the decrease in wildlife use.

a)



b)



c)

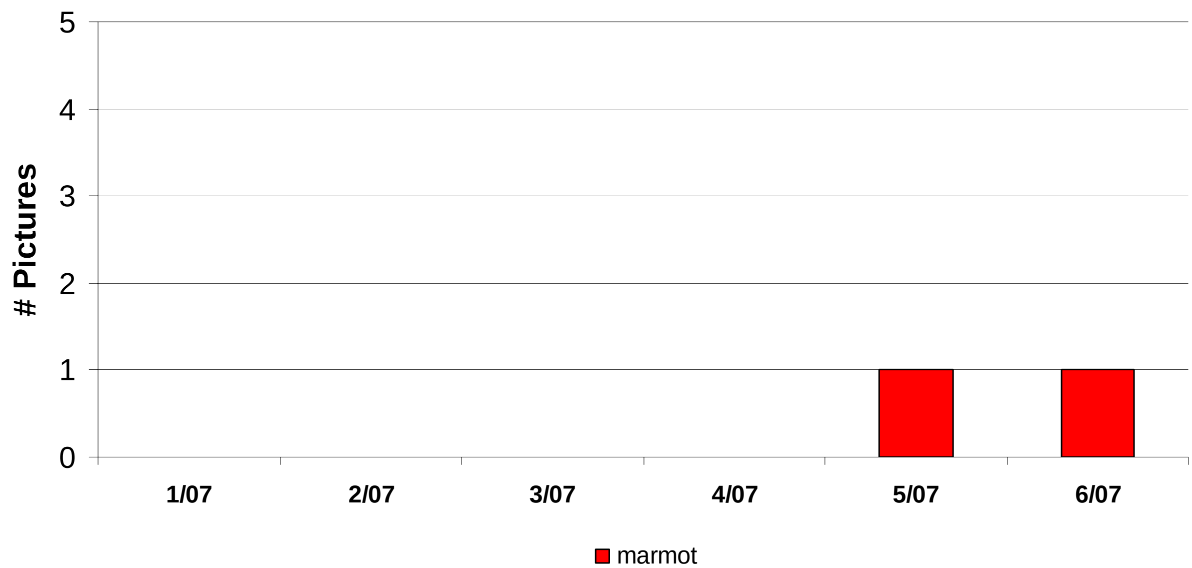


Figure 35. Monthly number of pictures taken by camera station WC from a) May 2005 to December 2005, b) January 2006 to December 2006, and c) January 2007 to June 2007. The camera was moved inside the underpass in December 2005; photographs taken prior to that date include species recorded at the underpass entrance; photographs taken after December 2005 are of species passing through the underpass.

Below is a brief review of conditions associated with the Wolf Creek MP 179 culvert:

<u>Vegetation regeneration</u>

- Evergreen tree cover within 10 feet at both entrances (see attached photos).
- Limited shrub and grass/forb cover at entrances

<u>Drainage</u>

- Culvert is not designed to carry water, but did have icing with 15 feet (4.6 m) of each entrance in spring 2005 due to snow melt and refreezing

<u>Environmental conditions</u>

- December 2004: 4+ feet (1.2+ m) snow accumulation and snowplow thrown snow completely cover both culvert entrances
- June 2005: all snow melted and no water in culvert
- September 2005: CDOT Maintenance builds 10 ft. (3 m) extension on north entrance and concrete barrier “snow fence” around south entrance to prevent snow from blocking entrances in winter 2005/2006

- December 2005: Camera moved inside culvert; both entrances clear of snow

The underpass is shown in Appendix B.4.

Observations and management suggestions

The small size of this tunnel eliminates the possibility of large mammals using the underpass. Prior to December 2005, when the camera was positioned outside the southern entrance to the underpass, several species were recorded, including marmots, mule deer, and a coyote. After the camera was repositioned inside the structure, marmot, porcupine, and rabbit use was documented. The south side of the underpass is offset from a clearing which recorded mule deer and coyotes (Impact Site 3SA in the Wildlife Underpass Mitigation section). These species were also detected across the road at the north approach (Impact Site 3NA). Although mule deer are not physically capable of using this small structure, the fact that coyotes did not (even though they were detected at the underpass entrance) demonstrates the preference to simply crossing over the highway as opposed to traveling through the long, narrow underpass. Such a scenario is also possible with lynx movement through this area, and without proper guidance to the underpass, use of these structures by carnivore species may be limited.

Although fencing might direct species to the structure, we recommend that fencing not occur along this highway unless there are adequate structures to allow for passage by larger mammals. Furthermore, the need for fencing in this area seems premature, due to the extremely low levels of AVCs along this stretch of road. We suggest creating vegetation pathways leading to the underpass entrance so that small and medium-bodied species have a higher probability of encountering the structure. Such strategies may increase the likelihood that certain species associated with particular vegetation types (i.e. lynx) travel along the vegetated pathway and have a greater chance of using the structure.

Winter snow throw from plows was a problem initially, however concrete barriers were placed above the entrance to this structure to prevent snow throw from accumulating at the underpass entrances. We suggest monitoring this structure during winter months to ensure the entrances remain relatively free of piled snow, thus increasing the chance that an animal will travel through the structure.

4.2 Lynx GIS Analysis

4.2.1 Goals and Objectives

The objective of this component of our project was to analyze 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. We also used the telemetry data to assess if any collared lynx were in the vicinity of our field monitoring sites described in the Wildlife Mitigation Structures (Section 3.0) and Lynx Mitigation Structures (Section 4.0) of this report, particularly given we never detected lynx via cameras at any of these locales.

4.2.2 Methods and Results

From February 1999 to May 2004, 131 lynx were reintroduced from populations in Canada to southwestern Colorado. These lynx were fitted with VHF radio-collars, and a total of 6,556 spatial locations were derived via ground and air tracking from October 2000 to January 2006. In addition, 125 of these lynx were fitted with satellite radio-transmitters (ARGOS), which were designed to provide locations at weekly intervals for 18 months. A total of 4,242 spatial locations were obtained for these lynx from October 2000 to January 2006; satellite location accuracy varied between 150 and 4000 m. We provide figures (Figures 36 and 37) that display 90% kernel density functions of the spatial locations of lynx derived from these two methods, which presents a visual impression of areas of high lynx use based on each method.

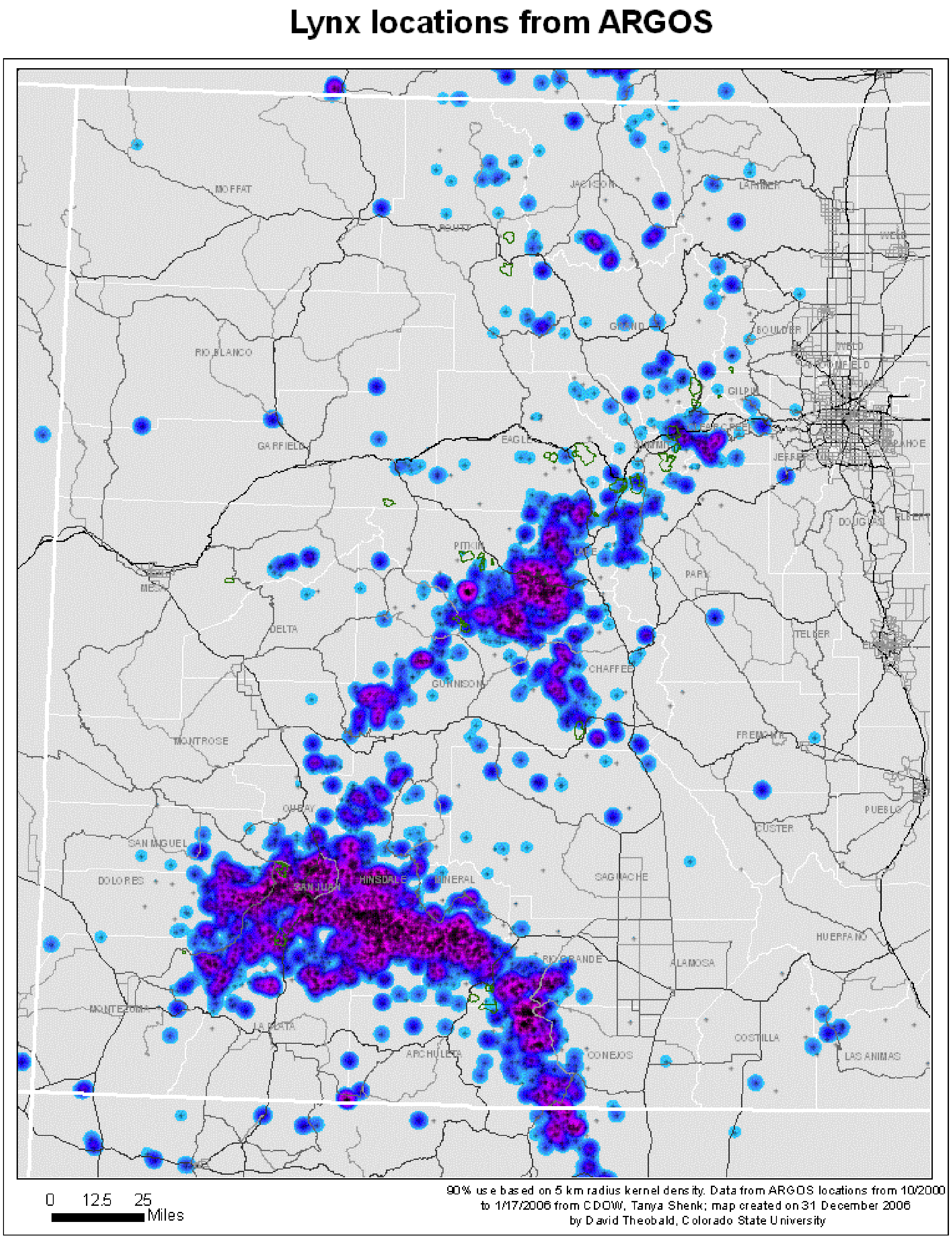


Figure 36. 90% kernel density function based on locations of 131 lynx from October 2000 to January 2006 derived from ARGOS satellites.

Lynx locations from VHF

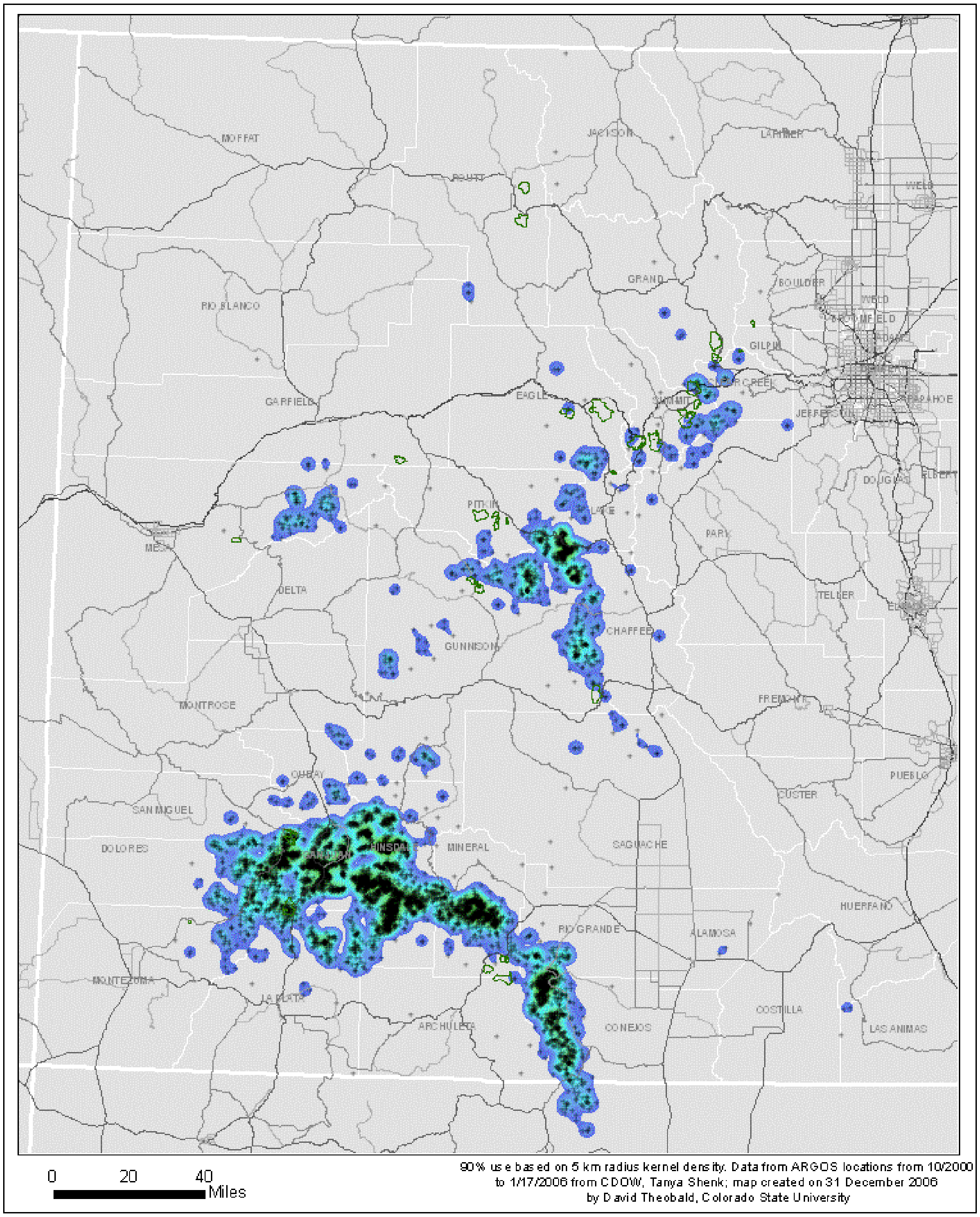


Figure 37. 90% kernel density function based on locations of 125 lynx from October 2000 to January 2006 derived from VHF radio-collars.

Figure 29 displays the specific study sites referenced in both the Wildlife Mitigation Structures (Section 3.0) and Lynx Mitigation Structures (Section 4.0) of this report. Maps which display spatial locations of lynx based on combined ARGOS and VHF spatial locations since relative to these structures are presented in Figures 38-44. To create a visual impression of areas of frequent use by lynx, these maps contain a 95% fixed kernel density function of lynx telemetry locations, where red represents the areas of maximum use, and blue represents areas seldom used by lynx. For each region, 2 maps are presented, displaying 1) all the available lynx telemetry data since October 2000 through January 2006, in order to evaluate the extent to which collared lynx were near the field sites both before and during monitoring, and 2) lynx telemetry data since the start of field surveys in October 2004, in order to evaluate the proximity of collared lynx during actual field monitoring.

The three northern Lynx Underpasses are located somewhat near areas of lynx activity, both in the full data set and in the points after October 2004 when monitoring began (Figures 38 and 39), but are not in particularly high use areas. Specifically, collared lynx were documented relatively near underpasses on US 40 Berthoud Pass and SH 9 during field monitoring, although they were never detected using any of the structures. The Conifer-Bailey and Durango-Bayfield WUMPS sites show no lynx activity after October 2004, thus no lynx monitoring would be expected for these sites (Figures 39-42). However, lynx do appear to have been active nearby these areas prior to 2004, so it is conceivable that some lynx crossings will occur in the future. The Wolf Creek Underpass and WUMPS site shows a moderately high level of lynx activity, indicating that this site has a relatively high potential for lynx use (Figures 43 and 44).

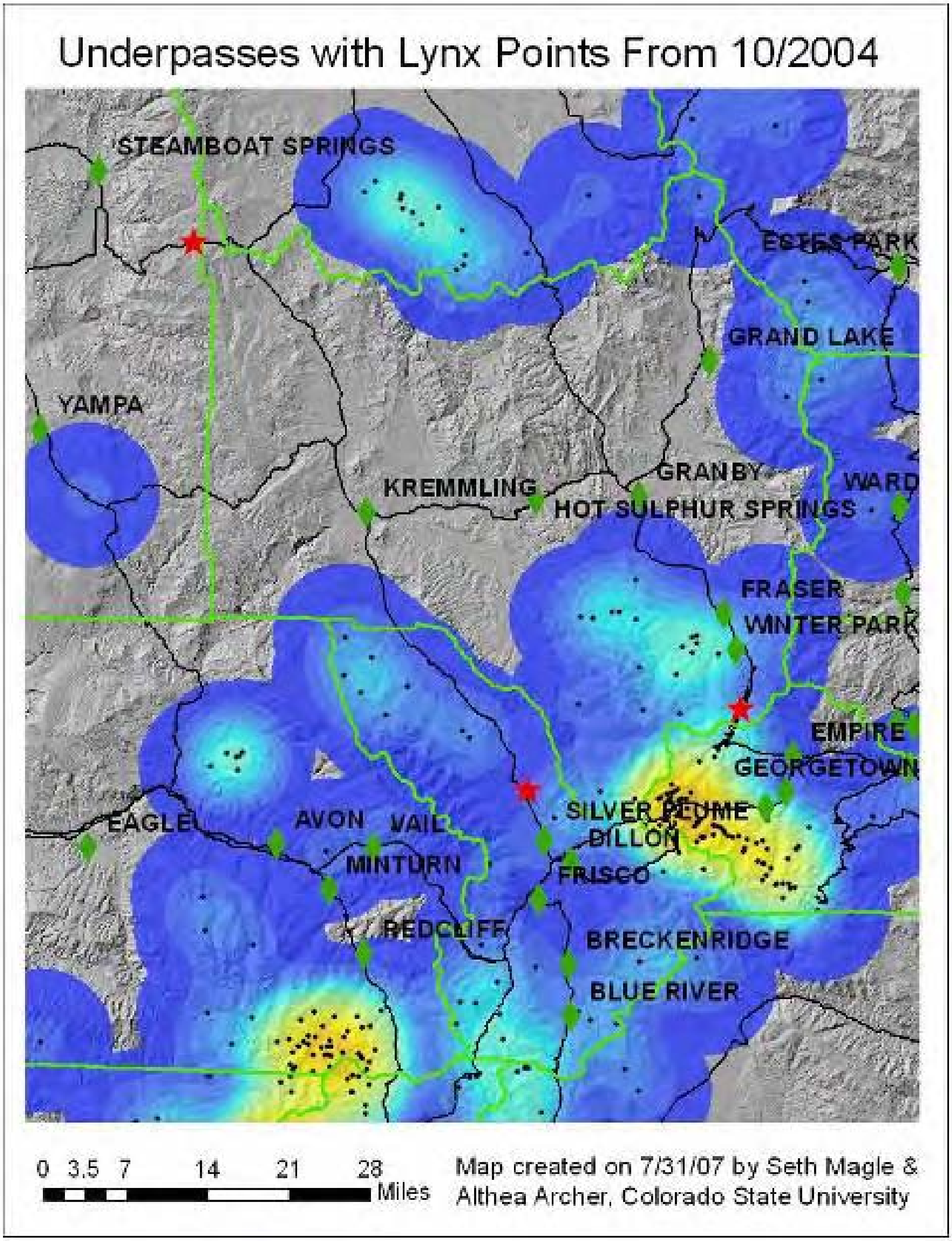


Figure 38. Map of monitored underpasses near northwestern Colorado (each red star indicating 2 nearby underpasses), including a 95% fixed kernel density function derived from VHF and GPS lynx telemetry locations collected from October 2004 to January 2006.

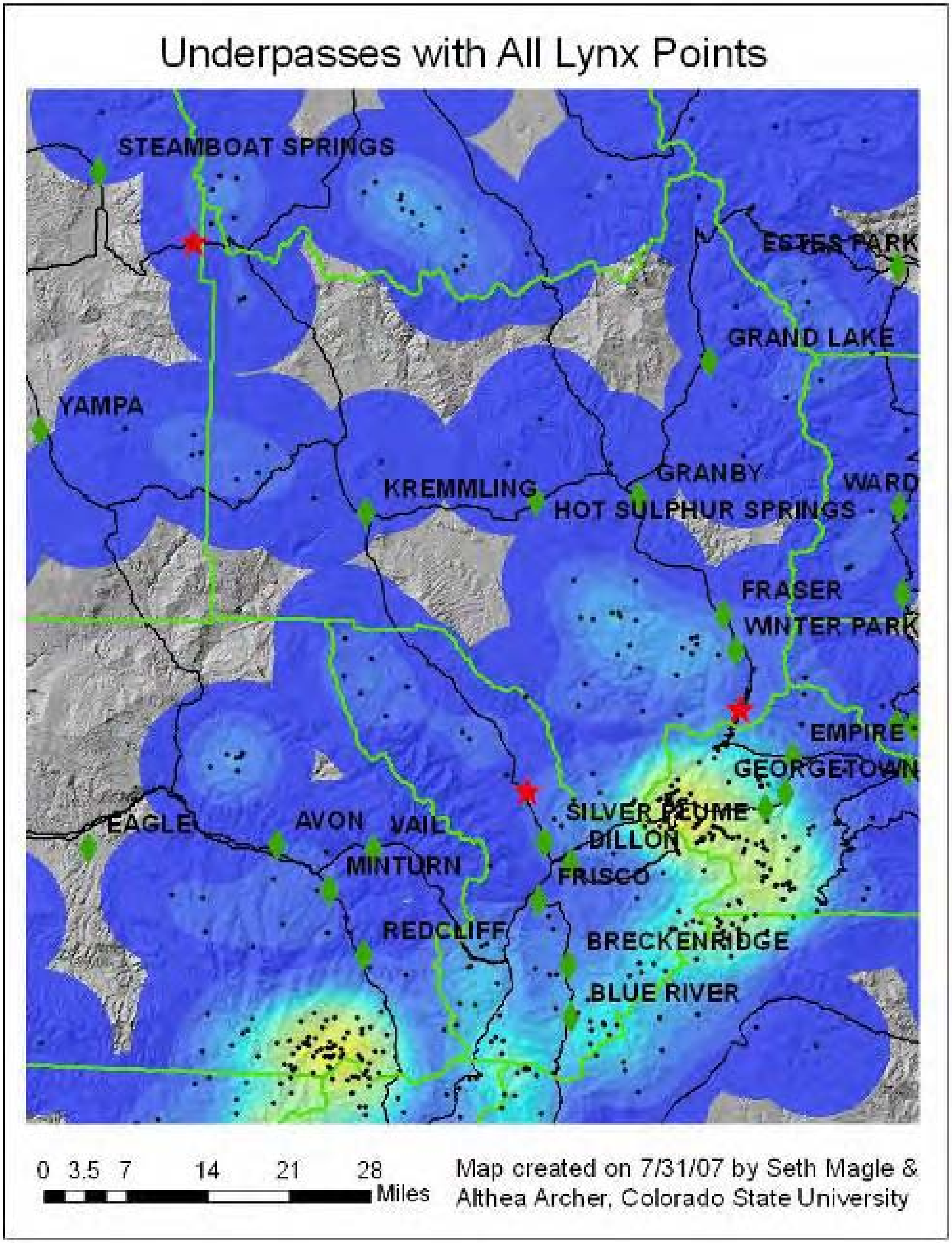


Figure 39. Map of lynx underpasses near northwestern Colorado (each red star indicating 2 nearby underpasses), including a 95% fixed kernel density function derived from all VHF and GPS lynx telemetry locations collected from October 2000 to January 2006.

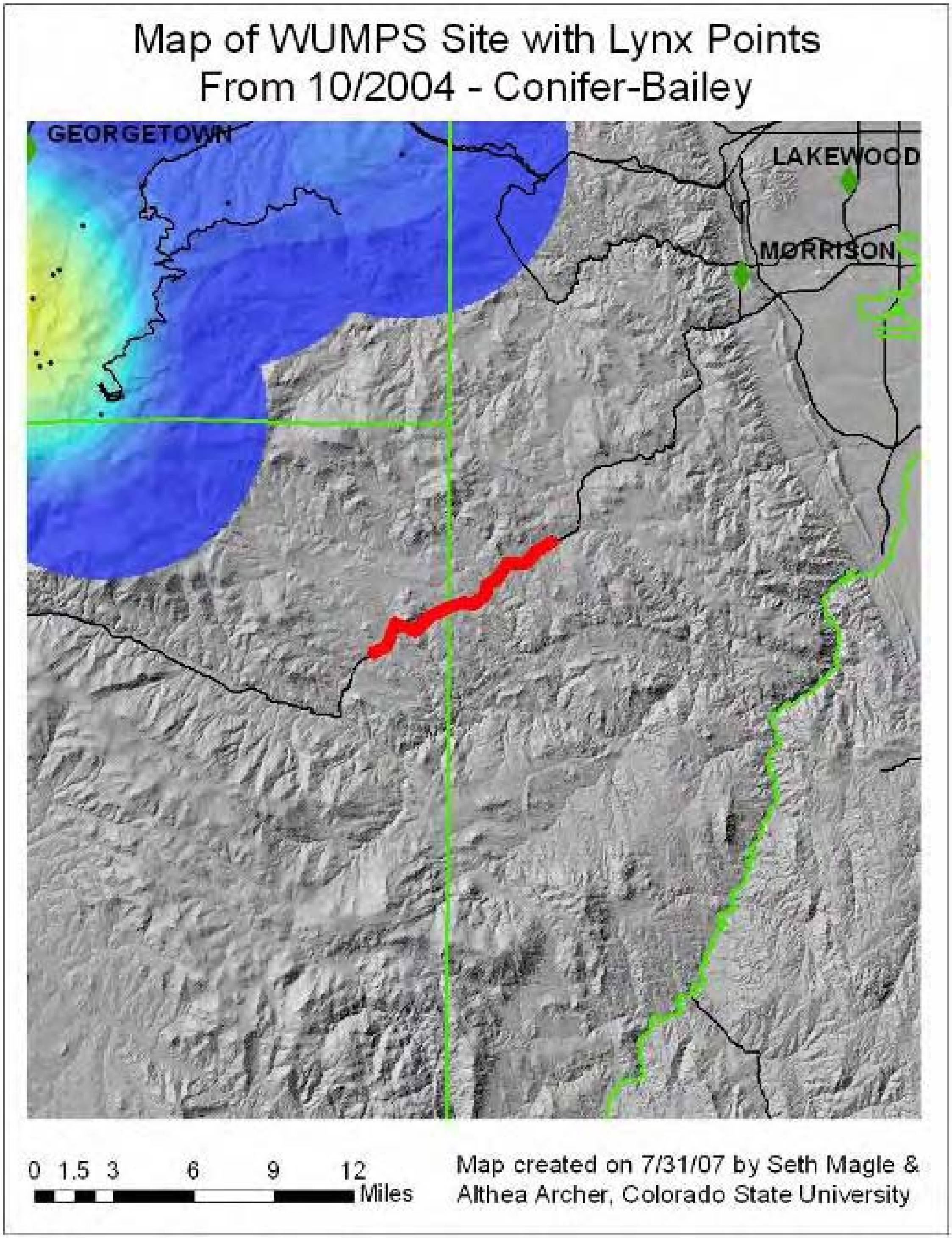


Figure 40. Map of WUMPS site near Conifer-Bailey (red line), including a 95% fixed kernel density function derived from VHF and GPS lynx telemetry locations collected from October 2004 to January 2006.

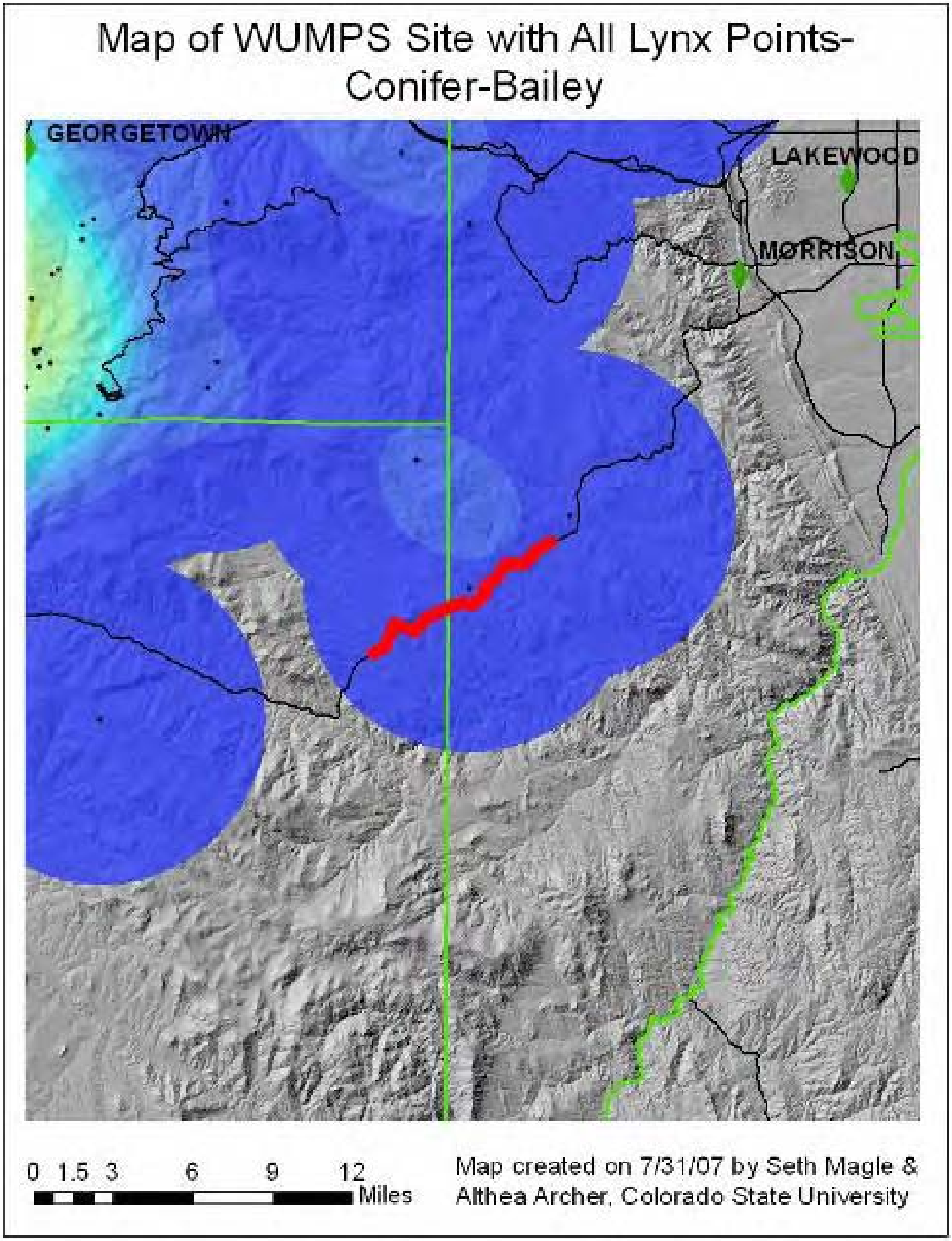


Figure 41. Map of WUMPS site near Conifer-Bailey (red line), including a 95% fixed kernel density function derived from all VHF and GPS lynx telemetry locations collected from October 2000 to January 2006.

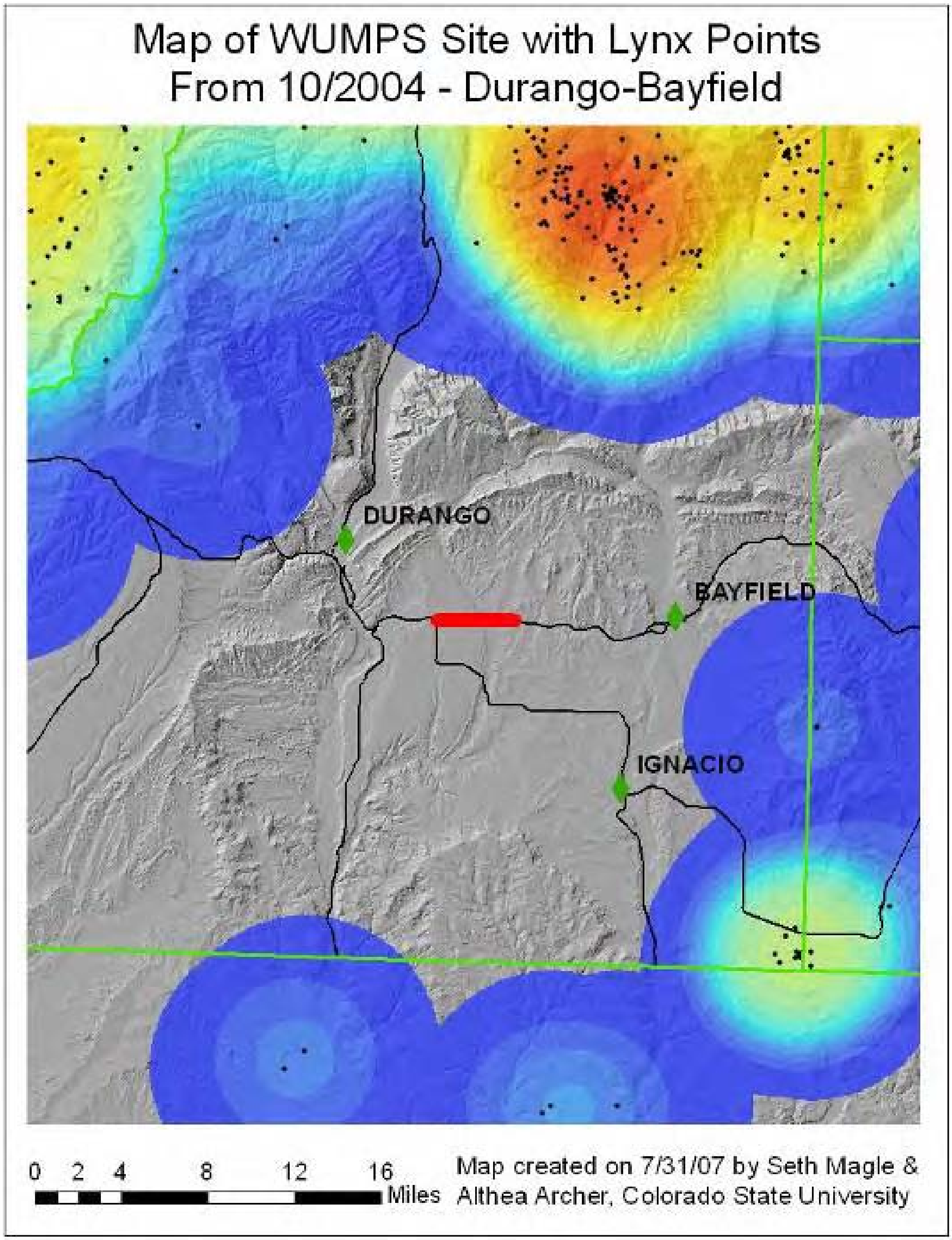


Figure 42. Map of WUMPS site near Durango-Bayfield (red line), including a 95% fixed kernel density function derived from VHF and GPS lynx telemetry locations collected from October 2004 to January 2006.

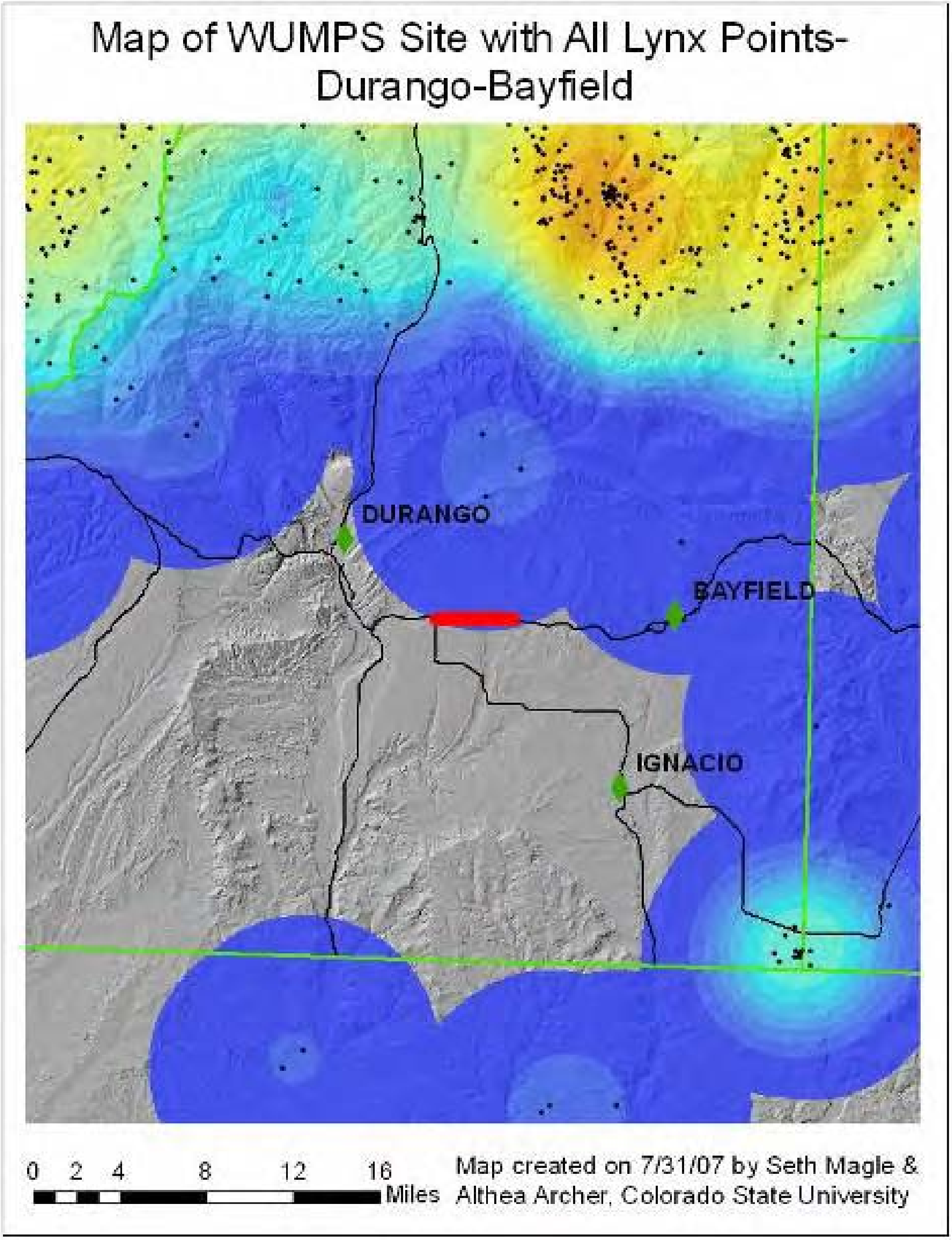


Figure 43. Map of WUMPS site near Durango-Bayfield (red line), including a 95% fixed kernel density function derived from all VHF and GPS telemetry locations collected from October 2000 to January 2006.

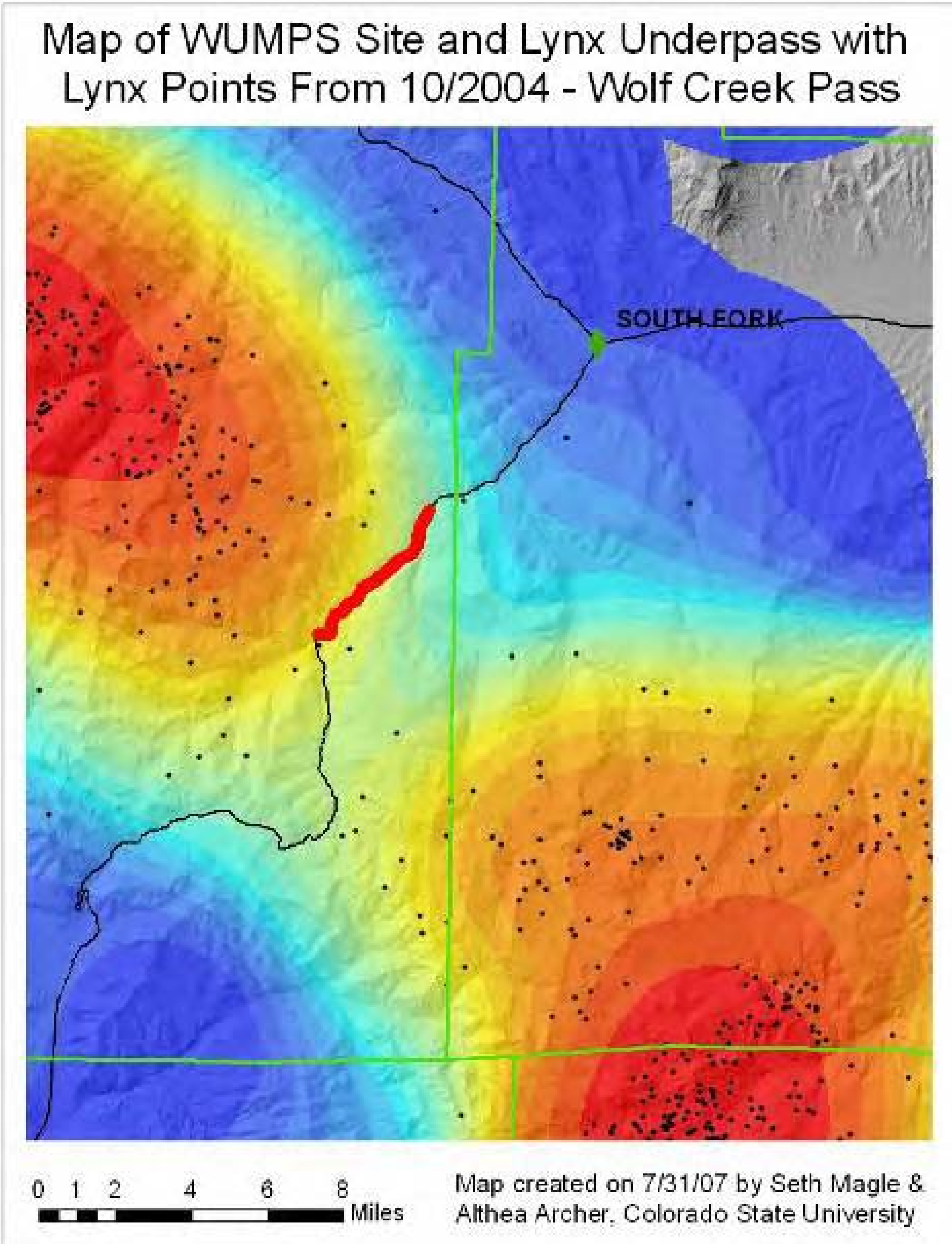


Figure 44. Map of WUMPS site (red line) near Wolf Creek, including a 95% fixed kernel density function derived from VHF and GPS lynx telemetry locations collected from October 2004 to January 2006.

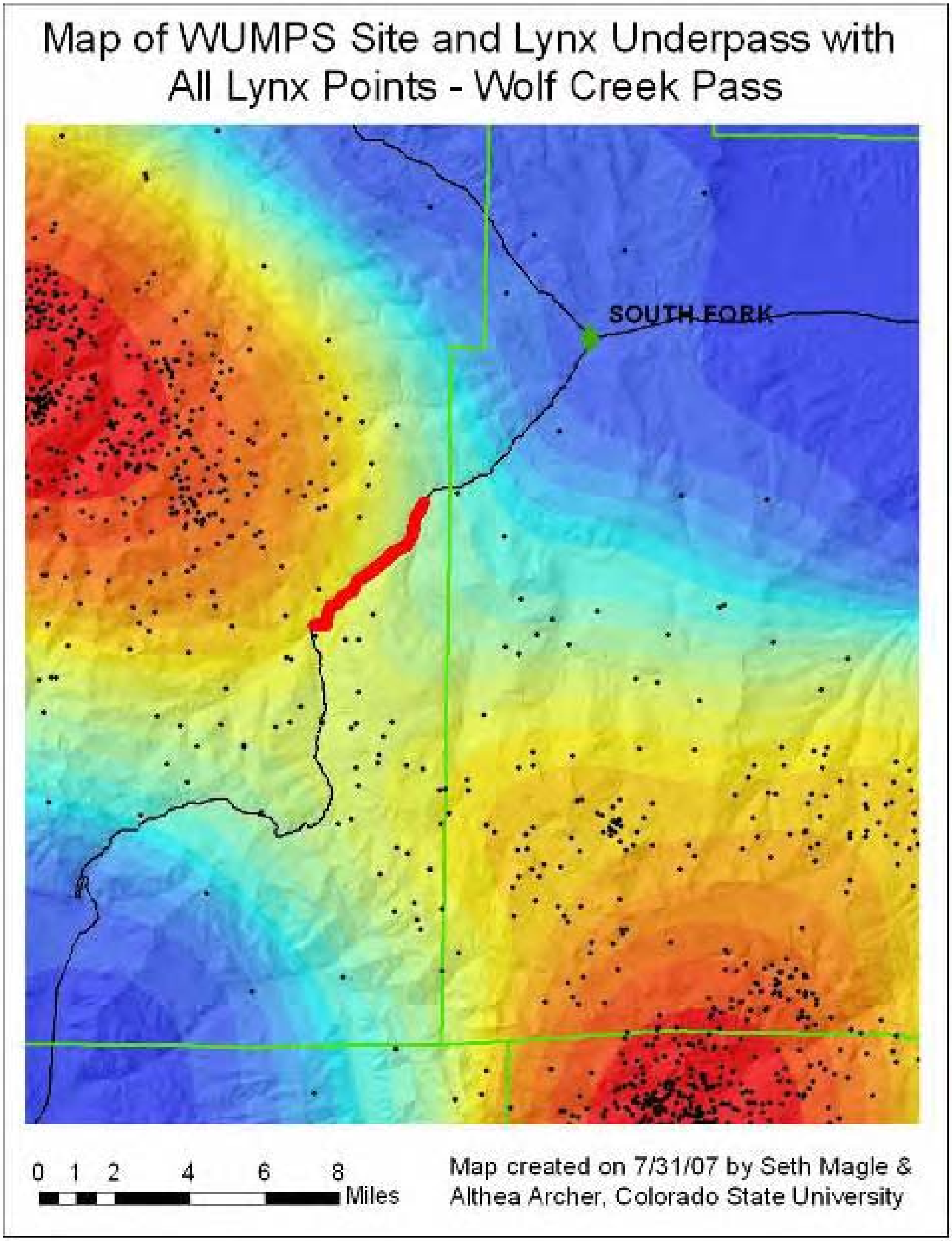


Figure 45. Map of WUMPS site near Wolf Creek (red line), including a 95% fixed kernel density function derived from all VHF and GPS lynx telemetry locations collected from October 2000 to January 2006.

To provide a basic analysis of whether lynx are avoiding highways in Colorado, we calculated the distance of each lynx ARGOS spatial point to the nearest highway, as defined by the CDOT's GIS highway layer (1:100000 scale). Only ARGOS points were used in this analysis, because VHF points were sampled more heavily along roads and in southern Colorado, and thus do not provide a representative sample throughout the state. For comparison, we then generated an equivalent number of random points (4,242) within a minimum convex polygon bounding all the existing lynx spatial points. We summarized the frequency of the distance of points from highways for both lynx spatial locations and random points (Figure 46). We performed a T-test comparing the average distance of lynx spatial points to highways (mean = 10.96 km) to the distance of random points within the same area to highways (mean = 8.41 km). This difference was significant ($T = 15.68$, $p < 0.001$, n = 8,484), providing some evidence that lynx in Colorado do avoid major highways.

We also identified potential areas of key lynx highways crossings throughout the state of Colorado. We used the ARGOS lynx spatial data as above and created lines connecting temporally consecutive points for individual lynx, unless those points were more than two weeks apart. This had the effect of creating movement paths for each individual lynx. We generated spatial points where these movement paths crossed major highways and then created a 95% fixed kernel density function of these points. This density function describes the locations where lynx highway crossings may be common in Colorado. We provide maps of potential hotspots of lynx highway crossings for all of Western Colorado (Figure 47), as well as more detailed maps of the West-Central Colorado area (Figure 48), the Monarch Pass area (Figure 49), and the Southwestern Colorado area (Figure 50), since these appear to be areas of particularly high potential road crossing activity.

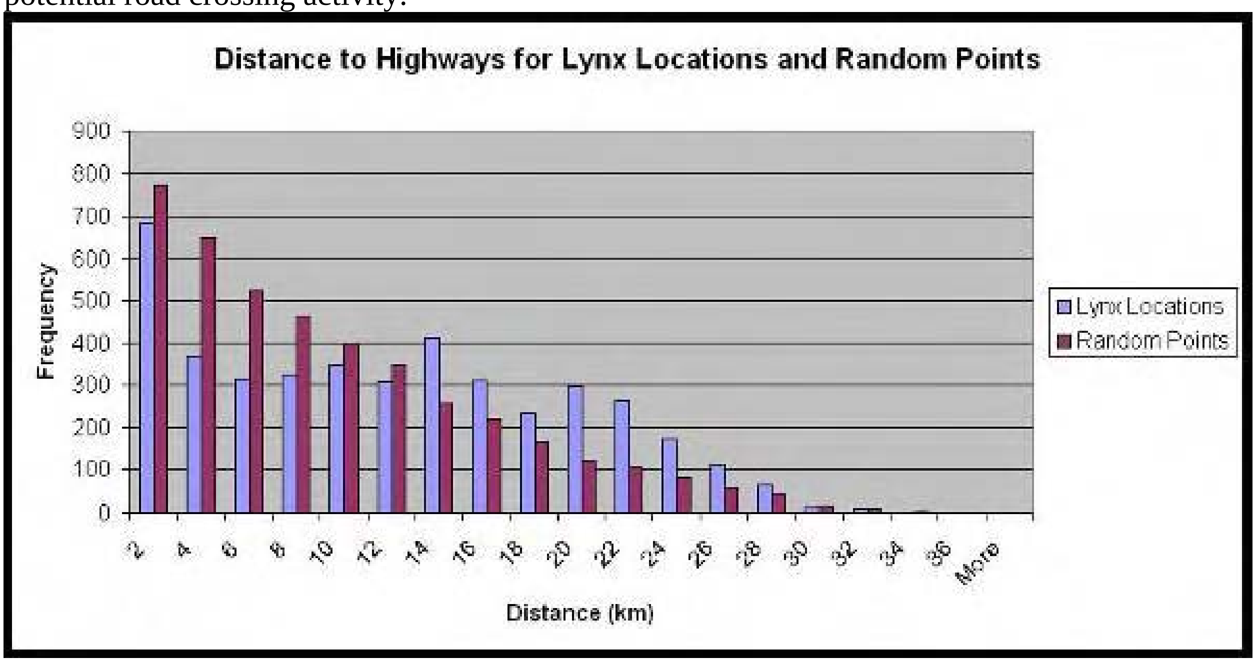


Figure 46. Frequency of distances between spatial data points and the nearest highway, compared for both spatial locations of lynx, and random points located within the same geographic area.

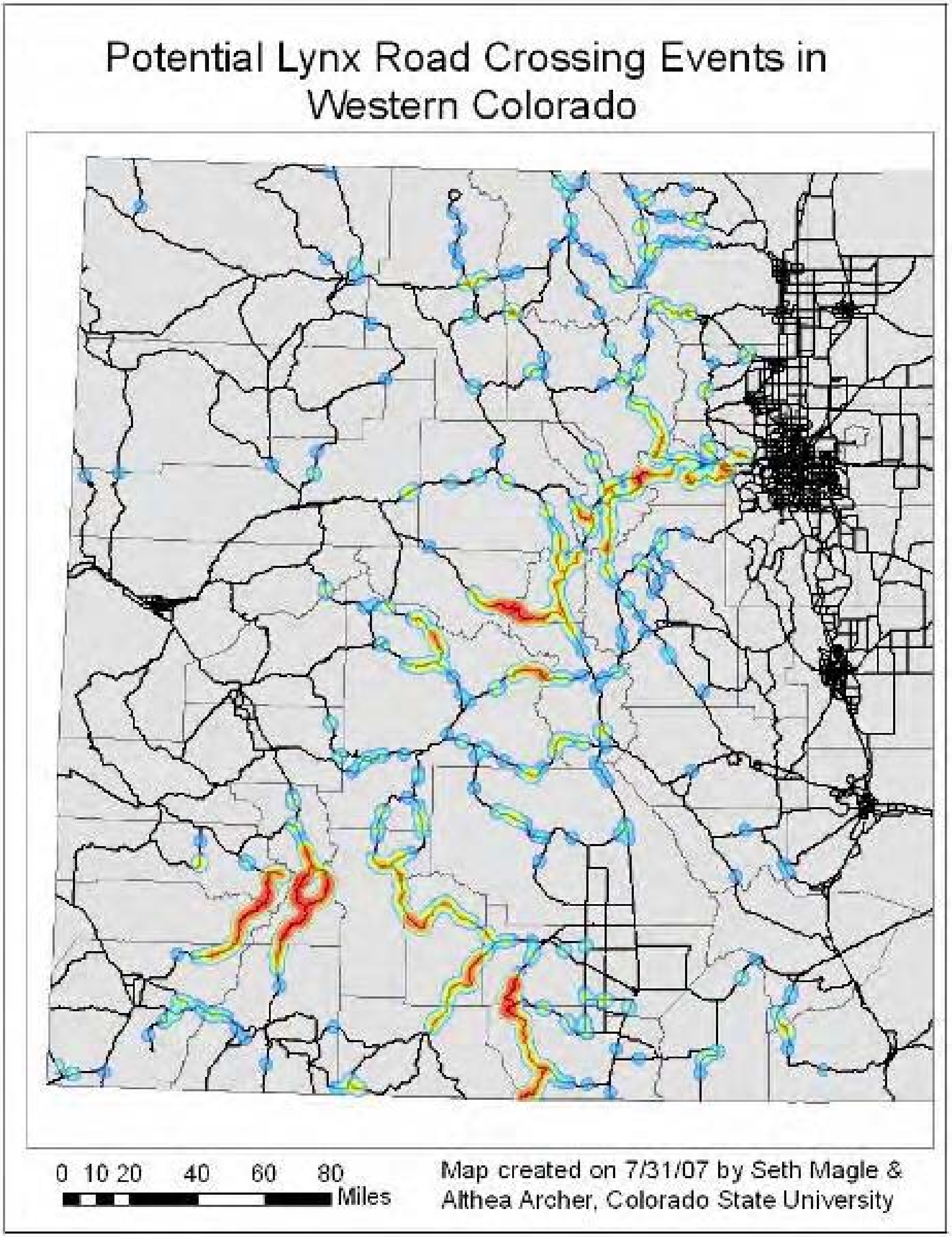


Figure 47. 95% kernel density map of potential areas of lynx highway crossings, based on straight-line connections between consecutive lynx spatial locations collected less than two weeks apart, as derived from ARGOS satellite telemetry.

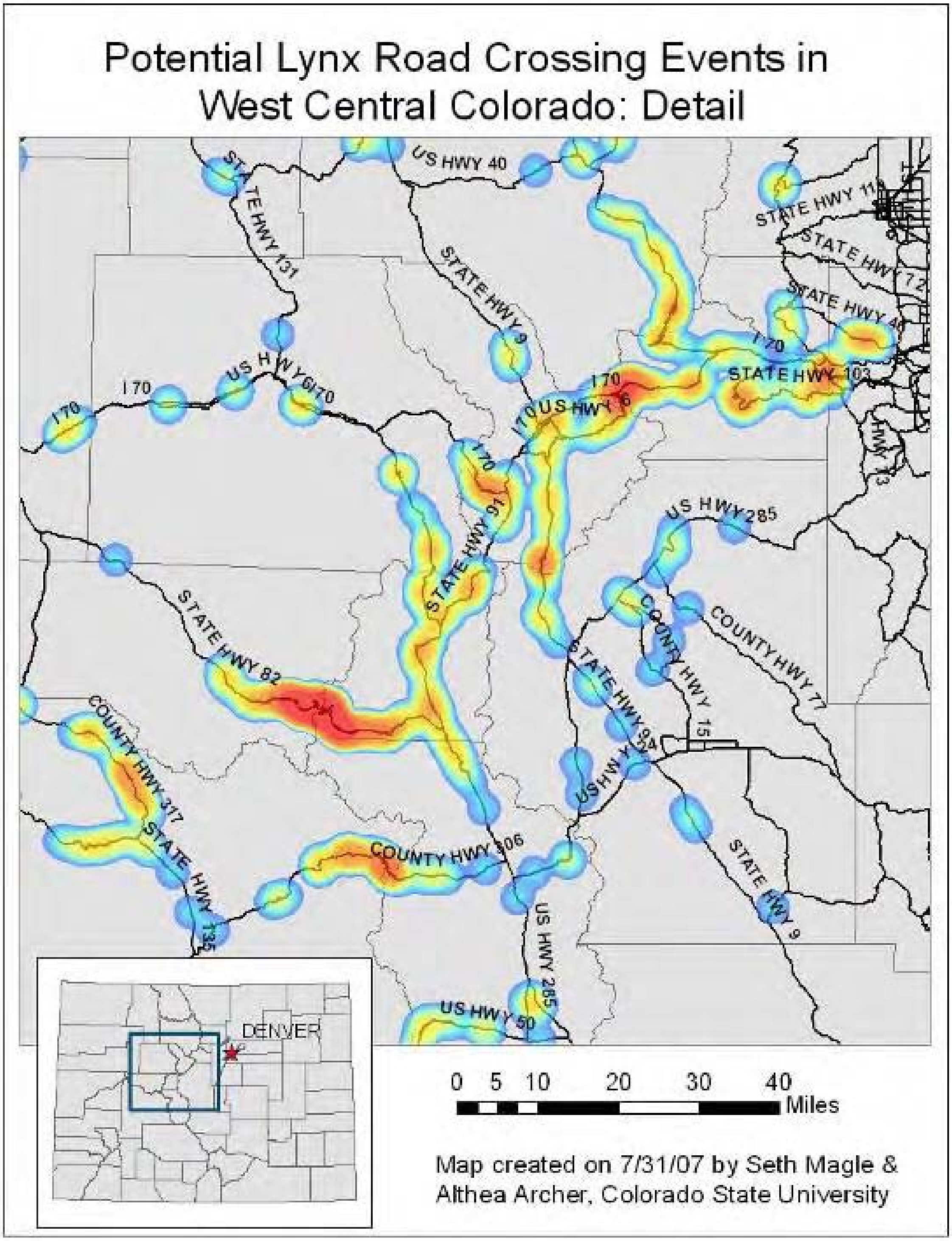


Figure 48. 95% kernel density map of potential areas of lynx highway crossings in west-central Colorado, based on straight-line connections between consecutive lynx spatial locations collected less than two weeks apart, as derived from ARGOS satellite telemetry.

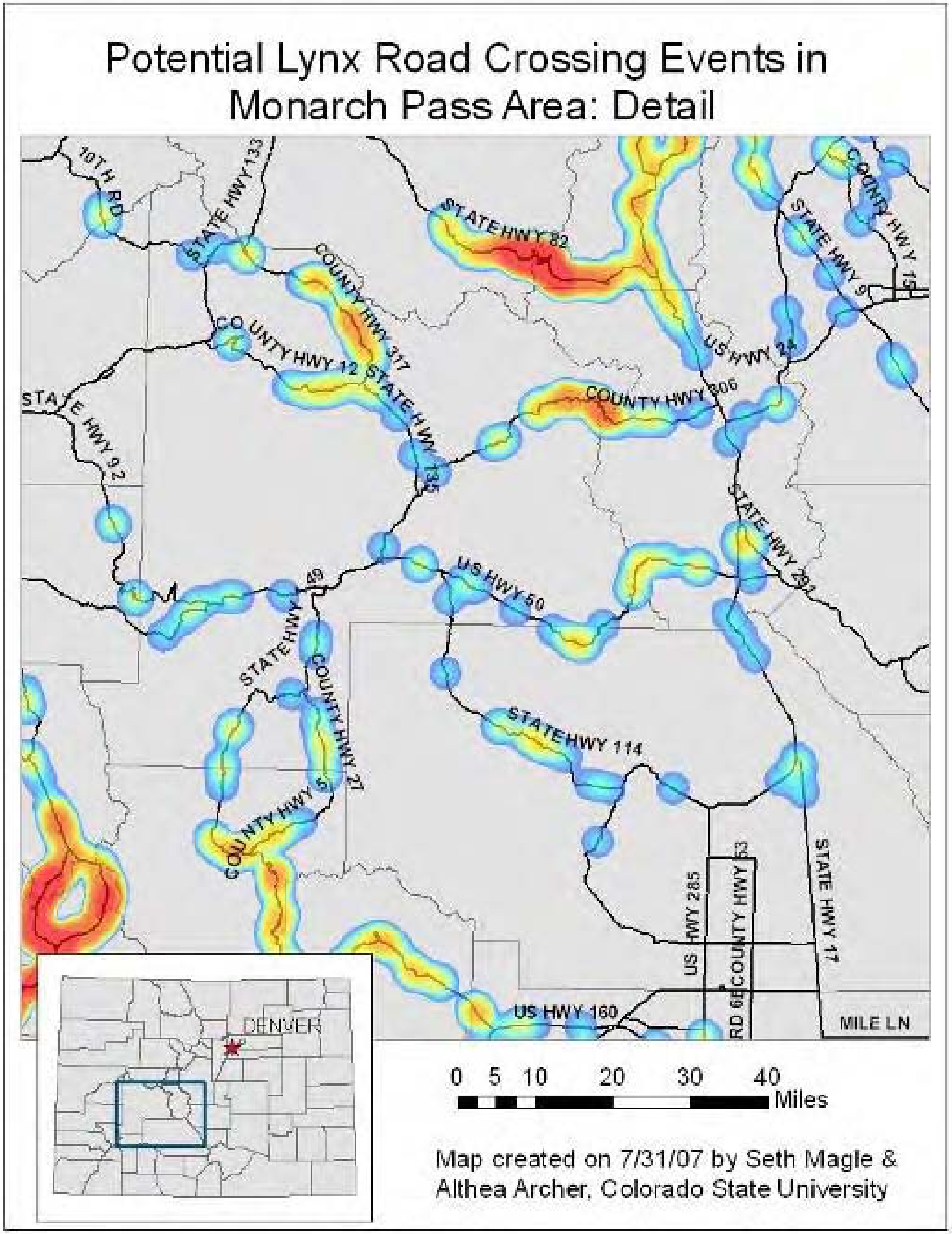


Figure 49. 95% kernel density map of potential areas of lynx highway crossings in Monarch Pass area, based on straight-line connections between consecutive lynx spatial locations collected less than two weeks apart, as derived from ARGOS satellite telemetry.

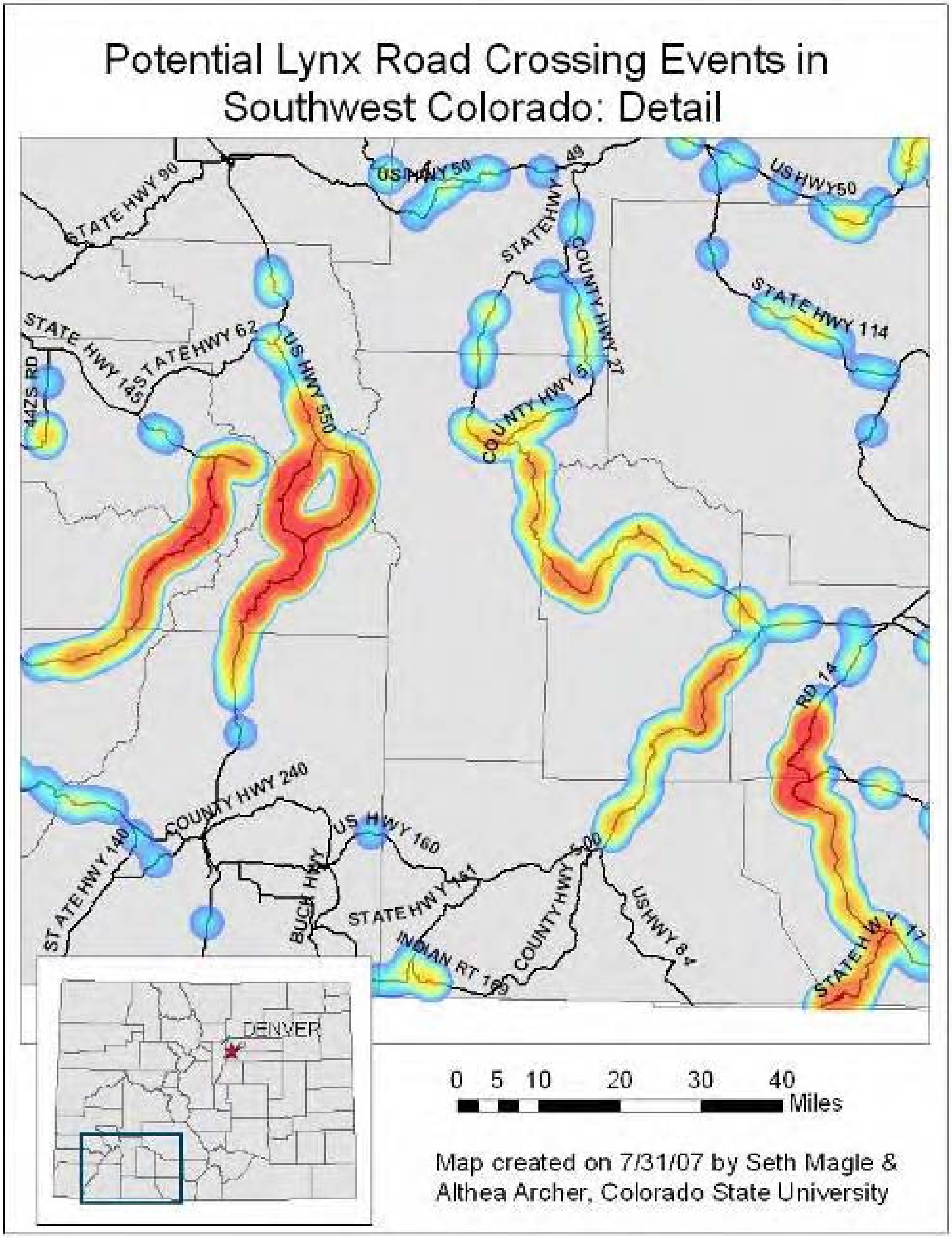


Figure 50. 95% kernel density map of potential areas of lynx highway crossings in south-west Colorado, based on straight-line connections between consecutive lynx spatial locations collected less than two weeks apart, as derived from ARGOS satellite telemetry.

4.2.3 Summary of Lynx GIS Analysis

Our analyses are intended to provide preliminary information useful for locating wildlife underpasses and other mitigation structures that enhance dispersal and reduce highway mortality for lynx. We provide maps which indicate that some existing underpasses have not exhibited frequent use because lynx have not been active in the vicinity during monitoring, with the possible exception of Wolf Creek Pass, Berthoud Pass, and SH 9. We provide evidence that lynx in Colorado are selectively avoiding highways. In addition, we provide a map of potential road crossing hotspots for lynx reintroduced into this state. We hope that this information is of use in determining future locations of underpasses and other road-related mitigation for wildlife species, and that future developments continue to minimize impacts to rare and imperiled species.

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6.0 Appendices

Appendix A.1. Reclassification table for land cover types used to characterize areas of high AVCs in Colorado from 1986-2004. Data source is the SW Regional Gap raster database (USGS National Gap Analysis Program 2004).

Value	Code	Description	CDOT analysis reclass
1	S001	North American Alpine Ice Field	Other
2	S002	Rocky Mountain Alpine Bedrock and Scree	Other
4	S004	Rocky Mountain Alpine Fell-Field	Other
5	S006	Rocky Mountain Cliff and Canyon	Other
7	S008	Western Great Plains Cliff and Outcrop	Other
8	S009	Inter-Mountain Basins Cliff and Canyon	Other
9	S010	Colorado Plateau Mixed Bedrock Canyon and Tableland	Other
10	S011	Inter-Mountain Basins Shale Badland	Other
11	S012	Inter-Mountain Basins Active and Stabilized Dune	Other
13	S014	Inter-Mountain Basins Wash	Other
14	S015	Inter-Mountain Basins Playa	Other
15	S016	North American Warm Desert Bedrock Cliff and Outcrop	Other
17	S018	North American Warm Desert Active and Stabilized Dune	Other
19	S020	North American Warm Desert Wash	Other
21	S022	North American Warm Desert Playa	Other
22	S023	Rocky Mountain Aspen Forest and Woodland	Forest
24	S025	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	Forest
26	S028	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	Forest
28	S030	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	Forest
29	S031	Rocky Mountain Lodgepole Pine Forest	Forest
30	S032	Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland	Forest
32	S034	Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland	Forest
33	S035	Madrean Pine-Oak Forest and Woodland	Forest

Value	Code	Description	CDOT analysis reclass
34	S036	Rocky Mountain Ponderosa Pine Woodland	Forest
35	S038	Southern Rocky Mountain Pinyon-Juniper Woodland	Forest
36	S039	Colorado Plateau Pinyon-Juniper Woodland	Forest
38	S042	Inter-Mountain West Aspen-Mixed Conifer Forest and Woodland Complex	Forest
40	S045	Inter-Mountain Basins Mat Saltbush Shrubland	Shrub/scrub
41	S046	Rocky Mountain Gambel Oak-Mixed Montane Shrubland	Shrub/scrub
42	S047	Rocky Mountain Lower Montane-Foothill Shrubland	Shrub/scrub
43	S048	Western Great Plains Sandhill Shrubland	Shrub/scrub
44	S050	Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland	Shrub/scrub
46	S052	Colorado Plateau Pinyon-Juniper Shrubland	Shrub/scrub
48	S054	Inter-Mountain Basins Big Sagebrush Shrubland	Shrub/scrub
50	S056	Colorado Plateau Mixed Low Sagebrush Shrubland	Shrub/scrub
53	S059	Colorado Plateau Blackbrush-Mormon-tea Shrubland	Shrub/scrub
56	S062	Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub	Shrub/scrub
58	S065	Inter-Mountain Basins Mixed Salt Desert Scrub	Shrub/scrub
62	S071	Inter-Mountain Basins Montane Sagebrush Steppe	Grassland/prairie
63	S074	Southern Rocky Mountain Juniper Woodland and Savanna	Grassland/prairie
64	S075	Inter-Mountain Basins Juniper Savanna	Grassland/prairie
67	S079	Inter-Mountain Basins Semi-Desert Shrub Steppe	Grassland/prairie
68	S080	Chihuahuan Gypsophilous Grassland and Steppe	Grassland/prairie
69	S081	Rocky Mountain Dry Tundra	Grassland/prairie
70	S083	Rocky Mountain Subalpine Mesic Meadow	Grassland/prairie
71	S085	Southern Rocky Mountain Montane-Subalpine Grassland	Grassland/prairie

Value	Code	Description	CDOT analysis reclass
72	S086	Western Great Plains Foothill and Piedmont Grassland	Grassland/prairie
73	S087	Central Mixedgrass Prairie	Grassland/prairie
74	S088	Western Great Plains Shortgrass Prairie	Grassland/prairie
75	S089	Western Great Plains Sandhill Prairie	Grassland/prairie
76	S090	Inter-Mountain Basins Semi-Desert Grassland	Grassland/prairie
77	S091	Rocky Mountain Subalpine-Montane Riparian Shrubland	Riparian/Wetland
78	S092	Rocky Mountain Subalpine-Montane Riparian Woodland	Riparian/Wetland
79	S093	Rocky Mountain Lower Montane Riparian Woodland and Shrubland	Riparian/Wetland
81	S095	Western Great Plains Riparian Woodland and Shrubland	Riparian/Wetland
82	S096	Inter-Mountain Basins Greasewood Flat	Riparian/Wetland
85	S100	North American Arid West Emergent Marsh	Riparian/Wetland
86	S102	Rocky Mountain Alpine-Montane Wet Meadow	Riparian/Wetland
92	S112	Madrean Pinyon-Juniper Woodland	Forest
95	S115	Madrean Juniper Savanna	Grassland/prairie
99	S120	Western Great Plains Floodplain Herbaceous Wetland	Riparian/Wetland
103	S125	Rocky Mountain Foothill Limber Pine-Juniper Woodland	Forest
104	S128	Wyoming Basins Low Sagebrush Shrubland	Shrub/scrub
106	S132	Western Great Plains Tallgrass Prairie	Grassland/prairie
108	S136	Southern Colorado Plateau Sand Shrubland	Shrub/scrub
109	S138	Western Great Plains Mesquite Woodland and Shrubland	Shrub/scrub
110	N11	Open Water	Other
111	N21	Developed, Open Space - Low Intensity	Human development
112	N22	Developed, Medium - High Intensity	Human development

Value	Code	Description	CDOT analysis reclass
113	N31	Barren Lands, Non-specific	Other
114	N80	Agriculture	Agriculture
115	D01	Disturbed, Non-specific	Disturbed
116	D02	Recently Burned	Disturbed
117	D03	Recently Mined or Quarried	Disturbed
118	D04	Invasive Southwest Riparian Woodland and Shrubland	Disturbed
119	D06	Invasive Perennial Grassland	Disturbed
120	D07	Invasive Perennial Forbland	Disturbed
121	D08	Invasive Annual Grassland	Disturbed
122	D09	Invasive Annual and Biennial Forbland	Disturbed
123	D10	Recently Logged Areas	Disturbed
124	D11	Recently Chained Pinyon-Juniper Areas	Disturbed
125	D14	Disturbed, Oil well	Disturbed

Appendix A.2. Top 1% (117 records) of AVCs count by mile marker and route combination of AVCs resulting in fatality and injury in Colorado from 1986-2004. ROUTE_MPR represents unique route segment and mile marker combination rounded to the nearest mile.

ROUTE_MPR	No. of AVCs
074A_3	9
285D_234	8
470A_1	8
160A_95	8
025A_157	8
070A_251	8
082A_10	8
285D_235	7
070A_157	7
025A_158	7
074A_6	7
550B_30	7
160A_96	6
285D_249	6
550B_29	6
160A_63	6
115A_41	6
006G_273	6
025A_191	6
082A_9	6
160A_100	6
160A_256	5
285D_245	5
285D_244	5
470A_2	5
093A_5	5
160A_70	5
034A_88	5
025A_165	5
025A_173	5
070A_165	5
070A_173	5
070A_253	5
070A_260	5

ROUTE_MPR	No. of AVCs
025A_78	5
025A_169	5
050A_277	5
070A_208	5
070A_305	5
070A_232	5
082A_22	5
285D_231	5
285D_238	5
006G_272	4
024A_281	4
070A_75	4
070A_59	4
070A_64	4
070A_250	4
025A_148	4
025A_155	4
025A_109	4
036B_23	4
070A_63	4
070A_96	4
025A_125	4
025A_151	4
025A_12	4
070A_111	4
025A_176	4
025A_140	4
025A_76	4
050A_89	4
040A_99	4
040A_119	4
070A_164	4
040A_140	4
025A_124	4

ROUTE_MPR	No. of AVCs
025A_185	4
040A_95	4
024A_299	4
036A_6	4
070A_257	4
058A_1	4
009D_134	4
025A_33	4
070A_256	4
025A_149	4
025A_171	4
082A_5	4
082A_4	4
285D_186	4
160A_94	4
160A_115	4
160A_68	4
550B_43	4
115A_27	4
160A_67	4
160A_192	4
160A_224	4
285D_233	4
470A_5	4
160A_265	4
285D_228	4
160A_268	4
285D_236	4
160A_91	4
093A_15	4
160A_71	4
160A_127	4
160A_52	4

ROUTE_MPR	No. of AVCs
160A_87	4
160A_107	4
285D_232	4
550B_28	4
285D_227	4
550A_2	4
160A_207	4
172A_19	4

Appendix A.3. Top 1% (94 records) of AVCs count by mile marker and route combination of AVCs resulting in property damage in Colorado from 1986-2004. ROUTE_MPR represents unique route segment and mile marker combination rounded to the nearest mile.

ROUTE_MPR	No. of AVCs
070A_254	83
006G_273	75
070A_251	70
285D_242	70
070A_255	62
070A_249	58
070A_247	58
070A_165	55
285D_243	55
074A_5	54
285D_235	53
470A_10	51
074A_6	50
285D_234	49
082A_8	48
082A_22	48
082A_14	48
160A_192	48
024A_300	46
070A_250	46
070A_256	46
285D_244	45
160A_207	44
160A_191	44
070A_248	42
040A_93	42
082A_33	41
093A_16	40
160A_256	40
040A_84	39
074A_3	39
285D_245	39
160A_89	39
082A_10	38

ROUTE_MPR	No. of AVCs
160A_95	38
036B_25	37
285D_250	37
036B_28	36
024A_299	36
040A_95	36
070A_253	36
040A_94	36
070A_158	35
040A_98	35
070A_260	34
050A_89	34
025A_155	34
160A_86	34
550B_118	34
036B_26	33
007A_1	33
470A_6	33
007A_2	32
082A_20	32
160A_100	32
074A_2	31
025A_148	31
070A_90	31
074A_4	31
285B_53	31
550B_25	31
160A_98	31
285C_132	31
070A_89	30
070A_232	30
082A_9	30
115A_45	30
115A_41	30

ROUTE_MPR	No. of AVCs
070A_75	29
025A_191	29
025A_147	29
025A_146	29
082A_7	29
082A_15	29
093A_1	29
550B_29	29
036B_37	28
070A_91	28
034A_5	28
070A_18	28
070A_259	28
082A_1	28
285C_131	28
470A_9	28
160A_96	28
285D_240	28
025A_125	27
025A_181	27
025A_124	27
036B_27	27
040A_99	27
082A_31	27
160A_50	27
285D_231	27

Appendix B.1. Coordinates of camera stations at the U.S. 285, Conifer- Bailey study site.

	UTM E[a]	*UTM N*
Impact Site 1[b]		
WA	470969	4371893
WU	470969	4371861
Impact Site 2		
EA	471536	4372361
EU	471540	471540
WU	471527	4372400
WA	471499	4372412
Impact Site 3		
WA	472493	4372697
Control Site 1		
EA	461507	4365919
EU	461478	4365916
WU	461466	4365931
WA	461402	4365925
Control Site 2		
EA	462460	4367294
EU	462409	4367307
WU	462386	4367340
WA	462393	4367357

[a] *locations obtained in WGS84 datum*
[b] *camera stations include eastern approach (EA), eastern underpass (EU), western underpass (WU), and western approach (WA)*

Appendix B.2. Representative site photos from U.S. 285, Conifer-Bailey study site.

Impact Site 1: fill slope, west side

Impact Site 2: Green Valley Grill underpass before construction

Impact Site 2 during construction of the southbound U.S. 285 portion of the underpass

Impact Site 2 after construction

Control Site 1: Deer Creek span bridge[1]

Control Site 2: Roland Gulch culvert, west entrance

[1] Photo courtesy of Colorado Department of Transportation

Appendix B.3. Coordinates of camera stations at the U.S. 160, Wolf Creek Pass study site.

	UTM E[a]	*UTM N*
Impact Site 1[b]		
NA	346923	4161540
Impact Site 2		
SA	347306	4161840
SU	347235	4161824
NU	347224	4161832
NA	347174	4161856
Impact Site 3		
SA	347537	4162689
U[c]	347478	4162670
NA	347425	4162608
Impact Site 4		
SA	347737	4163279
SU	347694	4163301
NU	347683	4163323
NA	347677	4163332
Impact Site 5		
SA	345098	4160016
SU	345045	4159985
NU	345035	4159994
NA	345061	4160063
Control Site 1		
SA	343812	4158743
SU	343792	4158757
NU	343772	4158769
NA	343752	4158805
Control Site 2		
SA	344754	4159614
SU	344724	4159600
NU	344700	4159598
NA	344679	4159635

[a] locations obtained in WGS84 datum

b camera stations include southern approach (SA), southern underpass (SU), northern underpass (NU), and northern approach (NA)

[c] one camera was placed inside the temporary lynx crossing structure

Appendix B.4. Representative site photos from U.S. 160, Wolf Creek Pass study site.

Impact Site 2: Park Creek Campground

Impact Site 2: looking south

Impact Site 3: temporary lynx structure

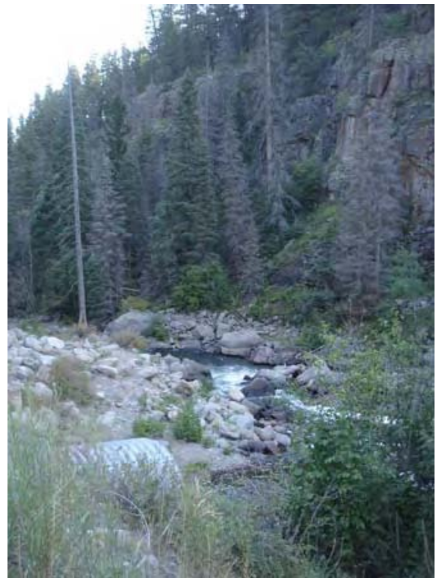
Impact Site 3: looking east

Impact Site 4: looking west toward Lynx Crossing H

Impact Site 5: looking west toward Lynx Crossings B1, B2, and B3

Control Site 1: Lake Creek, looking north

Control Site 1: looking south at outlet to South Fork Rio Grande



Control Site 1: looking east

Control Site 2: looking west

Control Site 2: looking east along South Fork Rio Grande

Appendix B.5. Coordinates of camera stations at the U.S. 160, Durango-Bayfield study site.

	UTM E[a]	*UTM N*
Impact Site 1[b]		
NA	255279	4123907
Impact Site 2		
SA	255808	4123820
U[c]	255811	4123851
NA	255817	4123859
Impact Site 3		
SA	256601	4123753
SU	256585	4123780
NU	256596	4123800
NA	256633	4123830
Control Site 1		
SA	259008	4123471
SU	259013	4123498
NU	259016	4123530
NA	259023	4123557
Control Site 2		
SA	259387	4123436
SU	259444	4123475
NU	259450	4123497
NA	259467	4123513

[a] locations obtained in WGS84 datum
b camera stations include southern approach (SA), southern underpass (SU), northern underpass (NU), and northern approach (NA)
[c] one camera was placed under the Florida River bridge

Appendix B.6. Representative site photos from U.S. 160, Durango-Bayfield study site.

Impact Site 2: Florida River bridge

Impact Site 3: Long Hollow, looking east

Impact Site 3: Long Hollow culvert[2]

Control Site 1: fill slope at MP 95.7

Control Site 1: looking east toward Control Site 2

Control Site 2: south entrance to culvert

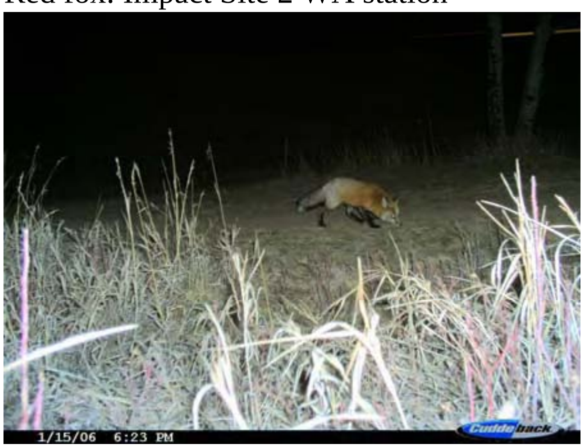
[2] Photo courtesy of Southern Rockies Ecosystem Project

Appendix B.7. Representative photos of species detected at the U.S. 285, Conifer-Bailey study site.

Elk: Impact Site 1 WU station

Mule deer: Impact Site 1 WU station

Red fox: Impact Site 2 WA station



Red fox black phase: Impact Site 2 EA station

Mule deer using Green Valley Grill underpass

Mule Deer: Impact Site 3 WA station

Coyote: Control Site 1 EA station

Elk: Control Site 1 EA station

Red fox: Control Site 1 EA station

Great blue heron: Control Site 1 EU station, Deer Creek bridge

Mule deer: Control Site 1 EU station, Deer Creek Bridge

Muskat: Control Site 2 SU station, Roland Gulch culvert

Appendix B.8. Representative photos of species detected at the U.S. 160, Wolf Creek Pass study site.

Coyote: Impact Site 2 SA station

Mule deer: Impact Site 3 SA station

Marmot: Impact Site 3, temporary lynx structure

Elk: Impact Site 4 SA station

Mule deer: Impact Site 4 SA

Coyote: Impact Site 4 NA station

Bobcat: Impact Site 5 NA station

Coyote: Impact Site 5 NA station

Red fox: Impact Site 5 NA station

Mule deer: Control Site 1 NA station

Mule deer: Control Site 1 SA

Red fox: Control Site 2 NA station

Appendix B.9. Representative photos of species detected at the U.S. 160, Durango-Bayfield study site.

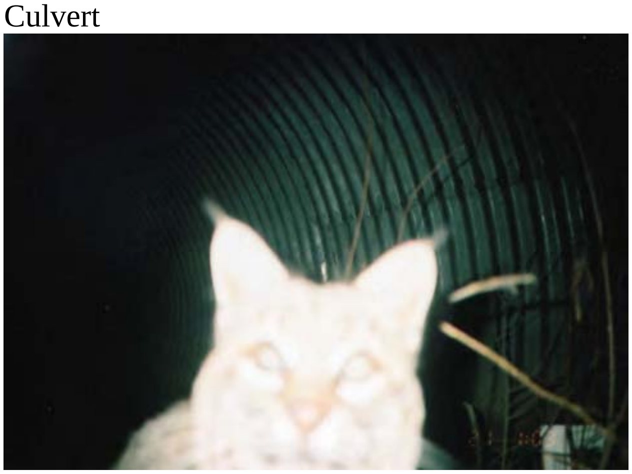
Mule deer: Impact Site 2 NA station

Mule deer: Impact Site 2 U station, Florida River

Striped skunk: Impact Site 2 U station, Florida River Bridge

Mule deer: Impact Site 2 SA station

Bobcat: Impact Site 3 SU stations, Long Hollow Culvert



Mule deer: Impact Site 3 SA station

Mule deer: Control Site 1 NA station

Bobcat: Control Site 1 NU station, culvert

Elk: Control Site 2 NA station

Coyotes: Control Site 2 NU station, at culvert entrance

Badger: Control Site 2 NU station, culvert

Bobcat: Control Site 2 NU station, culvert

Appendix C.1. Coordinates of lynx underpasses.

	UTM E[a]	*UTM N*
U.S. 40, Muddy Pass (MP1)	363974	4472432
U.S. 40, Muddy Pass (MP2)	364143	4471989
U.S. 40, Berthoud Pass (BP1)	433127	4404299
U.S. 40, Berthoud Pass (BP2)	432575	4403756
SH 9, Silverthorne (S1)	402632	4398466
SH 9, Silverthorne (S2)	403087	4400992
U.S. 160, Wolf Creek (WC)	347478	4162670

[a] *locations obtained in WGS84 datum*

Appendix C.2. Representative photos of species detected at the U.S. 40, Muddy Pass MP1 underpass.

Red Fox

Snow Shoe Hare

Black Bear

Porcupine

Mule Deer

Marmot

Appendix C.3. Representative site photos and underpass conditions at the U.S. 40, Muddy Pass MP1 underpass.

August 2005 (grass regeneration east side)

August 2006 (grass regeneration west side)

April 2006 (heavy snow conditions)

May 2006 (ground water flow through tunnel)

Appendix C.4. Representative photos of species detected at the U.S. 40, Muddy Pass MP2 underpass.

Marmot

Snow Shoe Hare

Mule Deer

Bat

American Marten

Long Tail Weasel

Golden Mantled Ground Squirrel

Red Fox

Porcupine

Human

Appendix C.5. Representative site photos and underpass conditions at the U.S. 40, Muddy Pass MP1 underpass.

August 2006 (grass regeneration east side)

August 2006 (grass regeneration west side)

March 2006 (snow drift inside looking west)

April 2006 (west side)

Appendix C.6. Representative photos of species detected at the SH 9, Silverthorne S1 underpass.

Deer (leg, bottom right)

Black bear

Marmot

Moose

Golden Mantled Ground Squirrel

Red Fox

Appendix C.7. Representative site photos and underpass conditions at the SH 9, Silverthorne S1 underpass.

July 2006 (grass regeneration west side)

July 2006 (grass regeneration east side)

March 2007 (snow and ice west side)

January 2007 (snow outside east side)

Appendix C.8. Representative photos of species detected at the SH 9, Silverthorne S2 underpass.

Red Fox

Golden Mantled Ground Squirrel

Domestic Dog

Domestic Cat

Cottontail Rabbit

Raccoon

Appendix C.9. Representative site photos and underpass conditions at the SH 9, Silverthorne S1 underpass.

August 2006 (grass regeneration east side)

August 2006 (grass regeneration west side)

February 2006 (snow conditions east side)

February 2006 (snow conditions west side)

Appendix C.10. Representative site photos and underpass conditions at the U.S. 40, Berthoud Pass BP1 underpass.

August 2006 (grass regeneration north side)

August 2006 (grass regeneration south side)

April 2006 (snow conditions north side)

April 2006 (snow conditions south side)

Appendix C.11. Representative site photos and underpass conditions at the U.S. 40, Berthoud Pass BP2 underpass.

September 2005 (grass regeneration south side)

August 2006 (grass regeneration north side)

March 2006 (snow conditions north side)

May 2007 (snow conditions north side)